Hipparchos

The Hellenic Astronomical Society Newsletter

Hellenic Astronomical Society

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Message from the President

Dear friends and colleagues,

On behalf of the new Governing Council of HelAS I wish to thank you for your vote with which you trusted to our hands the helms (and the problems) of our beloved Society.

The usual phrase I should say at that point is that you should "rest assured that we will work with all our strength to make our Society better". I am afraid that I cannot say something like that. No member of this Society can rest leaving others to work for them. HELAS is the scientific expression of all astronomers and not just of the Governing Council. We are not a professional syndicate that looks after astronomer's interest. We form a scientific body reflecting to Greece and to the whole world our caring for the research in Astronomy and for the teaching of Astronomy.

The recent elections hit an alarming bell and we all feel that we are at a critical point in the short history of our Society. Of course the number of our members is not dwindling. In fact we have now more members than ever (238), but this happens because new members are enrolled. Although these members are mainly young graduate students of astronomy and related scientific fields and they will form eventually the main healthy body of the Society, an alarming number of old members are loosing interest in the Society's life. Among them are members who served in the past as elected members of the Governing Council. A large number of these members have not even paid their dues to the Society (ninety-five members have not paid for more than 3 years now and forty-four among them - including twelve founding members - have not paid even once their dues!). This brings us in a great difficulty to face the usual expenses of running the Society and financing the next Meeting. It is evident that we should approach these members and persuade them to join again the ranks of the active members.

In the next few days I will contact personally all these members who used to support warmly our proceedings, and find out the reason that drove them away from the main body of the Society.

I hope that we will be able to revive the interest of all professional astronomers and related scientists to the Society. Moreover, I hope that every one of you will contact us with suggestions that will help HelAS. I don't want idealistic approaches for things that should be done. I want straightforward solutions to our problems and new goals that can be reached.

I would like to thank wholeheartedly the previous President of the Society, Professor John Seiradakis, who was the driving force in forming this Society back at 1992 and who served two terms as President and two as a Secretary of HelAS. Also I would like to thank the previous Governing Council (Vice - President Prof. Nick Kylafis, Secretary Dr. Harris Varvoglis, Treasurer Dr. Panagiotis Niarchos and Members Dr. Manolis Plionis, Dr. Helen Livaniou -Rovithis and Dr. Stavros Avgoloupis.), for the special contribution of each one of them. Dr. Manolis Plionis, who has been elected again as a member of current G.C, will continue the editing of "Hipparchos".

I should thank at this point Dr. Vassilis Charmandaris, who has accepted to continue preparing the Electronic Newsletter with our Secretary, Prof. Kanaris Tsinganos.

I wish to all of you health, happiness and success in your projects. Let us all make HelAS one of our projects and let us hope that at the next General Assembly of HELAS will find our Society at an even better shape.

Professor Paul G. Laskarides

Inside this issue:

1. The 18th General Assembly of Hel.A.S., Constitutional changes and Elections.

The 18th General Assembly of Hel.A.S. took place on June 18 2002. After the approval of the doings of council, the assembly also approved the following amendments of the Constitution of Hel.A.S.which will be put to force by the new Council:

- The body of Auditors of Hel.A.S. consists of three (3) members (with the current Constitution the number "3" is not explicitly mentioned. It is only implied).
- The voting during elections starts immediately after the General Assembly and finishes 4 hours later (with the current Constitution it starts 4 hours before sunset and finishes at sunset).
- It should be explicitly mentioned that the Budget of Hel.A.S. is deposited in the records of the relevant Tax Office (this is not explicitly mentioned in the current Constitution, although it was regularly practiced by the Treasurer of Hel.A.S.).
- The elections of Hel.A.S. take place during the summer months (with the current Constitution they take place in June).
- The Newsletter of Hel.A.S. is called "*Hipparchos*" (the "*Hipparchos*" is not mentioned in the current Constitution).
- The transfer of duties to the newly elected Council takes place within a month after the elections (with the current Constitution there is am apparent gap of power between elections and the formation of the new Council).

Prior to the Assembly, at noon, Prof. Kostas Kokkotas (University of Thessaloniki) gave an invited seminar entitled "*Gravitational Waves: a new window to the Universe*".

In the elections that followed, the members of Hel.A.S. voted for a new President, as well as new Council and Auditors. The results of the elections were:

President : P. Laskarides, Univ. of Athens (71 votes)

Council:

- E. Antonopoulou, Univ. of Athens (31 votes)
- D. Hatzidimitriou, Univ. of Crete (22 votes)
- M. Mathioudakis, Univ. of Thessaloniki (23 votes)
- M. Plionis, Nat. Obs. of Athens (37 votes)
- E. Theodossiou, Univ. of Athens (27 votes)
- K. Tsinganos, Univ. of Athens (27 votes)

Auditors:

- M. Danezis, Univ. of Athens (40 votes)
- T. Grammenos, Univ. of Athens (21 votes)
- D. Papadopoulos, Univ. of Thessaloniki (22 votes).

We should note that even though Prof. X.Moussas received 23 votes, he remains a substitute member of the Council and his position to Council was taken by Prof. D. Hatzidimitriou. This was done because, according to article 31 of the Constitution of Hel.A.S., at least a fraction of 3/7 of the members of the Council should be working outside the Athens metro area.

The newly elected Governing Council of Hel.A.S. convened on July 4 2002 and appointed the officers of the Society for the term 2002-2004. These arr P. Laskarides (President), E.Antonopoulou (Vice-President), K.Tsinganos (Secretary), E.Theodossiou (Treasurer) and D. Hatzidimitriou, M. Mathioudakis and M. Plionis (members), while M. Danezis, T. Grammenos, and D. Papadopoulos (auditors).

2. The first Honorary President of the Hellenic Astronomical Society

During the 18th General Assembly of Hel.A.S., the Academician George Contopoulos was unanimously voted as the 1st Honorary President of the Hel.A.S., after the proposal of its previous Council.

3. Honorary Retirement

During the 7th Astrophysics Summer School, organized by the Institute of Astronomy & Astrophysics of NOA (September 2002), the staff of the IAA presented an honorary medal to Dr. Petros Rovithis for his long-lasting contribution to the National Observatory.

4. International Conference "*Quantum Gravity and Random Geometry*"

Critical questions regarding the fundamental properties of space-time and their Cosmological consequences were discussed in the International Conference "Quantum Gravity and Random Geometry", held in the Orthodox Academy of Crete between the 7th and 15th of September as part of a specialized European Program ("Discrete Random Geometry: from solid state physics to quantum gravity"). The scope of this program is to give the possibility of collaboration between young scientists from different European countries.

The Greek participation to the Program is through the Institute of Nuclear Physics of the Democritus Research Center, with principal Investigator Prof. G. Savvidy, who also organized the previously mentioned conference. Scientists from more than 15 countries participated in this conference, which was dedicated to attempts to construct a concise quantum gravity theory. Among the many issues discussed in the meeting was a new approach, pioneered by Prof. G.Savvidy, which is based on the angle-side (γωνιεδρική =γωνία + έδρα) string theory. For more details check the following webpage:

www.inp.demokritos.gr/~savvidy/eurogrid2002.html

Grant Award "X-ray Astrophysics with ESA's Mission XMM" to the IAA-NOA

The General Secretariat of Research & Technology, after an open call for proposals and an international peer review, have recently funded the X-ray Cosmology Group at the Institute of Astronomy & Astrophysics of the National Observatory of Athens with the amount of 350000€ in order to expand its research on ***X-ray Cosmology and Accretion Processes***. The specific project for which the group is funded is to perform a survey using data from ESA's cornerstone mission XMM. For extended objects (groups and clusters of galaxies) and Active Galactic Nuclei using fields from a wide angle (5 sq. degrees) XMM survey (18 shallow fields, 5 ksec each and one deep field, 30 ksec). These areas are part of the Anglo-Australian telescope 2-df survey and therefore have already complementary imaging and spectroscopic coverage in the optical. The unprecedented effective area and the good spatial resolution of XMM render the scientific output of this survey compelling. The resulting X-ray selected sample of low luminosity clusters and groups of galaxies will have important cosmological implications. The cosmological information will be derived through a) the luminosity-temperature relation in clusters b) morphology studies and the presence of cluster substructure c) the number density of groups and low luminosity clusters and their contribution to the X-ray background d) the metallicity and thus the history of star-formation. Moreover, this XMM survey will be used for the detection of hundreds of obscured AGN yielding information on the accretion history of the Universe. Finally, it will serve as a pilot study for the detection of clusters of galaxies at high redshift (z>1) on *publicly available* fields from the XMM database. As the number density of high redshift clusters is extremely sensitive on cosmological models such a survey will provide tight constraints on the matter density of the Universe. The majority of the detected sources will be Active Galactic Nuclei (AGN). We expect about 500 AGN in our XMM fields. Given XMM's high effective area at hard energies a large number will be heavily obscured AGN, mostly at high redshift. These objects, which remained undetected so far in optical and soft X-ray surveys, will help us to better understand the AGN unification schemes and explore a so far 'hidden' population.

It is worth expanding a bit on the issue of the data that this project will analyse which are mostly data from one of the key guaranteed time XMM projects (University of Leicester/National Observatory of Athens) which is a shallow survey of about 18 fields covering 5 square degrees on the sky. These adjacent fields have been previously observed with the Anglo-Australian 2-degree facility and therefore spectroscopic observations exist for all galaxies and QSOs down to B=19-20 mag. Half of the fields can be observed from both the south and north hemisphere while the other half can be obtained from the south only. The power of the survey's set-up is that as our fields are adjacent we can obtain further spectroscopic follow-up of 10 XMM fields using the 2df in a single observation (eg. in service mode). The National Observatory of Athens has also obtained deeper XMM time (30 ksec in open AO-1 time) on a region covered by the AAT-2df. These observations will be combined with the "shallow" survey in order to extend the luminosity-redshift coverage. Finally, we note that in collaboration with the University of Durham the group has obtained several pointings, with NASA's X-ray mission Chandra, in these areas (10 snapshot observations of 10 ksec each) as well as a deep pointing (75 ksec) on the area of the William Herschel Deep Field. Although the Chandra observations cover an area much smaller than the XMM survey, they may prove very useful in the detection of extended emission in many cases. So far we have obtained the vast majority of our XMM fields (16 out of 18) and analysis is under way.

This project presents unique strengths and benefits for the development of Space Sciences in Greece in the next few years as:

- It is mainly based on data analysis from ESA's cornerstone mission XMM. The Greek Secretariat of Research & Technology (GSRT) is currently under an agreement of scientific collaboration with ESA. The target is for Greece to fully join ESA within the next 4 years. It is evident that the proposed project will provide valuable training for young research personnel in the area of Space Sciences acting as a liaison for future Greek involvement in ESA's X-ray Astronomy missions such as XEUS.
- This project will make extensive use of the Greek ARISTARCHOS 2.3-m telescope and will again help in the training of Greek Researchers in optical observations techniques. This telescope is already built by Carl Zeiss GmbH and will be put at an altitude of 2.300-m on Mount Chelmos, in the Greek mainland. The first light is expected within 2003. This is currently the largest Basic Research Project in Greece representing an investment of 5 M€ and is funded by the GSRT.
- The close links of the *X-ray Cosmology Group* with leading Institutes abroad (Univ. of Leicester, Univ. of Durham, Imperial College, Univ. of Southampton, Center for Astrophysics, GSFC-NASA) guarantees that in the end of the project the IAA of NOA will have developed one of the most experienced groups on X-ray Astronomy and Observational Cosmology in Europe.

Ioannis Georgantopoulos
Manolis Plionis
Emilios Harlaftis

A memorable meeting: Euroconference and IAU Colloquium 188 on "Magnetic Coupling of the Solar Atmosphere", Santorini , June 11-15, 2002

Solar physics is a rapidly evolving research field, which includes theory, data analysis, simulations, and observations made from space and ground observatories. Due to the variety of instruments, observational methods and theoretical tools involved, the solar community has diversified considerably. At the same time a coherent picture of solar physics from deep inside the Sun to large distances is gradually emerging. It was, therefore, considered of utmost importance –and at the same time feasible- that conscious effort should be made to strengthen the coherence of the community and its interdisciplinary links. The spirit of the meeting was to bring together researchers from different subfields of solar physics and give them the opportunity to share their expertise with an ultimate goal to develop a global view of the Sun's atmosphere.

The topic of the meeting was inspired by the recognition that the solar magnetic field, extending from subphotospheric levels up to the corona and the interplanetary medium, is the key agent, which couples the very different solar layers to each other. Indeed, an ongoing study of the solar phenomena suggests that although they occur on vastly different scales, they are, in fact, intimately linked and the linking mechanism is provided by the magnetic field. The magnetic field does not appear at the visible surface in a continuum form but, instead, in an intensely fibril state with almost all of the individual magnetic flux bundles of small diameter (~100 km) below the limit of resolution of existing ground-based telescopes. Nowadays, the scientific challenge is to determine precisely how convection creates the quasi-periodic magnetic fields and why these fields are broken up into the remarkable concentrated fibril form that appears at the visible surface. We also need to know how these fibrils behave as they rise to the surface and emerge into view, where their active dissipation produces the variety of phenomena known as solar activity.

The scientific goal of the meeting was the identification and understanding of the detailed physical processes by which magnetic fields are generated in the solar interior and, rising through the inner atmosphere, couple to the outer atmosphere and ultimately to the heliosphere. The impetus for such a conference was a series of major advances in both observational and theoretical solar physics over the past decade: the results from space missions such as Yohkoh, SOHO and TRACE and from a large number of ground-based telescopes that have enormously advanced our understanding of the role played by the magnetic field in the dynamical state of the solar atmosphere; the development of very sophisticated instrumentation and interpretation techniques that include vector magnetic field measurements, polarimetric analyzers, speckle image reconstruction, inversion techniques, etc; the generally accepted view of the involvement of the magnetic fields in the heating of the solar atmosphere; and the realistic numerical simulations of their three-dimensional behaviour due to the increasing power capabilities of the new generation computers. It was also the realization that we were at a crossroads, where achievements of the previous decade should be appreciated and expectations from an "armada" of new-generation spacecraft to be launched the next years (Solar-B, STEREO, SDO, Solar Probe, Solar Orbiter) and from ground-based instruments to be installed (ATST, SOLIS) should be updated. In this context, the timing for the Euroconference and IAU Colloquium 188 on the Magnetic Coupling of the Solar Atmosphere that took place in Santorini, Greece, on June 11-15, 2002, was ideal. The conference addressed a wide range of topics related to the main characteristics and critical issues of the solar surface magnetism with particular emphasis on how all physical processes and manifestations couple to a global system. The knowledge gained from existing ground-based or space-borne instruments was reviewed. Solar physicists were introduced to the most forefront problems in solar physics and emphasis was given in the scientific merits and prospects of the future ground and space observatories. Specific questions were actively debated by more than the 160 participants from 27 countries worldwide, that attended the meeting. From the participation, the

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International Workshop on "Galaxies and Chaos. Theory and Observations", Athens, September 16 - 19, 2002.

The Research Center for Astronomy (KEAEM) of the Academy of Athens organized an International Workshop on *"Galaxies and Chaos. Theory and Observations"* in Athens on September 16-19, 2002.

A total number of 76 participants from 21 Countries from all over the world attended the Workshop. There were 45 talks (23 of them invited talks) and 10 posters. The Workshop brought together the experience of people working on Galactic Dynamics and Galaxy Formation (theory and observations) with the experience of people working on Nonlinear Dynamical Systems, Celestial Mechanics, Chaotic Dynamics, Integrals of motion, etc.

The talks summarized the most recent advancements in both theoretical and observational aspects of galactic dynamics. The main issue addressed was the role of chaos in galaxies. The study of both stellar and gas motions in galaxies has provided ample evidence in favor of the existence of chaotic structures that affect significantly the morphology and evolution of galaxies. Nonlinear phenomena are particularly important near the main resonances of rotating galaxies (e.g. corotation and the Lindblad resonances) and also near the centers of elliptical galaxies with cuspy density profiles. A comprehensive summary of the new results was made by the chairman of the scientific committee, Prof. G. Contopoulos, during the closing session.

A conclusion drawn from many presentations is that we are entering the era of detecting observational signatures of chaos both in the photometry and the spectroscopy of galaxies, and thus to verify or rule out existing theoretical models. Until now, photometric observations in the near-IR allowed the estimation of the mass distribution in real galaxies and hence the recovering of the gravitational potential. Thus the orbital structure of disk galaxies could be found. The development of the instrumentation promises to give the missing kinematical information, in the near future. Interesting reviews were made regarding the mass distribution of the dark matter, which also affects the orbits of stars in galaxies.

Another subject was that of N-body simulations. These are very helpful in understanding the dynamics induced by the interaction between different components of galaxies. Some impressive applications were presented during the Workshop, including live halos that interact with rotating bars, disk galaxies that merge to form giant elliptical galaxies, collapsing protogalaxies from cosmological initial conditions that form counterrotating cores, and violently relaxing N-body systems with smooth distribution functions.

Finally, there were some very interesting talks on the links between Galactic Dynamics and Nonlinear Dynamics in general. For example, it was shown that concepts from the theory of nonlinear waves, such as solitons and breathers, find very useful applications in collective phenomena appearing in galaxies, such as spirals and bars. In addition, it is possible to find a one to one correspondence between the classical theory of the third integral and the theory of solitons and discrete breathers. It was also interesting to see that the treatment of some quite different problems of celestial mechanics (e.g. the stability of the Trojans or the orbits of planets in newly discovered extrasolar planetary systems) requires methods of chaotic dynamics that are very similar to those applied in galaxies.

Apart from a rich scientific content, all participants expressed their enthusiasm about the hospitality provided to them by the Greek sponsors and hosts. Furthermore, new bonds of friendship were developed during the workshop among the participants. Finally, a comment by Professor Lynden-Bell, University of Cambridge, during the closing session in the Academy building is worth mentioning. He said: "...being in this historical place, the time has come to recognize that the so-called heliocentric system of Copernicus was in fact found about 2000 years ago by Aristarchos in ancient Greece".

Christos Efthymiopoulos
Research center for Astronomy, Academy of Athens

Review Article: Gravitational Wave Astronomy

By Kostas Kokkotas, Aristotelian University of Thessaloniki

In a series of two articles we will try to present the recent developments in the search for the elusive gravitational waves. The successful detection, which is expected in the next 2-3 years, is going to open a new window into the Universe and gravitational wave astronomy will complement the classical astronomy in the exploration of Cosmos. In this first article the reader will be introduced in the theory of gravitational waves while in the next one we will describe the detectors, the sources and the information carried by gravitational waves [1].

In the next few years we will witness the opening of the gravitational window for observing the Universe using a world wide network of cryogenic resonant bar and kilometer baseline interferometric gravitational wave detectors. In less than ten years, the space based gravitational wave antenna, LISA will hopefully launched to routinely observe gravitational waves.

Detection of gravitational waves is important for two reasons: Firstly, their detection is expected to open up a new window for observational astronomy, since the information carried by gravitational waves is very different from that carried by electromagnetic waves. This new window into the Universe will complement our view of the cosmos and will help us unveil the fabric of spacetime around black holes, observe directly the formation of black holes or the merging of binary systems consisting of black holes or neutron stars, search for rapidly spinning neutron stars, dig deep into the earliest moments of the origin of the Universe, and look at the very center of the galaxies, where supermassive black holes weighting millions of solar masses are hidden. These are only a few of the great scientific discoveries that scientists will witness during the first decade of the 21st century. Secondly, detecting gravitational waves is important for our understanding of the fundamental laws of physics; the proof that gravitational waves exist will verify a fundamental 85-year old prediction of General Relativity. Also, by comparing the arrival times of light and gravitational waves from e.g. supernovae, Einstein's prediction that light and gravitational waves travel at the same speed could be checked. Finally, we could verify that they have the polarization predicted by General Relativity.

Gravitational waves are propagating fluctuations of the gravitational field, that is, "ripples" in spacetime, generated mainly by moving massive bodies. These distortions of spacetime travel at the speed of light. Every body in the path of such a wave feels a tidal gravitational force that acts perpendicular to the wave's direction of propagation; these forces change the distance between points, and the magnitude of the changes is proportional to the distance between the points. Gravitational waves can be detected by devices which measure the induced length changes.

The frequencies and the amplitudes of the waves are related to the motion of the masses involved. Thus, the analysis of gravitational waveforms allows us to learn about their source and, if there are more than two detectors involved in the observation, to estimate the distance and position of their source on the sky. Einstein first postulated the existence of gravitational waves in 1916 as a consequence of his theory of General Relativity, but no direct detection of such waves has been made yet. The best evidence, thus far, for their existence is due to the work of 1993 Nobel laureates Joseph Taylor and Russell Hulse. These two scientists observed, in 1974, two neutron stars orbiting faster and faster around each other – exactly at the rate expected if the binary neutron star were losing energy in the form of emitted gravitational waves. The predicted rate of orbital acceleration caused by gravitational radiation emission according to General Relativity was verified observationally, with high precision.

How will we detect them? Up to now, the only indication of the existence of gravitational waves is the indirect evidence that the orbital energy in the Hulse-Taylor binary pulsar is drained away at a rate consistent with the prediction of General Relativity. The gravitational wave is a signal, the shape of which depends upon the changes in the gravitational field of its source. As it has been mentioned earlier, any body in the path of the wave will feel an oscillating tidal gravitational force that acts in a plane perpendicular to the wave's direction of propagation. This means that a group of freely moving masses, placed on a plane perpendicular to the direction of propagation of the wave, will oscillate as long as the wave passes through them, and the distance between them will vary as a function of time as in Figure 1. Thus, the detection of gravitational waves can be accomplished by monitoring the tiny changes in the distance between freely moving test masses. These changes are extremely small; for example when the Hulse-Taylor binary system finally merges, the strong gravitational wave signal that will be emitted will induce changes in the distance of two particles on Earth, that are 1km apart, much smaller than the diameter of the atomic nucleus! To measure such motions of macroscopic objects is a tremendous challenge for experimentalists. As early as the mid sixties, Joseph Weber designed and constructed massive metal bars, seismically isolated, to which a set of piezoelectric strain transducers were bonded in such a way that they could detect vibrations of the bar if it had been excited by a gravitational wave. Today, there is number of such apparatuses operating around the world, which have achieved unprecedented sensitivities, but still they are not sensitive enough to detect gravitational wave.

[1] The non expert reader can omit the section *Fundamentals of Gravitational Wave Theory*.

distance between two well-separated masses. Such devices are basically kilometer sized laser interferometers consisting of three masses placed in an "L" shaped configuration. The laser beams are reflected back and forth between the mirrors attached to the three masses, the mirrors lying several kilometers away from each other. A passing by gravitational wave will cause the lengths of the two arms to oscillate with time. When one arm contracts, the other expands, and this pattern alternates. The result is that the interference pattern of the two laser beams changes with time. With this technique, higher sensitivities will be achieved than those within the reach of the bar detectors. It is expected that laser interferometric detectors will be the first to resolve gravitational wave signals.

Properties of Gravitational Waves: Gravitational waves, once they are generated, propagate almost unimpeded. Indeed, it has been proven that they are even harder to "stop" than neutrinos! The only significant change they suffer as they propagate is the decrease in amplitude while they travel away from their source, and the redshift they feel (cosmological, gravitational or Doppler), as is the case for electromagnetic waves.

There are other effects that marginally influence the gravitational waveforms, for instance, *absorption* by interstellar or intergalactic matter intervening between the observer and the source. *Scattering* and *dispersion* of gravitational waves are also practically unimportant; though they may have been relevant during the early phases of the Universe (this is also true for the absorption). Gravitational waves can be focused by strong gravitational fields and can also be *diffracted*, exactly as it happens with the electromagnetic waves.

There are also a number of "exotic" effects that gravitational waves can experience, which are due to the nonlinear nature of Einstein's equations (purely general-relativistic effects), such as: scattering by the background curvature, the existence of tails of the waves that interact with the waves themselves, *parametric amplification* by the background curvature, *nonlinear coupling of the waves with themselves* (creation of geons, that is, bundles of gravitational waves held together by their own self-generated curvature) and even formation of singularities by colliding gravitational waves. These aspects due to non-linearity affect the majority of gravitational wave sources and from this point of view our understanding of gravitational-wave generation is based on approximations. However, we believe that the error in these approximations for most of the processes that generate gravitational waves is quite small. Powerful numerical codes, using state of the art computer software and hardware, have been developed worldwide for minimizing all possible sources of error.

For most of the properties mentioned above there is a correspondence with electromagnetic waves. But still, gravitational waves are fundamentally different entities when compared to electromagnetic waves, even though they share similar wave properties away from the source. Gravitational waves are emitted by coherent bulk motions of matter (for example, by the implosion of the core of a star during a supernova explosion) or by coherent oscillations of spacetime curvature, and thus they serve as a probe of such phenomena. By contrast, cosmic electromagnetic waves are mainly the result of incoherent radiation by individual atoms or charged particles. As a consequence, from the cosmic electromagnetic radiation we mainly investigate the properties of matter in various regions of the universe, gaining information especially about its temperature and density, or about the existence of magnetic fields. Strong gravitational waves, on the other hand, are emitted from regions of spacetime where gravity is very strong and the velocities of the bulk motions of matter are near the speed of light. Since most of the time these areas are either surrounded by thick layers of matter that absorb the electromagnetic radiation or they do not emit any electromagnetic radiation at all (black-holes), the only way to observe these regions of the universe is via the emitted gravitational waves.

Fundamentals of Gravitational Wave Theory: Let us assume that an observer is far away from a given static matter distribution and the spacetime in which he/she lives is described by a metric $g_{\mu\nu}$. Any change in the matter distribution, will induce a change in the gravitational field, which will be recorded as a change in the metric. The new metric will be

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} + h_{\mu\nu} \qquad (1.1)$$

where $h_{\mu\nu}$ is a tensor describing the variations induced in the spacetime metric. This new tensor describes the propagation of ripples in spacetime curvature, i.e. the *gravitational waves.* In a simplified approximation, which however is appropriate to most situations, one can easily prove (Einstein himself proved it shortly after the discovery of general relativity) that $h_{\mu\nu}$ obeys a simple wave equation

$$\left(-\frac{\partial^2}{\partial t^2} + \nabla^2\right)\tilde{h}^{\mu\nu} = 0 \qquad (1.2)$$

where $\tilde{h}_{\mu\nu}$ is the "trace reverse" of $h_{\mu\nu}$ and describes the gravitational field. Equation (1.2) shows that gravitational waves are spacetime perturbations propagating with velocity c (the speed of light). The solutions of this equation are of the form

$$\tilde{h}^{\mu\nu} = A^{\mu\nu} e^{ik_\alpha x^\alpha} \qquad (1.3)$$

where k_α is a constant 4-vector, the *wave vector* that determines the direction of propagation and its frequency. $A^{\mu\nu}$ is a constant symmetric tensor, the *polarization tensor*, in which information about the amplitude and the polarization of the waves is encoded. It can be shown that $A^{\mu\nu}$ has only two independent components, this means that a gravitational wave is completely described by two dimensionless amplitudes, h_+ and $h_\times$, say. In order to study the effect of gravitational waves on material bodies we will consider two freely moving particles along geodesics with coordinates $x^\mu(\tau)$ and $x^\mu(\tau)+\xi^\mu(\tau)$ (for a given value of the proper time τ, $\xi^\mu(\tau)$ is the displacement vector connecting the two events); it can be shown that in the case of slowly moving particle

$$\frac{d^2\xi^k}{dt^2} \approx \frac{\partial^2 h_j^k}{\partial t^2}\xi^j \qquad (1.4)$$

This is a simplified form of the so called equation of *geodesic deviation*. The solution of this equation for a gravitational wave, with the polarization (+), traveling in the z-direction, says that the measured distance ξ^x between two particles along the x-direction, originally at a distance ξ_0^x, will be

$$\xi^x = \left[1-\frac{1}{2}h_+\cos\left[\omega(t-z)\right]\right]\xi_0^x \qquad (1.5)$$

which implies that the relative distance $\delta\xi^x$ between the two particles will oscillate with frequency ω. This does not mean that the particles' coordinate positions change; instead they remain at rest relative to the coordinates, but the coordinate distance oscillates. Similarly, if the particles were placed originally along the y-direction the coordinate distance would oscillate according to:

$$\xi^y = \left[1+\frac{1}{2}h_+\cos\left[\omega(t-z)\right]\right]\xi_0^y \qquad (1.6)$$

In other words, the coordinate distances along the two axes oscillate out of phase. The effects are similar for the other polarization. This can be visualized in Figure 1, where the effect of a passing gravitational wave on a ring of particles is shown as a series of snapshots closely separated in time. This discussion leads to a very simple formula for the tidal displacement produced by an impinging gravitational wave. The variation of the distance ℓ between two bodies due to an impinging gravitational wave of amplitude h is given by the relation

$$\frac{\Delta\ell}{\ell} = h \qquad (1.7)$$

Gravitational waves carry energy and cause a deformation of spacetime. The stress-energy carried by gravitational waves cannot be localized within a wavelength. Instead, one can say that a certain amount of stress-energy is contained in a region of the space which extends over several wavelengths. For the special case of a plane wave propagating in the z-direction, which we considered earlier, the stress-energy tensor has only three non-zero components, which take the simple form

$$t_{00}^{GW} = \frac{t_{zz}^{GW}}{c^2} = -\frac{t_{0z}^{GW}}{c} = \frac{1}{32\pi}\frac{c^2}{G}\omega^2\left(h_+^{\,2}+h_\times^{\,2}\right) \qquad (1.8)$$

Where t_{00}^{GW} is the energy density, t_{zz}^{GW} is the momentum flux and t_{0z}^{GW} the energy flow along the z-direction per unit area and unit time. The energy flux has all the properties one would anticipate by analogy with electromagnetic waves: (a) it is conserved (the amplitude dies out as $1/r$, the flux as $1/r^2$), (b) it can be absorbed by detectors, and (c) it can generate curvature as any other energy source in Einstein's formulation of relativity. As an example, we will estimate the energy flux in gravitational waves from the core collapse to create a 10 solar mass black hole at a distance of 15 *Mpc* (Virgo cluster). A conservative estimate of the amplitude of the waves on Earth is of the order of 10^{-22} (at a frequency of about 1 *kHz*). This corresponds to a flux of about 3 *erg/cm*^{2}*·s*, which is an enormous amount of energy flux and is about ten orders of magnitude larger than the observed energy flux in electromagnetic waves! The basic difference is the duration of the two signals; the gravitational wave signal will last a few milliseconds while the electromagnetic signal lasts many days.

Generation of Gravitational Waves: For strong gravitational fields there is a number on nonlinear effects that influence the generation and propagation of gravitational waves. For example, nonlinear effects are significant during the last phases of black hole formation. The analytic description of such a dynamically changing spacetime is not possible, and until numerical relativity provides us with accurate estimates of the dynamics of gravitational fields under such extreme conditions we have to rely on order of magnitude estimates only. Furthermore, there are differences in the predictions of various relativistic theories of gravity in the case of high concentrations of rapidly varying energy distributions. However, all metric theories of gravity, as long as they admit the correct Newtonian limit, make similar predictions for the total amount of gravitational radiation emitted by "weak" gravitational-wave sources, that is, sources where the energy content is small enough to produce only small deformations of the flat spacetime, and where all motions are slow compared to the velocity of light.

For general relativity the gravitational radiation is of quadrupolar, or higher, nature and is directly linked to the quadrupole moment of the mass distribution. As early as 1918, Einstein derived the so called quadrupole formula for gravitational radiation. This formula states that the wave amplitude h_{ij} is proportional to the second time derivative of the quadrupole moment of the source:

$$h_{ij} = \frac{2}{r}\frac{G}{c^4}\ddot{Q}_{ij}^{TT}\left(t-r/c\right) \qquad (1.9)$$

Where

$$Q_{ij}^{TT}(x) = \int \rho \left(x^i x^j - \frac{1}{3}\delta^{ij} r^2 \right) d^3x \quad (1.10)$$

is the quadrupole moment in the "Transverse Traceless" gauge, evaluated at the retarded time $t - r/c$ and ρ is the matter density in a volume element d^3x at the position x^i. This result is quite accurate for all sources, as long as the reduced wavelength $\lambdabar = \lambda / 2\pi$ is much longer than the source's size R. One can derive the luminosity in gravitational waves as a function of the third-order time derivative of the quadrupole moment tensor. This is the famous quadrupole formula

$$L_{GW} = -\frac{dE}{dt} = \frac{1}{5}\frac{G}{c^5}\left\langle \dddot{Q}_{ij}\dddot{Q}_{ij} \right\rangle \quad (1.11)$$

Based on this formula, we will derive some additional formulae, which provide order of magnitude estimates for the amplitude of the gravitational waves and the corresponding power output of a source. First, the quadrupole moment of a system is approximately equal to the mass M of the part of the system that moves, times the square of the size R of the system. So the third-order time derivative of the quadrupole moment is:

$$\dddot{Q}_{ij} \sim MR^2/T^3 \sim M\upsilon^2/T \sim E_{ns}/T \quad (1.12)$$

where υ is the mean velocity of the moving parts, E_{ns} is the kinetic energy of that component of the source's internal motion which is non-spherical and T is the time-scale for a mass to move from one side of the system to the other. The timescale (or period) is actually proportional to the inverse of the square root of the mean density of the system $T \sim \sqrt{R^3/GM}$. Then, the luminosity in gravitational waves of a given source is approximately

$$L_{GW} \sim \frac{G}{c^5}\left(\frac{M}{R}\right)^5 \sim \frac{G}{c^5}\left(\frac{M}{R}\right)^2 \upsilon^6 \sim \frac{c^5}{G}\left(\frac{R_{Sch}}{R}\right)^2 \left(\frac{\upsilon}{c}\right)^6 \quad (1.13)$$

Where $R_{Sch} = 2GM/c^2$ is the Schwarzschild radius of the source. It is obvious that the maximum value of the luminosity in gravitational waves can be achieved if the source's dimensions are of the order of its Schwarzschild radius, and the typical velocities of the components of the system are of the order of the speed of light. This explains why we expect that the best gravitational wave sources are highly relativistic compact objects. The above formula sets also an upper limit on the power emitted by a source, which for $R \sim R_{Sch}$ and $\upsilon \sim c$ is:

$$L_{GW} \sim c^5/G = 3.6 \times 10^{59} erg/s \quad (1.14)$$

This is an immense power, often called the *luminosity of the Universe*. Using the above order of magnitude estimates, we can get a rough estimate of the amplitude of gravitational waves at a distance r from the source:

$$h \sim \frac{G}{c^4}\frac{E_{ns}}{r} \quad (1.15)$$

As an example, we consider an event (perhaps a supernovae explosion) in the Virgo cluster, during which an energy equivalent to 10^4 solar masses is released in gravitational waves. The typical frequency is of the order of 1 *kHz* and the duration of the event of the order of 1 *ms*. The gravitational wave amplitude on Earth will be:

$$h \approx 10^{-22}\left(\frac{E}{10^{-4} M_{Sun}}\right)^{1/2}\left(\frac{f}{1\ kHz}\right)^{-1}\left(\frac{\tau}{1\ \ ms}\right)^{-1/2}\left(\frac{r}{15\ \ Mpc}\right)^{-1} \quad (1.16)$$

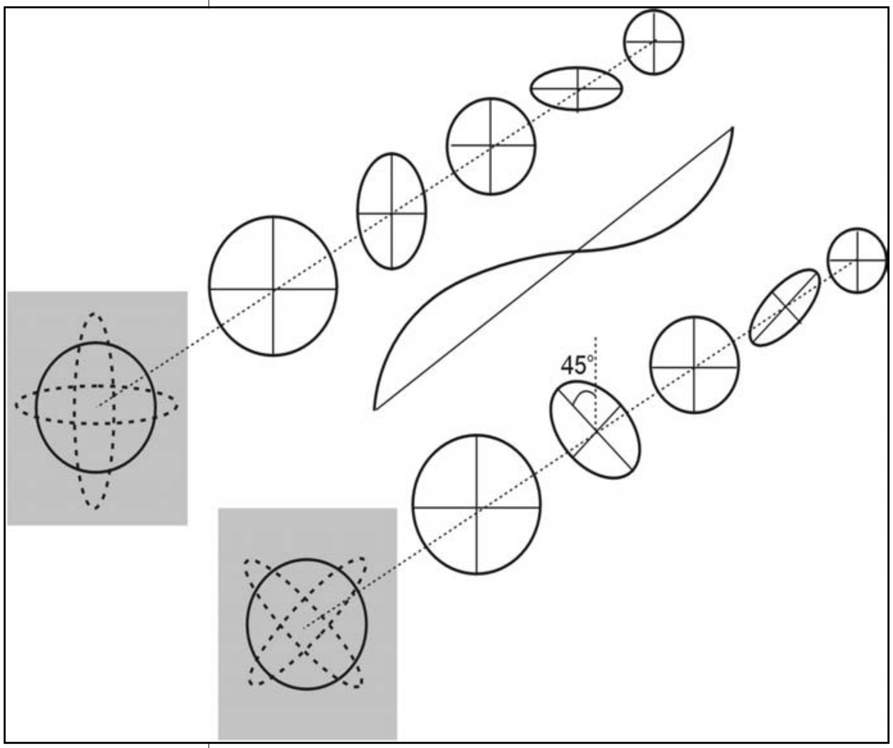

Figure 1: The effects of a gravitational wave traveling perpendicular to the plane of a circular ring of particles are sketched as a series of snapshots. The deformations due to the two polarizations are shown.

For a detector with arm length of 4 km we are looking for changes in the arm length of the order of

$$\Delta\ell = h \cdot \ell = 10^{-22} \cdot 4km = 4 \times 10^{-17} cm!!! \quad (1.17)$$

This explains the difficulty of the task and why all detection efforts till today have not been successful.

Review Article: *How Many Coalescing Binaries are there Waiting to be Detected as Gravitational-Wave Sources ?*

By Vassiliki Kalogera , Northwestern University

Double compact objects (neutron stars and black holes) found in binaries with small orbital separations are known to spiral in and are expected to coalesce eventually because of the emission of gravitational waves. Such inspiral and merger events are thought to be primary sources for ground based gravitational-wave interferometric detectors (such as LIGO). In this article, I present a brief review of estimates of coalescence rates and I examine the origin and relative importance of uncertainties associated with the rate estimates. The implications of these estimates for gravitational wave detection are also discussed.

One of the great challenges of modern astrophysics is understanding the physics of compact objects: white dwarfs, neutron stars (NS), and black holes (BH). These objects are the endpoints of ordinary stars when they run out of nuclear fuel in their cores. Once a core is dead, gravity can either be balanced by pressure forces of high-density, degenerate matter (and thus form a white dwarf or a neutron star), or win altogether and lead to complete gravitational collapse and the formation of a black hole. Binary systems are especially interesting because they can revive the mostly unobservable compact objects as sources of electromagnetic and gravitational radiation. Specifically, the orbital evolution of systems with two compact objects (NS or BH) is driven by the loss of angular momentum and energy due to the emission of gravitational waves. If the binary orbits are tight enough, then the ensuing inspiral can lead to a merger event within a Hubble time.

The prototype progenitor system of such inspiral events is the binary pulsar PSR B1913+16 (the "Hulse-Taylor" pulsar; Hulse & Taylor 1975). Sensitive pulsar timing measurements have revealed that the orbital period decreases at a rate comparable (to better than 1%) to that predicted by general relativity for the emission of gravitational waves (Taylor & Weisberg 1982, 1989). The ultimate coalescence of the two neutron stars seems inevitable.

Although PSR B1913+16 will not reach coalescence for another 300 Myr, similar inspiraling systems in the Milky Way and nearby galaxies are thought to be primary sources of gravitational radiation for ground-based interferometric gravitational-wave detectors, currently in operation or under construction, e.g., LIGO (initial and advanced), VIRGO, GEO600. Such detectors are sensitive to gravitational-wave frequencies in range from a few tens of Hz to possibly up to a few thousand Hz. Given this frequency range they will be sensitive to the very late stages of the inspiral phase when binary orbital periods become shorter than a fraction of a second! The characteristic gravitational-wave signal of an inspiral event is chirp-like: both the amplitude and frequency of the signal increase with time. Given the scales involved such signals in the relevant frequency band are expected to last for just a few minutes. In addition to NS-NS binaries, NS-BH and BH-BH binaries are also expected to form through the evolution of massive binaries and to contribute to the detection of inspiral events.

Assessment of the detectability of compact object inspiral events is crucial for the development of gravitational-wave detectors. It depends on two factors: (i) The strength of the inspiral gravitational radiation signal in the frequency range of interest, which determines the maximum distance (D_{max}) out to which coalescing binaries could be detected given a certain detector. For advanced (and initial) LIGO, the most recent estimates of D_{max} are (Finn 2001): 350 Mpc (20 Mpc) for NS-NS binaries, 740 Mpc (45 Mpc) for NS-BH binaries, and 1000 Mpc (105 Mpc) for BH-BH binaries (assuming 10 $M_\odot$ BH). (ii) The rate of coalescence events out to these maximum distances. This rate depends on our expectation of the Galactic coalescence rates and their extragalactic extrapolation. Using the above D_{max} estimates and the method of extrapolation to galaxies other than the Milky Way developed by Phinney (1991) (based on the blue-light luminosities associated with galaxy star formation history), it can be estimated that the Galactic coalescence rates *required* for and advanced LIGO detection rate of 1-2 events per year are $\sim 10^{-6}\,yr^{-1}$ (NS-NS coalescence) and $\sim 10^{-8}\,yr^{-1}$ (BH-BH coalescence).

On the issue of detectability then the main question concerns estimates of the Galactic coalescence rates derived based on our current astrophysical understanding of coalescing binaries. This question has occupied the astrophysics community for about ten years now. Formation rates of *coalescing* compact binaries (systems with tight enough orbits that merge within a Hubble time $\sim 10^{10}$ yr) have been calculated so far using two very different methods: either entirely theoretically, based on binary evolution models, or, for NS-NS binaries, empirically, based on the observed NS-NS sample. A number of studies have appeared in the literature with a wide range of results that often create a confusing picture for the outside reader. In this article I will present an up-to-date review focusing on our best current bet for a coalescence rate estimate and its most important uncertainties.

Theoretical Rate Estimates: The formation rate of coalescing binary compact objects can be calculated, given a sequence of evolutionary stages leading to binary compact object formation. Over the years, a relatively standard picture has been formed describing the birth of such systems based on considerations of NS-NS binaries (Bhattacharya & van den Heuvel 1991). The main picture is as follows: the initial binary progenitor consists of two binary members massive enough to eventually collapse into a NS or a BH. The evolutionary path involves multiple phases of stable or unstable mass transfer, common-envelope phases (where one or possibly two stellar cores spiral in the envelopes of evolved stars and eventually lead to the ejection of these envelopes), and accretion onto compact objects, as well as two core collapse events. The final outcome of interest is the formation of binary compact objects in close binary orbits.

Such theoretical modeling has been undertaken by a number of different groups by means of population syntheses. This provides us with *ab initio* predictions of coalescence rates. Monte Carlo numerical techniques are employed in following the evolution of a large ensemble of primordial binaries with certain assumed initial properties through a multitude of channels until compact object binaries are formed. The changes in the properties of the binaries at the end of each stage are calculated based on our current understanding of the various evolutionary processes involved: wind mass loss from massive hydrogen- and helium-rich stars, mass and angular-momentum losses during mass transfer phases, dynamically unstable mass transfer and common-envelope evolution, effects of highly super-Eddington accretion onto NS, and supernova explosions with kicks imparted to newborn NS or even BH. Given our limited understanding of some of these phases, the results of population synthesis are expected to depend on the assumptions made in the treatment of the various processes. Therefore, exhaustive parameter studies are required by the nature of the problem. Predictions for coalescence rates are obtained from a calibration of the models based on current estimates of supernova rates (Cappellaro et al. 1999).

Recent studies of the formation of compact objects and calculations of their Galactic coalescence rates (Belczynski, Kalogera & Bulik 2002, and references therein) have explored the input parameter space and the robustness of the results at different levels of (in) completeness. Almost all of these groups have studied the sensitivity of the predicted coalescence rates to the average magnitude of the kicks imparted to compact objects at birth. The range of predicted NS-NS Galactic rates obtained by varying the kick magnitude alone is found in the range $<10^{-7}$ to $\sim 5 \times 10^{-4}$ yr^{-1}. This large range is mainly due to uncertainties associated with supernovae (two in this case) in the evolution of massive binaries. Variations in the assumed mass-ratio distribution for the primordial binaries can *further* change the predicted rate by about a factor of 10, while assumptions of the common-envelope phase add another factor of about 10-100. Variation in other parameters typically affects the results by factors of two or less. Predicted rates for BH-NS and BH-BH binaries lie in the ranges $<10^{-7}$ to 10^{-4} yr^{-1} and $<10^{-7}$ to 10^{-5} yr^{-1}, respectively when the kick magnitude to both NS and BH is varied. Other uncertain factors such as the critical progenitor mass for NS and BH formation lead to variations of the rates by factors of 10-50.

Based on these estimates, expected detection rates for advanced (and initial) LIGO are: 0.1 - 50 yr^{-1} (2×10^{-5} to 10^{-2} yr^{-1}), for NS-NS; 1 - 1000 yr^{-1} (2×10^{-4} to 2×10^{-1} yr^{-1}), for BH-NS; 20 - 2000 yr^{-1} (5×10^{-3} to 4×10^{-1} yr^{-1}), for BH-BH binaries. It is evident that theoretical predictions for coalescence rates cover a wide range of values (typically 3-4 orders of magnitude), because the various input parameters and assumptions affect strongly the absolute normalization (birth rate) of the modeled populations. Given these results, it seems fair to say that, at least at present, population synthesis calculations have a rather limited predictive power and provide fairly loose constraints on coalescence rates. In contrast, predictions of distributions of binary physical properties (e.g., masses, birth orbital separations) exhibit a much higher degree of robustness.

Empirical Rate Estimates: The large range of theoretically predicted Galactic coalescence rates of double compact objects motivates us to examine other ways of obtaining rate estimates. The observed sample of coalescing NS-NS binaries found in the Galactic field (PSR B1913+16 and PSR B1534+12) provides us with alternative estimates of their coalescence rate. “Empirical” estimates can be obtained using the observed pulsar and binary properties along with models of selection effects in radio pulsar surveys (Phinney 1991; Narayan et al. 1991). For each observed object, a scale factor can be calculated based on the fraction of the Galactic volume within which pulsars with properties identical to those of the observed pulsar could be detected by any of the radio pulsar surveys, given their detection thresholds. This scale factor is a measure of how many more pulsars like the ones detected in the coalescing NS-NS systems exist in our galaxy. The coalescence rate can then be calculated based on the scale factors and estimates of detection lifetimes summed up for all the observed systems. Based on this method these first two studies concluded that the NS-NS Galactic coalescence rate is $\cong 10^{-6}$ yr^{-1}.

Since then, estimates of the NS-NS coalescence rate have known a significant downward revision primarily mainly because of the increase of the Galactic volume covered by radio pulsar surveys with no additional coalescing NS-NS being discovered (Curran & Lorimer 1995). Further, it has been realized that a number of upward correction factors must be included, most importantly to account (i) for the beamed nature of pulsar emission and correct for all the binary pulsars with beams that our line of sight does not intersect, and (ii) for the faint end of the pulsar luminosity function and correct for those systems that are too faint to be detected. These two correction (multiplication) factors have so far typically been assumed to be $\cong 3$ and $\cong 10$, respectively.

More recently, we especially focused on all the uncertainties associated with these empirical estimates (Kalogera et al. 2001). We found that the upward correction factor for the faint end of the pulsar luminosity is the most important source of uncertainty. However, it is highly sensitive to the number of observed objects and its distribution function widens dramatically for small-number samples. For a sample of two objects (as the observed one) the faint-pulsar correction factor can vary from very small (close to unity) to as high as ≅ 500 (see following subsection). Beyond the issue of faint pulsars, we considered a number of uncertainties and correction factors. Based on recent observational data for both PSR B1913+16 and PSR B1534+12, we found that the beaming correction factor is higher than previously thought (≅ 6) but with a rather small uncertainty (≅ 10%). Other factors, such as pulsar ages and lifetimes, and spatial distribution, lead to an uncertainty factor of about two.

Small-Number Sample & Pulsar Luminosity Function: One important limitation of empirical estimates of the coalescence rates is that they are derived based on *only two* observed NS-NS systems, under the assumption that the observed sample is representative of the true population, particularly in terms of their radio luminosity. Assuming that the recycled pulsars in NS-NS binaries follow the radio luminosity function of young pulsars and that therefore their true Galactic population is dominated in number by low-luminosity pulsars, it can be shown that the current empirical estimates most probably *under*estimate the true coalescence rate. If a small-number sample is drawn from a parent population dominated by low-luminosity (hence hard to detect) objects, it is statistically more probable that the sample will actually be dominated by objects from the high-luminosity end of the population. The result is that the population overall is thought to be brighter than it really is, and therefore, detectable over a larger Galactic volume. Consequently, the empirical estimates based on such a sample will tend to overestimate the detection volume for each observed system, and therefore underestimate the scale factors and the resulting coalescence rate.

This effect can be clearly demonstrated with a Monte Carlo experiment (Kalogera et al. 2001) using simple models for the pulsar luminosity function and the survey selection effects. As a first step, the average observed

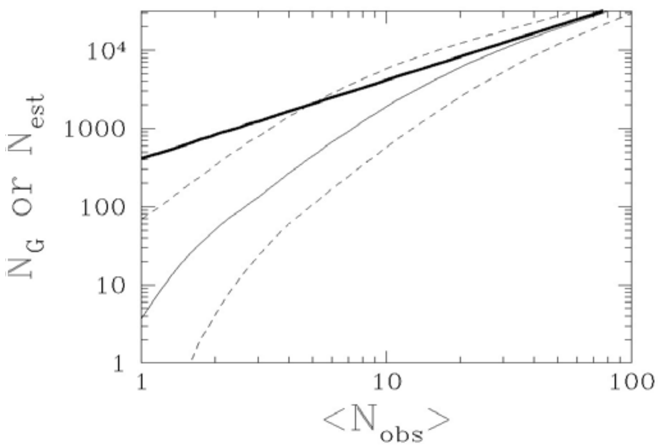

Figure 1:
Bias of the empirical estimates of the NS-NS coalescence rate because of the small-number observed sample. See text for details.

number $<N_{obs}>$ of pulsars is calculated given a known "true" total number of pulsars in the model Galaxy (thick-solid line in Figure 1). As a second step, a large number of sets consisting of "observed" (simulated) pulsars are realized using Monte Carlo methods. These pulsars are drawn from a Poisson distribution of a given mean number ($<N_{obs}>$) and have luminosities assigned according to the assumed luminosity function. Based on each of these sets, one can estimate the total number of pulsars in the Galaxy using empirical scale factors, as is done for the real observed sample. The many (simulated) ``observed'' samples can then be used to obtain the distribution of the estimated total Galactic numbers ($<N_{est}>$) of pulsars. We find that these $<N_{est}>$ distributions are very strongly skewed and lead to possible correction factors for the faint pulsars in a wide range of values (covering typically a couple of orders of magnitude). The median and 25% and 75% percentiles of this distribution are plotted as a function of the assumed number of systems in the (fake) "observed" samples in Figure 1 (thin-solid and dashed lines, respectively).

It is evident that, in the case of small-number observed samples (less than ~10 objects), the estimated total number, and hence the estimated coalescence rate, can be underestimated by a significant factor. For observed samples with an expected number of objects equal to two, for example, the true rate may be much higher by more than a factor as high as ≅ 500. This underestimation factor represents an upward correction factor that must be applied to the rate estimated using the observed sample of *coalescing* NS-NS binaries. We conclude that correcting for the undetected, faint pulsars in the population cannot be decoupled from the problems of a small-number sample because of the assumption of the observed sample being representative of the population, implicit in the method.

Given that this uncertainty cannot be reduced unless more NS-NS systems are discovered, at a minimum we can pose the question: within this large range of uncertainty, can we identify the "most likely" value of the rate ?

The Probability Distribution of Galactic Coalescence Rates: Most recently a new method has been developed that allows the calculation of not just an estimate of the coalescence rate of binary pulsars, but of the detailed rate probability distribution (Kim, Kalogera & Lorimer 2003). For the first time we are in a position to identify the *most likely* value of the rate assign statistical significance to the uncertainties. The method can be applied to any radio pulsar population, but here we are interested in the case of the NS-NS coalescence rate.

Our basic method is one of "forward" analysis. By this we mean that we do not attempt to invert the observations to obtain the total number of NS-NS binaries in the Galaxy. Instead, using Monte Carlo methods, we populate a model galaxy with populations of NS-NS binaries (that match the spin properties of

PSR B1913+16 and PSR B1534+12) with pre-set properties in terms of their spatial distribution and radio pulsar luminosity function.

For a given physical model, we produce synthetic populations of different total numbers of objects (N_{tot}). We then produce a very large number of Monte Carlo realizations of such pulsar populations and determine the number of objects (N_{obs}) that are observable by all large-scale pulsar surveys carried out to date by detailed modeling of the detection thresholds of these surveys. This analysis utilizes code to take account of observational selection effects in a self-consistent manner, developed and described in detail by Lorimer et al. (1993). Performing this analysis for many different Monte Carlo realizations of the physical model allows us to examine the distribution of N_{obs}. We find, as expected and assumed by other studies, that this distribution closely follows Poisson statistics, and we determine the best-fit value of the mean of the Poisson distribution λ for each population model and value of N_{tot}.

The calculations described so far are performed separately for each of PSR B1913+16 and PSR B1534+12 so that we obtain separate best-fit λ values for the Poisson distributions. Doing the analysis in this way allows us to calculate the *likelihood of observing just one example of each pulsar in the real-world sample*. Given the Poissonian nature of the distributions this likelihood is simply: $P(1;\lambda)=\lambda\ \exp(-\lambda)$. We then calculate this likelihood for a variety of assumed N_{tot} values for each physical model.

The probability distribution of the total coalescence rate $\mathcal{R}_{tot}$ is derived using the Bayesian analysis and the calculated likelihood for each pulsar. The derivation of this probability distribution allows us to calculate the most probable rate as well as determine its ranges of values at various statistical confidence levels. Finally, we extrapolate the Galactic rate to the volume expected to be reached by LIGO and calculate the detection rate, $\mathcal{R}_{det}$.

In Figure 2, we show the probability distribution of the total NS-NS coalescence rate in the Milky Way $P(\mathcal{R}_{tot})$ along with the probability distributions for the two types of populations we are considering $P(\mathcal{R}_{1913})$ and $P(\mathcal{R}_{1534})$. It evident that the uncertainty of many orders of magnitude is present but only at very high statistical significance. Even at 99% the uncertainty is restricted to a factor of ~60 (Still large of course but not as large as previously thought!). The peak rate for most of our models is found to be 8 Myr^{-1}. We have explored the sensitivity of the results on the parameters of the assumed spatial and luminosity distributions, and found that the latter is more important. For various models consistent with radio pulsar observations, the most likely values for the detection rates are ~(1 - 30) x 10^{-3} yr^{-1} and ~4 - 100 yr^{-1}, for the initial and advanced LIGO, respectively.

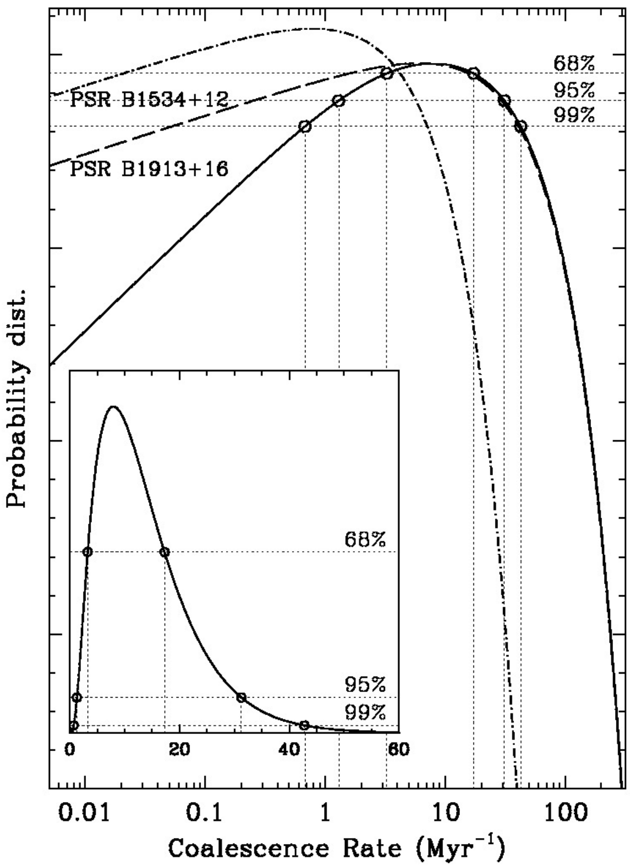

Figure 2:
The probability distribution function of coalescence rates in both a logarithmic and a linear scale (small panel). The solid line represents $P(\mathcal{R}_{tot})$ and the long and short dashed lines represent $P(\mathcal{R})$ for PSR B1913+16 like and PSR B1534+12 like populations, respectively. The dotted lines indicate the confidence levels for $P(\mathcal{R}_{tot})$.

Conclusions: So far we have dealt with coalescing binaries formed in galactic fields. Formation of coalescing binaries in globular clusters involves a whole range of very different processes mostly dominated by stellar interactions and also differs because of the absence of ongoing star formation over timescales comparable to the lifetimes of these binaries. The contribution of clusters to NS-NS coalescence has been found to be negligible (Phinney 1991). However, a recent study (Portegies, Zwart & McMillan 2000) examined the formation of BH-BH binaries with coalescence times shorter than 10^{10}yr and concluded that their formation rates are quite high possibly leading to advanced LIGO detection rates of ~100 per year (one event per two years for the initial LIGO). Although these predicted rates may be lower because of necessary cosmological corrections and loss of systems with very short coalescence timescales, they are still more than encouraging!

Clearly the answer to the question of detection rates is clouded by large uncertainties. However, overall it seems fair to say that, despite the uncertainties, the prospects for gravitational wave detection of

Continued in page 18

Greece as a partner in OPTICON

OPTICON is a research Infrastructure Coordination Network (ICN, 2000-2003) funded by the European Commission's 5th Framework Programme (**FP5**). It is managed by a consortium of partners (the Executive or Managerial Board) consisting of: (a) national funding agencies, (b) operators of major ground-based facilities (including ESO) and (c) a number of individual Institutes. It is chaired by Professor **G. Gilmore** (Institute of Astronomy, University of Cambridge, UK). Under the management of the Board seven working groups have been established in order to implement a variety of strategic activities concerning European co-operative astronomical research (see http://www.astro-opticon.org).

One of the most active working groups is the one dealing with the Coordinated Operation of Medium-Sized European Telescopes (**COMET**) in which the National Observatory of Athens, equipped with its new acquisition - the 2.3m ARISTARCHOS telescope - participated actively from the onset of the working group. Now, with the space and the new generation of 8m-10m telescopes, the role and scientific potential of the medium-sized telescopes is been re-considered in order to enhance their efficiency and productivity. One of the aims of the COMET network is to subsidize travel and subsistence for European astronomers to work with medium size telescopes on high-quality scientific programs, promoting international cooperation and training of young scientists. National observing time will be opened to European astronomers, who do not have access to such facilities, using a user-fee system (cash for time) implemented through COMET.

Until now, European facilities have been diverse and mostly confined within national borders. Often, due to lack of cooperation, their activities are duplicated. In an attempt to solve these problems, the COMET working group has brought together the major operators of 2m-4m telescopes in Europe (ESO, Canary Observatories, EAS and other smaller organizations) and has initiated a dialogue for coordinating and integrating their activities.

Under the 6th Framework Program (**FP6)** for Research and Technology (which was launched in November 2002), the EC DG XII, with a budget ~5% of the total public national budgets in EU, is promoting the European Research Area using three new tools: (a) integrated projects, (b) centres of excellence and (c) large infrastructures (see FP6 document on ERA; *Physics Today*, September 2002 and http://europa.eu.int/comm/research/conferences.2002/index_en.htm). It is envisaged that 15-20 large infrastructures will be funded by FP6 for the next 4-5 years to facilitate common research infrastructures in Europe. At the moment, several proposals are being actively prepared by European scientists on several topics including *neutron and muon beam sources, astro-particle physics, radio astronomy* and, of course, *optical and infrared astronomy (OPTICON)* to mention a few from the physics community).

It is obvious that, within the framework of FP6, the OPTICON infrastructure network will be transformed to a much larger entity embracing the European astronomical activities in the optical and infrared. Its Executive Board will be formed by representatives from national funding agencies aiming (a) to strengthen the entire European astronomical community (integrating the medium-size facilities under a single virtual infrastructure, promoting new technologies, enhancing the human potential across Europe) and (b) to build the largest optical telescope in the world (ELT). Greece was invited to join the present Executive Board at the Paris 2002 Board meeting and participate in the developments. There, Greece was represented (for the first time) in the OPTICON Board by the Greek National Committee for Astronomy (GNCA), the advisory committee for astronomy matters to the General Secretariat of Research and Technology (GSRT) of the Ministry of Development. In Paris, the new management structure was defined. Individual activities were split into *networks*, *transnational access* and *joint research projects*. During the discussions, it was confirmed that the National Observatory of Athens (NOA), will participate in the transnational access activity COMET with its new 2.3m telescope. During the next meeting, at Tenerife, Spain, on January 24th 2003, the full draft proposal for the Integrated Infrastructure Initiative (I3; a new initiative by the EC for large European infrastructures) of FP6 will be presented for final discussion before submission to the EC in April 2003. It is anticipated that Greece will be represented to the next Executive (managerial) Board by GNCA/GSRT and to the Medium-Sized European Telescopes activity by NOA (2.3m ARISTARCHOS telescope).

The final meeting of OPTICON's Executive Board under FP5 will be held at Chania, Crete, in September 2003, where hopefully the announcement of funding the next OPTICON I3 proposal (under FP6), will be celebrated. This will be a historic step, with perhaps profound implications, for European astronomy and its future but also a very important step for the Greek community which will enjoy the benefits immediately: access and traveling expenses to large European telescopes (including ESO/La Silla, La Palma, Calar Alto, UKIRT/Mauna Kea), access to technology projects and partial operational expenses to NOA for opening up its new 2.3m telescope to the European community. Indeed, OPTICON offers the first international cooperation for astronomical research, which will boost further the already advancing Greek astronomical community (see related article by Harlaftis, this issue) through its interaction with ESO, PPARC, the Max Planck Society, CNRS and other European organizations.

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BOOK REVIEWS

Order and Chaos in Dynamical Astronomy

by George Contopoulos

Springer, Berlin, 2002. ISBN:3540433600

Chaotic dynamics was born at about the beginning of the 20th century, with the works of Henri Poincare' on the orbits of the restricted three -body problem. The big progress in this scientific field is linked with the evolution of computers, which has taken place in the last few decades. Nevertheless, before the computers era, there have been major theoretical advancements, such as the KAM theory and the application of a ``third'' integral in conservative systems. Nowadays chaos is important for many branches of science and technology and is ubiquitous in all kinds of dynamical systems we encounter in astronomy. How well can one summarize the evolution of the ideas in non-linear dynamics over one century and simultaneously review the contribution of the chaos theory in our understanding of so many astronomical phenomena? Very well indeed, judging from the book *Order and Chaos in Dynamical Astronomy*, by George Contopoulos, which appeared recently in the series ``Astronomy and Astrophysics Library'' of Springer-Verlag, Berlin-Heidelberg, 2002.

At nearly 600 pages the book covers all topics related with non-linear dynamics in astronomy. It is divided in four parts. The *first part* is a historical introduction, unique in books on dynamical systems. The reader can also find a newly proposed classification of dynamical systems that goes beyond the old concepts of either integrable, or fully ergodic systems. The *second part* is a comprehensive and lucid introduction to order and chaos in general. The reader will appreciate the presentation of all kind of dynamical phenomena one could meet in papers on this subject and the clarification of the relevant terms. There is of course no room here to name all of them. I will only quote some of the topics touched. Thus, the reader can find information about: integrable and chaotic systems, KAM theory, Nekhoroshev theory, adiabatic invariants, asymptotic curves and homoclinic points, cantori and stickiness, diffusion, escapes, dynamical spectra, Lyapunov Characteristic Numbers, N-body chains, fractals, and many others. The *third,* and in my view the most exciting part of the book, deals with order and chaos in galaxies. Galactic dynamics, together with celestial mechanics, is the branch of astronomy which has mostly benefited by the progress of order and chaos theory. Here is presented the state of the art of the subject, valuable for anyone working on the field. Some of the topics treated are: Periodic orbits in non-rotating and rotating galaxies, resonances, third integrals in galaxies, the dynamics behind the morphology of spiral and barred galaxies, the dynamics of ellipticals, secular evolution, galaxy formation, statistical mechanics and N-body simulations. The *fourth* and last part elaborates non-linear phenomena in celestial mechanics, general relativity and cosmology. Here one reads about orbits in the restricted 3-body problem, order and chaos in the solar system, orbits in the general theory of relativity, and the mixmaster universe model. The book concludes with a list of open problems.

The book is intended to serve both as a textbook on dynamical systems for students in physics as well as a reference for researchers and succeeds in both goals. The widespread interest in non-linear dynamics has produced a number of excellent monographs on the subject. However, there was until now not a single example where the researcher could find the latest ideas in the field and by the same token a reference to all topics needed for the advancement of his/her own research. In this respect it fills a gaping hole in the relevant literature. Written by a person who plays for more than 50 years a seminal role in the development of chaos theory in astronomy, the book is also particularly useful for graduate students. It leads them right up to the forefront of current research and helps equip them with useful tools and sound intuition for research beyond.

Panos .A. Patsis

KEAEM, Athens Academy

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Colleagues, participate and express your views !

Astronomy Paper Growth in Greece between 1981-1998

In a recent article, the number of astronomy papers published at MNRAS, AA, ApJ and AJ were shown for the period 1981-2001 (408 for 1981-1998; Harlaftis, Ventura and Seiradakis, 2002, Hipparchos, No. 11). Data compiled by Paul Murdin from ISI's National Science Indicators (1999 release) gives for Greece a larger number of papers (993) since more journals are included under the search field "astrophysics". Table 1 shows the refereed paper numbers and citations for the world, USA and the EU (total and individual countries) which can help the reader in deducing various estimates.

Table 1: Note that for individual countries the numbers are correct but their total sum exceeds the world total since for example a paper with authors from Greece and the UK counts twice. Note that the quoted EU total is more representative (with both authors in the EU, the paper will count only once under an "EU" search in the ISI database).

	Citations	Papers	%
WORLD	2.128.346	114.168	100.0
US	1.078.024	54.897	48.1
EUROPEAN UNION	622.349	46.497	40.7
UK	227.514	13.971	12.2
GERMANY	179.649	12.794	11.2
FRANCE	115.541	8.858	7.8
ITALY	83.314	7.473	6.5
NETHERLANDS	76.491	4.333	3.8
SPAIN	29.765	3.406	3.0
SWEDEN	22.119	1.592	1.4
BELGIUM	12.219	1.246	1.1
DENMARK	14.501	1.092	1.0
GREECE	**5.022**	**993**	**0.9**
FINLAND	8.121	915	0.8
AUSTRIA	4.461	659	0.6
NORWAY	4.889	484	0.4
IRELAND	2.688	240	0.2
PORTUGAL	745	129	0.1

Table 2 includes columns of the normalised paper number of Greece (by 993/408) and the world for each year between 1981-1998. The growth in published output is graphically displayed for a number of EU countries, including Greece for comparison (the logarithmic scale is better suited to present the different growth rates). Greece shows the largest growth rate at the figure, second only to Spain, with local peaks of output at the years 1985, 1994 and 2000. The average growth rate between 1981-1998 is 3.5 ranging between 2.6 to 4.3 at the 90% significance level which exceeds considerably the world (similar to EU/USA) average increase of 1.6 for the same period and resulted in passing the 1% world output, for the first time, in 1994 and then again in 1998.

Table 2: Data from Harlaftis et al. (*Hipparchos, No. 11, 2002*) but normalised to total No of papers by 993/408.

Year	Greek papers	World papers
1981	19	5139
1982	19	4899
1983	27	5149
1984	36	4819
1985	44	5406
1986	49	5950
1987	36	5694
1988	46	5759
1989	29	5865
1990	39	6250
1991	41	6269
1992	44	6504
1993	66	6970
1994	90	7845
1995	58	7936
1996	66	7912
1997	78	8312
1998	87	7490

This is a considerable achievement since if one considers the poor resources available by the state (instrumentation, post-doctoral fellowships, studentships, software/hardware, travel expenses, operational and development expenses for facilities), the productivity increase effectively may be even larger than the EU/USA average (but it has to be shown by a separate study including normalisations for population and GDP).

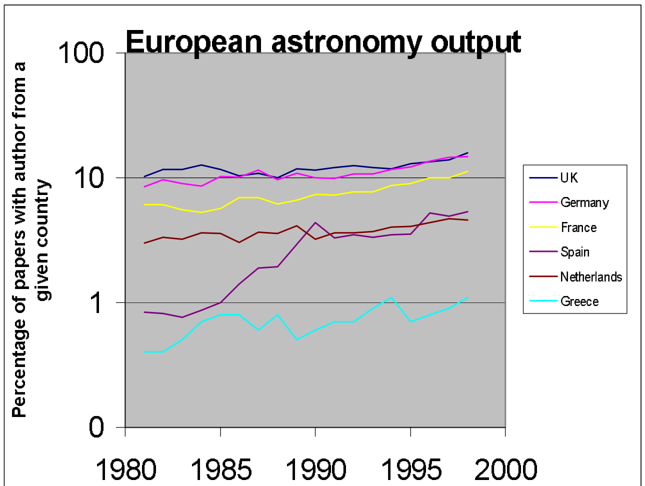

Figure 1: Published paper growth for a number of European countries (color coded as indicated). Greece shows the second largest growth rate after Spain.

It is notable that the current trend is still increasing, reaching 5.5 times the output for the period 1999-

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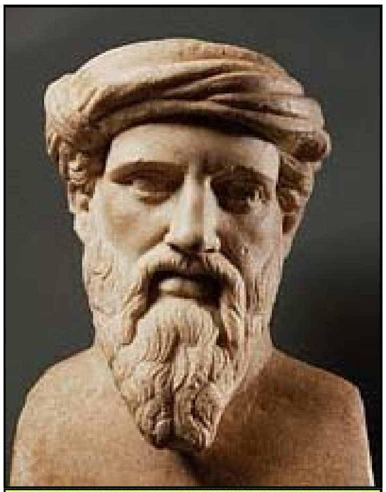
EDITOR'S COMMENT

For those interested in the history and evolution of human thought, the question of who was the first to put forward the heliocentric model for the motion of our planetary system has a special place. It is now well established that *Copernicus* was not the first to put forward this model but rather it was *Aristarchos of Samos*, student of *Straton* from *Lampsakos* and head of the *Peripatic School* of thought, around 280 BC. However, scientific and gnosiologic breakthroughs come about after the "painful" and slow accumulation of knowledge through the centuries of human experience. The bases that allowed *Aristarchos* to reach his conclusion should be searched at least to two sources: (a) to the Pythagoreans and especially to *Philolaos of Croton* who lived the 5th century BC in "*Magna Grecia*" and the work of which is said to have influenced the writings also of *Timeus* by *Plato* and (b) to *Heraclides of Pontos* who lived the 4th century BC and who was an offspring of Platos Academy. *Philolaos* (literally meaning *friend of the People*) was a student of *Lysis,* one of the two only Pythagoreans that survived the destruction of the Pythagorean brotherhood in Croton by its ruler. It seems that *Philolaos* himself did not avoid a similar end to his predecessors. He was murdered accused erroneously of wanting to establish tyranny in Croton (a common excuse used to exterminate opponents at those times). *Philolaos* put forward a Cosmological model in which the Cosmos and all it contains are made of infinite and finite things. According to *Stobaios*, in the model of *Philolaos* the *Cosmos* is one and started structuring itself from a center outwards. The center is the *Estia,* the central fire, then is *Antihthon*, then the Earth that moves in a circular orbit around the *Estia* and exactly anti-diametrical with *Antihthon* (for which reason we cannot see this body), then the moon, the Sun that just reflects the light of the *Estia*, and the other cosmic bodies. According also to *Diogenius Laertius, Philolaos* was the first to put forward the notion of the circular motion of the Earth, although he also mentions another possibility of a predecessor to this idea, *Iketas of Syracuse.* In any case it seems that the idea that the Earth moves in an orbit around a hot central object was a necessary prior step that helped *Aristarchos of Samos* to put forward the heliocentric model of planetary motion. Furthermore, the outcome of the studies of *Herclides* gave a further push to *Aristarchos* in forming his model. *Heraclides* found out that Mercury and Venus always appear within a limiting angular separation from the Sun and concluded that this could be only due to their revolution around the Sun and not the Earth, creating therefore the notion of another center of revolution of the heavenly bodies. Furthermore, he also suggested that the apparent revolution of the Cosmos around the Earth could be due to an actual revolution of the Earth around its own axis, if such did exist. Therefore, these two fundamental observations seem to have opened the way for *Aristarchos* to put forward his truly revolutionary theory. Although we do not have direct evidence that *Aristarchos* did prove his suggestion, since his relevant book is lost and we know it only through *Archimedes*, in his book *"Psammites",* it did have a huge impact to the establishment of his time, which can be compared to the impact that all revolutionary theories have, that of *Copernicus* as well. It created a backclash and a condemnation of *Aristarchos* and his teachings, seen as a challenge to the "theocratic" establishment. For example, it is said that *Cleanthis*, the head of the Stoics in Athens called for the condemnation of *Aristarchos* as an "atheist". The ideological marginalization of Aristarchos was so efficient that only one more of the ancients is known to have supported his heliocentric views, which as we saw before were the ripe fruit of the accumulated knowledge of the previous generations of physical philosophers. *Selefcos of Babylon*, who lived a century later than *Aristarchos*, attempted to establish the heliocentric model but in vain. It took humanity more than 1800 years to put Sun to its rightful position and shift the geocentric view to the so-called *Copernician* world view.



Pythagoras:

Capitoline Museum, Rome Italy (there are no monuments depicting Aristarchos of Samos or Philolaos of Croton).

Ancient Coin depicting Pythagoras

Continued from page 4

discussions and the interaction among participants our impression is that the meeting was successful and that it accomplished its scientific goal. It was also generally felt that more such well focused meetings should be organized in the future.

The SOC and the LOC had made every effort to invite young review speakers and support young applicants in order to attend the meeting. The program was specially designed to give some young researchers the chance to present results of their work probably for the first time in an international conference. It is worth noting the active presence of the Greek solar community, especially of several young researchers, who gave oral talks (Archontis, Georgoulis, Nindos, Patsourakos, Tziotziou) or presented their work in posters. Dr Bonnet, ex-ESA's scientific director, in his closing remarks mentioned that he was impressed by the active participation and the skills of our young colleagues. He probably didn't know that almost all these young solar physicists are working abroad and that they can easily find employment in Europe or the United States, but unfortunately not in their motherland.

The great success of the meeting would have been impossible without the efforts and assistance of many people and institutions. The meeting was sponsored by the European Commission, while the IAU provided supplemental funding that permitted the participation of several young and senior solar physicists from non-European countries. Additional funding came from several sponsors like the Max-Planck Institut fuer Aeronomie, Astrium, ESA, Hellenic Aerospace Industry, Euro bank and the University of Athens. Apart from the members of the LOC, i.e., A. Anastasia is and G. Tsiropoula from the National Observatory of Athens, K. Tsinganos and P. Preka-Papadema from the University of Athens, and L. Vlahos from the University of Thessaloniki, active contributions to the success of the meeting came also from the following: K. Tziotziou, D. Paronis, G. Karagiannidis, A. Maraghoudaki, M. Glezos, M. Lignos and C. Doumas.

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the inspiral of compact binaries appear to be quite promising, when it comes to BH-BH binaries with the) initial interferometers, and even with the pessimistic estimates for the advanced interferometers.

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Continued from page 16

2001 in comparison to the output in the beginning of the 1980's. Spain displays the largest growth in astronomical literature (13 times during the period 1981-1998) placing the country in the top-10 world league now, obviously a combined result of state support – astronomy in Spain is designated nationally as a high priority science area - and international cooperation (using its natural resources, particularly the observing sites in the Canary Islands, under a very effective management). In comparison, Greece has a healthy production rate of astronomical papers when compared with other EU countries of similar population (Portugal, Austria). However, it has half the production of papers and 1/3 the citation impact of Finland (normalised to the population) whose technology expertise and participation in the Nordic Optical Telescope has led her to a successful ESA membership a couple of years ago and most likely to ESO membership by 2003.

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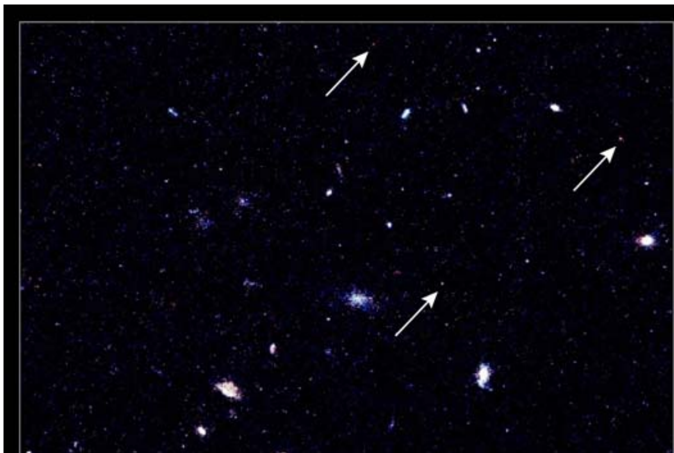
Continued from page 2

5. Witnessing the end of the Cosmic "Dark Ages"

NASA recently released a report regarding a very exciting discovery. Researchers using the Hubble Space Telescope "saw" the end of the cosmic "Dark Ages" about a billion years after the Big-Bang.

Modern cosmological theories hold that for a period of time after the Big-Bang the universe was in pure darkness. Time had to pass before the temperature would drop sufficiently to form neutral hydrogen atoms from free protons and electrons. More time had to pass for matter fluctuations to collapse and form the first gravitationally bound objects that emit ultraviolet radiation. However, the abundant neutral hydrogen absorbed such radiation and only after a period of about a billion years, when the hydrogen becomes re-ionized, light from the first galaxies can penetrate the "dark" veil and reach the observer. An Arizona State University team using Hubble's Advanced Camera for Surveys and studying a small part of the sky near the constellation of Virgo, found a large umber of faint objects that may be young star-forming galaxies seen when the universe was less than a billion years old. The team of experts estimate that at least 400 million such objects filled in the entire universe at this cosmic epoch to the limiting magnitude of this Hubble image.



Distant Galaxies
Hubble Space Telescope • Advanced Camera for Surveys
NASA, H.-J. Yan, R. Windhorst and S. Cohen (Arizona State University) • STScI-PRC03-01b

6. A New Planet, *Quaoar*, revolving around our Sun?

Recent observational indications, from NASA's Hubble space telescope, have brought about the possible existence of a tenth member of the family of planets of the Solar system. It appears to have half the size of Pluto and it is the farthest object ever detected to revolve around the Sun, at a distance of ~$4x10^9$ miles. The discoverers, Michael Brown and Chadwick Trujillo of Caltech, used a ground based telescope to discover "Quaoar", and the Advanced Camera for Surveys on the Hubble Space Telescope to estimate its true angular size (it has a diameter of ~1300 km). Its orbit was estimated to be very circular while its volume is more than that of all the asteroids put together. The name of this possibly icy world, given by the two scientists that discovered it, is the name of the creation God of a Californian native American tribe.

Artist's View of Kuiper Belt Object "Quaoar"
NASA and G. Bacon (STScI) • STScI-PRC02-17a

7. Poetry and Astronomy event

On the 20th of September 2002 the Institute of Astronomy & Astrophysics of the National Observatory of Athens together with the British Council organized a novel *Poetry and Astronomy* evening on the Nymphs's hill-side, where the National Observatory of Athens resides. In an atmosphere of passion, under the moonlight, the mildly lighted domes of the Sina building and of the Doridis telescope and opposite the holy rock of Acropolis, Greek and British poets read poetry regarding the Stars and Cosmos. The poems were read by the well known Greek theatrical actor George Kimoulis and the distinguished British poet and critic of the *Times Literary Supplement*, Lavinia Greenlaw, who came to Greece specifically for this event. The whole event was coordinated with brief literary contributions by the Director of the Institute of Astronomy & Astrophysics, Prof. Christos Goudis. From the Greek side poems were read of Kostis Palamas, Odisseas Elytis, Georgios Seferis, Andreas Empeirikos, Nikos Eggonopoulos, Titos Patrikios and Christos Goudis, whereas from the British part poems were read of T. S. Eliot, W. H. Auden, Gerald Manley Hopkins, Robert Garioch and Lavinia Greenlaw.

The large audience waited patiently after the end of the event, to visit the historical Dorides telescope, which opened to the public for the first time after many years. This exciting tour was led by Nikos Matsopoulos who showed to the public the operation of the telescope and responded to their many enquiries after they had the opportunity to observe the moon. Furthermore, the event was supported by known amateur astronomers who excited the public with their telescopes and observations of many celestial objects.

The event was greeted by the Director of the British Council in Greece, Chris Hickey, while decisive to the success of the event was the role of Kostas Caldis, Mary Charoyianni and Harris Karnezi of the British Council. The poems and other texts of the event, relevant articles of Lavinia Greenlaw and Christos Goudis as well as British poems, translated by Christos Goudis, have been published (January 2003) in an artistic volume of the cultural center of Patras "About Arts" under the title "Poetry and Astronomy", edited by Christos Goudis himself.

The poet Lavinia Greenlow, Prof. Christos Goudis and the actor George Kimoulis during the Poetry and Astronomy Evening.

8. The New Astronomical Station of NOA on Helmos (by P.Hantzios)

The National Observatory of Athens finished the construction of the new astronomical station on the "Neraidorrahi" top of Mount Helmos at an altitude of 2340 meters above sea level. The new station will house the 2.3-m ARISTARCHOS telescope in 2003. The whole project was funded by EPET II of GSRT, with a total budget of 5.173.573 Euros, and it started on July 1998 with Carl Zeiss Jena GmbH being the contractor for the construction of the 2.3-m optical telescope. The Greek construction company PROTER A.T.E. constructed the new astronomical station, performing a work of excellent quality in a very short time interval (2 summers) and being congratulated for this by German technical companies. The new observatory consists of two buildings: the telescope tower and the operation and control building. The two buildings are 35 meters away from each other so that human activity and the heat from machines, computers, etc, do not affect the performance of the telescope and particularly the image quality. The observatory is equipped with a 4x4 vehicle, a snow vehicle, power generators, computer center, microwave link with Penteli, and can accommodate up to 4 observers and technicians. The "ARISTARCHOS" telescope is now on the final stages of its construction in Jena – Germany and is expected to be installed on Mt. Helmos in 2003. With the installation of the new remotely controlled telescope our country will import advanced technology and will be able to participate in modern observational projects. Moreover, since the new telescope will be the largest telescope in the Balkans and the East Mediterranean, Greece will play an important role in the direction of a wide astronomical collaboration in the area. In addition, "ARISTARCHOS" will be able to

The operation and control building

The telescope tower

be connected to scientific institutions, schools, etc, through the network and contribute to the propagation of astronomy, and education of the public.

Are you a member of the Hellenic Astronomical Society ? Have you paid your membership fee ?