Report to Anaximander

Weygaert, R. van de

Published in:
EPRINTS-BOOK-TITLE

Publication date:
2002

REPORT TO ANAXIMANDER:
A DIALOGUE ON THE ORIGIN OF THE COSMOS IN THE CRADLE OF WESTERN CIVILIZATION

Rien van de Weygaert
Kapteyn Institute, University of Groningen, Groningen, the Netherlands
weygaert@astro.rug.nl

[1]

"The Apeiron, from which the elements [are formed],
is something that is different"

Anaximander of Miletus (610-546 B.C.)

SCHOOL OF ATHENS ...

Pentelic mountain, solid rock in the city of the goddess Athena, patron of wisdom. In search of the foundations of our world there is hardly a more symbolic site. It welcomed us for a two-day expedition to the outer reaches and first instances of our cosmos, a "symposion" on the origin, evolution and future of the world.

To Athens Pentelic mountain fulfils a similar role as the city itself does to the human quest for the very origins and workings of humanity, the world, the cosmos. Its quarries provided the "elements" for the eternal, solemn and awe-inspiring monuments that still stand as testimony for an epoch in which humanity reached out for unprecedented, thrilling and almost divine heights of intellectual endeavour, creativity, and inspiration !

The city, obedient to her patron of wisdom, likewise passed on the elements and foundation for scientific inquiry. Perhaps unsurpassed in beauty and profoundness, it is Raffaello's "Scuola di Atene" which embodies the most proper expression of gratitude and respect owed by the whole world to ancient Greek society. Gratitude for leading the way and

[1]Conference summary 2nd Hellenic Cosmology workshop, April 19-20, 2001

bestowing upon us the duty to explore and further our understanding of the Universe, for showing that one cannot imagine a duty more sacred than this intellectual and artistic quest for truth.

It is therefore with proper modesty that I set out to enumerate some of the highlights of these very enjoyable days in April 2001 ... days which to us cosmologists stood for a profound and thought-provoking experience at the birthplace of science itself ...

Figure 1. Euclides and the geometry of the world. Detail from "Scuola di Atene" in the Stanza della Segnature, Raffaello Sanzio (1483-1520). photo: Rien van de Weygaert 2001

"THE NOTION OF A POINT IS POINTLESS ... "

As if not yet sufficient, I soon realized that it is futile to strive for a summary that evokes the spirit of a meeting to its full and proper extent. As was stressed by Spiros Cotsakis, discussing the relativity of matters, "the notion of a point is pointless ...".

Yet, it were *"lines"* dominating the meeting. *"Wordlines"* first and foremost, as cosmologies' principal item. Yet, also the combination of all pursued lines of cosmological research whose assembly gave this meeting such an tantalizing flair and scope. So varied, nicely complementary and intertwining were these lines that the comparison with the construction of a temple of Pentelic marble occurred to me as a suitable analogy.

CONSTRUCTING THE COSMOS ON PENTELIC MARBLE

The collection of presentations provided the attendants with a nicely balanced and properly representative overview of the beautiful and rich edifice into which physical cosmology has matured over the past decades. As it were, we were presented with a full plenary gathering of the three branches of cosmological architecture. First, there were the sessions of the **"Architects"**. Sessions discussing *"fundamental cosmology"*, focussing on the topology and geometry of our Universe and the fundamental physical laws and processes at work in those first decisive moments of the (Very) Early Universe. Having been provided with these cosmic blueprints, the **"Constructors"** set out to present their investigation into the ultimate realization of the cosmic framework. In line with the *Classics* of cosmology, they discussed the best available estimates of the parameters characterizing the Friedmann-Robertson-Walker metric, by an impressive body of evidence the architectural plan for the cosmos of which we have found ourselves to be tenants. To them the verdict on the ultimate fate of our world ! Finally, the **"Interior Decorators"** taking care of the cosmic **"Infrastructure"**. It is the realm for the cosmological artisans studying the tantalizing and beautiful patterns and objects which render our Universe such an awe-inspiring realm of beauty and wealth. Part of them kept it clean, concentrating on the works of the prime agent responsible for Megaparsec cosmic structure, forming structure through gravitational instability. Others were to be seen as the new heroes of cosmology, the ones whose *"dirty"* works combine gravitational, hydrodynamic, radiative, stellar and a variety of other dissipative processes into a courageous attempt towards understanding the lights in the cosmos. In presentations of a variety of state-of-the-art projects into *"astrophysical cosmology"* we got granted some intriguing pages from the chronicles reporting on the formation of galaxies and stars in the Universe, as the lights went on and we got around for admiring them ...

THE ARCHITECTURE

During the late seventies and eighties the image of the "cosmic snake" emerged as a symbol for a profound link between the physics of the very smallest and the physics of the very largest. Cosmology became a forum where an exciting mix of views on the workings of our world came to meet. Following shortly after overwhelming feats such as the corroboration of Big Bang predictions of cosmological light element nucleosynthesis and the discovery of the Microwave Background Radiation by Penzias & Wilson, the realization had grown that the early Universe provides a unique testbed for fundamental physicists and astrophysicists alike. It spawned the rise of "astroparticle" physics. The astrophysicists yearned for physics providing a compelling set of physical laws. Such cosmological theory and framework would allow them to interpret the rising tide of observations and understanding of the large-scale cosmos. On the other hand, physicists hoped to reduce the "dirty" Universe of astrophysics into the bare and useful pieces of information on the fundamental workings of nature. In the view of some (Veltman 2001) this has succeeded in only one instant, astrophysical cosmology having taught particle physicists that there are no more than 3 neutrino species, constrained by the measured abundances of light elements produced in the very first minutes of the Big Bang.

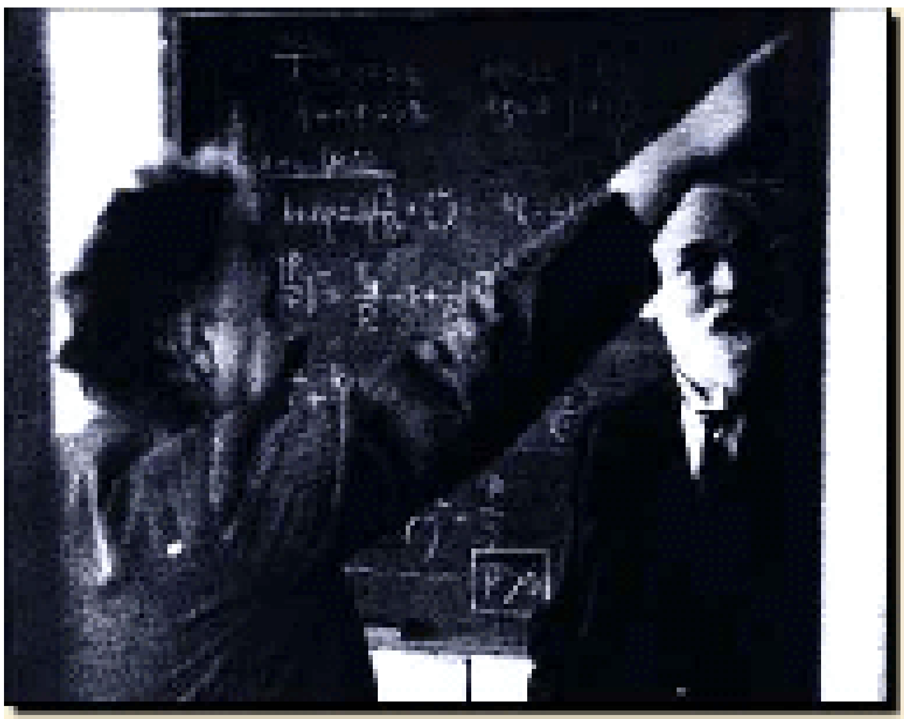


Figure 2. Albert Einstein and Willem de Sitter discussing the cosmological equations for describing the Universe. Copyright: Wide World Photos, New York. From: exhibit Albert Einstein, Center for History of Physics, American Institute of Physics.

In this context it is good to realize that one of the most fundamental and best understood tenets of cosmology is that General Relativity is the proper encryption of the cosmologically dominant force of gravity. That while solid thorough experimental evidence – i.e. other than circumstancial – for GR fully describing gravitational intereactions is still merely confined to the puny region of our own Solar System (at least in the view of an orthodox and sceptical physicist's view). The Solar System may hardly be considered a representative cosmological realm given the fifteen orders of magnitude it is removed from the global Hubble radius.

As much of fundamental importance may be the meaning of a vacuum energy density "cosmological constant" Λ. With some justification we may see the evidence accumulated over the past years for a non-zero value of Λ as the currently most significant and fundamental development in the field of cosmology. It may provide us with a key for unlocking the workings of gravity at the very first instances. The quest for the origin of the cosmological constant and its possible significance as a fundamental trace of quantum cosmological processes is, in my view, one of the most exciting and illustrious scientific endeavours in early 21st century physics. It brings us to the very first moments of our Cosmos, an epoch at which it resided in a still largely mysterious era of quantum gravity. It may be here that we can expect to run into the very secrets of the ultimate creation of the Universe. In the light of such considerations there is some urge in investigating the foundations and assumptions upon which our "standard" cosmological framework stands. A more lucid understanding of the specific position of the standard Friedmann-Robertson-Walker within a wider context of cosmological theories is necessary. Various contributions involved attempts to adress the issue of this special role and position of FRW Universes. The string of presentations on fundamental cosmological issues in a general relativistic context constituted a fruitful and useful forum for further contemplations along this line, triggering many stimulating thoughts.

For natural sciences, it is ultimately compelling to turn to the mathematical framework in which the science is enabled to mature. Only then the full richness of links and parallels can be discerned which are so necessary for uncovering the fundamental issues and laws. Therefore, it was the contribution by S. Cotsakis which functioned as a beautiful frame for the works on the issues of fundamental cosmology. To see cosmological world models treated as mathematical objects is particularly usuful to the astrophysical community, making them to realize into which narrow lanes they tend to channel their results and observations, ad well as for grasping the wider significance of their work. Outlining the 3 basic ingredients which constitute a complete theory – the corresponding theory of gravity, the spacetime structure and geometry, and the matter fields which form its content – it paved the way for contributions on specific elaborations on various specific topics.

Directly tangible is the ingredient of matter and energy content of our Universe. Still puzzling are the nature of dark matter, so tangible present in its gravitational influence, as well as the elusive vacuum energy which is responsible for the cosmological constant Λ, which in recent years seems to have surfaced as an inescapable presence. As for the nature of dark matter, its properties can best be determined from its presence on galactic scales, in particular its immediate influence on the rotation curves of large galaxies. Justifiable a discussion on this issue was a necessary ingredient within this meeting, taken care of in the contribution by Spyrou. Also with respect to the untangible component of vacuum density, the current popularity and high interest in the cosmological constant did not leave the capital of Attica untouched. It was entertaining to notice how the symbol of its traditional rival in Laconia, Λ, still managed to incite hot discussion and contention ... for sure still a sensitivity that does not seem to have subsided ...

The second ingredient, that of spacetime geometry, got further elaborated on by Christodoulakis and G. Papadopoulos. They discussed the specific spacetime structure of a few classes of spatially homogeneous Bianchi cosmologies. Centering more specifically on the widely accepted Friedman-Robertson-Walker Universes, Tsamparlis tried to answer the question whether or not these models do also form the worldmodel in situations where symmetry assumptions are less strong. Intentionally focussing on the issue of time, Kehagias traced and investigated its extreme ramifications in the context of time machines.

Combining all three basic ingredients, including those of the gravitational force, Cotsakis' extensively discussed the stability considerations of such mathematical world models. Particularly stressed was the fundamental fundamental significance of *singularities* ("functions, just like living beings, are characterized by their singularieis"). Drawing particular to the global FRW Universes, Cotsakis finished this issue with a discussion of the important question of the stability of the global FRW Universes. Whether it is indeed a stable solution along the lines of cosmological attractor theory is highly relevant for simple perturbation considerations in conventional structure formation considerations, which tend to neglect the fact that these are less well-posed in a full relativistic setting than often presumed.

Given the statement that nearly all viable cosmological solutions are likely to form singularities in a finite time, we quickly arrive at the overriding question whether *quantum gravity* is really necessary to resolve these singularities. If so, implying the need for a bigger encompassing theory of cosmology, we may indeed get to the inescapable conclusion that the notion of a point is rendered obsolete, for sure in those very first decisive instances. Elaborating on this issue of a fundamental connection between the quantum world and gravity, it may be found through the elusive Λ term. Elizalde focussed on this connection by discussing the Casimir effect, which should help us in understanding the gravitational action of the vacuum energy density.

Extrapolating the discussion on the cosmological constant Λ to the very first moments of the Universe, its present value may be a mere small remnant of the overriding power it unfolded during early phases of inflationary expansion. This provided the backdrop for the discussions by Papantonopoulos, Miritzis and Dimopoulos. Embedding inflation within a multi-dimensional brane cosmology is one of the currently investigated attempts to develop a proper understanding of why we ended up in a FRW Universe (Papantonopoulos). Very interesting would be the possibility of inflation leaving an observational and measurable imprint in the form of primordial magnetic fields, the seeds for the currently not yet understood relatively strong galactic magnetic fields. The origin of these galactic fields is still an as yet unsolved riddle in the astrophysical realm. The suggestion that they may have been a remnant of cosmic inflation provides an intriguing and relevant connection between the world of the very early Universe and that of our observable Universe. Tsagas subsequently discussed the possibility of such cosmic magnetic fields so strongly coupling to the spacetime geometry that they would not leave the universal expansion untouched.

THE CONSTRUCTION

The architects finally agreed on handing over a world model scheme to the constructors, in the form of the homogeneous, isotropic and uniformly expanding Friedmann-Robertson-Walker model Universe. This agreed upon, discussions opened on the precise parameter values which characterize its realization in the case of the world we live in. While great strides forward have been made with respect to setting the values the crucial cosmological parameters – the curvature of spacetime, the mass-energy density Ω in terms of the critical density and the expansion rate in terms of the Hubble parameter $H_\circ$ – not all have been determined with comparable accuracy.

An extensive and very informative presentation by Gaztañaga centered on the large scale distribution of matter and galaxies and the microwave background radiation as seemingly inexhaustible sources of information on the fundamental cosmological parameters. It set the scene for the contributions on the first day of the meeting, providing the background for all ensuing presentations on structure and galaxy formation. During many decades of cosmological observations, the overall construction plan in terms of the FRW blueprint has accumulated an impressive record of observational evidence. Of decisive influence has been the discovery of the perfectly thermal microwave background radiation field. The thermal spectrum of the microwave background, outlining the surface of last scattering at the epoch of recombination, has been measured by COBE's FIRAS instrument to a degree of precision inconceivable to the vast majority of astronomical observations. Its tight Planckian blackbody behaviour is the most convincing evidence for the reality of the early hot and highly dense epoch (the 'Hot' of the Big Bang) out of which the present Universe emerged

Despite such solid and practically irrefutable evidence, the basic specification of the FRW Universe description in terms of its curvature, the expansion rate, and the content in matter and energy is still not settled to any desirable and needed precision. However, we have witnessed great

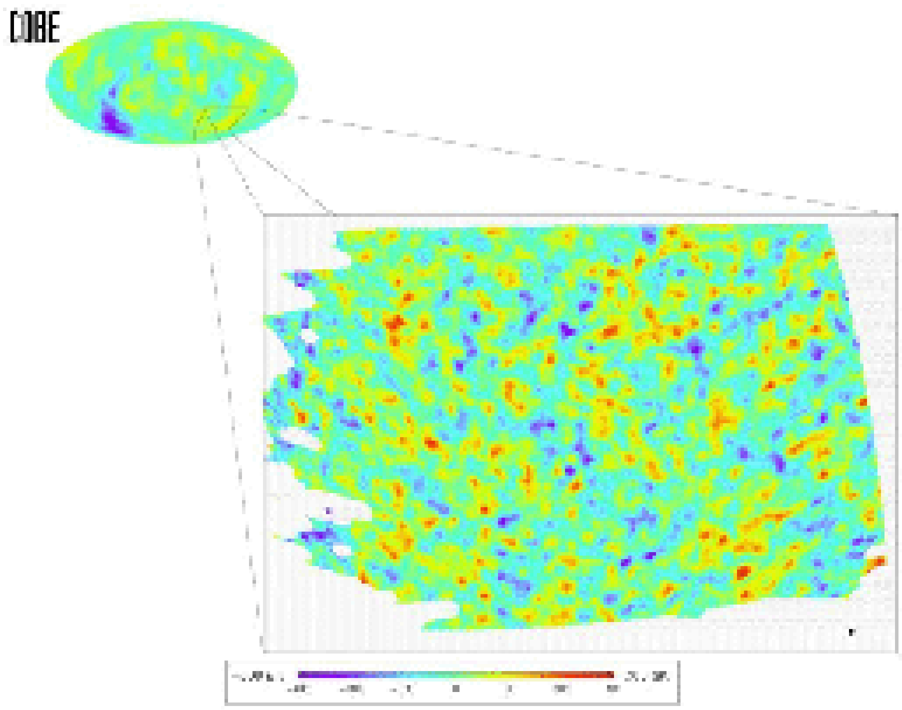


Figure 3. The Cosmic Blueprint (?): Boomerang map of the Microwave Background, image obtained from the maiden voyage of the balloon-borne instrument around the Antarctic (2000). The BOOMERANG image covers approximately 2.5revealing hundreds of complex structures that are visible as tiny variations – typically only 100 μK – in the temperature of the CMB. The patterns visible in the image are consistent with those that would result from sound waves racing through the early universe, creating the structures that by now have evolved into giant clusters and super-clusters of galaxies. Courtesy: Boomerang Collaboration.

progress during the past two decades, and cosmology has managed to break away from a bare search for two numbers and develop into one of sciences' most prospering activities, encompassing and combining a rich and sumptuous palet of relevant areas of interest. Even more impressive, possibly conclusive, advances are shortly to be expected. It therefore does not anymore seem an exaggeration to claim that the fundamental cosmic parameters will get fully fixed within the near future. Within a decade we may have fully determined the past, history and fate of our Universe. Nonetheless, if blessed with some feeling for historic awareness we should be rather weary of such firm statements and claims. After all, with a Universe whose energy content is seemingly dominated by a dark matter component and an additionally even more enigmatic dark energy contribution responsible for the cosmological constant Λ it may not be entirely unwarranted to suspect that we are missing out on some fundamental and systematic aspect of our worldview. After all, the physical nature of the dark matter is currently still as puzzling as it was more than a decade ago. Even more humbling we should be with respect to Λ, the essence of the corresponding vacuum energy density even being further beyond our grasp (see discussion above, and Weinberg, S., 1989, Revs. Mod. Phys. 61, 1).

The value of the curvature parameter k has been converging strongly towards that of a flat $k = 0$ value. The work involved with the high-redshift Supernovae SNI has been yielding substantial support towards this geometry. Almost inescapable evidence has been provided by the Cosmic Microwave Background balloonborne experiments. The MWB balloon experiments – currently most prominently represented by the Boomerang and Maxima project(s) – have provided us with an unprecedented, detailed and tantalizing view of the pristine Universe (Fig. 3). Their measurements so strongly suggest a flat $k = 0$ Universe that to escape this value would almost imply a flaw in our understanding of MWB physics. With only a few years since the detection of the first Sachs-Wolfe fluctuations on an angular scale of $\theta \approx 7^\circ$ by the COBE satellite in 1992, one cannot help but being impressed by the achievements of the balloon measurements at a vastly more detailed resolution of $10-20$ arcmin. With the newest results having an effective resolution allowing the detection of even a second and third Doppler peak in its angular fluctuation power spectrum, it is hard to escape the conclusion that the Universe is indeed a flat one, $k = 0$.

More problems still seem to be involved with the value of the current expansion rate of the Universe, encapsulated in terms of the Hubble parameter $H_\circ$. Progress has been substantially hampered by the lack of really significant advances in the quality of distance estimators, with which we mean improvements by an order of magnitude. Yet, in comparison to 2 decades ago, an enormous investment of effort has been yielding a gradually convergence of estimates of $H_\circ$ onto a tighter and tigher region of acceptable values. Indeed, the main HST Hubble project has been succesfull in the sense of having produced convincing constraints on a value of $H_\circ \approx 70$ km/s/Mpc.

Leaves us the issue of whether we are really closing in on settling the cosmological energy density content. The radiation contribution $\Omega_{radiation}$ is known to high precision, ever since COBE demonstrated the precision of the Planck spectrum and nailed its temperature to $T = 2.728 \pm 0.004$K we may consider this issue to be set. Once we have established the value of the Hubble parameter we then have a firm estimate for Ω_b, the contribution by plain baryons to the cosmic density. Its value of $\Omega_b \approx 0.043 \pm 0.03 h_{65}^{-2}$ is tightly fixed by the light element abundances produced during the cosmological nucleosynthesis processes in the very first minutes of the Big Bang. Telling for the rapid progress in this field is the fact that at the meeting the seemingly low amplitude of the Doppler peak in the first round of Boomerang results were still discussed in the sense of being problematic for the value of the cosmic baryonic matter density. In the meantime new Boomerang results have branded this problem as a non-existent one. Leaves us to mention the estimated contributions of matter in total and the contribution involved with Λ. The currently favorite value for the total matter density is $\Omega_{matter} \approx 0.3$, including the enigmatic dark matter contribution. However, one cannot help but sensing that a clear view of matters still seems to be removed beyond our immediate grasp. Interestingly, the stated Ω_{matter} value and the estimate for the vacuum energy density, $\Omega_\Lambda \approx 0.7$, have acquired a status of "standard" model. However, one cannot be completely unjustified in feeling rather uneasy about the wide agreement on values whose inherent uncertainty should suggest one to expect a large spread in measured values. Purely because of arguments based on simple freshmen statistics !

Despite some side remarks on present-day affairs we may go along with the optimism of Gaztañaga's contribution on the final settling of the Universe's parameters. It will be the MWB experiments that will fully settle the values of some 15-18 fundamental cosmological parameters at presently unimaginable levels of accuracy at sub-percent level. It will be up to the recently launched MAP satellite and ultimately the superior performance of the European Planck satellite to settle the record.

It is therefore not entirely unreasonable to be delighted with respect to upcoming events, enthusiasm which possibly may be tempered when considering your subsequent job prospects as cosmologist. To some extent these experiments may signify the end of cosmology as the science involved with measuring the parameters specifying the structure of the global Universe. Roads of cosmologists may split into two different directions. One road will lead back into time, towards the very first instances in which the many truely fundamental riddles await us for further elucidation. Others may be inclined to follow the Universe's direction of time, and pursue their study forward from the post-recombination Universe onward.

Naturally, the global cosmological parameters are not only affecting the evolution of the Universe on the very largest scales of the Hubble radius. Gaztñaga assessed the way in which the cosmological parameters will be reflected in the kinematic and structural evolution on more local cosmic scales. The morphology, kinematics and dynamics of the Megaparsec cosmic foam, of clusters, and even of galaxies will be influenced to a considerable extent by the properties of the global Universe in which they emerge. In turn, understanding these influences provides us with additional means of determining the cosmological parameters from local measurements. This is currently also one of the most pursued strategies, profiting from the large amount of available and well understood observational information.

In the end local measurements may yield cleaner signals than feasible on the basis of the Supernovae SNI results. The latter still pose us with questions concerning the intricate, complex and only partially understood physical processes in the supernovae. Equally interesting will be to compare these local measurements with those yielded by global determinations, it may inform us of systematic problems with our world models. One example of such situation would be a cosmological evolution of fundamental physical constants, as some have claimed the fine structure constant α is doing. In line with such considerations, Perivolaropoulos dicussed the possibility of identifying the effect of a finite cosmological constant on the dynamics of clusters, groups of galaxies as well as those of galaxies. His conclusion that clusters of galaxes may indeed evidence of detectable dynamical effects of a cosmological constant (while the available technology will not be able to find any comparable clear signature on the scales of galaxies) again stresses the significance of the dynamically young yet outstanding clusters of galaxies as important cosmological laboratories.

THE INFRASTRUCTURE

Gaztañaga henceforth laid out the context of the subsequent contributions by describing how from the parameter specification of the cosmic blueprint we can set out to study the development of its internal organization. Once the global cosmic parameters have been fixed and set, we may establish a proper and clean basis of initial cosmological conditions.

One of the major developments in our cosmological worldview over the past quarter of the century involved our radically changed view of the spatial organization of matter in the Universe. Not only does it involve an interesting issue in its own right, and does it involve the issue of how the galaxies and stars have finally emerged. It may indeed be claimed to hold the key towards solving the very riddle of the Universe itself. Its origin can be traced back to the linear embryonic structure at the epoch of recombination. Its properties, via the specifying power spectrum, holds the most direct observable link to the physical processes

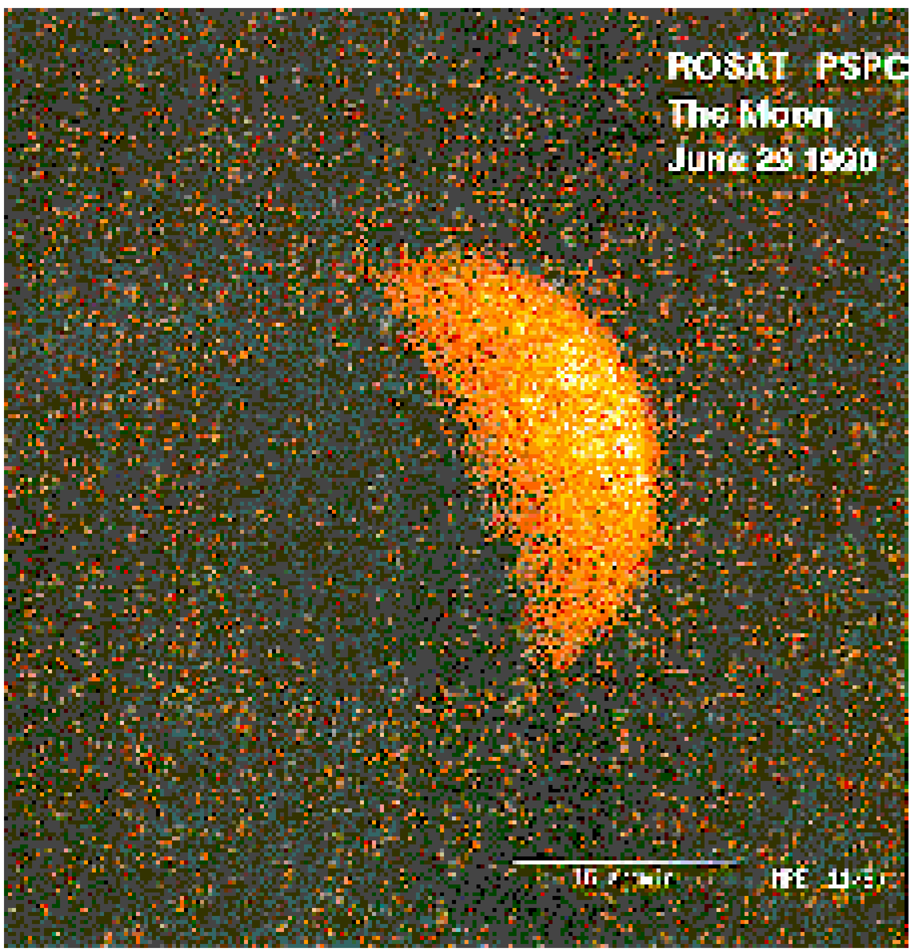


Figure 4. The X-ray cosmic background exposed ! X-ray image of the moon in the 0.1-2 kEV. Note the decrease in the XRB in the dark side of the moon (from Schmitt et al., 1991, Nature 349, 5583). Courtesy: MPE, Garching, Germany.

operating at the very first stages of our universe. Ultimately, we may therefore even hope to use the accumulated understanding of the cosmic structure formation process towards solving the thrilling riddles of the very nature and origin of the Cosmos itself.

To study the emergence and evolution of structure within the Universe we need to identify those structures and natural processes and phenomena that still have retained a memory of earlier cosmological conditions. Within our cosmos the Microwave Background (Gaztañaga), Megaparsec scale cosmic structures (Basilakos, Georgantopoulos, Plionis, van de Weygaert) and even the rotation of galaxies (Voglis) are examples of such precious *"COSMIC FOSSILS"*. These cosmic fossils will enable us to reconstruct the history of the Universe. The cosmic history from the Recombination Epoch onward, and perhaps even that of the preceding eons !!!

The Holy Grail of many structure formation studies is the recovery of the fluctuation power spectrum. Once we have a situation in which the primordial density and velocity perturbations are of a basic Gaussian nature and in which the gravitational instability mechanism functions as the prime mover of the migration currents of matter through their cosmic volume the power spectrum fully specifies the evolution of the internal matter distribution. As for the two conditions, it has yet again been the COBE satellite which produced the most substantial and solid evidence for the reality of these circumstances. Apart from a few recent claims for minor (measured) deviations, the basic Gaussian nature of the patterns on the surface of last scattering is irrefutable. As for the gravitational instability mechanims, COBE was not only an overwhelming success for discovering the reality of the fluctuations in the pristine Universe. Equally important almost was its finding that the amplitude of the fluctuations was almost fully in accordance with the expected values implied by the density contrast of structures in the local, present-day, Universe. It may indeed be considered as one of the most impressive triumphs of cosmology that it managed to tie together structures over a vast range of spatial scales and predict on the basis of the structures on Megaparsec scale how large the Sachs-Wolfe fluctuations in the MWB would approximately be (except for some minor modifications).

Once we have mapped out the primordial field of density and velocity perturbations on the surface of last scattering (given the global cosmic context and the relative contributions of baryonic matter, dark matter and radiation to the energy density of the Universe) we have at our disposal all necessary information to set out a detailed track for the evolution and emergence of structure in the Universe. We may then finally hope to develop a properly detailed understanding of the formation of the cosmic matter distribution into its salient Megaparsec patterns, and even obtain a reasonably detailed view of the way in which galaxies have formed and the stars started to shine. When indeed we have reached this stage, astrophysical cosmology will be able to focus exclusively on the purely astrophysical phenomena and processes that shaped the infrastructure of the Universe.

For the determination of the form and amplitude of the primordial power spectrum which underlies the formation of all structures and objects in our Universe, we need to combine information from a large variety of sources, structures and physical processes. With each structure, process and object corresponds a characteristics spatial range at which they are optimally sensitive to the original power spectrum.

The MWB experiments provide the most direct and cleanest power spectrum signal available. In principle the CMB yields information on fluctuations ranging from the very largest scales (the COBE resolution of $\theta \approx 7^\circ$ corresponds to structures in the order of a Gpc) down to scales comparable to supercluster and cluster scales. The clustering of conspicuous and outstandin objects like AGNs and quasars can provide useful information on intermediate scale fluctuations. However, we still do not really understand their role in the cosmic scheme of structure formation (see contribution Basilakos). In the end, this is a necessary condition if we wish to relate their clustering to the underlying matter distribution.

On scales of a hundred to a few hundred Megaparsec we may hope to infer some useful information from the peculiar motions of galaxies. However, uncertainties in distance estimates still poses overriding problems for such estimates to improve in quality in the foreseeable future. Supreme signatures are already being inferred on the basis the weak lensing signatures by large scale structures on similar scales. These measurements are indiscriminately sensitive to the full matter content and hence "dark" matter proof. This makes them a source of tremendous future potential and promise, a promise that materialize soon now sensitive wide-field instruments are rapidly being commissioned into operation. The "cosmic shear" in deformed background galaxy images has already been translated into a beautiful set of measurements of $P(k)$ over a range of quasi-linear and linear multi-Megaparsec scales.

At the small scale end, down to a scale in the order of a Megaparsec, we are confined to the distribution of galaxies in the cosmic web (see contributions van de Weygaert and Plionis). It is here that careful statistical analysis of uniform galaxy samples have played an instrumental role. Gaztañaga sketched his work on the APM catalogue of galaxies, as yet still the largest sample of (projected sky) galaxy locations available.

We may hope that with the completion of the SDSS redshift survey, as well as from the accompanying deep five-colour photometric sky survey, we will be able to extract statistically equally clear results on the full 3-D galaxy distribution. There have been some tantalizing indications from the recently completed 2dF survey for an interesting feature at the interesting scale of around $100h^{-1}$Mpc, a feature that has also been claimed to be observable in the APM power spectrum and as well in the new CMB Boomerang and Maxima data at $k \approx 0.06 - 0.6$. It would indeed be a thrilling and highly meaningful result, suggested by some to be the result from a phase transition associated with spontaneous symmetry breaking in the early Universe. Nonetheless, the reality of the signal is still contrived, and it may have surfaced as it occurs on the fringe of what is technically feasible.

At much smaller scales direct measurements of the primordial power spectrum will become increasingly difficult to obtain and to isolate from other effects. The formation and shaping of structure gets increasingly influenced by the full arsenal of dissipative hydrodynamic, radiative and stellar processes. Therefore, it would be unjustifiably optimistic to claim that sufficiently unaffected information on the (primordial) power spectrum $P(k)$ can be extracted on these subgalactic scales. Nonetheless, theoretical and numerical work has helped to show that even on such nonlinear scales we may find direct traces to primordial circumstances. In fact, some of the most conspicuous and telling traces in our astronomical world (see Voglis).

Infrastructure: Gravity and the Web

Over the past two decades we have witnessed a paradigm shift in our perception of the Megaparsec scale structure in the Universe. As increasingly elaborate galaxy redshift surveys charted ever larger regions in the nearby cosmos, an intriguingly complex and salient foamlike network in the cosmic matter and galaxy distribution got to unfold itself. This distinctive foamy pattern is characterizied by galaxies accumulating in walls, filaments and dense compact clusters surrounding large near-empty void regions (see contribution van de Weygaert). As borne out by a large sequence of computer experiments, such weblike patterns in the overall cosmic matter distribution do represent a universal but possibly transient phase in the gravitationally propelled emergence and evolution of cosmic structure.

The gravitational dominance in the shaping of cosmic structure is mostly confined to that of the global Universe down to scales of a few Megaparsec. The cosmic large scale structure and the various elements of the cosmic foam have been such a prominent item of scientific interest over the past few decades because of this direct relation to the circumstances in the Early Universe, the ideal "cosmic fossil".

On galaxy scale, however, there is at least one prominent aspect which relates straightly to the gravitational formation process itself. In hierarchical scenarios of structure formation the rotation of galaxies is induced by the gravitational torqueing of the collapsing density peaks. The tidal torque generation of galaxy angular momentum was the subject of the presentation by Voglis. An interesting observation has been the finding of galaxy cores that counterrotate with respect to the main body of the galaxy. Voglis discussed the possibilities of explaining and working out such a phenomenon within scenarios where a core would result from a massive merger event or where it would result from a successive infall from many small clumps. It resulted into a solid, mathematically well-founded, expose on important dynamical aspects. Indeed, it opened insights into seeing how the existence of such cores may be linked to the cosmological conditions, which makes it into a welcome small-scale "cosmic fossil".

Moving up in scale, we know that the Megaparsec cosmic web is most characteristically outlined by its filamentary features. These filaments result from the anisotropic gravitational collapse of overdense matter regions. With this in mind Plionis set out to describe how one can exploit their properties to understand the dynamical development of clusters and filaments in hierarchical structure formation scenarios. Filamentary patterns correspond to intermediate evolutionary phases, having established a pronounced appearance and contrast with respect to the surrounding Universe but not yet having fully contracted onto self-gravitating and virialized entities. Within the context of the cosmic foam in which they are embedded, these anisotropic structures form connecting bridges between its most compact elements, the clusters of galaxies. The evolution of cosmic structure involves a systematic migration of matter towards the high-density regions, in which filaments function as channels along which matter gets gradually transported towards clusters. Given their dynamical youth within the cosmic sheme, clusters being the youngest fully collapsed components and filaments still in an intermediate yet pronounced stage, they should form one of the most dynamically active sites in cosmic Megaparsec scale structure. These Megaparsec scale structures are the present-day equivalents of the similarly active but much smaller regions at earlier cosmic epochs, at an epoch at which the cosmic matter distribution resided in a dynamically younger phase. A closer assessment of the processes involved with these filament and cluster junctions is compelling in that it will inform us about the very buildup of the cosmic web structure itself. Plionis therefore focussed specifically on the ramifications of the implied anisotropic inflow of material along filamanets onto clusters. On the basis of a sample of 952 APM clusters he presented convincing evidence for alignments between neighbouring clusters. Moreover, the dynamical youth of the clusters is underlined by the presence of significant substructure in some $30-40\%$ of the clusters. Most strongly and telling was the finding of the alignment of these substructures with the surroundings, highly suggestive of their inflow along the anisotropically outlined channels formed by the filaments.

While Plionis focussed on the aspect of the filamentary elements of the cosmic foam, using the presence of relevant and readily exploitable observational material to study its properties in the real universe, Van de Weygaert choose to emphasize the geometric nature of the cosmic foam in an attempt to provide a universal theoretical frame for its distinct nontrivial morphology. He described the intrinsically mathematical concept from the field of "stochastic geometry", the Voronoi model. The geometric Voronoi model seeks to exploit the distinct geometric nature of the patterns in the cosmic matter distribution. It attempts to combine two crucial and salient properties of the cosmic foam. Firstly, the stochastic (yet, not Poissonian !!!!) spatial setting of distinct geometrical elements, walls, filaments and high density nodes (clusters). Secondly, the distinct cellular morphology which forces the elements of walls, filaments and vertices in a definite and tight mutual relationship to each other. Clusters are found at specific locations (vertices) within such geometric networks, at the interstices where filaments and walls connect. In turn, the filaments and walls surround and thus avoid the large voids, which take up most of the spatial volume in the Universe. On the basis of these properties, which are indeed prevalent in the real Universe as well as in N-body computer models of gravitationally induced structure formation, Van de Weygaert showed the presence of a definite "geometric bias" in the superclustering of clusters. The most massive clusters will, as a consequence of their distinct spatial locations, form massive supercomplexes, whose sizes may supersede the basic voidsize by an order of magnitude. Geometric simulations revealed the presence of seemingly flattened superclusters over enormous spatial scales of hundreds of Megaparsec. Mathematically, it seems to indicate a beautiful, hitherto unknown, pattern of similarity. Cosmologically, it may form an indication for the presence of a purely "geometric" biasing effect, a ramification of the observed foamlike galaxy distribution.

Indeed, the clustering of different populations of special astrophysical objects may be easier understood within the context of taking into account the context of the cellular geometry of the matter and galaxy distribution in the Universe. An important aspect of this was touched upon in the contribution of Basilakos. Over the years, there have been various attempts to measure clustering in the Universe on the largest scales, far exceeding the clustering of normal galaxies on scales of a few up to a few tens of Megaparsec. Both clusters of galaxies as well as classes of Active Galaxies, quasars and radio galaxies are noteworthy examples. The high luminosity of AGNs makes them ideal to probe cosmic structure over vast reaches of the observable Universe. As they form a sparsely sampled reflection of the underlying patterns and appear to be located in or near the highest density regions within the cosmic network, they are a valuable complementary population for tracing cosmic structure on the largest ($> 100h^{-1}$Mpc). Conventional approaches were often hampered by the ill-defined selection criteria of the AGN samples. Proper selection is of utmost importance, even more so as the physical nature and therefore location of these sources within the cosmic matter distribution still evades full understanding. Basilakos managed to get rid of a few of such considerations, by studying cleanly defined samples on the basis of uniform X-ray selected samples of AGNs. This allowed him to adress in a clearly defined fashion the question of the particular "bias" of such source populations with respect to the large scale structure outlined by normal galaxies. Within a set of structure formation scenarios (mainly ΛCDM and τCDM), three different bias descriptions were tested. These ranged from bias-free to the population evolving merging bias prescription of Mo & White. While it allowed to put constraints on the validity of the scenarios, and corresponding bias descriptions, the main theme was the wider scenario-independent conclusion that indeed AGNs can offer us a valuable tracing of structure on the very largest scales otherwise unreachable by normal galaxy samples.

With Basilakos having stressed the importance of AGNS for studying large scale structure, and having argued how their X-ray emission can be exploited as an optimal selection criterion, it is a natural step to extrapolate this to the high redshift Universe. We know that at high redshift the volume density of such X-ray emitting AGNs and quasars is far higher than locally (peaking at around $z \approx 1-2.5$), and it may therefore not be a surprise that the first X-ray satellite, before the discovery of the MWB background, discovered an almost isotropic background of X-ray radiation (to within a few percent), except for a dipole component completely in accordance with that in the MWB. Still, I consider the wonderful ROSAT picture of the obscured moon as one of astronomy's "richest" symbolic images (Fig. 4). Georgantopoulos described the exciting recent developments in unravelling the secrets of this diffuse X-ray background. Since the operation of ROSAT and in particular since the superb spatial and spectral resolution of the new Chandra and XMM X-ray satellite observatories have been put into operation, the essential significance of the X-ray background may be regarded as settled. For many years, it was not clear whether the origin of the X-ray background had to be found in a diffuse hot IGM or in an unresolved population of discrete high-redshift sources. Since COBE, which did not find any trace of spectral distortions due to a hot IGM, the point source interpretation has quickly shown to be the proper one. ROSAT resolved 70% of the soft XRB into point sources, many of which belong to a QSO population at $z \approx 1.5$, while others are probably obscured AGNs. The recent Chandra deep field results showing that more than 80% of the XRB in the $2-10$keV is due to resolved sources nearly appear as "famous last words" on the matter. On the other hand, the fact that only 8 X-ray sources could be identified in the Hubble Deep Field of 3000 optical galaxies should be seen as the start of a new era, in which the X-ray observations will help us to gain extremely important insight into the formation of galaxies. Georgantopoulos described the Herschel Deep Field project which forms an attempt to get a better idea of the nature of the various X-ray emitting sources. QSOs and AGNs are obvious candidates, but also early-type galaxies may be avid X-ray emitting sources. Problematic identifications may concern X-ray emitting QSOs, whose redshift $z > 5$ prevents them to be visible in optical images. In my view, such studies are extremely important in unravelling the nature of QSOs and AGNs, to find their differences as well as their similarities to normal galaxies. Still, we seem to have no understanding whatsoever of why such "cosmic beasts" get formed at all, that while we know that their formation will hold tremendous repercussions for their environment and for cosmic evolution in general. After all, their role in lifting the epoch of the "Dark Ages" may have been all-decisive and overriding !

Infrastructure: Gas, Stars and (G)Astrophysics

The jewels in the 'Crown of Creation' (Jefferson Airplane 1968). This obviously subjective description of the function of *galaxies* in the global context of the Cosmos is certainly not an entirely unjustifiable opinion. Galaxies certainly are amongst the most beautiful, complex and awe-inspiring creations in the Universe. They are largely self-organizing entities, cosmic cities harbouring a rich variety of ingredients, such as gas clouds in highly diverse physical states, stars and planets. All these aspects are elements of a highly complex state of organization, connected through an ingeneous and intricate "life" cycle of mutually influencing

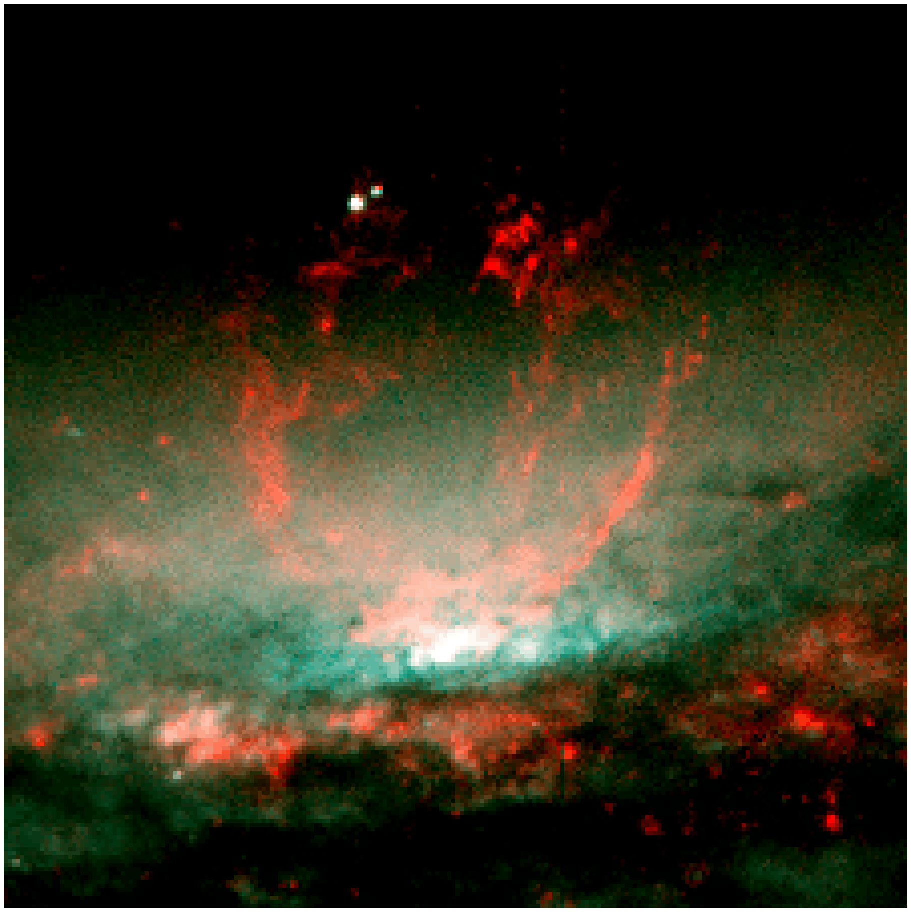


Figure 5. The gastrophysical Universe: dramatic events in the core of the galaxy NGC 3079, where a hot bubble of gas is rising from a cauldron of glowing matter. NGC 3079 may semble to a reasonable extent the dramatic phenomena taking place in young galaxies in the high-redshift Universe. Huge bursts of star formation, triggering violently driven winds, will be but one of the many diverse manifestations marking the Universe's youthful years. Credit: NASA, STScI, G. Cecil, S. Veilleux, J. Bland-Hawthorn, A. Filippenko.

physical processes, phenomena and manifestations. Given the almost perfectly homogeneous Universe at recombination, it may be clear that the rise and growth of such complex entities in the Universe poses a daunting challenge for science. As "clean" gravitational studies have cleaned large parts of the road, succesfully breaching many hurdles, astrophysics is gradually preparing itself for the considerably more daunting world of "gastrophysics".

In marked contrast to the situation with respect to studying the Megaparsec scale structure, where observational and theoretical advances went hand-in-hand, the complexities involved with galaxy formation processes are so enormous that the field is practically exclusively driven by observations. This may be no surprise, given the fact that the astrophysical processes involved with shaping the galaxies are so complex and of such wide variety. Gravity is no longer alone in beating the drum. Gas dynamical processes, radiative generation and transfer processes, the still even in our own Galactic circumstances largely ununderstood stellar formation processes, feedback by phenomenon such as supernovae and stellar winds, the chemical enrichment going along with the evolving stellar populations, its transport throughout a galaxy, the influence of magnetic fields are but a few of the examples of important contributors to the shaping of a galaxy.

In a nice sequel of related contributions Van der Werf, Ivinson and Papadopoulos presented a broad and profound overview of the present-day status of our insight into the cosmic star formation history (Van der Werf), the kinematic evolution of galaxies (Van der Werf), the nature and identification of high redshift galaxies (Ivinson), and the ultimate source of cosmic beauty and shining (galaxies and stars alike), the nature and constitution of gas in the Early Universe (P. Papadopoulos).

Concerning the basic constituents of the cosmic star formation history, the state of the gaseous component may arguably be seen as the most fundamental one. In particular the molecular phase is tightly coupled with the fueling of the subsequent star formation. P. Papadopoulos presented his instrumental work on the presence of molecules at high redshifts. From the nearby Galactic circumstances we know that gas has to get congregate into giant molecular clouds, which "fragment" into a whole range of compact "subclumps". In such dense, optically thick, circumstances become favorable for the ultimate collapse into a gaseous object that manages to generate its own energy by thermonuclear reactions: a star is born. However, we have but a superficial view of the situation in the outer reaches of the Universe. The basic molecular component of molecular clouds are evidently the simplest ones around, H_2. However, these suffer from notorious symmetry, so that we cannot exploit the radiation involved with "dipole" transitions. Luckily, CO may operate as a tracer molecule. The calibration of the tracer may still involve considerable uncertainties. Yet the detection of CO emission in 4C60.07 at $z = 3.79$, probably involving a primeval merger, may certainly be considered a major achievement ! It has established observations of molecules as a fantastic way of studying the star formation circumstances in the high redshift Universe, out to redshifts of at least

$z \approx 4$! With ALMA getting into operation over the coming decade, a whole new era for the diagnostics of the physical conditions over a wide span of the cosmological timeline seems to have been opened up !

Turning to the very history of cosmological star formation itself, Van der Werf first pointed out that we do not even have a proper definition of what we mean by " the formation of a galaxy". A good working hypothesis may be to consider the onset of star formation in galaxies as such. It remains to be seen whether this is always a useful definition in case we have very early star formation in small clumps that only later fall into the larger peers that ultimately will start resembling the objects we nowadays describe as galaxy. Given the working definition, we may turn to the issue of star formation throughout the Universe. Van der Werf discussed the list of possibilities to trace such processes. These are based upon well-known symptoms of star formation in our immediate cosmic neighbourhood. Such tracers concern the emission of the newly formed stars themselves, the reprocessed radiation by the surrounding dust (SCUBA submm observations, COBE/DIRBE observations of the IR background) or the emission by surrounding gas excited or ionized by the newly formed star (Hα, Lα). With the help of corresponding observations at different redshifts one may (boldly) attempt to draw up a global cosmic star formation history. The pioneers investigations by Madau and Lilly have in the meantime been followed up by many related studies, incorporating the full arsenal of available observational information.

Van der Werf described to some extent his own work on emission-line studies of cosmic star formation out to $z \approx 2.2$. This involved the first untargeted Hα survey at $z = 2.2$. Overall, his conclusion was that the Madau diagram is largely corroborated by most later work. Nonetheless, an important pitfall remains the fact that we do not really have an understanding of the physical circumstances surrounding star formation processes at high z. Theoretical understanding will certainly have to play a crucial in converting the available circumstantial evidence into inescapable conclusions. The fact that we do not even seems to understand star formation locally remains a factor of suspicion.

Extremely interesting was the evidence presented on the formation and (dynamical) evolution of galaxy disks (Van der Werf). The question of the origin of galactic disks is evidently one of the most pressing within the whole of the galaxy formation process. Interestingly, we have learned that the large disks like that of our own Galaxy are certainly fully in place at rather moderate (cosmological) redshifts, $z \approx 0.5 - 1.0$. The intriguing work by N. Vogt, who managed to measure rotation curve of disk galaxies at $z \approx 1.00$, has indicated that even the Tully-Fisher relation seems to have settled by that epoch. Van der Werf described how one can follow up on these results by extending the study of the growth of disks to the higher redshifts at which it apparently must occur. He argued for Hα as a perfect means of seeing the disk buildup at around $z \approx 2$.. Indeed a most thrilling prospect !

Ivinson subsequently gave a clear review of the various ways in which we can find galaxies at the even higher redshifts, beyond $z > 2$. Being enabled to trace galaxies the hope is to infer at which epoch the galaxies formed their stars. Evidently, following the star formation history itself is an obvious first way. In the meantime, a variety of strategies have emerged as additional and complementary possibilities. Several colour and spectrum based techniques have materialized as effective selection methods for luminous galaxies. At radio wavelengths, one may for example look for sources with an ultra-steep spectrum. Over the past years the highly succesfull colour dropout techniques have evolved into a major industry for selecting out galaxies that are not only confined to the class of the very brightest galaxies.

Particular emphasis was put on submm waveband observations. This benefits greatly from a welcome virtue of high-z dust emission, its negative k-correction. As a consequence the flux of such emission remains the same over a wide frequency range. The SCUBA instrument formed a major step in utilizing this possibility. A remaining problem is still the identification of sources in SCUBA observations with counterparts at other wavelengths. The identification with optical galaxies remains a cumbersome affair, as evidenced by the scarce overlap with the HDF image evidences. More promising appears to be the correspondence with radiogalaxies, leading to a prudent identification of SCUBA sources with highly clustered ellipticals at very high redshifts. They may therefore be thé way of probing the formation of galaxies in the very highest density regions, and hence of the formation of elliptical galaxies.

Having arrived at the outer reaches of the observable yet familiar Universe, we had been offered a "gastrophysical" taste of the thrilling developments that are awaiting us on what must be one of the most challenging cosmic Odysseys in the history of astronomy. Also, we got to appreciate that the treasures which we may encounter on this voyage of discovery will be beautiful, rich, opulent. We may be justified in characterizing this as the search for the Holy Grail of cosmology and astrophysics. Perhaps, with some more nuance, the Holy Grail of Post-Planck Cosmology ... As yet we only obtained a very first impression of the first islands of the cosmic archipelago. Evidently, nothing has firmly settled yet, and this renders these explorations all the more exciting for the coming generations ...

What a deception therefore to note the audacity with which P. Papadopoulos described it all as *"Astro in a coffeecup ..."* This, with Greek gastronomy in mind shattered the high expectations of a mere barbarian from the north. A barbarian who for years had been indoctrinated with excessive laudations on the Greek cuisine ... yet, how fine it is then to have family who save the day and manage to repair such misunderstandings in preparing opulent tables filled with the most wonderful and delicious Epicurean delights ...

CONCLUSION

Having arrived at the end of this wonderful and memorable cosmic Odyssey along the Cosmos, having been offered beautiful vistas along such richly varied directions, we maybe should properly finish with a return to the ancient masters who set us onto this never-ending voyage across space and time. A proper "admonition" to all scientists with pretensions too audacious, an advice to remain modest in the light of eternity,

Acknowledgments

Looking back over the past months, the wonderful and enjoyable experience to which the organizers and these spring days of April 2002 treated us has grown into a happy and vivid memory of the best science has to offer. I feel truely priviliged to have attended a sparkling forum and 'symposion'.

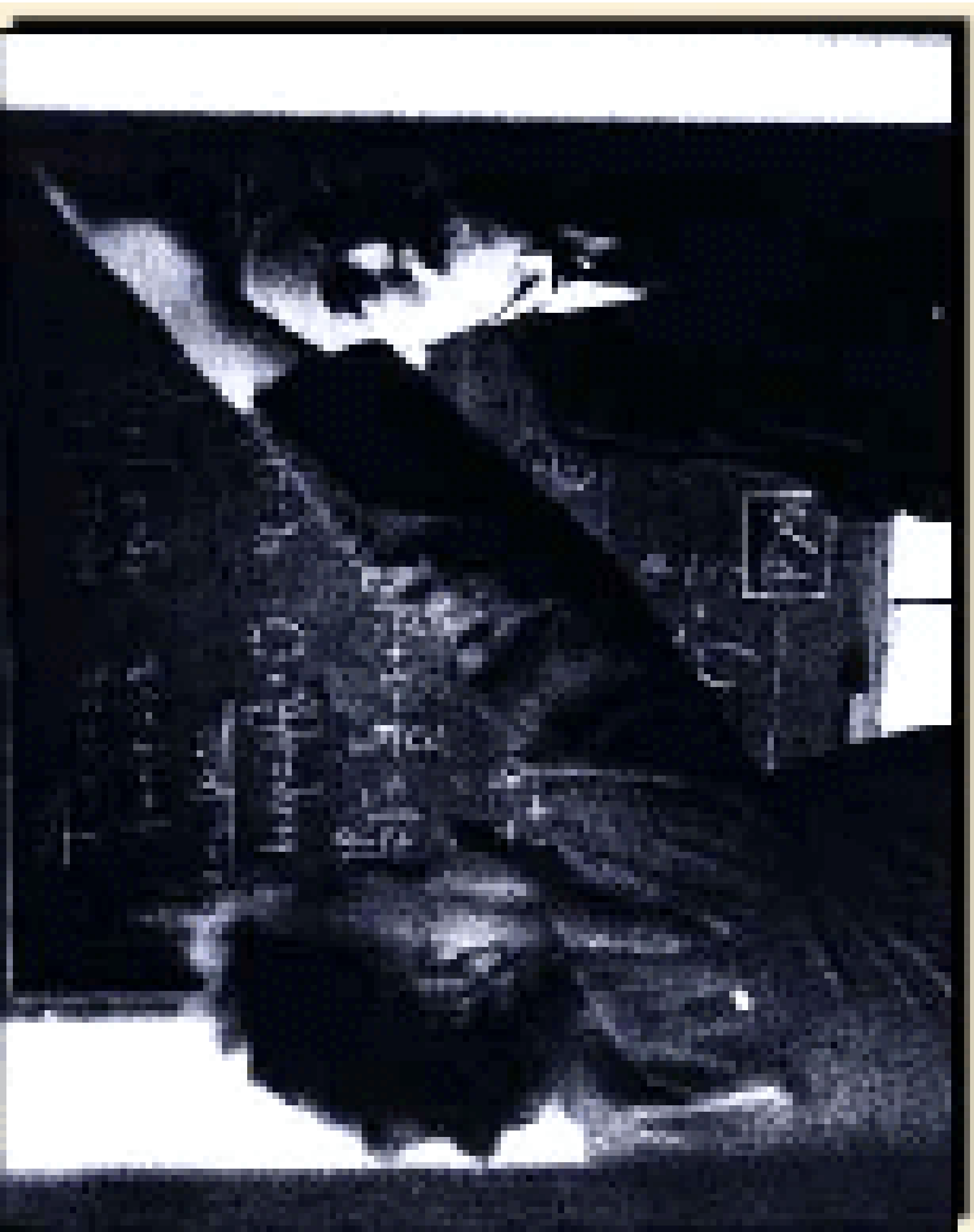
On behalf of all participants I would therefore like to express warm gratitude to the organizers, Manolis Plionis, Spiros Cotsakis and Ioannis Georgantopoulos. A gratitude which naturally extends to Koumentakou Ourania, whose support guaranteed the smooth and perfect organization. In this workshop, they provided all of us with a great example of how scientific curiosity and discussion can benefit from an environment of legendary Greek hospitality ...

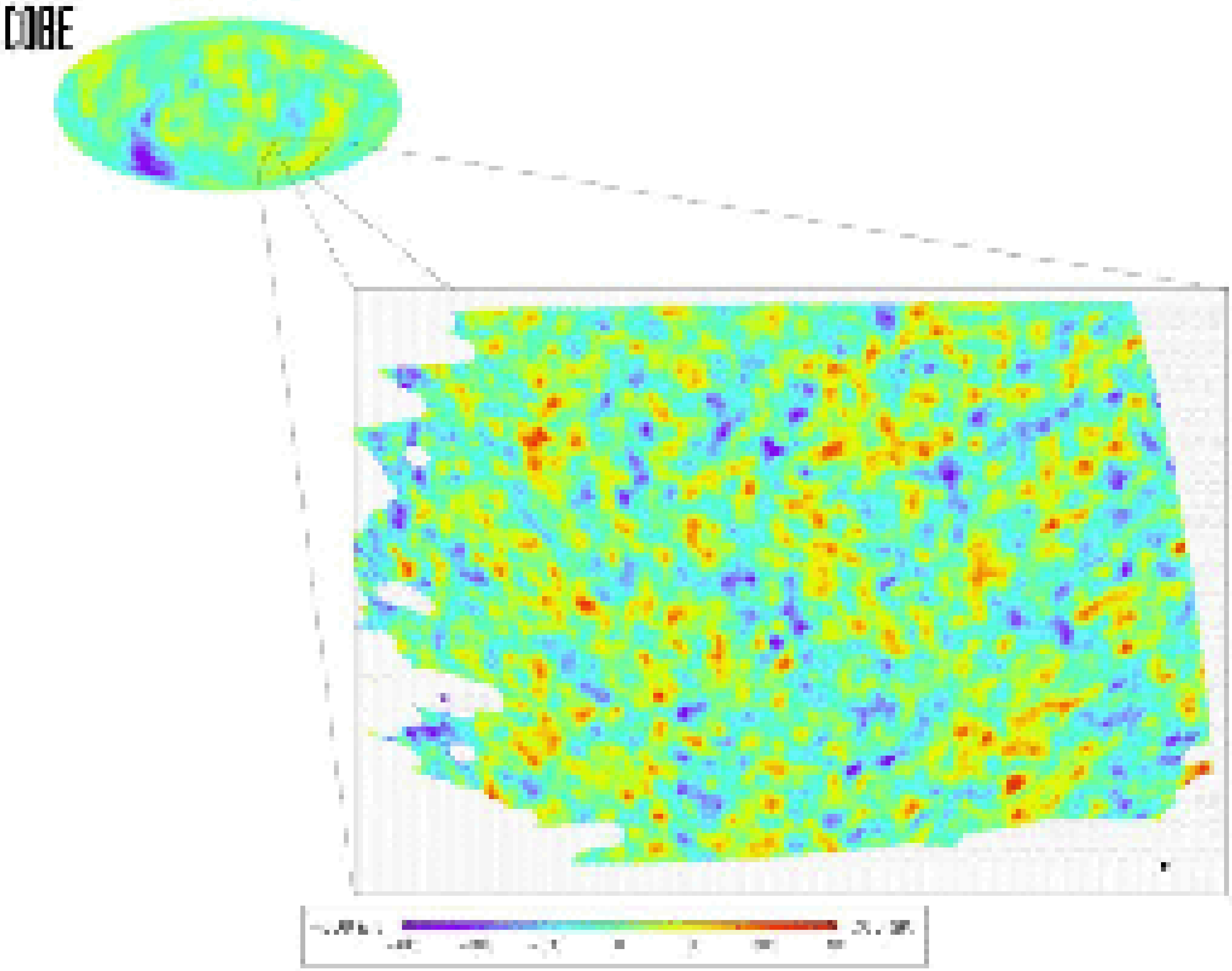
Figure 6. The Academia of Plato, anno 2001. "The world of Becoming; everything in this world 'comes to be and passes away, but never really is' " (Plato, Timeaus). Yet, his world of ideas remained ever-Existent ! Notice how even nowadays the basic forms do show around the Academia ! photo: Rien van de Weygaert 2001

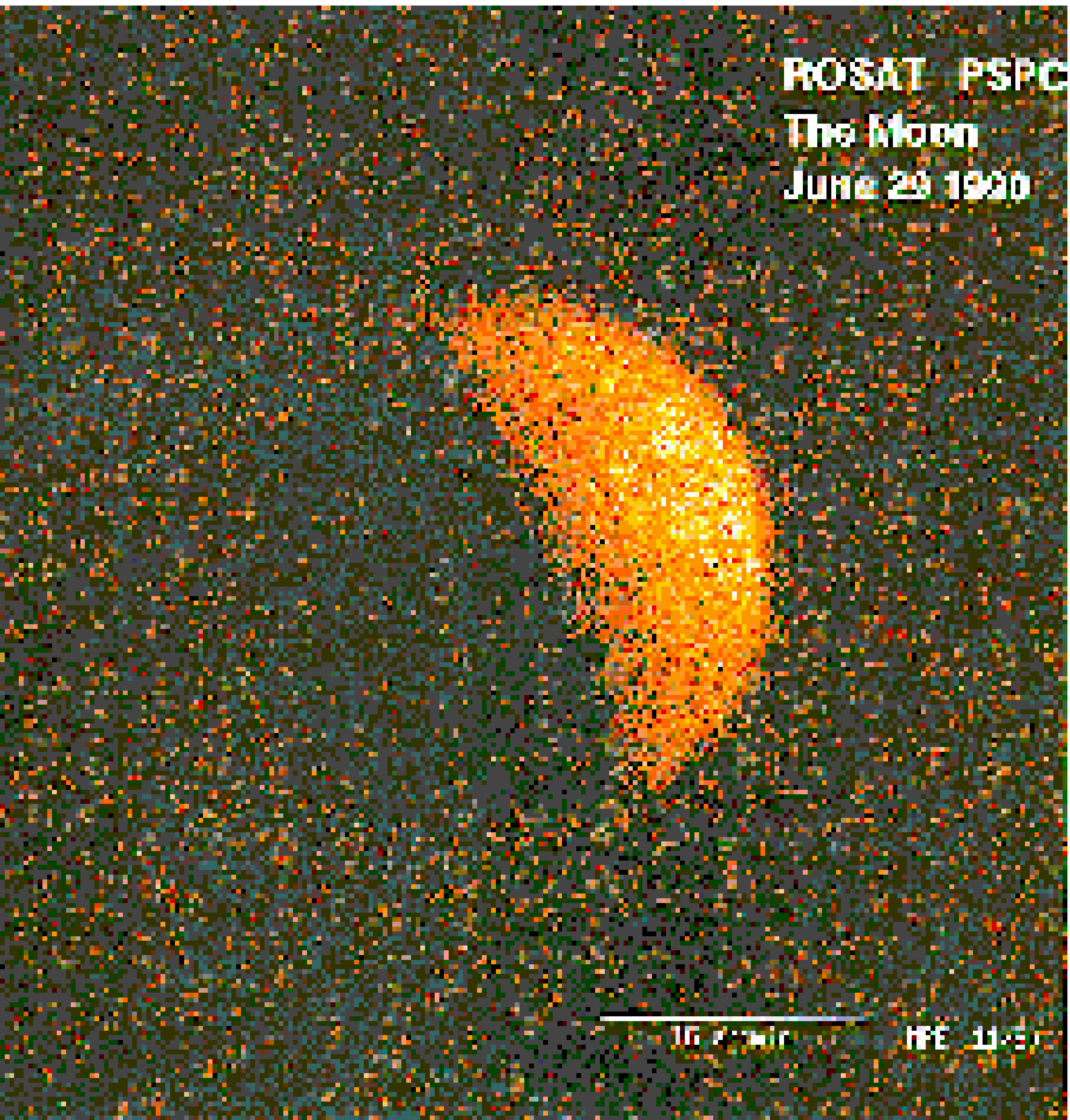
As for the world
– call it that or cosmos or any other name acceptable to it –
we must ask about it the question one is bound to ask
to begin with about anything:
whether it has always existed and has not beginning,
or whether it has come into existence and started from some beginning.
The answer is that it has come into being;
for it is visible, tangible and corporeal,
and therefore perceptible to the senses,
and, as we saw,
sensible things are objects of opinion and sensation
[...]
Don't therefore be surprised, Socrates,
if on matters concerning the gods and the whole world of change
we are unable in every respect and on every occasion
to render consistent and accurate account.

Plato (427-347 B.C.), *Timaeus*

Figure 7. In Athens, Plato and Aristoteles conversing on the Universe. Detail from “Scuola di Atene” in the Stanza della Segnature, Raffaello Sanzio (1483-1520). Courtesy: Christus Rex, Inc. and Michael Olteanu, MS.




COBE


ROSAT PSPC
The Moon
June 29 1990