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Theoretical Nuclear Structure and Astrophysics

A Progress Report for 1996

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This document is a progress report concerning the research carried out under U. S. Department of Energy Contract No. DE–FG02–96ER40963 with the University of Tennessee entitled *Theoretical Nuclear Structure and Astrophysics.* Period: Jan. 15, 1996–Jan. 14, 1997; Principal Investigators: M. W. Guidry, W. Nazarewicz, and M. R. Strayer; Co-Investigator: A. Mezzacappa.

1 Introduction

Our effort is directed toward theoretical support and guidance for the fields of radioactive ion beam physics, gamma ray spectroscopy, computational and nuclear astrophysics, and the interface between these disciplines. We shall report substantial progress in all those areas. One measure of progress is publications and invited material. The research described here has led to more than 43 papers that are published, accepted, or submitted to refereed journals, and to 15 invited presentations at conferences and workshops.

Research has been carried out by principal investigators M. W. Guidry, W. Nazarewicz, and M. R. Strayer, co-principal investigator and research assistant professor A. Mezzacappa, postdoctoral fellows W. Satuła and Y. Sun, 5 graduate students, and a variety of visitors. The research program that we summarize is highly leveraged. Our effort profits immensely from our strong overlap with the Theoretical and Computational Physics Section of the Oak Ridge National Laboratory, and from collaborations with long and short-term visitors sponsored by the Joint Institute for Heavy Ion Research (JIHIR) and the Science Alliance of the University of Tennessee.

DISCLAIMER

2 Nuclear Structure Physics

A major component of our research lies in nuclear structure physics. This nuclear structure research has two central themes: (1) Support of the fields of radioactive ion beam physics and gamma ray spectroscopy with both established and new theoretical frameworks, and (2) The introduction into nuclear structure physics of new algorithms and state-of-the-art computational methods. These efforts may be broken approximately into two general categories: (1) *Mean Field Methods* that emphasize the roles of (deformed) mean fields with an average description of pairing, and (2) Methods that seek to go beyond the mean field by incorporating the effect of one and two-body residual interactions (*Shell Model Methods*).

2.1 Mean-Field Methods

Our main effort in this area is directed toward theoretical support and guidance for the developing field of radioactive ion beam (RIB) physics. Many projects involve questions of low- and high-spin spectroscopy, often detailed, and often in intimate collaboration with experimental groups (including ORNL, ANL, LBNL, LLNL, Eurogam, and Gammasphere).

2.1.1 Nuclei Far from Stability and Radioactive Ion Beam Physics

The advent of radioactive nuclear beams provides many exciting opportunities to create and study unstable nuclei far from the β stability valley. Below are listed our major accomplishments in this area in 1996.

1. Ground-state properties of exotic even-even nuclei with extreme neutron-to-proton ratios were described in the framework of the self-consistent mean-field theory with pairing formulated in coordinate space. This theory properly accounts for the influence of the particle continuum, which is particularly important for weakly bound systems. The pairing properties of nuclei far from stability are studied with several interactions emphasizing different aspects, such as the range and density dependence of the effective interaction. Measurable consequences of spatially extended pairing fields are presented, and the sensitivity of the theoretical predictions to model details were discussed. **Paper 5.2.10.**

2. The isospin structure of the density matrices and self-consistent mean fields was discussed in the Hartree-Fock-Bogoliubov theory assuming the time reversal invariance. This theory allows for a consistent microscopic description of pairing correlations in all isospin channels. The resulting HFB equations have interesting properties. For spherical nuclei only the ($T = 1$, $J = 0$) nucleonic pairs are allowed (the presence of the (T=0, $J \neq 0$) pairs would necessary lead to deformed mean fields). **E. Perlińska et al., in preparation; Proc. Int. Conf. Hirschegg '96, p. 228.**

3. Deformation properties of weakly-bound nuclei were discussed in the deformed single-particle model. It has been demonstrated that in the limit of a very small binding energy the valence particles in specific orbitals, characterized by very small projection of single-particle angular momentum onto the symmetry axis of a nucleus, can give rise

to the halo structure which is completely decoupled from the rest of the system. The quadrupole deformation of the resulting halo is completely determined by the intrinsic structure of a weakly bound orbital, irrespective of the shape of the core. This work constitutes the Ph.D. Thesis of Toshiyuki Misu. **Paper 5.3.15.**

4. Properties of proton-rich nuclei around doubly magic ${}^{48}_{28}\mathrm{Ni}_{20}$ were studied in the framework of the self-consistent mean-field theory. Various effective interactions were employed to investigate two-proton separation energies, deformations, single-particle levels, proton average potentials, and diproton partial decay half-lives in this mass region. An overall agreement with experimental data and shell model calculations for S_{2p} in the *sdf* region is satisfactory. In particular, the mean-field calculations systematically predict the two-proton drip line to lie between ^{42}Cr and ^{44}Cr, ^{44}Fe and ^{46}Fe, and ^{48}Ni and ^{50}Ni. Self-consistent Coulomb energies, taking into account the Thomas-Ehrman shift, allowed us to estimate the single-particle levels around the unbound doubly magic nucleus ^{48}Ni. According to our study, diproton emission half-lives depend mainly on the two-proton separation energy and very weakly on the intrinsic structure of diproton emitters. **Paper 5.2.2.**

5. We have examined the systematic predictions for proton and neutron radii in even-even nuclei made by the self-consistent Skyrme-Hartree-Fock-Bogoliubov theory. Such an approach allows us to describe nuclei far from stability, where the spatial extensions of a nuclear system crucially depend on the continuum effects. The influence of spherical shell structure on global behavior of radii, and the (N,Z)-localization of neutron and proton skins were discussed. **Paper 5.2.5.**

6. Masses, deformations, radii, two-neutron separation energies, and single-particle properties of Si, S, Ar, and Ca isotopes have been investigated in the framework of the self-consistent mean-field theory. The microscopic structure of these nuclei is of particular interest for astrophysics: the neutron-rich $N\approx28$ nuclei play an important role in the nucleosynthesis of the heavy Ca-Ti-Cr isotopes. The calculations confirm strong deformation effects for $N\approx28$ isotones. Based on our prediction, the existence of the deformed "island of inversion" around ^{44}S has recently been confirmed experimentally by the relativistic Coulomb excitation experiments carried by the MSU group. Our results also suggest a possibility of large isovector-deformation effects for exotic nuclei, in particular those close to the neutron drip line. **Paper 5.2.6.**

7. A cranked mean-field model with two-body $T=1$ and $T=0$ pairing interactions has been presented. Our calculations suggest the simultaneous presence of both $T=0$ and $T=1$ pairing modes in $N=Z$ nuclei. The transitions between different pairing phases are discussed as a function of neutron/proton excess, T_z, and rotational frequency, $\hbar\omega$. The additional binding energy due to the $T=0$ *np*-pairing correlations, is suggested as a possible microscopic explanation of the Wigner energy term in even-even nuclei. **Paper 5.2.23.**

2.1.2 Properties of the Superheavy Elements

We have applied the Harteree-Fock (HF) method with two different Skyrme interactions, SkP and SLy7, and the macroscopic-microscopic approach, to the study of superheavy elements (SHE) with $108 \leq Z \leq 128$ and $150 \leq N \leq 192$. The overall agreement with existing experimental data for the heaviest known elements is satisfactory. In particular, the HF calculations predict the increased stability due to the deformed shell effect at N=162. However, the self-consistent and macroscopic-microscopic approaches give different results when extrapolated to still heavier elements. The fact that the former methods treat correctly the interplay between the nuclear and Coulomb properties, which is crucial for the physics of SHEs, gives us more confidence in self-consistent results. Predictions have been made for binding energies, shell energies, deformations, reaction energies, and half-lives. In general, both SkP and SLy7 Skyrme parametrizations give similar results.

According to our study, the doubly-magic superheavy element is that with Z=126 and N=184. This system is unstable with respect to the β^+/EC, proton, and α decays, and it fissions. However, its half-life is governed by the α-decay ($T_\alpha < 1\ \mu$s). The alleged magic gap at Z=114 does not show up in our HF calculations. Its presence in the models, based on the macroscopic-microscopic approach, is due to the lack of a self-consistent treatment of surface properties (in particular: proton diffuseness). In the self-consistent theory we obtain an increased shell stability of spherical nuclei with $N \approx 184$ and $Z > 114$, which gives rise to increased α-decay half-lives and opens up a possibility to access experimentally new higher-Z superheavy elements. **Paper 5.2.22.**

2.1.3 High Spins

A significant part of our effort has concentrated on the theoretical description of high-spin states. We have used a wide variety of methods ranging from shell correction approach to cranked self-consistent Hartree-Fock-Bogolyubov method.

1. The phenomenon of identical bands was studied by analyzing the distributions of fractional changes in the dynamical moments of inertia of pairs of bands in superdeformed (SD) nuclei. These distributions are found to have nearly Gaussian shapes with a centroid of nearly zero. Their widths increase in going from SD bands in the mass A$\sim$150, to SD bands in the mass $\sim$190, and to normally-deformed bands in the rare-earth region. Consequently, there exists a significant excess of identical bands in SD nuclei compared to normally-deformed nuclei at low spins. This is attributed to the weaker pairing correlations and the stabilizing role of intruder orbitals on the structures of SD bands. **Paper 5.2.4.**

2. Influence of the quadrupole and hexadecapole residual interactions on rotational bands was investigated in a single-j shell model. An exact shell-model diagonalization of the quadrupole-plus-hexadecapole Hamiltonian demonstrates that the hexadecapole-hexadecapole interaction can sometimes produce a staggering of energy levels in the yrast sequence, however, long and regular ΔI=2 sequences are not obtained. This negative result suggests that the experimental data cannot probably be explained in terms of the coupling between rotation and hexadecapole vibrations. The shell-model

results are discussed in terms of the intrinsic deformations extracted by means of the self-consistent Hartree-Fock method. **Paper 5.3.17.**

3. Quadrupole and hexadecapole moments of SD bands in the $A\sim150$ mass region have been analyzed in the cranking Skyrme-Hartree-Fock model. It is demonstrated that, independently of the intrinsic configuration and of the proton and neutron numbers, the charge moments calculated with respect to the doubly-magic superdeformed core of ^{152}Dy can be expressed very precisely in terms of independent contributions from the individual hole and particle orbitals. The relative quadrupole moments calculated with respect to the ^{152}Dy SD core follow experimental trends rather well, and they are rather strong indicators of underlying intrinsic configurations. Our results, together with the previous systematics of experimental moments of inertia, strongly suggest that the SD high-spin bands around ^{152}Dy are excellent examples of an almost undisturbed single-particle motion. **Paper 5.3.14.**

4. Shapes and high spin properties of nuclei from the neutron-rich ($N>56$) zirconium region have been calculated using the Nilsson-Strutinsky method with the cranked Woods-Saxon average potential and pairing. The shape coexistence effects and the competition between rotationally-aligned neutron and proton bands is discussed. Predictions were made for the low-lying superdeformed bands in this mass region characterized by the intruder states form the $\mathcal{N}=5$ and 6 oscillator shells. **S. Mizutori et al., in preparation.**

2.1.4 Other Nuclear Structure

1. The experimental and theoretical evidence for intrinsic reflection asymmetric shapes in nuclei has been reviewed. The theoretical methods discussed cover a wide spectrum of techniques based on the mean field theory and its extensions as well as algebraic and cluster approaches. The experimental data for nuclear ground states and at low and high spin, cited as evidence for reflection asymmetry, are collected here and categorized. The extensive data on electric dipole transition moments and their theoretical interpretation are surveyed, as well as available data on electric octupole moments. The evidence for reflection-asymmetric molecular states in light nuclei is summarized. The application of reflection asymmetric theories to descriptions of the fission barrier, bimodal fission, superdeformation, and hyperdeformations is reviewed, and some other perspectives in the wider context of nuclear physics are also given. **Paper 5.1.3.**

2. We have investigated the pairing treatment with approximate particle-number projection in connection with nuclear Hartree-Fock models. A prescription for the pairing strength has been developed. It is based on the average gap method and employs a Thomas-Fermi model to estimate the average level density at the Fermi surface. The second-order variance of the particle-number gives a feedback to the self-consistent density and thus to the mean field. This effect turns out to be small but non-negligible. Pronounced effects on deformation energy surfaces were found, leading to sizeable differences in the deformation energies. **Paper 5.2.9.**

3. From γ-ray coincidence studies following spontaneous fission of ^{252}Cf, direct measurements of yields and neutron multiplicities were made for Sr-Nd, Zr-Ce, Mo-Ba, Ru-Xe, and Pd-Te correlated pairs. Mean field calculations predict a hyperdeformed third minimum in the PES for ^{252}Cf involving the ^{142}Ba cluster, and extremely deformed ^{146}Ba fragment in the asymmetric fission channel of ^{252}Cf. **Paper 5.2.11.**

4. The particle-plus-rotor model has been employed to study the fine structure seen in the α decay of even-even neutron-deficient nuclei in the Hg-Po region. The configuration mixing resulting from the shape coexistence between well-deformed prolate bands and spherical (or quasi-rotational oblate) structures in the daughter nuclei was considered. The experimental α decay branching ratio are reproduced within one order of magnitude. **Paper 5.3.16.**

2.2 Shell Model Approaches

Our program emphasizes 3 categories of shell model research: (1) Traditional large-scale shell models (and Monte Carlo shell model approaches that replace the shell model diagonalization by Monte Carlo path integral evaluations); (2) Projected shell models that use projection techniques applied to mean fields to produce a truncated basis for laboratory-frame diagonalization of shell model effective interactions; (3) Symmetry-dictated truncations that use principles of dynamical symmetry to select highly truncated shell model spaces for diagonalization of an effective interaction.

2.2.1 Large-Scale Shell Model

We have performed an extensive series of calculations that apply the shell model technique to a variety of physical problems:

1. The positive-parity bands in odd-A nuclei around ^{45}Sc are among the most spectacular examples of shape coexistence in atomic nuclei. The collectivity of those bands can be primarily attributed to the number of valence proton and neutron pairs in the fp shell. Large-scale, M-scheme calculations have been remarkably successful in reproducing on the same footing *both* nearly-spherical negative-parity ($0\hbar\omega$) states and collective positive-parity ($1\hbar\omega$) structures in ^{45}Sc and ^{45}Ti. The shell model calculations were supplemented by the cranked mean-field calculations which describe intruder states in terms of the cross-shell particle-hole excitation associated with a strong quadrupole core-polarization. **Papers 5.2.8. and 5.3.13.**

2. We have performed systematic analysis of the Wigner energy in nuclei close to the $N=Z$ line. The experimental systematics in the sd and fp regions are interpreted using the large-scale shell model. **J. Gary et al., in preparation.**

3. We have continued collaboration with D. Dean and CalTech group in applications of Monte Carlo Shell Model to various aspects of nuclear structure. Two examples are: (i) Description of rotational bands in the rare earth nuclei, and (ii) Calculations of ground-state properties of the $A\approx80$ nuclei.

2.2.2 Projected Shell Model

The Projected Shell Model (PSM) is an extension of the traditional shell-model that implements the shell model truncation in a deformed quasiparticle basis. Thus, correlations important in a deformed and superfluid system can be taken into account within a manageable configuration space. We have intitiated an extensive series of calculations that apply the PSM technique to a variety of physical problems:

1. We have shown that the PSM reproduces moments of inertia in normally-deformed rare-earth nuclei exhibiting identical bands. This suggests strongly that the inclusion of correlations beyond the mean field is necessary to understand the phenomenon of identical bands. **Paper 5.2.13.**

2. We have shown that the PSM gives a quantitative description of even and odd-mass superdeformed moments of inertia in the mass-130 region using parameters obtained by a prescription analogous to that employed for normally deformed nuclei in this region. Thus, we have strong preliminary evidence that the PSM can give a unified description of even and odd mass superdeformed nuclei in a theory that conserves angular momentum. **Paper 5.3.4.**

3. We have shown that $\Delta I = 4$ bifurcation occurs in the PSM as a consequence of interferences in the rotation from intrinsic to lab frames, without the explicit introduction of terms in the Hamiltonian having C_4 symmetry or I^4 terms. Thus, we have provided the first candidate microscopic theory for this phenomenon. We have argued that the mechanism we have proposed for $\Delta I = 4$ bifurcation should also occur in normally deformed nuclei, and have presented a series of calculations and pedagogical arguments suggesting likely candidates for observation of such bifurcations in normally deformed nuclei. **Papers 5.2.19. and 5.2.20.**

4. We have shown that the PSM is capable of correctly predicting the spins of superdeformed bands where the decay-out transitions have been measured so that the spins are known. Of 6 reported cases, we have correctly predicted the spin of 5, and missed the 6th by one unit, with no adjustment of parameters specifically for spin predictions. **Paper 5.3.3.**

5. We have initiated a series of calculations in collaboration with J. Hirsch to see whether the PSM can be applied to the double beta-decay problem in deformed nuclei.

2.2.3 Symmetry-Truncated Shell Models

Several important results have emerged concerning the Fermion Dynamical Symmetry Model (FDSM) and related symmetry-dictated shell model truncations:

1. A major review on numerical applications of the truncated shell model methods inspired by the FDSM has been published. The McGraw-Hill Encyclopedia of Science and Technology 1996 Yearbook has published an article on dynamical symmetries in nuclear structure. **Papers 5.1.1. and 5.2.15.**

2. We have demonstrated that the systematics of the even platinum isotopes can be described by numerical FDSM calculations that do not assume a particular dynamical symmetry, and that this description produces a quantitative agreement with the data using a simpler Hamiltonian than is required in IBM-2 (no Majorana term is required). **Paper 5.3.2.**

3. We have argued that the recently observed isotopes of Z=110-111 may actually represent the original island of superheavy nuclei, but shifted to much lower neutron number by microscopic shell model effects not incorporated in standard shell model calculations. **Paper 5.2.21.**

4. We have published a systematic series of calculations in the mass-130 region suggesing that the FDSM gives a unified description of even and odd nuclei that is comparable in quality to IBM and Nuclear Supersymmetry calculations, but with fewer parameters and a firm microscopic basis. **Paper 5.3.4.**

3 Computational and Nuclear Astrophysics

We have inititated a major research effort in computational and nuclear astrophysics. This effort is presently concentrated in two major areas: (1) the production of proton-rich elements in nova outbursts by the rapid proton capture process, and (2) the core-collapse supernova mechanism. These are of fundamental importance in astrophysics, but they also relate to our present and future nuclear structure interests: The former is of direct relevance to the elements to be studied in the new RIB facility at Oak Ridge; the latter to elements that might be produced in a future IsoSpin Laboratory. Below listed are our main accomplishments in computational and nuclear astrophysics.

1. We continue the development of several new computer codes that will simulate element production in a variety of astrophysical settings, including novae and supernovae. All approaches are being developed to allow direct, modular coupling to hydrodynamics. These codes will be able to simulate the hot-CNO cycle and p-, r-, and rp-process nucleosynthesis, which are of strong interest to the radioactive ion beam project at ORNL. One method uses fully implicit finite differencing to guarantee stability for the stiff system of rate equations. Moreover, no approximation in the rate equations are made in order to linearize the nonlinear finite-differenced rate equations; the full nonlinearity is treated by linearizing via a Newton-Raphson algorithm. Another method uses Monte Carlo methods to evolve the abundances. Preliminary sensitivity and Monte Carlo analyses have been carried out with these codes to consider the astrophysical implications of reaction rate measurements at RIB. The network codes will be used after this to study the nova ignition mechanism. This will be done in conjunction with the codes for one- and two-dimensional hydrodynamics that are being used by our group to simulate core collapse supernovae, as described below.

2. We have modified the Piecewise Parabolic Method hydrodynamics code VH–1 to accept the general equations of state in multidimensional hydrodynamics simulations of

supernovae. Previous versions of the code were able to simulate only constant gamma, gamma-law equations of state, which is insufficient to consider core collapse supernova matter, whose thermodynamic state is described by an elaborate equation of state for nuclei, nucleons, the transition to incompressible nuclear matter, relativistic electrons of arbitrary degeneracy, etc. EVH–1 has been used in a series of 2-dimensional core collapse supernova simulations that are described in the next several items. The code is a new and important tool in multidimensional computational astrophysics research.

3. We have shown that "prompt convection" is wiped out in fractions of a millisecond by sufficiently realistic neutrino transport. This is a dramatic and new effect. Our numerical results, which were obtained with 2-dimensional PPM hydrodynamics coupled to 1-dimensional MGFLD neutrino transport, are supported by timescale analyses and by an analytical model we have developed. Specifically, we have demonstrated that neutrino transport reduces the prompt convection growth rate and the asymptotic convection velocities by a factor of 4 at 10^{11} g/cm^3 and 250 at 10^{12} g/cm^3. The net result is no evidence of significant outward convective transport of entropy and leptons relative to the bulk inflow of matter. We conclude with this compelling evidence that prompt convection plays no central role in the supernova mechanism. **Papers 5.3.6, 5.3.7.**

4. With MGFLD neutrino transport and 2-dimensional PPM hydrodynamics, we have shown that "neutrino-driven convection" does not yield explosions in the Newtonian limit for what should be an optimistic 15 $M_\odot$ model. Our initial conditions for post-bounce convection and evolution are obtained from core collapse and bounce simulations that implement MGFLD. Because of our detailed treatment of neutrino transport during core collapse and bounce, our shock stalls catastrophically at a deeper point in the gravitational field. As a result, our initial conditions for prompt and neutrino-driven convection are pessimistic. Moreover, our neutrino luminosities, mean square energies (neutrino spectra), and inverse flux factors (a measure of the anisotropy in the neutrino radiation fields), all of which enter the neutrino heating rate behind the shock and all of which are computed using MGFLD neutrino transport, define a heating rate that remains too low to generate explosion. General relativity and more massive stars with fatter iron cores will be even more pessimistic cases. **Papers 5.3.8, 5.3.9**

5. The work described in the preceding two items gives very strong evidence that the key to the supernova mechanism lies not in convective multidimensional effects but in proper treatment of the neutrino transport. We are running a series of calculations with the Boltzmann transport code BOLTZTRAN, developed by Tony Mezzacappa, that will represent the first full Boltzmann transport calculations of the infall and postbounce phases of core collapse supernovae. Preliminary calculations indicate that full Boltzmann transport will increase the neutrino inverse flux factors by as much as 30% in the reheating region behind the stalled shock, relative to our multigroup, flux-limited diffusion calculations. This directly translates to an equal increase in the neutrino heating rate. Differences of this magnitude are significant and can make or break explosions. More important, the Boltzmann calculations give 2-3 times greater *net* heating in regions directly above the electron neutrino and antineutrino gain radii.

This has multiple ramifications: (1) There is an increased probability of generating explosion in one dimension in the absence of convection. (2) There is an increased probability of generating explosion in two dimensions because of the increased heating and because the increase occurs at the base of the convecting region and should therefore generate more vigorous convection than was seen in our 2-dimensional simulations that implemented MGFLD neutrino transport, which did not yield explosions. **Papers 5.3.10, 5.3.11**

6. This past year we have submitted to the DOE HPCC Grand Challenge Application Program a Supernova Grand Challenge that involves 17 investigators from 12 institutions nationwide under the direction of Principal Investigator Tony Mezzacappa. We have assembled leaders in all key areas for the development of the needed computational astrophysics research tools for the accurate simulation of core collapse supernovae in one, two, and three dimensions: neutrino transport; multidimensional hydrodynamics; high-density, neutron-rich nuclear physics; general relativity; and parallel computing. The Grand Challenge research will stem from work that has been carried out at UT and ORNL over the past two years, the highlights of which have been outlined above. The goals of the Grand Challenge are: (1) to parallelize BOLTZTRAN and carry out the first 1-dimensional core collapse supernova simulations that implement neutrino transport without approximation in an effort to determine whether or not approximations to the neutrino transport have been at the root of failures to obtain explosions numerically in the absence of convection; (2) to develep RADHYD, a code for the accurate simulation of 2-dimensional multigroup neutrino radiation hydrodynamics that will be used to investigate the potential benefits of prompt and neutrino-driven convection in accurate fully self-consistent simulations that couple 2-dimensional transport and 2-dimensional hydrodynamics; (3) to develop next-generation astrophysics research tools for multidimensional *multigroup* radiation hydrodynamics — current industry standards can treat only the gray case.

4 Invited Talks at Workshops and Conferences, 1996

M.W. Guidry

1. "New Developments in the Mechanism of Type-II Supernovae", *Workshop on Supernovae and Neutron Stars*, Trento, Italy, June, 1996.

2. "The Role of Convection and Neutrino Transport in the Core-Collapse Supernova Mechanism," *30th Anniversary meeting of the Brazilian Physical Society*, Aguas Lindoia, Brazil, September, 1996.

A. Mezzacappa

1. "Deciphering Core Collapse Supernovae: Is Convection the Key?" *18th Texas Symposium on Relativistic Astrophysics*, Chicago, Illinois, December 15-20, 1996.

W. Nazarewicz

1. "New Vistas in High Spin Physics", *PEX Workshop*, NBI, May 6-7, 1996, Risø, Denmark.

2. "Physics of Dripline Nuclei", *The Nordita study weekend on Euroball physics*, NBI, May 9-11, 1996, Copenhagen, Denmark.

3. "Masses and Isotope Shifts", *ECT★ Workshop on Structure of Nuclei far from Beta Stability*, May 20-31, 1996, Trento.

4. "Physics of Exotic Nuclei", *Belgian Physical Society General Scientific Meeting*, Plenary talk, June 6-7, 1996, Brussels, Belgium.

5. "Physics of Radioactive Nuclear Beams", *Midsummer Workshop on Nuclear Physics*, June 26-29, 1996, Jyvaäskylä, Finland.

6. "Exotic Nuclei with Gammasphere", *Workshop on the Science and Operation of Gammasphere at ATLAS*, July 27, 1996, Argonne, Illinois.

7. "High Spin Physics", *International School of Nuclear Physics on 4π High-Resolution Gamma Ray Spectroscopy and Nuclear Structure*, September 16-24, 1996, Erice, Italy.

8. "Perspectives in Nuclear Structure", *1996 Fall Meeting of the APS Division of Nuclear Physics*, Plenary talk, October 2-5, 1996, Cambridge, Massachusetts, USA.

W. Satuła

1. "A number-projected Model with Generalized Pairing Interaction in Application to Rotating Nuclei", *Int. Conf. on "Nuclear Structure at the Limits", Argonne*, July 22-26, 1996, ANL, USA.

2. "Quadrupole Polarizabilities in A$\sim$150 Superdeformed Nuclei", *1996 Fall Meeting of the APS Division of Nuclear Physics*, October 2-5, 1996, Cambridge, Massachusetts, USA.

Y. Sun

1. "The Projected Shell Model and Its Application to High-Spin Spectroscopy", *XIX Symposium on Nuclear Physics*, Oaxtepec, Mexico, Jan. 1996.

2. "Systematic Description of Superdeformed Bands in the Mass-190 Region", *Int. Conf. on "Nuclear Structure at the Limits", Argonne*, July 22-26, 1996, ANL, USA.

5 Publications 1996; Refereed Journals

5.1 Reviews

1. "Solution of the Nuclear Shell Model by Symmetry Dictated Truncation", M. W. Guidry, D. H. Feng, X.-W. Pan, and C.-L. Wu, J. Phys. **G22**, 425 (1996).

2. "Nuclear Deformations", W. Nazarewicz and I. Ragnarsson, in *Handbook of Nuclear Properties*, ed. by D.N. Poenaru and W. Greiner, (Clarendon Press, Oxford), 1996, p. 80.

3. "Intrinsic Reflection Asymmetry in Atomic Nuclei", P. Butler and W. Nazarewicz, Rev. Mod. Phys. **68**, 349 (1996).

5.2 Papers Published and In Press

1. "The Observation of Superdeformed Structure in Mass 80 Nuclei", P.J. Dagnall, A.G. Smith, J.C. Lisle, D.H. Smalley, R. Chapman, C. Finck, B. Haas, M. Leddy, D. Prévost, N. Rowley, H. Savajols, T.R. Werner, and W. Nazarewicz, Acta. Phys. Pol. **B27**, 155 (1996).

2. "Structure of proton drip-line nuclei around doubly magic ^{48}Ni", W. Nazarewicz, J. Dobaczewski, T.R. Werner, J.A. Maruhn, P.-G. Reinhard, K. Rutz, C.R. Chinn, A.S. Umar,and M.R. Strayer, Phys. Rev. **C53**, 740 (1996).

3. "Comment on 'Shape and superdeformed structure in Hg isotopes in relativistic mean field model' and 'Structure of neutron-deficient Pt, Hg, and Pb isotopes'", K.Heyde, P.Van Duppen, M.Huyse, J.L.Wood, and W.Nazarewicz, Phys. Rev. **C53**, 1035 (1996).

4. "Rotational Inertia of Superdeformed Nuclei: Intruder Orbitals, Pairing, and Identical Bands", G. de France, C. Baktash, B. Haas, and W. Nazarewicz, Phys. Rev. **C53**, R1070 (1996).

5. "Neutron Radii and Skins in the Hartree-Fock-Bogolyubov Calculations", J. Dobaczewski, W. Nazarewicz, and T. Werner, Z. Phys. **A 354**, 27 (1996).

6. "Ground State Properties of Exotic Si, S, Ar, and Ca Isotopes", T.R. Werner, J.A. Sheikh, M. Misu, W. Nazarewicz, J. Rikovska, K. Heeger, A.S. Umar, and M.R. Strayer, Nucl. Phys. **A597**, 327 (1996).

7. "Perspectives in High Spin Physics (Theoretical Remarks)", W. Nazarewicz, Acta. Phys. Pol. Acta Phys. Pol. **27** (1996).

8. "High Spin States in the Odd-Mass $f_{7/2}$ Nuclei", P. Bednarczyk, R. Broda, M. Lach, W. Meczynski, J. Styczeń, D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N. Medina, C. Petrache, C. Rossi-Alvarez, F. Scarlassara, C. Signorini, F. Soramel, E. Ormand, and W. Nazarewicz, Acta Phys. Pol. **27** (1996).

9. "The Lipkin-Nogami Pairing Scheme in Self-Consistent Nuclear Structure Calculations", P.-G. Reinhard, W. Nazarewicz, M. Bender, and J.A. Maruhn, Phys. Rev. **C53**, 2776 (1996).

10. "Mean-Field Description of Ground-State Properties of Drip-line Nuclei: Pairing and Continuum Effects", J. Dobaczewski, W. Nazarewicz, T.R. Werner, J.F. Berger, C.R. Chinn, and J. Dechargé, Phys. Rev. **C53**, 2809 (1996).

11. "New Spontaneous Fission Mode for ^{252}Cf: Indication of Hyperdeformed ^{144,145,146}Ba at Scission", G.M. Ter-Akopian, J.H. Hamilton, Yu.Ts. Oganessian, A.V. Daniel, J. Kormicki, A.V. Ramayya, G.S. Popeko, B.R.S. Babu, Q.-H. Lu, K. Butler-Moore, W.-C. Ma, S. Ćwiok, W. Nazarewicz, J.K. Deng, D. Shi, J. Kliman, M. Morhac, J.D. Cole, R. Aryaeinejad, N.R. Johnson, I.Y. Lee, F.K. McGowan, and J.X. Saladin, Phys. Rev. Lett. **77**, 32 (1996).

12. "Physics with Radioactive Ion Beams", W. Nazarewicz, B. Sherrill, I. Tanihata, and P. van Duppen, Nuclear Physics News **6**, 17 (1996).

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14. "The Fermion Dynamical Symmetry Model for the Even-Even and Even-Odd Nuclei in the Xe-Ba Region", X.-W. Pan, J.-L. Ping, D. H. Feng, C.-L. Wu, and M. W. Guidry, Phys. Rev. **C53**, 715 (1996).

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16. "E3 Transition Probabilities in the Pt, Hg and Pb isotopes", J.L. Egido, V. Martin, L.M. Robledo, and Y. Sun, Phys. Rev. **C53**, 2855 (1996).

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18. "The Projected Shell Model and Its Newest Applications to High-Spin Spectroscopy", Y. Sun, J.-y. Zhang, M.W. Guidry, and D.H. Feng, Rev. Mex. Fis., **42** (1996) supl. 1.

19. "Optimal Conditions for the Observation of ΔI = 4 Bifurcation", Y. Sun, J.-y. Zhang, and M. W. Guidry, In Press, Phys. Rev. C.

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21. "Z=110-111 Isotopes and the Stability of Heavy and Superheavy Elements", C.-L. Wu, M. W. Guidry, and D. H. Feng, In Press, Phys. Lett. B.

22. "Shell Structure of the Superheavy Elements", S. Ćwiok, J. Dobaczewski, P.-H. Heenen, P. Magierski, and W. Nazarewicz, In Press, Nucl. Phys. A.

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5.3 Papers Submitted

1. "The Composite Particle Representation Theory and the Baryon Spectrum", Y.-Y. Zhu, M. W. Guidry, Z.-P. Li, and C.-L. Wu, submitted to Phys. Rev. C.
2. "Systematics of Platinum Isotopes in the Fermion Dynamical Symmetry Model", J.-L. Ping, I. Zlatev, X.-W. Pan, D. H. Feng, and M. W. Guidry, submitted, Phys. Rev. C.
3. "Systematic Description of Yrast Superdeformed Bands in the Even-Even Mass-190 Region", Y. Sun, J.-y. Zhang, and M. W. Guidry, submitted, Phys. Rev. Lett.
4. "Unified Description of Superdeformed bands in Even and Odd Nuclei", Y. Sun, J.-y. Zhang, and M. W. Guidry, submitted, Phys. Lett. B.
5. " 'Chaos' in Nuclear High Spin Spectroscopy, Y. Sun, D. H. Feng, H. T.Chen, H. Wu and M. W. Guidry, submitted J. Mod. Phys.
6. "Deciphering Core Collapse Supernovae: Is Convection the Key? I. Prompt Convection", A. Mezzacappa, A. C. Calder, S. W. Bruenn, J. M. Blondin, M. W. Guidry, M. R. Strayer, and A. S. Umar, Submitted, Ap. J. Lett.
7. "A Two-Dimensional Study of Prompt Convection in Core Collapse Supernovae", A. C. Calder, A. Mezzacappa, S. W. Bruenn, J. M. Blondin, M. W. Guidry, M. R. Strayer, and A. S. Umar, Submitted, Ap. J.
8. "Deciphering Core Collapse Supernovae: Is Convection the Key? II. Neutrino-Driven Convection", A. Mezzacappa, A. C. Calder, S. W. Bruenn, J. M. Blondin, M. W. Guidry, M. R. Strayer, and A. S. Umar, Submitted, Ap. J. Lett.
9. "A Two-Dimensional Study of Neutrino-Driven Convection in Core Collapse Supernovae", A. C. Calder, A. Mezzacappa, S. W. Bruenn, J. M. Blondin, M. W. Guidry, M. R. Strayer, and A. S. Umar, Submitted, Ap. J.
10. "Deciphering Core Collapse Supernovae: Is Improved Transport the Key?" A. Mezzacappa, O. E. B. Messer, S. W. Bruenn, and M. W. Guidry, Submitted, Ap. J. Lett.
11. "A Comparison of Boltzmann and Multigroup Flux-Limited Diffusion Neutrino Transport in Postbounce Supernova Environments", O. E. B. Messer, A. Mezzacappa, S. W. Bruenn, and M. W. Guidry, Submitted, Ap. J.
12. "Binding Energies of Even-Even C, O, Ne, and Mg Nuclei in Hartree–Fock + Pairing and Shell Models", J. Rikovska, P. D. Stevenson, K. Heeger, J. M Libby, T. M. Siiskonen, A. S. Umar, C. R. Chinn, M. R. Strayer, and M. W. Guidry, submitted to Phys. Rev. C.

13. "Coexistence of Collective and Non-Collective Structures in the Odd-A $f_{7/2}$ Nuclei", P. Bednarczyk, J. Styczeń, R. Broda, M. Lach, W. Męczyński, W. Nazarewicz, W.E. Ormand, W. Satuła, D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N. Medina, C. Petrache, C. Rossi Alvarez, F. Scarlassara, G.F. Segato, C. Signorini, and F. Soramel, submitted to Phys. Lett. B.

14. "Additivity of Quadrupole Moments of Superdeformed Bands: Single-Particle Motion at Extreme Conditions", W. Satuła, J. Dobaczewski, J. Dudek, and W. Nazarewicz, submitted to Phys. Rev. Lett.

15. "Deformed Nuclear Halos", T. Misu, W. Nazarewicz, and S. Åberg, submitted to Nucl. Phys. A.

16. "Alpha Decay and Shape Coexistence in the Alpha-Rotor Model", J.D. Richards, T. Berggren, C.R. Bingham, W. Nazarewicz, and J. Wauters, submitted to Phys. Rev. C.

17. "Quadrupole and Hexadecapole Correlations in Rotating Nuclei Studied within the Single-j Shell Model", P. Magierski, K. Burzyński, E. Perlińska, J. Dobaczewski, and W. Nazarewicz, submitted to Phys. Rev. C.