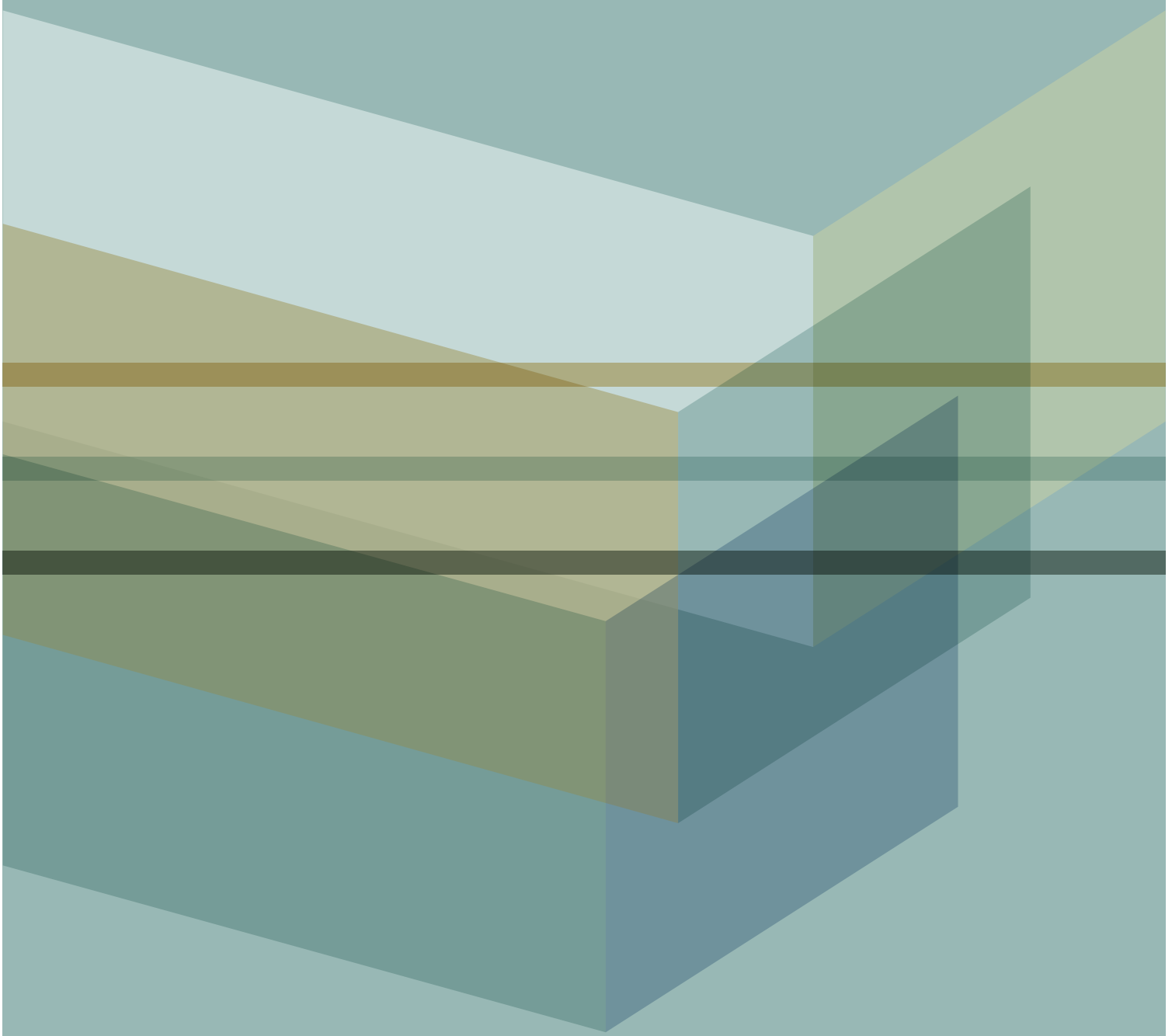
Dublin Institute for Advanced Studies



RESEARCH REPORT 2009

DUBLIN INSTITUTE FOR ADVANCED STUDIES RESEARCH REPORT 2009

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School of Celtic Studies

1 Research Work

Annual report of the Governing Board of the School of Celtic Studies for the year ending 31 December 2009 [adopted at its meeting of 10 June 2010].

Foireann agus Scoláirí/Staff and Scholars

Senior Professors: Liam Breatnach, Pádraig A. Breatnach (Director from 19 November), Fergus Kelly (Director to 19 November)

Professors: Malachy McKenna, Pádraig Ó Macháin

Assistant Professors: Aoibheann Nic Dhonnchadha, Michelle O Riordan (Publications Officer)

Bibliographer: Alexandre Guilarte

Dialectologist: Brian Ó Curnáin

Bergin Fellows: Clodagh Downey, Roisin McLaughlin,

O'Donovan Scholars: Nora White, Freya Verstraten Veach, Eoin O'Flynn, Gordon Ó Riain (until 1 October), Anna Matheson (from 1 October), Helen Imhoff (from 1 October)

Librarian: Margaret Kelly

Library Assistant: Órla Ní Chanainn

School Administrator: Eibhlín Nic Dhonncha

Technical Staff: ISOS: Anne Marie O'Brien

IT support: Andrew McCarthy (part-time), Stephen McCullagh (part-time)

1.1 Taighde/Research

Dialect Studies

Brian Ó Curnáin continued his work on the Irish of Co. Galway, and recorded speakers from Connemara (Ros Muc and Achréidh na Gaillimhe). He made progress on the preparation of his monograph on the Irish of East Galway. He maintained communication with Séamas Ó Direáin regarding his *Survey of spoken Irish in the Aran Islands*, which is being prepared for submission to the School of Celtic Studies. He commenced work on the transcription of his recordings for the School of Celtic Studies sound archive, *Glór*.

Malachy McKenna continued work on a draft of his publication *The Irish of Rann na Feirste: a phonemic study*, and conducted field-work in Rann na Feirste.

Textual Editions, etc.

Liam Breatnach continued work on his edition of the Old Irish law-tract *Córus Bésgnai*, as well as collecting material for his projected *Grammar of Middle Irish*.

P. A. Breatnach prepared for press *The Four Masters and their works: a team enterprise* (2008 Statutory Public Lecture, School of Celtic Studies, expanded with appendices). He completed a comprehensive study entitled 'The Ó Cléirigh recension of *Leabhar Gabhála*' (for publication in Éigse vol. XXXVII, 2010). He carried out research on the sources of the Book of O'Conor Don, collating items of bardic verse shared with the manuscripts from St Anthony's College, Louvain in particular. He continued work on the Catalogue of Irish manuscripts in Brussels and visited the Bibliothèque royale de Belgique (16-19 April); he advanced his edition of *Chronicle poems of the Nine Years' War* (Dubhthach Ó Duibhgeannáin), and his editions of apocryphal texts *(Airdena inna cóic lá ndéc ria mbráth; Airecc na nApstal)* (with study visit to British Library, 12-15 November). He worked also on a volume of oral traditions from Paróiste Mórdhach, West Kerry (Scéaltóireacht, filíocht agus mionseanchas ó Bhaile Uí Churráin, Paróiste Mórdhach, Corca Dhuibhne) (to be published 2010).

Clodagh Downey continued her research project to edit the corpus of poetry of the Middle Irish poet Cúán ua Lothcháin.

Fergus Kelly continued with his edition of an Old Irish text on legal disputes within marriage (D. A. Binchy, *Corpus Iuris Hibernici* i 44.5–150.16). He also continued with his edition of the Legal Treatise attributed to Giolla na Naomh Mac Aodhagáin (*Corpus Iuris Hibernici* ii 691.1–699.4).

Roisin McLaughlin continued work on editions of *Mittelirische Verslehren III, In Lebor Ollaman* and *Cédaín in Braith* (a Latin-Irish Homily in the Leabhar Breac).

Nora White continued work on her edition of the rule of Mo Chutu. She completed work on the *Monasticon Hibernicum* online database project which was launched in July on the School's website.

Helen Imhoff was awarded a doctorate for her PhD thesis entitled 'Pre-Christian Characters in Medieval Irish Literature: An Examination of *Fástini Airt meic Cuind, De Suidigud Tellaig Temra, Aided Chonchobair* and *Aided Echach maic Maireda*'. She is also working on an edition of *Fástini Airt meic Cuind*.

Anna Matheson continued research in relation to her doctoral dissertation 'Madness as Penance in Medieval Gaelic Sources: a Study of Biblical and Hagiographical Influences on the Depiction of Suibne, Lailoken and Mór of Munster'. She also continued working on an article discussing the late Old Irish legal tract *Do Drúthaib ocus Meraib ocus Dásachtaib (Corpus Iuris Hibernici* iv 1276. 18-1277.13).

Historical Studies

Michelle O Riordan continued her research work on 17th-century political poetry; and on emotive 12th-17th century poetry for the Arlen Press Pamphlets series (now under a new imprint).

Eoin O'Flynn continued work on his PhD thesis. His general area of interest is the political history of the Irish midlands; more specifically, his current research is focused on the early history of the Clann Cholmáin dynasty.

Cataloguing of Manuscripts

Aoibheann Nic Dhonnchadha continued work on cataloguing the Irish medical manuscripts in the Library of Trinity College Dublin.

1.2 Tionscnamh *Leabhar Breac/Leabhar Breac* Project

Liam Breatnach continued with his team project which will provide a diplomatic edition of the *Leabhar Breac*, in both printed and digitised form. The team currently consists of Clodagh Downey, Roisin McLaughlin, and Nora White.

1.3 Meamram Páipéar Ríomhaire/Irish Script on Screen (ISOS)

The Irish Script on Screen project (ISOS) continues under the direction of Pádraig Ó Macháin. Digitisation was carried out at the Royal Irish Academy in January, and at the Russell Library, NUI Maynooth, from June to December. Additional material (deeds and manuscript fragments) from Clonalis House was digitised and catalogued at the School of Celtic Studies. The second of the School's manuscripts (Séamus Ó Fearáoill 1835-6) was digitised and catalogued in house, as was a manuscript in private ownership written by Piarus Grás in 1810. All of this digitised material was subsequently processed and is now on display on the project's website (www.isos.dias.ie) The popularity of the website continued to grow: this year 2,700,000 visits were recorded.

The year saw further collaborations on the ISOS project established between DIAS and other institutions. Agreement was reached with the University of Melbourne regarding the processing and display of digital images of two 19th-century Irish manuscripts held at Newman College, and the manuscripts are now on display on the project's website. A similar agreement was subsequently finalised with the Benedictine Monastery of New Norcia, Western Australia, for the processing and display of digital images of an Irish manuscript held there, now also online. Towards the end of the year discussions were concluded with the National Library of Scotland, Edinburgh, on a collaboration involving the processing and display of digital images of their extensive collection of Irish manuscripts. It is intended that this collaboration will begin in 2010.

Arising from the digitisation of the Book of the O'Conor Don in 2009, the School hosted a colloquium on this unique and important manuscript on 16 May before an attendance of 70. Our guest at this colloquium was the owner of the manuscript, Mr Pyers O'Conor-Nash of Clonalis House, who opened the Colloquium. The following papers were presented:

Pádraig Ó Macháin (DIAS): An introduction to the Book of the O'Conor Don.

Katharine Simms (TCD): The selection of poems for inclusion in the Book of the O'Conor Don

Salvador Ryan (NUIM): Somhairle Mac Domhnaill's florilegium of faith: the religious poems in the Book of the O'Conor Don (1631)

Ruairí Ó hUiginn (NUIM): Captain Sorley/Samhairle and his books revisited

Pádraig A. Breatnach (DIAS): Bardic verse in the Book of the O'Conor Don and the manuscripts of St Anthony's College, Louvain

Gordon Ó Riain (DIAS): Textual aspects of the Book of the O'Conor Don

Benjamin Hazard (UCD): 'This New Troy': the Irish presence at Oostende in the first half of the seventeenth century.

Liam Mac Mathúna (UCD): Douglas Hyde the scholar

Nollaig Ó Muraíle (NUIG): Keeping the embers alive: the role of Charles O Conor of Bellanagare near the close of the Irish manuscript tradition

It is intended to publish the colloquium's proceedings in 2010.

1.4 Tionscnamh Bibleagrafaíochta/ Bibliography Project

Alexandre Guilarte continued work on the compilation of the fourth volume of the *Bibliography of Irish Linguistics and Literature*, concentrating particularly on learned journals in the field of Irish studies. A searchable on-line version of the bibliography is being maintained and updated at the School of Celtic Studies website.

1.5 Eagarthóireacht/Editing

Liam Breatnach: Co-editor (with Damian McManus) *Ériu*, vol. 59, published by the Royal Irish Academy (December).

Pádraig A. Breatnach: Editor of Éigse: *A Journal of Irish Studies*, vol. 37 (publication date 2010).

Fergus Kelly: Co-editor of *Celtica 26*.

Malachy McKenna: Co-editor of *Celtica 26*.

Aoibheann Nic Dhonnchadha: Comheagarthóir, *An Linn Bhuí: Iris Ghaeltacht na nDéise*, imleabhar 13.

Michelle O Riordan: Arranged for the printing of School of Celtic Studies publications.

Pádraig Ó Macháin: Comheagarthóir, *An Linn Bhuí: Iris Ghaeltacht na nDéise*, imleabhar 13.

1.6 Foilsitheoireacht/Publishing

As one of its statutory functions, in addition to research and publication by its own staff, the School provides for the assessment, editing, and publishing of books and papers by outside scholars. The following book was published in 2009:

Pádraig de Brún, *Scriptural Instruction in the Vernacular: The Irish Society and its Teachers*.
ISBN 978-1-85500-212-8

Reprints

The following reprints were seen through the press by the School's Publications Officer, Michelle O Riordan:

Terence McCaughey, *Dr Bedell and Mr King: the Making of the Irish Bible*.
ISBN 978-1-85500-213-5

Tomás de Bhaldraithe, *The Irish of Cois Fhairrge, Co. Galway: a phonetic study*
ISBN 978-0-901282-51-4

Riseard B. Breatnach, *The Irish of Ring, Co. Waterford: a phonetic study*
ISBN 978-0-901282-50-7

Gordon Mac Gill-Fhinnein, *Gàidhlig Uidhist a Deas (téacsleabhar)*
ISBN 978-1-85500-215-9

Brian Ó Cuív, *Aspects of Irish Personal Names*
ISBN 978-0-901282-87-3

Christine Mohrmann, *The Latin of Saint Patrick: Four Lectures*
ISBN 978-0-901282-27-9

Máire Mhac an tSaoi (ed.), *Dhá sgéal Artúraíochta, mar atá Eachtra Mhelóra agus Orlando, agus Céilidhe Iosgaide Léithe*
ISBN 978-1-85500-013-1

Sir Ifor Williams, *Lectures on Early Welsh Poetry*
ISBN 978-0-901282-26-2

Roparz Hemon (ed.), *Les fragments de La Destruction de Jérusalem et des Amours du Vieillard (texts en moyen-breton), traduits et annotés*
ISBN 978-0-901282-03-3

Pádraig de Brún, Breandan Ó Buachalla and Tomás Ó Concheanainn (ed.), *Nua-Dhuanaire – Vol. 1*
ISBN 0-901282-18-9

Fergus Kelly, *A Guide to Early Irish Law* (with revised Bibliography)
ISBN 978-1-85500-214-2

1.7 Díolachán Leabhar/Sale of books

Promotion of publications was effected by the School Administrator, Eibhlín Nic Dhonncha, through advertising in national and international newspapers, *Books Ireland, National Concert Hall Annual Brochure, Comhar, Saol, Foinse, Lá, Conradh na Gaeilge: Clár Seachtain na Gaeilge, An tOireachtas: Clár na Féile, Lámhleabhar An Choláiste Ollscoile Baile Átha Cliath, Library News*.

1.8 Foilseacháin/Publications

Liam Breatnach: '*Araile Felmac Féig don Mumain:* Unruly Pupils and the Limitations of Satire', Ériu 59 (2009) 111-37.

Clodagh Downey: 'Dindshenchas and the Tech Midchúarta' (forthcoming)

Fergus Kelly: 'The recovery of stolen property: notes on legal procedure in Gaelic Ireland, Scotland, and the Isle of Man' (for a Festschrift). 'Cauldron imagery in a legal passage on judges (*CIH* iv 1307.38-1308.7)' (for *Celtica 26*). 'The relative importance of cereals and livestock in the medieval Irish economy: the evidence of the law-texts' (for Fondazione Centro Italiano di Studi sull' Alto Medioevo, Spoleto, Italy)

Roisin McLaughlin: 'Fénius Farsaid and the Alphabets', *Ériu 59* (2009) 1-24.

Michelle O Riordan: *Palgrave History of Ireland*, chapter 2: 600-1800, New Approaches (April 2009).

Aoibheann Nic Dhonnchadha: 'The "Book of the O'Lees" and other medical manuscripts and astronomical tracts', in *Treasures of the Royal Irish Academy Library* (ed. Bernadette Cunningham and Siobhán Fitzpatrick, Dublin 2009) 81-91

Brian Ó Curnáin: 'Canúineolaíocht' in *An tSochtheangeolaíocht: Feidhm agus Tuairisc* réitithe (forthcoming publication 2010). 'Mionteangú na Gaeilge', *Léachtaí Cholm Cille* 39, 90-153 (eag. Brian Ó Catháin, 2009).

Pádraig Ó Macháin: 'Bardic poetry in the Academy's collection of Irish manuscripts', in *Treasures of the Royal Irish Academy Library* (ed. Bernadette Cunningham and Siobhán Fitzpatrick, Dublin 2009) 57-68. 'Irish manuscripts in the nineteenth century', in *Treasures of the Royal Irish Academy Library* (ed. Bernadette Cunningham and Siobhán Fitzpatrick, Dublin 2009) 161-71. 'Gadaithe agus Gaibhne: teagasc an Athar de Bhál 3', *An Linn Bhuí* 13 (2009) 217-39. 'An Irish manuscript at Glin Castle', in Tom Donovan (ed.), *The Knights of Glin: seven centuries of change* (Glin 2009) 263-71.

Alexandre Guilarte contributed entries on Celtic Studies publications to the Brepols International Medieval Bibliography.

Nora White: The *Monasticon Hibernicum* online database for the School of Celtic Studies website was launched in July.

Freya Verstraten Veach: *Review of Government, War and Society in Medieval Ireland: Essays by Edmund Curtis, A. J. Otway-Ruthven and James Lydon*. Edited by Peter Crooks (*Irish Historical Studies* vol. 36, no. 144).

Eoin O'Flynn: 'The career of Máelsechnaill II', *Ríocht na Midhe* 20 (2009) 29-68.

1.9 Leabharlann/Library

Current and retrospective cataloguing continued. Acquisitions continued in subject areas relevant to the research needs of the School. Regular updates on recent accessions and current periodicals were issued and research and bibliographical queries from members of the School were dealt with. Inter-library loans were ordered, consulted and returned to the lending institutions.

The following online resources were added to the library website: EBSCO A to Z, JSTOR Ireland collection, *Patrologia Latina, Bibliography of British and Irish History* and *The Dictionary of Irish Biography*.

A reception was held to mark the official opening of the Mac Cana Library on 26th February. The family of the late Professor Proinsias Mac Cana were present for the opening.

Alex Kouker began work as a library volunteer in June. He worked on the retrospective cataloguing project, one day per week over a six-month period. The Librarian Margaret Kelly became Secretary of the Academic and Special Libraries section of the Library Association of Ireland. This committee meets once a month and organises an annual seminar along with informal networking evenings and training courses. She was involved in the organisation of a one-day seminar entitled *Book to Button: Transitions in Library Service Delivery* which was hosted by the Academic and Special Libraries section of the LAI. The seminar was

held on 12th February in the Radisson SAS Hotel. For Library Ireland Week Margaret Kelly gave a careers talk to the students at the UCD School of Information and Library Skills. Órla Ní Chanainn attended CONUL (Consortium of National and University Libraries) information literacy seminar which was held on 28th May in Trinity College, Dublin.

1.10 Imeachtaí/Events

Statutory Public Lecture

This year's Statutory Public Lecture was delivered by Professor Fergus Kelly on the subject of 'Women's rights and duties in early Irish law, with special reference to marriage'. It was delivered as part of the Tionól at Trinity College Dublin, on Friday 20th November to an audience of approximately 150 people.

Other Lectures

On 16 May a one-day Conference was organised by Professor Pádraig O Macháin on the Book of the O'Conor Don to an audience of approximately 70 people.

Tionól 2009

The School's annual Tionól took place on 20 and 21 November 2009, organised by Clodagh Downey assisted by Roisin McLaughlin, Alexandre Guilarte, and the School Administrator Eibhlín Nic Dhonncha. It attracted a very large attendance with numbers exceeding one hundred on both days. Papers on various aspects of Celtic Studies were delivered by twenty speakers from Germany, the Netherlands, Finland, United States of America, Wales, England, and Ireland

The following is the list of speakers and papers:

Sìm Innes (University of Glasgow): Local piety in medieval Highland Perthshire

Caoimhín Breatnach (University College Dublin): A poem on the fifteen signs before Doomsday ascribed to Donnchadh Mór Ó Dálaigh

Richard Glyn Roberts (University College Dublin): The genealogy of orality

Gerald Manning (School of Celtic Studies, DIAS): TCD MS E.3.3 (now no. 1432) and *Uraicecht Becc*

Michael Clarke (National University of Ireland, Galway): The pseudohistorical preface to the late Middle Irish *Togail Troí* Recension III

Roisin McLaughlin (School of Celtic Studies, DIAS): *Cédaín in Braith:* a Latin text on fasting in the *Leabhar Breac*

Aidan Breen (National University of Ireland, Galway): Jonas and the library of seventh-century Bobbio

David Howlett (University of Oxford): Gematria among the Irish

Jürgen Uhlich (Trinity College Dublin): On the transmission of the Cambrai Homily

David Stifter (University of Vienna): Lexicon Leponticum

Ciarán Ó Coigligh (Coláiste Naomh Phádraig, B.Á.C): Graiméar Rudolf Thurneysen: Foinse eolais ar chanúintí na Nua-Ghaeilge

Diarmuid Ó Sé (University College, Dublin): The colour terms of Irish

Dónall Ó Baoill (Queen's University, Belfast): Mantfhocail i nGaeilge Iarthuaisceart Thír Chonaill

Jacopo Bisagni (National University of Ireland,Galway): The origins of the preterite of the Old Irish copula and substantive verb

Aaron Griffith (University of Vienna): The etymology of Old Irish *ocus* 'and'

Iwan Wmffre (University of Ulster, Coleraine): The so-called 'diphthongs' *<ia, ua>* in Gaelic

Lisa Fraser (University of Aberdeen): A new etymology for Hamlet? The names *Admlithi, Amlethus,* and *Amlódi*

Deborah Hayden (University of Cambridge): Natural and artificial language in *Auraicept na nÉces*, revisited

Mícheál Ó Mainnín (Queen's University, Belfast): Ráith Arda Macha: The topography and toponymy of the medieval settlement of Armagh

Ruairí Ó hUiginn (National University of Ireland, Maynooth): The *Gamanrad*

Seminars

Liam Breatnach held seminars on the Old Irish law-text *Críth Gablach* (January-May), on a selection of Middle Irish prose and verse texts (October-December), and on the Old Irish law-text *Bretha Nemed Toísech* (October-December)

Pádraig A. Breatnach held seminars on texts from the Four Masters (March-May) and 'Togha na héigse 1700-1800' (Feabhra-Bealtaine).

Clodagh Downey held a seminar on 'The poetry of Cúán ua Lothcháin' (January-April).

Fergus Kelly held a seminar on 'An Old Irish law-text on disputes within marriage' (January- February).

Breandán Ó Buachalla, Professor of Irish Language and Literature at the University of Notre Dame, gave two seminars on metrical topics (4, 9 March).

1.11 Léachtaí (foireann agus scoláirí)/ Lectures (staff and scholars)

Liam Breatnach: 'Law and Literature in mediaeval Ireland', (LVII Settimana di studio, Fondazione Centro Italiano di Studi sull' Alto Medioevo, Spoleto, Italy) 17 April.

Pádraig A. Breatnach: 'Bardic verse in the Book of O'Conor Don and the manuscripts of St Anthony's College, Louvain' One-Day Colloquium on the Book of the O'Conor Don, SCS (16 May).

Fergus Kelly: 'Irish Farming in the time of Saint Kevin' (Roundwood and District Historical and Folklore Society) 26 January. 'The relative importance of cereals and livestock in the medieval Irish economy: the evidence of the law-texts' (LVII Settimana di studio, Fondazione Centro Italiano di Studi sull' Alto Medioevo, Spoleto, Italy) 18 April. 'A joint School of Celtic Studies and School of Theoretical Physics Project; laser-scanning the Ogam stones' (Conference to celebrate Werner Nahm's 60th birthday, Royal Dublin Society, Ballsbridge) 21 November.

Pádraig Ó Macháin: 'Canon Patrick Power and his collection of placenames': Waterford County Library, (March). 'In search of Tadhg Dall Ó hUiginn': Sligo (May). 'An introduction to the Book of the O'Conor Don': DIAS (May).'Patrick Carmody and the Irish Language': Kilrossanty, Co. Waterford, (October). 'The poetry of Tadhg Dall Ó hUiginn: themes and sources': UCC, (November). 'Gaelic manuscript production in the Early-Modern period': National Library of Ireland, (November). 'ISOS: cúlra agus dul chun cinn': St Patrick's College, Drumcondra (December). 'The poems composed by Fearghal Óg Mac an Bhaird for Flaithrí Ó Maoil Chonaire: background and interpretation': University College Dublin (December).

Clodagh Downey: 'Slane in medieval sources', Slane Historical Society (April).

Michelle O Riordan gave a paper entitled 'Tadhg Dall Ó hUiginn – the poet', Irish Texts Society, Cork (November). She also gave a seminar to graduate studies programme in University College Dublin, Belfield, on the *Leabhar Branach*.

Roisin McLaughlin: 'The transmission and interpretation of didactic texts in medieval Ireland', M. Phil. Seminar, Trinity College Dublin (February). '*Cédaín in Braith:* A Latin text on fasting in the Leabhar Breac' (Tionól SCS, November)

Aoibheann Nic Dhonnchadha: 'The Irish translation of the "Tacuini aegritudinum" of Ibn Jazla (d. 1100)'. Wellcome Trust Centre for the History of Medicine at University College, London (January). 'The Book of the O'Lees', Royal Irish Academy, Dublin (May).

Gordon Ó Riain: 'A fifteenth-century apologue on the death of Cú Chulainn', School of Celtic Studies Tionól (November).

Freya Verstraten Veach: 'Survival of the Fittest Law: Het Ierse Brehon en het Engelse Gewoonterecht in de Late Middeleeuwen'. A. G. van Hamel Lezing at the University of Utrecht (December).

Eoin O'Flynn 'Colmán Már and/or Bec? Confusion in Clann Cholmáin's earliest history.' James Lydon Research Seminar in Medieval History, Trinity College Dublin (January)

Nora White: post-graduate seminar on the transmission and dating of the Rule of Mo Chutu, School of Irish, Trinity College Dublin (April).

1.12 Cúrsaí in ollscoileanna Éireannacha/ Courses in Irish universities

Brian Ó Curnáin: léachtaí in Acadamh na hOllscolaíochta Gaeilge, Ollscoil na hÉireann, An Cheathrú Rua, Co. na Gaillimhe, don Chúrsa MA sa Phleanáil Teanga.

Michelle O Riordan: 'Module on Irish Literature' for first-year Bachelor in Arts and Theology (BARSI), Mater Dei Institute of Education, Dublin City University.

Nora White: part-time course on Early Irish Literature for the Department of Adult and Community Education at NUI Maynooth (September–December);

1.13 Scrúdaitheoireacht Sheachtrach, etc./ External Examining etc.

Liam Breatnach: external examiner for Early and Medieval Irish, National University of Ireland, Maynooth.

Fergus Kelly: external examiner, Department of Early and Medieval Irish, University College, Cork (2008-'09). External examiner for M.A. thesis (Department of Early and Medieval Irish, University College Cork). External examiner for M.Phil. thesis (Department of Early and Medieval Irish, University College Cork).

Malachy McKenna: assessor for a grant application to the Austrian Science Foundation; external examiner for PhD. thesis (Queen's University, Belfast.)

Michelle O Riordan: external examiner for first year BARSI students in DCU (Mater Dei Institute).

Pádraig Ó Machain: external examiner for PhD thesis (University College Cork)

1.14 Na Meáin Chumarsáide agus Aithne Phoiblí/Media and Public Awareness

Website of the School of Celtic Studies

New content was added to the School of Celtic Studies website (www.celt.dias.ie) on a continuing basis under the direction of Professor Pádraig Ó Macháin and Andrew McCarthy. Queries from outside scholars, students and the general public were dealt with.

Television and Radio

Pádraig Ó Macháin did a number of interviews on Raidió na Gaeltachta. Brian Ó Curnáin was interviewed on Raidió na Gaeltachta when he received the Comórtas Liteartha an Oireachtais 2009 prize for his article 'Mionteangú na Gaeilge'. He also did an interview on Nuacht TG4 on the draft document 'Plean Fiche Bliain don Ghaeilge'.

1.15 Coistí/Committees

Liam Breatnach: Local President of the Organising Committee of the XIV International Congress of Celtic Studies to be held in Maynooth, 1st–5th August, 2011.

Pádraig A. Breatnach: Member of Council, Royal Irish Academy (2009-'10). Member, Irish New Testament Apocrypha Project (Editorial Committee). Ball de Choiste Náisiúnta Léann na Gaeilge (Acadamh Ríoga na hÉireann). Advisor, Centre International de Codicologie (Bulletin Codicologique), Brussels. Chairman, Publications Committee of the School of Celtic Studies, DIAS.

Clodagh Downey: Member of Peer Review panel of the journal K*eltische Forschungen*.

Fergus Kelly: Member of advisory panel of eDIL (Supplement to the *Dictionary of the Irish Language)* meeting at Royal Irish Academy, Dublin, 10 November.

Margaret Kelly (Librarian): appointed to the committee of the Academic and Special Libraries Section of the Library Association of Ireland (www.libraryassociation.ie).

Michelle O Riordan: Member of Ralahine Utopian Studies Seminar. Member of Cork Historical and Archaeological Society and member of the Dublin Mediaeval Society.

Aoibheann Nic Dhonnchadha: Ball de Fhochoiste na Leabharlainne, Coláiste na Rinne, Rinn Ó gCuanach, Dún Garbhán, Co. Phort Láirge.

1.16 Bord Rialúcháin Scoil an Léinn Cheiltigh/ Governing Board of the School of Celtic Studies

Professor Anders Ahlqvist (Chairman)
Professor Angela Bourke
Professor Máire Herbert
Professor Liam Mac Mathúna
Dr Eilís Ní Dheá
Professor Dónall Ó Baoill
Dr Nollaig Ó Muraíle
Professor Ruairí Ó hUiginn
Dr Katharine Simms
Professor Liam Breatnach
Professor Fergus Kelly
Professor Pádraig A. Breatnach

The Governing Board of the School of Celtic Studies met three times in 2009: 11 June, 1 October, 19 November.

1.17 Cuairteoirí agus Comhaltaí/Visitors and Associates

Visiting Professors

Professor Pierre-Yves Lambert (École Pratique des Hautes Études, France)

Professor Jószi Nagy (University of California Los Angeles, USA)

Dr Morfydd Owen (Bryn Eithin, Aberystwyth, Wales)

Professor Neil McLeod (Murdoch University, Western Australia)

Professor Markku Filppula (University of Joensuu, Finland)

Professor Tomás Ó Cathasaigh (Harvard University, USA)

Professor Pádraig Ó Néill (The University of North Carolina at Chapel Hill, USA)

Professor Melita Cataldi (University of Turin, Italy)

Professor Nancy Stenson (University of Minnesota, USA)

IRCHSS Post-doctoral Fellow

Dr Gerald Manning

Research Associates

Dr Gwenllian Awbery, University of Wales, Cardiff (1990)

Dr John Carey, National University of Ireland, Cork (1990)

Professor Thomas Charles-Edwards, University of Oxford (1990)

Professor Toshio Doi, Nagoya Women's University, Japan (1991)

Professor David N. Dumville, University of Aberdeen (1989)

Professor D. Ellis Evans, University of Oxford (1990)

Professor William Gillies, University of Edinburgh (1989)

Professor Geraint Gruffydd, Centre for Advanced Welsh and Celtic Studies, Aberystwyth (1989)

Professor Eric P. Hamp, University of Chicago (1989)

Dr Anthony Harvey, Royal Irish Academy (2004)

Professor Donald MacAulay, University of Glasgow (1989)

Professor James McCloskey, University of California, Santa Cruz (2004)

Dr Martin McNamara, MSC, Milltown Institute of Theology and Philosophy (1989)

Professor Toshitsugu Matsuoka, Hosei University, Tokyo (1991)

An tOllamh Donnchadh Ó Corráin, Coláiste na hOllscoile, Corcaigh (1991)

An tOllamh Ruairí Ó hUiginn, Ollscoil na hÉireann, Má Nuad (1999)

Dr Tom O'Loughlin, University of Wales, Lampeter (2003)

Professor Pádraig Ó Néill, The University of North Carolina at Chapel Hill (1990)

Dr Morfydd Owen, Bryn Eithin, Aberystwyth (2003)

Dr Brynley F. Roberts, National Library of Wales, Aberystwyth (1990)

Professor R. Mark Scowcroft, Catholic University of America (1990)

Professor Richard Sharpe, University of Oxford (1988)

Professor Calvert Watkins, Harvard University (1990)

Visiting Student Researchers

Stephanie Rousseau
Christina Cleary

Visiting Scholars

Overseas scholars (apart from those listed above under Visiting Professors) who availed of library and research facilities are included in the following list. In addition to these, the School accords library and research facilities to Irish-based scholars when it holds materials which are lacking in the scholars' own institutions and in the major libraries in Dublin.

Nora Bermingham (University of Birmingham, England)

Jacqueline Borsje (University of Amsterdam, The Netherlands)

Aidan Breen (University of Massachusetts, Boston, USA)

Margo Griffin-Wilson (Harvard University, USA)

Katrina Burge (University of Melbourne, Australia)

Nina Cherkonadskaya (Moscow State University, Russia)

Piero de Gennaro (Turin, Italy)

Riitta Latvio (University of Helsinki)

Macsaim Fomin (University of Ulster, Ireland)

Edyta Lehmann (Harvard University, USA)

Réamonn Ó hÍcí (University of Essen, Germany)

Peadar Ó Muircheartaigh (University of Edinburgh, Scotland)

School of Cosmic Physics

Astronomy and Astrophysics

1 Highlights

In 2009 the combined Astronomy and Astrophysics Section has:

- been praised for the international quality of its research by the quinquennial external peer review of the School;
- published 55 refereed publications with a further 10 preprints submitted and 29 nonreferreed articles;
- elucidated the mode of formation of the so-called "elephant trunks" seen in star-forming regions using advanced computational simulations;
- confirmed long-standing theoretical expectations with the detection of the star-burst galaxy NGC 253 as a HESS source;
- joined the Japanese Astro-H consortium;
- begun work on the MIRI software development;
- deployed the first stage of the e-INIS national data store and lambda-switched interconnect;
- obtained 4.3 million core-hours of computing time under the PRACE proto-type testing programme to run the HYDRA code;
- obtained funding for and ordered a new 3D projection system to enhance the Dunsink open night experience;
- hosted an international workshop on radiation hazards associated with the international space station.

2 Staff

Senior Professors Luke Drury, Evert Meurs

Professors Felix Aharonian, Tom Ray

Emeritus Professors Denis O'Sullivan, Alex Thompson, Ian Elliott, Tao Kiang[1]

Honorary Professor of Computational Science Jean-Christophe Desplat, Associate Director of ICHEC

Schroedinger Fellows Andy Lim (to 30 Nov), Carlos del Burgo (to 30 Sep), Masha Chernyakova, Aya Bamba (from 1 Nov) Aleks Scholtz (from 1 Nov)

EU Marie Curie Fellow Stefano Gabici (to 30 Sep)

JETSET Project Positions Emma Whelan (academic administrator until 28 Feb), Jose Gracia (researcher until 31 Jan), Perikles Rammos (until 31 Jan)

IRCSET Fellows Deirdre Coffey, Paul Dempsey (to 28 Aug), Linda Podio (to 16 Dec), Emma Whelan (from 1 Sep)

SFI-funded Researchers Alessio Caratti o Garatti (from 12 Jan), Gareth Murphy (from 15 Jan)

EI-funded Researchers Julien Morin (from 9 Nov), Anna Scaife (from 1 Dec)

Visiting Scientists Mark Dieckmann (Norköping University, Sweden), Turlough Downes (on secondment from DCU), Dirk Froebrich (University of Kent), Rebeca Garcia Lopez (Rome Observatory), Jason Kirk (University of Cardiff), Subu Mohanty (Imperial College London), Antonella Natta (Arcetri Observatory, Florence), Malcolm Walmsley (Arcetri Observatory, Florence).

Hamilton Scholars Sean Delaney, Jonathan Mackey, Denys Malyshev, Lisa Fallon, Laure Barreyre, Nakisa Nooraee

Lindsay Scholar (jointly with Armagh Observatory) Gráinne Costigan (from 1 Oct)

Experimental Officer (IT support unit) Stephane Dudzinski

Senior Technical Officer (Dunsink Observatory) Mike Smyth

Technical Officers Anne Grace, Hilary O'Donnell, Eileen Flood

Secretarial and Reception Phyllis Daly, two vacancies

IT support Philippe Grange

Groundsman (Dunsink Observatory) Tomás Ó Gríofa

e-INIS project coordinator and outreach officer Keith Rochford

JETSET project positions Emma Whelan (academic administrator, to 28 Feb), Jose Gracia (researcher, to 31 Jan), Perikles Rammos (database architect, to 31 Jan)

1 *Obit 3 Apr 2009*

Research Associates Dr Peter Duffy, UCD; Professor A Lawrence FRSE, Royal Observatory Edinburgh; Professor Brian McBreen, UCD; Dr VF Polcaro, Istituto di Astrofisica Spaziale; Dr Mark Wilkinson, Institute of Astronomy, University of Cambridge; Dr Laura Norci, DCU; Dr Brian Espey, TCD; Dr Matthew Redman, NUIG; Dr Justin Donnelly, DIT; Mr Brendan Jordan; Dr Gareth Murphy, Grenoble; Dr Stephen O'Sullivan, UCD; Dr Dazhuang Zhou, Houston; Mr John Walsh, TCD; Dr Brenda Frye, DCU (from 5 Sep).

3 Research Reports

3.1 High-Energy Astrophysics

Felix A. Aharonian

My research activity is focused on topics of High Energy Astrophysics with an emphasis on the phenomenological and theoretical studies of multi-wavelength properties of cosmic gamma-ray sources. A significant fraction of my research is related, in one way or another, to observations of very high energy gamma-ray sources with the HESS array of imaging atmospheric Cherenkov telescopes, and interpretation of these data. I am also collaborating closely with the Japanese Suzaku X-ray mission team (ISAS, Tokyo), as well as with the NANTEN team (Nagoya University) on CO observations of the interstellar medium; both wavelength domains are of great importance for identification and understanding of the nature of very high energy gamma-ray sources. In the so-called hadronic scenarios, gamma-radiation is accompanied by the production of high energy neutrinos. This motivates my involvement in projects related to high energy neutrino astronomy, in particular in the context of design studies of the cubickilometer-volume underwater neutrino detector in the Mediterranean Sea (KM3NeT). I am also a member of the ROTSE-III collaboration studying the optical properties of prompt gamma-ray burst afterglows. Finally, I am selected by the European Space Agency (ESA) as a representative of ESA in the science working group of the future JAXA-NASA X-ray mission ASTRO-H. The main topics of my research conducted in 2009 are described below.

3.1.1 Nonthermal Radiation of Young Supernova Remnants

Zirakashvili, V. N.; Aharonian, F. A. The Astrophysical J., vol. 708, pp. 965-980 (2009); eprint arXiv:0909.2285

A new numerical code, designed for the detailed numerical treatment of nonlinear diffusive shock acceleration, is used for modelling of particle acceleration and radiation in young supernova remnants. The model is based on spherically symmetric hydrodynamic equations complemented with transport equations for relativistic particles. For the first time, the acceleration of electrons and protons by both forward and reverse shocks is studied through detailed numerical calculations. We model the energy spectra and spatial distributions of nonthermal emission of the young supernova remnant RX J1713.7-3946 and compare the calculations with the spectral and morphological properties of this object obtained in broad energy band from radio to very high energy gamma-rays. We discuss the advantages and shortcomings of the so-called hadronic and leptonic models which assume that the observed TeV gamma-ray emission is produced by accelerated protons and electrons, respectively. We discuss also a "composite" scenario when the gamma-ray flux from the main parts of the shell has inverse Compton origin, but with a non-negligible contribution of hadronic origin from dense clouds interacting with the shell.

3.1.2 Broad-band Non-thermal Emission from Molecular Clouds Illuminated by Cosmic Rays from nearby Supernova Remnants

Gabici, S.; Aharonian, F. A.; Casanova, S. Monthly Notices of the Royal Astronomical Society, vol. 396, pp. 1629-1639 (2009)

Molecular clouds are expected to emit non-thermal radiation due to cosmic ray interactions in the dense magnetized gas. Such emission is amplified if a cloud is located close to an accelerator of cosmic rays and if energetic particles can leave the accelerator site and diffusively reach the cloud. We consider here a situation in which a molecular cloud is located in the proximity of a supernova remnant which is efficiently accelerating cosmic rays and gradually releasing them in the interstellar medium. We calculate the multiwavelength spectrum from radio to gamma rays which is emerging from the cloud as the result of cosmic ray interactions. The total energy output is dominated by the gamma-ray emission, which can exceed the emission in other bands by an order of magnitude or more. This suggests that some of the unidentified TeV sources detected so far, with no obvious or very weak counterparts in other wavelengths, might be in fact associated with clouds

illuminated by cosmic rays coming from a nearby source. Moreover, under certain conditions, the gamma-ray spectrum exhibits a concave shape, being steep at low energies and hard at high energies. This fact might have important implications for the studies of the spectral compatibility of GeV and TeV gamma-ray sources.

3.1.3 Revisiting the Diffuse Neutrino Flux from the Inner Galaxy Using New Constraints from very High Energy γ -ray Observations

Taylor, A.; Gabici, S.; White, R.; Casanova, S.; Aharonian, F. NIMPA, vol. 602, pp. 113-116 (2009)

Following the MILAGRO collaboration's recent publication of the detection of diffuse multi-TeV emission from a region close to the inner Galaxy, we revisit the diffuse neutrino flux calculation from this region. Conventional models following cosmic ray (CR) propagation through the Galaxy, tuned to reproduce the locally observed CR spectrum, give rise to diffuse fluxes that are significantly below the detected diffuse flux. Assuming that this excess is hadronic in origin and is representative of the whole inner Galactic region, we estimate the expected diffuse neutrino flux from a region of the Galactic disk with coordinates $-40 < l < +40$. The diffuse flux of neutrinos, for this hadronic only scenario, is found to be detectable by a km-scale detector located in the northern hemisphere.

3.1.4 A Peculiar Jet and Arc of Molecular Gas toward the Rich and Young Stellar Cluster Westerlund 2 and a TeV Gamma Ray Source

Fukui, Y.; Furukawa, N.; Dame, T.; Dawson, J.; Yamamoto, H.; Rowell, G.; Aharonian, F.; Hofmann, W.; de OŰa Wilhelmi, E.; Minamidani, T.; Kawamura, A.; Mizuno, N.; Onishi, T.; Mizuno, A.; Nagataki, S. PASJ, vol.61, pp.L23–L27 (2009)

We have discovered remarkable jet-and arc-like molecular features toward the rich and young stellar cluster Westerlund 2. The jet has a length of ≈ 100pc and a width of ≈ 10pc, while the arc shows a crescent shape with a radius of ≈ 30pc. These molecular features each have masses of ≈ 10^4 $M_\odot$, and show spatial correlations with the surrounding lower density H I gas. The jet also shows an intriguing positional alignment with the core of the TeV gamma-ray source HESS J1023-575 and with the MeV/GeV gamma-ray source recently reported by the Fermi collaboration. We argue that the jet and arc are caused by an energetic event in Westerlund 2, presumably due to an anisotropic supernova explosion of one of the most massive member stars. While the origin of the TeV and GeV gamma-ray sources is uncertain, one may speculate that they are related to the same event via relativistic particle acceleration by strong shock waves produced at the explosion or by remnant objects, such as a pulsar wind nebula or a microquasar.

3.1.5 Molecular Clouds as Cosmic-Ray Barometers

Casanova, S.; Aharonian, F.; Fukui, Y.; Gabici, S.; Jones, D. ; Kawamura, A.; Onishi, T.; Row-ell, G.; Torii, K.; Yamamoto, H. Submitted to PASJ, eprint arXiv:0904.2887 (2009)

It is generally assumed that the flux of cosmic-rays observed at the top of the Earth's atmosphere is representative of the flux in the Galaxy at large. The advent of high sensitivity, high resolution gamma-ray detectors, together with a knowledge of the distribution of the atomic hydrogen and especially of the molecular hydrogen in the Galaxy on sub-degree scales, as provided by the NANTEN survey, creates a unique opportunity to explore the flux of cosmic rays in the Galaxy. We present a methodology which aims to provide a test bed for current and future gamma-ray observatories to explore the cosmic ray flux at various positions in our Galaxy. In particular, for a distribution of molecular clouds and local cosmic ray density as measured at the Earth, we estimate the expected GeV to TeV gamma-ray signal, which can then be compared with observations. An observed gamma-ray flux less than predicted would imply a CR density in specific regions of the Galaxy less than that observed at Earth, and vice versa. The methodology presented will profit from the upcoming gamma-ray data from the Fermi observatory and from future very high resolution, very high energy telescopes.

3.1.6 Acceleration and Radiation of Ultrahigh Energy Protons in Galaxy Clusters

Vannoni, G.; Aharonian, F. A.; Gabici, S.; Kelner, S. R.; Prosekin, A. submitted to Astronomy & Astrophysics (2009) eprint arXiv:0910.5715)

Clusters of galaxies are believed to be capable to accelerate protons at accretion shocks to energies exceeding 10^18eV. At these energies, the losses caused by interactions of cosmic rays with photons of the Cosmic Microwave

Background Radiation (CMBR) become effective and determine the maximum energy of protons and the shape of the energy spectrum in the cutoff region. The aim of this work is the study of the formation of the energy spectrum of accelerated protons at accretion shocks of galaxy clusters and of the characteristics of their broad band emission. The proton energy distribution is calculated self-consistently via a time-dependent numerical treatment of the shock acceleration process which takes into account the proton energy losses due to interactions with the CMBR. We calculate the energy distribution of accelerated protons, as well as the flux of broad-band emission produced by secondary electrons and positrons via synchrotron and inverse Compton scattering processes. We find that the downstream and upstream regions contribute almost at the same level to the emission. For the typical parameters characterizing galaxy clusters, the synchrotron and IC peaks in the spectral energy distributions appear at comparable flux levels. For an efficient acceleration, the expected emission components in the X-ray and gamma-ray band are close to the detection threshold of current generation instruments, and will be possibly detected with the future generation of detectors.

3.1.7 HESS J0632+057: A New Gamma-Ray Binary?

Hinton, J. A.; Skilton, J. L.; Funk, S.; Brucker, J.; Aharonian, F. A.; Dubus, G.; Fiasson, A.; Gallant, Y.; Hofmann, W.; Marcowith, A.; Reimer, O. The Astrophysical Journal Letters, vol. 690, pp. L101-L104 (2009)

The High Energy Stereoscopic System (HESS) survey of the Galactic plane has established the existence of a substantial number (≈ 40) of Galactic TeV γ-ray sources, a large fraction of which remain unidentified. HESS J0632+057 is one of a small fraction of these objects, which is point-like in nature (< 2′ rms), and is one of only two point-like sources that remain unidentified. Follow-up observations of this object with XMM-Newton have revealed an X-ray source coincident with the TeV source and with the massive star MWC 148, of the spectral type B0pe. This source exhibits a hard spectrum, consistent with an absorbed power law with $\Gamma = 1.26 \pm 0.04$, and shows significant variability on hour timescales. We discuss this spatial coincidence and the implied spectral energy distribution of this object and argue that it is likely a new γ-ray binary system with a close resemblance to the three known members of this class and, in particular, to LS I +61 303. Further, X-ray, radio, and optical observations of this system are needed to firmly establish HESS J0632+057 as a new member of this rare class of Galactic objects.

3.1.8 The Radio Counterpart of the likely TeV Binary HESS J0632+057

Skilton, J.; Pandey-Pommier, M.; Hinton, J.; Cheung, C.; Aharonian, F.; Brucker, J.; Dubus, G.; Fiasson, A.; Funk, S.; Gallant, Y.; Marcowith, A.; Reimer, O. Monthly Notices of the Royal Astronomical Society, vol. 399, pp. 317-322 (2009)

The few known γ-ray binary systems are all associated with variable radio and X-ray emission. The TeV source HESSJ0632+057, apparently associated with the Be star MWC148, is plausibly a new member of this class. Following the identification of a variable X-ray counterpart to the TeV source we conducted Giant Metrewave Radio Telescope (GMRT) and Very Large Array (VLA) observations in 2008 June-September to search for the radio counterpart of this object. A point-like radio source at the position of the star is detected in both 1280-MHz GMRT and 5-GHz VLA observations, with an average spectral index, $\alpha \approx 0.6$. In the VLA data there is significant flux variability on month time-scales around the mean flux density of about 0.3 *mJy*. These radio properties (and the overall spectral energy distribution) are consistent with an interpretation of HESSJ0632+057 as a lower power analogue of the established γ-ray binary systems.

3.1.9 Study of the Spectral and Temporal Characteristics of X-Ray Emission of the Gamma-Ray Binary LS 5039 with Suzaku

Takahashi, T. Kishishita, T.; Uchiyama, Y.; Tanaka,T.; Yamaoka, K.; Khangulyan, D.; Aharonian, F.; Bosch-Ramon, V.; Hinton, J.A. The Astrophysical Journal, vol. 697, pp. 592600 (2009)

We report on the results from Suzaku broadband X-ray observations of the galactic binary source LS 5039. The Suzaku data, which have continuous coverage of more than one orbital period, show strong modulation of the X-ray emission at the orbital period of this TeV gamma-ray emitting system. The X-ray emission shows a minimum at orbital phase 0.1, close to the so-called superior conjunction of the compact object, and a maximum at phase 0.7, very close to the inferior conjunction of the compact object.

The X-ray spectral data up to 70 keV are described by a hard power law with a phase-dependent photon index which varies within Γ: 1.45 – 1.61. The amplitude of the flux variation is a factor of 2.5, but is significantly less than that of the factor 8 variation in the TeV flux. Otherwise the two light curves are similar, but not identical. Although periodic X-ray emission has been found from many galactic binary systems, the Suzaku result implies a phenomenon different from the "standard" origin of X-rays related to the emission of the hot accretion plasma formed around the compact companion object. The X-ray radiation of LS 5039 is likely to be linked to very high energy electrons which are also responsible for the TeV gamma-ray emission. While the gamma rays are the result of inverse Compton (IC) scattering by electrons on optical stellar photons, X-rays are produced via synchrotron radiation. Yet, while the modulation of the TeV gamma-ray signal can be naturally explained by the photon-photon pair production and anisotropic IC scattering, the observed modulation of synchrotron X-rays requires an additional process, the most natural one being adiabatic expansion in the radiation production region.

3.1.10 X-ray Observations of PSR B125963 near the 2007 Periastron Passage

Chernyakova, M.; Neronov, A.; Aharonian, F.; Uchiyama, Y.; Takahashi, T. Monthly Notices of the Royal Astronomical Society, vol. 397, pp. 2123-2132 (2009)

PSR B1259-63 is a 48-ms radio pulsar in a highly eccentric 3.4-yr orbit with a Be star SS 2883. Unpulsed γ-ray, X-ray and radio emission components are observed from the binary system. It is likely that the collision of the pulsar wind with the anisotropic wind of the Be star plays a crucial role in the generation of the observed non-thermal emission. The 2007 periastron passage was observed in unprecedented details with Suzaku, Swift, XMM-Newton and Chandra missions. We present here the results of this campaign and compare them with previous observations. With these data we are able, for the first time, to study the details of the spectral evolution of the source over a 2-month period of the passage of the pulsar close to the Be star. New data confirm the pre-periastron spectral hardening, with the photon index reaching a value smaller than 1.5, observed during a local flux minimum. If the observed X-ray emission is due to the inverse Compton (IC) losses of the 10-MeV electrons, then such a hard spectrum can be a result of Coulomb losses, or can be related to the existence of the low-energy cut-off in the electron spectrum. Alternatively, if the X-ray emission is a synchrotron emission of very high-energy electrons, the observed hard spectrum can be explained if the high-energy electrons are cooled by IC emission in Klein-Nishina regime. Unfortunately, the lack of simultaneous data in the TeV energy band prevents us from making a definite conclusion on the nature of the observed spectral hardening and, therefore, on the origin of the X-ray emission.

3.1.11 Looking Into the Fireball: ROTSEIII and Swift Observations of Early Gamma-ray Burst Afterglows

Rykoff, E. et al The Astrophysical Journal, vol. 702, Issue 1, pp. 489-505 (2009)

We report on a complete set of early optical afterglows of gamma-ray bursts (GRBs) obtained with the Robotic Optical Transient Search Experiment (ROTSE-III) telescope network from 2005 March through 2007 June. This set is comprised of 12 afterglows with early optical and Swift/XRay Telescope observations, with a median ROTSE-III response time of 45 s after the start of γ-ray emission (8 s after the GCN notice time). These afterglows span 4 orders of magnitude in optical luminosity, and the contemporaneous X-ray detections allow multi-wavelength spectral analysis. Excluding X-ray flares, the broadband synchrotron spectra show that the optical and X-ray emission originate in a common region, consistent with predictions of the external forward shock in the fireball model. However, the fireball model is inadequate to predict the temporal decay indices of the early afterglows, even after accounting for possible long-duration continuous energy injection. We find that the optical afterglow is a clean tracer of the forward shock, and we use the peak time of the forward shock to estimate the initial bulk Lorentz factor of the GRB outflow, and find $100 < \Gamma < 1000$, consistent with expectations.

3.1.12 Centaurus A as TeV γ-ray and Possible UHE Cosmic-ray Source

Rieger, F. M.; Aharonian, F. A. Astronomy and Astrophysics, vol. 506, pp. L41-L44 (2009)

The most nearby active galaxy Cen A has attracted considerable attention as a detected TeV gamma-ray and possible ultrahigh energy (UHE) cosmic-ray emitter. Aims: We investigate the efficiency of particle acceleration close

to the supermassive black hole (BH) horizon assuming that accretion in the innermost part of the disk occurs in an advection-dominated (ADAF) mode. Methods: We analyze the constraints on the achievable particle energies imposed by radiative losses and corotation for conditions inferred from observations. Results: We show that for an underluminous source such as Cen A, centrifugally accelerated electrons may reach Lorentz factors of up to $\Gamma > 10^7$, allowing inverse Compton (Thomson) up-scattering of ADAF sub-mm disk photons into the TeV regime with an associated maximum (isotropic) luminosity of the order of a few times 10^{39}ergs^{-1}. Up-scattering of Comptonized disk photons is expected to lead to a TeV spectrum with a spectral index 1.5-1.9, consistent with HESS results. The corresponding minimum variability timescale could be as low as $r_L/c \approx 1$h for a typical light cylinder radius of $r_L \approx 5r_s$. While efficient electron acceleration appears to be well possible, protons are unlikely to be accelerated into the extreme UHECR regime close to the central black hole. We argue that if Cen A is indeed an extreme UHECR emitting source, then shear acceleration along the kpc-scale jet could represent one of the most promising mechanisms capable of pushing protons up to energies beyond 50 EeV.

3.1.13 Spectral Shape and Photon Fraction as Signatures of the GreisenZatsepin-Kuzmin Cutoff

Taylor, Andrew M.; Aharonian, Felix A. Physical Review D, vol. 79, Issue 8, id. 083010 (2009)

With the prospect of measuring the fraction of arriving secondary photons, produced through photo-pion energy-loss interactions of ultra-high-energy cosmic ray (UHECR) protons with the microwave background during propagation, we investigate how information about the local UHECR source distribution can be inferred from the primary (proton) to secondary (photon) ratio. As an aid to achieve this, we develop an analytic description for both particle populations as a function of propagation time. Through a consideration of the shape of the Greisen-Zatsepin-Kuzmin cutoff and the corresponding photon fraction curve, we investigate the different results expected for both different maximum proton energies injected by the sources, as well as a change in the local source distribution following a perturbative deformation away from a homogeneous description. At the end of the paper, consideration is made as to how these results are modified through extragalactic magnetic field effects on the proton's propagation. The paper aims to demonstrate how the shape of the cosmic ray flux in the cutoff region, along with the photon fraction, are useful indicators of the cutoff origin as well as the local UHECR source distribution.

3.1.14 Very High Energy Gamma Rays from e± Pair Halos

Eungwanichayapant, A.; Aharonian, F. International Journal of Modern Physics D, vol. 18, pp. 911-927 (2009)

We study the formation of giant electron-positron pair halos around the powerful high energy extragalactic sources, in particular active galactic nuclei. We investigate the dependence of radiation of pair halos, in particular the spectral and angular distributions on the energy spectrum of the primary gamma rays, the redshift of the source, and the flux of the extragalactic background light.

3.1.15 Development of the ASTRO-H Satellite

Aya Bamba, Felix Aharonian

ASTRO-H is a next generation X-ray satellite currently under construction in Japan. Aya Bamba and Felix Aharonian have joined the ASTRO-H mission to contribute to both the hardware development and the science case study. Aya Bamba has a responsibility to minimise the effects of out-gassing in the satellite and has begun to design the out-gas shield for the X-ray CCDs on ASTRO-H. She is also the leader for the public outreach programme of ASTRO-H. Felix Aharonian has been invited to the selected Science Working Group of ASTRO-H, whose main task is discussing the main science cases of ASTROH and making requirement for the detector design. As part of the science case studies and to promote awareness of ASTRO-H an international meeting "Exploring Supernova Remnants and Pulsar Wind Nebulae in X-rays: before and after ASTRO-H" will be held at ISAS/JAXA, Japan, in Feb 2010 organised by F. Aharonian and A. Bamba.

3.1.16 X-ray Follow-ups of TeV Sources

Aya Bamba, Takayasu Anada (ISAS/JAXA), Ryoko Nakamura (ISAS/JAXA), Yoshitomo Maeda (ISAS/JAXA), Jacco Vink (Utrecht U.), et al.

We have made X-ray follow-up observations of TeV sources to point out their origin and emission mechanism. HESS J1809–193 has been recognised as a pulsar wind nebula (Anada, Bamba, et al., PASJ, in press), whereas W28, an old

SNR detected by HESS, showed us that the north-eastern shock just hit a giant molecular cloud (Nakamura, Bamba, et al., PASJ, submitted). From Cas A, the youngest SNR in our Galaxy, we found that synchrotron X-rays mainly comes from the reverse shock (Maeda et al., PASJ, 61, 1217), which is also bright in TeV gamma-rays. Magnetars are energetic sources in the X-ray band, and recently some people claims that magnetars could be TeV gamma-ray emitters. Vink and Bamba (2009, ApJL, 707, 148) discovered nebula around a magnetar for the first time, which will be an important key to understand the nature of magnetars.

3.1.17 Study of Gamma-ray Loud Binaries in the Fermi Era

M.Chernyakova, A. Neronov (ISDC), D. Malyshev

γ-ray-loud binary systems (GRLB) are a newly identified class of X-ray binaries in which either accretion onto the compact object (a neutron star, or a black hole), or interaction of an outflow from the compact object with the wind and radiation emitted by the massive companion star leads to the production of very-high energy (VHE) γ-ray emission. Four such systems PSR B1259–63, LS 5039, LSI +61° 303 and HESS J0632+057, have been firmly detected as persistent or regularly variable TeV γ-ray emitters. Most of the variable and transient Galactic sources of GeV γ-ray are expected to belong to the GRLB class.

With the launch of the Fermi it becomes possible to complete the multi wavelength spectrum of GRLBs with the data in GeV domain. Two of γ-ray-loud binaries, LSI +61° 303 and LS 5039, turned out to be bright in GeV energy domain. In both binaries a spectral cutoff at several GeV has been detected. Our studies of the LSI +61° 303 behaviour at different wave length showed that the effect of γ–γ pair production can not explain the cutoff at GeV energies and the difference in the orbital modulation of the source flux at GeV and TeV energies, and that one has to consider a possibility that GeV and TeV γ -rays are produced via different mechanisms (e.g. synchrotron and inverse Compton) and/or by different particle populations (e.g. electrons and protons). One of the main observational evidence proving the hadronic model of source activity would be a detection of the neutrino signal from the source. In our work we worked out firm predictions for the expected neutrino signal from the source in this case.

We have also started a project aimed to study in detail variable sources of GeV emission located in the galactic plane, as these sources has a big chance to belong to still puzzling and unrepresentative GRLB class.

3.1.18 INTEGRAL Hard X-ray Spectra of the Cosmic X-ray Background and Galactic Ridge Emission

M. Chernyakova, M. Turler (ISDC), A. Neronov (ISDC)

We derive the spectra of the cosmic X-ray background (CXB) and of the Galactic ridge X-ray emission (GRXE) in the 20200 keV range from the data of the IBIS instrument aboard the INTEGRAL satellite obtained during the four dedicated Earth-occultation observations of early 2006. We analyse the modulation of the IBIS/ISGRI detector counts induced by the passage of the Earth through the field of view of the instrument. Unlike previous studies, we do not fix the spectral shape of the various contributions, but model instead their spatial distribution and derive for each of them the expected modulation of the detector counts. The spectra of the diffuse emission components are obtained by fitting the normalizations of the model lightcurves to the observed modulation in different energy bins. The obtained CXB spectrum is consistent with the historic HEAO-1 results and falls slightly below the spectrum derived with Swift/BAT. A 10% higher normalization of the CXB cannot be completely excluded, but it would imply an unrealistically high albedo of the Earth. The derived spectrum of the GRXE confirms the presence of a minimum around 80 keV with improved statistics and yields an estimate of $\approx 0.6 M_{\odot}$ for the average mass of white dwarfs in the Galaxy. The analysis also provides updated normalizations for the spectra of the Earth's albedo and the cosmic-ray induced atmospheric emission.

3.2 Theory

Luke Drury

3.2.1 Particle-in-cell Simulations of Mildly Relativistic Plasma Collisions

Gareth Murphy, L Drury, M Dieckmann

The acceleration of particles by mildly relativistic shocks requires plasma effects to inject a seed population of electrons. Particlein-cell (PIC) codes have been successful in modelling plasmas but are computationally expensive. We ported the particle-in-cell code PSC code to ICHEC

BlueGene/L and Altix ICE architecture and modified the code to allow for inline data analysis and parallel data output. We were awarded a total of 205,000 hours core time for the project from ICHEC. We carried out successful large-scale simulations of magnetised mildly relativistic plasma collisions which show promising results for magnetic field amplification (ten times that expected from shock compression) and electron acceleration to Lorentz factors of ≈ 200. We showed that filamentation is not suppressed by a quasi-parallel magnetic field. We also found evidence for decay of filaments into magnetic bubbles. See Fig 1 for a snapshot from one of the simulation runs.

3.2.2 How Cold can Supernova Remnants be?

L. O'C. Drury, F. A. Aharonian, D. Malyshev, S. Gabici Astron. and Astrophys. (2009) 496 1-6.

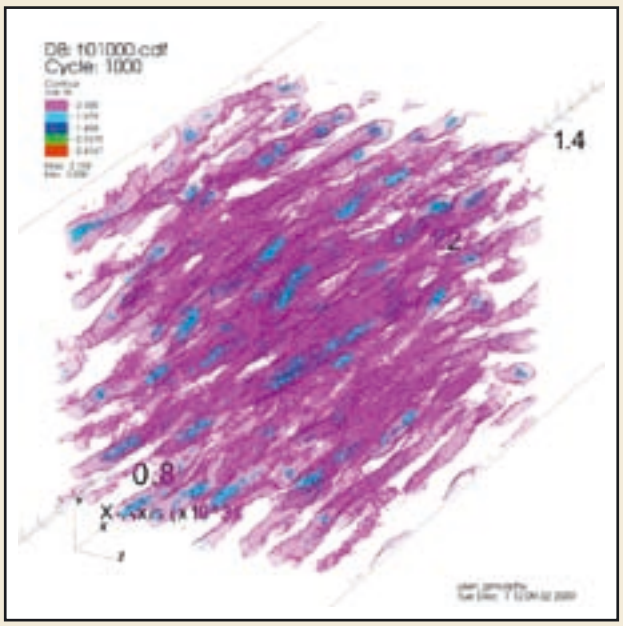

Figure 1: The Figure shows three-dimensional filaments formed by Weibeltype instabilities in a magnetised plasma shock. The filaments mix and merge in three dimensions and amplify the local magnetic field, enabling emission of synchrotron radiation.

Multiwavelength observations of supernova remnants can be explained within the framework of the diffusive shock acceleration theory, which allows effective conversion of the explosion energy into cosmic rays. Although the models of nonlinear shocks describe reasonably well the nonthermal component of emission, certain issues, including the heating of the thermal plasma and the related X-ray emission, remain still open. To discuss how the evolution and structure of supernova remnants is affected by strong particle acceleration at the forward shock analytical estimates were combined with detailed discussion of the physical processes. The overall dynamics is shown to be relatively insensitive to the amount of particle acceleration, but the post-shock gas temperature can be reduced to a relatively small multiple, even as small as six times, the ambient temperature with a very weak dependence on the shock speed. This is in marked contrast to pure gas models where the temperature is insensitive to the ambient temperature and is determined by the square of the shock speed. It thus appears to be possible to suppress effectively thermal X-ray emission from remnants by strong particle acceleration. This might provide a clue for understanding the lack of thermal X-rays from the TeV bright supernova remnant RX J1713.7-3946.

3.2.3 Comparison of *Ansätze* for Semi-analytic Models of Non-linear Particle Acceleration in Shocks

Luke Drury, Elena Amato (Arcetri)

As part of the programme of work of the Kavli Institute for Theoretical Physics workshop on particle acceleration in astrophysical plasmas it was decided to directly compare the various approximate Ansätze that have been proposed in semi-analytic treatments of steady non-linear shock acceleration. The differences are remarkably small, and early indications are that the more sophisticated models are little better, and in some cases worse, than the simpler ones, contrary to expectation.

3.2.4 Computational Studies of ISM Turbulence

T. Downes, S.O'Sullivan (DCU)

Observations of molecular clouds indicate that they are turbulent. This turbulence is dynamically significant and may well affect both the overall evolution of molecular clouds as well as the progress of star formation within these clouds. However, the properties of turbulence in such clouds is not well understood. Although much work has been done on studying turbulence in these clouds under the assumption of ideal magnetohydrodynamics we know that multifluid effects are important on scales of less than a parsec or so.

The first phase of a study of the decay of multifluid MHD turbulence in molecular clouds using the HYDRA code was published in early 2009 and showed that multifluid effects cause turbulence to decay more rapidly. They also reduce

the number of small-scale density structures within the cloud produced by the turbulence. The former result implies that, in order to maintain the level of turbulence observed, the driving source must supply energy at a greater rate. This study has been continued and is now nearly complete. The results support the conclusions of the first phase. Plans are now being made to perform simulations of driven multifluid MHD turbulence to investigate the statistical properties of clouds subject to this kind of turbulence for comparison with observations.

3.2.5 PRACE Prototype Supercomputer Testing

T. Downes

As part of a Europe-wide competition, 4.3 million core hours were awarded by PRACE (see http://www.prace-project.eu/) to investigate the performance of three different supercomputing architectures using the HYDRA multifluid MHD code. This award amounted to 95% of all the time awarded in that competition. HYDRA was shown to scale well to petascale systems on the JUGENE Blue Gene/P system at FZ-Juelich. Excellent performance was also found on the Bull Nehalem system JuROPA at FZ-Juelich, despite some technical system issues with running very large jobs. FZ-Juelich has given T. Downes an ongoing account on JuROPA to perform a joint study to resolve these issues. The performance of the Cray XT5 system at CSC in Finland was somewhat disappointing and Cray Inc have since contacted T. Downes to begin a joint study to pin-point the source of the poor performance.

Following from the success of HYDRA on the JUGENE system, IBM invited T. Downes to make a presentation at the Blue Gene Consortium meeting held at SC09 in Portland, Oregon. DIAS has also been invited to formally join the Blue Gene Consortium.

3.3 Star Formation

Tom Ray

3.3.1 Brown Dwarf Outflow Studies

E. Whelan, L. Podio, T.P. Ray with F. Bacciotti (Arcetri) and S. Randich (Arcetri)

Spectroscopic studies have strongly supported the assertion that protostellar accretion and outflow activity persist to the lowest masses. Observations to date have concentrated on studying the forbidden emission line (FEL) regions of young brown dwarfs and in all cases data have been collected using the UV-Visual Echelle Spectrometer (UVES) on the ESO Very Large Telescope. Because these outflows are so faint, and most of the emission is within the 'seeing disk', we have to resort to the special technique of spectro-astrometry to recover information on milli-arcsecond scales. Application of the method, using orthogonal slits, allows us to recover 2-D spatial data. In particular the brown dwarf ISO-Oph 32 was shown to drive a blueshifted outflow with a radial velocity of 10-20 km s^{-1} at a position angle of 240°± 7° . Another brown dwarf, ISO-ChaI 217 was found to have a bipolar outflow (with radial velocities of ¥20 km s^{-1} and +40 km s^{-1}) and a position angle of around 200°. A striking feature of the ISO-ChaI 217 outflow is the strong asymmetry between the red-and blue-shifted lobes. This asymmetry is revealed in the relative brightness of the two lobes (the redshifted lobe is brighter), the factor of 2 difference in radial velocity (the redshifted lobe is faster) and the difference in the electron density (again higher in the red lobe). Such asymmetries are common in jets from low-mass protostars and the observation of a marked asymmetry at such a low masses supports the idea that brown dwarf outflow activity is scaled down from low-mass protostellar activity.

Studies of mass loss rates for our sample of brown dwarf outflows show these to be comparable to the mass accretion rates. This result however is preliminary as it relies on a small sample and the proxies for accretion in brown dwarfs may not be as reliable as those in classical T Tauri stars.

3.3.2 First Detection of Acceleration and Deceleration in Protostellar Jets

A. Caratti o Garatti

For the first time a multi-epoch (20 year baseline) kinematical investigation of a number of Herbig-Haro (HH) objects has been achieved. Optical and near-IR narrowband imaging, along with medium (optical) and high resolution (NIR) spectroscopic analysis, have been used to probe the kinematical and physical changes in outflows over time. By means of multi-epoch and multi-wavelength narrow-band images, we derived proper motions (hence tangential velocities), and flux variability of the knots. Radial velocities and physical parameters of the gas were derived from spectroscopy. Finally, spatial velocities and inclination of

the flows were obtained by combining both imaging and spectroscopy. In 20 years, about 60% of the observed knots show some degree of flux variability. For the first time acceleration and deceleration in protostellar jets are detected. Our set of observations apparently indicates acceleration and deceleration in a variety of knots along the jets. For about 20% of the knots, mostly coincident with working surfaces or interacting knots along the flows, a significant change in both flux and velocity is observed. We argue that such changes are related and that all, or part, of the kinetic energy lost by the interacting knots is successively radiated. Several knots are deflected and this is likely the result of the flow colliding with a dense cloud or with clumps.

3.3.3 Simulations of Interacting Herbig-Haro objects and Comparison with Observations

F. De Colle (now Lick Observatory, formerly DIAS) and A. Caratti o Garatti

We are investigating protostellar jet time-variability using 2-D axisymmetric magneto-hydrodynamic (MHD) simulations. In particular, we wish to reproduce the emission and velocity variability, observed in interacting knots along the jets. To understand the process responsible for such changes, the simulations are carried out by periodically pulsing the jet and comparing the results obtained with observations. In our simulations, the variability is assumed to be due to the interaction between knots traveling with different shock speeds and densities.

3.3.4 NIR Spectroscopic Survey of Jets from Massive Young Stellar Objects

A. Caratti o Garatti in collaboration with B. Stecklum (Tautenburg), C. Davis (JAC), H. Linz (MPIA), T. Stanke (ESO), and H. Zinnecker (AIP).

The detection and study of jets and outflows from high-mass young stellar objects (HMYSOs) is of primary importance in understanding the mechanism which produces massive stars. Using the 4.5 μm excess (IRAC, band 2) as a tracer of shocked H_2, we have identified about 160 candidate protostellar outflows in the Spitzer GLIMPSE survey. In order to verify their nature, a follow-up campaign for H_2 1–0 S1 (2.12 μm) imaging has been carried out. using different IR detectors (ESO-NTT/SofI, TNG/NICS, ARC3.5m/NICFPS). About half of the observed targets have been detected at 2.12 μm. The non-detections point to large dust column densities and/or different excitation conditions. Additionally, we undertook an unbiased spectroscopic follow-up of the H_2 emissions detected during our previous imaging runs (ESO-NTT/SofI, TNG/NICS), to clarify the nature and the origin of such emissions (shock vs. fluorescence; jet vs. photo-dissociation region), derive their excitation conditions (temperature, extinction), and the flow properties (mass, mass ejection rate, H_2 luminosity), correlating them with the evolutionary stage of the driving YSO. The analysis has not yet been completed.

3.3.5 YSO NIR Spectral Survey: L1641 Star Forming Region

A. Caratti o Garatti, L. Barreyre, and T. Ray in collaboration with Rome and Tautenburg Observatories

Our classification of young stellar objects (YSOs) is empirical, based on the Spectral Energy Distribution (SED). Recent studies revealed the limitations of such a classification, which does not provide any information on the physical properties of the protostar itself, as well as on the processes related to the accretion/ejection activity, occurring in the circumstellar environment. Additionally, such empirical 'miss-classification' can introduce huge errors in determining the lifetimes associated with the various stages of YSO evolution. A correct classification can be obtained from a large sample of objects, combining the YSO SEDs analysis with their mass accretion rates, derived from spectroscopy. We have thus started an optical and infrared spectroscopic survey, using the ESO/NTT and SOFI, of YSOs located in six nearby molecular clouds of the Gould Belt (a star formation ring centred roughly on the Sun). These spectra are complementary to the SEDs derived from Spitzer, 2MASS, and optical photometry. In particular, the DIAS group is studying the YSO sample in L1641 star forming region.

3.3.6 Spitzer Gould Belt Survey: Corona Australis Star Formation Region

A. Caratti o Garatti, T.P. Ray and the Spitzer Gould Belt Team

We have investigated Spitzer Space Telescope IRAC and MIPS observations of a 0.85 deg^2 field including the Corona Australis (CrA) star forming region. At a distance of 130 pc, CrA is one of the closest regions known to be actively forming stars, particularly within its embedded association, the Coronet. We have identified and classified 40 young

stellar objects (YSOs) in CrA through Spitzer and near-infrared 2MASS photometry. In addition we have used multi-epoch H_2 maps, which allowed us to detect jets and outflows, studying their proper motions, and identifying their exciting sources.

3.3.7 Constraining the Inventory of Star Forming Regions and the Initial Mass Function

A. Scholz, R. Jayawardhana (Univ. Toronto), V. Geers (Univ. Toronto), D. Froebrick (Univ. Kent), C.J. Davis (Joint Astronomy Center) et al.

Identifying the young objects in star forming regions is the prerequisite for any study of the early phases of stellar evolution. Our goal to derive a census of young stars and brown dwarfs in nearby clusters. This enables us to put constraints on key diagnostics for our understanding of star formation, including the Initial Mass Function, and to study fundamental problems, e.g. the relevance of dynamical interactions and turbulent fragmentation for the formation of stars.

The specific goal of the SONYC survey (short for Substellar Objects in Nearby Young Clusters) is to carry out extremely deep observations to identify objects down to only a few Jupiter masses (0.005 solar masses). We want to study the substellar part of the IMF and find the lowest mass limit for star formation. In this project we use optical and near-infrared wide-field imaging from 8-m telescopes (Subaru, VLT) combined with mid-infrared data from the Spitzer Space Telescope to select candidates. This is followed by low-resolution spectroscopy to look for evidence of youth and thus confirm the nature of the candidates. In the first SONYC publication focused on the cluster NGC1333 we found anomalies in the mass function at substellar masses -a high fraction of brown dwarfs and a cut-off in the mass distribution at 0.015-0.02 solar masses. Currently we are finishing the analysis for the Rho-Oph star forming region, where we identify a new sample of brown dwarf candidates. The analysis for the third region Chamaeleon-I is in progress.

In addition, we have almost finished a survey in the small molecular cloud IC1396W. At a distance of 750 pc, this region is a challenge for current instrumentation. We developed a combined colour-variability criterion to identify young stellar objects, based on a imaging time series obtained with the UKIRT telescope. We found only very few young stars in IC1396W, which points to star forming efficiency much lower than in nearby regions. Serendipitously the survey yielded two new eclipsing binaries.

3.3.8 Characterising Young Stellar Objects and Their Environment

A. Scholz, A Caratti o Garatti, D. Wilner (Center for Astrophysics), R. Jayawardhana (Univ. Toronto), K. Wood (St. Andrews), B. Stelzer (Palermo) et al.

In a number of detailed case studies we aim to provide a close-up view on young stellar objects and their environment. This includes their natal cloud, the envelope, accretion disk, as well as the innermost accretion zone. In addition, we want to provide improved constraints on the fundamental properties of the central sources, to be able to put the objects in an Hertzsprung-Russell diagram. The hope is to use these case studies improve our understanding about the early evolutionary phases of young stars and brown dwarfs.

We have almost finished an extensive study of the protostellar system IRAS04325+2512 in the Taurus-Auriga star forming region. For this multiple system we have obtained images and spectra from Gemini, the Submillimeter Array, and ESO, complemented by data from Spitzer and various archives. All our images have a spatial resolution of 1 arc-second or better (i.e. less than 150 AU). Based on this rich dataset we derive effective temperatures for the central sources and provide robust constraints for the complex spatial configuration. For this particular case there is some evidence for primordial misalignments in the disk-binary orientation, which favours turbulent fragmentation as a formation scenario.

The object FU Tau A is a brown dwarf recently identified as part of a binary system that has most likely formed in isolation. Based on Chandra observations we have now evidence for strong accretion-induced X-ray emission from this source. This is the most X-ray active brown dwarf ever identified. Using optical spectra and the available archive photometry our goal is to understand the accretion process for this prototypical sub-stellar object. Strong variability in the accretion rate and/or configuration is likely. These results will be published as a Letter in Monthly Notices of the Royal Astronomical Society.

3.3.9 Measure variations in Accretion and Outflow in a Large Sample of Protostars

G.M. Costigan, A. Scholz and J. Vink (Armagh Observatory)

Young stars are observed to accrete gas from a circumstellar disk. This is the final phase of the accretion of matter and angular momentum. The most successful model for this process is magnetospheric accretion, i.e. the funneling of gas along the lines of strong magnetic fields. Until recently disk accretion was mostly studied as a static phenomenon, despite the overwhelming observational evidence for strong variations. In addition, accretion variability has only been studied for small samples of objects.

In a project dubbed LAMP (Long-term Accretion Monitoring Program) we aim to make progress in understanding the dynamics of the accretion process. The core of the program is a multi-epoch time series obtained with FLAMES at the VLT. FLAMES is a fibre spectrograph which we use to observe about 50 young stars in the Chamaeleon I star forming region. Ultimately we hope to obtain about 20 high-resolution spectra for each of these objects, covering timescales from weeks to three years.

As part of her new PhD project, the Lindsay Scholar, G. M. Costigan, has recently started to analyse the first set of FLAMES spectra. She has measured line-widths for accretion-related emission lines and identified the variable sources in the sample. These measurements will lead to the first reliable assessment of accretion rate changes for a large sample of young stars.

3.3.10 Investigating Gas Physical Conditions and Dust Reprocessing in Jets from Young Stars

Linda Podio, D. Coffey, E. Whelan and T. Ray

This research activity is focused on studying the physics and the origin of stellar jets through the analysis of spectroscopic observations at optical and near-infrared wavelengths.

Application of spectral diagnostic techniques to velocity resolved spectra (taken with EFOSC2 at the 3.6m ESO telescope, HIRES at the KECK telescope, and ISAAC at the ESO Very Large Telescope) have allowed us to study the jet physical structure as a function of the gas velocity and to investigate the origin of different velocity components in the jets. Interestingly, we found that, in agreement with the predictions from shock models and magneto-centrifugal models proposed to explain jet launching, the high velocity component is denser and more excited (Podio et al. 2009, Podio et al. in preparation, Garcia Lopez et al. 2009).

In parallel, the analysis of high angular resolution observations taken with the Hubble Space Telescope allowed us to trace the morphology, physics, and kinematics of the jet down to 15 AU from the source and across its axis, thus probing the region where the flow is accelerated and collimated. This provides stringent constraints on the mechanism generating the jet. For example, we showed that the high velocity gas in the jet is denser and more excited and is confined to the jet axis, i.e. the collimation angle increases at lower velocities (Bacciotti et al., in preparation).

Moreover, we investigated dust reprocessing in stellar jets, a topic that has been poorly explored to date. This analysis showed that the jet still contains a measurable amount of dust (Podio et al. 2009, Podio et al. in preparation). This finding put severe constraints on the extent of the region from which the jet is launched (Podio et al. 2009).

Finally our spectral diagnostic technique have been applied to analyse faint forbidden lines detected in the spectra of young brown dwarfs. This allowed us to estimate the mass loss rate for these sources. We found that the mass ejection to mass accretion ratio is 0.1, suggesting brown dwarfs are very similar to solar mass Classical T Tauri star outflows (Whelan et al. 2009).

3.3.11 Formation of Structures in HII Regions

J. Mackey and A.J. Lim

J. Mackey has developed a modular Magneto-Hydrodynamics (MHD) code with ray-tracing radiative transfer as part of his PhD thesis supervised by A. Lim. This code has been used to study the evolution of ionised Hydrogen (H II) regions which grow around young massive stars. We have performed high-resolution parallel 3D numerical simulations of the formation of dense pillars of gas (known as elephant trunks) which are observed on the boundaries of large H II regions. Our results demonstrate that a mechanism based on the shadowing of radiation from nearby young stars is a viable explanation for the formation of these pillars. Detailed analysis of our simulation data also provides a possible explanation for unusual

velocity measurements obtained from the Eagle Nebula (M16) pillars.

The simulations were run on the ICHEC supercomputing system "Stokes". Early results from this research were presented at the European Week of Astronomy and Space Sciences (incorporating the RAS NAM2009 and EAS JENAM2009 meetings) from 20-23 April 2009, and were the subject of a press release which attracted media interest including an RTE television news piece (23rd April 2009) and a Space.com online article http://www.space.com/scienceastronomy/090422-nebula-pillars.html.

We are currently extending our research by investigating the influence of an ambient magnetic field on the types of structures generated by the shadowing mechanism. Initial results indicate the strength and orientation of the field to be an important component of this theory of pillar formation.

3.3.12 Observing Outflows Close to the Ejection Engine

Deirdre Coffey, Linda Podio and T. Ray

Research continued to consolidate findings that jets from young stars rotate, in order to address the issue of how angular momentum is removed during star formation. More statistical evidence is required, such as examining jets at various evolutionary stages, and examining the disks of systems for which the supposed jet rotation has been measured. The Gemini near-infrared spectrograph (GNIRS) on GEMINI South revealed possible rotation signatures in near infrared lines of 4 outflow sources from embedded Class 0 and I stars, giving an indication of the possible evolution of angular momentum extraction over time. (Coffey et al., 2010 submitted). Observations have been conducted with the AO-assisted near-infrared integral field spectrometer (NIFS) on GEMINI North of the disk of the T Tauri star, RY Tau for which the supposed sense of jet rotation is known (P.I. Coffey). Furthermore, time has also been granted on ESO's VLT CRyogenic high-resolution InfraRed Echelle Spectrograph (CRIRES) to study, using spectroastrometry, the disk of the T Tauri star Th 28 (P.I. Coffey). These 2 cases will increase to 5 the number of targets for which both jet and disk rotation sense have been measured, allowing us to test further whether we are observing jet rotation.

Other work included investigation of the origin of permitted lines which are easily excited in the circumstellar region of young accreting stars. These lines may include contributions from both the accretion columns and the outflowing material, and thus their analysis can shed light on the central engine for the jet launching and its relationship with magnetospheric accretion. Direct observations were reported of the high excitation H I lines of Paschen Beta and Brackett Gamma from the Th 28 T Tauri outflow within the first arcseconds of the jet launching region using the VLT Infrared Spectrometer And Array Camera (ISAAC), thus confirming that hydrogen permitted lines are not only tracers of accretion but also ejection (Coffey et al., submitted).

3.3.13 Anomalous Microwave Emission

A. Scaife

The complete characterization of the "anomalous" microwave emission from spinning dust grains is a key question in both astrophysics and cosmology. It probes a region of the electromagnetic spectrum where a number of different astrophysical disciplines overlap. It is important for cosmic microwave background (CMB) observations in order to correctly characterise the contaminating foreground emission; for star and planetary formation it is important because it potentially probes a regime of grain sizes that is not otherwise easily observable.

Although a number of objects have now been found to exhibit anomalous microwave emission, attributed to spinning dust, it is still unclear what differentiates those objects from the many other seemingly similar targets that do not show the excess.

A. Scaife (AS) is working on the identification and characterization of the anomalous emission attributed to spinning dust. In a recent paper (arXiv0910.4011) she published the first observational evidence for a spatial correlation between the anomalous microwave emission and MIR emission from very small dust grains.

AS is PI of a large joint observing program with the AMI telescope at 12–18 GHz (UK) and the SZA telescope at 30 GHz (USA) to study the microwave spectrum of star formation regions selected from the Spitzer c2d program. This project is in collaboration with colleagues in the UK and the USA.

AS is PI of an observing program with the MUSTANG camera on the GBT to investigate the 90 GHz emission from a previously identified sample of star formation regions which exhibit anomalous microwave emission. This project is in collaboration with colleagues in the UK and the USA.

AS is PI of an observing program with the HARP instrument on the JCMT to investigate the possibility of previously unidentified VeLLoS within star formation regions which exhibit anomalous dust emission. This project is in collaboration with colleagues in the UK.

AS is involved in the Canadian-lead science case for a Q Band instrument on the ALMA telescope (arXiv0910.1609) with respect to studying anomalous dust emission.

3.3.14 The Magnetic Universe

A. Scaife

AS is part of the management team for the LOFAR Magnetism Key Science Project (MKSP). This KSP aims to investigate fundamental astrophysical questions on the distribution of magnetic fields in the Universe in order to understand the origin of cosmic magnetism. Polarimetry with LOFAR will allow investigations of the so far unexplored domain of extremely weak magnetic field strengths via Faraday rotation. This is a large international project with contributions from 12 countries.

AS is co-I of the proposed Cosmic Magnetism KSP for the MeerKAT telescope, the South African SKA pathfinder instrument. This project aims to investigate the magnetic field structure of the inter-galactic filaments in galaxy groups and clusters. This project is in collaboration with colleagues in the UK, Germany, the Netherlands and Australia.

3.3.15 The Sunyaev–Zel'dovich Effect

Anna Scaife

AS leads the Galactic science program for the AMI telescope (UK) and is part of the consortium for the blind SZ cluster survey being carried out with this instrument. SZ cluster surveys will provide an important constraint on the structure formation of the Universe which is not well understood from CMB cosmology.

AS is leading the SZ side of a joint AMI–XMM project to provide combined analysis of high temperature galaxy clusters.

3.3.16 Starburst Evolution

Anna Scaife

AS is involved in a multi-frequency analysis of the radio spectrum of Ultra Luminous IRAS Galaxies (ULIRGs). AS visited the GMRT (India) to make new observations of the low frequency emission from these objects and is co-I on an observing project with the AMI LA (UK) to make high resolution, high frequency measurements of the same sample of objects. This work will investigate the discrepancy between the thermal fraction indicated by free-free absorption at the low end of the frequency spectrum and a steepening of the spectral index at the higher end. These projects are in collaboration with colleagues in Italy.

3.3.17 Magnetic Fields of Fully-Convective Stars

J. Morin

Spectropolarimetric observations of main sequence M dwarfs have already led to very important results. In particular, previous work has demonstrated that stars just below the full-convection divide are able to trigger strong and long-lived large-scale fields much more efficiently than more massive partly-convective ones. The most recent observations reveal that below 0.2 $M_{\odot}$ stars with very similar masses and rotation rates unexpectedly host radically different magnetic fields.

This first survey will be completed to explore the dynamo response of moderately active fully-convective objects, and to assess the existence of magnetic cycles. The behaviour of late-type objects will be studied through combined spectropolarimetric and radio observations, in order to understand why very similar stars generate such widely different fields. In parallel, new MHD simulations of dynamo action in fully-convective stars will aim to understand the discrepancies between the first observations and theoretical studies. Spectropolarimetric observations of T Tauri stars will be carried out in parallel to highlight similarities and differences between dynamo processes in main sequence and pre-main sequence fully convective stars.

3.3.18 JETSET

T.P. Ray, JETSET Network Coordinator

The final meeting of the JETSET Consortium was held in Dornberg Castle near Jena in Germany in January. Here presentations were made by early stage and experienced

network researchers of their work to date. All students were on course to finish their PhD studies and submit their thesis within a few months of the termination of the network. A discussion was held on possible industrial links that the network could develop to strengthen any future application for continued funding under Framework 7's Marie Curie Programme. A final report was presented to the Commission which clearly illustrated the enormous success of JETSET not only in training but also in terms of new scientific collaborations (for example, the network produced a total of approximately 200 joint publications). This report was approved and the outstanding funding (10% of the total budget) distributed to the nodes.

An application for continuation of the network, with ten industrial partners including Springer-Verlag and Astrium EADS and three new full partners including IBM, PALS in Prague and the Max Planck Institute for Astronomy in Heidelberg, was submitted for consideration by the Commission.

3.3.19 MIRI

T. Ray with B. Espey (TCD) and B. Frye (DCU)

The Mid-Infrared Instrument (MIRI) for the James Webb Space Telescope (JWST) is on track for delivery to NASA Goddard in early 2011 following testing of the Flight Model (FM). The FM is currently under construction and will be tested under cryogenic conditions (7K) at the Rutherford Appleton Laboratory (RAL). As the FM DIAS filters and beam-splitters have been delivered, the Irish hardware contribution to MIRI is now complete. NASA have informed the MIRI Consortium that want the consortium to provide much of the software for pipeline calibration and subsequent data analysis. Funding was secured for two software developers (at the DIAS Scientific Officer grade) under the ESA/Prodex programme and two two-year positions were advertised on appropriate mailing lists. Both positions were filled and Julien Morin (formerly from Grenoble) and Anna Scaife (formerly from Cambridge) took up their posts in November and December respectively. It is also worth noting that Enterprise Ireland have indicated their willingness to continue supporting MIRI software development, subject to available funds,from the next tranche of Prodex funding, until launch (2013).

The MIRI software team will eventually be coordinated from the Astronomy Technology Centre (ATC) in Edinburgh and will consist of 6 FTEs (possibly growing to 8 FTEs immediately prior to launch). Fred Lahuis (SRON in the Netherlands) will act as the interim software lead. It is thus envisaged that DIAS will be in a position to make a major contribution to the MIRI software effort in collaboration with the Space Telescope Science Institute in Baltimore.

Work has begun on defining the core (guaranteed time) program using MIRI. T.P. Ray is involved with E. Dishoek (Leiden) and Henrik Beuther (Heidelberg) in the star formation proposal. Preliminary discussions were held with our US colleagues (responsible for supplying the MIRI focal plane detectors) to pool our guaranteed time resources.

It is worth also mentioning that a large allocation (approximately 600 hrs) of extended Multi-Element Radio Linked Interferometer Network (e-MERLIN) time has been granted to survey jets from young stars as part of the e-MERLIN Legacy Programme. e-MERLIN is currently being commissioned and will provide the deepest radio images yet of these outflows.

3.4 GRB and Stellar Evolution Studies

Evert Meurs

3.4.1 Gamma Ray Bursts: REM Telescope Observations and Afterglow Lightcurves

E.J.A. Meurs, L. Norci and P. Ward (DCU), E. Molinari, S. Covino, et al. (Brera Observatory)

Only a couple of Gamma Ray Burst (GRB) afterglows (one of which a first detection) could be detected with the REM Telescope throughout the year, which was a consequence of the observing programme of the Swift satellite.

Further work was carried out on modelling supernova contributions to GRB afterglow lightcurves, which employs the cosmological K-corrections that we have developed for all main types of supernovae.

3.4.2 High Resolution Echelle Spectroscopy of GRB Afterglows

E.J.A. Meurs, L. Norci and P. Ward (DCU), F. Fiore, V. DÕElia, S. Piranomonte (Rome Observatory)

High-resolution echelle spectroscopy is a relatively new and exciting tool for GRB astronomy. Data may now be obtained only minutes after a burst has occurred, which is important

because of the transient nature and decreasing brightness of the afterglows. The echelle spectroscopy highlights the presence of intervening material along the line of sight, in the immediate surroundings of a burst as well as in separate intervening systems.

The analysis of our high signal-to-noise, high-resolution spectrum of the GRB afterglow of the 'naked-eye' burst, GRB080319B, was finalised, emphasizing the strongest Fe II fine structure lines ever observed for a GRB. The decrease in optical depth and in optical/UV flux of these lines in a spectrum taken a few hours later demonstrates that the excitation of the fine structure lines is due to UV pumping. The line-of-sight absorbers in the host galaxy are found to be at 2-6 kpc from the GRB site. Several absorbing systems lying between us and GRB080319B, along the line-of-sight to this GRB, could also be studied, featuring absorption lines due to Mg II and other species. The distribution of Mg II line strengths is in agreement with the excess of strong Mg II absorbers for GRBs as compared to quasar lines-of-sight. This difference is not caused by a difference in size of the GRB and quasar emitting regions.

Detailed echelle spectra had also been secured for the burst GRB080330. Assuming again UV pumping, the bluemost absorption component in the host galaxy system appears to be much closer to the burst in this case, at about 0.3 kpc from the GRB site. For this study, as well as the previous one on GRB080319B, a novel time-dependent photo-excitation code was employed. .

3.4.3 Echelle Spectroscopy of Normal and Runaway OB Stars

E.J.A. Meurs, C. OÕMaoileidigh, L. Norci (DCU), C. Rossi and V.F. Polcaro (Rome), R. Gualandi (Loiano)

Two programmes of optical spectroscopy have been conducted, employing the 1.52 m telescope of Loiano Observatory (Italy). For one programme, aimed at determining rotational velocities of OB runaway stars, a few additional spectra were obtained. The results support the idea that the O type runaways, rather than the B types, acquired their velocities as a result of a supernova event in a binary (mass transfer episode leading to increased rotational velocity). In the other programme we are completing a census of all Northern OB stars with magnitude V<9, to find hitherto unrecognised runaway objects.

3.4.4 OB Runaway Star Lightcurves

E.J.A. Meurs, S. Reynolds (DCU)

High-precision photometric lightcurves of OB runaway stars may allow to recognise collapsed companions (i.e., neutron stars) to these stars. The presence of a (close) collapsed companion would be noticeable from the gravitational distortion of the shape of the normal star (the runaway star as such), which causes small, periodic light variations. Recognising a collapsed companion is relevant in view of the likely occurrence of a supernova in a binary that led to the observed high space velocities of these stars. The database used for this investigation is provided by the results of photometric measurements that were carried out with the Hipparcos astrometric satellite. A couple of promising cases emerged from this project.

3.4.5 High-energy Emission from Young Stellar Clusters

E.J.A. Meurs, P. Kavanagh and L. Norci (DCU)

We are examining the youngest Galactic stellar clusters at X-rays (using Chandra and XMM-Newton data), to confront models of high-energy emission from such very young clusters with the observational reality, without yet the complications of evolved binaries (i.e., X-ray binaries) or supernova remnants. Our analysis of X-ray data for the very young Galactic Super Star Cluster Westerlund 1 focussed on assessing the role of Pre-Main Sequence stars as potential contributors to the diffuse hard X-ray emission component in this cluster.

3.4.6 AGN Contributions to HDF Galaxies

E.J.A. Meurs, C. Helly (DCU)

For a particular colour versus spectral slope diagram for high redshift galaxies in the Hubble Deep Fields, tracks were calculated that represent varying levels of an active nucleus contribution to the light emission from these objects, for several relevant models of galaxies.

3.5 Dosimetry for Biological Experiments in Space (Dobies)

Denis O'Sullivan

3.5.1 ISS Flight 13S

Much of the DOBIES research completed in 2009 concerned the experiment carried out on the ISS 13S flight of the

Space Shuttle in the autumn of 2008 (12th -24th October) in the Kubic facility in the European Columbus Module. This work is a collaboration with SCK-CEN, Belgium; JSC, Houston; NPI, Prague; OSU, USA; and DIAS. DIAS/JSC are responsible for determining the cosmic ray linear energy transfer (LET) spectra in the exposed detectors. Preliminary results obtained by the DIAS/JSC team for one detector stack were reported at the Prodex meeting in Dublin in April 2009. Work continued throughout the summer and the final results for three detector stacks were presented at the international "Workshop on Radiation Measurements on the International Space Station", WRMISS, held in Dublin in September 2009. Trends observed in the preliminary data were confirmed and the analysis showed higher doses of radiation exposure than those observed in the experiments undertaken in 2006 (see Fig 2). The magnitude of the increase was consistent with the phase of the solar cycle which was closer to the minimum in late 2008 and this allowed a greater flux of galactic cosmic rays to penetrate to near the International Space Station orbit.

3.5.2 Expose-E and Ying B1 and B2

In 2007 DIAS/JSC detector stacks were installed on the Columbus maiden flight in collaboration with DLR and SCK-Centre detectors and were exposed on a platform outside the ISS for about 2 years. These detectors measured the direct radiation intensity in space and obtained very valuable data regarding extra vehicular activities. The detectors were returned in the autumn of 2009 and analysis will begin in 2010. DIAS/JSC detectors were exposed also on the Japanese missions Ying B1 and B2 between 30.9.2009 and 11.10.2009. Analysis will start shortly.

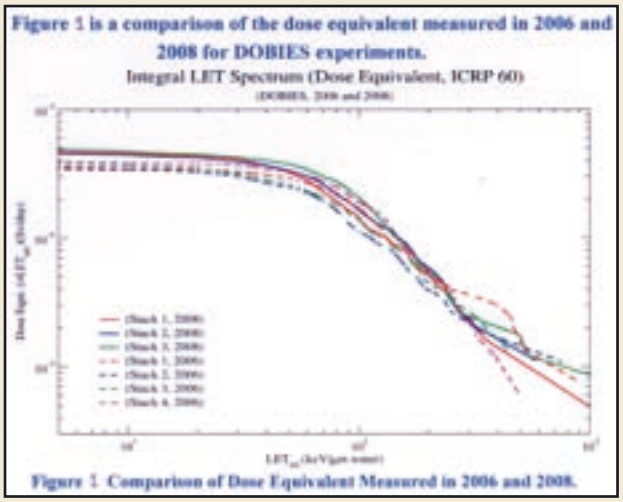

Figure 2:

4 Publications

4.1 Refereed Publications

Note that all the publications listed as Aharonian et al (HESS collaboration) include F. Aharonian, L. Drury and S. Gabici as co-authors from DIAS. Almost all these publications are available online as a private library under the ADS using the following URL:

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname= Ref2009&libid=4794ca7845

1. Aharonian, F., et al.: Probing the ATIC peak in the cosmic-ray electron spectrum with H.E.S.S. *Astronomy and Astrophysics* (2009) **508** 561-564.

2. Aharonian, F., et al.: Discovery of Very High Energy γ-Ray Emission from Centaurus a with H.E.S.S. *Astrophysical Journal* (2009) **695** L40-L44.

3. Aharonian, F., et al.: Simultaneous Observations of PKS 2155-304 with HESS, Fermi, RXTE, and Atom: Spectral Energy Distributions and Variability in a Low State *Astrophysical Journal* (2009) **696** L150-L155.

4. D'Elia, V., et al.: The Prompt, High-Resolution Spectroscopic View of the "Naked-Eye" GRB080319B *Astrophysical Journal* (2009) **694** 332-338.

5. Hinton, J. A., et al.: HESS J0632+057: A New Gamma-Ray Binary? *Astrophysical Journal* (2009) **690** L101-L104.

6. Rykoff, E. S., et al.: Looking Into the Fireball: ROTSE-III and Swift Observations of Early Gamma-ray Burst Afterglows *Astrophysical Journal* (2009) **702** 489-505.

7. Acciari, V. A., et al.: Radio Imaging of the Very-High-Energy γ-Ray Emission Region in the Central Engine of a Radio Galaxy *Science* (2009) **325** 444

8. O'C. Drury, L., Aharonian, F. A., Malyshev, D., & Gabici, S.: On the plasma temperature in supernova remnants with cosmic-ray modified shocks *Astronomy and Astrophysics* (2009) **496** 1-6.

9. Takahashi, Tadayuki, Kishishita, Tetsuichi, Uchiyama, Yasunobu, Tanaka, Takaaki, Yamaoka, Kazutaka, Khangulyan, Dmitry, Aharonian, Felix A., Bosch-Ramon, Valenti, & Hinton, Jim A.: Study of the Spectral and Temporal Characteristics of X-Ray Emission of the Gamma-Ray Binary LS 5039 with Suzaku *Astrophysical Journal* (2009) **697** 592-600.

10. Aharonian, F., et al.: Discovery of Gamma-Ray Emission From the Shell-Type Supernova Remnant RCW 86 With Hess *Astrophysical Journal* (2009) **692** 1500-1505.

11. Aharonian, F., et al.: A Search for a Dark Matter Annihilation Signal Toward the Canis Major Overdensity with H.E.S.S. *Astrophysical Journal* (2009) **691** 175-181.

12. Aharonian, F., et al.: Spectrum and variability of the Galactic center VHE γ-ray source HESS J1745-290 *Astronomy and Astrophysics* (2009) **503** 817-825.

13. Aharonian, F., et al.: Simultaneous multiwavelength observations of the second exceptional γ-ray flare of PKS 2155-304 in July 2006 *Astronomy and Astrophysics* (2009) **502** 749-770.

14. Aharonian, F., et al.: Constraints on the multi-TeV particle population in the Coma galaxy cluster with HESS observations *Astronomy and Astrophysics* (2009) **502** 437-443.

15. Aharonian, F., et al.: Very high energy gamma-ray observations of the galaxy clusters Abell 496 and Abell 85 with HESS *Astronomy and Astrophysics* (2009) **495** 27-35.

16. Gabici, S., Aharonian, F. A., & Casanova, S.: Broad-band non-thermal emission from molecular clouds illuminated by cosmic rays from nearby supernova remnants *Monthly Notices of the Royal Astronomical Society* (2009) **396** 1629-1639.

17. Taylor, Andrew M. & Aharonian, Felix A.: Spectral shape and photon fraction as signatures of the Greisen-Zatsepin-Kuzmin cutoff *Physical Review D* (2009) **79** 083010

18. Acero, F., et al.: Detection of Gamma Rays from a Starburst Galaxy *Science* (2009) **326** 1080

19. Aharonian, F., et al.: Detection of very high energy radiation from HESS J1908+063 confirms the Milagro unidentified source MGRO J1908+06 *Astronomy and Astrophysics* (2009) **499** 723-728.

20. Vannoni, G., Gabici, S., & Aharonian, F. A.: Diffusive shock acceleration in radiation-dominated environments *Astronomy and Astrophysics* (2009) **497** 17-26.

21. Whelan, E. T., Ray, T. P., & Bacciotti, F.: Uncovering the Outflow Driven by the Brown Dwarf LS-RCrA 1: Hα as a Tracer of Outflow Activity in Brown Dwarfs *Astrophysical Journal* (2009) **691** L106-L110.

22. Aharonian, F., et al.: HESS observations of γ-ray bursts in 2003-2007 *Astronomy and Astrophysics* (2009) **495** 505-512.

23. Kirk, Jason M., et al.: The Spitzer Survey of Interstellar Clouds in the Gould Belt. II. The Cepheus Flare Observed with IRAC and MIPS *Astrophysical Journal Supplement Series* (2009) **185** 198-249.

24. Skilton, J. L., et al.: The radio counterpart of the likely TeV binary HESSJ0632+057 *Monthly Notices of the Royal Astronomical Society* (2009) **399** 317-322.

25. Vergani, S. D., Petitjean, P., Ledoux, C., Vreeswijk, P., Smette, A., & Meurs, E. J. A.: Statistics and characteristics of MgII absorbers along GRB lines of sight observed with VLT-UVES *Astronomy and Astrophysics* (2009) **503** 771-781.

26. Aharonian, F., et al.: HESS upper limit on the very high energy γ-ray emission from the globular cluster 47 Tucanae *Astronomy and Astrophysics* (2009) **499** 273-277.

27. Aharonian, F., et al.: HESS Observations of the Prompt and Afterglow Phases of GRB 060602B *Astrophysical Journal* (2009) **690** 1068-1073.

28. Zapatero Osorio, M. R., Mart'n, E. L., del Burgo, C., Deshpande, R., Rodler, F., & Montgomery, M. M.: Infrared radial velocities of vB 10 *Astronomy and Astrophysics* (2009) **505** L5-L8.

29. Fukui, Yasuo, et al.: A Peculiar Jet and Arc of Molecular Gas toward the Rich and Young Stellar Cluster Westerlund 2 and a TeV Gamma Ray Source Publications of the *Astronomical Society of Japan* (2009) **61** L23

30. D'Elia, V., et al.: UVES/VLT high resolution absorption spectroscopy of the GRB 080330 afterglow: a study of the GRB host galaxy and intervening absorbers *Astronomy and Astrophysics* (2009) **503** 437-444.

31. Dionatos, O., Nisini, B., Garcia Lopez, R., Giannini, T., Davis, C. J., Smith, M. D., Ray, T. P., & DeLuca, M.: Atomic Jets from Class 0 Sources Detected by Spitzer: The Case of L1448-C *Astrophysical Journal* (2009) **692** 1-11.

32. Vink, Jacco & Bamba, Aya: The Discovery of a Pulsar Wind Nebula Around the Magnetar Candidate AXP 1E1547.0-5408 *Astrophysical Journal* (2009) **707** L148-L152.

33. Aharonian, F., et al.: Very high energy γ-ray observations of the binary PSR B125963/SS2883 around the 2007 Periastron *Astronomy and Astrophysics* (2009) **507** 389-396.

34. Rieger, F. M. & Aharonian, F. A.: Centaurus A as TeV γ-ray and possible UHE cosmic-ray source *Astronomy and Astrophysics* (2009) **506** L41-L44.

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37. Acero, F., et al.: Localizing the VHE γ-ray source at the Galactic Centre *Monthly Notices of the Royal Astronomical Society* (2009) 1915

38. Podio, L., Medves, S., Bacciotti, F., Eislöffel, J., & Ray, T.: Physical structure and dust reprocessing in a sample of HH jets *Astronomy and Astrophysics* (2009) **506** 779-788.

39. Chernyakova, M., Neronov, A., Aharonian, F., Uchiyama, Y., & Takahashi, T.: X-ray observations of PSR B1259-63 near the 2007 periastron passage *Monthly Notices of the Royal Astronomical Society* (2009) **397** 2123-2132.

40. Suzuki-Vidal, F., et al.: Formation of episodic magnetically driven radiatively cooled plasma jets in the laboratory *Astrophysics and Space Science* (2009) **322** 19-23.

41. Caratti o Garatti, A., Eislöffel, J., Froebrich, D., Nisini, B., Giannini, T., & Calzoletti, L.: First detection of acceleration and deceleration in protostellar jets?. Time variability in the Chamaeleontis II outflows *Astronomy and Astrophysics* (2009) **502** 579-597.

42. O'C Drury, L.: Energetic particles in the universe; how does nature beat CERN? *Plasma Physics and Controlled Fusion* (2009) **51** 124005

43. Maeda, Yoshitomo, et al.: Suzaku X-Ray Imaging and Spectroscopy of Cassiopeia A *Publications of the Astronomical Society of Japan* (2009) **61** 1217

44. Whelan, E. T., Ray, T. P., Podio, L., Bacciotti, F., & Randich, S.: Classical T Tauri-like Outflow Activity in the Brown Dwarf Mass Regime *Astrophysical Journal* (2009) **706** 1054-1068.

45. Hess Collaboration, et al.: HESS upper limits on very high energy gamma-ray emission from the microquasar GRS 1915+105 *Astronomy and Astrophysics* (2009) **508** 1135-1140.

46. Melnikov, S. Yu, Eislöffel, J., Bacciotti, F., Woitas, J., & Ray, T. P.: HST/STIS observations of the RW Aurigae bipolar jet: mapping the physical parameters close to the source *Astronomy and Astrophysics* (2009) **506** 763-777.

47. Downes, T. P. & O'Sullivan, S.: Nonideal Magnetohydrodynamic Turbulent Decay in Molecular Clouds *Astrophysical Journal* (2009) **701** 1258-1268.

48. Mullen, Marie, Brennan, Conor, & Downes, Turlough: A Hybridized Forward Backward Method Applied to Electromagnetic Wave Scattering Problems *IEEE Transactions on Antennas and Propagation* (2009) **57** 1846-1850.

49. Taylor, Andrew M., Gabici, Stefano, White, Richard J., Casanova, Sabrina, & Aharonian, Felix A.: Revisiting the diffuse neutrino flux from the inner Galaxy using new constraints from very high energy γ-ray observations *Nuclear Instruments and Methods in Physics Research A* (2009) **602** 113-116.

50. Downes, Turlough P.: Large-Scale Jet Simulations *Lecture Notes in Physics, Berlin Springer Verlag* (2009) **791** 137

51. Gracia, José, de Colle, Fabio, & Downes, Turlough: Jets From Young Stars V *Lecture Notes in Physics, Berlin Springer Verlag* (2009) **791**

52. Zacharopoulou, Olga, Khangulyan, Dmitry, & Aharonian, Felix: Modification of High Energy γ-RAY Spectrum of Blazars due to Internal and Intergalactic Absorption *International Journal of Modern Physics D* (2009) **18** 1661-1664.

53. Dempsey, Paul & Rieger, Frank M.: On Particle Acceleration in Rotating AGN Flows *International Journal of Modern Physics D* (2009) **18** 1651-1654.

54. Eungwanichayapant, A. & Aharonian, F.: Very High Energy Gamma Rays from e± Pair Halos *International Journal of Modern Physics D* (2009) **18** 911-927.

55. G Reitz, Thomas Berger, ... Denis O'Sullivan ... (38 authors): Astronaut's organ dose inferred from measurements using a human phantom outside the International Space Station, *Radiation Research* (2009) **171** 225-235.

4.2 Non-refereed Publications

These are available online at:

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname= NonRef2009&libid=4794ca7845

1. Brunetti, G., Blasi, P., Cassano, R., & Gabici, S.: High energy emission from galaxy clusters and particle acceleration due to MHD turbulence *American Institute of Physics Conference Series* (2009) **1112** 129-137.

2. Covino, S., et al.: GRB 090102: REM observations of a bright afterglow. *GRB Coordinates Network* (2009) **8763** 1

3. Chernyakova, Maria, Uchiyama, Yasunobu, Takahashi, Tadayuki, Aharonian, Felix, & Neronov, Andrii: X-ray Observations of PSR B1259-63 2007 Periastron Passage *American Institute of Physics Conference Series* (2009) **1126** 271-274.

4. Ray, T. P.: Getting to Grips with the Unknown: How Important are Magnetic Fields in Outflows from Young Stars? *Revista Mexicana de Astronomia y Astrofisica Conference Series* (2009) **36** 179-185.

5. Whelan, Emma M., Ray, Tom, Bacciotti, Francesca, Randich, Sofia, & Natta, Antonella: Searching for Brown Dwarf Outflows *Protostellar Jets in Context* (2009) 259-265.

6. Zapatero Osorio, M. R., Martin, E. L., Del Burgo, C., Deshpande, R., Rodler, F., & Montgomery, M. M.: Infrared radial velocities of vB10 (Zapatero+, 2009) *VizieR Online Data Catalog* (2009) **350** 59005

7. Cabrit, S., et al.: Dynamics of magnetized YSO jets: Examples of results from the JETSET network *Revista Mexicana de Astronomia y Astrofisica Conference Series* (2009) **36** 171-178.

8. Del Burgo, C., Martin, E. L., Zapatero-Osorio, M. R., & P. Hauschildt.: Infrared spectra of 9 T dwarfs (del Burgo+, 2009) *VizieR Online Data Catalog* (2009) **350** 11059

9. Casanova, S., Aharonian, F. A., Gabici, S., Torii, K., Fukui, Y., Onishi, T., Yamamoto, H., & Kawamura, A.: On the level of the cosmic ray sea flux *American Institute of Physics Conference Series* (2009) **1112** 95-100.

10. Whelan, E. T., Ray, T. P., & Bacciotti, F.: Searching for Optical Outflows Driven by Young Brown Dwarfs with the ESO UV-Visual Echelle Spectrometer UVES *American Institute of Physics Conference Series* (2009) **1094** 39-44.

11. Stecklum, Bringfried, Caratti O Garatti, Alessio, Davis, Chris, Linz, Hendrik, Stanke, Thomas, & Zinnecker, Hans: Verification of Candidate Protostellar Outflows in GLIMPSE *Protostellar Jets in Context* (2009) 619-621.

12. Melnikov, Stanislav, Eislöffel, Jochen, Bacciotti, Francesca, Woitas, Jens, & Ray, Tom: The Physical Properties of the RW Aur Bipolar Jet from HST/STIS High-Resolution Spectra *Protostellar Jets in Context* (2009) 585-587.

13. McGroarty, Fiona, Podio, Linda, Bacciotti, Francesca, & Ray, Tom: Line Diagnostics of Large Scale Jets from Classical T Tauri Stars: The Case of DG Tau *Protostellar Jets in Context* (2009) 577-579.

14. Jones, Aoife C., Shadmehri, Mohsen, & Downes, Turlough P.: Multifluid Simulations of the Kelvin-Helmholtz Instability in a Weakly Ionised Plasma *Protostellar Jets in Context* (2009) 547-549.

15. de Colle, Fabio & Caratti O Garatti, Alessio: Interacting Knots in Jets: Simulations vs. Observations *Protostellar Jets in Context* (2009) 531

16. Colle, Fabio & Caratti O Garatti, Alessio: Interacting Knots in Jets: Simulations vs. Observations *Protostellar Jets in Context* (2009) 531-533.

17. Lopez, Rebecca Garcia, Nisini, Brunella, Giannini, Teresa, Eislöffel, Jochen, Bacciotti, Francesca, & Podio, Linda: Velocity Resolved IR Diagnostics of Class I Jets *Protostellar Jets in Context* (2009) 485

18. Garcia Lopez, Rebecca, Nisini, Brunella, Giannini, Teresa, Eislöffel, Jochen, Bacciotti, Francesca, & Podio, Linda: Velocity Resolved IR Diagnostics of Class I Jets *Protostellar Jets in Context* (2009) 485-490.

19. Downes, Turlough P.: Driving Mechanisms for Molecular Outflows *Protostellar Jets in Context* (2009) 395-404.

20. Caratti O Garatti, Alessio & Eislöffel, Jochen: Jet kinematics *Protostellar Jets in Context* (2009) 329-339.

21. de Colle, Fabio, Del Burgo, Carlos, & Raga, Alejandro C.: Application of Tomographic Techniques to Stellar Jets *Protostellar Jets in Context* (2009) 311

22. Podio, Linda, Medves, Silvia, Bacciotti, Francesca, Eislöffel, Jochen, & Ray, Tom: Position-Velocity Analysis of HH 111: Physical Structure and Dust Content *Protostellar Jets in Context* (2009) 305-310.

23. Caratti O Garatti, Alessio, Eislöffel, Jochen, Froebrich, Dirk, Nisini, Brunella, & Giannini, Teresa: Protostellar Jets Driven by Intermediate-and High-Mass Protostars: An Evolutionary Scenario? *Protostellar Jets in Context* (2009) 267-272.

24. Coffey, Deirdre, Bacciotti, Francesca, Chrysostomou, Antonio, Nisini, Brunetta, & Davis, Chris: Searching for Jet Rotation Signatures in Class 0 and I Jets *Protostellar Jets in Context* (2009) 241-245.

25. Suzuki-Vidal, Francisco, et al.: Formation of Episodic Magnetically Driven Radiatively Cooled Plasma Jets in Laboratory Experiments *Protostellar Jets in Context* (2009) 195-204.

26. Murphy, Gareth C., Zanni, Claudio, & Ferreira, Jonathan: Magnetic Field Advection in Weakly Magnetised Viscous Resistive Accretion Disks: Numerical Simulations *Protostellar Jets in Context* (2009) 117-122.

27. Tsinganos, Kanaris, Ray, Tom, & Stute, Matthias: Protostellar Jets in Context *Protostellar Jets in Context* (2009)

28. Covino, S., et al.: GRB 090509: REM NIR afterglow. GRB *Coordinates Network* (2009) **9327** 1

29. Mohanty, Subhanjoy, et al.: Bridging the Gap Between Stars and Planets: The Formation and Early Evolution of Brown Dwarfs *astro2010: The Astronomy and Astrophysics Decadal Survey* (2009) **2010** 212

4.3 Preprints

As a matter of policy all major publications are posted to ArXiV as publicly available preprints. Those which had not yet appeared in print at the end of 2009 are listed below and are available online at:

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname= Preprints2009&libid=4794ca7845

1. Casanova, S., Aharonian, F. A., Fukui, Y., Gabici, S., Jones, D. I., Kawamura, A., Onishi, T., Rowell, G., Torii, K., & Yamamoto, H.: Molecular Clouds as Cosmic-Ray Barometers *ArXiv e-prints* (2009) arXiv:0904.2887

2. Chernyakova, M., Neronov, A., & Ribordy, M.: Study of gamma-ray loud binaries in the Fermi era *ArXiv e-prints* (2009) arXiv:0912.3821

3. Garcia Lopez, Rebeca, Nisini, Brunella, Eisloeffel, Jochen, Giannini, Teresa, Bacciotti, Francesca, & Podio, Linda: IR diagnostics of embedded jets: kinematics and physical characteristics of the HH46-47 jet *ArXiv e-print*s (2009) arXiv:0912.2043

4. Mackey, Jonathan & Lim, Andrew J.: Dynamical Models for the Formation of Elephant Trunks in H II Regions *ArXiv e-prints* (2009) arXiv:0912.1499

5. Quirrenbach, A., et al.: CARMENES: Calar Alto high-Resolution search for M dwarfs with Exo-earths with a Near-infrared Echelle Spectrograph *ArXiv e-prints* (2009) arXiv:0912.0561

6. Vannoni, G., Aharonian, F. A., Gabici, S., Kelner, S. R., & Prosekin, A.: Acceleration and radiation of ultra-high energy protons in galaxy clusters *ArXiv e-prints* (2009) arXiv:0910.5715

7. Scaife, Anna M. M., et al.: High resolution AMI Large Array imaging of spinning dust sources: spatially correlated 8 micron emission and evidence of a stellar wind in L675 *ArXiv e-prints* (2009) arXiv:0910.4011

8. Dieckmann, M E, Murphy, G, Meli, A, & Drury, L O C: Particle-in-cell simulation of a mildly relativistic collision of an electron-ion plasma carrying a quasi-parallel magnetic field: Electron acceleration and magnetic field amplification at supernova shocks *ArXiv e-prints* (2009) arXiv:0910.0225

9. Tibbs, Christopher T., et al.: VSA Observations of the Anomalous Microwave Emission in the Perseus Region *ArXiv e-prints* (2009) arXiv:0909.4682

10. Costamante, L., Aharonian, F., Buehler, R., Khangulyan, D., Reimer, A., & Reimer, O.: The new surprising behaviour of the two "prototype" blazars PKS 2155-304 and 3C 279 *ArXiv e-prints* (2009) arXiv:0907.3966

11. Raue, M., et al.: Discovery of VHE gamma-rays from Centaurus A *ArXiv e-prints* (2009) arXiv:0904.2654

4.4 Books and Conference Proceedings

1. Tsinganos, K., Ray, T.P., & Stute, M., (Editors), 2009, Protostellar Jets in Context, Proceedings of the International JETSET Conference organised in Rhodes, Greece, Springer-Verlag

5 Invited Talks

- Luke Drury

  1. "A Cross-Scale view of Shock Acceleration", Cross-scale meeting, Cozena, Italy, 9 March.
  2. "How does Nature beat CERN?", European Physical Society Plasma Physics Meeting, Sofia, Bulgaria, 2 July.
  3. "On the plasma temperature in SNRs" Kavli Institute for Theoretical Physics, Santa Barbara, California, 3 September.
  4. "On the plasma temperature in SNRs" UCSD Physics Departmental Seminar, San Diego, California, 24 September.
  5. Three lectures on "The non-thermal Universe" at the Erlangen Astroteilchen Schule, Oberbärenfels, Germany, 8-10 October.
  6. "Recent Progress in Shock Acceleration Theory" HEPRO-II meeting, Buenos Aires, Argentina, 26 October.

- Felix Aharonian

  1. "Probing Cosmic PeVatrons with hard X-rays and low-energy gamma rays", Joint Gamma-ray Mission Meeting 2009, Tokyo, Japan, March 2009
  2. "Exploring Extreme Cosmic Accelerators with gamma-rays, neutrinos and hard X-rays", Leeds University, Leeds, England, March 2009
  3. "Nature's Extreme Particle Accelerators", KIT (Karlsruhe Institute of Technology), Karlsruhe, June 2009
  4. "Discovery of Very High Energy gamma-rays from Centaurus A", talk at the International Workshop "The Many Faces of Centaurus A", Sydney, June 2009
  5. "Gamma-ray/X-ray astrophysics and future directions", invited plenary talk at Australian Astronomical Society Annual Meeting, Melbourne, July 2009

6. "Gamma Ray Astrophysics", invited plenary talk at the 12th Marcel Grossmann Meeting, Paris, France, July 2009.

7. "Why do you see so many TeV galactic sources?" invited talk at the International workshop "The bright gamma-ray sky", Frascati, September 2009

8. "Relativistic plasmas in the Universe", invited plenary talk at the International Conference on "Plasmas in the Laboratory and in the Universe: interactions, patterns, and turbulence", Como, Italy, Dec 2009

- Tom Ray

1. "The Mid-Infrared Instrument on JWST", Enterprise Ireland, 16 April

2. "Primeval Jets and Outflows", IAU Joint Discussion 7, Astrophysical Outflows and Associated Accretion Phenomena, Rio de Janeiro, 6-7 August

3. "Jets on Planetary Scales", IAU Special Session 7, Young Stellar Objects, Brown Dwarfs and Disks, Rio de Janeiro, 11-13 August

4. "Outflows from Brown Dwarfs", Max Camenzind Festschrift, Max Planck Institute for Astronomy, Heidelberg, 26 November

- Stefano Gabici

1. "Cosmic ray propagation and high energy radiation from molecular clouds", Workshop: Molecular clouds as probes of cosmic ray acceleration in supernova remnants, Palavas-les-Flots/Carnon, 7-9 September 2009

- Denis O'Sullivan

1. "Humans in Space", invited talk at the Physics Department, University of Thessaloniki, Greece, April.

6 Observing Runs: Completed or Awarded in 2009

- A. Caratti o Garatti

1. **Getting more than a GLIMPSE -Verification of Outflows from massive YSOs**

   June 2009 - 5 nights with SofI at ESO/NTT. PI/CoI: Stecklum B., Caratti o Garatti A., Davis C.J., Linz H., StankeT., Zinnecker H.

   July 2009 - 5 nights with NICS at TNG. PI/CoI: Stecklum B., Caratti o Garatti A., Davis C.J., Linz H., StankeT., Zinnecker H.

2. **A detailed study of Class I YSOs in CrA**

   June/July 2010 - 19 hrs at ISAAC at ESO/VLT. PI/CoI: Caratti o Garatti A., Garcia Lopez R., Antoniucci S., Peterson D., Bourke T., Barreyre L., Ray T.

- D. Coffey

1. **Testing the theory of magneto-centrifugal ejection from T Tauri disks**

   August 2010 - 13 hrs using NIFS on Gemini. Program ID: GN-2009B-Q-43. PI/CoI: Chrysostomou, Coffey, Cabrit, Bacciotti, Dougados

2. **Protoplanetary disk rotation probed via spectroastrometry**

   May 2010 - 6 hrs using CRIRES on the VLT. Program ID: 385.C-0365(A). PI/CoI: Coffey, Whelan, Podio, Bacciotti, Curran

3. **Investigation Jet Rotation in Young Stars via High Resolution UV Spectra**

   2010 - 18 orbits using STIS on HST. Program ID: 11660. PI/CoI: Bacciotti, Coffey, Eislöffel, Ray

- E. J. A. Meurs

1. Loiano Observatory (Italy), 18-22 March

2. Loiano Observatory (Italy) , 18-22 November

7 Current Grants

- Luke Drury
    1. PRTLI-4 e-INIS, Project Coordinator
    2. EU Marie Curie fellowship
    3. SFI RFP, one postdoc
- Felix Aharonian
    1. EU FP6 Design Study KM3NeT, 40K, Preparatory Phase 30K
    2. SFI RFP, two postgrads
    3. IRCSET, one postdoc
- Tom Ray
    1. EU JETSET, one postdoc and an administrator, until March 2009
    2. PRODEX MIRI, two scientific officers
    3. SFI RFP, one postdoc and one postgrad
    4. IRCSET, two postdocs
    5. Lindsay Scholarship (DIAS & Armagh Observatory), one postgrad
- Denis O'Sullivan (emeritus)
    1. DOBIES – from Enterprise Ireland under PRODEX, 24k over 2 years

8 Proposals Submitted

- PRTLI5 – Submission from DIAS, which included support for CTA and a plan for the redevelopment of Dunsink, was unsuccessful.
- RFP09 – two proposals submitted by new Schrödinger fellows Drs Bamba and Scholz, results not expected until March 2010.
- FP7 – JETset-II proposal submitted but disqualified on technical ground of lack of industrial partners -will resubmit in next round with industry; CORE proposal for e-Infrastructure in support of CTA submitted with DIAS as a partner to call "INFRA2010-1.2.3: Virtual Research Communities" on Nov 24.

9 Community Service etc

- Luke Drury:
    1. Member of the ICHEC oversight board
    2. Member of the H.E.S.S. Collaboration Board
    3. Member of the KM3NeT consortium
    4. Member of the Council of the RIA
    5. Member of the Grid-Ireland board
- Felix Aharonian:
    1. Co-PI of the ROTSE project
    2. Member of the H.E.S.S. Collaboration Board
    3. Member of the Consortium of the KM3NeT
    4. Member of the working group "Science with NeXT" (Japanese next generation X-ray mission)
    5. Member ("Principal Scientist/Professor") of the Heidelberg Graduate School of Fundamental Physics at the University of Heidelberg
    6. Adjunct Professor of the International Center for Relativistic Astrophysics Network, Pescara/Rome
    7. Course of lectures on radiation process in high energy astrophysics, TCD, February
    8. External scientific member of the MPIK in the High Energy Astrophysics Group
    9. Co-director of LEA -European Associated Laboratory on High Energy Astrophysics (jointly supported by CNRS and MPG)
    10. Member of the European Astronet Infrastructure Roadmap Panel A: "High energy, astro-particle astrophysics and gravitational waves"
    11. Member of the International Review Panel of the Helmholtz Association: "Astroparticle Physics"
    12. An Editor of the International Journal of Modern Physics D

- Evert Meurs:
  1. Member of the REM consortium
  2. Member of the RIA Astronomy and Space Science Committee
  3. Member of the Space Strategy Working Group (Space Industry Skillnet)
  4. Adjunct Professorship Dublin City University
  5. Course of lectures on High Energy Astrophysics, DCU
  6. Member of the Joint Management Committee, Armagh Observatory and Planetarium (until February)
- Tom Ray
  1. Co-PI of the MIRI project
  2. Member of the e-MERLIN Steering Committee (Steering committee for national radio astronomy facilities in the UK)
  3. Robert Ball Professorship Trinity College Dublin
  4. Member of the Herschel Observatory Time Allocation Committee
  5. Member of the Physical and Chemical Sciences Committee, Royal Irish Academy
  6. Member of the European MIRI Steering Committee (an ESA committee)
  7. Member of the Gogarty Scholarship Committee to assist students attend the international Space Studies Program or complete a M.Sc. in Space Studies or Space Management
  8. Member of the Management Committee of Armagh Observatory
  9. Elected to membership of the Royal Irish Academy
  10. National representative at the International Astronomical Union General Assembly, Rio de Janeiro
- Masha Chernyakova
  1. Member of the XMM-Newton AO-9 proposal review panel

10 Public Outreach

10.1 Statutory Public Lecture

Professor Simon White, Director of the Max-Planck-Institut for Astrophysics in Garching, gave the School's statutory public lecture in UCD on 12 October. His well-attended talk was entitled "All from Nothing: the structuring of our Universe". He provided the following abstract for his talk which was chaired by Prof Peter Duffy of UCD, a former scholar and current research associate of the School.

Telescopes are time-machines. They allow us to see into the distant past. Our deepest images show the Universe not as it is today, but as it was just 400,000 years after the Big Bang. At that time there were no galaxies, no stars, no planets, no people, no familiar elements other than hydrogen and helium. The cosmos contained nothing but weak sound waves in a near-uniform fog. Supercomputers can compress thirteen billion years of cosmic evolution into a few months of calculation to show how these sound waves developed into the rich structure we see around us today. A study of their harmonic content gives clues to their origin. They appear to be an echo of quantum zero-point fluctuations occurring a tiny fraction of a second after the Big Bang. Thus our entire world may be a consequence of the nature of this early vacuum. In a very real sense, everything may have come from nothing.

He was interviewed by Dick Ahlstrom of the Irish Times in advance of his visit, http://www. irishtimes.com/newspaper/sciencetoday/2009/1001/1224255600204.html.

10.2 IYA2009

A number of events to mark the International Year of Astronomy were organised jointly with other institutions involved in the public promotion of astronomy.

E.J.A. Meurs gave assistance at the ESO stand at the Young Scientists Exhibition (RDS, Dublin), 9 and 10 January.

In collaboration with Blackrock Castle Observatory in Cork Brother Guy Consolmagno SJ, curator of meteorites in the Vatican Observatory and a well-known author of popular astronomy books, was invited to Ireland. He visited from 19 to 28 March and gave talks in Gonzaga college, Dunsink Observatory, the Cosmos star party in Tullamore and in Black-rock Castle Observatory. His visit attracted considerable media interest, especially when he was photographed with Rory Gallagher's guitar during his visit to Cork.

In collaboration with Armagh Observatory and Blackrock Castle Observatory Caroline Porco, PI of the Cassini mission, was invited to Ireland and gave talks on "Tripping the light fantastic at Saturn" in Dunsink on June 30th, in Cork on July 3rd and in Armagh on July 8th. This visit also attracted considerably media interest with good coverage in both print and radio, for example http://www.irishtimes.com/newspaper/sciencetoday/2009/0625/1224249487277.html

In collaboration with Deirdre Kelleghan of the IFAS, Blackrock Castle Observatory, and the Birr castle science centre a touring exhibition of astronomical art was presented in various venues around the country.

D. Coffey gave a public outreach talk entitled "Exploring the Cosmos: the view from Hubble and Beyond" at the Hill of Tara Visitors' Centre in July 2009 as part of the annual Tara Lecture Series, and to celebrate the International Year of Astronomy 2009.

T. Ray gave a number of public talks including ones to Galway Astronomical Society (February), Dunsink Observatory (February, October and November), Irish Astronomical Association, Belfast (September).

E.J.A. Meurs assisted with the organisation of the digital astronomical photography competition "EYE on the SKY", organised by the School of Physical Sciences of DCU. He also was member of the jury for this competition.

10.3 Science Week

The popular scheme of inviting a primary school to visit Dunsink during the day and a secondary school during the evening was followed again in 2009.

Date	School	Principal Speaker
9 Nov	Roselawn National School Loretto Secondary School Bray	S Delaney J Flannery
10 Nov	Blanchardstown NS St MacDara's school, Templeogue	D Kelleghen D Kelleghen
11 Nov	Scoil Oilibhear, Blanchardstown Loretto Whitehall	D Malyshev P Dempsey

10.4 Dunsink Events

The normal programme of Open Nights concluded in March and recommenced in October. In a welcome development it was supplemented by a growing number of special events for specific interest groups (see Table 1). In addition the Irish Astronomical Society were facilitated by being allowed the use of Dunsink for their meetings (including some evenings devoted to practical instruction). A significant number of events related to the International Year of Astronomy were also held in Dunsink.

Table 1: Dunsink Events in 2009

Date	Event Principal	Speaker
7 Jan	Open night	Paul Dempsey
19 Jan	Joint IAS and open night	Denis O'Sullivan
21 Jan	Parent and child event	Emma Whelan
23 Jan	Russian evening	Masha Chernyakova
4 Feb	Open night	Tom Ray
16 Feb	IYA2009	Mike Redfern
18 Feb	Open night	Brian Espey
1 Mar	IFAS workshop	Paul Dempsey
4 Mar	Mature UCD students' evening	J Quinn
9 Mar	Russian educate together group	MChernyakova
	IAS meeting	J Flannery
11 Mar	Education officers meeting	C Raftery
27 Mar	IYA2009 event	Br G Consolmagno
1 Apr	Hope foundation evening	D Kelleghen
2 Apr	Open night	M McConnell
8 Apr	WITS book launch	D Donnelly
24 Apr	Irish Guides event	D Kelleghen
27 Apr	IAS meeting	
6 May	Hope foundation	
7 May	extra open night	D Gabuzda
9 May	National Art Day	D Kelleghen
11 May	IAS meeting	S Roche
20 Jun	Solar Fest	
30 Jun	IYA2009 talk	C Porco
15 Sep	Invited IYA2009 event	C Odmann
7 Oct	Open night	T Ray
19 Oct	Joint IAS/DIAS event	B O'Halloran
21 Oct	Open night	D Malone (NUIM)
27 Oct	International Young People's evening	M Chernyakova
31 Oct	International Young People's evening	D Malyshev
14-15 Nov	Astronomy weekend multiple	
16 Nov	IAS meeting	D Malyshev
17 Nov	Art exhibition event	
18 Nov	Open night	P Rammos
24 Nov	Mount Merrion Art club	D Malyshev
25 Nov	Castleknock Art club	D Malyshev
3 Dec	Open night	M Shadmehri
15 Dec	Google social group	P Rammos
16 Dec	Open night	P Callanan (UCC)

11 Conferences Organised

11.1 Workshop on Radiation Measurements on the International Space Station

Denis O'Sullivan

The 14th Workshop on Radiation Measurements on the International Space Station (WRMISS) was held in Dublin Castle on 8-10 Sept and was opened by Professor Dervilla Donnelly, chairperson of the Council of DIAS. D. O'Sullivan was the local scientific organiser. The Dublin Castle conference centre was provided free of charge by the Irish Government. Previous workshops in the series were held in Oxford, Paris, Berkeley and several other universities and research centres. Preparations for the meeting were the responsibility of Eileen Flood and Anne Grace of DIAS who also took care of all the administration during the workshop. The main funding was supplied by DIAS and the ESA Prodex Office helped also. The meeting was run without a delegate registration fee, as is customary. There were 56 attendees and the distribution, by country, was as follows, USA (14), Germany (9), Hungary (5), Canada (4), Japan (4), Ireland (1), Austria (3), Russia (3), Belgium (2), Czech Republic (2), Greece (2), Sweden (2), Bulgaria (1), Italy (1), Poland (1), The Netherlands (1) United Kingdom (1). In all, 42 papers were read covering a wide range of topics related to experiments already carried out on the ISS, some in progress and others at the planning stage. D O'Sullivan presented the latest DOBIES results. A Workshop dinner was held at the Merrion Hotel on Sept 9th. Fig 3 shows some of the delegates at the Workshop venue.

Figure 3: Group photograph in Dublin Castle

School of Cosmic Physics
Geophysics Section

1 General

1.1 Mandate and Activities

In the work undertaken by the Section since formation, understanding of the Earth has come, almost exclusively, through observational activities, with the Section's predominant activity historically being driven by, and aligned with, the research interests of the incumbent Senior Professor. This has changed radically since the appointment of the current serving Senior Professor, Alan G. Jones, as the Section now undertakes far broader theoretical, numerical, computational and observational geophysical studies, and is far more involved, and far better known, internationally that at any time in its past.

Geophysics is needed by society now more than ever before, and the nature and variety of the problems have become far more complex. In terms of the Solid Earth, the easy work on the plate tectonic paradigm was done in the 1970s, but now the hard work begins as we try to understand Earth processes, particularly the role of mantle-lithosphere-crust interactions and vertical movements, both upwelling and subsidence, and the interaction between deep-Earth processes and surface processes, such as post-glacial rebound, ice-mass changes, climatological processes and long-term ocean dynamics. The greatest scientific challenges are at the interfaces between the various sub-disciplines of geophysics, and between geophysics and the other geosciences; geology, petrology, geochronology and geochemistry.

Non-academic geophysics used to be primarily focussed on resource discovery, particularly in industry, but now there are many other societally-relevant issues to which geophysics can contribute, such as CO_2-sequestration, methane clathrate identification, groundwater mapping and contamination surveys, engineering geophysics, hazard mitigation through understanding, etc., as well as cross-involvement in areas thought to be the exclusive domain of other disciplines. One example of this is the closer cooperation that is required between geophysics and geodesy. It has become clear that to define a Terrestrial Reference Frame (TRF), which is usually a task for geodesists, is impossible without geophysical knowledge and modelling if TRFs in the future should be determined with very high precision consistent with the precision of geodetic observations, such as GPS, VLBI, SLR, etc.

The Section is biased on the academic side of the full spectrum of geophysical activity, but also is involved in solving societally-relevant issues where they pose interesting and stimulating intellectual problems. In alignment with the Mission of the Institute and of the Mission Statement of the School, we pursue knowledge at its frontiers.

With the hiring of Professor Zdenek Martinec in 2009, the Section is now very well-rounded with strengths in many areas of geophysics and is able to address newer and more complex problems. For example, over the last few years Jones has been moving towards formal quantitative joint inversion of MT data with seismological data.

Over the next quinquennial period (2009-2014), the overarching primary foci of our activities will include, but not be limited to:

- Consolidate the gains of the last five years in the elevation of DIAS's Geophysics Section to one of world renown and prominence and a premier destination for short and long-term academics, scholars and students.
- Develop a broad-based approach to the investigation of the continental lithosphere and underlying asthenosphere through seismological, electromagnetic, geodetic and geomagnetic observations and numerical modelling studies coupled with other geophysical (thermal), geological, petrological and geochemical data.
- Build a research centre of excellence focussed on studies of the continents.
- Pursue formal joint inversion of multi-parameter data.
- Establish the need and resources for an Irish National Seismic Network.
- Take greater advantage of the high performance computing resources available to the Institute through ICHEC.
- Take advantage of serendipitous funding opportunities, such as SFI's new Energy mandate.

1.2 2009 Research Review

The most important internal event of the year was the quinquennial review of the School of Cosmic Physics for 2004-2009 that was conducted in August, 2009. All Geophysics members met the Review Committee.

Subsequently, the Chair of the Committee made a verbal report to the Chairman of DIAS's Council and to the Governing Board. The opening statement made by the Review Committee Chair about Geophysics over the period 2004-2009 was "*Dreams Come True!*". The written report of the Review Committee states that "*Through new staffing, the School has become an emerging world leader in electromagnetic geophysics, seismology, marine geophysics and geodynamics.*" The committee also made very complimentary remarks about the research activities of Professors Jones, Lebedev and Martinec.

1.3 2009 Capital Acquisition

Another significant development during 2009 was the acquisition of geophysical and computational hardware through a special funding allocation from the Department of Education. The Irish National Seismic Network will be expanded from two permanent stations to five, with very broadband seismometers measuring seismic signals to periodicities of 240 seconds at each station. Twenty new portable broadband seismic systems were acquired, to replace the aging fleet of existing equipment. Four more broadband magnetotelluric (BBMT) and ten long-period magnetotelluric (LMT) systems were acquired, bringing the number of MT systems owned by the Section to ten BBMTs and 22 LMTs – the largest fleet of MT equipment owned by any academic group worldwide. A controlled-source electromagnetic (CSEM) system was acquired, allowing us to study structures from the surface to typically a kilometre. Finally, a data storage system was acquired that will take care of the needs of the Geophysics Section for the next five years.

1.4 Personnel Highlights

The personnel highlight for the year was the arrival in August of Professor Zdenek Martinec from Germany (GeoForschungsZentrum, Potsdam) and the Czech Republic (University of Prague) in the post of Professor of Geophysics. Professor Martinec expands considerably the breadth of activities of the Geophysics Section with his numerical modelling of Earth processes from the surface to the deep mantle.

Dr. Mark Muller accepted the five-year position of Schrödinger Fellow in the Geophysics Section and began in July. Dr. Muller's interests are broadly-based, with lithospheric work in Southern Africa his current focus and with an interest in growing a programme of crustal and lithospheric geophysics in Ireland.

Three Post-Doctoral Fellows started in 2009, all on two-year appointments. Dr. Celine Tirel, an expert on geodynamics of the lithosphere, started in March arriving from Utrecht University to work with Assistant Professor Sergei Lebedev on lithospheric deformation funded by an SFI RFP grant. Dr. Jan Vozar, with skills in large-scale electromagnetic induction, started in May from the Geophysical Institute of the Slovak Academy of Sciences, where he holds a permanent position, to work with Senior Professor Alan Jones on the INDEPTH project Phase IV activities on the northern rim of the Tibetan Plateau, also funded by an SFI RFP grant. Dr. Javier Fullea, a numerical petrophysicist who has developed a programme for modelling surface observables based on the three-dimensional distribution of minerals within the subsurface (LitMod3D), joined DIAS in May from the Earth Sciences Institute in Barcelona to work with Jones on the tectonics of Morocco. Dr. Fullea is funded by an IRCSET grant for Irish contributions to the TopoMed Coordinated Research Project under the EUROCORES TOPO-EUROPE programme.

Three Ph.D. students began their studies in 2009. Florian Le Pape, from France, started in January working with Jones on INDEPTH funded on the SFI RFP grant. Duygu Kiyan, from Turkey, started in July working with Jones on TopoMed funded on the IRCSET grant. Andrew Schaeffer, from Canada, started in November working with Lebedev on seismic-velocity structure and dynamics of the North American continent, also funded on an SFI RFP grant.

Two undergraduate students from Dublin universities, Paula Keogh (TCD) and Damien Middleton (DCU), completed successful summer internships with the seismology group, with results of their projects presented at a major international conference. The seismology group has also hosted an undergraduate researcher from Germany, Stefan Bartzsch (University of Jena), for a 6-week internship.

During 2009 the Section saw the Institute's longest serving academic and second longest-serving member, Assistant Professor Peter Readman, retire in April after almost thirty years with the Geophysics Section. Readman came with skills in rock and paleomagnetism, and broadened considerably to work in potential field studies and passive and active seismology. The Section is very pleased that Dr.

Readman will continue his work as an Emeritus Professor focussing on the ISLE/ISUME experiment and supervising a PhD student (Gulten Polat) funded by an SFI RFP grant.

1.5 Research Highlights

The main overarching qualitative results from the SAMTEX MT project were published in Jones et al. (2009) showing a correlation between non-diamondiferous kimberlites, indicative of lithosphere thinner than about 160 km, and diamondiferous kimberlites, indicative of lithosphere greater than about 160 km, and the edges of highly resistive regions. These results are guiding the SAMTEX industry partners in their exploration programme for discovering new diamond fields.

The PICASSO/TopoMed MT work in Morocco was initiated in the Autumn after a postponement due to the unexpectedly low solar activity. Data were acquired at 43 locations on two profiles, despite very trying field conditions including the theft of a long period magnetometer.

The La Palma shallow EM survey demonstrated that there is indeed cause for concern about the possibility of a major fault being weak. This might lead to a significant collapse of the western flank of Cumbre Vieja causing a significant tsunami in the northern Atlantic.

Under geodynamic research activities we resolved various mass-redistribution processes that operate upon and within the Earth, focusing on areas of past and present-day glaciation, such as Greenland, Fennoscandia, Laurentide and Antarctica. This required the identification of the spatial and temporal changes in the Earth's gravity field from GRACE observations, surface-elevation changes in the ice sheets as measured by the ICESat satellite mission, crustal-displacement measurements from GPS, and sea-level change observations as revealed by sea-level indicators and tide-gauge data.

We designed the adjoint sensitivity analysis for interpreting the time series of CHAMP satellite magnetic data such that the complete time series, not only their parts, can be considered in inverse modelling and still be computationally feasible. We applied this advanced method to the year 2001 CHAMP satellite time series with a time step of 1 hr and demonstrated the sensitivity of mantle conductivity structure to satellite observations.

1.6 New External Funding Received in 2009

1.6.1 SFI Proposals Funded:

A proposal by Lebedev to study continental dynamics, with a focus on North America. Funded for four years at €116,616 and supports a Ph.D. student, Andrew Schaeffer.

1.6.2 Other Proposals Funded:

Jones successfully applied for an SFI Short-Term Travel Fellowship (STTF) to visit Professor Andrea Tommasi at the University of Montpellier (France) for a month in the Spring, 2010. Jones also successfully applied for a Ulysses award to initiate cooperation between Montpellier and DIAS with scientist and scholar exchanges during 2010.

O'Reilly obtained funding from INFOMAR (INtegrated Mapping FOr the Sustainable Development of Ireland's MARine Resource) to conduct work on "Deep-water sediment transport on the margins of Rockall Trough: new interpretation from high-resolution multibeam and sidescan sonar TOBI data". The project's objectives are to reprocess multibeam bathymetric data gathered by the Geological Survey of Ireland within the Irish Exclusive Economic Zone and high resolution TOBI backscatter data to develop an improved understanding of the Irish margins.

2 Organisation of the Geophysics Section

The Section currently comprises a total of 33.5 people, which is by far the largest that the Section has ever been in its history, with most of the growth occurring in 2003-2004 when the numbers grew from 8.5 in April, 2003 to 25.5 in July, 2004.

The research and support activities of Section members fall broadly as follows *(names in italics are former Section members who left during prior to 2009; projects in italics are completed):*

2.1 Electromagnetism:

2.1.1 Observational Studies:

PICASSO/TopoMed	Jones, Fullea, Kiyan, Schmoldt, <scholar vacancy>
INDEPTH	Jones, Le Pape, Vozár
SAMTEX	Jones, Khoza, Miensopust, Muller, Share, *Hamilton, Garcia, Spratt*
ISLE-MT	*Rao, Moorkamp*, Jones
Slave2Bear	Jones, *Spratt*
Marine EM	*Garcia*
Melville Peninsula	Jones, Hogg
Mining-scale AMT	Jones, Hogg
Deep mantle conductivity	Martinec, <scholar vacancy>

2.1.2 Theoretical/Numerical Studies:

3D MT Inversion	Miensopust, Jones, *Avdeev, Avdeeva*
Joint Inversion	Roux, Mandolesi, Jones, Moorkamp
Multi-parameter modelling	Fullea, Jones
Time series analysis	Schmoldt, Jones

2.2 Seismology:

2.2.1 Observational Studies:

ISLE/ISUME	Readman, O'Reilly, Polat, *Do*
LEGS	Readman, O'Reilly
EAGLE	O'Reilly
Tibet	Agius, Lebedev
South Africa	Adam, Lebedev
The Aegean	Lebedev, Tirel
North America	Schaeffer, Lebedev
Mongolia	Middleton, Agius, Lebedev
Tuscany	Keogh, Adam, Lebedev
Europe	Lebedev
Global seismic imaging	Lebedev

2.2.2 Theoretical/Numerical Studies:

Imaging methods	Lebedev, Adam, Agius
Seismic imaging of the lithosphere-asthenosphere boundary	Lebedev

2.3 Marine Geophysics and Seismology:

Marine wide-angle studies	O'Reilly, Readman, Hauser
HADES	O'Reilly, Readman, *Chabert, Gernigon, Ravaut*

2.4 Geodynamics:

Numerical Studies	Tirel, Lebedev, Sheehan, *Yamasaki*
Numerical/Analogue	Sheehan, O'Reilly
Glacial rebound studies	Martinec

2.5 Seismic Network:

Network manager	Blake
Network technical support	Collins, Horan, Wallace

2.6 Outreach:

Outreach Officer	Blake

2.7 Irish Geoscience Graduate Programme:

Programme Leader	Jones
Co-ordinator	Kennedy

2.8 Support:

Outreach Officer	Blake
IT manager	O'Sullivan
Electronics technician	Wallace
Technicians	Collins, Horan
MT technician	Hogg
Webmasters	Collins, Sewielska
Graphics	Horan
Secretary	Sewielska

2.9 Health and Safety:

Assistant H&S Officer	Blake
Fieldwork H&S Officer	Hogg
H&S Staff representative	Horan
First Aid trained	Blake, Hogg, Horan, Le Pape

The Section has very much a global flavour, with staff and students heralding from Canada, Czech Republic, France, Germany, Ireland, Italy, Malta, Poland, Russia, South Africa, Slovakia, Spain, Turkey and the U.K.

3 General Geophysics Activities

3.1 CHIGI – Irish Geoscience Graduate Programme

A.G. Jones, B. Kennedy

The Irish Geoscience Graduate Programme is an All-Ireland initiative from the heads of geoscience schools/departments at five universities and one research institute involved in the training of post-graduate students in the geosciences. It has a visionary and unique objective, which is to establish a robust, holistic, broad-based training programme for post-graduate students, wherever they are registered for their fourth level degree (primarily Ph.D.) on the island of Ireland.

Currently, approximately fifty permanent staff faculty at the six institutions train approximately sixty post-graduate students in predominantly the rather narrow fields of research of the students' respective supervisors. Approximately fifteen new post-graduate students are taken on each year. The dual objectives of the IGGP are to broaden the knowledge acquired by Irish graduate students, and to double their numbers by 2013 in line with the Government's seven year Strategy for Science Technology and Innovation 2006-2013.

The IGGP involves the Geophysics Section of DIAS, the Department of Earth and Ocean Sciences of the National University of Ireland Galway, the Department of Geology of Trinity College Dublin, the Department of Geology of University College Cork, the School of Geological Sciences of University College Dublin and the School of Environmental Sciences [Geophysics Group] of the University of Ulster Coleraine as partner institutions. There are links with the Geological Survey of Ireland and the Geological Survey of Northern Ireland as well as the School of Geography, Archaeology and Palaeoecology of Queen's University Belfast and the Department of Geography of the National University of Ireland Maynooth. All these institutions have agreed to offer modules [worth from 2.5 to 10 ECTS credits] under the programme. Other bodies, such as the Institute of Geologists of Ireland and the Irish Association for Economic Geology, may also offer modules from time to time. The modules will be either lecture, or laboratory or field based or a combination of these. It is planned to start the programme fully in September 2010, but it may be launched in a pilot phase in January 2010. Uncertainties over structures and funding in the universities and the development of broad research cooperation between institutions, such as the Programme for Research in Third Level Institutions [PRTLI] 5, has made progress in planning difficult to complete in the first half of 2009. It is hoped that this will improve significantly later in the year when decisions on PRTLI 5 are made and universities can see their way forward better. This Irish Geoscience Graduate Programme (IGGP) plans to at least double, if not treble, that number within a period of five to seven years, and to broaden the scope of the research while maintaining standards of research excellence. With the introduction of a system of modular courses during the four year PhD programme, students will be better prepared for their research with skill sets capable of flexibly addressing Ireland's geoscience needs into the future. These courses will represent a high quality response to the challenge of the Bologna Process which requires that all Doctoral programmes contain both generic and subject specific competence training.

IGGP was funded by a Griffith Award of the Department of Communications, Energy and Natural Resources to Jones of €416,000 for a period of seven years. These funds are being used for a two-year Co-ordinator, Professor Ben Kennedy, who is tasked with initiating the IGGP, and an Administrator for the remaining five years.

3.2 European Plate Observing System (EPOS)

Europe needs a long-term integrated strategic research infrastructure plan to promote innovative approaches for a better understanding of the physical processes controlling earthquakes, volcanic eruptions and tsunamis as well as those driving tectonics and Earth surface dynamics. This plan should aim at integrating the currently scattered, but highly advanced European facilities geared towards studying these topics into one, distributed, but coherent multidisciplinary

Research Infrastructure (RI) allowing sustainable long-term Earth science research strategies and an effective coordinated European-scale monitoring facility for the solid Earth dynamics. This integration can and should take full advantage of new e-science opportunities. EPOS is such a Research Infrastructure plan that anticipates a thorough understanding of the dynamic tectonic processes by integrating data and experiments at a wide variety of spatial and temporal scales.

The European Plate Observing System (EPOS: http://www.epos-eu.org) is an initiative in response to the EU policy for a coordinated approach to support and develop research infrastructures. EPOS is a proposal submitted for the update of the European roadmap for research infrastructure coordinated by the European Strategic Forum on Research Infrastructures (ESFRI) in the framework of the Seventh Research Framework Plan (FP7).

The vision is to integrate real time observations from permanent national and regional geophysical networks, with the observations from "in-situ" experiments and temporary monitoring experiments through a cyber-infrastructure for data mining and assimilation, and facilities for data integration, archiving and exchange. Making observations of solid Earth dynamic processes controlling natural phenomena immediately available and promoting their comparison with experimental observations from cutting-edge laboratory experiments and their interpretation through theoretical analyses and numerical simulations will represent a multidisciplinary platform for discoveries which will foster scientific excellence in solid Earth research. In Europe the conditions now exist to integrate research across a broad range of Earth sciences by pooling efficiently the scattered national research infrastructure initiatives into one European Plate Observing System (EPOS) thus improving significantly our capacity to investigate Earth processes and their impact on natural resources and hazards.

EPOS will:

- Create a single sustainable, permanent observational infrastructure, integrating geophysical monitoring networks (e.g. seismic networks), local observatories (e.g. volcano observatories) and experimental laboratories in Europe and adjacent regions.
- Provide open access to distributed geophysical and geological data and modelling tools, enabling a step change in multidisciplinary scientific research into natural hazards, environmental change, and energy resources.
- Build a strongly competitive European research infrastructure providing a radically new landscape and widening horizons for solid Earth science research in Europe through a comprehensive e-infrastructure.
- Foster trans-national coordination of solid Earth observing systems at the European level.
- Promote cross-disciplinary approaches to challenging scientific and technological issues in Earth sciences through links with marine and space observations.

Ireland, through the leadership of the Geological Survey of Ireland, is a partner in the EPOS initiative, and Assistant Professor Sergei Lebedev is the National Point of Contact.

3.3 Qualitative Correlations between Seismological and Magnetotelluric Observations

A.G. Jones,M. Muller, with S. Fishwick (U. Leicester), D. Eaton (U. Calgary), R. Evans (WHOI).

In general, seismic velocity is primarily a function of bulk properties of the media and electrical resistivity is usually primarily a function of the properties of a minor phase in the rock (low order partial melt, presence of conducting irons, oxides, etc.), so one might not expect the two to correlate.

Modelling and inversion of continental and regional seismic data for southern Africa yield a variety of compressional and shear velocity models. These models differ in the data used, either surface waves or body waves, and in the techniques applied. Magnetotelluric (MT) data from SAMTEX (Southern African Magnetotelluric Experiment) yield models and images of the electrical resistivity of the lithospheric mantle of Southern Africa.

Comparisons at various depths of slices from a new high-resolution (1.5 deg) seismic model, derived from surface wave inversion of events along continental paths, and new electrical images, including the data from Phase IV of SAMTEX, reveal correlations at both large and small scales. The existence of these correlations, which can be defined quantitatively by a quadratic regression between log

(resistivity) and velocity, indicates that the two are functions of the same parameters, namely temperature, physical state, magnesium number, and composition. This suggests that joint inversion would be worthwhile, where the two datasets should be inverted directly for petrophysical parameters.

Publication:

Jones, A.G., R.L. Evans, and D.W. Eaton (2009), Velocity-conductivity relationships for mantle mineral assemblages in Archean cratonic lithosphere based on a review of laboratory data and Hashin-Shtrikman extremal bounds. *Lithos, 109*, 131-143, doi: 10.1016/j.lithos.2008.10.014.

Presentations:

Jones, A.G., R.L. Evans, and D.W. Eaton (2009), Velocities and conductivities of mantle mineral assemblages for cratonic lithosphere based on laboratory observations coupled with extremal bound theory. Contributed paper at: IASPEI, Cape Town, 10-16 January.

Jones, A.G., S. Fishwick, **M.R. Muller** and the SAMTEX Team (2009), Physical properties of Southern Africa lithosphere: Comparison of seismic and electrical parameters. Contributed paper at: EGU 2009, Vienna, 19-24 April.

Jones, A.G., S. Fishwick, R.L. Evans, and the SAMTEX Team (2009), Correlation of lithospheric velocity and electrical conductivity for Southern Africa. Contributed paper at: SAGA, Swaziland, 16-18 September.

3.4 Joint Inversion of Electromagnetic and Seismic Data

A.G. Jones, E. Roux, E. Mandolesi, S. Lebedev, with M. Moorkamp (U. Kiel) and S. Fishwick (Leicester)

A joint inversion of long-period MT data and teleseismic Receiver Functions (RF) and Surface Wace (SW) dispersion data for a 1D isotropic media using a Genetic Algorithm was undertaken by Dr. Max Moorkamp with Jones and colleagues (Moorkamp et al., 2007, 2010).

The isotropic version of the code has been successfully extended for 1D anisotropic media, inversion of surface wave dispersion curves and long-period magnetotelluric data. This new approach has been tested with synthetic datasets and promising results were obtained, showing that joint inversion has the potential to improve the model resolution in comparison to separate inversions (Roux et al., 2009).

Because of existing data and knowledge, we, Roux, Jones and colleagues, have chosen to apply this new joint inversion method to a real dataset from Central Germany. We are looking for a 1D anisotropic structure combining seismological and magnetotelluric observations, aiming to improve the resolution of deep structures such as the lithosphere/asthenosphere boundary. This work is still in progress but promising results have been obtained so far and presented at several international conferences (Roux et al., 2009).

Besides the 1D anisotropic joint inversion, the possibility of extending this code to 2D is being investigated. The starting approach has been linking seismic and electrical structure geometrically. This approach was tested with synthetic electromagnetic data keeping fixed the seismic structure and the results were presented at the AGU Fall Meeting (Mandolesi et al., 2009).

Publication:

Moorkamp, M., **A.G. Jones**, and S. Fishwick (2010), Joint inversion of receiver functions, surface wave dispersion and magnetotelluric data. Journal of *Geophysical Research – Solid Earth*, accepted, 16th December, 2009.

Presentations:

Mandolesi E., A.G. Jones, E. Roux, and **S. Lebedev** (2009), Common structure in Different Physical Properties: Electrical Conductivity and Surface Wave Velocity, contributed paper at Fall American Geophysical Union meeting (poster), San Francisco, California, USA.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of magnetotelluric and surface-wave data in an anisotropic earth, contributed paper at Fall American Geophysical Union meeting (talk), San Francisco, California, USA.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of different geophysical datasets: synthetics and real test cases, invited talk at Geological Survey Canada, Ottawa, Ontario, December.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of magnetotelluric and surface-wave data in an anisotropic Earth, contributed paper at DefLAB Workshop (talk), Dublin, Ireland.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of magnetotelluric and surface-wave data in an anisotropic Earth, contributed paper at European Geophysical Union (talk), Vienna, Austria.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of magnetotelluric and surface-wave data in an anisotropic Earth, contributed paper at Frontiers of Seismology Workshop (talk), Edinburgh, UK.

3.5 Petrophysical Modelling of the Continental Upper Mantle

J. Fullea, A.G. Jones, M. Muller, with J.C. Afonso (U. Macquarie, Sydney, Australia)

Several tasks were completed during 2009. Two papers were published on the lithospheric modelling software LitMod3D (Fullea et al., 2009). The first one is intended to introduce the code to the Earth Sciences community, and the second one shows an application of the code: the study case of the Atlantic – Mediterranean Transition Zone (Fig 3.4.1). Furthermore, the electrical conductivities of the mantle as a function of temperature and composition were integrated as an additional output of LitMod. A number of conductivity laboratory experiments for the relevant mineral phases, and different averaging schemes, were used to define a realistic conductivity model for the bulk mantle rock. A 1D version of LitMod including the calculation of MT responses (apparent resistivity and phase) and Rayleigh and Love surface wave dispersion curves was developed. This 1D version, which solves the forward problem, is the core of an inversion scheme aimed to investigate the lithospheric structure using different geophysical data (elevation, surface heat flow, surface waves and magnetotelluric impedancies). The inversion scheme is currently being applied to study the lithosphere in different scenarios: Mongolia, Southern Africa and the Atlas Mountains (Morocco).

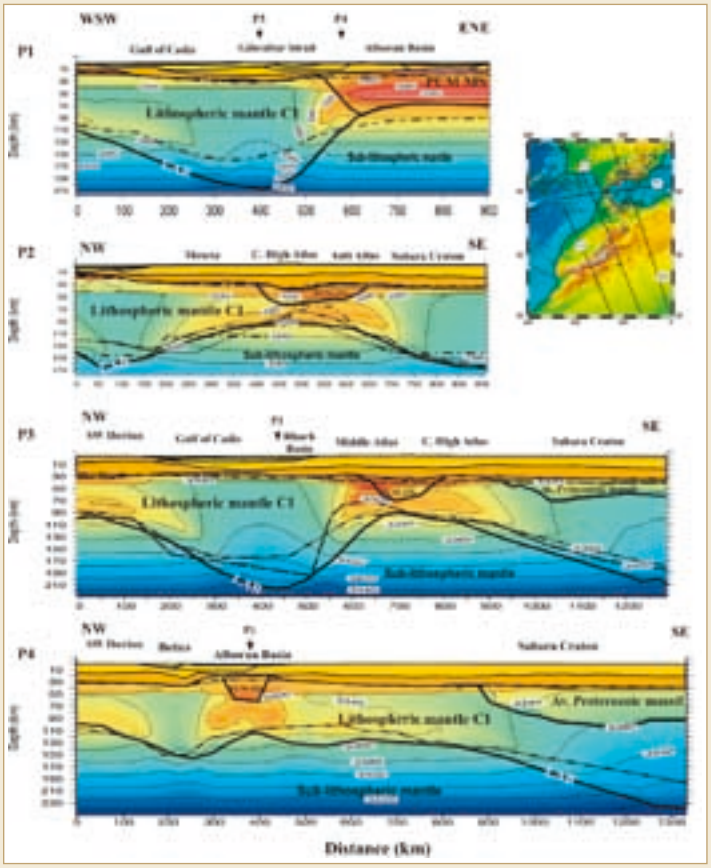

Figure 3.4.1. Selected lithospheric cross-sections of the mantle density in the Atlantic-Mediterranean Transition region (thick solid lines) and superimposed crust-mantle boundary and LAB geometries from previous work. Isolines of density at 20 kg/m^3 intervals. The vertical arrows show the crossover between the different profiles. Inset shows the location of profiles. From Fullea et al. (2010).

Publications:

Fullea, J., J.C. Afonso, J.A.D. Connolly, M. Fernàndez, D. García-Castellanos, and H. Zeyen. (2009), LitMod3D: an interactive 3D software to model the thermal, compositional, density, rheological and seismological structure of the lithosphere and sublithospheric upper mantle, *Geochemistry Geophysics and Geosystems*, doi: 10.1029/2009GC002391.

Fullea, J., J.C. Afonso, M. Fernàndez, and J. Vergés. The structure and evolution of the lithosphere-asthenosphere boundary beneath the Trans-Mediterranean region, *Lithos*, in press.

Presentations:

Fullea, J., J.C. Afonso , J.A.D. Connolly, M. Fernàndez, and D. García-Castellanos (2009), Characterizing the lithospheric-sublithospheric upper mantle system: its thermal, compositional, seismological, and rheological structure in 3D. Contributed at: DefLAB, Dublin, 3-5 June.

J. Fullea, M. Fernàndez, J.C. Afonso, J. Vergés, and H. Zeyen (2009), Geophysical modelling of the lithosphere-asthenosphere boundary beneath the Atlantic-Mediterranean Transition Region: integrating potential field, surface heat flow, elevation, seismological and petrological data, Contributed paper at: Fall AGU, San Francisco, U.S.A., 14-18 December.

4 Electromagnetic Research Activities

Group Leader: Senior Professor Alan G. Jones

4.1 SAMTEX (Southern African Magnetotelluric Experiment)

A.G. Jones, M. Muller, M. Miensopust, D. Khoza, P.-E. Share

Southern Africa, particularly the Kaapvaal Craton, is one of the world's best natural laboratories for studying the lithospheric mantle given the wealth of xenolith and seismic data that exist for it. The Southern African Magnetotelluric Experiment (SAMTEX) was launched to complement these databases and provide further constraints on physical parameters and conditions by obtaining information about electrical conductivity variations laterally and with depth. Initially it was planned to acquire magnetotelluric data on profiles spatially coincident with the Kaapvaal Seismic Experiment, however with the addition of seven more partners to the original four through the course of the experiment, SAMTEX was enlarged from two to four phases of acquisition, and extended to cover much of Botswana and Namibia. The complete SAMTEX dataset now comprises MT data from over 730 MT sites and ~14,000 line kilometres of profiling in an area of over one million square kilometres, making SAMTEX the largest regional-scale MT experiment conducted to date.

Schrödinger Fellow Dr. Mark Muller has completed the 2-D electrical resistivity modelling of the KIM-NAM profile across the Kaapvaal Craton, Rehoboth Terrane and Damara Mobile Belt (Figure 4.1.1), providing the first deep lithospheric images ever of the latter two terranes, and new electrical images of the Kaapvaal Craton where previously imaged only by seismic methods. Significant lateral heterogeneity is indicated in lithospheric structure and, as temperature is the primary control on the resistivity of mantle minerals, the MT derived lithospheric thicknesses provide a very reasonable proxy for the "thermal" thickness of the lithosphere in each terrane, allowing approximate present-day geotherms to be calculated (Figure 4.1.1). A comparison of the present-day lithospheric structure (from MT) with previously published mantle xenolith P-T arrays and mantle geochemistry data that define the palaeo-strucutre at the time of kimberlite eruption (~120 – 70 Ma) provide strong evidence that the lithospheric strucutres of both the Kaapvaal Craton and Rehoboth Terane were physically, thermally and geochemically modified during the thermalism associated with kimberlite eruption. Such lithospheric modification would have a significant isostatic uplift/subsidence response, with predictable changes in surface elevation, and therefore on erosion and sediment deposition during the period 120 Ma to present. Muller, in collaboration with Post-Doctoral Fellow Dr. Javier Fullea, is currently working on modelling the variations in surface elevation predicted by changes in lithospheric thickness and composition (Figure 4.1.2) and is comparing these predicted variations with constraints from the recent geological record of southern Africa provided by erosion levels and thickness of the Karoo succession, and the thickness of recently deposited Kalahari Basin sediments.

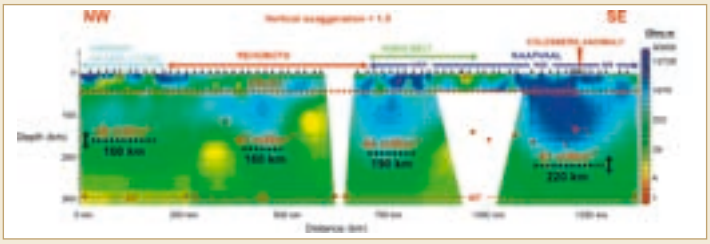

Figure 4.1.1. Composite 2-D electrical resistivity model of the KIM-NAM profile with annotations showing estimated lithospheric thickness and inferred present-day geotherm for each terrane traversed. Vertical black arrows indicate the uncertainty in the estimate of lithopsheric thickness (±20 km). Decomposition strike direction used for each terrane is shown at the bottom of the section. Red diamonds indicate depths to the base of the chemically depleted lithosphere estimated from Cr-Ca compositions of garnets contained in mantle xenoliths from individual kimberlite pipes. Model is blanked where poorly constrained. From Muller et al. (2009).

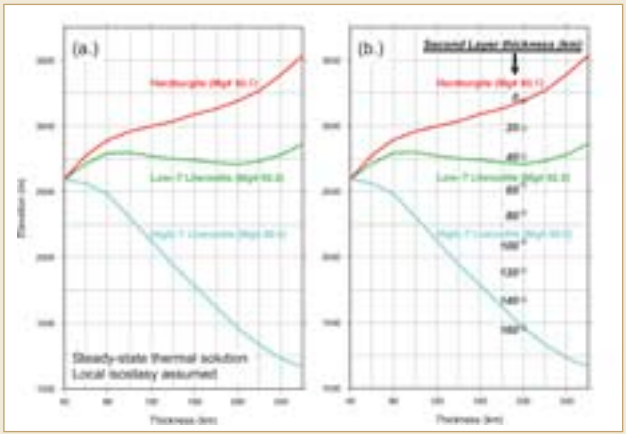

Figure 4.1.2. (a.) Variations in surface elevation predicted by the self-consistent 1-D modelling of variation in lithopsheric thickness for three different lithospheric mantle compositions. In (b.) surface elevation changes (diamonds) are shown as a function of increasing thickness of a more- fertile lower lithospheric mantle layer, with respect to an original 200 km thick lithopshere of harzburgitic composition.

Further ongoing work by Muller within the SAMTEX project includes the modelling of three MT profiles that traverse the poorly understood Okwa Terrane located in central and southern Botswana, largely hidden beneath Kalahari sand cover. Determining the tectonic relationship between the Okwa Terrane and the terranes located at its margins is critical to understanding the Archaean and Proterozoic accretionary history of southern Africa.

Senior scholar Marion Miensopust focussed on investigation of the 600km long ZIM line profile crossing the Zimbabwe Craton (ZC), Magondi Mobile Belt (MMB) and Ghanzi-Chobe Belt (GCB). The MT data modelling (Fig. 4.1.3) showed that the ZC is characterised by thick (> 220 km) resistive lithosphere, which is consistent with geochemical and geothermal estimates from kimberlite samples of the Orapa and Letlhakane pipes (>175 km west of the profile). The lithospheric mantle of the GCB is resistive but the lithosphere is only about 180 km thick.

At crustal depths (Fig. 4.1.4) a northwards dipping boundary between the GCB and the MMB was identified and two middle/lower crustal conductors were found in the MMB. The terrane boundary between MMB and GCB was found to be located further to the north, and the southwestern boundary of the ZC might be further to the west, than previously estimated using potential field data. MT data from sites above the highly resistive Okavango dyke swarm showed that in the area close to Maun the dilatation of dykes estimated from the magnetic anomaly is too small (2.6%) to enhance the resistivities significantly and that conductive near-surface layers mask its small effect. An anisotropic or fault-like structure was found to be orientated perpendicular to the dyke swarm direction and extending from about 10 – 15 km depth down into the lithospheric mantle, to 120 km or deeper.

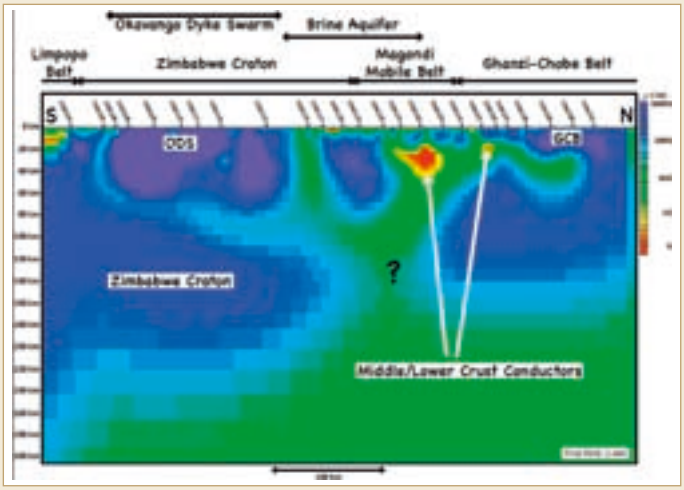

Figure 4.1.3. Lithospheric scale model of the MT data from the ZIM profile.

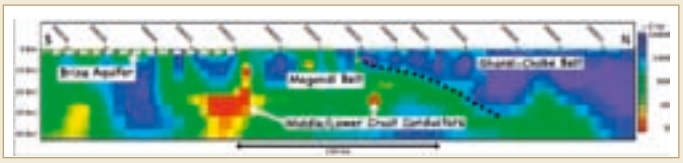

Figure 4.1.4. Crustal scale model of the MT data from the ZIM profile

The work by Scholar David Khoza focuses specifically on the collisional boundary belt between the Rehoboth terrane and the Angola Craton. The nature and geometrical relation of the boundary between the Kalahari craton and the Damara orogenic belt is unknown. This current study aims to understand the nature of the geometry of the Ghanzi-Chobe-Damara (DMB) belt in relation to both the Rehoboth (Kalahari) and Angola craton and to compare lithospheric thickness variations of these three tectonic units. Regional-scale resistivity models constructed from two-dimensional inversions of the MT data indicate significant variations in lithospheric resistivity structure along and across strike from the younger orogen to the older

adjacent cratons. The Damara belt lithosphere, although generally more conductive and significantly thinner (<100 km) than adjacent Angola craton and Rehoboth terrane, exhibits upper resistive upper crustal features tentatively interpreted to be caused by igneous intrusions emplaced during a Pan-African magmatic event. The southern Congo craton is mapped as a thick (>150 km), resistive lithospheric feature. These results constrain the geographical position of the craton boundary margin and its geometry at depth and provide the first pseudo three dimensional tectonic structures of the Damara orogen and adjacent terranes.

A somewhat unique component of SAMTEX is the additional work done for the Namibian Power Corporation and being undertaken by Scholar Pieter-Ewald Share. In the near future a high-voltage direct current (HVDC) power line will be constructed between the Otjiwarongo and Katima Mulilo regions. The main purposes of my project are to obtain electrical conductivity models of the two areas, to aid in the optimal placement of the HVDC earth electrodes, and to use the two models together with other conductivity models in between and in the vicinity of Otjiwarongo and Katima Mulilo as input to a 3D DC forward modelling code to try to predict the DC current return path. Previous magnetometer array studies suggest the existence of a long continuous conductive belt situated within the orogenic Neo-Proterozoic Ghanzi-Chobe/Damara belts (collectively termed the Damara Mobile Belt (DMB)). Results from 2D inversions of the AMT and BBMT data recorded during SAMTEX confirm the findings of these previous studies, and mapping the observed mid-crustal conductive region to the surface shows good correlation with the proposed conductive belt in regions where MT data are available. Due to the higher resolution achieved with the MT method the conductive belt is shown to be discontinuous and more variable in width than initially estimated with the magnetometer array studies. The result leads to speculation regarding the nature of connectivity of the conductive belt not only across its width, but also its length. Interpolation between the regions of known conductivity, as determined with AMT and BBMT data, to optimally approximate the regions of unknown conductivity is therefore a critical step in the prediction of DC return current flow. During interpolation different scenarios are tested, varying in smoothness, to obtain the best 3D interpolated conductivity model that is both consistent with our data and the understanding of conductivity variations within the Earth. The model is then used as input to a 3D DC resistivity forward modelling code to try to predict the return path that the DC current will follow between the Otjiwarongo and Katima Mulilo regions.

Publications:

Jones, A.G., R.L. Evans, **M.R. Muller**, M.P. Hamilton, **M.P. Miensopust, X. Garcia**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S Fourie, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Area selection for diamonds using magnetotellurics: Examples from southern Africa, *Lithos, 112S*, 83-92.

Muller, M.R., A.G. Jones, R.L. Evans, H.S. Grütter, C. Hatton, **X. Garcia**, M.P. Hamilton, **M.P. Miensopust**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J. Fourie, H.A. Jelsma, T. Aravanis, S.J. Webb, J. Wasborg, and the SAMTEX Team (2009), Lithospheric structure, evolution and diamond prospectivity of the Rehoboth Terrane and western Kaapvaal Craton, southern Africa: constraints from broadband magnetotellurics. *Lithos, 112S*, 93–105, doi:10.1016/j.lithos.2009.06.023.

Presentations:

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Jones, A.G., M.R. Muller, M.P. Miensopust, M.P. Hamilton, R.L. Evans, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, M. Doucoure, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Geometry and structures of the Southern African lithosphere revealed through deep-probing electromagnetics: The SAMTEX project. **Invited Keynote Presentation** at: IASPEI, Cape Town, 10-16 January.

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Jones, A.G., M.R. Muller, M.P. Miensopust, D. Khoza, P.-E. Share and the The SAMTEX Team (2009), Results from SAMTEX: The Southern African lithospheric mantle–electrical structures and geometries and comparison with

seismological information. Contributed paper at: EGU 2009, Vienna, 19-24 April.

Jones, A.G., R.L. Evans, M.R. Muller, M.P. Hamilton, **M.P. Miensopust, X. Garcia**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, S. Evans, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), The SAMTEX experiment: Overview and Preliminary Results. Invited Keynote Presentation at: SAGA, Swaziland, 16-18 September.

Khoza, D.T., A.G. Jones, M.R. Muller, R.L. Evans, M.P. Hamilton, **M.P. Miensopust, X. Garcia**, P. Cole, T. Ngwisanyi, D. Hutchins, W. Pettit, H. Jelsma, T. Aravanis, C.J.S. Fourie, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Geo-electrical Structural Directions and Dimensionality of Damara belt and surrounding cratons, Spring AGU May 2009, Poster presentation.

Khoza, D.T., A.G. Jones, M.R. Muller, R.L. Evans, M.P. Hamilton, **M.P. Miensopust, X. Garcia**, P. Cole, T. Ngwisanyi, D. Hutchins, W. Pettit, H. Jelsma, T. Aravanis, C.J.S. Fourie, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Magnetotelluric Imaging across a Neoproterozoic collision zone:Damara belt and surrounding tectonic blocks, SAGA conference, September.

Khoza, D.T., A.G. Jones, M.R. Muller, and The SAMTEX Team (2009), The lithospheric architecture of a Neoproterozoic collision zone in Southern Africa inferred from deep probing magnetotelluric data, Fall AGU Conference, December.

Miensopust, M.P., A.G. Jones, M.R. Muller, M.P. Hamilton, X. Garcia, R.L. Evans, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009). Magnetotelluric study in northeastern Botswana. Talk at: EMFT meeting, Seddiner See, Germany, 28 September–2 October.

Miensopust, M.P., A.G. Jones, M.R. Muller, M.P. Hamilton, **X. Garcia**, R.L. Evans, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Magnetotelluric study in northeastern Botswana. Talk at: South African Geophysical Association (SAGA) meeting, Swaziland, 16–18 September.

Muller, M.R., A.G. Jones, R.L. Evans, H.S. Grütter, C. Hatton, **X. Garcia**, M.P. Hamilton, **M.P. Miensopust**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J. Fourie, C.M. Doucouré, T. Aravanis, W. Pettit, S.J. Webb, J. Wasborg, and The SAMTEX Team (2009), Lithospheric structure, evolution and diamond prospectivity of the Rehoboth Terrane and western Kaapvaal Craton, southern Africa: constraints from broadband magnetotellurics. IASPEI General Assembly, Cape Town, South Africa, 10-16 January.

Muller, M.R., A.G. Jones, R.L. Evans, H.S. Grütter, C. Hatton, **X. Garcia**, M.P. Hamilton, **M.P. Miensopust**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J. Fourie, H.A. Jelsma, S.F. Evans, T. Aravanis, W. Pettit, S.J. Webb, J. Wasborg, and The SAMTEX Team (2009), Rapid Mesozoic thermal and chemical modification of the Rehoboth Terrane and Kaapvaal Craton from broadband magnetotellurics and xenolith geochemistry. 11th Biennial Technical Meeting of the South African Geophysical Association, Swaziland, 15-17 September.

Muller, M.R., A.G. Jones, R.L. Evans, and The SAMTEX Team (2009), Constraints from deep-imaging magnetotellurics on the lithospheric structure and evolution of the enigmatic Okwa Terrane, Botswana. AGU Fall Meeting, San Francisco, USA, 14-18 December.

Share, P., A.G. Jones, R.L. Evans, **M.R. Muller**, M.P. Hamilton, **D. Khoza, M.P. Miensopust, X. Garcia**, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, H.A. Jelsma, T. Aravanis, W. Pettit, S.J. Webb, J. Wasborg, and The SAMTEX Team (2009), Prediction of DC current flow between the Otjiwarongo and Katima Mulilo regions, using 3D DC resistivity forward modelling and magnetotelluric and audio-magnetotelluric data recorded during SAMTEX. Contributed paper at: SAGA, Swaziland, 16-18 September.

Share, P., A.G. Jones, M.R. Muller, M.P. Miensopust, D. Khoza, C.J.S. Fourie, S.J. Webb, H. Thunehed, and The SAMTEX Team (2009), Prediction of DC current flow between the Otjiwarongo and Katima Mulilo regions, using 3D DC resistivity forward modelling and magnetotelluric and audio-magnetotelluric data recorded during SAMTEX. Contributed paper at: AGU Fall meeting, San Francisco, USA, 14-18 December.

Webb, S.J., and **A.G. Jones** (2009), Delineating prospective kimberlite regions using potential field methods – from space to surface. Invited Keynote Presentation at: IASPEI, Cape Town, 10-16 January.

4.2 PICASSO (Programme to Investigate Convecting Alboran Sea System Overturn) and TopoMed (Plate Re-organisation in the Western Mediterranean: Lithospheric Causes and Topographic Consequences)

A.G. Jones, J. Fullea, J.-P. Schmoldt, D. Kiyan, with colleagues from the University of Barcelona, the University of Bari, and from Spain, Morocco and the U.S.A.

To improve our understanding of the details of continental collision, a consortium of Earth scientists from Europe, the U.S.A., and Morocco is collaborating on an international, multi-disciplinary geoscientific project for studying the active tectonics of the Africa-Eurasia diffuse plate boundary zone in the western Mediterranean. Within the project area lies the Betic-Rif mountain system of southern Spain and northern Morocco (Gibraltar Arc), the purported active lithospheric delamination occurring in the Alboran Sea, the active subduction in the Gulf of Cadiz, and the far-field effects observed in central Spain and the Atlas mountains. Despite many years of geological study, the nature of the orogen is controversial, with a wide variety of models being permitted principally due to the paucity of high precision geometrical and physical property information for the lithospheric mantle beneath the region.

This project, primarily being organised by Spanish (leader: Dr. Ramon Carbonnell, Institut de Cienciès de la Terra "Jaume Almera", Barcelona, Spain) and U.S. (leader: Prof. Alan Levander, Rice University, Houston, Texas) investigators, is named PICASSO for Program to Investigate Convective Alboran Sea System Overturn, and has been selected as a pilot program for the nascent EuroArray and TOPO-EUROPE programs. A parallel project called TopoMed, under the auspices of the ESF EUROCORE project TOPO-EUROPE, is focussed particularly on the Atlas Mountains. Irish involvement in both is funded through grants to Jones from SFI for PICASSO and IRCSET for TopoMed.

The principle, overarching objective of joint projects PICASSO/TopoMed is to determine the three-dimensional internal structure of the crust and lithosphere, with special emphasis in the geometry of the upper mantle, in order to deduce the lithospheric processes that are taking place. The putative delamination beneath the Alboran Sea is one of the key targets of PICASSO, but understanding the whole orogen holistically is its primary objective.

PICASSO (funded by SFI) and TopoMed (funded by IRCSET) are companion projects studying the collision of Africa with Europe as expressed in the western Mediterranean. The focus of PICASSO by the DIAS MT group is primarily Iberia and northern Morocco, whereas the focus of TopoMed is the Atlas Mountains. Both projects have very extensive international partners and linkages, both within Europe and North America (U.S.A. and Canada).

Intensive work has been carried out on the magnetotelluric dataset collected during the PICASSO project Phase I fieldwork and results have been presented to a wide audience at international meetings in the USA, Austria, and Ireland. In addition to the investigation of the Alpine orogenic and subsequent tectonic processes forming the Betic Mountain Chain work has been focused on identification of Mohorovičić discontinuity and Lithosphere-Asthenosphere Boundary (LAB) beneath the Iberian mainland in terms of their electric conductivity parameters. For that reason our findings have been contrasted with the outcome of various other geophysical methods previously recorded in that area in order to constrain our data and enhance the confidence in our results.

Due to the fact that the observed combination of low signal activity and high noise levels in the area caused parts of the dataset to be of poor quality a concept of an innovative approach of noise cancellation using wavelet-based polarization filtering has been developed. Work on this topic has been advanced by sending Scholar Jan-Philipp Schmoldt for one week to Barcelona in order to collaborate with Dr. Xavier Garcia at the CSIC Marine Institute.

The TopoMed project's objective is to develop a better understanding of the internal structure of the crust and lithosphere of the Atlas Mountains of Morocco. The first phase of the magnetotelluric (MT) experiment of the project was carried out in Atlas Mountains region from end of September to mid-December 2009. Two different types of MT equipment (broadband and long period MT recording systems) were used along two profiles (Figure 4.2.1).

MT data were acquired at 23 locations along the MAR profile, with LEMI data at 9 of these. The recording of LEMI data was extended due to the very low solar activity

in 2009–there were no sunspots observed on 260 days (71%) of the year (NASA Report). Simultaneously, the broadband MT (BBMT) data were collected at 20 sites along the southern part of the MEK profile which extends for approximately 500 km from the Rif to the sand dunes of the Sahara (Figure 1). In December 2009, the LEMI acquisition started at 13 sites on the northern part of the profile from Meknes to the Rif. The second phase of the MT survey scheduled for February is to continue data collection along this part of the MEK profile. Further acquisition is needed to complete the intended profiles and possibly another profile across the High Atlas Mountains.

DIAS PICASSO web site: http://www.geophysics.dias.ie/projects/PICASSO/index.htm
TopoMed ESF web site: http://www.esf.org/activities/eurocores/running-programmes/topo-europe/the-crps/topomed.html

Figure 4.2.1. Map of the survey region showing the MT profiles.

Presentations:

Kiyan, D., J.-P. Schmoldt, A.G. Jones, C. Hogg, and O. Rosell (2009), The PICASSO project: MT Investigation in Southern Spain and Morocco–Results of Phase I and outlook on Phase II. Contributed paper at AGU fall meeting 2009, San Francisco, 14-18 December.

Schmoldt, J.-P., A.G. Jones, C. Hogg, and O. Rosell (2009), PICASSO Phase I: MT Investigation of Spain from Madrid to the Betics–preliminary results and models. Contributed paper at: EGU 2009, Vienna, 19-24 April.

Schmoldt, J.-P., A.G. Jones, C. Hogg, and O. Rosell (2009), PICASSO Phase I: Magnetotelluric (MT) Investigation of Spain from Madrid to the Betics–preliminary results and models. Contributed paper at: 52nd Irish Geological Research Meeting (IGRM), Dublin, 20-22 February.

4.3 INDEPTH (InterNational DEep Profiling of Tibet and the Himalaya)

A.G. Jones, J. Vozar, F. Le Pape

The Tibetan Plateau, with the adjacent Himalayan Mountain Belt to the south and the regions to the north of the Plateau in China, remain the world's foremost natural laboratory for investigating continental collisional tectonics. There is still continuing and diverse debate, after almost a century of conjecture, over how the Asian continent has responded, and continues to respond, to the embedding of the Indian subcontinent. Theories have revolved around a plethora of concepts such as distributed shortening, wholesale continental underthrusting, indentor tectonics, orogenic collapse, delamination, and, most recently and as a consequence of INDEPTH (InterNational DEep Profiling of Tibet and the Himalaya) investigations, ductile flow in the lower crust. Intrinsic to most, if not all, of these concepts is the degree of subduction of the Indian plate beneath the southern margin of Asia. Subduction of Asian continental crust beneath the Tibetan Plateau along its northern margin has received far less attention, but is a common theme of several recent geodynamic models and data analyses. It is this northern margin, and the large-scale geotectonic issues involved, that is the focus of INDEPTH Phase IV activities.

The INDEPTH project, initiated in 1992 between Cornell University and the Chinese Academy of Geological Sciences, has grown into a major international collaboration comprising scientists from China, the U.S.A., Germany, U.K., Canada and Austria. Led by the Chinese Academy of Geological Sciences, the institutions that have been involved include: China: the Chinese Academy of Geological Sciences

(CAGS), and the China University of Geological Sciences, Beijing (CUGB); USA: Boston U., Columbia U., Cornell U., U. Indiana, New Mexico State U., Oregon State U., Stanford U., SUNY at Albany, Syracuse U., UCSC, and U. Washington (UW); Germany: GeoForschungsZentrum Potsdam, U. Freiberg, U. Göttingen, U. Kiel, U. Karlsruhe, U. Potsdam, U. Tübingen, and U. Würzburg; UK: U. Cambridge; Canada: the Geological Survey of Canada (GSC), and U. Alberta (UofA); Austria: U. Vienna.

INDEPTH Phase I (1992-1994) comprised only vertical seismic reflection profiling. In Phase II (1995-1997), at the express invitation of the Chinese, magnetotellurics (MT) was added, and then Jones, together with Profs. J.R. Booker (UW) and M.J. Unsworth (UW, now UofA) and Profs. L. Chen and W. Wei and colleagues (CUGB), conducted the first modern MT acquisition on the plateau in 1995. The startling MT and seismic results from INDEPTH-II, published in Science (Nelson et al., 1996; Chen et al., 1996), gave unequivocal evidence for the existence of a mid-crustal fluid (Li et al., 2003) zone north of the Tsangpo (India-Asia) suture. The Nelson et al. (1996) Science paper, to which Jones contributed considerably, is cited 350 times to date and the results have led to major reinterpretations of geoscientific data and of significant new directions by those modelling geodynamic processes of collisional orogens. The Chen et al. (1996) paper that detailed the MT results, is cited to date 87 times, and the data were analysed, modelled and interpreted, and the paper was written, entirely by Jones, but for geo-political reasons Jones is the 3rd author of it.

In Phase III (1998-2000) this fluid zone was tracked using MT across the whole of the Tibetan Plateau to the Kunlun fault (Wei et al., 2001; Unsworth et al., 2004). More focussed MT interpretations identified the geometry of structures within suture zones (Solon et al., 2005; Spratt et al., 2005), and the results were key in the detection of the alpha to beta quartz transition in the crust (Mechie et al., 2004). By reaching out to other groups in Asia who also are studying the India-Asia collision zone in India and Nepal, Unsworth et al. (2005) demonstrated the remarkable along-strike continuity of processes acting at the Tsangpo suture.

INDEPTH-IV will complete the transect across the Tibetan Plateau by addressing another current major controversy in the inferred tectonic processes accommodating the indentation of India into Asia. The possible subduction of Asian continental crust beneath the Tibetan Plateau along its northern margin has received far less attention than the southern boundary, but is a common theme of recent numerical models and interpretations. It is this northern margin that is the focus of Phase IV.

During the Phase III surveys in 1999, broadband and long period magnetotelluric data were collected in Northern Tibet across the Kunlun Shan. The MT stations, placed along the northern part of the Lhasa to Golmud highway, defined the so-called 600-line profile extending from the middle of the Qiangtang Terrane to the southern edge of the Qaidam Basin. As part of Phase IV, seismic data crossing again the Kunlun Shan, is already being acquired east of the 600 line. At the end of April 2010 will start the MT acquisition part of INDEPTH Phase IV in collaboration with the University of Alberta, Canada and the CUGB, China. The fieldwork plan consists of two profiles crossing the Altyn Tagh fault and another profile east of the 600 line to complement the seismic data. In anticipation of the upcoming survey, the MT 600-line data were re-analysed and re-modelled. The Kunlun Fault is investigated as a rheological boundary in the middle and lower crust of northern Tibet, between a crust weakened by partial melting and a more stable (dry, cold) crust north of the fault.

Two 2D geoelectrical models crossing the Banggong-Nujiang suture roughly, along longitude of 89°E (longer 500 line) and 92°E (shorter 400 line), which separate Qiangtang and Lhasa terrane were inverted from MT INDEPTH data. The models show close-up information about the Banggong-Nujiang suture and its changes in geoelectrical structure between the longitude of 89°E and 92°E. The eastern profile exhibits shallower crustal conductive layer and sharp horizontal jump in conductivity just below the surface trace of the Banggong-Nujiang suture in comparison with western 500 line. The preliminary 3D models of INDEPTH region have been created with deep spherical (Kuvshinov–x3dg) and shallow planar (Mackie–mt3dfwd, Weerachai – WSINV3DMT) 3D modelling programs. To improve information about deep structures, much attention has been given to the generalized horizontal spatial gradient sounding method (GHSG) which results in impedance functions that in space and frequency domains closely resemble the magnetotelluric impedances. The code for practical application of GHSG method was prepared and long period magnetovariational scalar transfer functions from available observatory geomagnetic data have been determined.

Presentations:

Le Pape, F., A.G. Jones, J. Vozar, and The INDEPTH MT Team (2009), Evolution of the crustal and upper mantle structure beneath the Kunlun Shan in Northern Tibet from INDEPTH magnetotelluric data, poster presented at EMTF Colloquium, Germany, 28 September–2 October.

Le Pape, F., A.G. Jones, J. Vozar, and The INDEPTH MT Team (2009),, 2D Modelling of the Kunlun Shan area in Northern Tibet from INDEPTH magnetotelluric data, talk presented at INDEPTH Workshop, Dublin, 28-30 October.

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Vozar, J. (2009), MT models from Central Tibet, contributed at INDEPTH workshop, Dublin, Ireland, 28-30 October.

Vozar, J., A.G. Jones, F. Le Pape, and M. Unsworth (2009), Crustal structure of the Banggong-Nujiang suture from two INDEPTH magnetotelluric profiles, contributed paper at Fall AGU, San Francisco, U.S.A., 14-18 December.

4.4 3D MT Modelling/Inversion

M. Miensopust, A.G. Jones together with Prof. C. Farquharson (Memorial Univ. Newfoundland)

Three-dimensional (3D) forward and inversion programs for magnetotelluric data became more important recently going along with the increasing availability of huge computational power (fast CPUs with large memory). While a few 3D forward modelling codes became available, the accessibility of 3D inversion codes for academic purposes is very limited to not existing (or commercial and therefore expensive). The development of a new 3D edge finite-element inversion code will give us full access to this tool. Additional the code will address two problems that exist using observed magnetotelluric data. First, to avoid the noise propagation from one component of the impedance tensor into all the other elements by rotation we will rotate the noise-free synthetic data instead of the measured, as it is common practice. Second, galvanic distortion due to near-surface, small-scale resistivity heterogeneities disturb the magnetotelluric data. In 2D there are a few tools to deal with or at least minimise these effects, in 3D they are so far neglected. Our approach is to included the distortion parameters as inversion parameters and solve for them simultaneously to the resistivity structure (or include known distortion parameters as fixed variables for the inversion).

Presentations:

Miensopust, M.P., C.G. Farquharson, and **A.G. Jones** (2009), MCMT3DID–a finite-element, 3D MT inversion code using local coordinates for each site and solving for distortion parameters, contributed paper at Irish Geological Research Meeting (IGRM), Dublin, 20-22 February.

Miensopust, M.P., C.G. Farquharson, and **A.G. Jones** (2009), Inverting MT 3D data using local coordinates and taking distortion parameters into account: progress and preliminary results, contributed paper at EGU 2009, Vienna, 19-24 April.

Miensopust, M.P., C.G. Farquharson, and **A.G. Jones** (2009), Inverting MT 3D data using local coordinates and taking distortion parameters into account: progress and preliminary results, talk at IAGA meeting, Sopron, Hungary, 23-30 August.

4.5 LAPIS (La Palma Internal Structure)

A.G. Jones, with X. Garcia (Marine Institute, Barcelona)

A pilot MT survey was undertaken on La Palma in July 2007 to study the potential for catastrophic collapse of the flank of the Cumbre Vieja volcano that is modelled to pose an extreme tsunami hazard for the northern Atlantic.

Publication:

Garcia, X., and **A.G. Jones** (2010), Internal structure of the western flank of the Cumbre Vieja volcano (La Palma, Canary Islands) from land magnetotelluric imaging. *Journal of Geophysical Research – Solid Earth*, accepted, 26th February, 2010.

4.6 Melville Peninsula

C. Hogg, A.G. Jones, with J.E. Spratt and J. Craven (Geological Survey of Canada)

During the 2009 summer field season, the Geological Survey of Canada and DIAS collaborated on collecting magnetotelluric (MT) data from 29 locations along a 300-km-long regional profile across the Melville Peninsula, Nunavut, Canada. (See Figure 4.6.1.). The primary objectives

of the project are to resolve the nature of first order tectonic boundaries, to understand the structural evolution and tectonic processes from Archean to Phanerozoic times, and to determine the potential for mineral exploration in the region. First order observations of two-dimensional conductivity models derived from the MT data show a strong correlation with geological features mapped at the surface. These include the east-west trending faults that are imaged as less resistive structures cutting through highly resistive material, folding of strongly conductive Penrhyn Group units, and the presence of a deep penetrating near-vertical conductivity anomaly that coincides spatially with a shear zone interpreted to mark the northern extend of the Repulse Bay Block.

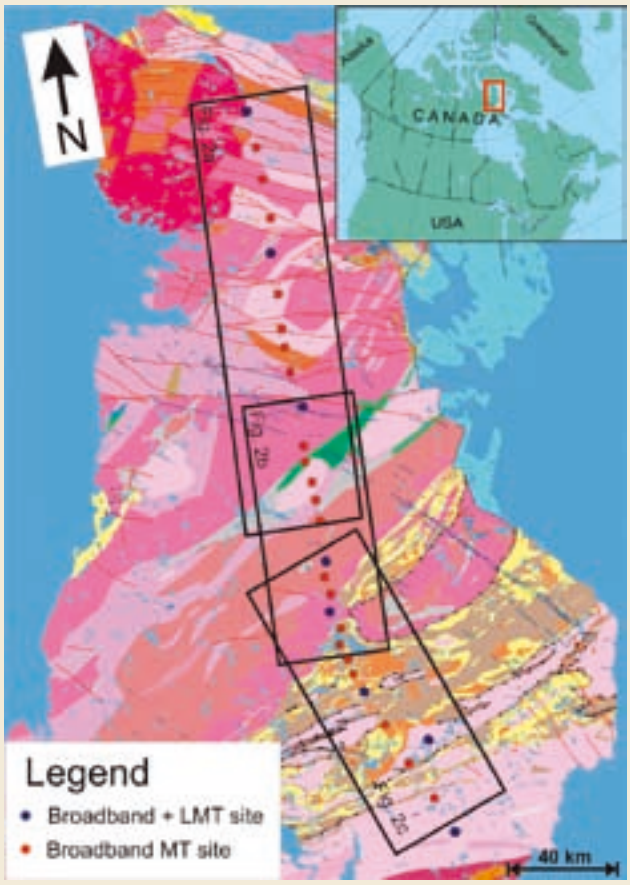


Figure 4.6.1. Map illustrating the MT site locations along with the regional geology of the Melville Peninsula.

4.7 Other

Other publications and presentations of work by EM group members of the Section are listed below.

Publications:

Gowan, E.J., I.J. Ferguson, **A.G. Jones**, and J.A. Craven (2009), Geoelectric structure of the northeastern Williston Basin and underlying Precambrian lithosphere, *Canadian Journal of Earth Sciences*, 46, 441-464.

Spratt, J.E., **A.G. Jones**, V. Jackson, L. Collins, and A. Avdeeva (2009), Lithospheric geometry of the Wopmay Orogen from a Slave Craton to Bear Province magnetotelluric transect, *Journal of Geophysical Research, 114*, B01101, doi: 10.1029/2007JB005326.

Vozar, J., and V. Semenov (2010), Compatibility of induction methods for mantle soundings, *Journal of Geophysical Research, 115*, XXXXXX, doi: 10.1029/2009JB006390, (in press).

Presentations:

Hogg, C., A.G. Jones, J. Spratt, and J.A. Craven (2009), A pilot study of underground Audio-magnetotelluric (AMT) measurements and its application for the mining industry, contributed paper at Irish Geological Research Meeting (IGRM), Dublin, 20-22 February.

Jones, A.G. (2009), The eLAB, Contributed paper at the DefLAB workshop, Dublin, 3-5 June.

Semenov V., M. Hvozdara, and **J. Vozar** (2009), Induction soundings of the mantle on the rotating Earth, contributed paper at the IAGA 11th Scientific Assembly, Sopron, 24-29 August.

Vozar, J., and V. Semenov (2009), Electromagnetic investigations of the lithosphere–asthenosphere boundary in Central Europe, contributed at DefLAB, Dublin, 3-5 June.

5 Geodynamic Research Activities

Group Leader: Professor Zdenek Martinec

5.1 Non-linear Rheology in Glacial Isostatic Adjustment Modelling

The improvement in understanding of dynamic processes in the earth mantle demands to consider a non-linear rheology of mantle material. Whereas this rheology is accepted in the studies of mantle convection, the need of a non-linear material behaviour in modelling of glacial isostatic adjustment (GIA) is still under discussion. Almost all the predictions of ongoing present-day processes

induced by GIA are based on the assumption of a linear Maxwell viscoelastic rheology. To study the influence of non-linear rheology on the GIA-induced motion, Martinec and Klemann implemented a non-linear H stress-dependent rheology in the spectral-finite element formulation of a viscoelastic self-gravitating sphere. The main effect of a non-linear rheology on the GIA-induced motion is for times when a surface ice-mass load is changing most rapidly because of large load-induced stresses. The results of this study will be presented at the EGU 2010 in Vienna.

5.2 Glacial Isostatic Adjustment in North America Inferred from GRACE

Sasgen and Martinec performed a joint inversion of gravity fields from the Gravity Recovery and Climate Experiment (GRACE) for glacial-isostatic adjustment over North America and present-day ice-mass change in Alaska and Greenland. We determine the Alaskan and Greenlandic contribution to sea-level change from the adjusted ice-mass change models. The residual misfit over the GIA-dominated region around the Hudson Bay is interpreted with regard to the mantle viscosities beneath North America by applying forward model calculations of the GIA signal in these regions. We compare our results based on satellite gravimetry with constraints derived from sea-level indicators, absolute gravimetry, tide-gauge stations and GPS, and show their sensitivity to the GRACE release considered, as well as to the glacial history underlying the GIA forward model. The results of this study will be presented at the EGU 2010 in Vienna.

5.3 Regional Ice-mass Variability from GRACE, InSAR and Surface-mass Balance

The Gravity Recovery and Climate Experiment satellite mission has allowed the resolution of temporal variations in the Earth's gravity field to serve as a new observable for monitoring mass changes in cryosphere. Sasgen and Martinec analysed the GRACE time series from August 2002 to August 2008 with regards to regional ice-mass variability in Greenland. We found that the mass change of the Greenland Ice Sheet amounts to cca 0.5 mm/a equivalent sea-level change and significantly accelerated during the observation period. The comparison with Interferometric Synthetic Aperture Radar (InSAR) data and output from surface-mass balance modelling indicates that mass-loss acceleration is mainly caused by increasing discharge in the Northwest starting in the year 2005. In the year 2007, mass loss additionally accelerates in the Southwest caused by a reduced surface-mass balance. We conclude that GRACE allows for the detection of regional scale mass variations, including accelerations, and may further contribute to the understanding the processes governing the current changes of Greenland Ice Sheet. The results of this study were submitted to a journal for publication in the later part of the year.

We estimate the mass balance of 8 drainage basins in West Antarctica (Figure 5.3.1) from the Gravity Recovery and Climate Experiment (GRACE) data (GFZ RL04, GSM Level 2) using an constrained inverse gravimetric approach. We consider InSAR observations of ice-surface velocity as an indication of mass change, assuming that large mass loss occurs in areas of fast glacier flow. From this mass distribution functions we construct forward models of the geoid-height change (Figure 5.3.2) and their spatial correlations for each drainage basin. Then, the difference between the GRACE data (Figure 5.3.2), corrected for the glacial isostatic adjustment (Figure 5.3.2), is minimized by adjusting the total amount of mass change within each drainage basin. Unconstrained (GRACE only) mass-change estimates can be recovered for 3 to 4 combined drainage basins. Independent GRACE and InSAR values differ mainly for the Pine Island Glacier and Getz Ice Shelf region. This difference results in an unconstrained GRACE total of –91.0 ± 3.5 Gt/a (years 2002 to 2008), which is significantly lower than the InSAR-based mass loss rate of –116.6 ± 19.0 Gt/a (Figure 5.3.3).

Figure 5.3.1.

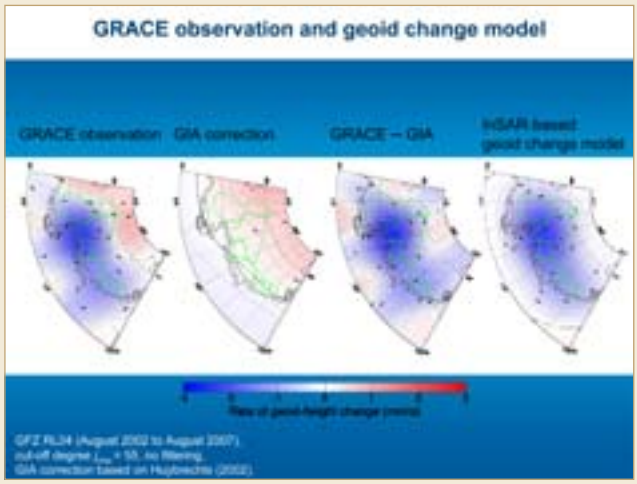
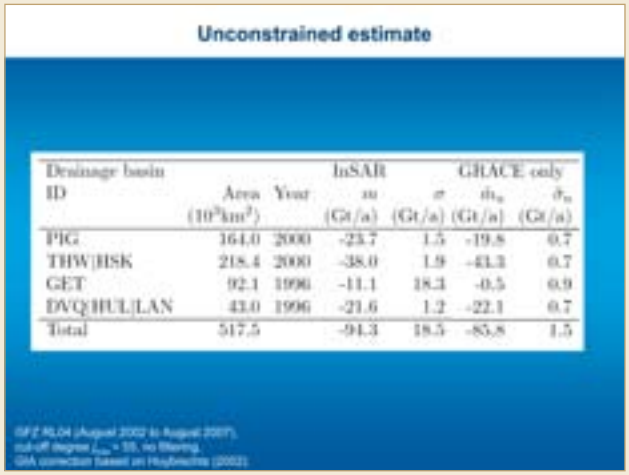


Figure 5.3.2.



Drainage basin ID	Area (10^3km^2)	Year	InSAR m (Gt/a)	InSAR σ (Gt/a)	GRACE only $\dot{m}_a$ (Gt/a)	GRACE only σ_a (Gt/a)
PIG	164.0	2000	-23.7	1.5	-19.8	0.7
THW|HSK	218.4	2000	-38.0	1.9	-43.3	0.7
GET	92.1	1996	-11.1	18.3	-0.5	0.9
DVQ|HUL|LAN	43.0	1996	-21.6	1.2	-22.1	0.7
Total	517.5		-94.3	18.5	-85.8	1.5

Figure 5.3.3.

Publication:

Sasgen, H. Dobslaw, **Z. Martinec**, and M. Thomas (2009), Satellite gravimetry observation of Antarctic snow accumulation related to ENSO, *Earth and Planetary Science Letters*, (submitted, 2009).

5.4 Benchmark Study for Glacial Isostatic Adjustment Codes

Modern modelling approaches to GIA are based on several techniques ranging from purely analytical formulations to fully numerical methods. Various European teams nowadays are independently working on the post-glacial rebound process in order to constrain the rheological profile of the mantle and the extent and chronology of the late-Pleistocene ice sheets which are prerequisites for the determination of the GIA contribution to geodetic observables. Martinec contributed to the benchmark study performed within the Working Group 4 of the ESF COST Action ES0701 "Improved constraints on models of Glacial Isostatic Adjustment" and focuses on i) load Love numbers and relaxation spectra, ii) the deformation and gravity variations driven by surface loads characterized by simple geometry and time-history, and iii) the rotational fluctuations in response to glacial unloading. The results of this study will be presented at the EGU 2010 in Vienna.

5.5 Electromagnetic Induction Generated by Ocean Circulation

The oceans play a special role in electromagnetic induction due to their relatively high conductivity and the dynamo effect of ocean currents. The magnetic field by ocean circulation motion can be divided into toroidal and poloidal parts. The toroidal magnetic field is generated by electric currents closing in vertical planes and is estimated to reach 100 nT in amplitude. The much weaker poloidal field, with amplitudes up to 10 nT, results from electric currents closing horizontally. It has a significant vertical component and reaches remote land and satellite locations. Much attention has been given to the periodic magnetic signals of ocean flow which is driven by the lunar tides but no attention has been devoted to the induced toroidal field. Dostal and Martinec developed the matrix propagator technique to compute the toroidal magnetic field inside the Earth and oceans with the aim to generate the secondary poloidal field due to electrical conductivity inhomogeneities in the Earth crust and lithosphere. The first estimate of its strength is up to 10 nT that may be detectable, summed up with the primary poloidal field by future SWARM satellite mission.

Publication:

Martinec, Z., and J. Velimsky (2009), The adjoint sensitivity method of global electromagnetic induction for CHAMP magnetic data, *Geophys. J. Int, 179*, 1372—1396, doi: 10.1111/j.1365-246X.2009.04356.x.

Presentation:

Martinec, Z. (2009), The adjoint sensitivity method of global electromagnetic induction for CHAMP magnetic data, The 11th IAGA Scientific Assembly, Sopron, August 26.

6 Seismological and Geodynamic Modelling Activities

Group Leader: Assistant Professor Sergei Lebedev

6.1 Seismic Study of Cratons: South Africa

J. Adam, S. Lebedev

Joanne Adam has continued her DIAS-funded Ph.D. project on the seismic study of South Africa, developing novel array processing methods and applying them to broadband array data. Azimuthal seismic anisotropy across the Kaapvaal Craton and the Limpopo Belt has turned out to be very small in the shallow mantle lithosphere, but it appears to be larger (over 1%) near the lithosphere-asthenosphere boundary. In most locations within the region, both the amplitude and the fast-propagation directions of the surface-wave-constrained anisotropy can be reconciled with published shear-wave splitting measurements. Importantly, the new measurements reveal the previously unknown depth distribution of anisotropy, contributing important new constraints on the dynamics of cratons.

Presentations:

Adam, J., and **S. Lebedev** (2009), Dispersion of surface waves in Southern Africa from inter-station measurements, 2009 SAGA Biennial Technical Meeting & Exhibition, Swaziland, September.

Lebedev, S., and **J. Adam** (2009), Seismic structure of southern Africa: New constraints from surface waves (Invited Keynote), 2009 SAGA Biennial Technical Meeting & Exhibition, Swaziland, September.

Adam, J., and **S. Lebedev** (2009), Structure and Anisotropy of Southern Africa's Lithosphere: Constraints from Broad-band Surface-Wave Dispersion, AGU Fall Meeting, San Francisco, December.

6.2 Continental Deformation: Seismic Imaging

M. Agius, P. Keogh, D. Middleton, S. Lebedev

The seismic component of this two-pronged, SFI-funded project is focussed primarily on the lithospheric structure and deformation in Tibet and East Asia. Seismic structure of the crust and underlying upper mantle beneath Tibet reflects the physical state of the rock at depth and offers essential information on the dynamics and evolution of the plateau. Data from a number of broad-band seismic experiments conducted in recent years, together with data from permanent stations in the region, produce dense coverage of the plateau and its surroundings. The project utilises a combination of two approaches: large-scale multimode tomography and array analysis. The results reveal strong north-south variations in the thermal structure and thickness of Tibet's lithosphere. The lateral and depth extent of the mid-crust low-velocity layer are also being mapped, with the layer most pronounced in the 25-45 km depth range, across the plateau.

In the summer of 2009, Lebedev, Adam and Agius also co-supervised two summer internships on continental dynamics. Undergraduates from Dublin universities, Paula Keogh (TCD) and Damien Middleton (DCU), studied the deep structure and lithospheric dynamics of Tuscany (Italy) and the mechanisms of the Cenozoic uplift and volcanism in the Hangai Dome region (Mongolia). The results of both projects were presented at the 2009 AGU Fall Meeting in San Francisco and are to be submitted for publication in international journals.

Presentations:

Agius, M.R., and **S. Lebedev** (2009), Surface-Wave Phase-Velocity Analysis Across the Tibetan Plateau Using Broadband Interstation Dispersion Measurements, The 5th International Symposium on Tibetan Plateau and the 24th Himalaya- Karakorum-Tibet Workshop, Beijing, 11-14 August.

Lebedev, S., and **M. Agius** (2009), Seismic structure of Tibet: New constraints from surface waves, The 5th International Symposium on Tibetan Plateau and the 24th Himalaya- Karakorum-Tibet Workshop, Beijing, 11-14 August.

Agius, M.R., and **S. Lebedev** (2009), Shear-Velocity Profiles Across the Tibetan Plateau, From Broadband Interstation Dispersion of Surface Waves, AGU Fall Meeting, San Francisco, December.

Keogh, P., **J. Adam**, and **S. Lebedev** (2009), A Surface-Wave Study of Structure and Anisotropy of Tuscany, AGU Fall Meeting, San Francisco, December.

Lebedev, S., M.R. Agius, and R.D. van der Hilst (INVITED) (2009), Lithospheric Structure of Tibet and East Asia: New Constraints From Surface Waves, AGU Fall Meeting, San Francisco, December.

Middleton, D., **M.R. Agius**, and **S. Lebedev** (2009), Lithospheric Structure of Mongolia and Surroundings: A Surface-Wave Study, AGU Fall Meeting, San Francisco, December.

6.3 Continental Deformation: Geodynamic Modelling

C. Tirel, S. Lebedev

The geodynamic component of the two-pronged, SFI-funded project on continental deformation targets lithospheric dynamics in different regimes: diffuse extension with exhumation of extensional domes; subduction with slab retreat, terrain accretion and compression; ridge-trench collision. The thermo-mechanical modelling software (PARAVOZ) enables realistic reproduction of visco-elasto-plastic deformation with very large strains. Boundary conditions and benchmarks are provided by various geological and geophysical observations. The thermal structure and thickness of the lithosphere, the thickness of the crust, and deformation-induced anisotropic fabric can be inferred from seismic analysis and are the links between the seismic and geodynamic components of this project.

Figure 6.3.1. A visco-elasto-plastic geodynamic model that reproduces subduction, trench retreat, accretion of continental crust, and the formation of a back-arc basin (Tirel et al., AGU 2009). Left: structure and topography (top). Right: strain rate and instantaneous flow field (arrows).

Presentations:

Tirel, C., J.-P. Brun, and E. Burov (2009), Dynamics of metamorphic core complex development, 52nd Irish Geological Research Meeting, Dublin, February.

Kaus, B.J.P., S.M. Schmalholz, **S. Lebedev**, and F. Deschamps (2009), Geodynamic constraints on stress and strength of the continental lithosphere during India-Asia collision, EGU Meeting, Vienna, April.

Tirel, C., J. Brun, E. B. Burov, M. J. Wortel, and **S. Lebedev** (2009), Processes of subduction and exhumation of continental blocks in collisional orogeny, AGU Fall Meeting, San Francisco, December.

6.4 Continental Dynamics: North America

A. Schaeffer, S. Lebedev

Andrew Schaeffer has initiated his SFI-funded Ph.D. project on the structure and dynamics of continents, using the newly-available EarthScope data as well as other seismic data from North America. The enormous volume of the new array data offers opportunities for breakthroughs in the study of continental dynamics. In the initial phase of the project, the focus has been on the challenges of the retrieval and processing of the unprecedentedly large amounts of broadband seismic data. Lebedev's international collaborations on the study of North America also continued.

Publications:

Darbyshire, F., and **S. Lebedev** (2009), Rayleigh wave phase-velocity heterogeneity and multilayered azimuthal anisotropy of the Superior Craton, Ontario, *Geophys. J. Int, 176*, 215-234.

Zhang, X., H. Paulssen, **S. Lebedev**, and T. Meier (2009), 3D shear velocity structure beneath the Gulf of California from Rayleigh wave dispersion, *Earth Planet. Sci. Lett, 279*, 255-262.

6.5 Seismic and Geodynamic Study of the Aegean Region

S. Lebedev, C. Tirel, in collaboration with B. Endrun (Potsdam), T. Meier, W. Friederich (Ruhr Univ Bochum), J.-P. Brun (Rennes), E. Burov (Paris VI)

Unlike the nearly rigid oceanic lithospheric plates, continental plates can undergo internal deformation across broad plate-boundary regions. The mechanism of this deformation is debated, due to the insufficiency of observational constraints on three-dimensional flow at depth. New measurements of Rayleigh-wave dispersion in the Aegean region reveal layered azimuthal anisotropy indicative of distributed deformation within the lithosphere. Across the northern Aegean, fast shear-wave propagation directions in the mantle lithosphere are parallel to the current extension direction at the surface. In the presently non-deforming Cyclades block, anisotropic fabric in the lower crust trends parallel to the direction of extension

in the Miocene. These results imply that the region-scale extension observed at the surface is accommodated, at least in part, by continuous, viscous-fluid-like deformation in the lower crust and lithospheric mantle.

Visco-elasto-plastic geodynamic modelling of the lithospheric extension in the Aegean confirms that the retreat of the Hellenic subduction zone is sufficient as a force driving the pervasive extension and flow of the weakened lithosphere of the Aegean. The large finite strains modelled in the lower crust and lithospheric mantle and associated with the extension and formation of metamorphic core complexes are consistent with the strong anisotropy observed seismically.

Publication:

Tirel, C., P. Gautier, D.J.J. van Hinsbergen, and M.J.R. Wortel (2009), Sequential development of interfering metamorphic core complexes: numerical experiments and comparison with the Cyclades, Greece in *Collision and Collapse at the Africa–Arabia–Eurasia Subduction Zone. The Geological Society, London, Special Publications*, 311, edited by D.J.J. van Hinsbergen, M.A. Edwards, and R. Govers, pp. 257–292. doi: 10.1144/SP311.10.

Presentation:

Lebedev, S., B. Endrun, **C. Tirel**, and T. Meier (2009), Crustal and Mantle Deformation in the Aegean Region: Evidence From Seismic Anisotropy and Geodynamic Modelling, AGU Fall Meeting, San Francisco, December.

6.6 Imaging the Earth with Seismic Surface Waves

S. Lebedev

Lebedev has continued his research on the development and application of seismic imaging methods. An on-going collaboration with colleagues in Ruhr University, Bochum, is focussed on the large-scale structure of the upper mantle beneath Europe. A new collaboration, with S. Bartzsch (Jena) and T. Meier (Bochum), is on the detection of the lithosphere-asthenosphere boundary using seismic surface waves.

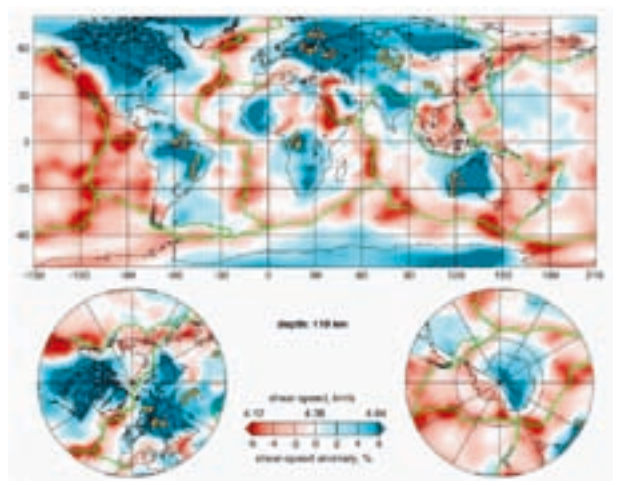


Figure 6.6.1. Station pairs (triangles) and inter-station paths used for broad-band, surface-wave dispersion measurements (Lebedev et al. 2009), plotted on the background of shear-wave speeds at a 110 km depth in the mantle according to the tomographic model of Lebedev and van der Hilst (2008). Almost all prominent high-velocity anomalies (blue) show stable Precambrian lithospheres of cratons (exceptions being high-velocity subducting lithospheres in subduction zones).

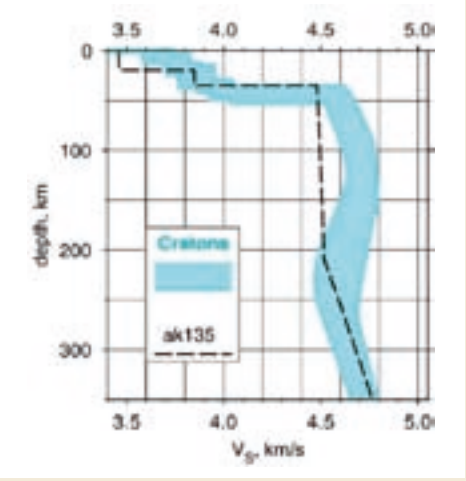


Figure 6.6.2. Summary profile of isotropic-average shear speed (Vs) beneath cratons, consistent with both global tomography and regional inversions of broad-band surface-wave dispersion (Lebedev et al. 2009). Shear speeds down to 150-200 km depth beneath cratons are much higher (and, thus, temperatures are much lower) than global continental average (approximated by the AK135 profile).

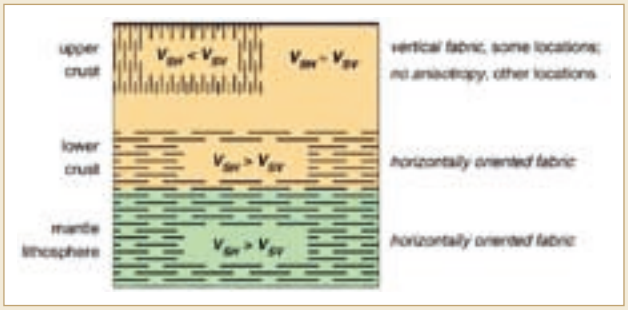


Figure 6.6.3. Interpretative summary of the observations of radial anisotropy within the upper Precambrian lithosphere (Lebedev et al. 2009). Anisotropy with horizontally polarised shear waves propagating faster than vertically polarised ones (Vsh > Vsv) is observed in the lower crust and mantle lithosphere and indicates horizontally oriented fabric. Anisotropy with Vsh < Vsv is observed in the upper crust beneath some of the locations and suggests the occurrence of vertically oriented fabric.

Publication:

Lebedev, S., J. Boonen, and J. Trampert (2009), Seismic structure of Precambrian lithosphere: New constraints from broadband surface-wave dispersion, *Lithos*, Special Issue "Continental Lithospheric Mantle: the Petro-Geophysical Approach", *109*, 96-111.

Presentations:

Lebedev, S. (2009), Seismic structure and dynamics of continental lithosphere: New constraints from broad-band surface-wave dispersion, New Views of the Earth's Interior, Meeting of the Mineralogical Society and the British Geophysical Association, London, February.

Lebedev, S. (2009), Seismic imaging of the deep structure and deformation of continents, 52nd Irish Geological Research Meeting, Dublin, February.

Lebedev, S. (2009), Imaging the lithosphere and asthenosphere: New advances from broadband array analysis of surface waves, Frontiers of Seismology, Earthquake and Exploration Seismological Research, A meeting for the UK seismological community, Edinburgh, 2-3 April.

Legendre, C., T. Meier, **S. Lebedev**, and W. Friederich (2009), Large-scale shear velocity structure of the upper mantle beneath Europe and surrounding regions, EGU Meeting, Vienna, 19-24 April.

Bartzsch, S., T. Meier, and **S. Lebedev** (2009), Constraints on the LAB depth and sharpness from measurements of Rayleigh wave dispersion curves, DefLAB: defining the lithosphere-asthenosphere boundary, ESF exploratory workshop, Dublin, June.

Legendre, C.P., T. M. Meier, **S. Lebedev**, and W. Friederich (2009), Large-scale shear velocity structure of the upper mantle beneath Europe and surrounding regions, AGU Fall Meeting, San Francisco, December.

7 Seismological and Potential Field Activities

Group Leader: Assistant Professor Brian O'Reilly

7.1 PIMS (Porcupine Irish Margin Seismics)

B.M. O'Reilly, P.W. Readman and F. Hauser

The Porcupine Irish Margins (PIMS) wide-angle seismic experiment was undertaken in 2004 and work on the very large dataset was completed during the year. This experiment used an array of three airguns, fired at 100-150m intervals, with twenty-five 3- and 4-component ocean bottom seismometers deployed at 10-12 km spacing along an axial N-S profile in the Porcupine Basin. Final forward-models for an axial and transverse profile within the basin, based on first arrivals and reflections, were developed. These results were integrated with newly analysed RAPIDS4 data to resolve details of the sedimentary and crustal structure.

Seismic wide-angle data from seven land stations deployed in southwest Ireland by personnel from the Dublin Institute for Advanced Studies (DIAS), during the month-long course of the PIMS experiment, were used to monitor changes in crustal structure between the basin centre and the Irish Mainland Platform (Figure 7.1.1). Prominent primary and secondary arrivals indicate the continental crust is extremely thin (locally less than 2 km) across the basin centre along both profiles.

The sedimentary succession is up to 12 km thick and comprises five distinctive seismic layers. The four uppermost layers are interpreted as mostly a post-rift succession of Cretaceous and Cenozoic strata. The lowermost (fifth) layer thins rapidly towards the basin centre along both the transverse (RAPIDS4) and the axial (PIMS) profiles and is interpreted as a succession of predominantly Jurassic syn-rift and older sediments.

Changes in both the geometry of the crust and the sedimentary layers are more complex than previously thought and are related to a simple shear mode of extension and the subsidence that it induced. The maximum amount of crustal thinning is greater than in the adjacent Rockall Basin and local exhumation of continental mantle lithosphere may have occurred. Furthermore, low upper mantle Pn velocities beneath the basin centre are compatible with larger amounts of mantle serpentinisation than in the Rockall Basin. The overall results have important implications for the basin's hydrocarbon prospectivity, as this region of the Porcupine Basin is largely unknown from previous scientific research and petroleum exploration efforts.

Results from the onshore component of the study were accepted for publication in Geophysical Journal International and a paper dealing with the anisotropic properties of the lower crust appeared in Tectonophysics. These results indicate that the velocity structure of lower crustal and its fine structure are most likely related to partial melting and metamorphism of accreted crust at the end of the Caledonian orogenic cycle. The subsequent Mesozoic extensional deformation of the lithosphere that formed the North Atlantic Mesozoic basin system does not seem to have strongly modified the lower crust beneath Ireland.

Publications:

O'Reilly, B.M., F. Hauser, and **P.W. Readman** (2009), A seismic study of the fine scale structure of the upper lithosphere within the Irish Caledonides using 1-D full-waveform methods: insights into Phanerozoic crustal formation processes, *Geophysical Journal International*, doi: 10.1111/j.1365-246X.2009.04420.x.

Readman, P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), Crustal anisotropy in southwest Ireland, from analysis of controlled-source shear-wave data, *Tectonophysics*, 474, 571-583. doi:10.1016/j.tecto.2009.04.029.

Presentations:

Hauser F., B.M. O'Reilly, and **P.W. Readman** (2009), First results from an onshore/offshore wide-angle seismic experiment in SW Ireland, Irish Geological Research Meeting, Dublin, 19-22 February.

O'Reilly B.M., F. Hauser, and **P.W. Readman** (2009), The VARNET-96 refraction seismic project re-visited: fine-scale structure within the Irish Caledonides, Irish Geological Research Meeting, Dublin, 19-22 February.

Readman P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), Seismic anisotropy in the crust of southwest Ireland from analysis of controlled-source shear-wave data, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 44.

Readman P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), How anisotropic is the Irish crust? Results from wide-angle shear-wave data, European Geophysical Union General Assembly, Vienna, 19-24 April, *Geophysical Research Abstracts*, 10, EGU2009-A-9733-1.

O'Reilly B.M., F. Hauser, and **P.W. Readman** (2009), Study of the fine scale structure of the upper lithosphere within the Irish Caledonides: the VARNET-96 project revisited, European Geophysical Union General Assembly, Vienna, 19-24 April, *Geophysical Research Abstracts*, 10, EGU2009-4345.

O'Reilly B.M., F. Hauser, and **P.W. Readman** (2009), The fine-scale structure of the upper lithosphere within the Irish Caledonides, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 40.

O'Reilly B.M., F. Hauser, and **P.W. Readman** (2009), The fine scale structure of upper continental lithosphere from seismic waveform methods: insights into Phanerozoic crustal formation processes, AGU Fall Meeting, San Francisco, 14-18 December, *Eos Trans. AGU*, 90(52) Fall Meet. Suppl., Abstract T51B-1532.

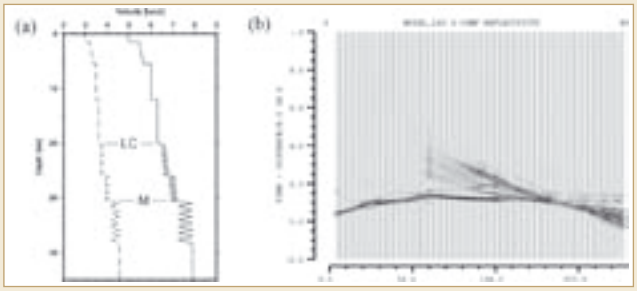


Figure 7.1.1. (a) Representative P- and S-wave 1-D velocity-depth functions used to compute full waveform response of fine structure in the lower crust and uppermost mantle in southwest Ireland as part of the PIMS project. (b) Theoretical full waveform response of the P-wave 1-D structure shown in (a). This reproduces the observed P-wave coda very well and raises important questions concerning the fine-scale structure of the upper lithosphere.

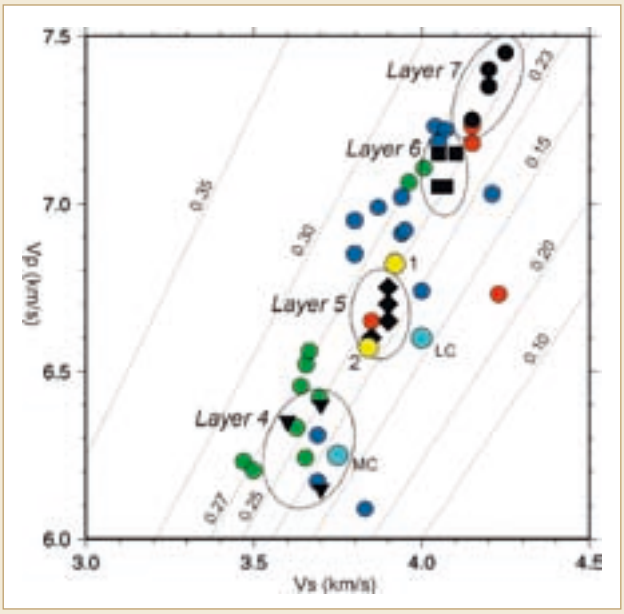


Figure 7.1.2. Measured wide-angle P-wave (V_p) and S-wave (V_s) velocities for mid- to lower crustal layers of the crust in southwest Ireland (indicated by the black symbols). The red circles show laboratory measurements from the Central Irish Xenolith Suite used to constrain the velocity models, with other coloured symbols from various other regions. Lines of constant Poisson's Ratio (e.g. $\sigma = 0.25$) are indicated.

7.2 HADES (Hatton Deep Seismic)

P.W. Readman, B.M. O'Reilly and A. Chabert, with P.M. Shannon, UCD School of Geological Sciences

The integration of seismic modelling results from the Hatton Basin and Hatton Continental Margin (Profiles 1 and 2) with borehole sonic and lithological information together with high resolution seismic reflection was finalised. Anne Chabert completed a final draft of her PhD thesis at the end of the year, with a submission date planned for early 2010.

Presentations:

Gernigon L., C. Ravaut, P.M. Shannon, A. Chabert, **B.M. O'Reilly**, and **P.W. Readman** (2009), The evolution of Irish passive margins: implications for locating the transition between continental and oceanic crust, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 31.

Ravaut C., **P.W. Readman, B.M. O'Reilly**, and P.M. Shannon (2009), Quantitative seismic imaging of the crust by frequency-domain full-waveform inversion, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Absract Volume, p. 43.

Ravaut C., **P.W. Readman, B.M. O'Reilly**, and P.M. Shannon (2009), Seismic imaging of the Hatton Continental Margin: results from travel-time tomography, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 43.

7.3 TRIM (Tobi Rockall Irish Margins)

B.M. O'Reilly, and colleagues from University College Dublin and the University of Ulster

A proposal entitled "Deep-water sediment transport on the margins of Rockall Trough: new interpretation from high-resolution multibeam and sidescan sonar TOBI data" was submitted to INFOMAR (INtegrated Mapping FOr the Sustainable Development of Ireland's MARine Resource). This project was funded (26,575 EURO) in December 2009.

The projects objectives are to reprocess multibeam bathymetric data gathered by the Geological Survey of Ireland within the Irish Exclusive Zone and high resolution TOBI backscatter data. This will provide additional information about the evolution of the continental slope, slope stability and dynamics of bottom current activity and related cold-water coral ecosystems found along the Irish continental margins.

Presentation:

O'Reilly B.M., P.W. Readman, and P.M. Shannon (2009), Cold-water coral ecosystem development in the NE Atlantic: evidence for strong coupling with Pleistocene and Holocene

climate change and slope failure, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 39.

7.4 ISLE (Irish Seismological Lithospheric Experiment)

P.W. Readman and B.M. O'Reilly, with J.P. O'Donnell and E. Daly, NUI Galway

The study on joint inversion of Irish gravity and ISLE seismic data (with J.P. O'Donnell, E. Daly (NUIG Galway) and C. Tiberi (Université Pierre et Marie Curie-Paris 6) was finalised and J.P. O'Donnell completed and submitted his PhD thesis. While it has been established that ancient Caledonian signatures pervade the upper lithosphere in Ireland (see PIMS Project), Cenozoic structure related to the Iceland Plume has been inferred to dominate the asthenosphere.

To address this apparent contradiction in the literature the 3D lithospheric and deeper upper mantle structure beneath Ireland has been imaged using non-linear, iterative joint teleseismic-gravity inversion using data from the ISLE (Irish Seismic Lithospheric Experiment), ISUME (Irish Seismic Upper Mantle Experiment) and GRACE (Gravity Recovery and Climate Experiment) experiments. The inversion combines teleseismic relative arrival time residuals with the GRACE long wavelength satellite derived gravity anomaly by assuming a depth-dependent quasi-linear velocity-density relationship.

It is argued that anomalies imaged at lithospheric depths probably reflect compositional contrasts, either due to terrane accretion associated with Iapetus Ocean closure, frozen Iceland plume material related magmatic intrusions, or a combination thereof. The continuation of the anomalous structure across the lithosphere/asthenosphere boundary is interpreted as evidence for sub-lithospheric small-scale convection initiated by the lithospheric compositional contrasts. This hypothesis reconciles the disparity that exists between lithospheric and asthenospheric structure beneath this region of the north Atlantic rifted margin. A predominantly non-thermal hypothesis may have important implications for the development of nearby hydrocarbon-rich sedimentary basins (also see PIMS). In the later part of the year a first draft of the paper on the results was prepared for submission to G-cubed.

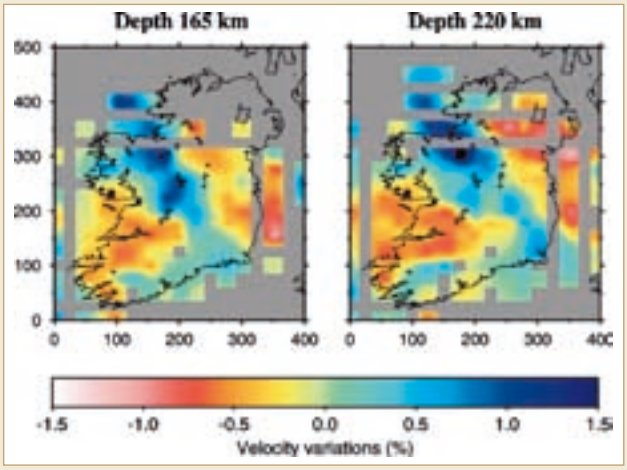


Figure 7.4.1. P-wave tomography images at 165 and 220 km depth showing high velocity zone (blue colour) orthogonal to the proposed trace of the Iapetus Suture Zone.

Presentations:

Readman P.W., F. Hauser, B.M. O'Reilly, and V.C. Do V.C (2009), Crustal anisotropy in southwest Ireland from analysis of controlled source shear-wave seismic data, Irish Geological Research Meeting, Dublin, 19-22 February.

Ritter J.R.R., and **The ISLE Working Group** (2009), The lithosphere-asthenosphere boundary underneath Ireland: data – interpretation – unknowns, DefLAB Workshop. Dublin Institute for Advance Studies. Dublin, 3–5 June.

7.5 ISUME (Irish Seismological Upper Mantle Experiment)

P.W. Readman, B.M. O'Reilly, F.Hauser and G. Polat

This project was began in October 2008 with the recruitment of a PhD student. Data collection continued throughout 2009 with the servicing and redeployment of stations to more strategic positions continuing (Fig. 7.5.1). A detailed analysis of suitable teleseismic data gathered since 2006 using the SKS splitting method was carried out during the year.

The results of this analysis strongly support the results obtained from those from the earlier ISLE experiment that were published in *Geophysical Research Letters* in 2006. A strong back-azimuthal dependency of the fast polarisation direction is also observed, suggesting that much of the detected anisotropy resides below the lithosphere, between the Earth's core-mantle boundary and its base.

Results from a study of elastic anisotropy in the lower crust, using controlled source data from VARNET were published in *Tectonophysics*. These results are important in interpreting the SKS results as they place upper bounds on the magnitude of anisotropy in the crust beneath southwest Ireland.

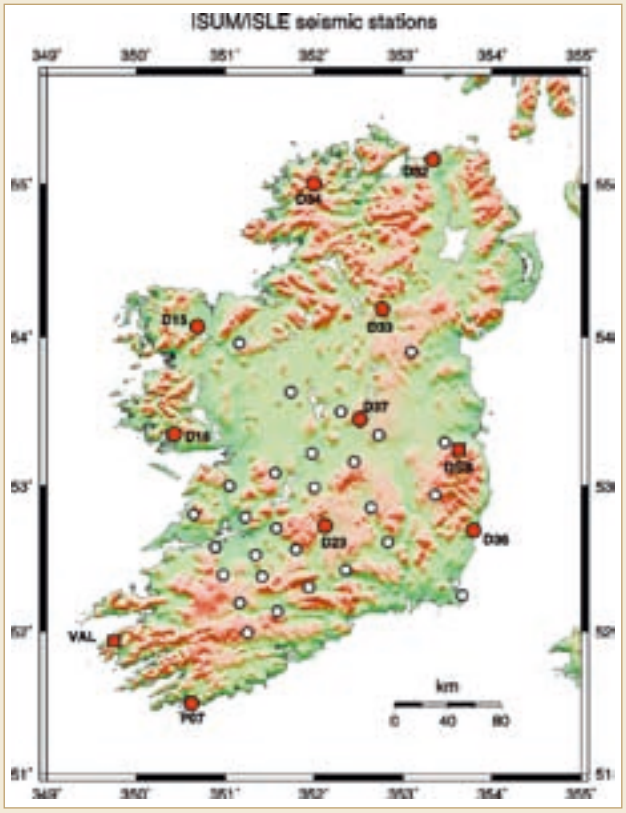


Figure 7.5.1. Layout of the seismic recording stations in the ISUME project is shown by the red symbols. White symbols show locations of stations previously deployed during the ISLE project.

Publication:

Readman, P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), Crustal anisotropy in southwest Ireland, from analysis of controlled-source shear-wave data, *Tectonophysics, 474*, 571-583. doi:10.1016/j.tecto.2009.04.029.

Presentations:

Polat G., M.N. Ozel, O. Tan, and S. Ergintav (2009), Crustal anisotorpy from local observations of shear wave splitting in the Marmara Region, Turkey, Irish Geological Research Meeting, Dublin, 19-22 February.

Readman P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), How anisotropic is the Irish crust? Results from wide-angle shear-wave data, EGU General Assembly, Vienna, 19-24 April, *Geophysical Research Abstracts*, 10, EGU2009-A-9733-1.

Polat G., P.W. Readman, B.M. O'Reilly, F. Hauser, and V.C. Do (2009), Deep-source anisotropy revealed by shear-wave splitting results from Ireland, AGU Fall Meeting, San Francisco, 14-18 December, *Eos Trans. AGU*, 90(52) Fall Meet. Suppl., Abstract D141B-1806.

7.6 NAPSA (North Atlantic Petroleum Systems Assessment group)

B.M. O'Reilly, and colleagues from Memorial University, Newfoundland and University College Dublin

This new project is founded upon the large amount of collective experience accumulated in DIAS and UCD over several decades in marine seismology and potential fields. The Irish – Newfoundland Partnership of the Department of an Taoiseach is involved, and provided seed funding through the Irish Newfoundland Partnership (INP) to discuss research initiatives and objectives. One aim of this project is to investigate and compare the crustal structure of the conjugate north Atlantic margin regions of Newfoundland and Ireland using potential field data and innovative modelling techniques.

Using the funding provided by INP, Dr Kim Welford from Memorial University, St John's Newfoundland visited DIAS in July 2009 to discuss work she had begun in 2008 on the Earth's gravity field across the Irish offshore basins. A 3-D density anomaly model of the Irish Atlantic continental margin was generated from a regional inversion of the free air gravity data constrained by bathymetric and sediment thickness information provided by "open source" data.

The model results compare well with velocity models from crustal-scale wide-angle reflection/refraction surveys and highlight trends due to the presence of large-scale continental rift zones. These results should be useful in future attempts at palaeo-reconstructions of North Atlantic rifting between Ireland and Newfoundland. The draft of a paper about the main results was finalised during Dr Welford's visit to DIAS.

Publication:

Welford, J.K., P.M. Shannon, **B.M. O'Reilly**, and J. Hall (2009), Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from constrainted 3-D gravity inversion, *Geophysical Journal International*, in review.

Presentations:

O'Reilly B.M., J.K. Welford, and P.M. Shannon (2009), Proposed new wide-angle seismic profiles across the Irish/Newfoundland continental margins: a requirement for continental reconstruction, Atlantic Ireland 2009 Conference: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 18.

O'Reilly B.M., F. Hauser, P.W. Readman, and P.M. Shannon (2009), Mantle exhumation and serpentinisation in the Porcupine Basin: seismic evidence, *Atlantic Ireland 2009 Conference*: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 38.

Welford J.K., P.M. Shannon, **B.M. O'Reilly**, and J. Hall (2009), Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from 3-D gravity inversion, *Atlantic Ireland 2009 Conference:* A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 51.

Hauser F., B.M. O'Reilly, P.W. Readman, and P.M. Shannon (2009), Regional basin and crustal structure offshore Ireland: A review, Atlantic Ireland 2009 Meeting: A Research Conference Sponsored by PIP-ISPSG, Dublin, 19-20 October. Abstract Volume, p. 6.

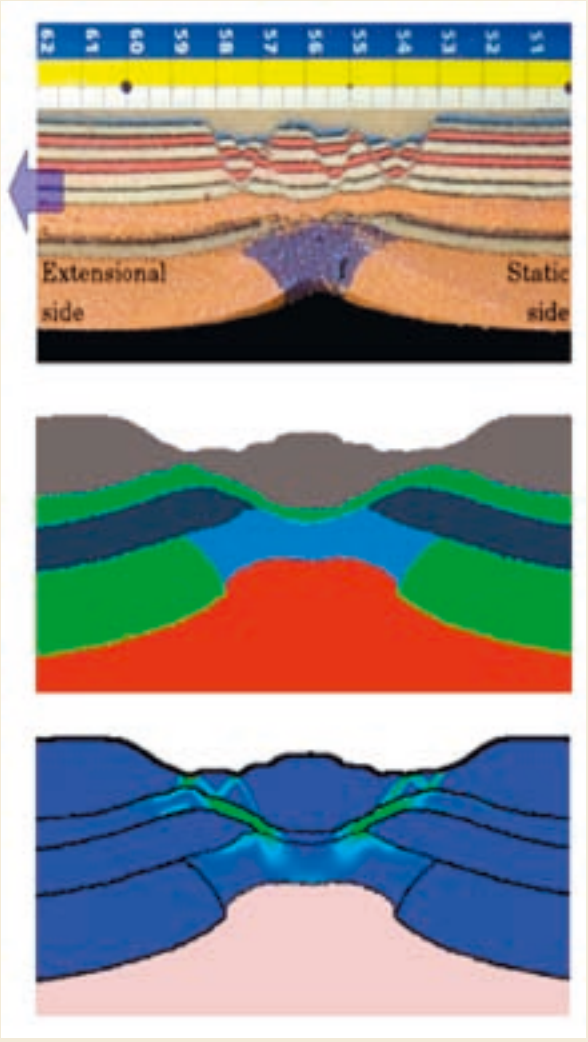
7.7 Geodynamic Modelling

J. Sheehan, B.M. O'Reilly and P.W. Readman, with D. Sokoutis, Vrije University, Amsterdam

The final comparative analysis of results between analogue modelling and numerical calculations was completed with reference to the "natural prototype", i.e. the Porcupine Basin, offshore Ireland (also see PIMS). A high resolution series of 2-D numerical simulations using the computational resources provided by the Cosmogrid Consortium were carried out at University College Dublin to investigate in more detail strain localisation within the brittle crust and the effect of strength heterogeneities within the upper lithosphere. Measured parameters for analogue models were exactly replicated to ensure a valid comparison, and the results were very similar (Figure 6.8.1).

These new results were presented at the Atlantic Ireland Conference in November 2009. John Sheehan submitted his thesis on this research and this was awarded, subject to some revision during the later part of the year. His presentation of his PhD results won the best poster award at the annual Irish Geological Research Meeting for its originality.

(a)



(b)

(c)

Figure 6.8.1. Comparison of the results from analogue and numerical modelling, using coarser mesh size: (a) shows a result from an analogue model with a weakened zone f (blue colour) located in the ductile mantle, (b) shows the materials deformation calculated from the numerical simulation of this model, and (c) maps the calculated strain rate. Note the similarity of the structure and features developed.

Publications:

Yamasaki, T., and L. Gernigon (2009), Styles of lithospheric extension controlled by underplated mafic bodies, *Tectophysics, 468,* 169-184.

Sheehan, J.D., B.M. O'Reilly, D. Sokoutis, and **P.W. Readman** (2009), The continental lithosphere in tectonic extension: a comparison between analogue and numerical experiments using the Porcupine Basin in the North Atlantic as a prototype, Submitted to *Geophysical Journal International*.

Presentations:

Sheehan, J.D., B.M. O'Reilly, and **P.W. Readman** (2009), A comparison between lithospheric scale numerical and analogue models, Irish Geological Research Meeting, Dublin, 19-22 February. (John Sheenan's poster entitled "A comparison between lithospheric scale numerical and analogue models" won the Best Poster award at the IGRM meeting (sponsored by the PESGB, Irish Exploration Group).

Sheehan, J.D., B.M. O'Reilly, D. Sokoutis, and **P.W. Readman** (2009), The continental lithosphere in tectonic extension: analogue and numerical experiments for the Porcupine Basin, Atlantic Ireland 2009 Conference. Abstract Volume, p. 46.

8 The Irish National Seismic Network

T. Blake, G. Wallace, C. Horan, L. Collins

The decision to decommission the short period seismic network was taken early in 2009 and this work was completed by June. Following capital acquisition in Sept for finance to upgrade and expand the existing real time permanent seismic recording network, reconnaissance began to establish the locations for three permanent real-time seismic recording stations. After initial site reconnaissance, 3 locations were identified and systematic noise tests were undertaken with seismic equipment on loan from BGS Edinburgh, to establish the site suitability for a permanent seismic station location.

The decommissioning of the Q3330 hardware at station DSB occurred during the year and the installation of a state of the art real-time Seiscomp data logger with ED digitizer was carried out. After a downtime of approximately 9 months, the station was brought back into operation.

9 Comprehensive Test Ban Treaty Organisation

T. Blake

Ireland is one of the State Signatories to the Comprehensive Test Ban Treaty and is the only European country that did not have a National Data Centre. In November 2009, the School of Cosmic Physics was informed by the Department of Foreign Affairs that it was successful in its bid to assume the role of National Data Centre (NDC) for the Comprehensive Test Ban Treaty (CTBT). Professor Luke Drury, as current Director of the School, is the ex-officio Head of the NDC and Blake is the designated Principal Point Of Contact (PPOC).

Blake attended the CTBTO Prep Commission Introductory On Site Inspection Course in Austria as the designated Irish nominee by the Dept of Foreign Affairs.

10 Collaboration with Wider Research Community

10.1 Visits to other Laboratories by Section Members

C. Hogg:	One week visit to CSIC Marine Institute, Barcelona, in May
A.G. Jones:	One-day visit to colleagues at National Research Institute for Astronomy and Geophysics (NRIAG), Helwan, Cairo, in April.
	One month visit to Geological Survey of Canada, Ottawa, in July.
E. Mandolesi:	One week visit to University of British Columbia, Vancouver, Canada, in November
E. Roux:	One month visit to Geological Survey of Canada, Ottawa, in November/December
J.-P. Schmoldt:	One week visit to CSIC Marine Institute, Barcelona, in May
J. Vozar:	One week visit to China University of Geoscience Beijing, China, in October

10.2 Visitors to the Section

February 13-21:	Professor David Jackson, UCLA, Los Angeles, USA
March 1 – April 12:	Mr. Stefan Bartzsch, University of Jena, Germany
May 14-16:	Dr. Piroska Lorinczi, University of Leeds, UK
May 26-28:	Dr. Juan Carlos Afonso, University of Macquarie, Sydney, Australia
July 6-18	Professor Colin Farquharson, Memorial University of Newfoundland, Canada
July 6-18:	Dr. Kim Welford, Memorial University of Newfoundland, Canada
July 29 – August 8:	Dr. Brigitte Endrun, University of Potsdam, Germany
August 10-11:	Professor Martyn Unsworth, University of Alberta, Edmonton, Canada
September 3-10:	Ms. Jessica Spratt, Geological Survey of Canada, Ottawa, Canada
October 9-17:	Dr. Evgeny Klimovic, Lviv Institute for Space Research, Ukraine
Oct 31 – Nov 3:	Dr. Don White, Geological Survey of Canada, Ottawa, Canada
November 4-8:	Dr. Max Moorkamp, University of Kiel, Germany
November 9-13:	Ms. Jessica Spratt, Geological Survey of Canada, Ottawa, Canada
Nov 14 – Dec 12:	Dr. Volker Klemann, GFZ, Potsdam, Germany
Nov 28 – Dec 13:	Dr. Jan M. Hagerdoorn, GFZ, Potsdam, Germany
Nov 30 – Dec 11:	Dr. Jonas Agren, University of Gävle, Sweden
December 1-3:	Dr. Rob Evans, WHOI, Woods Hole, Massachusetts, USA

10.3 Collaboration and Linkages with other Institutes

The Section has historical collaborations and linkages with many institutes and organisations worldwide. Active collaborations during 2009 are listed below:

10.3.1 Irish Institutions

- University College Dublin (Prof. P.M. Shannon) ongoing collaboration, since 1988: offshore seismic and sidescan sonar studies (RAPIDS, GLORIA, TRIM and HADES).
- NUI Galway
  - (Dr Eve Daly and J-P O'Donnell: 2006 – present. Collaboration on P-wave tomography of the crust and upper mantle using ISLE/ISUME data, and joint inversion of seismic and gravity data.
  - Dr. Colin Brown (appointed as the School's first Honorary Professor). Co-Supervision of Jones's Ph.D. students.
- University of Ulster (Sara Benetti), TRIM.

10.3.2 European Institutions

- University of Barcelona (Drs. J. Ledo, A. Marcuello and P. Queralt). This linkage is formalized through a Memorandum of Understanding between DIAS and UB. Besides scientific collaborative efforts, the linkage includes an educational component with exchanging students and invited lecture series.
- University of Leicester (Dr. S. Fishwick): Collaboration on joint interpretation/inversion of seismic and MT data
- PICASSO MT team (scientists from Barcelona, Bari and WHOI).
- Geophysics Institute, University of Karlsruhe (Joachim Ritter): ISLE.
- Vrije University, Amsterdam (Dimitrios Sokoutis): Rheological modelling.
- ETH Zurich (B. Kaus), 2008—present. Structure and dynamics of Tibet.
- Ruhr University Bochum (T. Meier, W. Friederich), 2003—present. Development and application of seismic methods. Tomography of Europe's upper mantle. Structure and deformation in the Aegean region.
- Univ. Paris VI (E. Burov), 2008—present. Geodynamic modelling.

10.3.3 International Institutions

- Memorial University of Newfoundland
  - Prof. C. Farquharson–ongoing since 2007: development of a 3D MT inversion code, supervision of Miensopust
  - Dr. Kim Welford: 3-D gravity inversion of structure within the north Atlantic basin system west of Ireland.
- Woods Hole Oceanographic Institution (Drs. A.D. Chave and R.L. Evans). Long-standing collaboration between Jones and Chave (since 1980s) and now with Evans (since late-1990s). Active collaboration is the SAMTEX and PICASSO projects.
- INDEPTH team (scientists from U. Alberta, China Univ. Geosciences Beijing, Cornell, Stanford, GeoForschungsZentrum Potsdam, Alberta, SUNY, NMSU). INDEPTH-IV activities on the northern margin of the Tibetan Plateau.
- SAMTEX MT team (scientists from WHOI, S.A. Council for Geoscience, U. Witwatersrand, DeBeers).
- MIT (R.D. van der Hilst), 2000—present. Regional and global seismic imaging
- University of Southern California (T. Becker), 2008—present. Seismic anisotropy and geodynamics

11 Public outreach: Seismology in Schools

T. Blake

A major highlight of the year was the success of the Schools participation in BTYSE in Jan 2009 and the awarding of "*International Year of Planet Earth Award*" and first prize in the "*Category Award: Chemical, Physical and Mathematical Sciences Senior*" to Denis Patterson and Shane Curry (Fig. 11.1) for their project entitled, "*Seismic Activity in the British Isles and the Wider World*. They are students at Scoil Chonglais Baltinglass, County Wicklow which participates in the Seismology in Schools Seismology in Schools (Seismeolaíocht sa Scoil)

Figure 11.1. Students Denis Patterson and Shane Curry with M Carter (IYPE) and T Blake (DIAS)

Blake attended Launch of the Seismology in Schools in Scotland which took place in British Geological Survey in Edinburgh with a view to twinning schools in the SIS project with similar level schools in Scotland.

The inclusion in to the SIS programme of the 3 schools which won the IYPE prizes in 2009 took place during the year, these schools were, Lucan Secondary School, Co Dublin, St Marys College Rathmines, Dublin 6 and St Marys Dundalk, Co Louth.

The development of the SIS website continued during the year with extensive support from IRIS in the US regarding style and content. Outreach to schools continued at a reduced level due to pressures of work in other areas, personnel issues and the reduced budgetary situation. Upwards of 50 primary and secondary school are now actively participating in the SIS programme (Fig 11.2).

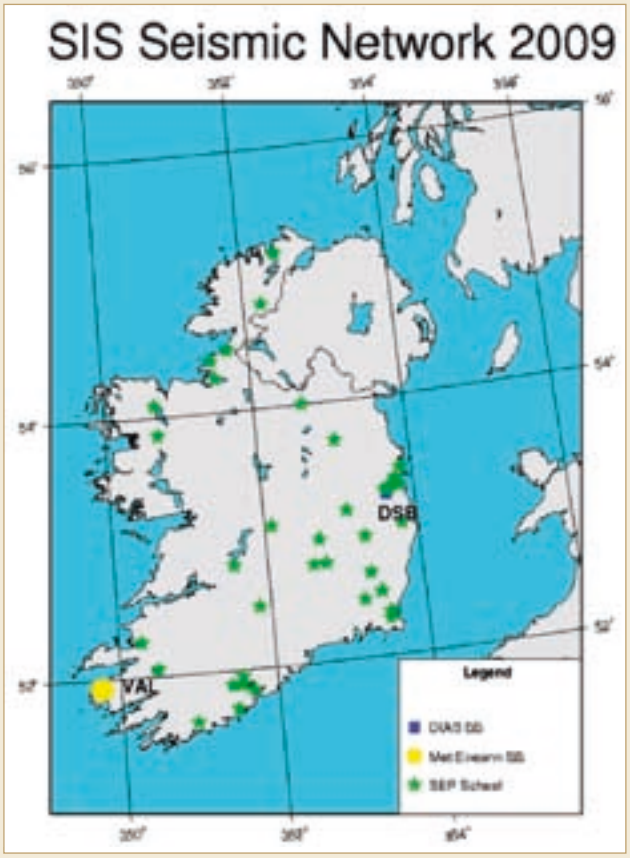


Figure 11.2. SIS Seismic Network 2009

Presentation:

Jones, A.G., and **T.A. Blake** (2009), Geo-sciences & Manpower, The DIAS Outreach Seismology in Schools (Seismeolaíocht sa Scoil) Pilot Programme, IASPEI Meeting, South Africa, January.

12 Internal Short Courses and Workshops

12.1 Short Courses

12.1.1 Inverse Theory

Five-day lecture course on Inverse Theory by Professor David D. Jackson

When: 16th to 20th February 2009

Where: Library, School of Cosmic Physics, 5 Merrion Square, Dublin 2.

Course was webcast and is available for viewing on the Section website.

12.1.2 ICHEC Courses

A four-day course run on 5-8 May by staff of the Irish Centre for High-End Computing (ICHEC) comprising three modules, a 1-day course on parallel computation, a 1-day course on OpenMP, and a 2-day course on MPI. The courses were all dynamic with attendees submitting jobs to ICHEC machines for processing.

12.1.3 Numerical Modelling for Geophysical Electromagnetic Methods

A five-day one hour lecture course by Professor Colin Farquharson.

Where: Library, School of Cosmic Physics, 5 Merrion Square, Dublin 2.

When: Monday 6th July, Tuesday 7th July, Thursday 9th July, Friday 10th July and Monday 13th July 2009.

Course was webcast and is available for viewing on the Section website.

12.2 Workshops

12.2.1 DefLAB: Defining the Lithosphere-Asthenosphere Boundary Beneath Continents

When: 3-5 June 2009

Where: 10 Burlington Road, Dublin 4

Dynamic processes within the *lithosphere* (the cool, rigid outer layer of the Earth some tens to hundreds of kilometres in thickness) and *asthenosphere* (the hot, convecting layer below) have shaped and continue to shape the continents that we live on. Volcanic activity, land rise and subsidence and sea-level variations are among well-known surface manifestations of these active processes. The lithosphere-asthenosphere boundary (LAB), that separates the lithosphere from the asthenosphere beneath it, cannot be observed directly, and its very nature has been uncertain and continues to be debated strongly. The central role of the LAB in the dynamics of the lithosphere-asthenosphere system has motivated vigorous research focussed on its properties in various fields of Earth science. The multi-disciplinary nature of the research that is required to understand the LAB has been a challenge but, at the same time, presents opportunities for productive, cross-field collaborative studies.

The European Science Foundation Exploratory Workshop on "Defining the Lithosphere-Asthenosphere Boundary Beneath Continents" (DefLAB) brought together geophysicists, geochemists, petrologists and mineral physicists; a total of 31 scientists from 10 European countries (Czech Republic, Denmark, Finland, France, Germany, Ireland, Netherlands, Poland, Spain, United Kingdom), as well as from the United States and Canada, who joined forces to focus on the LAB and its definition over three very full days.

The objectives of the workshop were:

- to discuss and evaluate critically a number of widely used proxies for the LAB;
- to compare these proxies with each other and with realistic rheological models of the "true" (i.e., mechanical) lithosphere;
- to assess the extent to which different techniques sense the same feature, and if so, to document its intrinsic characteristics; and,
- to plan for the future, by deciding what multi-disciplinary experiments need to be performed at which locations.

The Workshop program included:

- overviews of the current status of the study of the dynamics of the lithosphere-asthenosphere system and the role of the LAB;
- overviews of methods used in pertinent studies in different fields, with discussions on strengths and limitations of different approaches;
- presentations on major results and inferences regarding the properties of the LAB from recent disciplinary and inter-disciplinary studies;
- break-out sessions focussed on identifying the main problems in the study of the LAB and the lithosphere-asthenosphere system;
- break-out sessions aimed at identifying ways to solve the problems, including recommendations for future multi-disciplinary research.

Presentations and discussions during the workshop highlighted recent progress in the study of the lithosphere and asthenosphere made in seismology, electromagnetism, computational geodynamics, geochemistry, mineral physics, petrology and sedimentology. They exposed the complexity of the lithosphere-asthenosphere system, with the viscosity of the rock at depth dependent not only on its temperature and composition and on the lithostatic pressure, but also on the grain size and volatile content. Inter-connections between observations and models produced in different fields have also become more apparent.

The objectives of the workshop were achieved in the course of exciting, stimulating discussions over the 3 days of its duration. Crucially, the workshop helped to prepare ground for focussed, multi-disciplinary collaborative research to be undertaken in the near future.

The workshop was financially supported by ESF, DIAS, and the International Lithosphere Programme.

Figure 12.2.1.1. Attendees to DefLAB workshop

12.2.2 Seismology in Schools Inaugural Workshop for Teachers

When: 25 April 2009

Where: 10 Burlington Road, Dublin 4

An extremely successful- first Seismology in Schools workshop for teachers was held in Burlington Road, Dublin April 25th, 2009. A selection of international speakers gave very relevant presentations in various aspects of operational seismology and certificates of attendance were awarded

to the teachers presented by DIAS Chairman Prof Dervilla Donnelly. Fig 12.2.2.1

Figure 12.2.2.1. Presenters and Participants of the 1st SIS Workshop, DIAS, April 25th, 2009

12.2.3 INDEPTH

When: 28-30 October 2009

Where: 5 Merrion Square, Dublin 2

A workshop for members of the INDEPTH (InterNational DEep Profiling of Tibet and the Himalaya) project was held in DIAS in late-October. Seventeen participants came from Europe, North America and China to Dublin to discuss existing results from INDEPTH Phases I-III and future plans for INDEPTH Phase IV.

13 External Short Courses, Workshops and Training

13.1 MT Short Course

Jones presented a two-day Short Course on Magnetotellurics for Natural Resources to North African and Saudi Arabian scientists in Cairo, Egypt on 30-31 March, 2009 (Fig. 13.1.1).

Figure 13.1.1. Attendees of the MT Short Course in Cairo, March 2009.

13.2 Advanced MT Methods

Jones presented a three-hour Short Course on Advanced MT Methods as an Invited Keynote Presentation to 120 participants at the 9th China International Geo-Electromagnetic Workshop (CIGEW2009) held in Guilin, China, on 27-29 November.

13.3 AfricaArray Geophysical Field School

Jan-Philipp Schmoldt spent three weeks in South Africa during June/July as a mentor on the AfricaArray Geophysical Field School run by the Department of Geosciences of the University of the Witwatersrand, Johannesburg, South Africa.

13.4 Summer of Applied Geophysical Experience

Matthew Agius and Pieter Share attended the Summer of Applied Geophysical Experience (SAGE) field school in the USA.

14 Geophysics Seminars

Some of these seminars were webcast and are available for viewing at:

http://www.dias.ie/lang/en/cosmic/geo/geo_seminars.html

Date: 8th December
Speaker: Jonas Ågren, Lantmäteriet, Geodetic Research Division, Sweden
Title: Absolute Gravimetry to determine the postglacial rebound in Fennoscandia

Date: 7th December
Speaker: Jan M. Hagedoorn, GeoForschungsZentrum Potsdam, Germany
Title: The geomagnetic field at the core-mantle boundary

Date: 2nd December
Speaker: Rob Evans, Woods Hole Oceanographic Institution, USA
Title: Magnetotellurics at Subduction Zones: Constraints on Water Inputs and Melt Outputs

Date: 20th November
Speaker: Dr. Volker Klemann, GeoForschungsZentrum Potsdam, Germany
Title: Kinematics of the viscoelastic Earth due to glacial loading

Date: 13th November
Speaker: Gulten Polat, DIAS
Title: Crustal Seismic Anisotropy: Implications for Understanding Crustal Dynamics of Marmara region in Turkey

Date: 15th October
Speaker: Jan Dostal, GeoForschungsZentrum Potsdam, Germany
Title: Prediction of ocean-induced magnetic signals in the satellite observations due to tidal forcing

Date: 13th October
Speaker: Dr. Heather McCreadie, University Munich, Dept. Earth and Environmental Sciences, Germany
Title: The Sun's influence on the Earth's magnetic field

Date: 15th September
Speaker: Dr. Indrajit G. Roy, Onshore Energy and Minerals Division, Geoscience Australia
Title: Joint and cooperative inversion of seismic travel time, magnetotelluric and bouguer gravity data to define the architecture of the Millungera Basin, North Queensland, Australia

Date: 3rd September
Speaker: Thomas Kalscheuer, ETH Zuerich, Switzerland
Title: Radiomagnetotelluric 2-D forward and inverse modelling with displacement currents

Date: 4th September
Speaker: Thomas Kalscheuer, ETH Zuerich, Switzerland
Title: Error and resolution properties of 2-D resistivity models from the inversion of direct current resistivity and radiomagnetotelluric data

Date: 11th August
Speaker: Martyn Unsworth, University of Alberta, Canada
Title: Magnetotelluric observations of crustal flow in Tibet and the Himalaya

Date: 6th August
Speaker: Brigitte Endrun, University of Potsdam, Germany
Title: Imaging lithospheric structure in the Aegean region with seismic surface waves and receiver functions

Date: 31st July
Speaker: Matthew Aguis (DIAS)
Title: Surface-Wave Phase-Velocity Analysis across the Tibetan Plateau using Broadband Interstation Dispersion Measurements
and
Speaker: Joanne Adam (DIAS)
Title: Dispersion of surface waves informs us about structures in Southern Africa

Date: 21st July
Speaker: Javier Fullea (DIAS)
Title: Geophysical modelling of the lithosphere-asthenosphere boundary beneath the Atlantic-Mediterranean Transition Region: integrating potential field, surface heat flow, elevation, seismological and petrological data

Date: 8th July at 4pm
Speaker: Kim Welford (Memorial University of Newfoundland in St. John's, Canada)
Title: Lithospheric density variations and Moho structure of the Irish rifted continental margin from constrained 3 D gravity inversion

Date: 3rd July at 4pm
Speaker: David Khoza (DIAS)
Title: Magneto-telluric imaging across a Neoproterozoic collision zone: Damara belt and surrounding cratonic blocks

Date: 28th May, 4pm
Speaker: Dr. Juan Carlos Afonso (Macquarie University NSW, Australia)
Title: Internally consistent petrological-geophysical-geochemical models of the mantle: the next step

Date: 21st May, 4pm
Speaker: Dr. Jan Vozar (DIAS)
Title: Electromagnetic investigations in Central Europe and the numerical simulation of the induction soundings

Date: 14th May, 4pm
Speaker: Dr. Piroska Lorinczi (U. Leeds)
Title: Geodynamical Models of the formation of the Carpathian-Pannonian Region of Central and Eastern Europe

Date: 1st May, 4pm
Speaker: Jan-Philipp Schmoldt (DIAS)

Date: 6th April, 4pm
Speaker: Shane Murphy (University College Dublin)
Title: Estimating an earthquake's magnitude using initial P- and S-arrivals

Date: 3rd April, 4pm
Speaker: Ian Ferguson (University of Manitoba, Canada)

Date: 12th March, 4pm
Speaker: Sergei Lebedev (DIAS)
Title: Imaging the lithosphere-asthenosphere system with surface waves
and
Speaker: Stefan Bartzsch
Title: Exploration of the LAB using surface wave inversion

Date: 13th February, 4pm
Speaker: Said Gaci (DIAS)
Title: The application of Continuous Wavelet Transform (CWT) on seismic log data
and
Speaker: Florian Le Pape (DIAS)

Title: Energy flow modelling and Inversion in a 1D isotropic and anisotropic earth in marine Controlled-Source Electromagnetic (CSEM) Imaging

15 Miscellanea

T. Blake

- BBC Coast programme recording the experiments conducted by Robert Mallet on Killiney Beach, Jan 2009
- RTE radio interview "Pat Kenny Live Show" with regarding Robert Mallet July 2009
- Today FM radio interview with Sean Dukes, on earthquakes in Ireland, Nov 2009
- RDS Steering Committee on 2010 Bicentenary of Birth of Robert Mallet
- Principal Point of Contact (PPOC) for National Data Centre (NDC), CTBT, Ireland

A.G. Jones

- Elected to *Academia Europaea*
- Elected to Royal Irish Academy's Geosciences Committee
- Chairman, Committee of Heads of Irish Geoscience Institutes (CHIGI)
- Chief Delegate for Ireland to IAGA at Sopron IAGA Scientific Assembly
- National Correspondent for Ireland to IAGA
- Irish representative, European Science Foundation's Life, Earth and Environmental Sciences (LESC) Standing Committee
- International member, Chinese National Geo-electromagnetism Committee
- Adjunct Professor, NUI Galway, Ireland
- Visiting Professor, Trinity College Dublin, Ireland
- Honorary Professor, University of Leicester, UK
- Visiting Scientist, Geological Survey of Canada
- Honorary Professor, University of the Witwatersrand
- Associate Editor, *Journal of Geophysical Research*
- Overseas Editor, *Earth, Planets and Space*

S. Lebedev

- Associate Editor, *Geochemistry, Geophysics, Geosystems (G-cubed)*.
- Institutional representative, Incorporated Research Institutions for Seismology (IRIS)

16 Productivity

16.1 Publications in Peer-Reviewed International Literature

Darbyshire, F., and **S. Lebedev** (2009), Rayleigh wave phase-velocity heterogeneity and multilayered azimuthal anisotropy of the Superior Craton, Ontario, *Geophys. J. Int.*, 176, 215-234.

Fullea, J., J.C. Afonso, J.A.D. Connolly, M. Fernàndez, D. García-Castellanos, and H. Zeyen. (2009), LitMod3D: an interactive 3D software to model the thermal, compositional, density, rheological and seismological structure of the lithosphere and sublithospheric upper mantle, *Geochemistry Geophysics and Geosystems*, doi: 10.1029/2009GC002391.

Fullea, J., J.C. Afonso, M. Fernàndez, and J. Vergés. The structure and evolution of the lithosphere–asthenosphere boundary beneath the Trans-Mediterranean region, *Lithos*, in press.

Garcia, X., and **A.G. Jones** (2010), Internal structure of the western flank of the Cumbre Vieja volcano (La Palma, Canary Islands) from land magnetotelluric imaging, *Journal of Geophysical Research – Solid Earth*, accepted, 26th February, 2010.

Gowan, E.J., I.J. Ferguson, **A.G. Jones**, and J.A. Craven (2009), Geoelectric structure of the northeastern Williston Basin and underlying Precambrian lithosphere, *Canadian Journal of Earth Sciences*, 46, 441-464.

Jones, A.G., R.L. Evans, **M.R. Muller**, M.P. Hamilton, **M.P. Miensopust**, X. Garcia, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S Fourie, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Area selection for diamonds using magnetotellurics: Examples from southern Africa, *Lithos, 112S*, 83-92.

Jones, A.G., R.L. Evans, and D.W. Eaton (2009), Velocity-conductivity relationships for mantle mineral assemblages in Archean cratonic lithosphere based on a review of laboratory data and Hashin-Shtrikman extremal bounds. *Lithos, 109*, 131-143, doi: 10.1016/j.lithos.2008.10.014. In Special Issue of Lithos devoted to The Structure of the Lithosphere: the petro-geophysical approach workshop that was held in Merrickville, Ontario, Canada, 7–10 March 2007.

Lebedev, S., J. Boonen, and J. Trampert (2009), Seismic structure of Precambrian lithosphere: New constraints from broadband surface-wave dispersion, *Lithos*, Special Issue "Continental Lithospheric Mantle: the Petro-Geophysical Approach", *109*, 96-111.

Martinec, Z., and J. Velimsky (2009), The adjoint sensitivity method of global electromagnetic induction for CHAMP magnetic data, *Geophys. J. Int., 179*, 1372—1396, doi: 10.1111/j.1365-246X.2009.04356.x.

Moorkamp, M., **A.G. Jones**, and S. Fishwick (2010), Joint inversion of receiver functions, surface wave dispersion and magnetotelluric data. *Journal of Geophysical Research–Solid Earth*, accepted, 16th December, 2009.

Muller, M.R., A.G. Jones, R.L. Evans, H.S. Grütter, C. Hatton, X. Garcia, M.P. Hamilton, M.P. Miensopust, P. Cole, T. Ngwisanyi, D. Hutchins, C.J. Fourie, H.A. Jelsma, T. Aravanis, S.J. Webb, J. Wasborg, and the SAMTEX Team (2009), Lithospheric structure, evolution and diamond prospectivity of the Rehoboth Terrane and western Kaapvaal Craton, southern Africa: constraints from broadband magnetotellurics. *Lithos, 112S*, 93–105, doi:10.1016/j.lithos.2009.06.023.

O'Reilly, B.M., F. Hauser, and **P.W. Readman** (2009), A seismic study of the fine scale structure of the upper lithosphere within the Irish Caledonides using 1-D full-waveform methods: insights into Phanerozoic crustal formation processes, *Geophysical Journal International*, doi: 10.1111/j.1365-246X.2009.04420.x.

Readman, P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), Crustal anisotropy in southwest Ireland, from analysis of controlled-source shear-wave data, *Tectonophysics, 474*, 571-583. doi:10.1016/j.tecto.2009.04.029.

Readman, P.W., F. Hauser, B.M. O'Reilly, and V.C. Do (2009), Crustal anisotropy in southwest Ireland, from analysis of controlled-source shear-wave data, *Tectonophysics, 474*, 571-583. doi:10.1016/j.tecto.2009.04.029.

Sasgen, H. Dobslaw, **Z. Martinec**, and M. Thomas (2009), Satellite gravimetry observation of Antarctic snow accumulation related to ENSO, *Earth and Planetary Science Letters*, (submitted, 2009).

Sheehan, J.D., B.M. O'Reilly, D. Sokoutis, and **P.W. Readman** (2009), The continental lithosphere in tectonic extension:a comparison between analogue and numerical experiments using the Porcupine Basin in the North Atlantic as a prototype, Submitted to *Geophysical Journal International*.

Spratt, J.E., **A.G. Jones**, V. Jackson, L. Collins, and A. Avdeeva (2009), Lithospheric geometry of the Wopmay Orogen from a Slave Craton to Bear Province magnetotelluric transect, *Journal of Geophysical Research, 114*, B01101, doi: 10.1029/2007JB005326.

Tirel, C., P. Gautier, D.J.J. van Hinsbergen, and M.J.R. Wortel (2009), Sequential development of interfering metamorphic core complexes: numerical experiments and comparison with the Cyclades, Greece in *Collision and Collapse at the Africa–Arabia–Eurasia Subduction Zone. The Geological Society, London, Special Publications*, 311, edited by D.J.J. van Hinsbergen, M.A. Edwards, and R. Govers, pp. 257–292. doi: 10.1144/SP311.10.

Vozar, J., and V. Semenov (2010), Compatibility of induction methods for mantle soundings, *Journal of Geophysical Research, 115*, XXXXXX, doi: 10.1029/2009JB006390, 2010 (in press).

Welford, J.K., P.M. Shannon, **B.M. O'Reilly**, and J. Hall (2009), Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from constrainted 3-D gravity inversion, *Geophysical Journal International*, in review.

Yamasaki, T., and L. Gernigon (2009), Styles of lithospheric extension controlled by underplated mafic bodies, *Tectophysics, 468*, 169-184.

Zhang, X., H. Paulssen, **S. Lebedev**, and T. Meier (2009), 3D shear velocity structure beneath the Gulf of California from Rayleigh wave dispersion, *Earth Planet. Sci. Lett., 279*, 255-262.

16.2 Invited Presentations

Blake, T.A. (2009), Seismology in Schools (Seismeolaíocht sa Scoil) Pilot Programme, IGRM, TCD, February.

Blake, T.A. (2009), Keynote Lecture 5th Annual AfricaArray Workshop, School of Geosciences, University of the Witswatersrand, Johannesburg, South Africa on 'Promoting geosciences education through a simple seismic monitoring programme for schools, 6 July.

Jones, A.G., M.R. Muller, M.P. Miensopust, M.P. Hamilton, R.L. Evans, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, M. Doucoure, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), Geometry and structures of the Southern African lithosphere revealed through deep-probing electromagnetics: The SAMTEX project, invited Keynote Presentation at IASPEI, Cape Town, 10-16 January.

Jones, A.G., R.L. Evans, M.R. Muller, M.P. Hamilton, **M.P. Miensopust**, X. Garcia, P. Cole, T. Ngwisanyi, D. Hutchins, C.J.S. Fourie, S. Evans, H. Jelsma, T. Aravanis, W. Pettit, S. Webb, J. Wasborg, and The SAMTEX Team (2009), The SAMTEX experiment: Overview and Preliminary Results, invited Keynote Presentation at SAGA, Swaziland, 16-18 September.

Lebedev, S. (2009), Surface-Wave Anisotropy and Deformation of Continents, seminar at University of Leeds, January.

Lebedev, S., and **J. Adam** (2009), Seismic structure of southern Africa: New constraints from surface waves (keynote), 2009 SAGA Biennial Technical Meeting & Exhibition, September.

Lebedev, S., M.R. Agius, and R.D. van der Hilst (2009), Lithospheric Structure of Tibet and East Asia: New Constraints From Surface Waves, AGU Fall Meeting, San Francisco, December.

O'Reilly, B.M. (2009), Some speculations from seismology on crustal growth and tectonic processes in Ireland, invited talk at University College Cork, 19 March.

O'Reilly, B.M. (2009), Ideas regarding new long-range seismic refraction profiles across the Irish-Newfoundland conjugate basins and margins, invited talk at Department of Communications and Natural Resources, Dublin, 1 July.

Roux, E., M. Moorkamp, and **A.G. Jones** (2009), Joint inversion of different geophysical datasets: synthetics and real test cases, invited talk at Geological Survey Canada, Ottawa, Ontario, December.

Webb, S.J., and **A.G. Jones** (2009), Delineating prospective kimberlite regions using potential field methods – from space to surface, invited Keynote Presentation at IASPEI, Cape Town, 10-16 January.

School of Cosmic Physics

1. External Research Funding 2009

EXTERNAL RESEARCH PROGRAMMES FOR THE SCHOOL OF COSMIC PHYSICS	2009
External Income Funded by Irish Government Bodies	
HEA - PRTLI	2,553,754
SFI Funded Programmes	525,658
IRCSET Funded Programmes	242,323
Heritage Council and RIA	
Irish Schools, Forfas, Enterprise Ireland	10,560
Department of Marine and Natural Resources	63,050
Sub-Total - Irish Government External Income	**3,395,345**
Other External Income	
European Community	356,584
Industry and Other	125,549
Sub-Total - Other External Income	**482,133**
Income from External Research Programmes in 2009	**3,877,478**

School of Theoretical Physics

1 Report on Research Work

1.1 Work by Senior Professors and Collaborators

1.1.1 Discrete Hirota Equations

(W. Nahm & S. Keegan)

With S. Keegan several cases of the discrete Hirota equation were solved, as reported in previous years. The system is an important set of algebraic equations, which occur in various areas of mathematical physics. The equations have the form

$$\prod_{\quad} \quad \cdot \quad \cdot \quad \cdot$$

where $j \in \mathbb{Z}$, X is a Dynkin diagram, i takes values in the vertices of X, and $X(i)$ is the set of neighbors of i in X. For $X = A_r$ it had been shown that the set of solution is fibered over a maximal torus of the corresponding Lie group SL_{r+1}. For $X = D_r$ the generic solutions were found, but not yet a complete algebraic description of the full space of solution, as required for quantization. A fibration over a maximal torus of the D_r Lie group was expected, but Nahm found that this is not true in general. Instead there are certain loci in the solution space where two fibres intersect. What happens for $X = E_r$ is still unknown. S. Keegan had left DIAS after her PhD to take a teaching job in Oxford, but she will come back as a scholar.

1.1.2 Partition Functions for Constraint Random Walks

(W. Nahm & S. Keegan)

The context of the study of the discrete Hirota equation is a relation between algebraic K-theory and integrable quantum field theories, as reported last year. This involves a deep relation between the scattering matrices of integrable quantum field theories and modular properties of certain q-hypergeometric series. Mathematicians have been interested for a long time in a direct proof of this modular properties, but this is still elusive. A new approach was tried to rewrite the result of a modular transform of the function as a q series again, in the hope that the result would reproduce the original q-hypergeometric form. Instead the result was a quite different q series. This yielded the following identity

$$\sum \sum \quad \quad \prod \quad$$

Here P_k is the set of non-stationary paths of length k in the set $\mathbb{N}$, in other words of sequences $(n_1,...,n_k)$ such that $n_i \neq n_{i+1}$

$$\quad \quad \sum \quad \quad \quad$$

The derivation of this result is not yet rigorous, but it has been checked to high order in q. Attempts by mathematicians to obtain a direct proof have failed so far. The result corresponds to the simplest case of the relation between algebraic K-theory and physics mentioned above, namely the case of a free fermion, generalizations are possible and under study.

1.2 Edge States of Graphene-Like Materials

(W. Nahm & M. Leitner)

Edge states of graphene sheets and related systems have great industrial potential. They were studied from the point of view of boundary states of quantum field theories of free fermions, or equivalently from the theory of self-adjoint extensions of the Dirac operator. The most important result is that the excitations of the simplest boundary states have a fixed velocity which can take arbitrary values below the bulk velocity. Moreover, for every velocity there are exactly two possible boundary states.

The most general self-adjoint extensions can be described by von Neumann's theory, but the latter is not well adapted to the quantities of experimental relevance. Thus a modification of this theory was developed which should work for arbitrary differential operators. The work has been submitted to a journal and is currently under review.

2 Integrable Quantum Field Theories

(W. Nahm & D. Zagier)

Joint work on integrable deformations of conformally invariant quantum field theories was continued during a visit of W. Nahm to Bonn. In particular a better understanding of the integrals of motions of the connection with algebraic K-theory mentioned above was achieved which makes it likely that quantum field theory has deep undiscovered links with areas on the frontier of current mathematical research. Unfortunately mathematicians have great difficulty in understanding the physics literature on quantum field

theory. It would help to have some analogue to the hydrogen atom, something which is interesting, beautiful and under mathematical control. It is hoped that integrable deformations of minimal models can yield such a system, but before 2009 it was impossible to find more than some hours per year to work together. In August 2009 I visited Bonn for a month and we made a serious start. In particular the local integrals of motion were looked at, for which the first eight are known, but known algorithms become exponentially more difficult, when one goes to higher ones. New insight into this problem arose and it seems that they can be obtained in polynomial time.

2.0.1 Quantum Information

(T.C. Dorlas & C. Morgan)

Together with a Ph.D. student (Ciara Morgan) the classical capacity of two specific examples of quantum channels with long-term memory: a periodic channel and a random memoryless channel, each with branches given by depolarising channels were studied. Using King's theorem for depolarising channels, it was shown that the classical capacity of these channels is equal to their respective product-state capacities. Moreover, it was also shown that in the case of a random memoryless channel, this result extends to arbitrary memoryless branches for which additivity holds. These results were published in [2]. It was also shown that the strong converse does not hold in general for these types of channel.

2.0.2 Quantum Information

(T.C. Dorlas & N. Datta)

Together with Dr. Nilanjana Datta (Cambridge) a paper [3] on the classical capacity of a general quantum channel with classical (Markovian) memory was completed. A particularly interesting case turned out to be that of periodic channels with non-trivial internal loops.

2.0.3 Quantum Entanglement

(T.C. Dorlas & A. Ghesquiére)

Together with Anne Guesquiére a study has been undertaken of the decay of entanglement of two particles, initially in a Gaussian entangled state, due to the interaction with a heat bath. As the entanglement entropy of the initial Gaussian state is not a good measure of entanglement for mixed states, the so-called *logarithmic negativity* was computed instead. It was found that in the case of two freely evolving particles, this quantity vanishes after a finite time, a phenomenon known as 'entanglement sudden death'. When a harmonic interaction is added to the Hamiltonian, the behaviour changes.

2.0.4 Bethe Ansatz

(T.C. Dorlas & M. Samsonov)

Together with Dr. Maxim Samsonov, the thermodynamic limit of the six-vertex model was considered. This model is closely related to the Heisenberg chain in that the Bethe Ansatz equations are in fact the same! The difference is that only a restricted set of solutions, namely those corresponding to the ground state of the Heisenberg chain, is relevant for the six-vertex model. So far, two cases have been treated: those where the interaction parameter Δ takes values in the intervals $(0, 1)$ and $(-\infty, -1)$. In the first case, the Bethe-Ansatz equations can be written in a variational form with a functional which is convex. In the other, one can use a Fourier-transformed version of the equations, together with a contraction-mapping argument. See [09-03]. Numerically, it seems that this should work in general, but work on this has not succeeded yet and is still in progress. In the meantime work commenced on starting to extend the latter case to the inhomogeneous Heisenberg chain to prove the existence of the so-called "string solutions".

2.0.5 The Totally Asymmetric Exclusion Process

(T.C. Dorlas, V. Priezzhev & A. Povolotsky)

Together with Prof. Priezzhev (Dubna, Russia) and Dr. Alexander Povolotsky, progress was made with the study of the TASEP. A new model was introduced, which interpolates between the vicious walkers model and the TASEP. Using a fluctuation-dissipation theorem, this allowed the computation of the distribution of the total current in the TASEP model, giving rise to a new type of distribution function, similar to but different from the Tracy-Widom distribution. Some numerical computations were done to illustrate the shape of the distributions. The paper has been published [4].

2.0.6 A model for an Exciton in a Carbon Nanotube with Impurity

(T.C. Dorlas & P. Duclos)

Progress was made with the mathematical analysis of a simple model of an exciton in a carbon nanotube in the presence of a charged impurity. The model consists of two dynamic particles on a line with opposite charges (the exciton) and an attractive delta-interaction, together with a delta potential which is attracting for one, and repulsive for the other particle. Due to the competing interactions, the spectrum of this model is not easy to analyse. Numerical approximation is also inconclusive for small and large values of the exciton charges. However, in a collaboration with Pierre Duclos (Marseille) it was shown that there is in fact at least one bound state (discrete point in the spectrum) for arbitrarily small values of the charge. On the other hand, it was found that for high values of the charge, no bound state exists. The plan is to extend this analysis to the case where the two particles have different masses.

2.0.7 A Simple Model for Global Warming

(T.C. Dorlas)

With the ongoing controversy about global warming, a simple model was developed for explaining global warming in terms of the increase of CO_2 levels alone. This avoids the use of extensive computer models, which are of questionable value. Indeed, it seems unlikely that such a random system as the climate can be modelled with any confidence. On the other hand, it is not inconceivable that a simple trend like the global average temperature could be due to a single cause. It was found that the increase in CO_2 can indeed in principle explain a large part of the observed increase in global average temperature. It should be realised, however, that this increase is so far quite small (about 0.5°C since 1960) and is unlikely to be the principal cause of many of the supposedly related global changes, like glacier retreat or ocean acidification. One exception is the observed sea level rise, which can be explained almost entirely by thermal expansion. A report of these findings is in [31].

2.0.8 Research Overview

(Denjoe O'Connor)

We unfortunately find ourselves writing this research report at a very disheartening time. Especially, after what most would consider a successful year by the school of theoretical physics and its researchers: A year where, an external review committee of the highest international standards, assessed the activities of DIAS over the previous five year period very favourably: A year when this external review committee reiterated the recommendations of the previous committee for an expansion of the researcher base and resources available to the school. It is a time when those, like STP, who followed a prudent approach to the use of the resources available to it finds that it has its funding support virtually wiped out to pay for the profligate excesses of those who squandered and gambled resources they did not possess. The result was the elimination for 2010 of the STP visitor program.

The short-term savings accruing from the elimination of the DIAS visitor program will of course have longer term costs that are difficult to quantify, costs which will accumulate with the passage of time. For example it will make DIAS a less attractive place for the best postdoctoral researchers who will no longer be able to count on excellent personal contact with the international research community, a contact that has a significant impact on their future careers. It will make it more difficult for us to justify that a small institution such as STP at DIAS has the all necessary resources to carry out externally funded research on a European or world scale, where granting agencies usually require the institution to state if it has all of the necessary resources for the successful completion of the proposed research. In the past DIAS could proudly point to its international visitor programme and the workshops that it supported.

Of course much of the above is for next years report, however it is wise to signal now the implications of current decisions, in the hope that corrective action will be carried out and resources reinstated next year rather than some years down the line, when significant damage has already been done.

2.0.9 Fuzzy Physics & Emergent Geometry

(Denjoe O'Connor)

In 2009 work continued on the extension and consolidation of some of the ideas involved in emergent geometry.

This subject is closely related to non-commutative geometry and what is called "fuzzy field theory". Fuzzy field theories

are field theories where the algebra of functions of a manifold is replaced by a suitable matrix algebra, with matrix dimension N, and the Laplace-Beltrami operator by a suitable double commutator Laplacian mapping matrices to matrices of the same dimension. The triple of Matrix algebra, norm [illegible] and Laplacian defines the geometry of the fuzzy space.

The "fuzzy approach" provides a regularization of field theory (and hopefully string theory) that is well adapted to the nonperturbative study of both commutative and noncommutative field theories including those with chiral fermions. It is also well suited to the study of supersymmetric models as it is possible to truncate the theory to a finite number of degrees of freedom while retaining the exact supersymmetry. The ingredients are then a graded matrix algebra, where the matrix entries now contains both commuting and anti-commuting (or Grassmann) entries and the trace over matrices is replaced by a supertrace.

At the level of the classical Euclidean action, the method naturally preserves most of the fundamental symmetries of the theory in question, though these can be broken spontaneously. In recent years a continually increasing number of fuzzy spaces has become available. These include all flag and superflag manifolds as well as a further large class of algebraic varieties.

The new twist is that, when the field theory is of Yang-Mills type, as the parameters of the model are changed the background geometry itself becomes dynamical. This is a phenomenon closely related to that which occurs in $4 - d$ supersymmetric Yang-Mills theory, where at strong coupling the model is best described as a $10 - d$ supergravity theory or the low energy limit of a superstring theory.

The principal effort of the year was to extend the earlier studies to models including Fermions and to higher dimensional models. The studies are ongoing and involve the use of both analytical and numerical techniques.

2.0.10 Simulation of a Scalar Field on a Fuzzy Sphere.

(F.G. Flores, X. Martin & Denjoe O'Connor)

Here the ϕ^4 real scalar field theory on a fuzzy sphere is studied numerically. The phase diagram for this model is refined where three distinct phases are known to exist: a uniformly ordered phase, a disordered phase, and a non-uniform ordered phase where the spatial SO(3) symmetry of the round sphere is spontaneously broken and which has no classical equivalent. The three coexistence lines between these phases, which meet at a triple point, are carefully located with particular attention paid to the one between the two ordered phases and the triple point itself. In the neighbourhood of the triple point all phase boundaries are well approximated by straight lines which, surprisingly, have the same scaling. It is argued that unless an additional term is added to enhance the effect of the kinetic term the infinite matrix limit of this model will not correspond to a real scalar field on the commutative sphere or plane. The results were published in [5].

2.0.11 The Zero Temperature Phase Diagram of the Kitaev Model.

(C. Nash & Denjoe O'Connor)

It was shown that the zero temperature phase diagram of the vortex free sector of the Kitaev model is in one to one correspondence with that of the classical dimer model on the same lattice. It was found that the model generically has three distinct phases. On a honeycomb lattice with a 3 ¥ 3 fundamental domain all three phases are accessible. As the couplings are varied there are two distinct transitions. The new transition is one to a gapped phase that opens up in the interior of the B phase. The results were published in [6].

2.0.12 An ab initio Calculation of the Universal Equation of the $O(N)$ Model

(Denjoe O'Connor, J.A. Santiago & C.R. Stephens)

Using an Environmentally Friendly Renormalization Group an ab initio universal scaling form for the equation of state for the $\mathrm{O(N)}$ model, $\mathrm{y{=}f(x)}$, that exhibits all required analyticity properties in the limits $x \to 0$, $x \to \infty$ and $x \to -1$ was derived. Unlike current methodologies based on a phenomenological scaling ansatz the scaling function is derived solely from the underlying Landau-Ginzburg-Wilson Hamiltonian and depends only on the three Wilson functions γ_λ, γ_ϕ and γ_{ϕ^2} which exhibit a non-trivial crossover between the Wilson-Fisher fixed point and the strong coupling fixed point associated with the Goldstone modes on the coexistence curve. Explicit results for $\mathrm{N{=}2}$, 3 and 4 to one-loop order were given and compared with known results. The results were published in [7].

2.0.13 Topological Phase Transitions and Holonomies in the Dimer Model.

(C. Nash & Denjoe O'Connor)

It was demonstrated that the classical dimer model defined on a toroidal hexagonal lattice acquires holonomy phases in the thermodynamic limit. When all activities are equal the lattice sizes must be considered mod 6 in which case the finite size corrections to the bulk partition function correspond to a massless Dirac Fermion in the presence of a flat connection with nontrivial holonomy. For general bond activities it was found that the phase transition in this model is a topological one, where the torus degenerates and its modular parameter becomes real at the critical temperature. It is argued that these features are generic to bipartite dimer models and present a more general lattice whose continuum partition function is that of a massive Dirac Fermion. The results were published in [8].

2.0.14 Matrix Models, Gauge Theory and Emergent Geometry

(Rodrigo Delgadillo-Blando, Denjoe O'Connor, Badis Ydri)

Theoretical predictions and Monte Carlo simulations for a simple three matrix model that exhibits an exotic phase transition are presented. The nature of the transition is very different if approached from the high or low temperature side. The high temperature phase is described by three self interacting random matrices with no background spacetime geometry. As the system cools there is a phase transition in which a classical two-sphere condenses to form the background geometry. The transition has an entropy jump or latent heat, yet the specific heat diverges as the transition is approached from low temperatures. No divergence or evidence of critical fluctuations when the transition is approached from the high temperature phase was found. At sufficiently low temperatures the system is described by small fluctuations, on a background classical two-sphere, of a U(1) gauge field coupled to a massive scalar field. The critical temperature is pushed upwards as the scalar field mass is increased. Once the geometrical phase is well established the specific heat takes the value 1 with the gauge and scalar fields each contributing 1/2. Two new students Thomas Kaltenbrunner and Martin Vachovski joined the group. The results were published in [9].

2.1 Independent Work by Schrödinger Fellows

2.1.1 String Theory

(V. Braun)

V. Bruan's main area of research was in the general subject area of string theory, and in particular compactifications to 4 dimensions and their physical implications.

2.1.2 Numerical Hermitian Yang-Mills Connections

(V. Braun, B. Ovrut & L. Anderson)

Part of the supersymmetry equations of string theory is that the gauge field needs to satisfy the Hermitian Yang-Mills equation.

During 2009, joint work with B. Ovrut and L. Anderson made progress towards computing numerical approximations to $SU(n)$ gauge connections on a variety of Calabi-Yau manifolds. There are non-trivial obstructions to its existence as well as different 'failure modes' as one encounters obstructions, and the numerical computations reproduce these beautifully.

2.1.3 Non-Simply Connected Calabi-Yau Manifolds

(V. Braun, P.Candelas & R. Davies)

An important ingredient for phenomenologically interesting compactifications are manifolds that allow for discrete Wilson lines. In this case, the Hosotani mechanism can be used to break the (typically large) gauge group to the standard model gauge group. For this reason, there is a by now long history of manual searches for non-simply connected manifolds. During the year 2009 joint work with P. Candelas and R. Davies implemented a computer-based exhaustive search for a class of quotients of so-called complete intersection Calabi-Yau (CICY) manifolds. One of the surprises was that, next to the so-called Yau manifold, there is one more CICY quotient that leads to a three-generation 'standard embedding' model. The complete list of CICY quotients will be published shortly.

2.1.4 String and Gauge Theory

(S. Kovacs)

Dr. Kovacs' research focussed on the study of the interconnections between string and gauge theory. Work has been carried out on various aspects of the so-called AdS/CFT correspondence relating string theory in certain curved backgrounds to (supersymmetric) gauge theories in flat space. Since he joined the Institute in April work has continued on the following three projects which are briefly described below.

2.1.5 Light-cone Superspace and Dual Super-Conformal Invariance in $\mathcal{N}$ =4 SYM

(S. Kovacs, S. Ananth & H. Shimada.)

The $\mathcal{N}$ =4 supersymmetric Yang–Mills (SYM) theory has a number of interesting properties. It possesses the maximal amount of (rigid) supersymmetry in four dimensions and it is an example of an interacting conformally invariant theory. It is believed to also be invariant under a strong-weak coupling duality known as S-duality. This theory has been extensively studied in the past few years in the framework of the AdS/CFT correspondence. Among the numerous results which have emerged in this context, a particularly remarkable one is the discovery of an integrability structure underlying the spectrum of gauge invariant operators in the theory.

Another surprising feature of the theory is what has been referred to as *dual conformal invariance*. It has recently been observed that 'scattering amplitudes' originally computed in momentum space display a new symmetry when expressed in terms of certain auxiliary 'position variables'. The amplitudes satisfy the constraints of a superconformal symmetry in the auxiliary space parametrized by the new variables. This symmetry has so far only been studied in relation to scattering amplitudes which are not proper physical observables in a conformal field theory. Moreover the new symmetry has not been explained from first principles and its origin remains obscure.

Dr. Kovacs, in collaboration with Dr. Sudarshan Ananth (of the Indian Institute of Science Education and Research, Pune, India) and Dr. Hidehiko Shimada (of the Max-Planck-Insitut f-ur Gravitationsphysik, Potsdam, Germany) studied this topic utilising the formalism of light cone superspace. The formulation of N =4 SYM in light cone superspace originally allowed a proof of the absence of ultra-violet divergences in the theory to all orders in the perturbative expansion. The light cone formalism closely resembles the on-shell formalism used to analyse the dual superconformal invariance of scattering amplitudes. However, it is also suitable to compute off-shell observables such as correlation functions of gauge invariant operators. The current research has various objectives. It aims to clarify what type of constraints the dual super-conformal symmetry implies for correlation functions and to understand how to use these constraints to simplify perturbative calculations. At the same time an appropriate rewriting of the light cone superspace N =4 action should also allow one to shed light on the Lagrangian origin of the dual super-conformal symmetry.

A further extension of this project will investigate the role of this new symmetry in connection with the integrability of the spectrum of the $\mathcal{N}$ =4 SYM theory.

2.1.6 Instantons and Holography

(S. Kovacs)

The AdS/CFT correspondence is a remarkable duality relating a string theory, *i.e.* a theory of quantum gravity, in a certain bulk space to an ordinary quantum field theory that lives on the boundary of this space. As such it is referred to as a 'holographic duality'. The correspondence provides a prescription for computing observables in the boundary theory in terms of observables of the bulk theory and vice versa. One of the most interesting aspects of this duality is the fact that it relates the weak coupling limit of one theory to the strong coupling regime of the other theory. The AdS/CFT correspondence represents an explicit realisation of a more general 'holographic principle' which states that in a quantum gravity theory the dynamics in a certain region of space can be captured by degrees of freedom localised on a lower dimensional manifold.

The precise nature of the holographic relation between gauge theories and gravity theories has so far remained unclear, even in the case of the AdS/CFT duality. Specifically it is not understood how local properties in the bulk are encoded in the boundary theory. The study of instanton effects in the AdS/CFT correspondence provides a unique perspective into this issue. Instanton effects in the gauge theory are related to effects induced by so-called D-instantons in the dual string theory. A very precise relation between these two sources of nonperturbative effects has been established. The calculation of instanton contributions

to correlation functions of gauge invariant operators allows one to extract certain properties of the bulk geometry and of the supergravity solution defining the dual background.

Dr. Kovacs worked on a research project which focussed on the application of these ideas to a class of deformations of the $\mathcal{N}$=4 SYM theory. Among these theories there are examples for which the gravitational dual is known as well as examples for which the dual geometry is unknown. One of the objectives of this work is to explicitly construct, through the analysis of instanton induced correlators in the gauge theory, the complete supergravity solution describing a dual background which has not been obtained using different arguments.

Possible extensions of this project include the application of these ideas to gauge theories at finite temperature which the AdS/CFT dictionary relates to black hole geometries.

2.1.7 Holography in the Plane Wave Limit of the AdS/CFT Correspondence

(S. Kovacs & H. Shimada)

Dr. Kovacs has also worked with Dr. Hidehiko Shimada on a related project whose purpose is to better understand certain features of a special limit of the AdS/CFT correspondence. It has been observed that the so-called Penrose limit of an AdS geometry produces a plane-wave background in which string theory can be quantised rather straightforwardly. In the dual field theory this limit selects a particular class of operators, while all the remaining operators in the theory decouple. In this particular limit the spectrum of gauge theory operators and the spectrum of string states have been extensively compared. Very accurate tests have been successfully completed, providing convincing evidence in favour of the conjectured duality. However, the majority of the calculations done so far have focussed on two-point correlation functions which allow one to extract the scaling dimensions of gauge theory operators and the masses of the dual string states. A satisfactory understanding of higher-point functions is still missing. The purpose of Dr. Kovacs' research is to further test different proposed prescriptions for the calculation of generic n-point correlation functions, concentrating on non-perturbative effects induced by (D-)instantons. Previous experience shows that instanton effects capture in a more transparent way the bulk-boundary relation. Therefore this approach might allow one to single out the correct holographic prescription to be employed in the plane wave limit of the AdS/CFT correspondence.

2.1.8 Statistical Mechanics

(I. Lyberg)

Work has been pursued on various topics in statistical mechanics; correlation functions of the two dimensional Ising lattice, the Schramm-L-owner equation and finally point processes and distributions. This last topic is a joint project with T. Dorlas and A. Povolotsky.

2.1.9 Correlation Functions of The Two-Dimensional Ising Lattice and Isomonodromic Deformations

(I. Lyberg)

It was shown by Jimbo and Miwa in 1980 that the diagonal correlation function $\langle \sigma_{00}\sigma_{NN}\rangle$ is related to the sixth Painlevé equation. Furthermore, it was shown in 1976 by Wu, McCoy, Tracy and Barouch that all correlations $\langle \sigma_{00}\sigma_{MN}\rangle$ have similar 'form factor expansions'

$$\langle \sigma_{00}\sigma_{MN}\rangle = \sum_{n=1}^{\infty} f_n(M,N) \qquad (2.1)$$

and

$$\langle \sigma_{00}\sigma_{MN}\rangle = \sum_{n=1}^{\infty} f_n(M,N) \qquad (2.2)$$

where $\{f_n(M,N)\}_{n=1}^{\infty}$ are certain integrals.While the integrals as found by Wu and others are rather involved, Lyberg and McCoy showed in 2007 (arxiv:math-ph/0612051v1) that in the special cases $M = 0$ and $M = \mathrm{N}$ these integrals can be much simplified. A major unsolved problem is to show that $\langle \sigma_{00}\sigma_{0N}\rangle$ satisfies some differential equation. It should be possible to do this in a way similar to Jimbo's and Miwa's procedure, but the relationship between $\langle \sigma_{00}\sigma_{0N}\rangle$ and isonmonodromic deformation theory has not yet been fully investigated.

2.1.10 The Schramm-L-owner Equation

(I. Lyberg)

Interest in this topic arose at the congress organised by IAMP last summer in particular in the relationship between

SLE and conformal field theory. The notes by W. Kager and the book by G. F. Lawler have been studied.

2.1.11 Point Processes and Distributions

(I. Lyberg, T.C. Dorlas & A. Povolotsky)

If a particle of electrical charge $-N$ is fixed at the origin of the real line, and if N particles of charge 1 may move over $\mathbf{N}$ in such a way that at most one particle occupies any one site $n \in \mathbf{N}$, then the corresponding distribution function can be found in the limit $N \to \infty$, as shown by H. Monien in a recent paper (arxiv:0901.1883v1). However, it would be desirable to find a proof of the expression given in that paper. Furthermore, one should be able to find a solution for finite N, and not just for the limit of infinite N. The correlation functions in subsection 2.1.9 are given by certain Toeplitz determinants; that is determinants of matrices of the form (a_{ij}) where $a_{ij} = c_{i-j}$ only depends on $i - j$. Similarly, in the problem of point processes the partition function is given by certain Hankel determinants; that is determinants of matrices of the form (a_{ij}) where $a_{ij} = c_{i+j}$ only depends on $i+j$. This seems to indicate that one can use methods similar to those used by Lyberg and McCoy in arxiv:math-ph/0612051v1 to treat the case of finite N. It should be possible to find an exact solution of this problem for finite N as an expansion similar to (2.1).

2.2 Independent Work by IRCSET Fellows

2.2.1 Metric 3-Algebras

(V. Dotsenko, S. Cherkis & C. Saemann)

In a joint paper with Cherkis and Saemann [11], canonical metric 3-algebra structures on $*$-algebras were classified and novel three-dimensional conformally invariant actions in $N = 4$ projective superspace based on them were found. The relations of these actions with the $N = 2$ actions based on generalized 3-Lie algebras found earlier were explored and related to the original Bagger-Lambert-Gustavsson action.

2.2.2 Shuffle Operads and Gröbner Bases

(V. Dotsenko & A. Khoroshkin)

To deal with operations possessing symmetries, the notion of an operad is traditionally used. However, for purposes of linear and homological algebra, the fact that operads possess symmetries makes the actual computations really difficult at times. Together with Dr. Anton Khoroshkin (ETH Zürich), a new notion of a shuffle operad was introduced, and several effective approaches to shuffle operads were developed. Shuffle operads generalize usual (symmetric) operads, but they form a wider class. However, every symmetric operad, when considered as a shuffle operad, carries enough information to solve related algebraic questions. This year, three papers on this subject were completed, one jointly with Khoroshkin, with a definition and some applications [09-16], one by myself, with further applications [09-13], and one with Dr. Mikael Vejdemo Johannson (Stanford) where a computer implementation of the operadic Gröbner bases algorithm, due to myself and Khoroshkin, was presented [09-14].

2.2.3 Yang-Mills Theory.

(V. Filev)

One of the main objectives in the past year was to develop appropriate holographic techniques to study the effect of mass generation and chiral symmetry breaking in flavoured strongly coupled Yang-Mills theories in the presence of an external magnetic field. The focus was on flavoured gauge theories holographically dual to the Dp/Dq brane system. Interest was in the phase structure of the theory, as well as in the meson spectrum of the corresponding bound states. The study provided a holographic description of the chiral dynamics of the pseudo goldstone bosons. The corresponding dispersion relations were studied, both numerically and analytically. This project was completed.

Another goal was to extend previous studies of the thermal properties of gauge theories with holographic duals in external magnetic field. The field theory that was focussed on was the one dual to the D3/D5 system. The main goal was to study the confinement/deconfinement phase transition of the fundamental matter and to explore the effect that an external magnetic field has on that phase transition. One of the motivations was to compare the results with results obtained on the field theory side for the weakly coupled regime of the theory. This project was completed.

There was also interest in understanding the relationship between the concept of emergent geometry familiar from multi-matrix models and the one implicitly suggested by the AdS/CFT correspondence. The study involved multi-matrix models obtained from dimensional reduction of 1+3 dimensional N=4 Supersymmetric Yang-Mills theory. The

goal was to study the joint eigenvalue distribution near a commuting saddle, while taking into account higher loops corrections. This is an ongoing project.

Work has continued in exploring the properties of the strongly coupled three-matrix model. The motivation for this study is the possible applications of this model in studying the vacuum structure of Supersymetric Yang-Mills theories obtained by various relevant deformations of $N{=}4$ Supersymmetric Yang-Mills theory. This is an ongoing project.

2.2.4 Nonequilibrium Systems of Interacting Particles.

(A. Povolotsky)

A model of semi-vicious walkers, which interpolates between the totally asymmetric simple exclusion process and the vicious walkers model, having the two as limiting cases was proposed. For this model the asymptotics of the survival probability were calculated and a scaling function, which describes the transition from one limiting case to another was obtained. Then, a fluctuation-dissipation relation was used, which allowed one to reinterpret the result as the particle current generating function in the totally asymmetric simple exclusion process. Thus, the particle current distribution was obtained asymptotically in the large time limit as the number of particles is fixed. The results apply to the large deviation scale as well as to the diffusive scale. In the latter a new universal distribution, which has a skew non-Gaussian form was obtained.

2.2.5 Condensed Matter Physics

(J. Slingerland)

Dr. Slingerland studied topological phases in low dimensional condensed matter systems such as those occurring in the fractional quantum Hall effect, as well as their application to topological quantum computation. He also worked on topological excitations in gauge theories at high energies (especially monopoles).

2.2.6 Quantum Hall Effect in the Second Landau Level

(J. Slingerland, P. Bonderson, G. Möller & A. Feiguin)

With Drs. P. Bonderson (Microsoft), G. Möller (Cambridge) and A. Feiguin (Microsoft), a set of hierarchical trial wave functions for the second Landau level, proposed in the previous year was studied numerically. A preprint detailing the results for the state proposed at fraction 12/5 has appeared [09-02]. In another collaboration, various explanations for recent experimental results found in interferometric experiments at filling 5/2 were critically evaluated. It was concluded that tunneling of non-Abelian anyons provides the least problematic explanation of the observed phenomena. [17].

2.2.7 Transitions and Edges between Topological Phases

(J. Slingerland, F.A. Bais & S.M. Haaker)

With F.A. Bais and S.M. Haaker (University of Amsterdam), Dr. Slingerland continued work on the characterisation of phase transitions between topological phases induced by the condensation of bosonic quasi-particles. This has led to the following publication [18] focusing on the description of boundaries between regions supporting different topological phases. Two more preprints, detailing the role of the topological entanglement entropy and describing the relation with the Haldane Halperin hierarchy in the fractional quantum Hall effect are in preparation.

2.2.8 Lattice Models with Topological Phases

(J. Slingerland, J. Vala & J.K. Pachos)

With G. Kells and J. Vala (NUI Maynooth) Kitaev's spin model on the honeycomb lattice was investigated. This is a soluble model exhibiting two topological phases, one with Abelian and one with non-Abelian anyonic excitations. This resulted in the paper [16] which describes a new Jordan-Wigner type construction which solves the model without the introduction of non-physical degrees of freedom and with optimal use of the symmetry structure of the model. It also allows for easy comparison with extensive previously known pertubative results. In addition, a preprint has appeared [09-17] applying this solution method to a generalized model, the star lattice model, which provides an example of chiral spin liquid.

2.2.9 Magnetic Monopoles and Duality

(J. Slingerland, F.A. Bais, L. Kampmeijer & B.J. Schroers)

With Prof. F.A. Bais and Dr. L. Kampmeijer (University of Amsterdam) and Dr. B.J. Schroers (Heriot-Watt University), Dr. Slingerland studied magnetic monopoles in gauge theories where the gauge group is broken to a residual non-Abelian group. A set of fundamental monopole charges

was identified such that all monopoles can be seen as smooth deformations of monopoles that are constructed by patching together spatially separated fundamental monopoles [15]. Further work, [19], which has in the meantime been published, concentrated on finding the maximal symmetry group that is manifest in all phases of these gauge theories and on examining the representation theory of this 'skeleton group' and its implications for the spectrum and fusion of monopoles and dyons.

2.2.10 Theory of Anyon Models

(J. Slingerland, P. Bonderson & E. Ar-donne)

Collaborations in this area with P. Bonderson and with E. Ardonne were continued. Goals are to produce a catalogue of anyon models (unitary braided tensor categories) as well as more general unitary tensor categories with up to 6 objects, giving both explicit topological data useful for calculating e.g. interference amplitudes in experiments involving anyons and constructive analytic descriptions of the categories. In addition, infinite series of anyon models associated with the compact Lie groups of rank 2 were studied.

2.3 Independent Work by Research Scholars and Students

2.3.1 Scattering and Completeness of δ–Interacting Particles in One Dimension.

(P. Abramski)

A system of n particles interacting via δ–function repulsive potential is considered in one dimension. The scattering of particles by solving the stationary Schrödinger equation for the wave function of the system is described. Two approaches to the problem are used. The first approach is based on the representation of the wave function as a system of waves reflected and transmitted by the domain boundaries. Each domain represents a particular order of numbered particles, while the boundary corresponds to an elementary transposition of two particles. For each pair of neighbouring particles reflection corresponds to the interchange of particle momentums and transmitting is in correspondence with the interchange of particles relative position. It is assumed that the incoming wave has particular unit normalisation either in the incoming or outgoing domain. A universal formula is obtained for the wave function in an arbitrary domain for the case of 3 particles and with generalization to $n-$particle case. For the case of 3 particles clear geometrical interpretation of this result was obtained in the form of diagrams with the system of reflected and transmitted waves for each of 6 regions represented all possible relative positions of 3 particles. In order to establish and prove the completeness of a system of wave functions we need to integrate over all domain of momentum the product of adjusted wave function of x with is conjugate of y within each region of x, y. This integration involves evaluation of over 80 integrals of all terms in 3-particle case and can be performed with the help of particular change of variables, its own for each integral. If we express the wave function in matrix form then it is possible to transform matrices of x and y in such way that modification is correspondent to the system of changes of momentum variables. This problem recently was solved explicitly for 3particle case and now with the help of this example we can do the same for $n-$particle case but replacing this matrix form by the operator form which is more appropriate for larger number of particles because of the size $n! * n!$ of matrices.

2.3.2 Quantum Entanglement

(A. Ghesquiére)

When an entangled state is subjected to an environment, the entanglement vanishes in very short times. This phenomenon is know as entanglement sudden death (E.S.D.). In this project, a bipartite Gaussian state was evolved using the Non-Rotating Wave Master Equation and the covariance matrix of the resulting state was obtained. Using the logarithmic negativity, E.S.D. was found to occur. In an attempt at slowing down the vanishing of the entanglement, a harmonic interaction was allowed between the particles. The master equation was solved again and a new covariance matrix was obtained. Two different behaviours were observed, namely over-damped and underdamped, depending on the strength of the coupling to the environment and of the frequency of the interaction. In the over-damped case, it was found that adding the potential yields little difference on the vanishing of the entanglement. However, in the under-damped case, the results suggest that the entanglement oscillates to a stable value and in fact never disappears.

2.3.3 Study on Matrix Models

(T. Kaltenbrunner)

The first goal was to better understand the behaviour of a three matrix model which has been studied by O'Connor et. al. in various papers. Therefore a model which was successfully solved already was studied in order to learn the suitable techniques and to try and apply them to the model of interest.

2.3.4 Information-Carrying Capacity of Certain Quantum Channels

(C. Morgan)

It was decided to first concentrate on the *product-state* capacity of a particular quantum channel, that is, the capacity which is achieved by encoding the output states from a source into codewords comprising of states taken from ensembles of non-entangled (i.e. separable) states and sending them over copies of the quantum channel. Using the "single-letter" formula proved by Holevo and Schumacher and Westmoreland the product-state capacity of the qubit quantum amplitude-damping channel, which is determined by a transcendental equation in a single real variable and can be solved numerically, was obtained. It was demonstrated that the product-state capacity of this channel can be achieved using a minimal ensemble of *non-orthogonal* pure states. The product-state capacity of a convex combination of two memory-less channels, which is given by the supremum of the minimum of the corresponding Holevo quantities was investigated, and it was shown in particular that the product-state capacity of a convex combination of a depolarising and an amplitude-damping channel, is not equal to the minimum of their product-state capacities. These results were published last year in the following article. T.C. Dorlas & C. Morgan: Calculating a maximizer for quantum mutual information. *International Journal of Quantum Information* **6** (2008) 745-750.

The *classical capacity* of two quantum channels with memory namely, a periodic channel with quantum depolarising channel branches and a convex combination of quantum channels was considered. The classical capacity is defined as the limit of the capacity of a channel, using a block of states which are permitted to be entangled over n channel uses and divided by n, as n tends to infinity.

It was proven that the classical capacity for each of the classical memory channels mentioned above is, in fact, equal to the respective product-state capacities. For those channels this means that the classical capacity is achieved without the use of entangled input-states. It was also demonstrated that the method used in the proof of the classical capacity of a periodic channel with depolarising channels does not hold for a periodic channel with *amplitude-damping* channel branches. This is due to the fact that, unlike the depolarising channel, the maximising ensemble for a qubit amplitude-damping channel is not the same for all amplitude-damping channels. These results have been published in the following article [2].

2.3.5 Topological Phases of Matter

(O. Smits)

Research was focused on topological phases of matter, which constitute an area of research within Condensed Matter Physics. Topological systems are low-dimensional $(2+1)$ condensed matter systems effectively described by a topological quantum field theory. Such systems are said to be topologically ordered. A novel property of these systems is the presence of (non-)Abelian anyons – quasiparticles which obey a generalized form of exchange behaviour different from that of bosons and fermions. Realizations of topologically ordered systems are found in strongly correlated and strongly interacting systems. Understanding of the fundamental nature of topological order is currently lacking. Research was aimed at characterizing topological phases of matter within the framework of theoretical condensed matter. The focus lay on two particular systems which are known to exhibit topological behavior. These are the Fractional Quantum Hall Effect (FQHE) and the Levin-Wen model.

2.3.6 Interferometry in the (Non-Abelian) Fractional Quantum Hall effect

(O.Smits, J. Slingerland & S. Simon)

In the context of the FQHE techniques ranging from conformal field theory, quantum transport, Luttinger liquids, and other tools developed in recent years were applied and investigated. Focus lay on detection techniques relevant for experiments. A specific example was the calculation of the tunneling current and noise of a quantum Hall bar together with two point contacts. Quasiparticles which reside on the

edge are able to tunnel from one side of the quantum Hall bar to the other at the location of the point contacts. This effect is detectable by applying an external voltage to the quantum Hall device and contains footprints of the nature of the topological phase. A solution was accomplished

2.3.7 Lattice Gauge Theories

(O.Smits & J. Slingerland)

The Levin-Wen model is a general setup for a lattice gauge theory which exhibits topological order. These models have the advantage of being exactly solvable. Phase transitions between the different types of topological phases found in these models were investigated– specifically those transitions induced by Bose condensation of a bosonic-like anyon. This research was still at an exploratory stage.

2.3.8 Matrix Models

(M. Vachovski)

Some methods of quantum field theory on lattice-Monte-Carlo simulation methods were studied. These are to be applied in studies of matrix models. Simulating simple 1-matrix models commenced with plans to simulate more general ones, such as 2 and 3-matrix actions. The long-term goal is to study phase transitions in multi-matrix models.

2.4 Work by Research Associates

2.4.1 The Quantum Hall Effect

(B. Dolan & Cliff Burgess)

An ongoing collaboration with Cliff Burgess of the Perimeter Institute, Waterloo, Canada and McMaster University University, Hamilton, Ontario, Canada on duality and the modular group in the quantum Hall effect continued. The use of AdS/CFT correspondence techniques in condensed matter systems to describe modular symmetries in the quantum Hall effect and other strongly correlated electron systems is being investigated.

2.4.2 Non-Commutative Geometry

(B. Dolan, A. Balachandran, C Nash, D. O'Connor, P. Presnajder, A. Stern, K. Gupta & R. Szabo)

The programme is to develop closed matrix algebras approximating compact manifolds, one aim of which is numerical computation. There is an ongoing collaboration with Richard Szabo of Heriot-Watt university on equivariant dimensional reduction, using fuzzy spaces as internal spaces. In 2009 many of the details for fuzzy CP^2 were worked, including the complete spectrum of the Dirac operator on CP^2 coupled to topologically non-trivial equivariant $SU(2) \times U(1)$ bundles.

2.4.3 Gauge Field Theory

(D.H. Tchrakian)

Research on gauge fields in all spacetime dimensions and their topologically stable solutions was carried out. This included both Abelian and non-Abelian gauge fields interacting with gravity, or Higgs fields, or various sigma model fields.

2.4.4 Yang–Mills–Higgs Systems in all Dimensions

(D.H. Tchrakian)

This is a long standing project. During 2009 detailed notes on the construction of monopoles on R^D for all D commenced. When completed, this will lead to the (previously studied) subject of gauged sigma models in arbitrary dimensions.

2.4.5 Skyrmion–anti-Skyrmion Solutions

(D.H. Tchrakian & Y. Shnir)

This was a project started the previous year in collaboration with Ya Shnir. It is now completed.

2.4.6 Gravitating Yang–Mills in all Dimensions

(D.H. Tchrakian & E. Radu)

This is a longstanding project. An up to date review of this subject was written in collaboration with E. Radu. This was mainly for systems with Minkowskian signature, but work on Euclidean signature also featured in this review.

2.4.7 Non-Abelian Chern-Simons Models with Gauge Group $SO(D+2)$ on R^D: Higgs Models

(D.H. Tchrakian, E. Radu & F. Navarro-Lerida)

Having completed the construction of $\mathrm{SU}(2)$ Chern–Simons–Higgs vortices in $2{+}1$ dimensions in collaboration with E. Radu and F. Navarro-Lerida, the case of Yang-Mills–Chern–Simons–Higgs vortices in $2+1$ dimensions, was pursued, in collaboration with F. Navarro-Lerida.

Naturally, the special case of Yang-Mills-Higgs vortices was studied, which can be applied to *dual confinement*, and also to *cosmic strings*. While these solutions are generically sphaleron like, *i.e.,* unstable, it is argued that for certain values of the Higgs coupling in the $O(3)$ sigma model limit, they are stable. This question of stability is under active discussion.

2.4.8 Non-Abelian Chern-Simons Models with Gauge Group $SO(D+2)$ on (t, R^D): Gravitating Models

(D.H. Tchrakian, E. Radu & Y. Brihaye)

Here the Chern–Simons term in $4p+1$ dimensions, plays the same role played by higher order Yang–Mills terms, enabling the construction of finite energy regular and black hole solutions. The $4+1$ case was studied intensively in collaboration with E. Radu and Y. Brihaye. Special attention was paid to the application to AdS/CFT correspondence. It is planned to extend this work to the $6+1$ dimensional case in collaboration with E. Radu and F. Navarro-Lerida.

2.4.9 Construction of Gravitating Yang–Mills-Higgs Solutions

(D.H. Tchrakian & P. Breitenlohner)

This is a longstanding project. It enables the description of a system featuring a Non-Abelian connection with nonvanishing electric component, without recourse to spaces with Minkowkian boundary. The $d=4p$ and $d=4p+2$ examples are analysed, and the next step is to proceed to the case of **odd** d. This project is ongoing, in collaboration with P. Breitenlohner.

2.4.10 Non-Abelian Chern–Simons– Higgs Theories in Even Dimensional Spacetimes

(D.H. Tchrakian)

This is a completely new approach to the construction of sphaleron like monopoles in the appropriate dimensions. It is still in the planning stage.

3 Publications

3.1 Papers in Refereed Journals

[1] T. C. Dorlas: Probabilistic derivation of a noncommutative version of Varadhan's theorem. *Proc. Royal Irish Acad.* **109 A** (2009) 1-18.

[2] T.C. Dorlas & C. Morgan: The classical capacity of quantum channels with memory. *Phys. Rev.* **A 79** (2009) 032320.

[3] N. Datta & T.C. Dorlas: Classical capacity of quantum channels with general Markovian correlated noise. *J. Stat. Phys.* **134** (2009) 1173-1195.

[4] T.C. Dorlas, A.M. Povolotsky & V.B. Priezzhev: From vicious walkers to TASEP. *J. Stat. Phys.* **135** (2009) 483-517.

[5] F. Garcia Flores, X. Martin & Denjoe O'Connor: Simulation of a scalar field on a fuzzy sphere. Intern. *J. Mod Phys.* **A 24** (2009) 3917.

[6] C. Nash & Denjoe O'Connor: The zero temperature phase diagram of the Kitaev model. *Phys. Rev. Lett.* **102** (2009) 147203.

[7] Denjoe O'Connor, J.A. Santiago & C.R. Stephens: An ab initio calculation of the universal equation of state for the $O(N)$ Model. *J. Phys.* **A 42** (2009) 045003.

[8] C. Nash & Denjoe O'Connor: Topological phase transitions and holonamies in the dimer model. *J. Phys.* **A 42** (2009) 012002.

[9] R. Delgadillo-Blando, D. O'Connor & B. Ydri: Matrix models, gauge theory and emergent geometry. *JHEP* **0905** 2009 049.

[10] R. Blumenhagen, V. Braun, T.W. Grimm & T. Weigand: GUTs in type IIB orientifold compactifications. *Nucl. Phys.* **B 815** (2009) 1-94.

[11] S. Cherkis, V. Dotsenko & C. Saemann: Superspace actions for multiple M2-Branes, metric 3-algebras and their classification. *Phys. Rev.* **D 79** (2009) 086002.

[12] V. Dotsenko: Parking functions and vertex operators. *Selecta Mathematica* **14** (2009) 229-245.

[13] V. Dotsenko: Compatible associative products and trees. *J. Algebra & Number Theory* **3** (2009) 567-586.

[14] F.A. Bais & J.K. Slingerland: Condensate induced transitions between topologically ordered phases. *Phys. Rev.* **B 79** (2009) 045316.

[15] L. Kampmeijer, J.K. Slingerland, B.J. Schroers & F.A. Bais: Magnetic charge lattices, moduli spaces and fusion rules. *Nucl. Phys.* **B 806** (2009) 386-435.

[16] G. Kells, J. K. Slingerland & J. Vala: A description of Kitaev's honeycomb model with Toric-code stabilizers. *Phys. Rev.* **B 80** (2009) 125415.

[17] Waheb Bishara, Parsa Bonderson, Chetan Nayak, Kirill Shtengel & J. K. Slingerland: The non-Abelian interferometer. *Phys. Rev.* **B 80** (2009) 155303. *Editors' Suggestion* featured in a viewpoint in *Physics* **2** (2009) 82.

[18] F.A. Bais, J.K. Slingerland & S.M. Haaker: A theory of topological edges and domain walls. *Phys. Rev. Lett.* (2009) 102:220403.

[19] L. Kampmeijer, F.A. Bais, B.J. Schroers & J.K. Slingerland: Towards a non-Abelian electric-magnetic symmetry: the skeleton group. *JHEP* **01** (2010) 095.

[20] G.K. Brennen, S. Iblisdir, J.K. Pachos & J.K. Slingerland: Non-locality of non-Abelian anyons. *New J. Phys.* **11** (2009) 103023.

[21] E. Akofor, A.P. Balachandran, L. Pekowsky, A. Joseph and B.A. Qureshi: Constraints from CMB on spacetime noncommutativity and causality violation. *Phys. Rev.* **D 79** (2009) 063004.

[22] B. Dolan & R. Szabo: Dimensional reduction, monopoles and dynamical symmetry breaking. *JHEP* **0903** (2009) 059.

[23] B. Dolan & R. Szabo: Dimensional reduction and vacuum structure of quiver gauge theory. *JHEP* **0908** (2009) 038.

[24] V.G. Filev: Hot defect superconformal field theory in an external magnetic field. *JHEP* **0911** (2009) 123.

[25] V.G. Filev, C.V. Johnson & J.P. Shock: Universal holographic chiral dynamics in an external magnetic field. *JHEP* **0908** (2009) 013.

[26] R. Manvelyan, E. Radu & D.H. Tchrakian: New AdS non Abelian black holes with superconducting horizons. *Phys. Lett.* **B 677** (2009) 79-87.

[27] F. Navarro-Lerida, E. Radu & D.H. Tchrakian: Non Abelian ChernSimons-Higgs solutions in $(2+1)$ dimensions. *Phys. Rev.* **D 79** (2009) 065036.

[28] P. Breitenlohner & D.H. Tchrakian: Gravitating BPS Monopoles in all $\mathrm{d}{=}4\mathrm{p}$ Spacetime Dimensions. *Class. Quant. Grav.* **26** (2009) 145008.

3.2 Papers in Conference Proceedings

[29] Denjoe O'Connor: Emergent geometry. *Oberwolfach Reports* **6 Report 41** (2009) 2312-2315.

[30] E. Radu & D.H. Tchrakian: Gravitating Yang-Mills fields in all dimensions. *Conference Models of Gravity in Higher Dimensions: From theory to experimental search, Bremen, Germany, 25-29 Aug 2008*.

3.3 Miscellaneous

[31] T. C. Dorlas: On global warming.

[32] T. C. Dorlas: Translation of "Zur Theorie der Metalle" by H. Bethe, *Zeit. f. Phys.* **71** (1931) 205-226.

3.4 Preprints

DIAS-STP

[09-01] B.P. Dolan & R.J. Szabo: Dimensional reduction, monopoles and dynamical symmetry breaking.

[09-02] P. Bonderson, A.E. Feiguin, G. Möller & J.K. Slingerland: Numerical evidence for a $px - ipy$ paired fractional quantum Hall state at $\nu = 12/5$.

[09-03] T. C. Dorlas & M. Samsonov: On the thermodynamic limit of the 6vertex model.

[09-04] W. Bishara, P. Bonderson, C. Nayak, K. Shtengel & J.K. Slingerland: The non-Abelian interferometer.

[09-05] G. Kells, J.K. Slingerland & J. Vala: A description of Kitaev's honeycomb model with Toric-code stabilizers.

[09-06] B. Dolan & R. Szabo: Dimensional reduction over CP^2 and vacuum states of equivariant gauge theory.

[09-07] V.G. Filev, C.V. Johnson & J.P. Shock: Universal holographic chiral dynamics in an external magnetic field.

[09-08] V. Braun: Three generations on the quintic quotient.

[09-09] V. Braun, P. Candelas & R. Davies: A three-generation Calabi-Yau manifold with small Hodge numbers.

[09-10] V.G. Filev: Hot defect superconformal field theory in an external magnetic field.

[09-11] B.P. Dolan: Chiral fermions and torsion in the early universe.

[09-12] B. Qureshi & A.P. Balachandran: Quasi-Hopf symmetries from twisted noncommutative gauge theories and non-associative spacetime algebra.

[09-13] V. Dotsenko: Freeness theorems for operads via Gröbner bases.

[09-14] V. Dotsenko & M. V. Johannson: Implementing Gröbner bases for operads.

[09-15] V. Dotsenko & A. Khoroshkin: Free resolutions via Gröbner bases.

[09-16] V. Dotsenko & A. Khoroshkin: Gröbner bases for operads.

[09-17] G. Kells, J.K. Slingerland & J. Vala: Exact results for the star lattice chiral spin liquid.

[09-18] S.A. Cherkis, V. Dotsenko & C. Saemann: Superspace actions for multiple M2-branes, metric 3algebras, and their classification.

[09-20] F. Garcia Flores, X. Martin & Denjoe O'Connor: Simulation of a scalar field on a fuzzy sphere.

4 Programme of Scholarly Events

4.1 Lectures Organised by the School

- I. Lyberg(Université Catholique de Louvain, Belgium) *Fisher zeros and Brascamp-Kunz boundary conditions*. 11 February
- F. Franchini (Abdus Salem ICTP, Trieste) *Entanglement entropy in the XY model*. 11 February

4.1.1 Seminars Organised by The Theoretical Particle Physics Group

- A. Alexandrov (IHES, Bures-sur-Yvette, France) *Decomposition formulas and Virasoro constraints in matrix models*. 28 May
- R. Auzzi (Swansea) *Non-Abelian k-vortex dynamics in $N=1^*$ theory and its gravity dual*. 30 April
- W. Bietenholz (ICN, UNAM, Mexico) *Cosmic rays and the search for a violation of Lorentz invariance*. 11 December
- N. Evans (University of Southampton) *Holographic QCD and hadronization*. 28 October.
- V. Filev *Holographic chiral dynamics in external fields*. 19 March
- K. Gupta (Saha Institute, Kolkata) *Noncommutative black holes and quantum structure of spacetime*. 1 December
- M. Headrick (Brandeis) *Calabi-Yau metrics for dummies*. 29 October
- M. Kaminski (Universidad Autonoma de Madrid) *Holographic superconductivity-spontaneous symmetry breaking in AdS/CFT*. 20 May
- A. Khoroshkin (ETH Zurich) *Cohomology of Lie algebras of vector fields and its applications*. 3 December
- G. Krishnaswami (Durham) *Possible large-N fixed points and naturalness for O(N) scalar fields*. 21 May
- N. Lambert (King's College London) *Lagrangians for multiple M2-branes*. 2 March
- R. Meyer (Max Planck Institut f-ur Physik, Munich) *A matrix model proposal for the Friedmann-Robertson-Walker universe*. 7 August
- C. Nunez (Swansea University) *Aspects of gauge-strings duality*. 29 January
- A. O'Bannon (Max Planck Institut f-ur Physik, Munich) *Adding flavor to AdS4/CFT3*. 6 October
- E. O Colgain (Korean Institute for Advanced Studies, Korea) *BPS D0-D6 branes in supergravity*. 23 July
- M. Panero (ETH Zurich, Switzerland) *Holographic predictions and lattice results for a hot, colorful plasma*. 10 December
- O. Rosten (Sussex University) *Wilsonian renormalization of noncommutative scalar field theory*. 23 April
- J. Shock (IGFAE, University of Santiago de Compostela, Spain) *Holographic spectral functions in metallic AdS/CFT*. 2 December
- S.H. Simon (Oxford) *Chainmail: the geometry of topological lattice models*. 24 September

4.2 Symposia, Conferences, Workshops organised

The fifth in the series of **John Lewis Lectures** were delivered by Professor Nicolai Reshetikhin (University of California, Berkeley/Amsterdam). The lecture series is jointly organised by the Dublin Institute for Advanced Studies and the Hamilton Mathematics Institute at Trinity College Dublin with generous donation from Raymond Russell and Corvil Networks. The following lectures were delivered:

- *Dimer models in statistical mechanics: exact solution and spin structures*. 13 May
- *The 6-vertex model in statistical mechanics: from ice to quantum groups*. 18 May
- *Dimer models and the 6-vertex model in the thermodynamic limit: the limit shape phenomenon*. 19 May

Advances in Theoretical Physics: a conference in honour of Professor Werner Nahm was held from 20-22 November. The conference was organised by D. O'Connor (DIAS), A. Jaffe (Harvard) and S. Shatashvili (TCD).

The following lectures were delivered.

- L. Faddeev *New variables for the Einstein theory of gravitation.*
- R. Blumenhagen *Conformal field theories and geometry.*
- K. Wendland *Encounters with conformal field theory.*
- P. van Moerbeke *Dyson's non-intersecting Brownian motions and critical diffusions.*
- J. Froehlich *Quantum Brownian motion.*
- F. Kelly *A joint project of the School of Celtic Studies and the School of Theoretical Physics: laser scanning the Ogam stones.*
- D. Zagier *Differential equations and modular forms.*
- S. Shatashvili *SUSY gauge theories and quantization of integrable systems.*

A Workshop on Noncommutativity and Matrix Models was held from 23-27 November. The following talks were delivered.

- O. Lechtenfeld *Noncommutative solitons.*
- A.P. Balachandran *Forbidden transitions vs noncommutative spacetimes.*
- H. Steinacker *Emergent gravity from matrix models.*
- E. Maurel-Segala *Combinatorics of diffusions on matrix groups.*
- P. Presnajder *Principal representations of $SU(2,2)$ and field theory.*
- R. Szabo *UV/IR duality in noncommutative quantum field theory.*
- H. Grosse *Progress in solving a non-commutative quantum field theory in 4D.*
- J. Hoppe *On the topology of non-commutative surfaces.*
- S. Vaidya *QFT of an accelerated observable in Moyal spacetime.*

Causets at DIAS II: a workshop on recent progress in the Causal Set Approach to Quantum Gravity was held from 14-18 December. The following talks were delivered.

- R. Sorkin *Progress and open problems in causal sets.*
- D. Benincasa *The scalar curvature of a causal set.*
- J. Henson *Winnowing wheat from chaff.*
- M. Delph *Horizon entropy in causal sets.*
- D. Rideout *Matter in sequential growth models.*
- M. Luczak *Order-invariant measures on causal sets.*
- G. Brightwell *The large-scale structure of classical sequential growth models.*
- F. Dowker *The Piombino interpretation of quantum mechanics.*
- F. Dowker *The Kochen-Specker theorem in quantum measure theory.*
- R. Sorkin *Quantum field theory on causal sets.*
- R. Sorkin *Quantum field theory on causal sets II.*
- S. Surya *Complex percolation and vector measures.*
- X. Martin *The quantum random walk.*

- P. Wallden *Structure of quantum measure theory.*
- D. Rideout *Hints of De Sitter space from transitive percolation.*

Statutory Public Lecture

The Statutory Public Lecture delivered by Dr. Peter Goddard, FRS, Director of the Institute for Advanced Study, Princeton, was hosted by Trinity College Dublin and was held on 21 November. The title was *There are no excuses in paradise: the past, present and future of institutes for advanced studies.*

5 Presentations at Conferences or Seminars

5.1 Talks and Papers Presented

W. Nahm:

- Talk "Q-hypergeometric functions in quantum field theory", MPI for Mathematics, Bonn, 28 May.
- Talk "The Solution of the Discrete Hi-rota Equation", MPI for Mathematics, Bonn, 20 August.

T.C. Dorlas:

- Colloquium talk "Quantum channels with long-term memory", Chalmers Institute of Technology, Sweden, 26 January.
- Seminar talk "Thermodynamic Bethe Ansatz for the nonlinear Schrödinger model", Chalmers Institute of Technology, Sweden, 28 January.
- Colloquium talk "Schrödinger's Oeuvre", DCU, 26 February.
- Talk "Large Deviations and the Bethe Ansatz", conference in honour of Prof. J. Pulé, "Quantum Mechanics and Randomness", UCD, 21 March.
- Two 2-hour expositions about "L'Ansatz de Bethe" at the Centre de Physique Théorique, Marseille, 22 & 29 May.
- Seminar "The spectrum of an exciton in a (one-dimensional) nanotube in the presence of an impurity", Université de la Méditerrannee, Marseille, 8 July.
- Talk "Sudden disappearance of entanglement: an example", satellite conference of the IAMP Congress, "Mathematical aspects of quantum transport and applications in nanophysics", Aalborg, Denmark, 10-12 August.
- Talk "Spectrum of two attracting particles on a line in the presence of a scattering centre", miniconference on "Spectral Theory", in honour of Prof. D. Gilbert, Dublin Institute of Technology, Kevin Street, 8 September.

Denjoe O'Connor:

- Talk "Emergent geometry", Universidad Complutense de Madrid, 17 June.
- Talk "Emergent geometry", Oberwolfach conference "Noncommutative Geometry", organised by Alain Connes, Joachim Cuntz and Marc A. Rieffel, 612 September.
- Talk "Emergent and evaporating geometry", Annual meeting Copenhagen, 28 September - 2 October.

P. Abramski:

- Talk "Explicit formula for the wave function of the system of 3 and n delta-interacting particles in one dimension", Kevin Street, Dublin Institute of Technology, 20 May.

V. Braun:

- Talk "Numerical investigations into Calabi-Yau compactifications" at Workshop on "Kahler Geometry and Extremal Metrics", Simons Center for Geometry and Physics, Stony Brook, New York, 18-25 January.
- Talk "Numerical investigations into Calabi-Yau compactifications" at "GUT Workshop", DESY Hamburg, Germany, 3-5 February.
- Seminar Talk "Numerical investigations into Calabi-Yau compactifications", University of Edinburgh, UK, 16-17 February.
- Seminar Talk "Computing Hermitian Yang-Mills connections", Oxford University, UK, 27 February - 3 March.
- Seminar Talk "Calabi-Yau groups", Oxford University, UK, 27 February 3 March.

- Seminar Talk "Computing Hermitian Yang-Mills connections", Cambridge University, UK, 3-5 March.
- Seminar Talk "Computing Hermitian Yang-Mills connections", CERN, Geneva, Switzerland, 9-12 March.
- Talk "Calabi-Yau groups" at "Irish QFT Meeting", Dublin, 16 May.
- Talk "Computer-aided Heterotic strings" at "(0,2) Workshop", Max Planck Institute, Potsdam, Germany, 16-21 August.
- Seminar Talk "Computing Heterotic string compactifications", Cardiff, 22 October.
- Seminar Talk "Computing Heterotic string compactifications", Swansea, 23 October.

B. Dolan:

- Talk "Introduction to differential forms and the Cartan formulation of general relativity", Perimeter Institute, Waterloo, Canada, 10 June.
- Talk "Equivariant dimensional reduction and quiver gauge theories", Perimeter Institute, Waterloo, Canada, 10 July.
- Talk "Equivariant dimensional reduction and quiver gauge theories", Department of Physics, University of Winnipeg, 20 July.
- Talk "Equivariant dimensional reduction and quiver gauge theories", 2nd School and Workshop on "Quantum Gravity and Quantum Geometry", 17 September.
- Talk "Duality and its uses in quantum field theory", National Taiwan University, Taipei, Taiwan, 26 October.
- Talk "Duality in the quantum Hall effect", National Tsing Hua University, Hsinchu, Taiwan, 27 October.
- Talk "Duality in the quantum Hall effect", National Chung Hsing University, Taichung, Taiwan, 28 October.
- Talk "Monopoles and vortices – modular symmetry in SUSY QCD and in the quantum Hall effect", Department of Mathematics, University of Durham, England, 20 November.

V. Dotsenko:

- Talk "Gröbner bases for operads" was delivered at the following events:

  Conference "Operads 2009" CIRM Luminy, France, 28 April;

  Algebra seminar, University of Stockholm, Sweden, 20 May;

  International Conference on algebra and related topics, Guangzhou, China, 26 June;

  Algebra seminar, South China Normal University, China, 28 June;

  Workshop on algebra, combinatorics, and dynamics, Belfast, 19 August;

  Ukrainian Mathematical Congress, Kiev, Ukraine, 28 August.
- Talk "Parking functions and vertex operators" was delivered at the following events:

  Algebra seminar, University of Edinburgh, UK, 5 May;

  Geometry seminar, University of Manchester, UK, 7 May.

V. Filev:

- Talk "Holographic chiral dynamics in external fields" was delivered at the following locations:

  Max Plank Institute for Physics, Munich, March;

  Dublin Institute for Advanced Studies, March;

  University of Santiago de Compostela, March.
- Talk "Universal holographic chiral dynamics in external fields", Aspen Center for Physics, June.
- Poster presentation \Holographic flavour dynamics", RDS, Dublin, September.

C. Morgan:

- Talk "Classical capacity of two quantum channels with memory", National University of Singapore, 4-19 October.

J. Slingerland:

- Talk "Phase transitions and domain walls in $2+1$ dimensional topological field theory" at Mathematical Physics Seminar, School of Mathematics, Cardiff University, Wales, 12 February.
- Talk "Toward fusion rules for electric-magnetic charge sectors in non-Abelian gauge theory" at Theoretical Physics Seminar, Department of Physics, Swansea University, Wales, 13 February.
- Invited talk "Phase transitions and domain walls in $2+1$ dimensional topological field theory" at conference on "Modular Categories and Applications" Indiana University, Blooming-ton, Indiana, USA, 19-22 March.
- Invited talk "Toward fusion rules for electric-magnetic charge sectors in non-Abelian gauge theory" at Irish Quantum Field Theory meeting, Dublin, 15-16 May.
- Invited talk "Hierarchical Hall states for the second Landau level" at "Amsterdam Summer Workshop", Center for Mathematical Physics, Amsterdam, 6-11 July.
- Invited talk "Topological Bose condensation and fractional quantum Hall hierarchies" program on "Quantum Hall physics -Novel systems and applications" Nordita, Stockholm, 17 August -11 September.
- Invited talk "Hierarchical Hall states for the second Landau level" at "8th Symposium on Topological Quantum Computing" ETH, Zürich, Switzerland, 29-31 August.
- Talk "Anyonic interferometry: the current status" at Maynooth Workshop on "Quantum Information and
- Condensed Matter Physics" NUI Maynooth, 14-18 September.
- Talk "Anyons and topological quantum computation" at Physics seminar, University College Cork, 16 November.

O. Smits:

- Talk "Clustered states in the fractional quantum Hall effect" at "Low-D Quantum Condensed Matter 2009 workshop" University of Amsterdam, 6-11 July.
- Seminar "Tunneling in the fractional quantum hall effect" NUI, Maynooth, November.

6 Collaboration with the Wider Research Community

6.1 National

Lecture Courses, Conferences and Workshops

T.C. Dorlas:

- Co-organised a conference at UCD with Prof. Adrian Ottewill in honour of Prof. J. Pulé, 20-21 March entitled "Quantum Mechanics and Randomness".

Denjoe O'Connor:

- Organised Conference "Advances in Theoretical Physics", DIAS, 20-22 November.
- Organised a Workshop on "Recent Progress in the Causal Set Approach to Quantum Gravity", DIAS, 14-18 December.

V. Dotsenko:

- Course for undergraduates on *Linear Algebra*, Trinity College Dublin.

S. Kovacs:

- Course for undergraduates on *Classical Mechanics MA141*, Trinity College Dublin.
- Course for undergraduates on *Abstract Algebra MA114*, Trinity College Dublin.
- Course for undergraduates on *Classical Mechanics MA1241 & MA1242*, Trinity College Dublin.

Visiting Researchers from Irish Universities

- B. Dolan was on sabbatical from NUI Maynooth from 1-31 January.

Staff Acting as External Supervisors

Denjoe O'Connor:

- Ph.D. supervisor for Thomas Kaltenbrunner (NUI Maynooth).
- Ph.D. supervisor for Martin Vachovski (NUI Maynooth)

Staff Acting as External Examiners

J. Slingerland:

- Adjudication of a Ph.D. *candidate:* Leo Kampmeijer, *supervisor:* Prof. F.A. Bais, University of Amsterdam, The Netherlands, 27 February.

Speakers Sponsored at Outside Con-ferences/Meetings

- The School sponsored N. Berkovits (San Paulo State University) who delivered the Annual O'Raifeartaigh Lecture as part of the Sixteenth Irish Quantum Field Theory Meeting at Trinity College Dublin 15-16 May. Dr.Y-H. He (Oxford University) and Prof. U. Wolff (Humboldt University of Berlin) were also sponsored.

Research Associates

- AT&T: N. Duffeld
- BM Annaba University: B. Ydri
- DCU: E. Buffet, J. Burzlaff, E. O'Riordan
- DIT: D. Gilbert, M. Golden, B. Goldsmith, P Houston, E. Prodanov
- ICTP, TRIESTE: J. Chela-Flores
- IT, Athlone: M. Daly
- IT, CARLOW: D. O Sé
- IT, TALLAGHT: N. Gorman
- LUDWIG-MAXIMILIANS
- METEOROLOGICAL SERVICE: P. Lynch
- NUI, CORK: M. Vandyck
- NUI, GALWAY: J. Burns, M.P. Tuite
- NUI, MAYNOOTH: B. Dolan, D. Heffernan, C. Nash, A. O'Farrell, J. Slingerland, J. Vala, P. Watts
- OPEN UNIVERSITY: A.I. Solomon
- OXFORD UNIVERSITY: R.G. Flood
- TCD: P.S. Florides, J. Miller, D. Weaire
- UNIVERSITEIT LEIDEN: F. Freire
- UCD: A. Ottewill, J.V. Pulé, W. Sullivan
- UL: S. O'Brien
- University Warwick: N. O'Connell
- UNAFFILIATED: T. Garavaglia, M. Leitner, G.M. O'Brien, D. O Mathuna, J.A. Slevin, D.H. Tchrakian

6.2 International

Visiting Researchers

Prof. R.F. O'Connell, Louisiana State University, Baton Rouge, USA was on sabbatical in the School during part of the period 17 June to 7 August.

Short visits (up to one week):

- A. Alexandrov (Imperial College, London) 25 May -1 June
- R. Auzzi (Swansea University) 29 April -1 May
- V. Bergholm (Helsinki & Harvard University) 28 April -1 May
- W. Bietenholz (UNAM, Mexico City) 6-12 December
- D.E. Evans (University of Cardiff) 1923 November
- N. Evans (Univ. of Southampton) 2728 October
- D. Gaydashev (University of Bergen, Norway) 17-23 January
- T.R. Govindarajan (Institute of Mathematical Sciences, Chennai, India) 29 November - 5 December
- M. Headrick (Brandeis University, USA) 28-31 October
- M. Vejdemo Johansson (Stanford University, USA) 9-14 August
- M. Kaminski (IFT, UAM/CSIC, Madrid) 19-21 May
- A. Khoroshkin (ETH, Zurich) 30 November - 6 December
- Dr. Govind Krishnaswami (Durham University) 17-24 May
- N. Lambert (King's College London) 13 March
- I. Lyberg (University of Louvain, Belgium) 6-11 April

- R. Meyer (Max Planck Institute, Munich) 5-11 August
- C. Nunz (Swansea University) 29-30 January
- A. O'Bannon (Max Planck Institute, Munich) 4-7 October
- M. Panero (ETH, Zurich) 6-13 December
- O. Rosten (Sussex University) 23-25 April
- J. Shock (Santiago de Compostela, Spain) 2-6 December
- S.H. Simon (Oxford University & NUIM) 24 September
- A. Winter (University of Bristol) 27 April

Long visits:

- E. Colgin (Korean Institute of Advanced Study, Korea) 21-31 July
- K.S. Gupta (Saha Institute of Nuclear Physics, India) 15 November -5 December
- A. Povolotsky (Joint Institute for Nuclear Research, Dubna, Russia) 20 November -4 December
- N. Reshetikhin (University of California, Berkeley, USA) 12-20 May
- B. Ydri (Annaba Badji Mokhtar University Algeria) 5 March -2 April; 6 July -17 August

Research Visits by School Staff

W. Nahm:

- Scientific visit to Universit Lille 1, Lille, France, 3 July -2 August.
- Scientific visit to Max Planck Institute for Mathematics, Bonn, 3 August -1 September.

T.C. Dorlas:

- Research visit to Chalmers University, Göteborg, Sweden, 25-29 January.
- Research visits to the Centre de Physique Théorique in Marseille as "Enseignant invité", 25 March - 9 April; 20 May -3 June & 6-14 July.
- Visit to Brussels for discussion on European Grant Application, 16-18 April.
- Research visit to the Joint Institute of Nuclear Research, Dubna (Russia), 2128 June.
- Visit to Brussels for discussion on ESF Grant Proposal, 16-21 September.
- Visit to University of Gothenburg to finalise document for an ESF Grant Proposal, 9-12 October.

Denjoe O'Connor:

- Research visits to Universidad Carlos III de Madrid & Universidad Complutense de Madrid 16-20 June.

V. Braun:

- Research visits to University of Pennsylvania, 12-17 January, 26-31 January, 19-27 March, 19-28 June and 26 August -8 September.
- Visit to Oxford University, 27 February -3 March, 28 June -1 July.
- Visit to City University London, 28 June.
- Visit to Cardiff University, 19-23 October.
- Visit to Swansea University, 23 October.

B. Dolan:

- Research visit to Perimeter Institute, Waterloo, Canada under the PI Long-Term Visitor Programme, 1 February 31 July.
- Research visits to Taiwan National University, Taipei; National Tsing Hua University, Hsinchu and National Chung Hsing University, Taichung, 2630 October.

V. Dotsenko:

- Research visit to the University of Edinburgh, UK, 2-6 May.
- Research visit to University of Manchester, 7-8 May.
- Research visit to the University of Stockholm, Sweden, 15-24 May.

V. Filev:

- Visit to Univ. of Santiago de Compostela at Santiago de Compostela, 214 March.

- Visit to Max Planck Institute for Physics, Munich, 22-28 March.
- Visit to Aspen Center for Physics, Aspen, 24 May-15 June.

C. Morgan:

- Research visit to Centre for Quantum Technologies, National University of Singapore, 4-19 October.

B. Qureshi:

- Research visit to Departamento de Matematicas, Univ. Carlos III de Madrid, Madrid, 6-16 June.
- Visit to Erwin Schrödinger Institute, University of Vienna, 13-27 June.
- Visit to University of Vienna, Vienna, Austria, 20-28 June.
- Visit to Perimeter Institute, Waterloo, Canada, 3 September -3 October.
- Visit to Kavli Institute for Theoretical Physics, Univ. of California, Santa Barbara, 4-30 October.
- Visit to Syracuse University, Syracuse, USA, 31 October -9 November.

J. Slingerland:

- Visit to School of Mathematics, Cardiff University, Wales, UK, 12 February.
- Visit to Department of Physics, Swansea University, Wales, UK, 13 February.
- Visit to the Institute for Theoretical Physics, University of Amsterdam, Amsterdam, The Netherlands, 26 February -3 March.
- Visit to University College Cork, 16 November.

O. Smits:

- Visit to Shell Epicentre, Rijswijk, The Netherlands to receive Masters Student Award "Shell Theoretical Physics Stipends 2009" (Award Ceremony, 28 September.

T. Tchrakian:

- Visit to King's College, London, 23-26 November.

7 Participation in Outside Committees

W. Nahm:

- Evaluation of the International Max-Planck Research School "Mathematics in the Sciences", Leipzig, 8-10 January.
- Evaluation of The Institute for Studies in Theoretical Physics and Mathematics (IPM), Tehran, 13 April.
- Chair of the Interviewing Panel for the NUI Travelling Studentships 2009, 22 September.

T.C. Dorlas:

- Refereed a United States-Israel Binational Science Foundation grant application.

Denjoe O'Connor:

- Member of International Advisory board of the Central European Joint Programme of Doctoral studies in Theoretical Physics (http://umbriel.phy.hr/cejp/).

B. Dolan:

- Referee for proposal under the Netherlands Organisation for Scientific Research, Innovational Research Incentives Scheme (VENI) -2009 round.

8 Attendance at External Conferences, Workshops, Meetings and Lectures

8.1 Conferences/Workshops/Scientific Meetings Attended

W. Nahm:

- International Conference "Mock Theta Functions and Applications in Combinatorics, Algebraic Geometry and Mathematical Physics", Max Planck Institute for Mathematics, Bonn, 25-29 May.
- Meeting at Max Planck Institute for Mathematics, Bonn, 12-16 June.
- Meeting of the Energy Group of the German Physical Society in Bonn, 2223 October.

T.C. Dorlas:

- in honour of Prof. J. Pulé, on "Quantum Mechanics and Randomness", 20-21 March.
- Attended one day of the "Nobel Symposium on Quantum Computing and Information", Gothenburg, 25 May.
- Satellite conference of the IAMP Congress (Prague) on "Mathematical Aspects of Quantum Transport and Applications in Nanophysics", Aalborg, Denmark, 10-13 August.

Denjoe O'Connor:

- "Bayrischzell Workshop 2009", Munich, 15-18 May.
- Invited Speaker at "Conference on Noncommutative Geometry", Oberwolfach, Germany, 6-11 September.
- Midterm Review of the "EU Network on Noncommutative Geometry"& Conference " Non-commutative Geometry QSNG", University of Copenhagen, 27 September -2 October.
- Advances in Theoretical Physics, DIAS, 20-22 November.
- The Causal Set Approach to Quantum Gravity, DIAS, 14-18 December.

P. Abramski:

- Students Conference, Faculty of Science, Kevin Street, Dublin Institute of Technology, 20 May

V. Braun:

- Workshop on "Kahler Geometry and Extremal Metrics", Simons Center for Geometry and Physics, Stony Brook, New York, 18-25 January.
- "GUT Workshop", DESY Hamburg, Germany, 3-5 February.
- KITP Program "Fundamental Aspects of Superstring Theory", UCSB, Santa Barbara, USA, 31 March -1 May.
- "XVI Irish Quantum Field Theory Meeting", Dublin, 16 May.
- "String theory program", Benasque Center for Physics, 1-10 July.
- "(0,2) Workshop", Max Planck Institute, Potsdam,Germany, 16-21 August.

B. Dolan:

- Conference "Connections in Geometry and Physics", Perimeter Institute, Waterloo, Canada, 8-10 May.
- Conference "Effective Field Theories in Inflation", Perimeter Institute, Waterloo, Canada, 20-23 May.
- Conference "New Prospects for Solving the Cosmological Constant Problem", Perimeter Institute, Waterloo, Canada, 25-27 May.
- Conference "New Lights on Dark Matter", Perimeter Institute, Waterloo, Canada, 11-13 June.
- 2nd School and Workshop on "Quantum Gravity and Quantum Geometry", Corfu, 13-20 September.
- "Annual High Energy Theory Meeting", Durham, 17-19 December.

V. Dotsenko

- Conference "Quantization and Geometry", ETH, Zurich, 2-6 March.
- Workshop "Algebraic and Geometric Lie Theory", INI, Cambridge, UK, 2327 March.
- Conference "Operads 2009" at CIRM Luminy, France, 22-30 April.
- International Conference on "Algebra and Related Topics", South China Normal University, Guangzhou, China, 22-28 June.
- Workshop on "Algebra, Combinatorics and Dynamics", Queen's University, Belfast, 17-21 August.
- "Ukrainian Mathematical Congress", NASU Institute of Mathematics, Kiev, Ukraine, 26-30 August.

V. Filev

- Conference "Winter School on Super-gravity, Strings and Gauge Theories", CERN, Geneva, 8-13 February.
- Participate at AdS Collective at Univ. of Autonoma de Madrid, 16-18 February.

- "XVI Irish Quantum Field Theory Meeting", TCD, 15-16 May.
- Conference "String Duals of Finite Temperature & Low-Dimensional Systems", Aspen Center for Physics, Aspen, 24 May -15 June.
- Conference "XIV Itzykson Meeting on String Theory", Institut de Physique Théorique, Saclay, 16-22 June.
- 2009 IRCSET Symposium, Dublin, September.

A. Ghesquiére:

- "Quantum Mechanics and Randomness", a conference in honour of the 65th birthday of Professor J. Pulé, UCD, 20-21 March.
- Workshop "Quantum Information and Condensed Matter Physics", NUI Maynooth, 14-18 September.

T. Kaltenbrunner:

- Midterm Review of the "EU Network on Noncommutative Geometry"& Conference "Non-commutative Geometry QSNG", University of Copenhagen, 27 September -2 October.
- Workshop "Noncommutativity and Matrix Models", DIAS, 23-27 November.
- Workshop "Recent Progress in the Causal Set Approach to Quantum Gravity", DIAS, 14-18 December.

S. Kovacs:

- "XVI Irish Quantum Field Theory Meeting", Trinity College Dublin, 1516 May.
- Conference "Geometry and Physics: James MacCullagh, Life and Achievements", Royal Irish Academy, 14 May.
- Conference "Strings 2009", Rome, Italy, 22-26 June.

I. Lyberg

- Conference "XVI International Congress of Mathematical Physics", Prague, 3-8 August.

C. Morgan:

- Workshop "Operator Structures in Quantum Information", Fields Institute, Toronto, Canada, 6-10 July.

B. Qureshi:

- International Meeting on "High Energy Physics", Zaragoza, Spain, 7-12 June.
- Conference "XIV Itzykson Meeting on String Theory", Institut de Physique Théorique, Saclay, 17-19 June.
- Conference "Integrability in Gauge & String Theory", Max Planck Institut, Albert Einstein Insitut, Potsdam, Germany, 28 June -5 July.
- Conference "New Perspective on the Quantum State", Perimeter Institute, Waterloo, Canada, 27 September - 2 October.

J. Slingerland:

- Conference "Modular Categories and Applications", Indiana University, Bloomington, Indiana, USA, 19-22 March.
- "Seventh Mini-Symposium on TQC", Institut Henry Poincare (IHP), Paris, France, 30 March -1 April.
- XVI Irish Quantum Field Theory Meeting, TCD, 15-16 May.
- "Station Q Summer Meeting", Microsoft Station Q, University of California Santa Barbara, USA, 19-21 June.
- "Amsterdam Summer Workshop", Center for Mathematical Physics, Amsterdam, 6-11 July.
- Program on "Quantum Hall physics -Novel systems and applications", Nordita, Stockholm 17 August - 11 September.
- "8th Symposium on Topological Quantum Computing", ETH, Zürich, Switzerland, 29-31 August.
- "Maynooth Workshop on Quantum Information and Condensed Matter Physics", NUI Maynooth, 14-18 September.

O. Smits

- Amsterdam Summer Workshop "Low-D Quantum Condensed Matter 2009", Institute for Theoretical Physics, Univ. of Amsterdam, 6-11 July.
- "Sixth Mini-Symposium on Topological Quantum Computation", NUI Maynooth, 14-19 September.

M. Vachovski:

- Midterm Review of the "EU Network on Noncommutative Geometry"& Conference "Non-commutative Geometry QSNG", University of Copenhagen, 27 September -2 October.
- Workshop "Noncommutativity and Matrix Models", DIAS, 23-27 November.
- Workshop "Recent Progress in the Causal Set Approach to Quantum Gravity", DIAS, 14-18 December.

8.2 Lectures and Organisational Meetings Attended

T.C. Dorlas:

- John Lewis Lecture Series given by Professor Nicolai Reshetikhin (Berkeley/Amsterdam) 13, 18 & 19 May.
- Statutory Public Lecture by Professor Peter Goddard, director of the Princeton Institute for Advanced Study, RDS, 21 November.

I. Lyberg:

- Participated in weekly seminar organised by T.C. Dorlas & J. Pulé.

9 Research Grants/External Funds Secured

Denjoe O'Connor:

- 2007-2011: Node of Marie Curie Research Training Network €233,652.73.
- 2007-2009: An Embark Initiative Postdoctoral Fellowship to Babar Qureshi funded by IRCSET for a period of two years with effect from 1 December 2007.
- 2008-2010: An Embark Initative Postdoctoral Fellowship to Veselin Filev funded by IRCSET for a period of two years with effect from 1 October 2008.
- 2008-2010: An Embark Initative Postdoctoral Fellowship to Vladimir Dotsenko funded by IRCSET for a period of two years with effect from 1 October 2008.
- 2009-2011: Marie Curie Early Stage Research Fellowship to T. Kaltenbrunner, MRTN-CT-2006-031962
- 2009-2011: Marie Curie Early Stage Research Fellowship to M. Vachovski, MRTN-CT-2006-031962

V. Braun:

- ICHEC project "A Prelude to Numerical Calabi-Yau Geometry" (class C) was approved.

10 Honours/Awards/Special Achievements Received

O. Smits:

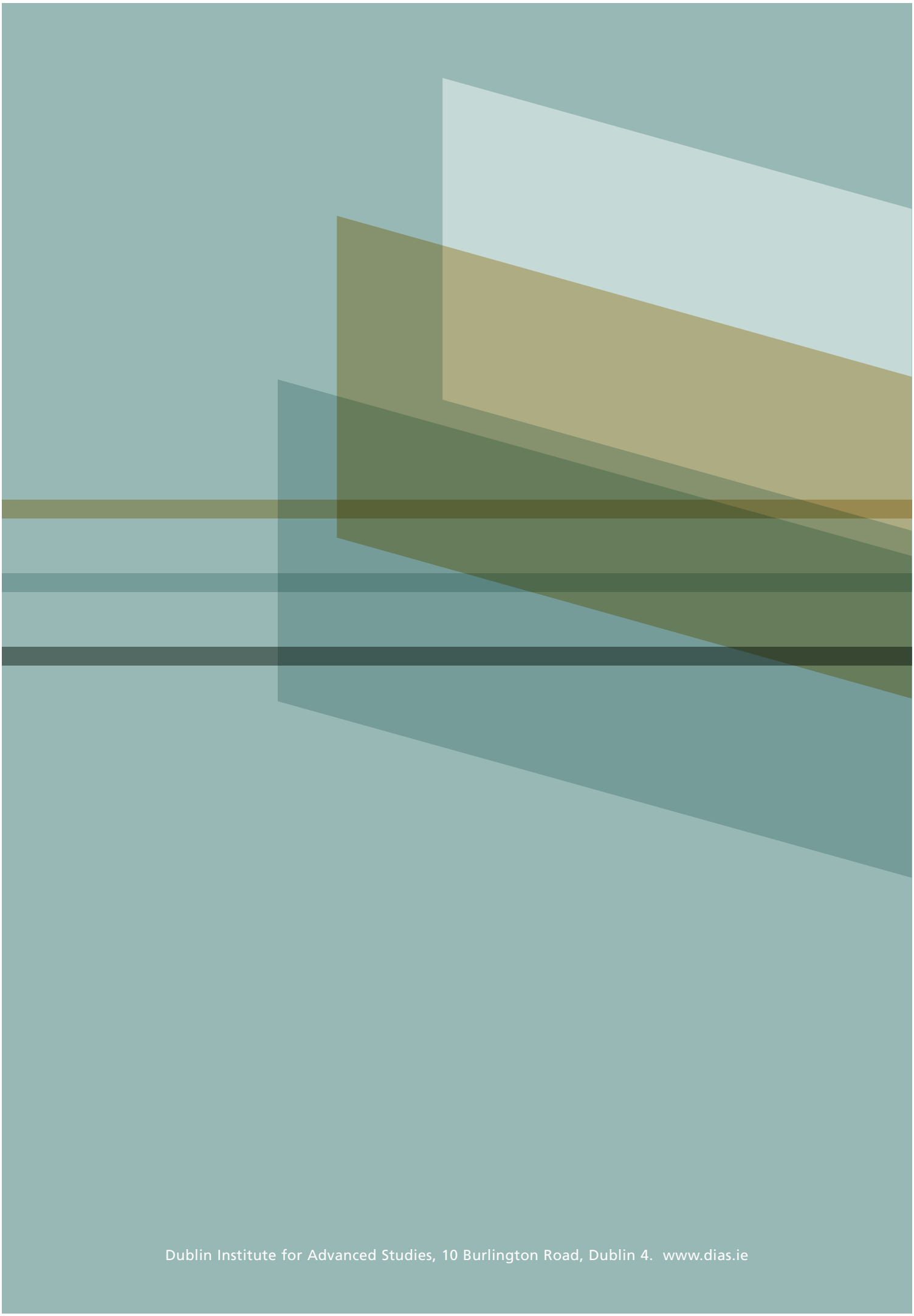
- **Shell Stipend** *Exceptional Master Student in Theoretical Physics 2008-2009*. Awarded annually to master students in theoretical physics graduated at a Dutch university. (€2,000)

11 Public Awareness Activities

11.1 Public Lectures

T.C. Dorlas:

- Talk "Global Warming", UCD Mathematics (Student) Society, 24 September.
- Popular talk "Quantum Computing", computing seminar of the Institute of Technology Tallaght, 26 November.



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