HIPPARCHOS

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50 Years of Space Exploration

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towards the next 50 years of space exploration

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Hipparchos publishes review papers, news and comments on topics of interest to astronomers, including matters concerning members of the Hellenic Astronomical Society

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Cover photo:
The participants of the 8th Hel.A.S. Conference at the Makryammos bungalows in the island of Thassos. See related article on page 34.

Editorial assistance is needed!

To improve the contents of Hipparchos please provide us with information related to your Institute or with exciting news from your field of research.

BRIEF SCIENCE NEWS

REVIEWS

CONFERENCES

Editorial

During the last four years I served as the editor of Hipparchos. It was really an exciting time and I am sure that my successor will realize the importance and the excitement of this duty. I would like to thank all the authors who volunteered to contribute in the various issues and special thanks go to our President (Kanaris Tsinganos), our Secretary (Vasillis Charmandaris) and to Manolis Plionis for their continuous input and editorial assistance. I am also grateful to ZITI Publications and especially to Nikos Nikolaidis for the careful editing and the time that they put in bringing Hipparchos in its present standards. Finally, I would like to thank all of you for giving me the opportunity to serve as the editor of Hipparchos.

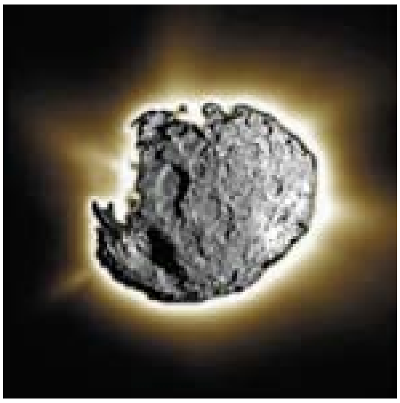
Kostas Kokkotas

Message from the President

Dear Hel.A.S. members,

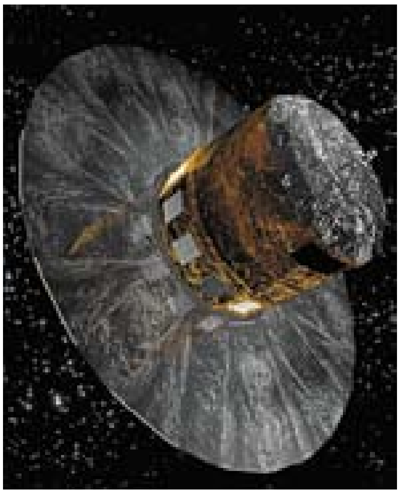
You have in your hands the 4th issue of the new (2nd) Volume of Hipparchos, the bi-annual publication of the Hellenic Astronomical Society. As the tradition holds, this note is a good opportunity for the President of Hel.A.S. to introduce you to the highlights of the issue and also summarize for you the important events that took place within our professional Society in the intervening several months since the publication of the previous issue last summer.

Thus, the present issue contains several interesting research articles written by Greek astrophysicists working abroad and in our country. We start with the closest star to us and its impressive workings in the Heliosphere inside which we live, the realm of the Sun, this brilliant *Rosetta Stone* of Astrophysics. Among the objects that periodically catch the public attention in our Heliosphere are Comets, first named by Aristotle who used the name *kometes* to depict them as "stars with hair". Presently, there are more than 3500 recorded comets, small pieces of precious debris left over from the formation of the Solar System. It was the interaction of those Comets with the solar wind which inspired Parker to formulate his celebrated solar wind theory. An interesting Comet who visits the inner solar system every 3.3 yrs is Encke, first discovered in 1786 and the second periodic Comet after Halley's famous one. Another conspicuous sight in the Heliosphere are Coronal Mass Ejections (CME), catastrophic ejections of billions of tons of hot and magnetized solar plasma zipping through the interplanetary medium with millions of km per hour, a nightmare for astronauts in space, or, high technology devices onboard hundreds of satellites. Dr Angelos Vourlidas, a prominent member of our Society who works at the U.S. Naval Research Laboratory, describes in the corresponding article recent interesting results on how Encke lost temporarily his tail during its interaction with a strong CME.



The next article is by a junior member of our Society, Dr Stelios Kazantzidis (USA), who takes us to the other extreme of astrophysical scales, the realm of the distant galaxies and supermassive black holes (SMBH). The discovery that massive galaxies host SMBHs at their center is one of the most important results of Astronomy of the last decade. In the accepted paradigm of structure formation, the *cold dark matter* model, galaxies merge continuously forming progressively large objects. A natural consequence of hierarchical merging is that two SMBH originally inside their parent galaxy might actually brought very close to each other during this galaxy interaction and eventually they may merge if their separation becomes small enough. This coalescing BHs should be the strongest emitters of gravitational waves (GW) and thus test Einstein's theory of General Relativity. Depending on their mass, this happens when the black holes approach to within a small fraction of a pc. The Laser Interferometer Space Antenna (LISA) which will be launched in the next decade jointly by our own ESA and NASA, has been specifically designed to detect such GWs from merging SMBH with masses from 10^4 to 10^7 Mo. It is thus important to determine the rate of galaxy mergers and subsequently the binary SMBH coalescence rates. Simulations in supercomputers are presently under way to determine those rates and solve the so-called *last pc problem*, and therefore estimate the likelihood of GW detection by LISA.

From the Sun and the cosmological distances, the third article brings us back in between, to the classical vast realm of the constituents of the Universe, galaxies, stars and the GAIA/ESA mission. GAIA is an ESA astrometry space mission, which is expected to be launched by ESA in the second half of 2011. It will determine the positions, distances and annual proper motions of about one billion of stars to magnitude 20 with an accuracy of about 20 μas at 15 mag and 200 μas at 20 mag. It will also provide radial velocity measurements, spectrophotometric and multi-epoch observation of each detected object. It will thus create an extremely precise 3-D map of stars throughout our Milky Way and beyond which will encode the origin and subsequent evolution of the Milky Way. This informative article is written by Prof. Mary Kontiza of the University of Athens, and



her recently finished PhD student, P. Tsalmantza. It refers to the Hellenic contribution to the preparation of GAIA mission, namely an extended library of synthetic galaxy spectra. The preparatory work discussed in the article will be valuable during the 2011-2016 period when GAIA will obtain low resolution optical spectrophotometry of several millions of unresolved galaxies all over the whole sky. It is a good example of the detailed studies performed in anticipation of the operation of the great space observatories.

Finally, from the visible spectrum, the fourth article co-authored by three scientists of the University of Crete, Prof. Despina Hatzidimitriou, her graduate student Ms. Valia Antoniou and Dr. Andreas Zezas who will soon commence his appointment Assistant Professor in Crete. This article takes us to star formation via X-rays and the high mass X-ray binaries in the neighboring Small Magellanic Cloud. These interesting stellar pairs, contain hot giant/supergiant stars and objects at the end of their stellar evolution surrounded by episodic accretion disks fueled by Roche lobe overflows, or stellar winds. Studying the star formation history in galaxies is among the most important studies in modern Astrophysics. The article takes advantage of recent Chandra and XMM surveys and one of its main goals is to investigate the connection between star formation history and X-ray binaries populations.

As for Hel.A.S., the central event of last year was the organization of the 8th Meeting of our Society in Thassos island, from September 13th to 15th, 2007. This was really a superb quality astronomical conference in a marvelous island.

Besides the many interesting contributed talks, the 8th conference was highlighted by very interesting reviews delivered by top European and American scientists, with a special session commemorating the 50th anniversary of Space exploration, after the launch of Sputnik in October 1957. The head of the Local Organizing Committee, Prof. Fr. George Anagnostopoulos of the Democritus University of Thrace, with the help of the other members of the Local Organising Committee made this conference a reality with unparallel enthousiasm and professionalism. There is an item in this issue with more details on this meeting. A proposal for next, 9th, Hel.A.S. Conference is that it takes place in Athens. An effort will be made to coordinate this event with other activities that will take place in Athens as part of the International Year for Astronomy 2009.

In the beginning of April, 2008 the minister of Development and the GSRT, Prof. I. Tsoukalas, named the new National Greek Committee for Astronomy (GNCA), the official body that advises the Greek Government on issues of Astronomy. The Chairman of the GNCA is now prof. C. Goudis, Director of the Institute of Astronomy and Astrophysics of the NOA with members, prof. N. Spyrou (University of Thessaloniki), prof. N. Kylafis (University of Crete), prof. V. Geroyannis (University of Patras) and myself representing the University of Athens and the Hel.A.S. Substitute members are I. Daglis, (Director of the Institute of Space Applications and Remote Sensing of NOA), M. Plionis (Institute of Astronomy and Astrophysics of the NOA), J. Seiradakis (University of Thessaloniki), I. Papamastorakis (University of Crete) and H. Varvoglis (University of Thessaloniki). It is worth to mention that this GNCA has an even geographical and scientific representation, including the Hel.A.S. as well, as it was proposed to the government by the previous GC of Hel.A.S. We thank the Chairman of the previous Committee, P. Laskaridis who worked well and in close coordination with Hel.A.S. during the previous GNCA term, to promote the interests of Hellenic Astronomy in various ways. It should also be noted that the president of Hel.A.S. has been named a member also of the new term starting in 2008 of the National Council for Research and Technology.

It is certainly good news also for Hellenic Astronomy that the National Council for Research and Technology unanimously approved the creation of a new Institute for Space and Ground-based Astrophysics at the Foundation for Research and Technology, in Heraklion, Crete. We hope that soon this new Institute will be materialized and will be a center of excellence in Astrophysics, continuing the research tradition already established by the Astrophysics group of the University of Crete and the Skinakas Observatory.

Finally, the end of the 2-year term of the present GC of the Society is almost in sight and, as you know, this coming June 20th we have elections for President and members of the GC of Hel.A.S. It is the appropriate time, then, to summarize the main achievements of the present GC since its election in September 2006. These were mainly directed towards im-

Message from the President *(cont'd)*

proving the services and the structural operation of Hel.A.S. In brief:

- ✓ The Hel.A.S has now a new, very functional and aesthetically appealing webpage (http://www.helas.gr).
- ✓ The contents and appearance of the monthly e-newsletter and Hipparchos have been upgraded.
- ✓ For transparency and better information, we commenced the policy of making the minutes of the meetings of the GC available in the webpage of Hel.A.S.
- ✓ For the convenience of our members all financial transactions with the Society, such as payment of the membership fees, can be done online using a credit card.
- ✓ The GC systematically used the possibilities of e-teleconferencing to minimize the operational expenses of the Society.
- ✓ The 8th Astronomical Conference of Hel.A.S. in the island of Thassos continued the good tradition of high quality conferences organized by the Society.
- ✓ Special volume of HIPPARCHOS devoted to the astronomical infrastructure in Greece
- ✓ Hel.A.S. continued sponsoring the Panhellenic high school student competition organized successfully by the Volos' Society of Astronomy and Space.
- ✓ The finances of the Society have improved, despite expenses associated to the previous mentioned activities.
- ✓ The status of the members of the Society has also improved. Many new members joined the Society over the past year, and most of members are active in the Society and they have fulfilled their financial obligations.
- ✓ Together with the GNCA the Hel.A.S. supported a petition to the government for financing the completion of the Aristarchos telescope at the Helmos Observatory.
- ✓ Four new fellowships were inaugurated by the National Fellowship Foundation (IKY) for post graduate studies in Astronomy, Astrophysics and Space Physics.

Clearly there is still plenty of room for more improvements in the Hellenic astronomical scene, many of which will be realized by careful coordination between Hel.A.S. and GNCA. The most import of all is to continue mounting pressure on the government for financing research groups in Astrophysics and Space missions (ESA), as well as to provide the funds necessary for joining ESO, and to support Astronomy in all wavelengths of the spectrum in our country.

Nevertheless, for making reality the above achievements, I would like to personally thank all members of the present GC, such as I. Daglis, M. Plionis and I. Papadakis. In addition, I thank the vice-president Kostas Kokkotas, a member of the Council of Hel.A.S. for the last four years, for his superb efforts as the editor of this continuously upgraded Hipparchos. Due to the constitutional rules, Kostas is not a candidate for the upcoming elections for the new GC, but we hope that he will have an equally good successor for the edition of Hipparchos.

I also thank the Secretary, Vassilis Charmandaris for his untiring efforts on several items having to do with a better organisational structure of HelAS, in particular, the preparation of the monthly e-newsletter, the new form of the webpage, etc. The Treasurer Apostolos Mastichiadis should also be acknowledged for his continuous efforts to achieve and maintain a healthy budget.

We hope that the elected GC will add new dimensions and new momentum in further promoting the interests of Hellenic Astronomy.

Kanaris Tsinganos

Astronomers Find One of the Youngest and Brightest Galaxies in the Universe*

NASA's Hubble and Spitzer space telescopes, with a boost from a natural "zoom lens," have uncovered what may be one of the youngest and brightest galaxies ever seen in the middle of the cosmic "dark ages," just 700 million years after the beginning of our universe.

The detailed images from Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) reveal an infant galaxy, dubbed A1689-zD1, undergoing a firestorm of star birth during the dark ages, a time shortly after the Big Bang but before the first stars reheated the cold, dark universe. Images from NASA's Spitzer Space Telescope's Infrared Array Camera provided strong additional evidence that it was a young star-forming galaxy in the dark ages.

"We certainly were surprised to find such a bright young galaxy 12.8 billion years in the past," said astronomer Garth Illingworth of the University of California, Santa Cruz, and a member of the research team. "This is the most detailed look to date at an object so far back in time."

"The Hubble images yield insight into the galaxy's structure that we cannot get with any other telescope," added astronomer Rychard Bouwens of the University of California, Santa Cruz, one of the co-discoverers of this galaxy.

The new images should offer insights into the formative years of galaxy birth and evolution and yield information on

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* Reprinted from the NASA/HST web site http://hubblesite.org/newscenter/archive/releases/2008/08/

Astronomers Find One of the Youngest and Brightest Galaxies in the Universe *(cont'd)*

the types of objects that may have contributed to ending the dark ages. The faraway galaxy also is an ideal target for Hubble's successor, the James Webb Space Telescope (JWST), scheduled to launch in 2013.

During its lifetime, the Hubble telescope has peered ever-farther back in time, viewing galaxies at successively younger stages of evolution. These snapshots have helped astronomers create a scrapbook of galaxies from infancy to adulthood. The new Hubble and Spitzer images of A1689-zD1 show a time when galaxies were in their infancy.

Current theory holds that the dark ages began about 400,000 years after the Big Bang, as matter in the expanding universe cooled and formed clouds of cold hydrogen. These cold clouds pervaded the universe like a thick fog.

At some point during this era, stars and galaxies started to form. Their collective light reheated the foggy, cold hydrogen, ending the dark ages about a billion years after the Big Bang.

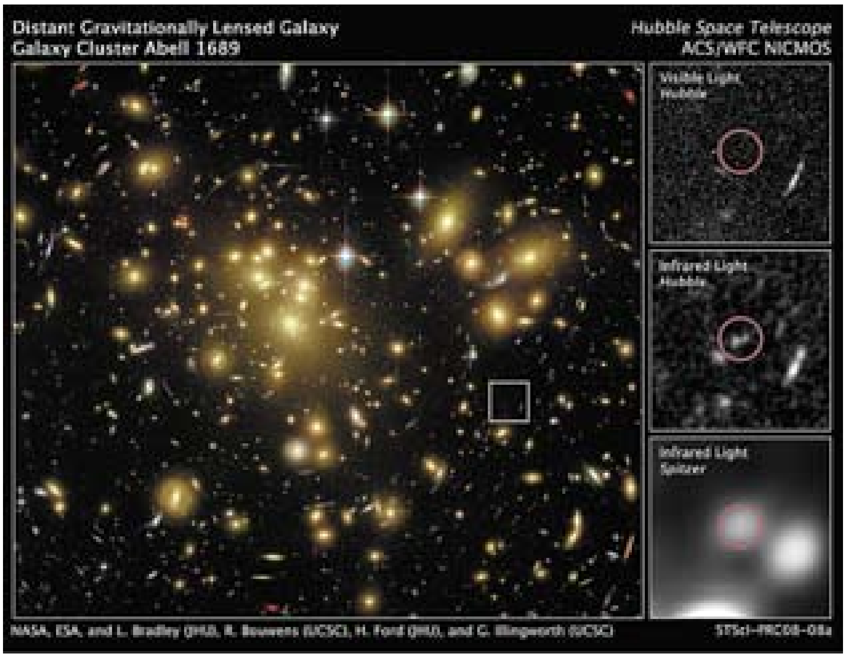
"This galaxy presumably is one of the many galaxies that helped end the dark ages," said astronomer Larry Bradley of Johns Hopkins University in Baltimore, Md., and leader of the study. "Astronomers are fairly certain that high-energy objects such as quasars did not provide enough energy to end the dark ages of the universe. But many young star- forming galaxies may have produced enough energy to end it."

The galaxy is so far away it did not appear in images taken with Hubble's Advanced Camera for Surveys, because its light is stretched to invisible infrared wavelengths by the universe's expansion. It took Hubble's NICMOS, Spitzer, and a trick of nature called gravitational lensing to see the faraway galaxy.

The astronomers used a relatively nearby massive cluster of galaxies known as Abell 1689, roughly 2.2 billion light-years away, to magnify the light from the more distant galaxy directly behind it. This natural telescope is called a gravitational lens.

Though the diffuse light of the faraway object is nearly impossible to see, gravitational lensing has increased its brightness by nearly 10 times, making it bright enough for Hubble and Spitzer to detect. A telltale sign of the lensing is the smearing of the images of galaxies behind Abell 1689 into arcs by the gravitational warping of space by the intervening galaxy cluster.

The images reveal bright, dense clumps of hundreds of millions of massive stars in a compact region about 2,000 light-years across, which is only a fraction of the width of our Milky Way Galaxy. This type of galaxy is not uncommon in the early universe, when the bulk of star formation was taking place, Bradley and Illingworth said.



Spitzer's images show that the galaxy's mass is typical to that of galaxies in the early universe. Its mass is equivalent to several billions of stars like our Sun, or just a tiny fraction of the mass of the Milky Way.

"This observation confirms previous Hubble studies that star birth happens in very tiny regions compared with the size of the final galaxy," Illingworth said.

Even with the increased magnification from the gravitational lens, Hubble's sharp "eye" can only see knots of the brightest, heftiest stars in the galaxy. The telescope cannot pinpoint fainter, lower-mass stars, individual stars, or the material surrounding the star- birthing region. To see those things, astronomers will need the infrared capabilities of NASA's JWST. The planned infrared observatory will have a mirror about seven times the area of Hubble's primary mirror and will collect more light from faint galaxies. JWST also will be able to view even more remote galaxies whose light has been stretched deep into infrared wavelengths that are out of the reach of NICMOS.

"This galaxy will certainly be one of the first objects that will be observed by JWST," said team member Holland Ford of Johns Hopkins University. "This galaxy is so bright that JWST will see its detailed structure. This object is a pathfinder for JWST for deciphering what is happening in young galaxies."

The astronomers noted that the faraway galaxy also would be an ideal target for the Atacama Large Millimeter Array (ALMA), which, when completed in 2012, will be the most powerful radio telescope in the world. "ALMA and JWST working together would be an ideal combination to really understand this galaxy," Illingworth said, noting that "JWST's images and ALMA's measurement of the gas motions will provide revolutionary insights into the very youngest galaxies.".

Hubble Finds First Organic Molecule on an Exoplanet[*]

NASA's Hubble Space Telescope (HST) has made the first detection ever of an organic molecule in the atmosphere of a Jupiter-sized planet orbiting another star. This breakthrough is an important step in eventually identifying signs of life on a planet outside our solar system.

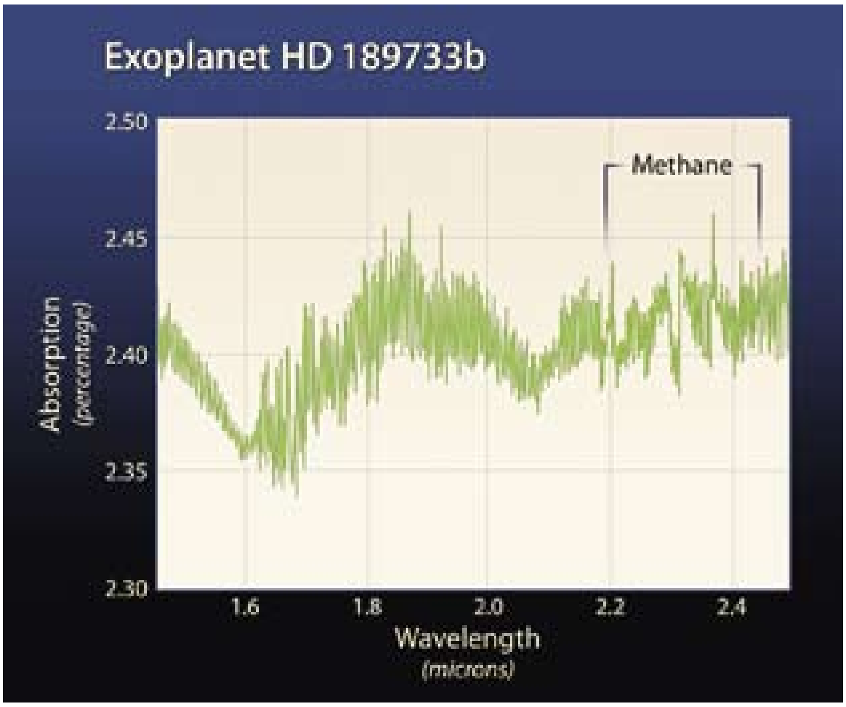
The molecule found by Hubble is methane, which under the right circumstances can play a key role in prebiotic chemistry –the chemical reactions considered necessary to form life as we know it.

This discovery proves that Hubble and upcoming space missions, such as NASA's James Webb Space Telescope, can detect organic molecules on planets around other stars by using spectroscopy, which splits light into its components to reveal the "fingerprints" of various chemicals.

"This is a crucial stepping stone to eventually characterizing prebiotic molecules on planets where life could exist," said Mark Swain of NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif., who led the team that made the discovery. Swain is lead author of a paper appearing in the March 20 issue of Nature.

The discovery comes after extensive observations made in May 2007 with Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS). It also confirms the existence of water molecules in the planet's atmosphere, a discovery made originally by NASA's Spitzer Space Telescope in 2007. "With this observation there is no question whether there is water or not – water is present," said Swain.

The planet now known to have methane and water is located 63 light-years away in the constellation Vulpecula. Called HD 189733b, the planet is so massive and so hot it is considered an unlikely host for life. HD 189733b, dubbed a "hot Jupiter," is so close to its parent star it takes just over two days to complete an orbit. These objects are the size of Jupiter but orbit closer to their stars than the tiny innermost planet Mercury in our solar system. HD 189733b's atmosphere swelters at 1,700 degrees Fahrenheit, about the same temperature as the melting point of silver.



The near-infrared spectrum of HD189733b.

Though the star-hugger planet is too hot for life as we know it, "this observation is proof that spectroscopy can eventually be done on a cooler and potentially habitable Earth-sized planet orbiting a dimmer red dwarf–type star," Swain said. The ultimate goal of studies like these is to identify prebiotic molecules in the atmospheres of planets in the "habitable zones" around other stars, where temperatures are right for water to remain liquid rather than freeze or evaporate away.

The observations were made as the planet HD 189733b passed in front of its parent star in what is known as a transit. As the light from the star passed briefly through the atmosphere along the edge of the planet, the gases in the atmosphere imprinted their unique signatures on the starlight from the star HD 189733.

The astronomers were surprised to find that the planet has more methane than predicted by conventional models for "hot Jupiters." "This indicates we don't really understand exoplanet atmospheres yet," said Swain.

"These measurements are an important step to our ultimate goal of determining the conditions, such as temperature, pressure, winds, clouds, etc., and the chemistry on planets where life could exist. Infrared spectroscopy is really the key to these studies because it is best matched to detecting molecules," said Swain. Swain's co-authors on the paper include Gautam Vasisht of JPL and Giovanna Tinetti of University College, London/European Space Agency.

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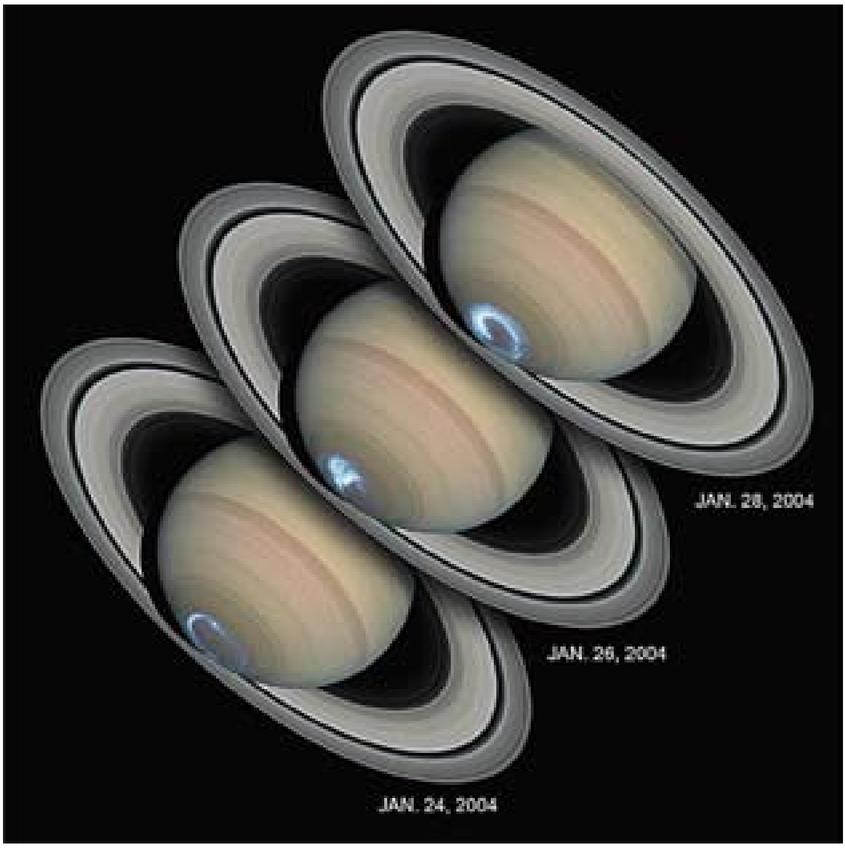
[*] Reprinted from the HST web site http://hubblesite.org/newscenter/archive/releases/2008/11/

Selection of Cosmic Vision 2015-2025 missions

Following the evaluation of proposals by the Solar System Working Group, following Solar System missions were selected by the Space Science Advisory Committee (SSAC) for further assessment and consideration for launch in 2017/2018:


JAN. 28, 2004
JAN. 26, 2004
JAN. 24, 2004

Cross-Scale - multi-scale coupling in space plasmas

Cross-Scale, proposed to employ 12 spacecraft, would make simultaneous measurements of plasma on different scales at shocks, reconnection sites, and turbulent regions in near-Earth space. It will address fundamental questions such as how shocks accelerate and heat particles or how magnetic reconnection phenomena generate or convert energy. If approved, the mission would be implemented in collaboration with JAXA, the Japanese space and exploration agency. There is a Greek participation in this mission through the Institute for Space Applications & Remote Sensing of the National Observatory of Athens (Dr. A. Anastasiadis).

Laplace - a mission to Europa and the Jupiter System

The Jovian System, with Jupiter and its moons, is a small planetary system in its own right. Unique among the moons, Europa is believed to shelter an ocean between its geodynamically active icy crust and its silicate mantle. The proposed mission would answer questions on habitability of Europa and of the Jovian system in relation to the formation of the Jovian satellites and to the workings of the Jovian system itself. The mission will deploy three orbiting platforms to perform coordinated observations of Europa, the Jovian satellites, Jupiter's magnetosphere and its atmosphere and interior. If approved, the mission would be implemented in collaboration with JAXA and NASA.

Marco Polo - a near-Earth object sample return mission

A sample-return mission to a near-Earth object (NEO), Marco Polo would characterise a NEO at multiple scales and return a sample. If approved, the mission would study the origins and evolution of the Solar System, the role of minor bodies in the process, origins and evolution of Earth and of life itself. It would consist of a mother satellite which would possibly carry a lander , sampling devices, reentry capsule as well as instruments. If approved, the mission would be implemented in collaboration with JAXA.

TANDEM - Titan AND Enceladus Mission

TANDEM has been proposed to explore two of Saturn's satellites (Titan and Enceladus) in-situ and from orbit. Building on questions raised by Cassini, the mission would investigate the Titan and Enceladus systems, their origins, interiors and evolution as well as their astrobiological potential. The mission would comprise two spacecraft - an orbiter and a carrier which will deliver a balloon and three probes onto Titan. If finally approved, the mission would be implemented in collaboration with NASA. There is a wide Greek participation in this mission through the Academy of Athens (Dr. S.M. Krimigis), the University of Athens (Prof. X. Moussas), the Foundation for Research & Technology in Crete (Prof. I. Vardavas), the Democritus University of Thrace (Prof. E.T. Sarris) and the Institute for Space Applications & Remote Sensing of the National Observatory of Athens (Dr. I.A. Daglis).

It is expected that a first down-select between Laplace or TANDEM, i.e. Jupiter or Saturn targets, will be made in consultation with foreign partners in the coming years.

Ioannis A. Daglis

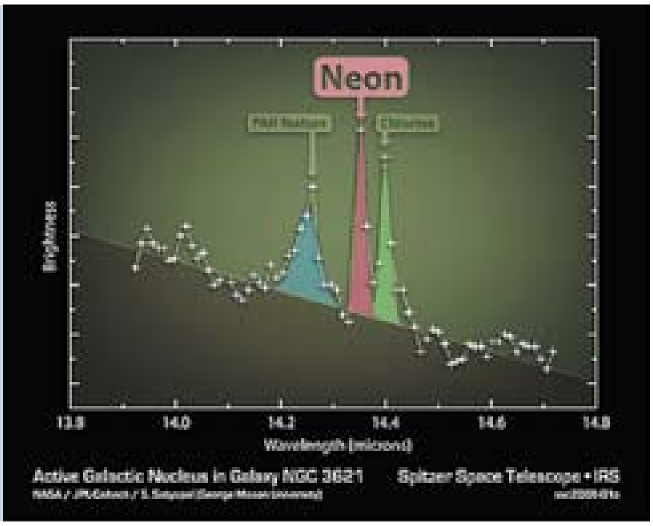
Institute for Space Applications and Remote Sensing / National Observatory of Athens

Thin Galaxies Grow Fat[*]

NASA's Spitzer Space Telescope has detected plump black holes where least expected – skinny galaxies.

Like people, galaxies come in different shapes and sizes. There are thin spirals both with and without central bulges of stars, and more rotund ellipticals that are themselves like giant bulges. Scientists have long held that all galaxies except the slender, bulgeless spirals harbor supermassive black holes at their cores. Furthermore, bulges were thought to be required for black holes to grow.

The new Spitzer observations throw this theory into question. The infrared telescope surveyed 32 flat and bulgeless galaxies and detected monstrous black holes lurking in the bellies of seven of them. The results imply that galaxy bulges are not necessary for black hole growth; instead, a mysterious invisible substance in galaxies called dark matter could play a role.



Part of the mid-infrared spectrum of NGC3621 obtained with the Infrared Spectrograph (IRS) on Spitzer. The presence of the [NeV] line at 14.3μm, with an ionization potential of 97eV, reveals the existence of an accretion disk around a central supermassive black hole.

«This finding challenges the current paradigm. The fact that galaxies without bulges have black holes means that the bulges cannot be the determining factor,» said Shobita Satyapal of the George Mason University, Fairfax, Va. «It's possible that the dark matter that fills the halos around galaxies plays an important role in the early development of supermassive black holes.»

Satyapal presented the findings today at the 211th meeting of the American Astronomical Society in Austin, Texas. A study from Satyapal and her team will be published in the April 10 issue of the Astrophysical Journal.

Our own Milky Way is an example of a spiral galaxy with a bulge; from the side, it would look like a plane seen head-on, with its wings out to the side. Its black hole, though dormant and not actively «feeding,» is several million times the mass of our sun.

Previous observations had suggested that bulges and black holes flourished together like symbiotic species. For instance, supermassive black holes are almost always about 0.2 percent the mass of their galaxies' bulges. In other words, the more massive the bulge, the more massive the black hole. Said Satyapal, «Scientists reasoned that somehow the formation and growth of galaxy bulges and their central black holes are intimately connected.»

But a wrinkle appeared in this theory in 2003, when astronomers at the University of California, Berkeley, and Observatories of the Carnegie Institution of Washington, Pasadena, Calif., discovered a relatively «lightweight» supermassive black hole in a galaxy lacking a bulge. Then, earlier this year, Satyapal and her team uncovered a second supermassive black hole in a similarly svelte galaxy.

In the latest study, Satyapal and her colleagues report the discovery of six more hefty black holes in thin galaxies with minimal bulges, further weakening the «bulge-black hole» theory. Why hadn't anybody seen these black holes before? According to the scientists, bulgeless galaxies tend to be very dusty, letting little visible light escape. But infrared light can penetrate dust, so the team was able to use Spitzer's infrared spectrograph to reveal the «fingerprints» of active black holes lurking in galaxies millions of light years away.

«A feeding black hole spits out high-energy light that ionizes much of the gas in the core of the galaxy,» said Satyapal. «In this case, Spitzer identified the unique fingerprint of highly ionized neon – only a feeding black hole has the energy needed to excite neon to this state.» The precise masses of the newfound black holes are unknown.

If bulges aren't necessary ingredients for baking up supermassive black holes, then perhaps dark matter is. Dark matter is the enigmatic substance that permeates galaxies and their surrounding halos, accounting for up to 90 percent of a galaxy's mass. So-called normal matter makes up stars, planets, living creatures and everything we see around us, whereas dark matter can't be seen. Only its gravitational effects can be felt. According to Satyapal, dark matter might somehow determine the mass of a black hole early on in the development of a galaxy.

«Maybe the bulge was just serving as a proxy for the dark matter mass – the real determining factor behind the existence and mass of a black hole in a galaxy's center,» said Satyapal.

Other authors of this study include: D. Vega of the George Mason University; R.P. Dudik of the George Mason University and NASA Goddard Space Flight Center, Greenbelt, Md.; N.P. Abel of the University of Cincinnati, Ohio; and Tim Heckman of the Johns Hopkins University, Baltimore, Md.

NASA's Jet Propulsion Laboratory, Pasadena, Calif., manages the Spitzer Space Telescope mission for NASA's Science Mission Directorate, Washington. Science operations are conducted at the Spitzer Science Center at the California Institute of Technology, also in Pasadena. Caltech manages JPL for NASA. Spitzer's infrared spectrograph was built by Cornell University, Ithaca, N.Y. Its development was led by Jim Houck of Cornell.

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[*] Reprinted from the NASA/SSC web site http://www.spitzer.caltech.edu/Media/releases/ssc2008-01/release.shtml

ESA's cosmic vision program: the Astronomy missions

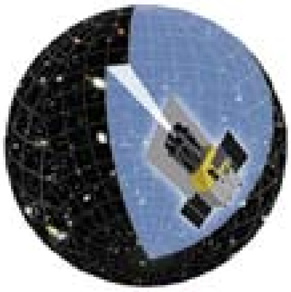
by Ioannis Georgantopoulos, *Institute of Astronomy & Astrophysics, National Observatory of Athens*

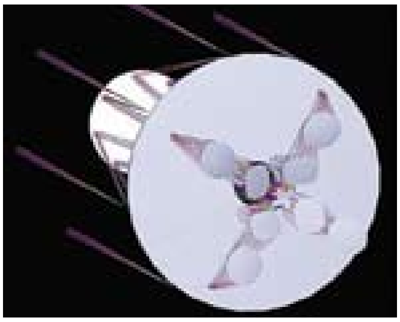
In its October 2007 meeting, the Space Science Advisory Committee (SSAC) of the European Space Agency, after hearing the recommendations of the Astronomy Working Group has decided on the candidate future European astronomy missions.

The candidate missions have been divided in two classes according to their cost envelope. The medium M-class missions for which the ESA contribution should amount up to 300 M€ and the large L-class missions with a contribution up to 600 M€.

Dark Energy

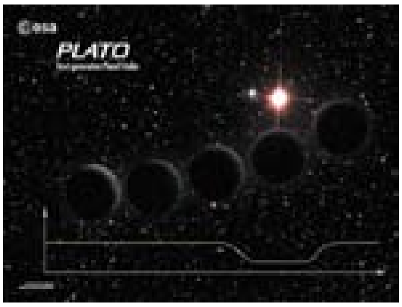
The large scientific importance of a **Dark Energy** mission has been recognized. Two such M-class proposals have been received: the **Dune** mission (Dark Universe Explorer) and **SPACE** (near-infrared all-sky cosmic explorer). Both missions propose to pursue the same science goal, the nature of the dark energy, but through different means. SPACE proposes to study the distribution of galaxies by obtaining spectra for millions of galaxies on the sky, while Dune is a photometric mission and will observe the effects of Dark Energy through weak lensing i.e. the tiny distortion of the shapes of galaxies due to the gravitational effects of intervening large gravitational potential wells**.** It has been decided that a follow-up study will evaluate the benefits of each technique and will recommend the optimum approach.





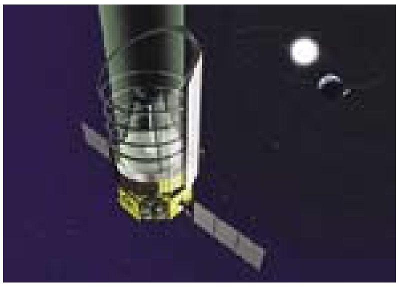
Plato

This M-class mission is the next-generation planet finder. This is a photometry mission which will detect transiting exoplanets and will perform seismic analysis of the parent stars. Plato will allow the determination of stellar and planetary masses to a precision of around 1%. Ages of the systems will also be possible to determine to within several hundred million years, allowing for an order of magnitude increase in our knowledge of planetary and stellar evolution. The science objectives of PLATO require both a very wide field of view (> 500 deg^2) and a large collecting area**.** Two fields will be observed continuously with a very high duty cycle, during the mission, each for 2.5 years.



Spica

Spica is a mission proposed as a collaboration between the Japanese Aerospace Exploration Agency (JAXA) and ESA. This is a medium and far-infrared M-class mission (5-210 micron) with a large (3.5-m) cryogenic (cooled down to very low temperatures) telescope. This telescope, which should be constructed in Europe, offers the advantage of low background and therefore unprecedented sensitivity. Apart from the high sensitivity photometric mapping, Spica will also perform spectral analysis. Spica will also carry a mid-infrared coronograph. Among the prime targets are expected to be protoplanetary disks, Galactic and extragalactic star forming regions as well Luminous IR galaxies, AGNs and starburst galaxies at high redshift.



XEUS

XEUS (X-ray Evolving Universe Spectroscopy) is the next generation X-ray space observatory. This L-class mission is expected to explore the growth of supermassive black holes, the interplay between AGN and galaxy evolution as well as gravity and matter under extreme conditions. XEUS will image energies up to 40 keV with unprecedented sensitivity in X-ray Astronomy. It will carry the largest telescope ever at these wavelengths having an area of 6 square meters. The goal for the spatial resolution is 2 arcsec. Apart from the Wide Field Imager (7 arcmin field-of-view) XEUS will carry a microcalorimeter. This will provide an energy resolution of 2-6 eV. Finally XEUS will carry an X-ray polarimeter, a hard X-ray camera and a high time resolution spectrometer (10 micro-sec timing capability). XEUS is a formation flying mission i.e. the telescope and the detector are hosted by two separate spacecrafts.

All the above candidate missions together with the Solar System missions and the LISA gravitational waves mission are now competing in a process which will terminate in 2011. However, before the end of this deadline there will be a first selection foreseen for 2009.

Artist's impression of the XEUS mission (credit: European Space Agency)

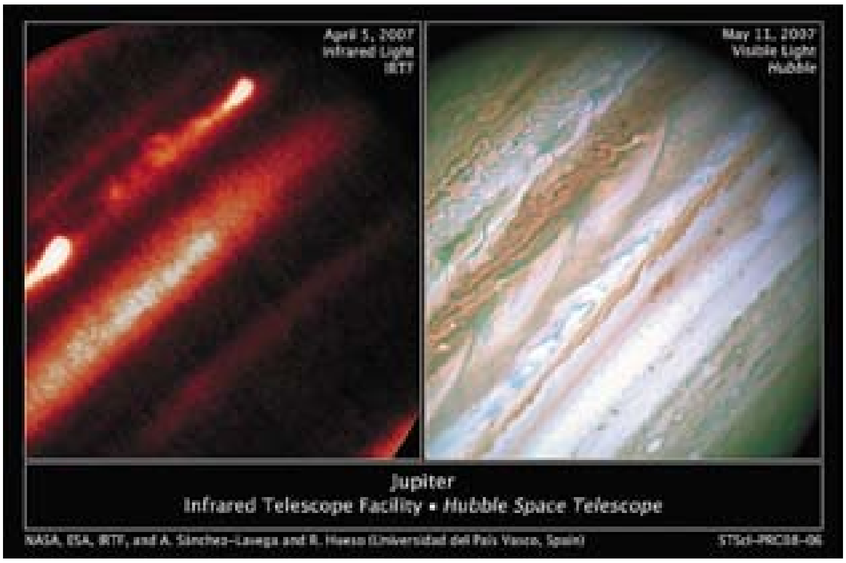
Internal Heat Drives Jupiter's Giant Storm Eruption*

Detailed analysis of two continent-sized storms that erupted in Jupiter's atmosphere in March 2007 shows that Jupiter's internal heat plays a significant role in generating atmospheric disturbances. Understanding this outbreak could be the key to unlock the mysteries buried in the deep Jovian atmosphere, say astronomers.

Understanding these phenomena is important for Earth's meteorology where storms are present everywhere and jet streams dominate the atmospheric circulation. Jupiter is a natural laboratory where atmospheric scientists study the nature and interplay of the intense jets and severe atmospheric phenomena.

An international team coordinated by Agustin Sánchez-Lavega from the Universidad del País Vasco in Spain presents its findings about this event in the January 24 issue of the journal Nature.

The team monitored the new eruption of cloud activity and its evolution with an unprecedented resolution using NASA's Hubble Space Telescope, the NASA Infrared Telescope Facility in Hawaii, and telescopes in the Canary Islands (Spain). A network of smaller telescopes around the world also supported these observations.



According to the analysis, the bright plumes were storm systems triggered in Jupiter's deep water clouds that moved upward in the atmosphere vigorously and injected a fresh mixture of ammonia ice and water about 20 miles (30 kilometers) above the visible clouds. The storms moved in the peak of a jet stream in Jupiter's atmosphere at 375 miles per hour (600 kilometers per hour). Models of the disturbance indicate that the jet stream extends deep in the buried atmosphere of Jupiter, more than 60 miles (approximately 100 kilometers) below the cloud tops where most sunlight is absorbed.

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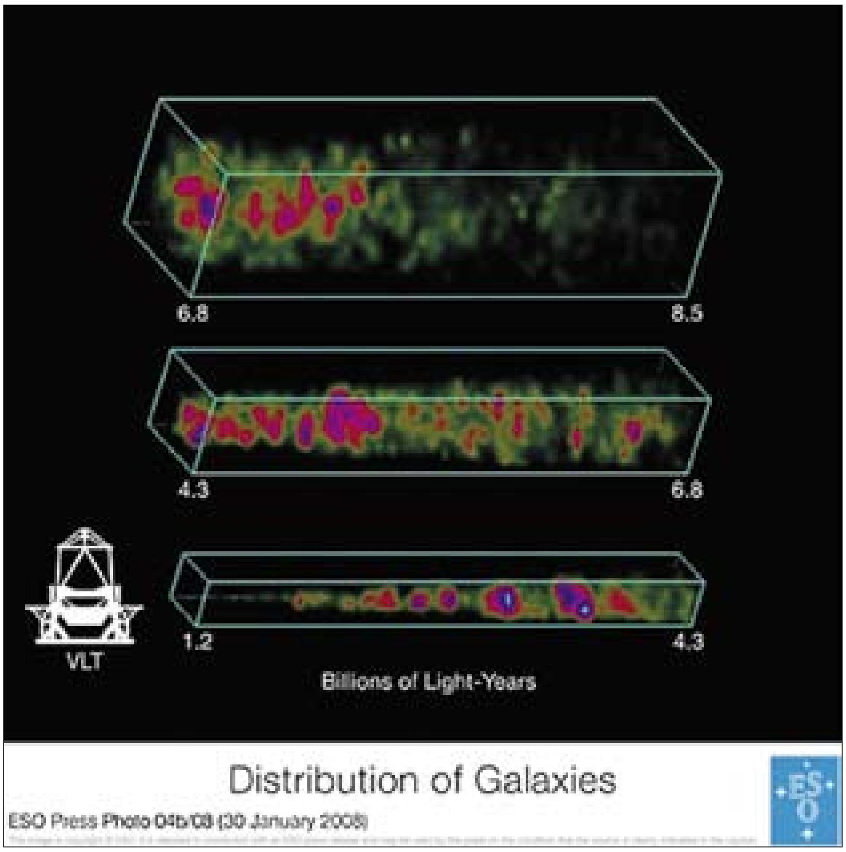
* Reprinted from the NASA/HST web site http://hubblesite.org/newscenter/archive/releases/2008/06/

New Light on Dark Energy*



Maps of the distribution of galaxies in the VVDS-Wide survey, showing the presence of large-scale structures. The colours indicate the density of galaxies - going from green to blue, the latter being the densest regions. The data have been cut into three xcones, from the closest galaxies (bottom) to the farthest. The sample includes galaxies whose light travelled between 1.3 and 8.5 billion years.

Astronomers have used ESO's Very Large Telescope to measure the distribution and motions of thousands of galaxies in the distant Universe. This opens fascinating perspectives to better understand what drives the acceleration of the cosmic expansion and sheds new light on the mysterious dark energy that is thought to permeate the Universe.

"Explaining why the expansion of the Universe is currently accelerating is certainly the most fascinating question in modern cosmology," says Luigi Guzzo, lead author of a paper published on Jan 31 2008 in Nature. "We have been able to show that large surveys that measure the positions and velocities of distant galaxies provide us with a new powerful way to solve this mystery." Ten years ago, astronomers using type la Sypernovae as standard candles made the stunning discovery that the Universe is expanding at a faster pace today than it did in the past.

"This implies that one of two very different possibilities must hold true," explains Enzo Branchini, member of the team. "Either the Universe is filled with a mysterious dark energy which produces a repulsive force that fights the gravitational brake from all the matter present in the Universe, or, our current theory of gravitation is not correct and needs to be modified, for example by adding extra dimensions to space."

Current observations of the expansion rate of the Universe cannot distinguish between these two options, but the international team of 51 scientists from 24 institutions found a way that could help in tackling this problem. The technique is based on a well-known phenomenon, namely the fact that the apparent motion of distant galaxies results from two effects: the global expansion of the Universe that pushes the galaxies away from each other and the gravitational attraction of matter present in the galaxies' neighborhood that pulls them together, creating the cosmic web of large-scale structures.

Guzzo and his collaborators have been able to measure this effect by using the VIMOS spectrograph on Melipal, one of the four 8.2-m telescopes that is part of ESO's VLT. As part of the VIMOS-VLT Deep Survey (VVDS), of which Le Fèvre is the Principal Investigator, spectra of several thousands of galaxies in a 4-square-degree field (or 20 times the size of the full Moon) at epochs corresponding to about half the current age of the Universe (about 7 billion years ago) were obtained and analysed. This is the largest field ever covered homogeneously by means of spectroscopy to this depth," declares Le Fèvre. "We have now collected more than 13,000 spectra in this field and the total volume sampled by the survey is more than 25 million cubic light-years."

The team compared their result with that of the 2dFGRS survey that probed the local Universe, i.e. measures the distortion at the present time. Within current uncertainties, the measurement of this effect provides an independent indication of the need for an unknown extra energy ingredient in the 'cosmic soup', supporting the simplest form of dark energy, the so-called cosmological constant, introduced originally by Albert Einstein. The large uncertainties do not yet exclude the other scenarios, though.

"We have also shown that by extending our measurements over volumes about ten times larger than the VVDS, this technique should be able to tell us whether cosmic acceleration originates from a dark energy component of exotic origin or requires a modification of the laws of gravity," explains Guzzo.

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* Reprinted from the ESO web site http://www.eso.org/public/outreach/press-rel/pr-2008/pr-04-08.html

The Encounter of Comet Encke with a Coronal Mass Ejection: A Unique Cosmic Collision

by A. Vourlidas
U.S. Naval Research Laboratory

Comets have captured the imagination and awe of mankind for thousands of years. Besides being spectacular celestial bodies, comets are also unique probes of the heliosphere. Observations of cometary tails have been our first indication for the existence of a solar wind (Biermann 1951), for example. The comet tail forms as solar radiation ionizes the gases in the coma which are then channeled radially away from the Sun by the interplanetary magnetic field (IMF) draping around the cometary ionosphere. This is a condition very similar to the interaction between the solar wind and the Earth's magnetosphere leading to the formation of the terrestrial magnetotail. The tail responds to changes in the IMF configuration or the ambient plasma density and acts as a remote sensor of the heliospheric conditions around the comet. The continuous interaction between the solar wind and the comet can occasionally result in a spectacular phenomenon; the abrupt disconnection of the entire plasma tail of the comet. The spacecraft flybys to comets Halley and Giacobini-Zimmer have established that DEs are magnetic in nature and the majority is associated with sector boundary crossings. However, about a quarter of the observed DEs cannot be explained by such crossings (Voelzke 2005). It is thought that encounters with coronal mass ejections (CMEs) could be responsible for these events but this prediction could not be easily tested for several reasons: CMEs occur intermittently, comets occupy a very small area in the heliosphere and synoptic imaging observations of the inner heliosphere were unavailable until recently. On few occasions, DEs have been observed around the time of the predicted passage of a CME over the comet location (Jones & Brandt 2004) based on observations with the LASCO coronagraphs (Brueckner et al. 1995). However, the actual interaction has never been observed directly, leaving open the question of how the CME plasma interacts with the comet.

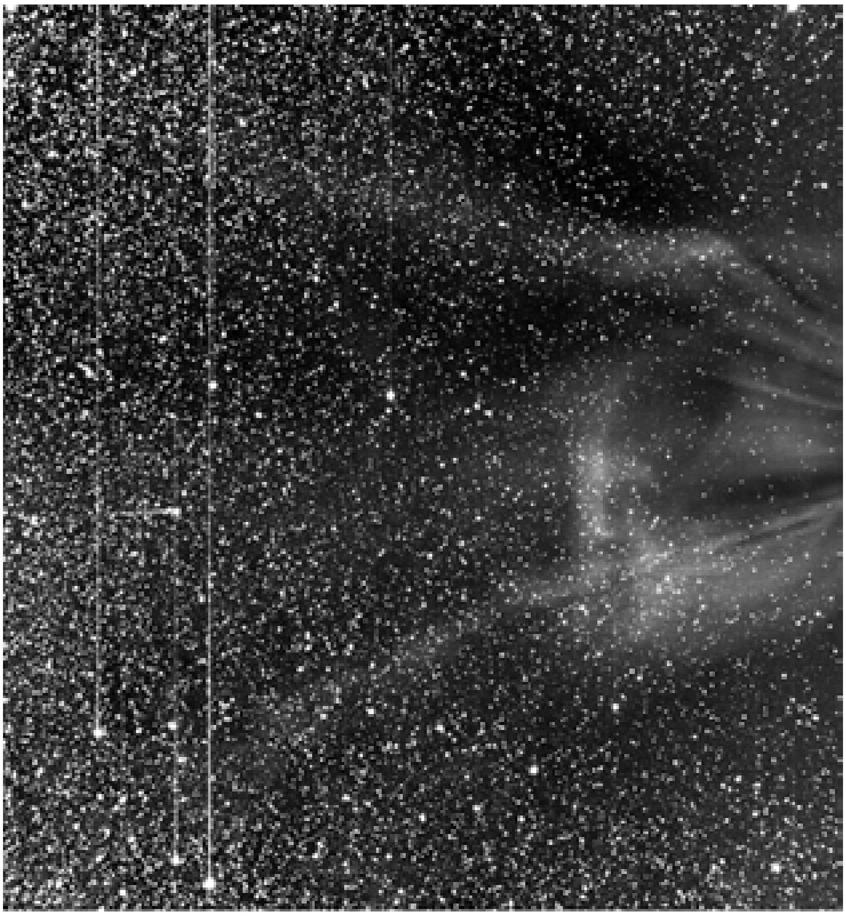

Figure 1. SECCHI/HI-1 observation of the encounter of a CME with comet Encke. The field of view is 20°. The Sun is located 4° beyond the right edge of the frame. The image was taken on April 20, 2007 at 2:50 UT. The CME is propagating with 500 km s^{-1} at 45° away from the Sun-Earth line. The comet is located inside Mercury's orbit at a distance of 0.34 AU from the Sun.

This is no longer the case as we will demonstrate in this article. Our SECCHI telescopes (Howard et al. 2008) on board the STEREO-A spacecraft (Kaiser et al. 2008) recorded a unique image sequence of the interaction of comet Encke with a CME in April 2007. The heliospheric imager (HI-1; Socker et al 2000) observed, with high cadence (45 min) and spatial resolution (2.5 arcmin), the collision of a large CME with comet Encke and the subsequent spectacular tail disconnection (Vourlidas et al 2007). Encke is a very-well observed comet, being the second periodic comet discovered after Halley's comet. It was first reported in 1786, and has an orbital period of 3.3 years with aphelion at 4.1 AU and perihelion at 0.33 AU. Comet Encke is relatively faint with a maximum apparent visual magnitude of 6.5. The comet was in the HI-1 field of view from April 16-26, 2007. The event occurred just after the perihelion passage of the comet on April 20.

The Encke-CME Collision

Figure 1 shows the heliosphere before the cosmic collision. The STEREO-A spacecraft is located ahead of the Earth and HI-1 is imaging the solar corona above the eastern limb of the Sun across the Sun-Earth line. The right-hand edge of the image is located 15 solar radii above the eastern solar limb and the size of the field of view is 20 degrees (about 80 solar radii). The comet is located on the left, at a distance of 0.34 AU from the Sun (within the orbit of Mercury). The CME is clearly seen on the right as the large diffuse feature and left the Sun on April 19. The CME is traveling at 500 km/s when it encounters the comet.

The details of the CME-comet interaction are shown in Figure 2 and more movies can be found in

http://www.nasa.gov/mission_pages/stereo/news/encke.html

The first frame shows the pre-event situation; the CME front is about 2 degrees and the narrow comet tail extends for at least 6° behind the coma. The existence of a tail is in itself a new observation. The longest known tail for this comet was 3°, and was reported in 1805 by Johann Sigismund Huth. The CME-comet interaction starts at approximately 15:30 UT. There is no evidence of tail disconnection until 18:50 UT after the CME front has passed the comet. A gap has developed in the tail ~0.5° behind the coma. The tail has also become brighter. By 20:50 UT the tail is clearly being carried off by the CME and a new tail, albeit only 1° long, has already formed.

Is the Tail Disconnection Driven by Magnetic Reconnection?

The images of the SECCHI COR2 instrument (between 2-15 solar radii) show that the CME is a typical example of a fluxrope-type event (Vourlidas et al 2000). In other words, the CME contains a large scale magnetic structure. Also, the CME is traveling at the same speed as the solar wind at the point of the collision (500 km/s). The CME front is, therefore, in pressure equilibrium and we can rule out plasma pressure as a candidate for the disconnection.

The mechanism for the tail disconnection is becoming clear by putting the three clues together: (i) the CME front consists of coronal plasma followed by a magnetic fluxrope, (ii) the disconnection occurs at the back of the CME front, and (iii) the tail seem to brighten up as the CME passes over it. The DE is likely a result of night-side reconnection between the interplanetary magnetic field draped around the coma and the magnetic field piled up at the front of the CME fluxrope as suggested by Russell et al (1986). A rendition of the proposed disconnection scenario is shown here

http://www.nasa.gov/mpg/191092main_EnckeFieldLines.mpg

A similar mechanism is invoked to explain the creation of plasmoids at the Earth's magnetotail during CME passages. This analogy helps illuminate the importance of this comet-CME observation: The comet gives us a unique chance to observe remotely processes similar to those around the Earth's environment which we can only sample in-situ. Further analysis of these observations could be used to probe the magnetic field inside the CME. This an important but unknown quantity which has important implications for understanding how CMEs affect the geospace environment and drive space weather.

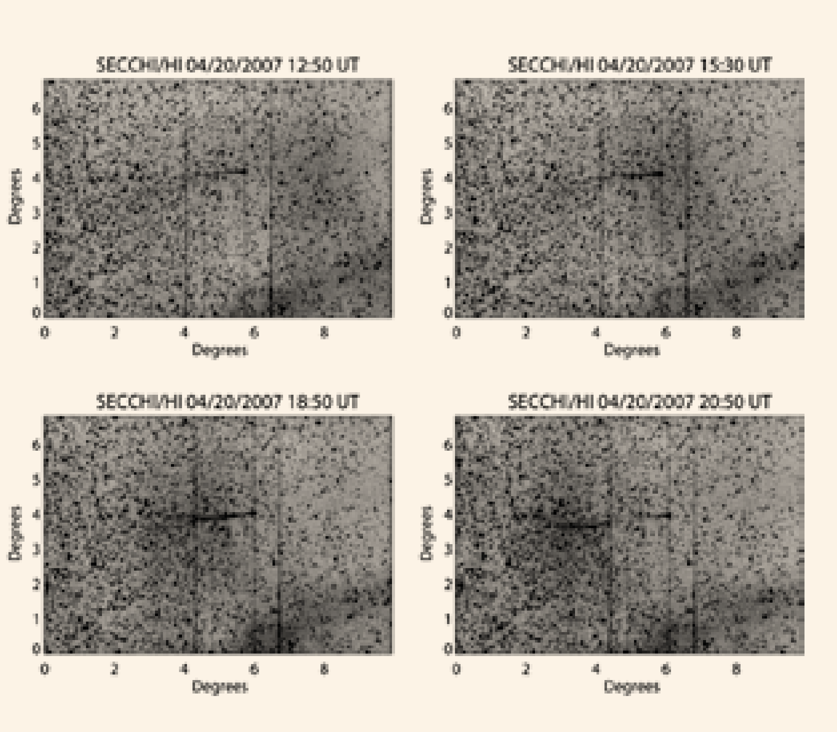

Figure 2. Detailed views of the tail disconnection of comet 2P/Encke. The 2° wide cloud approaching the comet is part of the CME front. The interaction starts at approximately 15:30 UT but the first evidence of disconnection is recorded on 18:50 UT. The tail is carried of by the CME front but a new tail has formed already by 20:50 UT.

Recent Results

The scant evidence of CME-comet interactions over the years suggested to us that the STEREO observations may had been a spectacular but one-off observation, unlikely to be seen again. How wrong we were!

The next large comet appeared in our telescopes in November 2007 and it, too, suffered tail disconnections from CMEs! Comet F1 LONEOS was at 0.4 AU from the Sun and was seen only in our HI-2 telescopes. Its tail extended for at least 40° and it appeared to be disconnected twice by CMEs. The HI-2 movie

http://stereo.gsfc.nasa.gov/gallery/stereoimages/loneos_hi2a.shtml

shows the transit of F1 LONEOS and the large variability of its ion tail. But the most unexpected observation of tail disconnection has come from an unlikely candidate, a sungrazer comet. These cometary objects are fragments of a larger object with a very close perihelion that has disintegrated repeatedly over the years. Such a sungrazer was detected by HI-1 on 19-20 February, 2008 and during its passage

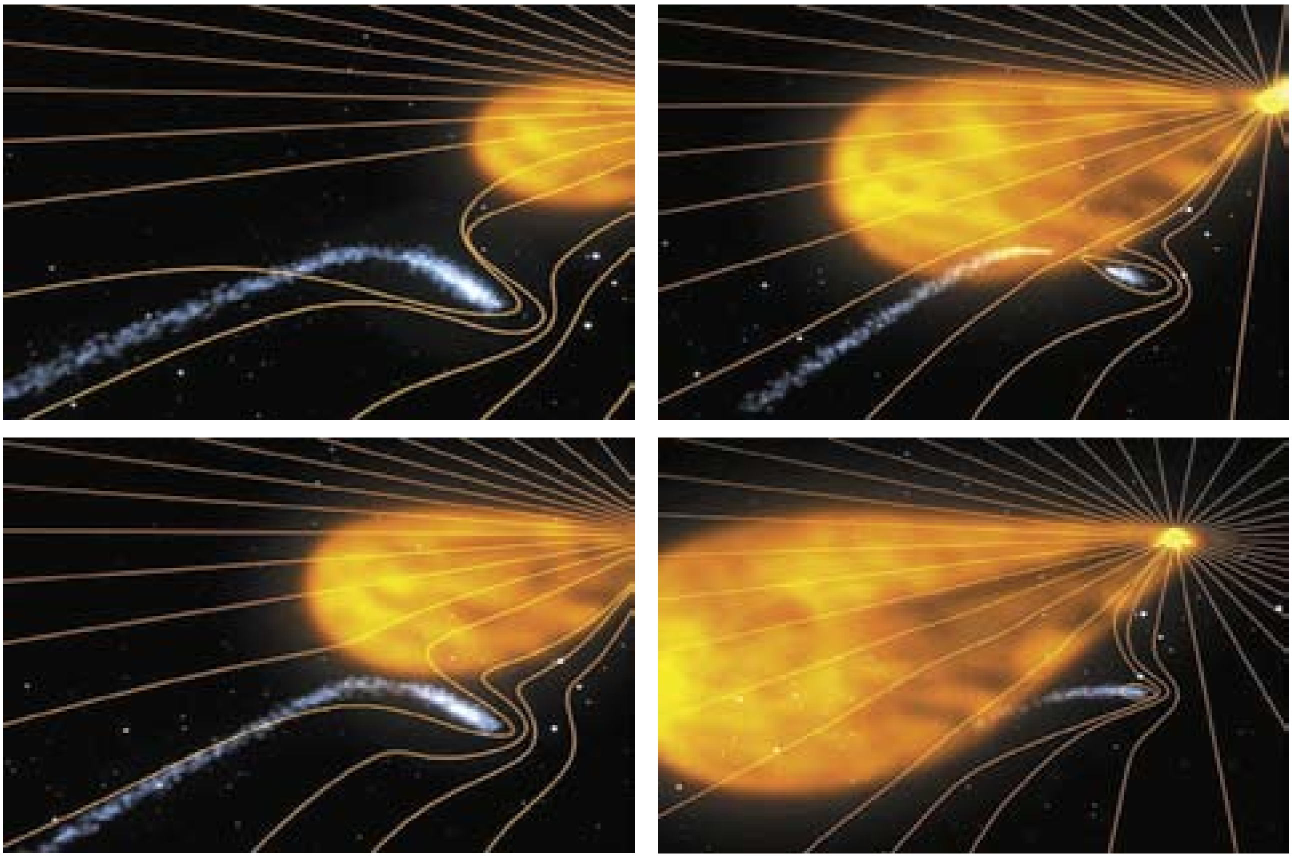

Figure 3. Snapshots from the rendition of the proposed desconnection scenario

through a coronal streamer, its tail was detached by a passing density blob (see http://ares.nrl.navy.mil/sungrazer/index.php?p=sungrazers for details)! It seems that comet-CME interactions and tail disconnections are not such a rare thing after all. Stay tuned for more spectacular observations of such cosmic collisions as the solar activity picks up over the next couple of years. We will surely be watching carefully comet Encke's next perihelion passage in 2011!

References

1. M. R. Voelzke, *Earth Moon Planets,* 97, 399-409 (2005)
2. G. E. Brueckner et al., *Sol. Phys.*, 162, 357-402 (1995)
3. G. H. Jones, J. C. Brandt, *Geophys. Res. Lett.*, 31, L20805 (2004)
4. D. G. Socker, R. A. Howard, C. M., Korendyke, G. M. Simnett, D. F. Webb, *Proc. SPIE*, 4139, 284-293 (2000)
5. R. A. Howard et al., *Sp. Sci. Rev.*, in press (2007)
6. M. L. Kaiser et al., *Sp. Sci. Rev.*, in press (2007)
7. A. Vourlidas et al., Astrophy. J. Lett, 2007, 668, 79
8. A. Vourlidas, P. Subramanian, K. P. Dere, R. A. Howard, *Astrophys. J.*, 534, 456-467 (2000)
9. Russell, C. T., Saunders, M. A., Phillips, J. L., and Fedder, J. A.: 1986, J. Geophys. Res. 91, 1417–1423.

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These web pages contain information about the Hellenic Astronomical Society (Hel.A.S.), the major organization of professional astronomers in Greece. On March 2007 a major "facelift" of the webpages took place, including a mySQL database for the members and the electronic newsletters of the Society along with a complete bilingual (english and greek) text for the whole server. The files reside in the web server of the Section of Astrophysics, Astronomy and Mechanics at the Department of Physics of the University of Thessaloniki in Greece.

Supermassive Black Holes
A Key to Fundamental Physics and Galaxy Formation

by Stelios Kazantzidis
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Abstract

In recent years, compelling dynamical evidence has indicated that supermassive black holes (SMBHs) are ubiquitous in galactic nuclei. According to the currently favored cold dark matter cosmological model, structures in the Universe grow through a complex process of continuous mergers and accretion of smaller systems. Thus, the hierarchical buildup of SMBHs by massive seed black holes present at the center of protogalaxies and the formation of SMBH binaries appear as natural consequences in any hierarchical cosmogony. Upcoming gravitational wave detection experiments such as the Laser Interferometer Space Antenna will be able to detect emission from coalescing SMBH binaries essentially to the edge of the observable Universe and provide a test of General Relativity as well as constraints on galaxy formation theories. The available observational data also reveal the existence of a remarkably tight correlation between the mass of the SMBH and the stellar velocity dispersion of the host galaxy spheroid, suggesting a fundamental connection between the growth of SMBHs and the assembly of galaxies. Numerical simulations constitute the most powerful tool for elucidating such a connection. In this article, I discuss recent results regarding the coevolution of SMBHs and their host galaxies using high-resolution supercomputer simulations of galaxy mergers. Such investigations can have profound implications for our current understanding of galaxy formation and evolution.

1. Introduction

The theory of General Relativity that Einstein developed about 90 years ago and which describes the behavior of gravity has been confirmed in many of its predictions. However, there is one major consequence of this theory that has yet eluded verification, and this is the existence of gravitational waves. Einstein's theory postulates that strong gravitational fields can deform the space-time fabric of the Universe and produce gravitational waves, the amplitude of which depends on the strength of the gravitational field. No direct detection of gravitational radiation has even been achieved. Coalescing supermassive black hole (SMBH) binaries would constitute one of the most prominent sources of gravitational waves in the Universe, so the prospect of detecting such waves from SMBHs is extremely exciting. Upcoming revolutionary, space-based instruments such as the Laser Interferometer Space Antenna (LISA) (http://lisa.nasa.gov/), a joint venture of ESA and NASA that is expected to be launched around 2015, will be able to detect gravitational radiation emission from merging SMBHs out to incredible distances and provide irrefutable proof of the existence of SMBHs. The LISA observatory is of primary importance for gravitational-wave science since the ground-based gravitational-wave detectors that are already in operation are inadequate to detect the long-wavelength gravitational waves produced by coalescing SMBH binaries.

The possibility of SMBH mergers follows naturally from two widely accepted facts. First, in the past decade, accumulating dynamical evidence has indicated that SMBHs with masses ranging from 10^6 to above 10^9 $M_\odot$ reside at the centers of most galaxies hosting spheroids (see review by Ferrarese & Ford 2005). Second, according to the standard modern theory of cosmological structure formation, the Cold Dark Matter (CDM) paradigm (Blumenthal et al. 1984), galaxies in the Universe grow through a complex process of continuous mergers and agglomeration of smaller systems. Thus, if more than one of the protogalactic fragments contained a SMBH, the formation of binary SMBHs during galaxy assembly will be almost inevitable.

Despite the fact that SMBH mergers are rapid events taking place in less than 100 million years (Escala et al. 2004), conclusive observational evidence has recently confirmed the existence of SMBH pairs in external galaxies (for a more complete review of this topic, see Komossa 2003). The left panel of Figure 1 shows what is thought to be the first example of two SMBHs in one galactic "system", in this case a pair of interacting galaxies near the center of the galaxy cluster Abell 400. The associated radio source 3C75 consists of a pair of twin radio lobes originating from the radio cores of the two galaxies and the projected separation of the cores is ~ 7kpc (Owen et al. 1985). Such double-jet systems are expected to be rare given the small fraction of giant elliptical galaxies that are associated with luminous radio sources. Overall, our ability to resolve both SMBHs in any given binary depends on the separation between them and on their distance from Earth. It is believed that the longest timescales in the evolution of a SMBH binary system leading up to coalescence is the stage in which the system is closely bound (~ 0.1–10 pc), meaning that in most of these systems the black hole pair can only be resolved by *Very Long Baseline Interferometry* (VLBI) observations. Recent VLBA observations have revealed the presence of two compact, active nuclei within the elliptical radio galaxy 0402+379 (Rodriguez et al. 2006). The projected separation between the two SMBHs is only 7.3 pc making this system the closest SMBH pair yet found by more than 2 orders of magnitude.

Galaxies in the late stages of a merger are the most plausible sites for binary SMBHs and many of these exhibit double nuclei in the optical or infrared (e.g., Carico et al. 1990). However, very few show unambiguous evidence of AGN activity in both nuclei, indicative of the

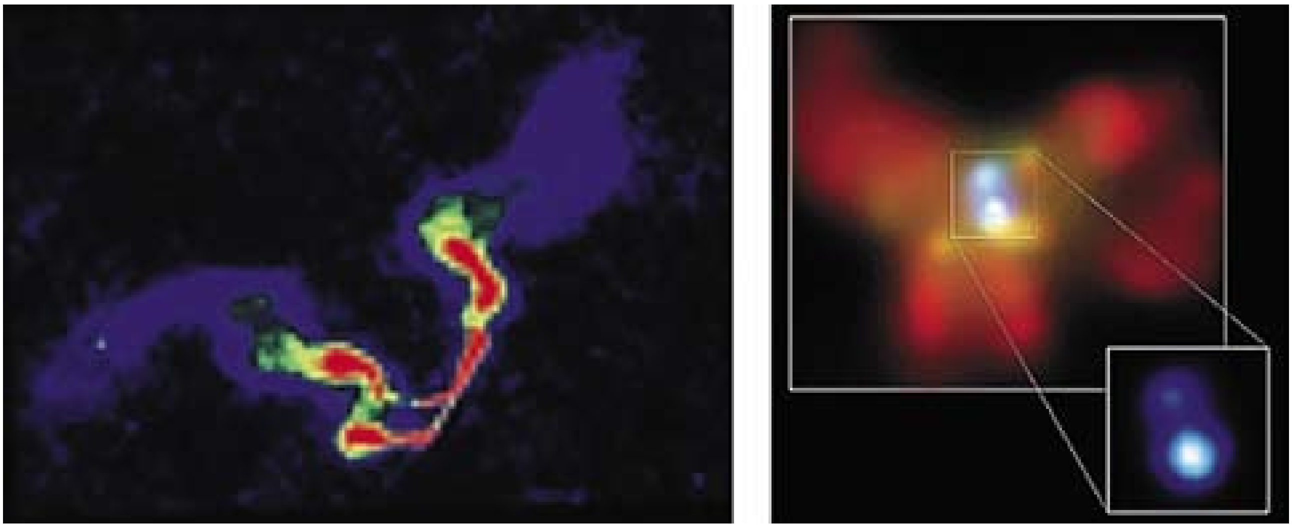

Figure 1. *Left:* VLA image of the radio source 3C75 in the cluster of galaxies Abell 400. The image consists of two, twin-jet radio sources associated with each of two elliptical galaxies. The jets bend and appear to be interacting. The projected separation of the radio cores is approximately 7 kpc (Image courtesy of NRAO/AUI and Owen et al.). *Right:* Chandra X-ray image of the merger remnant NGC 6240 revealing that its central region (inset) contains a double active galactic nucleus, indicative of a pair of SMBHs. At a distance of about 400 million light years, NGC 6240 is one of the nearest ULIRGs. The projected separation of the X-ray cores is 1.5 arcsec corresponding to a physical separation of 1.4 kpc (from Komossa et al. 2003).

presence of SMBHs. One striking exception is the ultraluminous infrared galaxy (ULIRG) NGC 6240, with a projected physical separation between the two nuclei of 1.4 kpc (Komossa et al. 2003; see right panel of Figure 1). This system shows conspicuous loops and tails suggesting that it is the product of the collision between two smaller systems. High-resolution, X-ray imaging spectroscopy of NGC 6240 with Chandra demonstrated that both nuclei exhibit the flat X-ray spectra characteristic of AGNs.

Numerical simulations constitute the most powerful tool for gaining insight into the complex, non-linear physical processes that determine the conditions and timescales for SMBH pairing and coalescence during galaxy collisions, and for elucidating the formation of galactic nuclei and the mechanisms for powering AGNs. Supercomputer simulations allow us to effectively compress the vast astronomical timescales that apply to these phenomena down to weeks of virtual time and are the ideal means by which to relate theoretical models with observational data. Advances in algorithms and supercomputer technology have recently provided the platform for increasingly realistic astrophysical modeling. In what follows, I summarize some recent results from numerical simulations of galaxy interactions designed to elucidate the coevolution of SMBHs and their host galaxies.

2. Pairing and Coalescence of SMBHs in Galaxy Collisions

The evolution of a pair of SMBHs during a galaxy merger can be divided into three main phases (Begelman et al. 1980): (1) the two black holes sink to the center of the common mass distribution by a process called dynamical friction that slows down the relative motions of the host galactic cores and causes the SMBHs to form a pair once the two galaxies merge; (2) the orbital radius of the SMBH pair continues to decay via three-body interactions in which stars on orbits intersecting the pair are ejected at velocities comparable to the binary's orbital velocity, carrying away energy and angular momentum; (3) if the binary's separation decreases to the point where the emission of gravitational waves becomes an efficient mechanism for further angular momentum loss, the SMBHs coalesce rapidly.

The transition from (2) to (3) consists the primary obstacle of a SMBH binary's path to coalescence, since the binary will quickly eject all stars on intersecting orbits, thus cutting off the supply of stars. This is called the "final parsec problem". However, there is a wealth of circumstantial evidence suggesting that efficient coalescence is the norm. For example, if binary SMBHs failed to merge efficiently, uncoalesced binaries would be present in many bright ellipticals, resulting in 3- or 4-body slingshot ejections when subsequent mergers brought in additional SMBHs. This would produce off-center SMBHs, which seem to be rare or non-existent. The most promising physical mechanism of continuing to extract energy and angular momentum from a binary SMBH leading to its coalescence is gasdynamical in origin. Observations of gas-rich interacting galaxies such as ULIRGs indicate that large amounts of gas are present in their central regions (Sanders & Mirabel 1996). Merging systems like Mrk 231, NGC 6240, and Arp 220 harbor large concentrations of gas, in excess of 10^9 M⊙, at their center in the form of either a turbulent irregular structure or a kinematically coherent, rotating disk (Downes & Solomon 1998; Davies et al. 2004; Greve et al. 2006). Such massive, nuclear gas concentrations will profoundly affect the evolution of a SMBH pair that forms in the nucleus following a galaxy merger. This stems from the fact that the gas, unlike the stars, is strongly dissipative, and thus it is expected to remain concentrated near the center.

Escala et al. (2004) studied numerically the role of a massive spherical gas cloud in driving the evolution of a binary SMBH. These authors followed the evolution of the binary through many orbits and close to the point at which gravitational radiation becomes important. Escala et al. explored a relatively simple idealized case in which the gas is assumed to be supported by a high virial temperature, so that the gas retains a nearly spherical and relatively smooth distribution. They found that in the early evolution of the binary, the separation decreased due to the dynamical friction exerted by the background gas. In the later stages, when the binary dominates the gravitational potential in its vicinity, the medium responded by forming an ellipsoidal density enhancement whose axis lags behind the binary axis, and this offset produces a gravitational torque on the binary that causes continuing loss of angular momentum and is able to reduce the binary separation to distances at which gravitational radiation is efficient. Assuming typical parameters from observations of ULIRGs, Escala et al. predicted that a black hole binary will merge within 10^7 yr. However, these simulations begin with ad hoc initial conditions, with the black holes already forming a loosely bound pair, while in reality the orbital configuration of the black holes and the structure and thermodynamics of the nuclear region, which can affect the drag, will be the end result of the complex gravitational and hydrodynamical processes involved in the galaxy merger. How a pair of SMBHs binds during a galaxy collision is thus still unclear.

A far more realistic approach which eliminates most of the aforementioned uncertainties consists of self-consistently modeling the formation of the nuclear region of the merger remnant and following the evolution of the SMBH pair inside the galactic nucleus. This can be accomplished by means of supercomputer simulations of merging galaxies with central SMBHs allowing for a considerable dynamic range to be resolved in the same calculation: from scales of hundreds of kiloparsecs at which the galaxies begin to interact to scales of parsecs that are relevant for the formation of SMBH binaries. Such theoretical efforts often employ spiral galaxies comprising a disk of stars and gas with a surface density distribution that follows an exponential law, a spherical stellar bulge, an extended spherical dark matter halo, and a central SMBH (Kazantzidis et al. 2005; Springel et al. 2005; Mayer et al. 2007). The parameters describing each component are independent, so that a wide range of morphological galaxy types can be specified. The collisionless material, which includes dark matter, stars, and black holes, is modeled as a collection of *N* massive, discrete particles which move under the influence of gravity. Given their initial positions, masses, and velocities, the problem of following the time evolution of these particles requires carrying out numerical simulations with an *N*-body algorithm. *N*-body simulations involve integrating the 6*N* ordinary differential equations which define the particle motions in Newtonian gravity. In practice, the number *N* of particles involved is usually in the order of millions, so powerful supercomputers with the ability to process an incredible number of floating point calculations are required.

Fundamentally different, the dissipative gaseous component evolves under the influence of both gravitational and hydrodynamical forces. Gas is segregated from the collisionless dark matter and stars through radiative dissipation of its gravitational energy. The popular in astrophysics technique of Smooth Particle Hydrodynamics (SPH) which represents fluid elements by particles (Lucy 1977; Monaghan 1992) is generally used for the hydrodynamical aspect of galaxy interactions. In SPH, fluid properties at a given point are estimated by local kernel-averaging over neighboring particles, and smoothed versions of the equations of hydrodynamics are solved numerically for the evolution of the fluid. The radiation physics is modeled via an effective equation of state that accounts for the net balance of radiative heating and cooling. For example, calculations that include radiative transfer show that the thermodynamic state of a solar metallicity gas heated by a starburst can be well approximated by an ideal gas with adiabatic index $\gamma = 7/5$ over a wide range of densities (Spaans & Silk 2000).

Initial conditions for the galaxy encounters are generated by building pairs of galaxy models, placing them on the chosen orbits, and rotating them to the desired orientations. The initial center-of-mass position and velocity of each galaxy is typically determined from a parabolic orbit of two point masses M_1 and M_2 with pericentric separation r_{peri} and time of pericenter t_{peri}. Initially, the separation of the two black holes evolves as that of the two galactic cores in which they are embedded. The galaxies approach each other several times as they sink into one another via dynamical friction (Figure 2). After about 2.9 Gyr the massive, dark matter halos have nearly merged and the two baryonic cores, separated by about 6 kpc, continue to spiral down. As much as 60% of the gas originally present in the galaxies has been funneled to the inner few hundred parsecs of each core by tidal torques and shocks occurring in the repeated fly-bys between the two galaxies. Each of the two SMBHs is embedded in a rotating gaseous disk of mass ~ $4\times10^8\,M_\odot$ and size of a few hundred parsecs, produced by such gas inflow. The gaseous cores finally merge at t ~ 3 Gyr, forming a single nuclear disk with a mass of ~$3\times10^9\,M_\odot$ and a size of ~75 pc. The two SMBHs are now embedded in this nuclear disk which is more massive than the sum of the two progenitor nuclear disks formed earlier. This is because further gas inflow occurs in the last stage of the galaxy collision. The nuclear disk is surrounded by several rings and by a more diffuse, rotationally-supported envelope extending out to more than a kiloparsec from the center (see last panel of Figure 2).

A background of dark matter and stars distributed in a spheroid is also present but the gas component is dominant in mass within a few hundred pc from the center. From that point on the orbital decay of the black holes is dominated by dynamical friction against the gaseous disk. The two SMBHs sink down to a few parsecs in less than a million years. At this point the two black holes are gravitationally bound to each other, as the mass of the gas enclosed within their separation is less than the mass of the binary. Dynamical friction against the stellar background would bring the two black holes this close only on a much longer timescale of the order of 50 million years. A short sinking timescale due to the gas is expected because of the high gas densities and the fact that the decay occurs in the supersonic regime (Ostriker 1999). These nuclear disks exhibit prominent non-axisymmetric features known to produce strong gas inflows. The gas inflows are likely responsible for fueling the central black hole, but even higher numerical resolution is needed to study this process in detail. Nevertheless, such simulations provide the first direct evidence that gas originally present in galaxies separated by hundreds of kiloparsecs can be collected to parsec scales simply as a result of the dynamics and hydrodynamics involved in the merger process.

Overall, the details of SMBH binding are extremely sensitive to gas thermody-

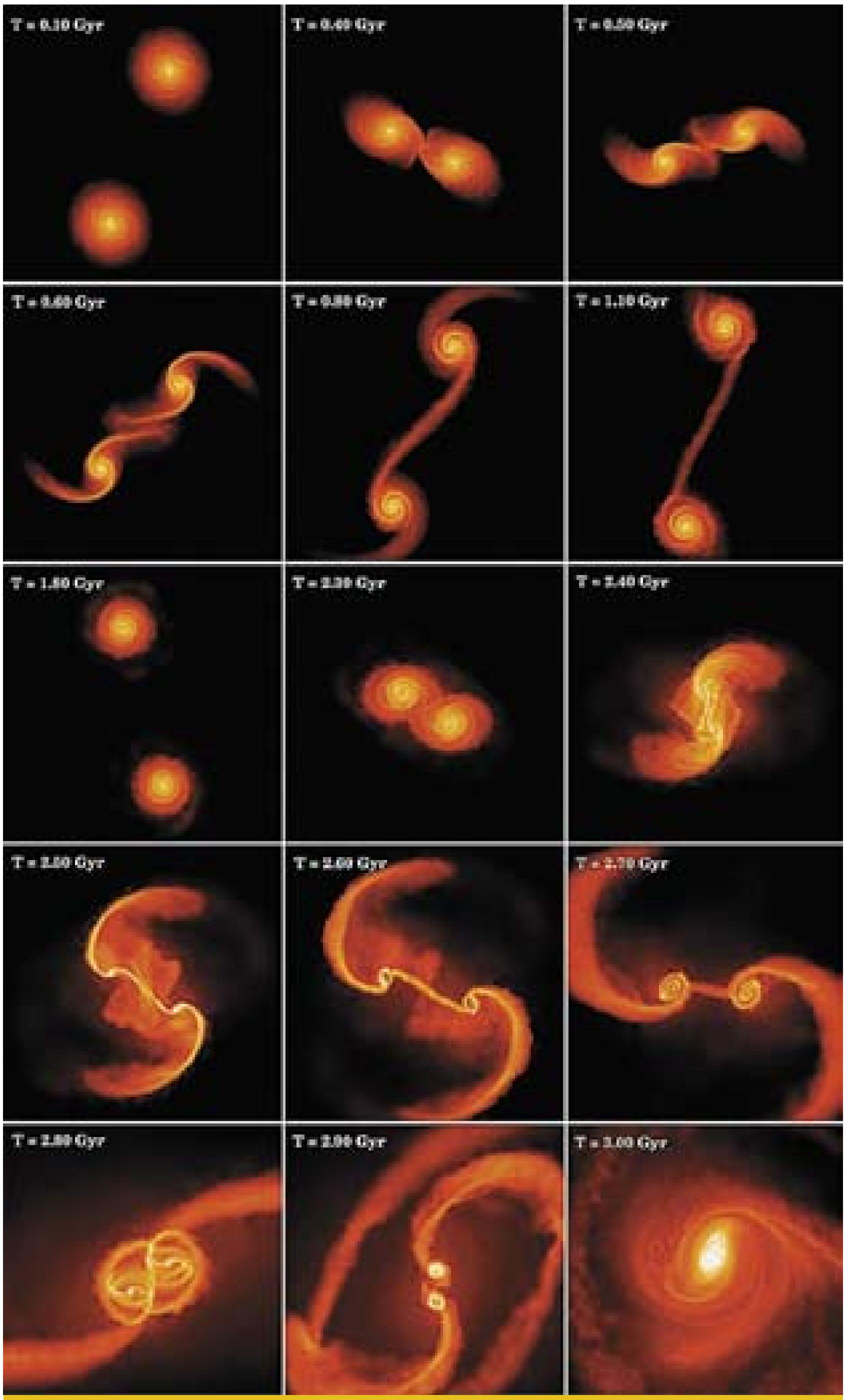

Figure 2. Images from a numerical simulation illustrating the complexity of dynamical evolution during a collision between two equal-mass spiral galaxies. The simulation follows dark matter, stars, gas, and supermassive black holes, but only the gas component is visualized. Brighter colors indicate regions of higher gas density and the time corresponding to each stage of the merger is given by the labels. These numerical simulations constitute among the most expensive calculations ever performed on the topic of galaxy interactions, consuming several months of computing time each at various supercomputer centers around the world. The first 10 images measure 200 kpc on a side, roughly seven times the diameter of the visible part of the Milky Way galaxy. The next five panels represent successive zooms on the central region. The final frame shows the inner 500 pc of the nuclear region at the end of the simulation. During the interaction violent tidal forces tear the galactic disks apart, generating spectacular tidal tails, plumes and prominent bridges of material connecting the two galaxies. The ultimate outcome of a series of increasingly close encounters is the inevitable merger of the disk galaxies into a single structure and the formation of a nuclear disk as shown in the last panel. These nuclear disks exhibit prominent non-axisymmetric features known to promote strong gas inflows that are likely responsible for fueling the central black hole (visualizations of galaxy interactions are available as supplementary material to this article at **http://www.helas.gr/news_suppl.php**).

namics. Figure 3 shows the orbital separation of SMBHs as a function of time during the last stages of the merger. Different lines correspond to different prescriptions for the equation of state of the gas. The γ =7/5 case (blue line), which was described above, approximates well the balance between radiative heating and cooling in a starburst galaxy, a system that is forming stars at a prodigious rate. If radiative cooling is completely suppressed during the merger, for example as a result of radiative heating following gas accretion onto the SMBHs (AGN feedback), the gas would evolve adiabatically (γ =5/3). In this case, the hardening process is significantly slowed down (red line), and gas and stars would contribute similarly to the drag.

Though much higher numerical resolution is required to explore the orbital decay of the SMBH binary at the point of gravitational wave emission, these findings support scenarios of hierarchical build-up of SMBHs, due to collisions and gas accretion, following the cosmological merger hierarchy from early times until present. It is worth emphasizing that in the previously described numerical simulations, the gas accounted for only 10% of the disk mass, a typical gas fraction in present-day spirals. Much larger gas fractions should be common at high redshift, when most of the merger activity takes place and massive galaxies have just begun to assemble their stellar component (Genzel et al. 2005). Thus, even more massive and denser nuclear disks could form and, since dynamical friction is proportional to the density of the background (Ostriker 1999), a pair of SMBHs could bind even faster. This implies that merging SMBH binaries should be common at high redshift with fundamental implications for the frequency of observing coalescence events with LISA.

3. M_{BH}-σ Relation in Galaxy Mergers

The advent of techniques for measuring the masses of SMBHs has established a remarkable correlation between the mass of a SMBH, M_{BH}, and the central stellar velocity dispersion of the host galaxy spheroid, σ. The M_{BH}-σ relation *locally* (z=0) is a tight, power-law correlation with a logarithmic slope estimated to be in the range ≈ 3.75–4.8 (Ferrarese & Merritt 2000; Gebhardt et al. 2000; Tremaine et al. 2002). What is so outstanding about this relation is that the

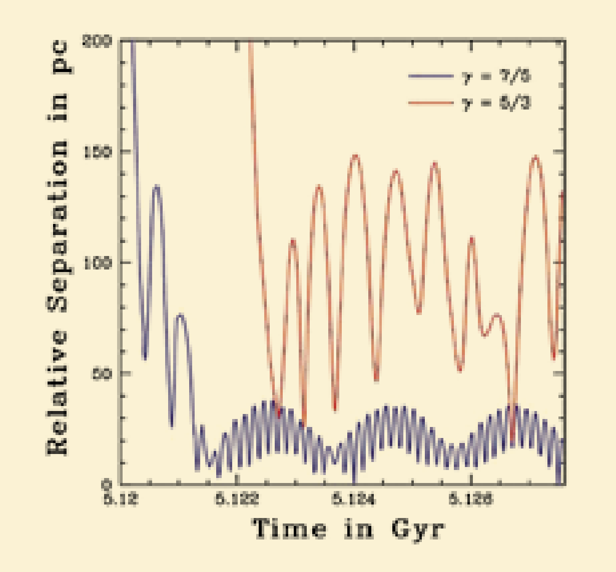

Figure 3. Orbital separation of a pair of SMBHs as a function of time during the last stages of a merger between two equal-mass spiral galaxies. Different lines correspond to different prescriptions for the equation of state of the gas. The γ =7/5 case (blue line) approximates well the balance between radiative heating and cooling in a galaxy that is forming stars at a prodigious rate ("starburst galaxy"). The γ =5/3 case (red line) pertains to galaxies, known as "active galactic nuclei" (AGN), the nucleus of which produces more radiation than the rest of the galaxy and which are thought to harbor SMBHs at their centers. The coalescence of the two black holes will likely occur when the merger remnant is a powerful starburst galaxy, such as a ULRIG, rather than an AGN (from Mayer et al. 2007).

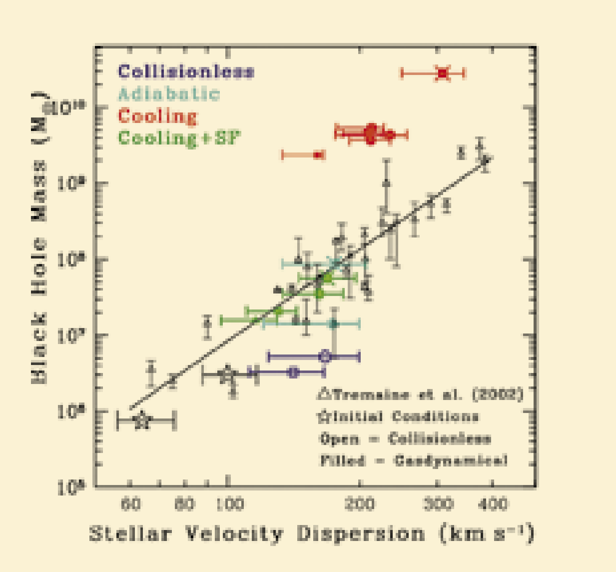

Figure 4. Evolution of the M_{BH}-σ relation in binary galaxy mergers. The triangles show data from the galaxy sample compiled by Tremaine et al. (2002) and the solid line corresponds to the best-fit correlation. Results for simulated merger remnants are shown in color and the initial galaxy models correspond to stars. Open and filled symbols correspond to collisionless and gasdynamical simulations, respectively. Circles and squares show equal- and unequal-mass mergers, respectively. Symbols outlined with crosses correspond to cases where the progenitor disk galaxies contained 50% gas fraction. In all other cases, the gas fraction was equal to 10%. The error bars show the spread about the mean value of in each remnant. Star formation is a key ingredient for maintaining the tightness of the M_{BH}-σ relation during galaxy mergers (from Kazantzidis et al. 2005).

measurements are derived using stars that are not directly influenced by the black hole's gravitational field. In other words, any given SMBH appears to know about the assembly process of its host galaxy. It is not yet understood if this relation was set in primordial structures and, consequently, how it is maintained throughout cosmic time with such a small dispersion or, indeed, which physical processes established such a correlation in the first place. A variety of theoretical models have been proposed to explain its origin, based on physical mechanisms such as viscous disk accretion (Burkert & Silk 2001), adiabatic black hole growth (MacMillan & Henriksen 2002), gas collapse (Adams et al. 2001), stellar capture by accretion disks (Miralda-Escudé & Kollmeier 2005), dissipationless merging (Ciotti & van Albada 2001), unregulated gas accretion (Archibald et al. 2002), and the self-regulated growth of black holes by momentum- or pressure-driven winds (Silk & Rees 1998).

Observations of active galaxies at z > 0 have yielded ambiguous inferences about the nature of the M_{BH}-σ relation at other redshifts, implying both redshift-dependent (Treu et al. 2004) and redshift-independent relations (Shields et al. 2003). Regardless, the strong link between the masses of SMBHs and the gravitational potential wells that host them suggests a common mechanism for assembling SMBHs and forming spheroids in galaxies. Knowledge of the evolution of the M_{BH}-σ relation over cosmological time is thus crucial to understanding galaxy formation and numerical simulations of merging galaxies constitute the ideal means to make progress toward this ambitious goal.

Figure 4 presents results from a series of supercomputer simulations designed to elucidate the evolution of the M_{BH}-σ relation in binary disk galaxy mergers. The mass ratios of the interacting systems are equal to 1:1 and 4:1 and the simulations include different physical processes. In the first set of numerical experiments, only the collisionless material (dark matter, stars, and black holes) is considered, while the second set includes gas whose dynamics is followed "adiabatically," i.e., without radiative cooling. A third set of simulations includes radiative cooling, while in the fourth set the cold gas is allowed to form stars. This figure presents the location of all merger remnants on the M_{BH}-σ plane together with real galaxy data and their best-fit correlation taken from Tremaine et al. (2002). The initial galaxy models start very close to the mean correlation and the error bars show the spread about the mean value of σ in each remnant.

The collisionless simulations reveal that when galaxies become gas-poor, which is likely at low z, the merger remnants will tend to move away from the mean relation. This suggests that gas-poor mergers act as a possible source of scatter in the mean M_{BH}–σ relation. In adiabatic simulations, the galaxies have in principle enough gaseous fuel to remain close to the relation, but the gas is too hot to accrete onto the SMBHs. In mergers with radiative cooling, the total amount of nuclear gas is more than one order of magnitude larger than needed to keep the galaxies close to the relation. This should also be regarded as an upper limit on the gas mass that may accrete onto the SMBHs, since feedback processes ensuing once the AGN becomes active will regulate the inflow and allow the accretion of only a fraction of this gas, thus limiting the SMBH growth (Silk & Rees 1998). If AGN feedback is strong enough to suppress cooling, a hot gas phase similar to that found in the adiabatic simulations is expected to form. Thus, the results from cooling and adiabatic simulations likely provide upper and lower bounds to the true physical behavior of the resulting remnants. When star formation is included, the amount of cold gas in the nuclear disks is reduced by more than 90% and the merger remnants move nearly parallel to the relation. This indicates that the interplay between strong gas inflows associated with the formation of the massive nuclear disks and the consumption of gas by star formation is a key ingredient for maintaining the tightness of the M_{BH}-σ relation. Interestingly, using similar hydrodynamical merger simulations, Robertson et al. (2005) find that the slope of this relation is insensitive to the redshift-dependent properties of merger progenitors and should be roughly constant at redshifts z=0-6.

4. Epilogue

Supermassive black holes constitute objects of extreme interest for a broad audience of scientists, including gravitational physicists, cosmologists, and astrophysicists. Compelling evidence for their existence at the centers of most galaxies hosting stellar spheroids has increased steadily in the past decade and the formation of SMBH binaries is a consequence of the prevailing modern theory of hierarchical galaxy formation. The detection of gravitational waves from coalescing SMBHs would permit the first real test of General Relativity, one of the most fundamental theories of Physics, in the so-called strong-field limit as well as would highlight the predictive power of the standard paradigm of galaxy formation and evolution. This should be regarded as one of the most beautiful examples of the deep connections between fundamental physics and astrophysics. Furthermore, by comparing the gravitational waves of coalescing black holes with detailed numerical simulations, the masses, spins, orientations and even distances of the two black holes could in principle be derived. By and large, determining whether the conditions for SMBH coalescence are met naturally in the Universe is of chief interest to a variety of scientific disciplines.

Remarkably, SMBHs appear to be linked in fundamental ways to the dynamics of the stellar and gaseous component of their host galaxies, both on large and small scales. It is now generally accepted that the formation and evolution of galaxies and SMBHs are tightly intertwined, from the early phases of proto-galactic formation, through hierarchical build-up in CDM-like cosmogonies, to recent galaxy mergers. Though substantial progress has been made in our understanding of SMBH formation and evolution and their impact on the formation of evolution of galaxies in general, several outstanding issues remain unresolved. For example, the connection between the coalescence of SMBHs and the energetic feedback arising from them is currently considered as one of the major missing ingredients necessary to understand how galaxies and clusters form and evolve with time. Furthermore, the details of the physical mechanisms responsible for transporting the gas that feeds the black holes from kiloparces scales down to sub-parsec scales are still elusive. Another major issue concerns the properties of the gas distribution below one parsec. These will determine whether a gap will be opened by the binary SMBH, slowing down significantly its orbital decay, or whether the black holes will sink at a faster rate as a result of torques by the asymmetries in the mass distribution surrounding them. Whether or not an appreciable fraction of the gas will be converted into stars by the time the binary separation has fallen below one parsec will also have an impact on the orbital decay of the black holes. This is because the conditions for gap formation will depend on the local gas density and, in addition, the overall sinking rate might have a non-negligible contribution from the newly formed stars.

References

Adams, F. C., Graff, D. S., & Richstone, D. O. 2001, ApJ, 551, L31

Archibald, E. N., Dunlop, J. S., Jimenez, R., Friaça, A. C. S., McLure, R. J., & Hughes, D. H. 2002, MNRAS, 336, 353

Begelman, M., Blandford, R., & Rees, M. 1980, Nature, 287, 307

Blumenthal, G. R., Faber, S. M., Primack, J.R., & Rees, M. J. 1984, Nature, 311, 517

Burkert, A., & Silk, J. 2001, ApJ, 554, L151

Carico, D.P., Graham, J.R., Matthews, K., Wilson, T.D., Soifer, B.T., Neugebauer, G., & Sanders, D.B. 1990, ApJL, 349, L39

Ciotti, L., & van Albada, T. S. 2001, ApJ, 552, L13

Davies, R. I., Tacconi, L. J. & Genzel, R. 2004, ApJ, 613, 781

Downes, D. & Solomon, P. M. ApJ, 1998, 507, 615

Escala, A., Larson, R. B., Coppi, P. S., & Mardones, D. 2004, ApJ, 607, 765

Ferrarese, L., & Ford, H. C. 2005, Space Sci. Rev., 116, 523

Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9

Gebhardt, K., et al. 2000, ApJ, 539, L13

Genzel, R., et al., Nature, 2005, 442, 786

Greve, T. R., Papadopoulos, P. P., Gao, Y., & Radford, S. J. E., 2006, submitted to ApJ (astro-ph/0610378)

Kazantzidis, S., et al. 2005, ApJL, 623, L67

Komossa, S., Proceedings of the American Institute of Physics Conference "The Astrophysics of Gravitational Wave Sources", College Park, Maryland, ed., Centrella, J.M., 2003, AIP, 686, 161

Komossa, S., Burwitz, V., Hasinger, G., Predehl, P., Kaastra, J. S., & Ikebe, Y. 2003, ApJ, 582, L15

Lucy, L. B. 1997, AJ, 82, 1013

MacMillan, J. D., & Henriksen, R. N. 2002, ApJ, 569, 83

Mayer, L., Kazantzidis, S., Madau, P., Colpi, M., Quinn, T., & Wadsley, J. 2007, Science, 316, 1874

Miralda–Escudé, J., & Kollmeier, J.A. 2005, ApJ, 619, 30

Monaghan, J. J. 1992, ARA&A, 30, 543

Ostriker, E. 1999, ApJ, 513, 252

Owen, F.N., Odea, C.P., Inoue, M., & Eilek, J.A. 1985, ApJL, 294, L85

Robertson, B., Hernquist, L., Cox, T. J., Di Matteo, T., Hopkins, P. F., Martini, P., & Springel, V. 2006, ApJ, 641, 90

Rodriguez, C., Taylor, G. B., Zavala, R. T., Peck, A. B., Pollack, L. K., & Romani, R.W. 2006, ApJ, 646, 49

Sanders, D., & Mirabel, I. 1996, ARA&A, 34, 749

Shields, G.A., Gebhardt, K., Salviander, S., Wills, B. J., Xie, B., Brotherton, M. S., Yuan, J., & Dietrich, M. 2003, ApJ, 583, 124

Silk, J., & Rees, M. J. 1998, A&A, 331, L1

Spaans, M., & Silk, J. 2000, ApJ, 538, 115

Springel, V., Di Matteo, T., & Hernquist, L. 2005, MNRAS, 361, 776

Tremaine, S. et al. 2002, ApJ, 574, 740

Treu, T., Malkan, M.A., & Blandford, R. D. 2004, ApJ, 615, L97

A Greek contribution to the preparation of the ESA space mission Gaia

An extended library of synthetic galaxy spectra

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National & Kapodistrian University of Athens

In this article we present a review of the work, completed so far, which is given in detail at the relevant technical reports of Gaia GAIA-C8-TN-UOA-PAT-001 and GAIA-C8-TN-UOA-PAT-002. This work represents the activities of the top-level work package GWP-S-832 (unresolved galaxy classifier) coordinated by Prof. M. Kontiza of University of Athens. The members of this work package are M. Kontiza[1], P. Tsalmantza[1], I. Bellas-Velidis[2], R. Korakitis[3], E. Kontizas[2], A. Dapergolas[2], E. Livanou[1], C.A. L. Bailer-Jones[4], B. Rocca-Volmerange[5], A. Vallenari[6] & M. Fioc[5]. The task of this WP is part of the activities of coordination Unit CU8 (Astrophysical Parameters, classification & parametrization) of the Gaia Consortium Data Processing Analysis (DPAC).

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1. Introduction

The Gaia astrometric survey mission will measure the positions, distances and many physical characteristics of some one billion stars in our Galaxy and beyond. Its observations will have a great impact in the study of the formation and evolution of our Galaxy, the distribution of dark matter, the stellar physics, extragalactic astronomy, the detection of supernovae, brown and white dwarfs, extra-solar planets etc. A schematic representation of the major science goals of Gaia mission is given in figure 1.

Large surveys of galaxies provide information on their global spatial distribution and the physical properties of individual galaxies. Such a survey will be obtained for the whole sky by the ESA mission, Gaia, from 2011-2016. During its five year mission, Gaia will obtain low resolution optical (3300-1000 nm) spectrophotometry of several million unresolved galaxies all over the whole sky. Although the survey's main goal is the stellar content and the structure of our galaxy, there remains a lot of important science to be extracted from the galactic component.

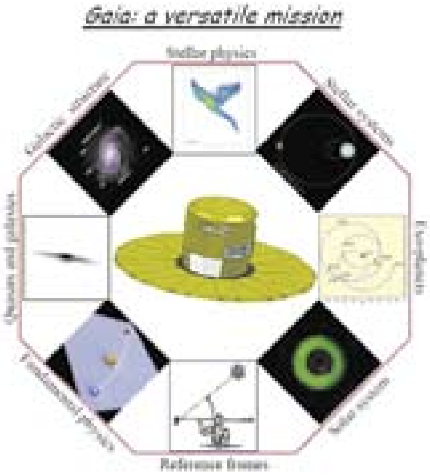

Figure 1. The various areas where Gaia will make significant contributions.

One of the objectives of Gaia is to classify and determine the astrophysical parameters of all the unresolved galaxies which will be observed by Gaia. In order to proceed with this task it is necessary to obtain a reliable library of galaxy spectra at the wavelength range that GAIA will observe. Such a library needs observational and synthetic data based on the theoretical Astrophysical Parameters (APs). The lack of that wavelength coverage by the existing telescopes is a constraint. Synthetic spectra can provide us with a homogeneous set of APs, which is not always the case for the observed spectra. However, the small number of the existing libraries of synthetic spectra of galaxies include too few spectra, they are based on a large number of free parameters and, therefore, are not appropriate for our classification and parametrization project. Thus, the creation of a new synthetic library of galaxy spectra is required.

For the production of the synthetic spectra we used the galaxy evolution model PEGASE (Projet d' Etude des Galaxies par Synthese Evolutive) (Fioc & Rocca-Volmerange 1997). The PEGASE.2 code is principally aimed at modeling the spectral evolution of galaxies (http://www2.iap.fr/users/fioc/PEGASE.html). It is based on the stellar evolutionary tracks from the "Padova" group, extended to the thermally pulsating asymptotic giant branch (AGB) and post-AGB phases (Groenewegen & de Jong 1993). These tracks cover all the masses, metallicities and phases of interest for galaxy spectral synthesis. PEGASE.2 uses the BaSeL 2.2 library of stellar spectra and can synthesize low resolution (R=200) ultraviolet to near-infrared spectra of Hubble sequence galaxies, as well as of starbursts. For a given evolutionary scenario (typically characterized by a star formation law, an initial mass function and, possibly, infall or galactic winds), the code consistently gives the spectral energy distribution (SED) and computes the star formation rate and the metallicity at any time. The nebular component (continuum and lines) due to HII regions is roughly calculated and added to the stellar component. Depending on the geometry of galaxy (disk or spheroidal), the attenuation of the spectrum by dust is then computed using a radiative transfer code. This code is taking into account the scattering.

2. The first library of synthetic galaxy spectra

Synthetic spectra for eight typical types of Hubble sequence galaxies (E, SO, Sa, Sb, Sbc, Sc, Sd and Im) have been produced with PEGASE.2. For each spectral galaxy type, the parameter set (Star formation law SFR(t), Initial mass function IMF, infall rate, galactic winds) is defined to reproduce the local Spectral Energy Distribution (SED) and colors of the type (Fioc 1997; Fioc & Rocca-Volmerange 1999a; Le Borgne & Rocca-Volmerange 2002). These synthetic spectra were compared with observations. The results of this comparison were very good and showed that these spectra represent the typical types of galaxies. The comparison was made with observations available at that time. Now that Sloan Digital Sky Survey (SDSS) is available, we used these data to fit our synthetic data and produce a large grid of realistic APs for our library. The comparison was made through SDSS color-color diagrams. Both the simulated photometry of SDSS spectra and of the synthetic spectra were produced by the appropriate module of the PEGASE.2 code, in order to treat both sets of data homogeneously. The position of the SDSS filters is shown in figure 2 superimposed on the synthetic spectra of the eight typical types. In this figure, the spectra (SEDs) produced by PEGASE have been normalized to the flux in a 50A wavelength interval centered on 5500A. The elliptical and SO galaxies have very small differences, apparent at the two extremes of the wavelength range. This implies faint differences in colors but not necessarily in magnitudes depending on masses. Taking into consideration that the u and g filters are out of the wavelength range of the Gaia observations we based our comparison in the synthetic colors produced by the g, r and i filters.

To obtain the observed spectra of galaxies included in SDSS we used the Data Release 4 (DR4), which is the latest one. We downloaded all the 1d spectra, including all other information like redshifts, line measurements etc. In order to select data suitable for our purposes, we applied the following criteria: the galaxies should not be near a CCD edge nor saturated and their errors should be small. Their redshifts should be less than 0.01, since the synthetic spectra of PEGASE.2 were produced for zero redshift. These restrictions led us to a sample of 1292 galaxies. We then proceeded to simulate their photometry in the same way as in the synthetic data and compared the two sets. The comparison showed very good agreement between the two sets of data (fig 3).

By varying the four most significant parameters of PEGASE models and using all their combinations in each of the eight typical models we managed to cover most of the space of the SDSS data in the color-color diagram. In many cases, however, there is no clear distinction between the colors of neighboring types. In order to avoid this degeneracy, as a first approximation we decided to keep in the library only the models that, in the color-color diagram, were positioned inside a circle, centered on the typical model and with radius equal to half of the distance to its closest neighboring typical model. In this way upper and lower limits of the values of the parameters were established for each type.

The library was produced for both a regular and a random grid of parameters (888 and 2709 synthetic spectra respectively). The set of spectra produced by the regular grid was extended to 4 regular values of redshift (0.05, 0.10, 015 & 0.20). The final library consisting of 7149 synthetic galaxy spectra is shown in figure 3. This library was simulated for Gaia observations and used for the first tests of classification and parametrization of galaxies.

3. Classification and parametrizasion

In the present work we used classification Support Vector Machines (SVMs) (C-classification) to determine morphological types and regression SVMs (epsilon-regression) to estimate the various astrophysical parameters. We use the libsvm library of Chang & Lin (2001) implemented in the e1071 package in the R statistics package (http://www.r-project.org).

3.1 Galaxies at zero redshift

3.1.1 Classification of the morphological type

First of all We tried to classify the regular set of Gaia-simulated galaxy spectra, at G=18 with zero redshift, into the seven Hubble types. This subset of the library includes characteristic noise and a wide range of interstellar extinction (from 0-10 mag in Av). It comprises 9691 spectra. This we divide at random into two subsets: 4846 for training the SVM classifiers and 4845 for evaluating their performance. As is recommendable with many machine learning methods, we first normalized the data by scaling each input (pixel) to have zero mean and unit standard deviation.

For the purpose of visualizing the data set only, we perform a Principal Components Analysis (PCA) on the set of

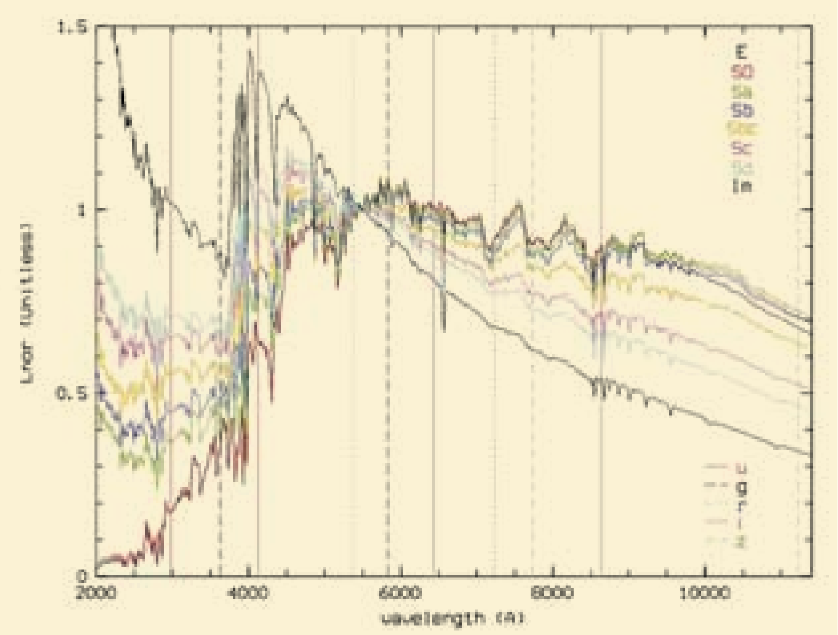

Figure 2. Position of the SDSS filters on the spectrum continua of the 8 typical types of galaxies produced by PEGASE.2. On the right side of the plot the color code corresponding to each type of galaxy (up) and to each SDSS filter (down) is shown. Emission lines are not traced.

9691 96-dimensional Gaia spectra. The first three Principal Components describe 78.25%, 20.44% and 1.02% of the data variance respectively (i.e. 99.71% together). In Fig. 4 we plot the data in projection onto the first three PCs. This diagram, plus the fact that the first three PCs explain almost all of the variance in the data, suggest that a good classification should be possible (the data have an intrinsic low dimensionality).

The results of training and testing the SVM classifier have very few misclassifications: only 6 and 14 in the training and testing set corresponding to an error of 0.12% and 0.29% respectively. While these results are very promising, it must be recalled that the way the library has been constructed avoids class overlap in the SDSS g-r, r-i colour space, which surely eases separation in the 96-dimensional BP/RP colour space.

3.1.2 Regression of astrophysical parameters

In addition to simulating an output spectrum, PEGASE.2 also derives 18 output astrophysical parameters for each galaxy. Of course, by construction we know that our synthetic spectra are uniquely defined by five parameters (p1, p2, infall timescale, age of the galactic winds and the Hubble type), so there can only be five equivalent independent parameters amongst these 18. Nonetheless, it would be useful to predict them directly. Here we build SVM regression models to separately predict the nine most significant ones. For each model we train on a randomly selected set of 4846 spectra and evaluate performance o the remaining 4845. In Fig. 5 we present an example of the true and the SVM-predicted values of one parameter on the test set (present SFR). The results are similar for all cases indicating that we can predict the parameters to good accuracy. More details are given in Tsalmantza et al. (2007).

3.2 Regression of redshift and classification of morphological type

We then enlarged the subset of the library we used in the previous tests by adding the same galaxies at four nonzero values of redshift, specifically 0.05, 0.1, 0.15, 0.2. The library for z=0 includes 9691 galaxies as described above. For each nonzero redshift there are 9757 giving a total sample of 48719 galaxies. (Recall that this includes each galaxy simulated at 11 regular values of Av). We now build another morphological type classification model as done in section 3.1.1, now with 6719 galaxies in the training set and 42000 galaxies for testing set.

We again applied a PCA to the data. This time the first three Principal Components describe 76.01%, 21.63% and 1.02% of the data variance respectively (i.e. 98.6% together), very similar to before. The corresponding PCA-project plot is Fig. 6. Comparing to Fig. 4 we can see how the redshift spreads out the previous loci of types. The performance of the SVM classifier is good considering the added complexity introduced by the redshift variations (and the corresponding increase in the sample size). The missclassification errors are 0.13% and 0.98% corresponding to 9 and 411 galaxies for the training and the testing data respectively.

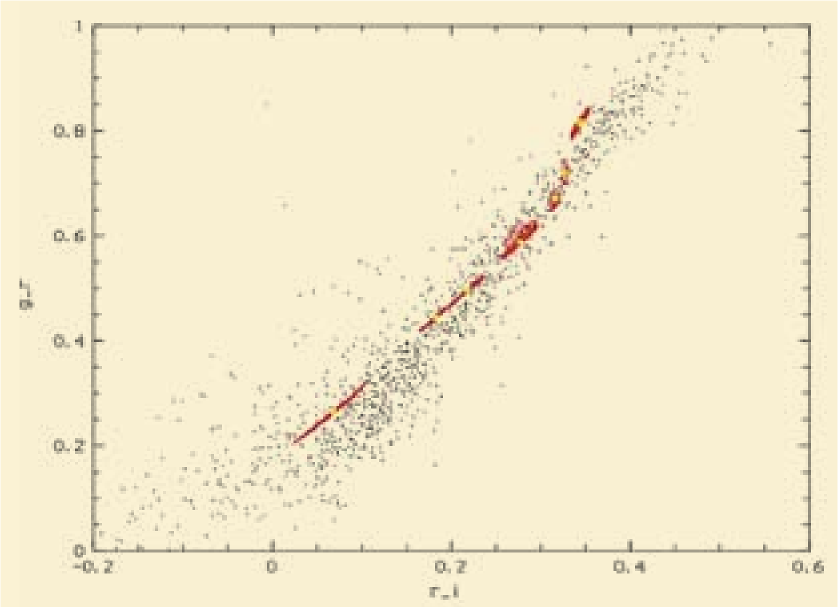

Figure 3. Color-color (g*-r vs r-i) diagram of simulated photometry of SDSS galaxy spectra (black) and of synthetic PEGASE spectra of the 8 typical models of PEGASE.2 (yellow). Moving from the lower left to the upper right part of the diagram we encounter types from Im to E. The red points around the typical models represent the spectra of both the regular and random library.

In practice we may want to first reduce spectra to the rest frame, for which we require an estimate of the redshift. Therefore, we also set up a SVM regression model to predict redshift, using the same training and test sets. The predicted values of redshift for each of the five true redshift values were quite good although we do not expect very good performance here, because the SVM is having to learn the effect of redshift based on just five different values.

4. The second library of synthetic galaxy spectra

The first library of synthetic galaxy spectra for zero redshift was compared with the SDSS data (DR4) of galaxies. Although the synthetic spectra were in very good agreement with the observational data a very small part of the SDSS color-color diagram was covered (figure 3). For the classification and parametrization tasks of GAIA the production of a large variety of galaxies is mandatory, to cover all aspects of the observational data. To accomplish that we tried to cover most of the SDSS color-color diagram in the second library.

For the extension of the first library of synthetic spectra of galaxies we had to overcome two deviations that we had noticed during the comparison with SDSS data (figure 3):

i) The spread of the blue part of the diagram, where the real data reveal the most significant variance, while all the synthetic irregular galaxies are distributed along a line.

ii) The deviation of the synthetic and real data in the red part of the diagram, where early type galaxies are located.

Those two issues were solved by adapting an exponential SFR for the early type

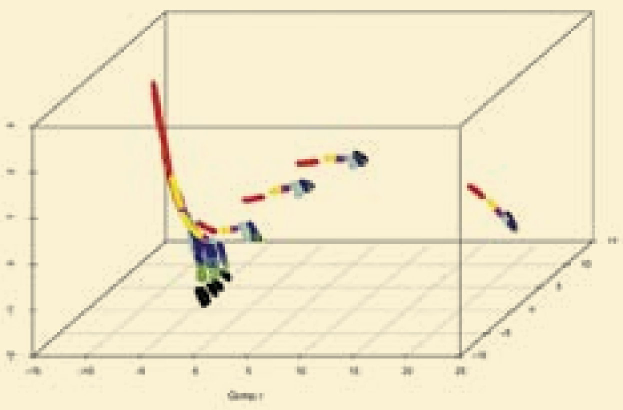

Figure 4. Galaxy classification with the SVM. The confusion matrix for the training set for galaxies at z=0. Columns indicate the true class, row the predicted ones.

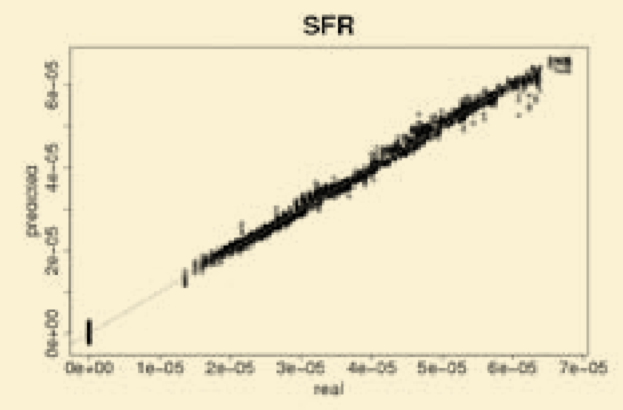

Figure 5. Galaxy parameter estimation performance. For each of the nine APs we plot the predicted vs true AP values for the test set. The red line indicates the line of perfect estimation.

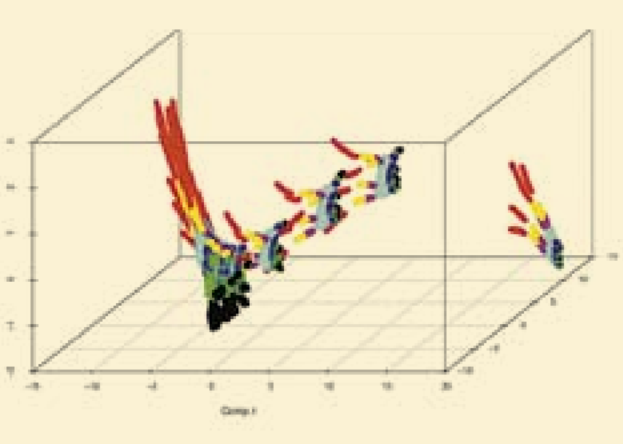

Figure 6. The 48\,719 simulated Gaia galaxy spectra with nonzero redshift plotted as their projections onto the first three Principal Components. Black, green, blue, light blue, magenta, yellow and red denote galaxies of type E, Sa, Sb, Sbc, Sc, Sd and Im respectively.

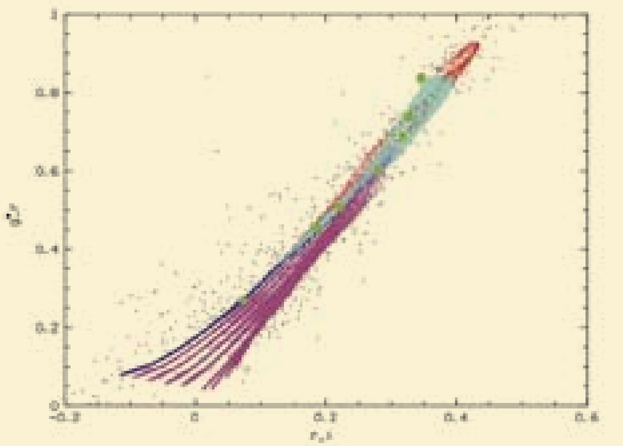

Figure 7. Models of irregular (blue), starburst (magenta), spirals (light blue) and early type galaxies (red). Black dots are SDSS galaxies and green the 8 typical synthetic spectra of PEGASE.2.

galaxies and adding models for starburst galaxies in our library. Having found those solution we were in position to extend the parameters of all models in a greater range of values and cover most of the observations as it is shown in figure 7.

As it can be seen by this figure the new library consists of four types of galaxies (early type galaxies, spirals, irregulars and starburst galaxies) instead of four that were included in the first version. In this way we managed to cover more space of the observational colour-colour diagram. The second library was produced again for a regular and a random grid of parameters for various redshifts and its Gaia simulations will provide a very good tool for the test of the classification and parametrization performance for the Gaia observations of unresolved galaxies.

References

Adams, F. C., Graff, D. S., & Richstone, D. O. 2001, ApJ, 551, L31

Chang C.-C., Lin C.-J., 2001, LIBSVM: a library for support vector machines, 2001,

Fioc M. 1997, PhD thesis

Fioc M. & Rocca-Volmerange B., 1997, A\&A, 326, 950

Fioc M. & Rocca-Volmerange B., 1999a, astroph 12179

Groenewegen M.A.T. & de Jong T., 1993, A\&A, 267, 410

Le Borgne D. & Rocca-Volmerange B., 2002, A\&A, 386, 446

P. Tsalmantza, M. Kontizas, R. Korakitis, B. Rocca-Volmerange, E. Kontizas, E. Livanou, I. Bellas-Velidis, A. Dapergolas, C. A. L. Bailer-Jones, A. Vallenari, M. Fioc, 2006, GAIA-C8-TN-UOA-PAT-001

P. Tsalmantza, B. Rocca-Volmerange, M. Kontizas, I. Bellas-Velidis, E. Kontizas, C. A. L. Bailer-Jones, R. Korakitis, A. Dapergolas, E. Livanou, M. Fioc, A. Vallenari, 2007, GAIA-C8-TN-UOA-PAT-002

P. Tsalmantza, M. Kontizas, C. A. L. Bailer-Jones, B. Rocca-Volmerange, R. Korakitis, E. Kontizas, E. Livanou, A. Dapergolas, I. Bellas-Velidis, A. Vallenari, M. Fioc, 2007, A&A, 470, 761

http://www2.iap.fr/users/fioc/PEGASE.html

http://www.r-project.org

http://www.csie.ntu.edu.tw/~cjlin/libsvm+

High mass X-ray binaries in the Small Magellanic Cloud

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Abstract

Using *Chandra*, *XMM* and optical data (both photometric and spectroscopic), we studied the X-ray binary population in the Small Magellanic Cloud (SMC), down to an X-ray luminosity of ~4×10^{33} erg s-1, thus allowing the investigation of the faintest of the high-mass X-ray binary populations. The regions were selected so as to have varying star formation histories, in order to investigate, using homogeneous and well defined samples, the connection between the Be-XRB phenomenon and SF history. The characterization of the X-ray sources discovered in our *Chandra* and *XMM* surveys and the selection of our sample of Be-XRBs, was based on a combination of X-ray and optical properties. We found that the number of Be/X-ray binaries (Be-XRBs) peaks at the age of 40-70 Myr ago. Finally, we constructed their X-ray luminosity function (XLF). There are very few X-ray sources above ~10^{35}ergs^{-1}, which is consistent with the transient nature of Be X-ray binaries. There is also indication for a flattening of the XLF at ~10^{35}ergs^{-1}, which would be consistent with the onset of the propeller effect.

1. Introduction

Nearby star-forming and spiral galaxies offer a unique environment in which to study the populations of ***High Mass X-ray binaries*** (HMXBs), as their proximity allows: (a) the detection of the majority of active X-ray binaries (and in some cases even of quiescent systems); and (b) the identification of their optical counterparts and the determination of the local star-formation parameters. The latter (which is particularly difficult to achieve in our Galaxy due to uncertainties in distance determination and often high extinction) is important for identifying the type of the donor star in the system.

Observations of galaxies in our ***Local Group*** and in particular of the nearest members, the Magellanic Clouds, allow us to probe the ***low-luminosity end*** of the X-ray binary populations. Here, we review the results we obtained from an extended study of the X-ray population in the Small Magellanic Cloud (SMC), with the *Chandra* and *XMM* space telescopes, down to an X-ray luminosity of ~4x10^{33} erg s^{-1}, allowing the investigation of the faintest of the HMXB populations. The fact that the SMC has experienced a burst of star-formation ~30-70 Myr ago (using data from Harris & Zaritsky 2004), which resulted in a large population of Be X-ray binaries (Be-XRBs), provides us with the opportunity to study this particular type of X-ray sources in detail.

1.1 General properties of X-ray binaries

X-ray binaries (XRBs) are stellar systems consisting of a compact object (neutron star, black hole, or, white dwarf) accreting material from a close companion star. They are the end points of stellar evolution, and their study can set constraints to models of stellar evolution and compact object formation. They have typical X-ray luminosities of ~10^{36}-10^{38}erg s^{-1}, when in outburst, and they are divided into two classes, depending on the mass of the donor star: Low Mass XRBs (LMXBs) for M_{donor}≤1 M⊙ and High Mass X-ray Binaries (HMXBs) for M_{donor} ≥10 M⊙.

The companion star in HMXBs is of O or B spectral type, with optical bolometric luminosity usually exceeding that of the accretion disk (e.g. van Paradijs & McClintock 1995). HMXBs can further be divided into two groups, the supergiant X-ray binaries (hereafter SG/XRBs), and the Be X-ray binaries (hereafter Be-XRBs). In the SG/XRB's, the primary is a supergiant of spectral type earlier than B2, or an Of star, that has evolved away from the main sequence (MS), while in the Be-XRBs, the primary is an Oe or Be star lying close to the MS. The optical spectra of Be-XRBs are characterized by emission lines (mostly of the Balmer series).

Different mechanisms are believed to be responsible for the mass transfer in these two groups of HMXBs. The most luminous SG/XRBs usually have an accretion disk fueled via Roche lobe overflow, while the less luminous systems may be fed by a supersonic stellar wind. In the Be-XRBs, Be stars are characterized by a low velocity, high density equatorial wind, resulting in periodic accretion episodes during the passage of the compact object through the decretion disk of the donor.

Be-XRBs often show pulsations and have hard X-ray spectra in the 1-10 keV range (i.e. with a power-law energy index of Γ~0-1.; e.g. White, Nagase & Parmar 1995, Yokogawa et al. 2003), which are signatures of accretion onto strongly magnetized neutron stars. In contrast, SG/XRBs have generally softer spectra, and do not always have a pulsar as the compact object. Be-XRBs are the most numerous sub-class of HMXBs. In the Milky Way as well as in the Large Magellanic Cloud (LMC), they constitute 60-70% of all HMXBs (Sasaki, Pietsch & Haberl 2003), while in the Small Magellanic Cloud (SMC) the percentage is significantly higher (only 2 SG/XRBs are known to date in the SMC Liu et al. 2005, Liu et al. 2006).

1.2 On the high mass X-ray binary population of the SMC

As already mentioned, the SMC has a large number of Be-XRBs, observed through moderate Galactic foreground absorption (N_H~$6x10^{20}cm^{-2}$) and well mapped extinction (Zaritsky et al. 2002). In addition, its well measured distance (60 kpc; e.g. van den Bergh 2000, Hilditch, Howarth & Harries 2005), small line-of-sight depth of the young populations in the main body (<10 kpc; e.g. Crowl et al. 2001; Harries, Hilditch & Howarth 2003), facilitate the interpretation of the results. Therefore, one can study in great detail and in a homogeneous way the faint end of the X-ray binary populations.

Several studies of the optical characteristics of the XRB systems in the SMC, have been published in the last few years. Haberl & Sasaki (2000), based on the ROSAT surveys of the SMC (reaching a non-uniform detection limit of ~5×10^{34}-10^{35} erg s^{-1}), identified and classified 25 X-ray sources as new Be-XRBs. Haberl & Pietsch (2004) extended this work presenting 65 SMC HMXBs, of which 45 are associated with an emission-line object indicating that they are Be-XRBs. In the latest census of HMXBs by Liu et al. (2005) 62 Be-XRBs are listed (out of 92 confirmed or proposed HMXBs). In addition, out of the 38 currently known X-ray pulsars in the SMC, 34 have identified optical counterparts (Coe et al. 2005).

XTE monitoring of the SMC has been consistently discovering new X-ray binary pulsars with periods ranging from ~10s up to ~1000s (e.g. Laycock etal 2005). The majority of those pulsars are located on the SMC bar.

2. The new *Chandra* and *XMM-Newton* surveys

Although the currently published surveys of the SMC mentioned in §1.2 provide important information about its XRB population, they are largely inhomogeneous, with uneven spatial coverage and detection thresholds only allowing the discovery of persistent HMXBs, or, Be-XRBs in outburst, thus missing the bulk of Be-XRBs in quiescence.

With our *Chandra* and *XMM-Newton* surveys we attempted to provide homogeneous coverage of the SMC Bar, as well as sample the outer regions which had been very poorly covered in the past. The various regions studied have different and well mapped (e.g. Harris & Zaritsky 2004) star formation (SF) histories. One of our main aims was to investigate the overall X-ray source populations in the context of the SF history at their birth-places.

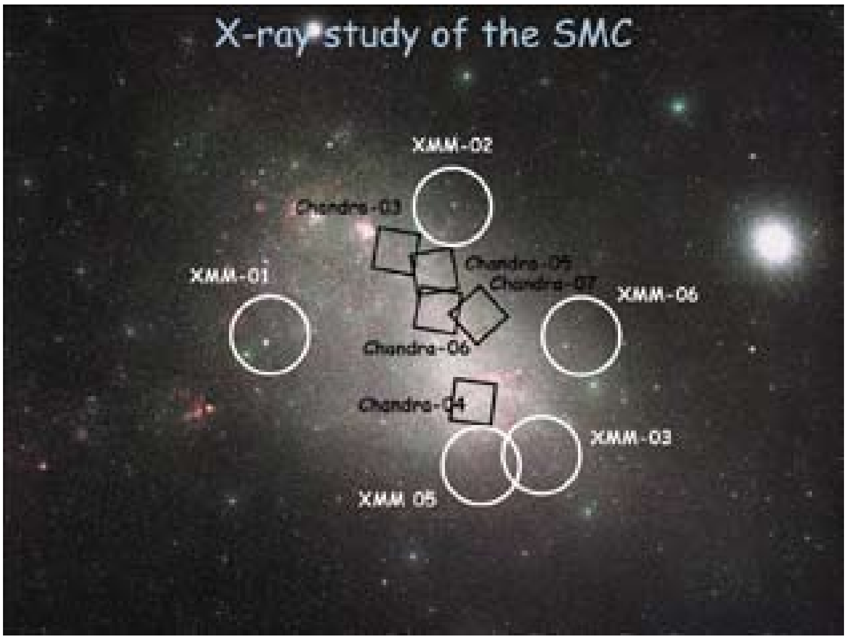

Figure 1. Overlayed on an optical image of the SMC (Photo by D. Malin, © Anglo-Australian Observatory and Royal Observatory Edinburgh) are the footprints of our 5 *Chandra* (black) and 5 *XMM-Newton* (white) fields.

2.1 Chandra Data

Using the ACIS-I detector (Advanced CCD Imaging Spectrometer) on board *Chandra* we observed, between May and October 2002, five fields with typical exposure times of 8-12 ks. The survey covers an area of 1280 arcmin^2 along the central, most actively star forming region of the SMC.

These observations yielded a total of **153 sources, down to a limiting luminosity of ~4×10^{33} $L_\odot$** (in the 0.7-10 keV band), reaching the luminosity range of quiescent HMXBs (typically L_X~10^{32}-10^{34} $L_\odot$; van Paradijs & McClintock 1995). The source-list and their X-ray luminosity functions are presented in Zezas et al. (2008), while their optical counterparts and resulting classification are presented in Antoniou et al. (2008a).

2.2 XMM-Newton Data

Our *XMM-Newton* survey consists of 5 observations conducted in April 2006, in the outer parts of the SMC, performed with the 3 EPIC (MOS1, MOS2 and PN) detectors in full-frame mode (see Figure 1). The observed fields were selected in order to sample stellar populations in a range of ages (~10-500 Myr). One of these fields was affected by high background flares and it is not included in the current study. We detected (simultaneously in all 5 energy bands, 0.2-0.5 keV, 0.5-1.0 keV, 1.0-2.0 keV, 2.0-4.5 keV, and 4.5-12.0 keV) a total of **186 sources down to a limiting luminosity of ~3.5×10^{33} $L_\odot$** (in the 0.2-12 keV band, Antoniou et al. (2008b).

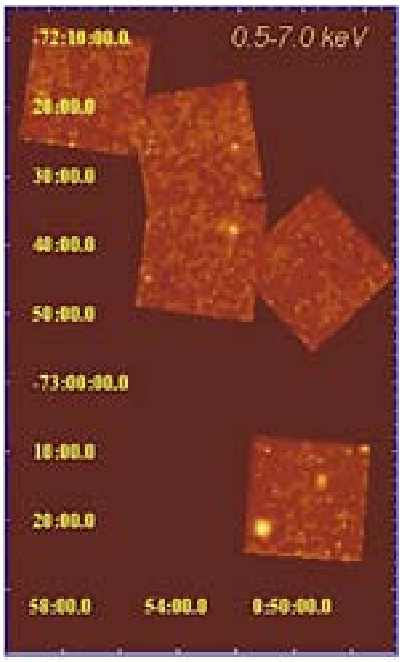

Figure 2. Chandra merged observations in the 0.5-7.0 keV band.

3. Optical Counterparts

The determination of the exact nature of the X-ray sources detected in the *Chandra* and *XMM-Newton* observations, requires the identification of the optical counterparts of the sources. To this effect, we cross-correlated the X-ray source coordinates with the *MCPS* (Zaritsky et al. 2002) catalogue, which fully covers all regions, and the *OGLE-II* (Optical Gravitational Lensing Experiment survey, Udalski et al. 1998a) catalogue, which has better resolution and photometric accuracy, but provides only partial coverage of the observed fields (e.g. field *XMM-2* is not covered at all).

The search radius around each X-ray source was determined on the basis of its positional uncertainty (estimated from the empirical formulae of Kim et al. 2004 and Cappelluti et al. 2007), the absolute astrometric error of the X-ray satellites (<0.6 arcsec, and ~2arcsec, at the 90% confidence level for *Chandra* and *XMM-Newton*, respectively), and the astrometric error of each optical catalogue (~0.7 arcsec for *OGLE-II* and ~1 arcsec, for *MCPS*).

To estimate the number of possible chance associations between the X-ray sources and the stars in the OGLE-II and MCPS catalogs, we followed a Monte-Carlo procedure, described in detail in Antoniou et al. (2008a). The results indicate that in the more densely populated *Chandra* fields, a relatively small fraction (<19%) of the bright blue ($M_{V_o} \leq -0.25$ and $(B-V)_o \leq -0.11$) optical counterparts can be considered as spurious matches, while in the more remote *XMM-Newton* fields the corresponding percentage is estimated to be much lower (<5%). Therefore, for the sources with multiple matches, we can assume that, if one of them is an early type star, it is the most likely counterpart. However, the high chance coincidence probability for the fainter optical sources does not allow us to securely identify an optical counterpart in these cases.

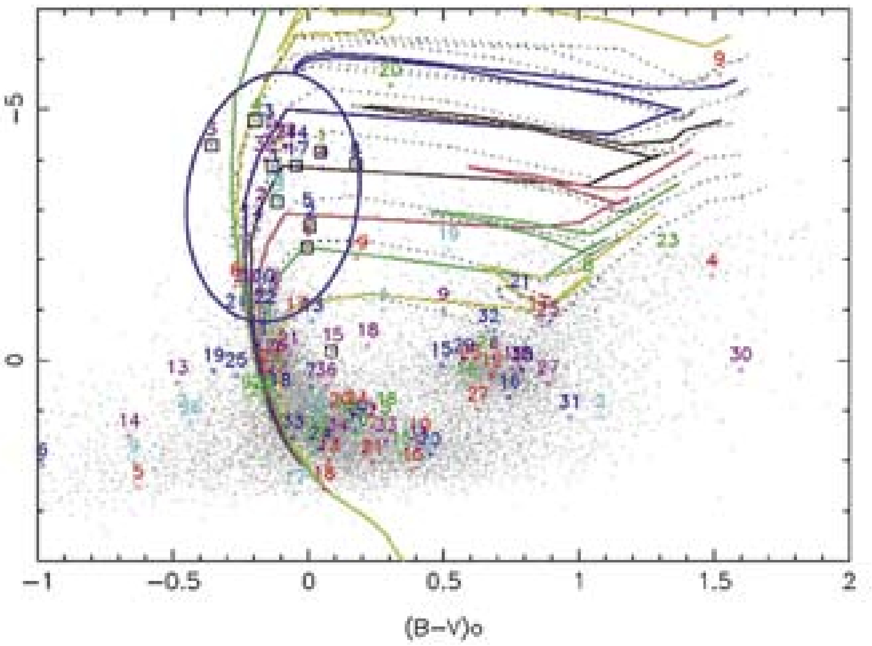

Figure 3. CMD of all single and the brightest of multiple matches of the *Chandra* sources. The optical sources are color coded as, *Chandra* field 3: cyan; 4: blue; 5: magenta; 6: green; 7: red; while the OGLE-II stars that lie in *Chandra* field 4 are indicated in grey small dots. With black squares we present the 10 candidate Be stars of Mennickent et al. (2002) that we have identified as optical counterparts. Overlaid are the isochrones (solid lines) and stellar evolutionary tracks (dotted lines) from Geneva database. (Lejeune & Schaerer 2001) for ages of 8.7, 15.5, 27.5, 49.0, 87.1, 154.9 and 275.4 Myr and initial stellar masses of 12, 9, 7, 5, 4, and 3 M_e stars (from top to bottom). Figure adapted from Antoniou et al. (2008a).

4. Classification of X-ray sources

The classification of an X-ray source as a HMXB (Be-XRB or SG/XRB), LMXB, supernova remnant (SNR), active galactic nucleus (AGN) or foreground ("normal" galactic) star is based on its X-ray properties (X-ray luminosity, hardness ratios or spectral characteristics and X-ray variability, whenever available, cf Pietsch et al. 2004) and the properties (magnitude, colour, spectral classification, optical variability, whenever available) of the optical counterpart of the source.

In the present, we limit ourselves to the identification of HMXBs in the SMC fields studied, utilizing all available X-ray and optical properties. As discussed in the previous paragraph, bright blue optical counterparts, which are consistent with HMXBs in terms of their luminosity, are unlikely to be due to chance coincidence.

In order to classify the X-ray sources we use the following criteria:

(i) ***Location on the CMD***: Figure 3 shows the $[M_{V_o}, (B-V)_o]$ CMD of all stars in the OGLE-II catalogue, lying within the *Chandra* 4 region. The magnitudes and colours (V, B-V) of the stars were corrected for the distance modulus of the SMC (using $(m-M)_o=18.89\pm0.11$mag from Harries et al. 2003) and for interstellar reddening (we adopted the value of $E(B-V)=0.09$ from Udalski et al. 1999). On the same diagram we have marked all single or brightest counterparts (in case of multiple matches) of our sources, using different colours for different fields. The ellipse marks the locus of Be stars determined from the data in Evans et al. (2004). Candidate optical counterparts within this locus are compatible with the characteristic of the donor star in Be-XRBs. It must be noted that supergiant systems would suggest absolute magnitudes of the counterpart brighter than $M_V \sim -5.9$ (see e.g. Trundle & Lennon 2005). None of the candidate counterparts of our sources meet this requirement, therefore none of the X-ray sources in our sample seem to be SG/XRBs[1].

(ii) ***X-ray hardness ratios:*** A hard ($\Gamma < 1.6$) X-ray spectrum or hardness ratio is indicative of a HMXB (e.g. Yokogawa et al. 2003). Sources with softer spectra could be either background AGNs, black-hole binaries or

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[1] It should be noted that the contribution of the accretion disk in the optical band is not expected to be significant for early type stars, while it becomes dominant for the later spectral types (van Paradijs & McClintock 1995).

neutron stars with weak magnetic fields. Although a subset of AGNs have hard X-ray spectra (Compton thick AGNs; e.g. Matt et al. 2000), the identification of a hard X-ray source with an early type star will strongly suggest that it is a HMXB.

(iii) ***Ha emission***: Ha emission comes from the decretion disk of the Be-XRB. So Ha emission from an optical counterpart, combined with OB spectral type (or location within the ellipse of Fig.3), signifies a Be-XRB. However, absence of Ha emission does not mean the source cannot be a Be-XRB, as the Ha line strength varies significantly, following the disappearance and reappearance of the decretion disk (McSwain et al. 2008). Unfortunately, spectral information is available for very few of our optical counterparts and existing catalogues of emission line objects (e.g, Meyssonnier & Azzopardi 1993) have limiting magnitudes that exclude the majority of our sources.

We conducted a spectroscopic survey of a subset of our candidate Be-XRBs as well as of known Be-XRBs, with the 2df multi-object spectrograph at the 4m-Anglo-Australian Telescope. An example spectrum is shown in Figure 4 below. We could confirm Ha emission for a total of 22 objects (Antoniou et al. 2008c).

(iv) ***X-ray variability:*** Most Be-XRBs show pulsations (pulsars). Information on pulsations is derived from the literature, and necessarily refers to already known Be-XRBs.

(v) ***Optical lightcurves:*** Be-XRBs are expected to show optical variability with typical amplitudes of ~0.2 mag (Mennickent et al 2002). Optical lightcurves for the bright blue counterparts of our sources were constructed from the OGLE-II (Szymański 2005 and Udalski et al. 1997) and MACHO databases. We find that most of these optical matches show some type of optical variability (either outbursts with even ~0.3mag change in ~2yr or more frequently periodic or quasi-periodic long-term oscillations of the order of ~0.05-0.1mag within 1yr). In Figure 5 we show the lightcurve of the optical counterpart of the Chandra source 5_3.

The classification scheme is the following: if an X-ray source has an optical counterpart lying within the ellipse of Fig. 3 (criterion -i), and has a hard spectrum (criterion -ii), it is a candidate Be-XRB. If criterion (iii) and/or (iv) are met, then the object is a certain Be-XRB. Optical variability (criterion –v) provides further confirmation of the classification.

Following this methodology, we identified a total of **29** Be-XRBs, or, candidate Be-XRBs in the *Chandra fields* and **8** in the *XMM-Newton* fields.

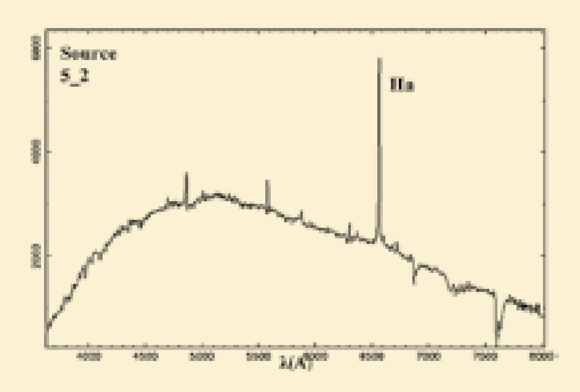

Figure 4. Spectrum of optical counterpart of Chandra source 5_2, showing a typical Be spectrum.

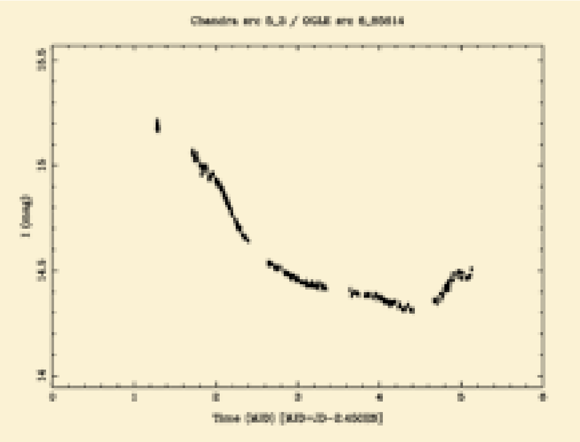

Figure 5. The OGLE lightcurve (in *I* magnitude) of the optical counterpart of the Chandra source 5_3, showing clear variability.

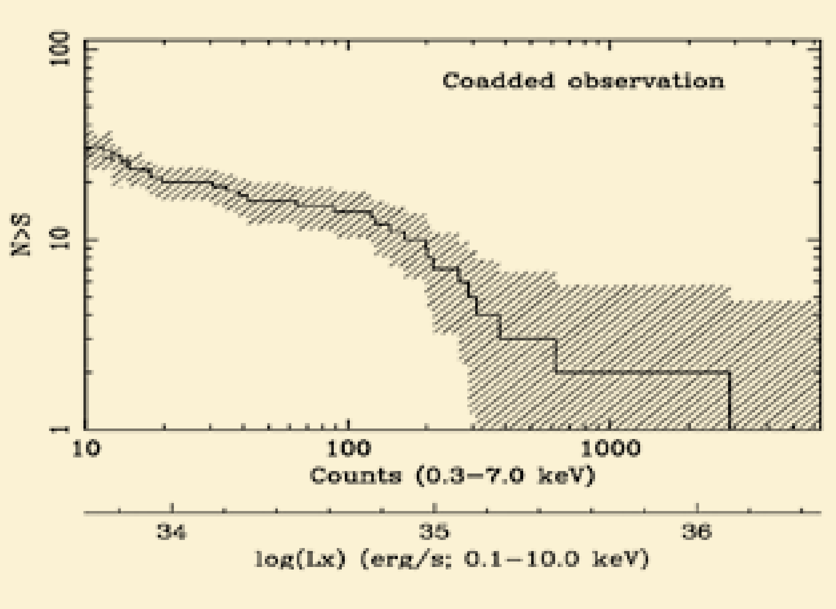

Figure 6. The XLF of X-ray sources with early-type optical counterparts observed in the 5 shallow Chandra observations on the SMC "bar". The hatched area indicates the uncertainties on the luminosity function taking into account the Poisson uncertainty in the luminosity of each source as well the uncertainty on the number of sources (see Zezas & Fabbiano 2002). Figure adapted from Zezas (2008).

5. X-ray source luminosity function

Based on the optical associations of the X-ray sources we can identify those associated with young stars and construct their X-ray luminosity function (XLF). Figure 6 shows the XLF of these young X-ray sources.

There are very few X-ray sources above ~1035ergs^{-1}, which is consistent with the transient nature of Be X-ray binaries (e.g. Laycock et al. 2005). There is also indication for a flattening of the XLF at ~10^{35}ergs^{-1}, which would be consistent with the onset of the propeller effect (cf Shtykovskiy & Gilfanov 2005). At fainter fluxes <10^{34}ergs^{-1} (close to our detection limit) there is indication for a turn-up of the XLF which could be due to an additional faint population that might be associated with quiescent Be-XRBs.

6. Star formation history

6.1 The Star Formation history of the *Chandra* and *XMM-Newton* fields

Using data from Harris & Zaritsky (2004) we derived the recent SF history in our *Chandra* and *XMM-Newton* fields (assuming a metal abundance of Z=0.008) by calculating the weighted average SF history of the MCPS regions (~12′×12′) that overlap with each region.

In the *Chandra* fields, the most recent major burst peaked at ~40 Myr ago and had a duration of ~40 Myr. In addition, there were older SF episodes (~0.4 Gyr ago) with lower intensity but longer duration, as well as a very recent episode in only one of the fields (~7 Myr).

In the *XMM-Newton* fields, the most recent major burst occurred ~70 Myr ago. We also observed two fields with very young populations (most recent major burst at ~11 and ~17 Myr ago, respectively), that both have additional less intense bursts at ~70 Myr ago. One of the fields contains only older populations (most recent burst at ~700 Myr ago).

6.2 SF history and Be-XRB formation

Here we investigate the connection between the SF history (i.e. SF rate versus age) of the *Chandra* and *XMM-Newton* fields and their population of Be-XRBs.

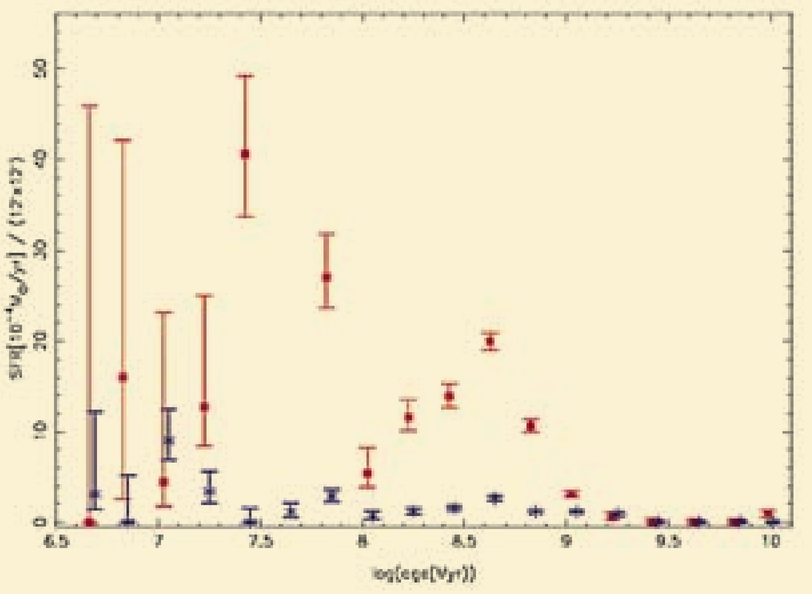

Figure 7. Weighted average SF rate (in 10^{-6} M⊙/yr/arcmin^2) versus age (from present). *Red data points:* for the MCPS regions that host at least one Be-XRB or candidate Be-XRB. *Blue data points:* for the regions that do not host such sources. Figure adapted from Antoniou et al. (2008b)

In Figure 7, we show the weighted average SF history for the MCPS regions that host at least one Be-XRB or candidate Be-XRB (red data points), and for the regions that do not host such sources (blue data points). This plot shows that the Be-XRB phenomenon is strongly related to the local SF history. The largest number of Be-XRBs appears in those fields that have a major SF burst ~40-70 Myr ago. This is clearly shown in Figure 8, where we have plotted the number density (normalized for an area equal to the area of an XMM field)

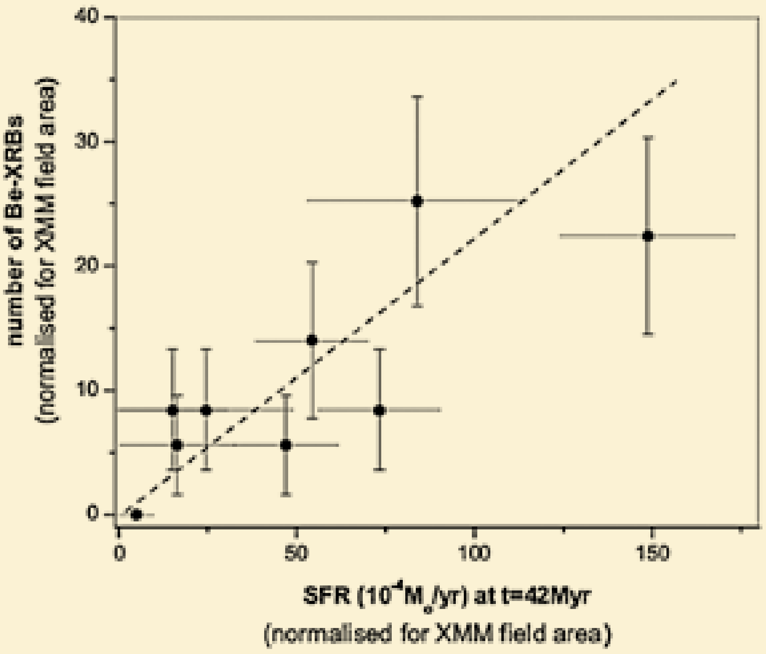

Figure 8. The number density (normalized for an area equal to the area of an XMM field) of Be-XRBs and candidates, against the size (in 10^{-4}M⊙/yr) of the SF rate peak, at 40 Myr. Figure adapted from Antoniou et al. (2008b)

of Be-XRBs and candidates, against the size (in $10^{-4}M_\odot$/yr) of the SF rate peak at 40 Myr. This plot can be used in an inverse fashion, to predict the expected number of Be-XRBs in a snapshot survey (down to a limiting X-ray luminosity of ~4×1033 L⊙) in any region with known SF history.

7. Conclusions

Using *Chandra, XMM* and optical data (both photometric and spectroscopic), we studied the X-ray binary population in the Small Magellanic Cloud (SMC), down to an X-ray luminosity of $\sim 4\times10^{33}$ erg s^{-1}, thus allowing the investigation of the faintest of the high-mass X-ray binary populations.

The regions were selected so as to have varying star formation histories, in order to investigate, using homogeneous and well defined samples, the connection between the Be-XRB phenomenon and SF history.

The characterization of the X-ray sources discovered in our *Chandra* and *XMM* surveys and the selection of our sample of Be-XRBs, was based on a combination of X-ray and optical properties.

We found that the number of Be/X-ray binaries (Be-XRBs) peaks at the age of 40-70 Myr ago.

Finally, we constructed their X-ray luminosity function (XLF). There are very few X-ray sources above $\sim 10^{35}$ergs^{-1}, which is consistent with the transient nature of Be X-ray binaries. There is also indication for a flattening of the XLF at $\sim 10^{35}$ergs^{-1}, which would be consistent with the onset of the propeller effect.

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We would like to thank our collaborators J. McDowell, V. Kalogera and E. O'Sullivan.

We are also grateful to Rob Sharp at the AAT, who conducted the 2df service observations on our behalf. This paper uses public domain data originally obtained by the MACHO Project, whose work was performed under the joint auspices of the US Department of Energy, National Nuclear Security Administration, by the University of California, Lawrence Livermore National Laboratory, under contract W-7405-Eng-48; the National Science Foundation through the Center for Particle Astrophysics of the University of California under cooperative agreement AST 88-09616; and the Mount Stromlo and Siding Spring Observatory, part of the Australian National University. This paper also uses public domain data obtained by the OGLE-II project.

References

Antoniou, A., Zezas, A., Hatzidimitriou, D., McDowell, J., 2008a, ApJ, under revision

Antoniou, V., Hatzidimitriou, D., Zezas, A.,.2008b, in preparation

Antoniou, V., Hatzidimitriou, D., Zezas, A., 2008c, in preparation

Campana, S., Stella, L., Israel, G. L., Moretti, A., Parmar, A. N., Orlandini, M. 2002, ApJ, 580, 389

Cappelluti, N., Hasinger, G., Brusa, M., et al. 2007, ApJSupp, 172, 341

Coe, M.J., Edge, W.R.T., Galache, J.L., & McBride, V.A. 2005, MNRAS, 356, 502

Crowl, H.H., Sarajedini, A., Piatti, A.E., Geisler, D., Bica, E., Clarià, J.J., & Santos, J.F.C., Jr., 2001, AJ, 122, 220

Haberl, F., & Sasaki, M. 2000, A&ASupp., 359, 573

Haberl, F. & Pietsch, W. 2004, A&A, 414, 667

Haberl, F., & Sasaki, M. 2000, A&A, 359, 573

Harris, J., & Zaritsky, D. 2004, AJ, 127, 1531

Harries, T.J., Hilditch, R.W., & Howarth, I.D. 2003, MNRAS, 339, 157

Hilditch, R.W., Howarth, I.D., & Harries, T.J. 2005, MNRAS, 357, 304

Kim, D.-W., Cameron, R. A., Drake, J. J., et al. 2004, ApJS, 150, 19

Laycock, S., Corbet, R.H.D., Coe, M.J., Marshall, F.E., Markwardt, C., & Lochner, J., 2005, ApJS, 161, 96

Lejeune, T., & Schaerer, D. 2001, A&ASupp., 366, 538

Liu, Q.Z., van Paradijs, J., & van den Heuvel, E.P.J. 2005, A&A, 442, 1135

Liu, Q. Z., van Paradijs, J., van den Heuvel, E. P. J. 2006, A&A, 455, 1165

McSwain, M.V., Huang, W., Gies, D.R., Grundstrom, E.D., Townsend, R.H.D. 2008, ApJ, 672, 590

Mennickent, R. E., Pietrzyński, G., Gieren, W., Szewczyk, O., 2002, A&A, 393, 887

Meyssonnier, N., & Azzopardi, M. 1993, A&ASupp, 102, 451

Pietsch, W., Misanovic, Z., Haberl, F., Hatzidimitriou, D., Ehle, M., Trinchieri, G., 2004, A&A, 426, 11

Sasaki, M., Pietsch, W., & Haberl, F. 2003, A&A, 403, 901

Shtykovskiy, P., & Gilfanov, M. 2005, MNRAS, 362, 879

Trundle, C., Lennon, D. J., 2005, A&A, 434, 677

Szymański M.,2005, Acta Astron., 55, 43

Udalski A., Kubiak M. and Szymański M.,1997, Acta Astron. 47, 319.

Udalski, A., Szymanski, M., Kubiak, M., Pietrzynski, G., Wozniak, P., & Zebrun, K. 1998, Acta Astronomica, 48, 147

van Paradijs, J., & McClintock, J.E. 1995, X-ray Binaries, eds. W.H.G.~Lewin, J.van Paradijs, and E.P.J. van den Heuvel (Cambridge: Cambridge Univ.Press), p.58

White, N.E., Nagase, F., & Parmar, A.N. 1995, X-ray Binaries, eds. W.H.G. Lewin, J. van Paradijs, and E.P.J. van den Heuvel (Cambridge: Cambridge Univ. Press), p.1

Yokogawa, J., Imanishi, K., Tsujimoto, M., Koyama, K., & Nishiuchi, M. 2003, PASJ, 55, 161

Zaritsky, D., Harris, J., Thompson, I.B., Grebel, E.K., & Massey, P. 2002, AJ, 123, 855

Zezas, A. 2008, Proceedings of «A population Explosion: The Nature and Evolution of X-ray Binaries in Diverse Environments», in press

Zezas, A., Fabbiano, G., Rots, A. H., & Murray, S.S. 2002, ApJ, 577, 710

Zezas A., Antoniou A., Taylor, P., et al. 2008, in preparation

International conference

X-ray Surveys: Evolution of Accretion, Star Formation and the Large-Scale Structure of the Universe

Rhodos island, 2-6 July 2007

The 3rd quatrannual International conference, organized by the "X-ray and Cosmology group" of the Institute of Astronomy & Astrophysics of the National Observatory of Athens, and entitled *Xray Surveys: Evolution of Accretion, Star Formation and the Large-Scale Structure of the Universe*, took place in Rhodos island between the 2nd and 6th of July 2007. The scientific organizing committee included prominent colleagues from the USA, France, Germany, UK, Spain, Italy and Japan (G. Fabbiano, N. White, R. Mushotzky, C. Canizares, M. Arnaud, H. Bohringer, G. Hasinger. M. Rowan-Robinson, A. Fabian, A. Parmar, M.G. Watson, X. Barcons, S. Borgani, Y. Ueda).

A large number of astronomers and postgraduate students (around 140) from all over the globe participated in the meeting, held at the Rhodos Palace Hotel, in which more than 10 invited reviews, 80 talks and 50 posters were presented. The topics covered spanned a large range of extragalactic high-energy astrophysics and observational cosmology. For example, very interesting contributions were presented on the topic of the AGN accretion history, the AGN environment and whether there is such a link to the nuclear activity, on the elusive population of obscured and Compton thick AGN, on the X-ray – infrared link, as well as on the coeval growth of galaxies and supermassive black holes. On the larger scales, there were many interesting presentations on the high-redshift large-scale structure as traced by X-ray selected AGN and clusters of galaxies and on the multitude of cosmological constraints that they can provide. Finally, the future prospects and missions like eROSITA, Con-X and XEUS were presented and their viability discussed.

There was a fairly strong Greek representation in the conference with ~20 participants (~15% of the total) who contributed 9 oral presentations including an invited review talk and 2 targeted talks. The power-point presentations of the reviews and talks, as well as photos from the event, can be found in the following address:

http://www.astro.noa.gr/~xray07/

Finally, we would like to note that the meeting was supported by the ministry of finance and the municipality of Rhodos.

8th CONFERENCE OF HEL.A.S.

The 8th conference of the Hellenic Astronomical Society, devoted to the 50-year anniversary of space exploration took place at the island of Thassos, in the period 13 - 15 of September 2007. More than 100 scientists from Greece and abroad convened to present their latest results and discuss major open issues in all areas of modern astrophysics. The University of Thrace undertook the main organizational load of the conference. In particular, Prof. Fr. George Anagnostopoulos (Chairman) and the members of the Local Organising Committee prepared the local organization of the conference with unparallel enthousiasm and professionalism.

As was the case with previous conferences of Hel.A.S. the presentations were divided in six major sessions, as follows.

- Session 1: Sun, Planets and Interplanetary Medium,
- Session 2: Our Galaxy (Stars, Planets and Interstellar Medium).
- Session 3: Extragalactic Astrophysics,
- Session 4: Theoretical Insights in Dynamical Astronomy, Relativity and Cosmology,
- Session 5: Instrumentation and Methods in Astronomical Observations,
- Session 6: History and Education in Astronomy.

In addition to these sessions, there was one more session devoted to the aniversary of 50 years from the launch of Sputnik in October 1957. The invited speakers in this session were Dr Thanasis Economou who talked on "50 years of space exploration: reminiscences by someone who was there almost from the very beginning", and prof. E. Sarris who talked on "the Earth's Space Environment".

Five other keynote speakers addressed the participants of the conference and presented excellent review talks on a wide variety of subjects. These were Prof. Tom Ray from the Dublin Institute for Advanced Studies, Ireland, who presented a review on "Observations of star formation", Dr. Jason Spyromilios

from ESO (Germany), who presented a review entitled "ESO and the European Extremely Large Telescope", Prof. Ewald Mueller from MPI (Germany) who discussed the resent developments on "Core Collapse Supernovae and their Gravitational Wave Signal", Prof. Wolfgang Baumjohann of the Austrian Academy of Sciences, with a review on "The Earth's Magnetosphere: An Astrophysical Plasma Laboratory" and Prof. Ofer Lahav of Univ. College London (UK) who presented a review on "Surveys on Dark Energy: Challenges and Prospects".

The Scientific Organizing Committee of the 8th conference of the Hellenic Astronomical Society was chaired by K. Tsinganos and included G. Anagnostopoulos, A. Anastasiadis, V. Charmandaris, I.A. Daglis, K. Kokkotas, N. Kylafis, A. Mastichiadis, M. Metaxa, P. Niarchos, M. Plionis, E. Theodossiou and H. Varvoglis.

The Local Organising Committee consisted of Fr. G. Anagnostopoulos [chair], V. Archontis, I. Louri, I. Karanikola, P. Marhavilas, E. Vassiliadis, E. Sarris and E. Trohoutsos. The program and the abstract book of the 8th conference can be found at the URL

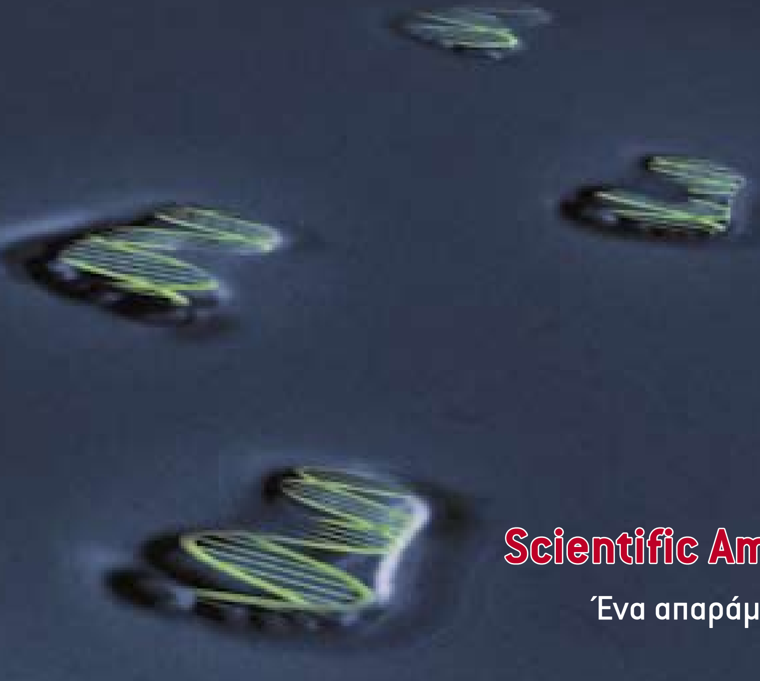
http://www.ee.duth.gr/hac/

and also at the Hel.A.S. webpage.

On Friday, 14/9/07, the General Assembly of the Hel.A.S. was held. The president K. Tsinganos, summarized the progress made in the past year in several fronts of the Society while the secretary V. Charmandaris summarized the current situation within the society wherein 30 new members had applied for membership and the GA approved their membership. The Treasurer A. Mastichiadis announced the new secure online webserver where members can at last pay their membership fees with their own credit card, etc. More details on the General Assembly can be found on the webpage of HelAS

http://www.helas.gr/council.php

Thanks to the efforts of the organizing committee, the quality of the science presented by the participants and the pleasant environment of the island of Thassos, the conference was a great success. We all look forward to an even better conference of the Society in 2009.



Σειρά: «θέματα του *Scientific American*».
Άρθρα του περιοδικού,
με θεματολογική συνάφεια,
σε μικρά, καλαίσθητα
και έγκυρα βιβλία

ΚΥΚΛΟΦΟΡΟΥΝ

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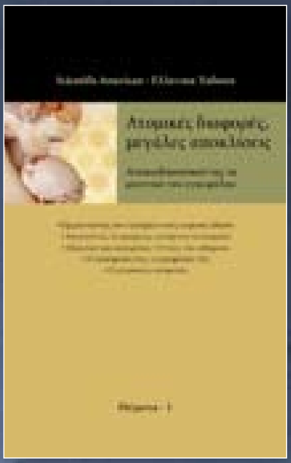

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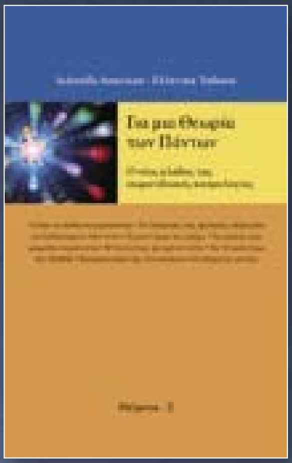

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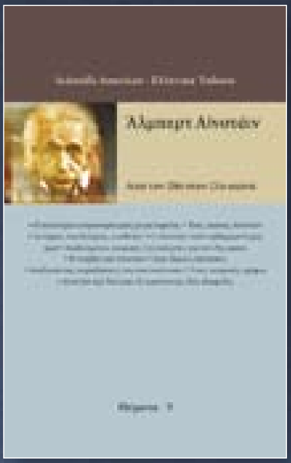
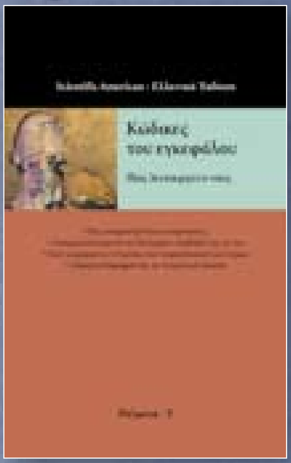
Ο νέος κλάδος της σωματιδιακής κοσμολογίας



Άλμπερτ Αϊνστάιν
Από τον 20ό στον 21ο αιώνα

Με τα μάτια στο μέλλον
Σωτηρία ή κατάρρευση μέχρι το 2050



Κώδικες του εγκεφάλου
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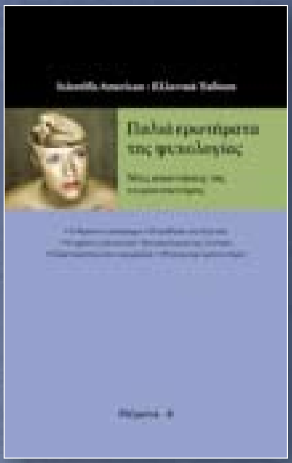

Παλιά ερωτήματα της ψυχολογίας
Νέες απαντήσεις της νευροεπιστήμης

Κοσμικοί γρίφοι
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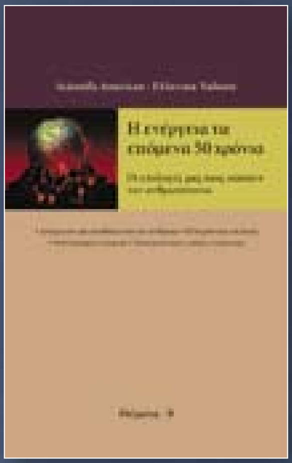

Η ενέργεια τα επόμενα 50 χρόνια
Οι επιλογές μας ίσως σώσουν την ανθρωπότητα