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WINTER SCHOOL

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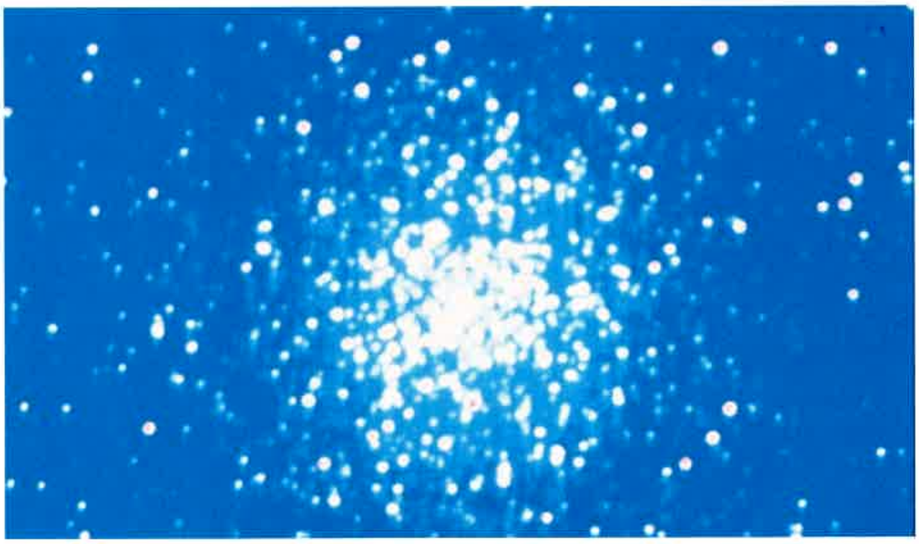
Faculties of Mathematics and Physics,
University of La Laguna (Tenerife)

16-27 / XI / 1998

Globular Clusters



Globular cluster M13, in the constellation Canis Venatici.

The IAC, in collaboration with the European Commission (*Training and Mobility of Researchers Programme*) and Iberia, has organized its tenth *Canary Islands Winter School of Astrophysics*, which is to take place from 16 to 27 November 1998 at the Faculties of Mathematics and Physics of the University of La Laguna (Tenerife). This year´s Winter School marks the tenth anniversary of this annual gathering in which young astrophysicists and lecturers of scientific prestige from all over the world meet and interact in a joint study of current astronomical topics. This year's Winter School lectures are to be given by eight experts in various fields of astrophysics relating to globular clusters, objects of importance for studying the age of the Universe, galaxy formation and stellar evolution. The participants are 66 students from 26 countries who either are in the process of preparing or have recently completed their doctoral theses on this year's topic. The course will end with visits to the Instituto de Astrofísica de Canarias in La Laguna and to the Roque de los Muchachos Observatory (La Palma) and Teide Observatory (Tenerife). As in previous years, the Winter School course will be published by Cambridge University Press.

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DIRECTOR'S WELCOME

Prof. FRANCISCO SÁNCHEZ
(Director of the IAC)

For a decade now the Instituto de Astrofísica de Canarias (IAC) has hosted the Canary Islands Winter School of Astrophysics, in which young astrophysicists from all over the world have the opportunity of meeting accredited specialists to study the topics of most active concern in present-day astronomy. During these ten years 80 lecturers and more than 600 students have attended the Winter School, an even higher number not being able to come due to the limited number of places available.

This year's Winter School is dedicated to GLOBULAR CLUSTERS, one of the basic sources of our knowledge concerning the lives of the stars and the physics of their evolution.

The Winter School is an enriching experience for all who take part. It gives the lecturers a much prized chance to pass on their knowledge to a select group of privileged students while at the same time receiving in return new ideas, inspiration and stimulus to bring to bear on their work. For the students, it is an opportunity not only to receive such special tuition, but also to experience direct contact with masters in the field concerned and gain the insights into their most recent investigations on the key issues of present-day astrophysics.

On the occasion of the tenth Winter School, I should like to reiterate yet again my long-held wish that those attending the School stay in contact with one another and with the IAC, in the manner of an informal club.

For our part, we undertake to stay in touch with you, wherever you may be and by whatever means of communication (you can contact us through Ana Quevedo at aqg@ll.iac.es to let us know of any changes in your personal data, changes of address, etc.). Besides any printed matter you may receive from us, you can also get the latest information concerning the IAC from our Web page http://www.iac.es/.

This tenth Winter School, marks a milestone on a long but gratifying journey, in spite of occasional difficulties. I am confident that the next ten Winter Schools will be equally beneficial for all who take part.

OUR THANKS TO:

The Local Government (Cabildo) of La Palma
The Local Government (Cabildo) of Tenerife
La Laguna Town Hall

SOME FIGURES:

Nº Lecturers:	8
Nº Students:	66
Nº Countries:	26
Nº Applications:	88

What will you find in this Special Issue?

This special issue of *IAC Noticias* is dedicated to the X Winter School and contains reports of interviews with each of the invited lecturers (pages 7-21), as in previous issues, as well as their individual answers to a set of common questions on various topics (pages 22-27). Further information on this and previous Winter Schools is also included.

GLOBULAR CLUSTERS

CARLOS MARTÍNEZ AND ISMAEL FOURNON
(organizers of the X Canary Islands Winter School of Astrophysics)

The study of globular clusters has been and still is essential for furthering our knowledge of such astrophysical phenomena as stellar and galactic evolution, variable and X-ray emission stars, chemical abundances (primordial nucleosynthesis), etc.

Carlos Martínez Roger

Globular clusters are ideal laboratories for testing theories of stellar evolution, the chemical evolution of the Universe and the dynamics of *N*-body systems. They are the oldest known objects whose ages can be independently determined, the closest in proximity to the origin of the Universe and the sole surviving structures of the first stages in the formation of the Galaxy. They provide us with important evidence concerning on the age and formation processes of the Galaxy. A fundamental unit of the known Universe, they are also found in all other galaxies within our observational grasp. They are possibly a necessary stage in the formation of galaxies.

Nevertheless, even though no researcher is in any doubt regarding relevance of globular clusters in the aforementioned fields, there have so far been no important congresses dedicated specifically to them since 1992 (*Structure and Dynamics of Globular Clusters:* UC Workshop, Berkeley, July 1992) and there has been no important international school on the subject.

As scientific research becomes ever more highly specialized, researchers, particularly those who are now beginning their careers in this atmosphere of intense specialization, are finding it harder and harder to keep abreast and properly orientated in all the disciplines related to their line of work. This Winter School was planned with a view to offering a thorough review of research on globular clusters and is intended to cover all the relevant disciplines with the aid of the best possible international team of specialists (Canada, Italy, South Africa, Spain, the United Kingdom and the United States), including the theoretical and observational aspects of stellar populations, stellar evolution and quemical abundances, dynamics, variable stars, X-ray sources and the globular clusters of other galaxies.

The *X Canary Islands Winter School of Astrophysics* aims to bring together doctoral students and recent PhDs on the one hand and a group of renowned specialists on the other in order to review the field of globular clusters. It is our intention to communicate a clear general overview that will enable researchers to link their own field of specialization to others related to it, thereby increasing their understanding of their own work. With regard to the young researcher we seek to instill in them an awareness of the "great game of investigation" enjoyed by their more experienced peers. The Winter School plays two fundamental roles: that of training researchers and that of providing a vehicle for publicizing new discoveries.

The lecturers have been invited to provide written versions of their talks for publication in the near future, since we believe that this would be a useful tool for both investigators in the field and students of astrophysics world wide.

Finally, we should like to express our gratitude to all who have made the *X Canary Islands Winter School of Astrophysics* possible. It has been the fruit of the good will of many individuals at the IAC, among whom we wish to mention Lourdes González, Nieves Villoslada, Jesús Burgos, Carmen del Puerto, Begoña López Betancor, Mónica Murphy and Campbell Warden. Finally, but no less importantly, our thanks are due to the participants themselves: the lecturers and students from over 25 countries, from all the continents, for their interest and the work they have presented from their most recent research.

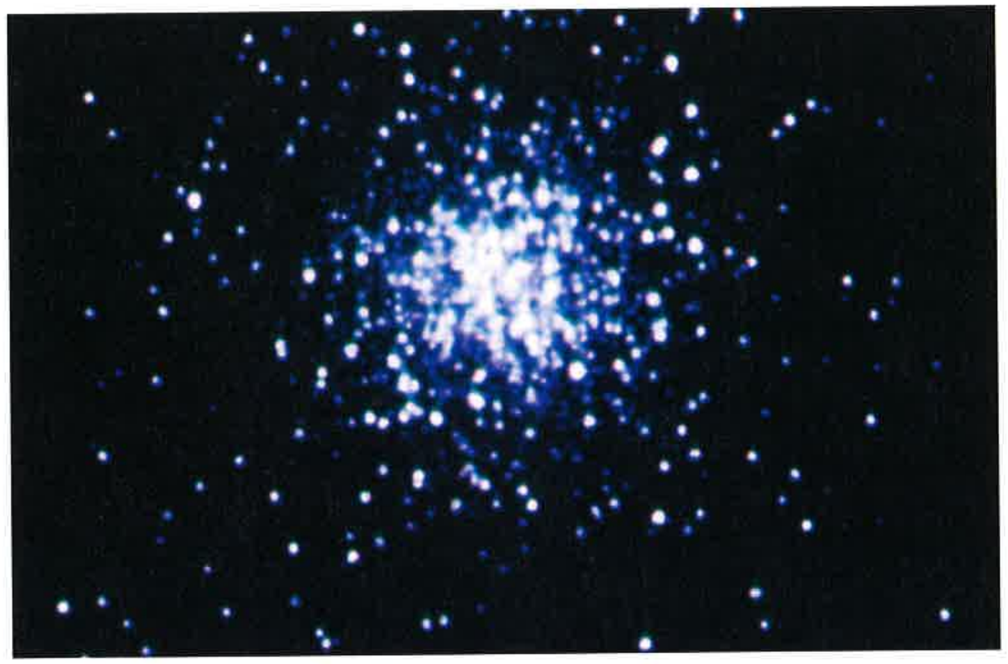
A decade of Winter Schools

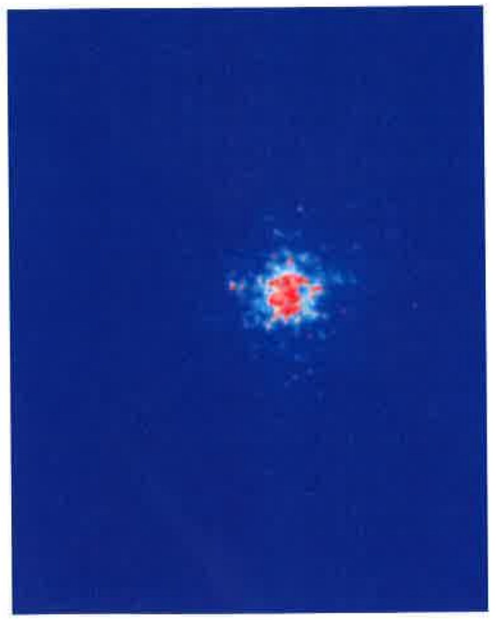
To date, over 600 students and some 80 lecturers have attended the ten Canary Islands Winter School of Astrophysics, organized each year by the IAC. The high standard of teaching at the Winter School is recognized internationally. This year in particular we have received financial assistance from the European Commission under the Training and Mobility of Researchers Programme to cover the costs of participants from the European Union and Eastern Europe.

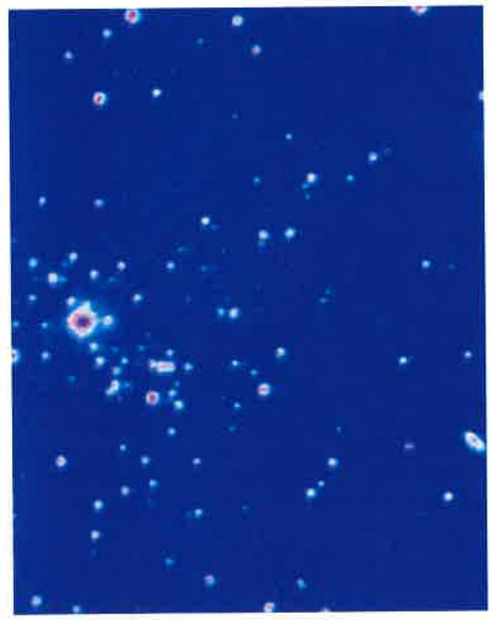
The IAC Winter School provides a unique opportunity for doctoral students from universities the world over to get to know other colleagues preparing their theses on related topics and to meet specialists of international repute in the topic covered by the Winter Schools. It also gives them the chance to see the IAC and its Observatories.

This year the talks at the Winter School will be imparted in the main lecture hall (*Aula Magna*) of the Faculties of Physics and Mathematics of the University of La Laguna. Through this means, it is our intention that the Winter School students and lecturers experience the University of La Laguna at first hand. Likewise, students at the Faculties of Physics and Mathematics can strike up acquaintances with students and lecturers from various countries at the same time as attending the Winter School lectures.

Isamel Perez Fournon







A sample of different globular clusters in our galaxy: M72 (top), NGC 6229 (left) and PAL 14 (right).

From ω Centauri to 47 Tucanae

Something more than just beauty in the sky

By CARMEN DEL PUERTO
(IAC Information and Publications Officer)

A globular cluster in M13

"THE MOST SPECTACULAR GLOBULAR CLUSTER IN THE NORTHERN HEMISPHERE IS M13 IN THE CONSTELLATION HERCULES. THIS CLUSTER IS ONE OF 103 OBJECTS CATALOGUED IN 1784 BY THE FRENCH ASTRONOMER CHARLES MESSIER (1730-1817). ITS NAME IS SIMPLY THE LETTER THAT IDENTIFIES THE CATALOGUE AND THE NUMBER THAT WITH WHICH IT IS DESIGNATED THEREIN. TODAY IT IS POPULARLY KNOWN AS THE HERCULES CLUSTER".

The constellation Centaurus contains what is for many the most beautiful globular cluster in the sky. The cluster Omega Centauri (ω Cen), with close to a million stars, has a stellar designation because to the German astronomer Johannes Bayer (1572-1625) it appeared as a fuzzy star of fourth magnitude.

Also in the southern hemisphere, in the constellation Toucan and competing in beauty, brightness and antiquity, is the splendid globular cluster 47 Tucanae (47 Tuc); once again, and for the reason just given, it is a cluster with a stellar name.

Both objects are observable with small telescopes, and even with the naked eye, which is why they are so well known among amateur astronomers. But their appeal goes far beyond their evident beauty: *ω Cen* and *47 Tuc* are representative of a class of objects in the Universe of particular interest to professional astronomy.

Guardians of secrets

Globular clusters hold many astronomical secrets. The technology of past centuries - unlike the giant telescopes of today with their advanced instrumentation - did not permit the contents of globular clusters to be clearly resolved. Today, we know that these attractive objects are very dense agglomerations of from tens of thousands to millions of stars distributed with the particularly spherical symmetry that their name indicates, and that they belong to what the celebrated astronomer Walter Baade in 1944 christened "Population II".

The members of this stellar population are old stars located in the halo of our Galaxy (and, by extension, in the halos of other galaxies), and with a very low metal content. This low metallicity means that globular clusters must have formed at an early stage in the life of their host galaxies, not long after the Big Bang and before the primordial hydrogen and helium were processed in the interiors of stars to form the heavier chemical elements.

All the stars in a globular cluster must have been formed at the same time, after the collapse of a single giant gas cloud. Their distribution in the "Hertzsprung-Russell diagram" (a graphical representation of the temperature or colour of each star plotted against its brightness or absolute magnitude) provides information concerning the common age and distance of all the stars in the cluster. The estimate thus obtained of cluster ages was, until recently, a matter of some controversy: the age of the Universe (some 15,000 million years) was incompatible with globular clusters having an age of 18,000 years. How could clusters that were older than the Universe itself possibly exist? Fortunately, as explained in this special issue of *IAC Noticias*, the paradox of the ages of the globular clusters has now been resolved after improved calculations of the distances to certain stars.

In our Galaxy there are 150 known globular clusters, scattered throughout the halo and with elliptical orbits about the Galactic centre; in contrast, open clusters, with younger and more metal-rich stars ("Population I") are concentrated in the disc of the Milky Way.

Globular clusters, so it would seem, are key topics for understanding such questions as the age of the Universe, galaxy formation, stellar evolution, etc. For this reason, as noted in their introduction by organizers of this Winter School, it is astonishing that globular clusters have warranted so few congresses and other scientific meetings. Hence the interest in, justification and theme of this *X Canary Islands Winter School of Astrophysics*, which marks the tenth anniversary of this annual event which provides an opportunity for young astrophysicists to meet and interact with lecturers of high scientific standing.

Just one recommendation before I sign off. Do have a look at what we have entitled 'Planets in other clusters' (pages 24-25), in which the Lecturers of the Winter School invite us to imagine how it would be to live inside a globular cluster.

Course: OBSERVATIONAL APPROACH TO POPULATIONS IN GLOBULAR CLUSTERS

Prof. Ivan R. King
University of California
U.S.A.

BROWN DWARFS IN THE HALO OF THE GALAXY

The brightest stars in present-day globular clusters, thousands of millions of years after their formation, have a mass less than 80 per cent of that of our Sun and still retain a portion of the elements of the cloud from which they were formed. The higher-mass stars leave fossil remnants, such as neutron stars and brown dwarfs, whereas lower-mass objects, like the substellar brown dwarfs, have yet to be detected in globular clusters. Professor Ivan R. King gives an overview of these stellar and substellar objects for the student of stellar evolution.

Do you think that it will be possible in the near future to discover brown dwarfs in globular clusters? How could they be imaged, by using microlensing effects?

"They will probably be discovered, won't be imaged, but probably detected by microlensing."

Wha fraction of the matter in the globular clusters could be in brown dwarfs if we extrapolate your results to low-mass stellar population?

"10 to 50% by number, but a much smaller fraction by mass."

What is the most interesting problem in your current investigation in relation to globular clusters?

"Pushing toward the hydrogen-burning limit."

Which discovery has had the greatest impact on your career in astrophysics?

"The whole development of the field of stellar populations."

"10 TO 50% OF LOW MASS STARS IN GLOBULAR CLUSTERS BY NUMBER, BUT A MUCH SMALLER FRACTION BY MASS, COULD ACTUALLY BE BROWN DWARFS."

PROFILE

IVAN R. KING was born in New York in 1927.
He studied at Harvard University, where he obtained his doctorate in 1952.
He then worked as a mathematician for a private firm, as an instructor for Harvard University (1951-52) and, during the following four years was attached on Active Duty to the US Naval Reserve and the Department of Defense (1954-56) as a methods analyst.
From then onwards, his career followed a more academic line: professor of the University of Illinois from 1956 to 1964, and Professor of the University of California Berkeley, where he occupied a chair from 1966 to 1992 and where his is a present Emeritus Professor.
King has served as President of the Dynamical Astronomy Division of American Astronomical Society and of the Astronomy Section of the American Association for the Advancement of Science (1973-1974). He was elected member of the American Academy of Arts and Sciences in 1980 and of the National Academy of Science in 1982.

Ivan R. King

Course: STELLAR POPULATIONS AND THE HISTORY OF THE GALAXY

Prof. Steven R. Majewski
University of Virginia
U.S.A

STELLAR EVOLUTION

The stars in globular clusters were formed, just like their host clusters, by a process of gravitational condensation inside galaxies. Thus were born, virtually simultaneously associations of millions of stars of various masses. Each would shine in its own special way and be blue, yellow or red in colour, depending on its mass. The advanced age of the globular clusters in the Galactic halo, however, is a parameter that was often used to define these types of objects. Younger globular clusters were discovered in the eighties ("age dispersion") although it might be, as Prof. Steven Majewski now explains, that the youngest globular clusters evolved in nearby dwarf galaxies.

Steven R. Majewski

"I AM PARTICULARLY INTRIGUED BY THE POSSIBILITY OF GATHERING A DETAILED PICTURE OF THE EVOLUTION OF THE MILKY WAY BY TRACING - VIA CHEMICAL AND SPATIO-KINEMATICAL DATA - SOME CLUSTERS BACK TO THEIR SITE OF ORIGIN IN DWARF GALAXIES."

What do you think are the most important constributions that result from the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"Globular clusters have provided an essential empirical check on one of this century's greatest astrophysical triumphs - the understanding of stellar evolution. By fortunate circumstance, the first intensive studies of globular cluster color-magnitude diagrams (with photographic data in the 1950's) by Sandage, Arp and others coincided with the birth and developement of modern theories of stellar evolution and nucleosynthesis. Since then, refinements of stellar evolution theory have been driven by observational aspects of star cluster CMD's, which provide almost the only real constraints on the models. Stellar evolution and nucleosynthetic theory, in turn, have given us the ability to age-date the clusters and read the levels of enrichment written both in the spectra of cluster members and in the shape of the cluster CMD. Age and abundance information from the clusters, in turn, have provided vital clues toward solving numerous other problems, from the formation of the Milky Way to setting the extragalactic distance scale and providing limits on the age of the universe.

In 1917, Harlow Shapley used the distribution of globular clusters to locate the true center and determine the relative size of the Milky Way. Globular clusters, by virtue of their luminosity and distinct morphology have continued to play a central role in mapping the shape of the Galaxy.

More recently, globular clusters have become pivotal in defining the chemodynamical attributes of old stellar populations in the Galaxy. This role will increase as we gather more data on the space motions and detailed abundance patterns of both globular and open clusters."

What is the minimum age dispersion in globular clusters? Is it correlated with their physical features? What kind of information does it provide in regard to the duration of the collapse of the protogalactic cloud?

"It has long been suspected that there are age differences within the halo globular cluster system. Two decades ago, on the basis of the so-called "second parameter" spread in the morphology of the horizontal branches (HBs) of cluster color-magnitude diagrams, Searle & Zinn postulated that an age spread existed in the outer halo globular cluster system. They proposed that this was the result of slower development of stellar populations in subsystems ("fragments") left behind as the interior of the Galaxy collapsed and developed. In this scenario, the age spread, at least that found in the outer halo globular clusters, is attributable more to the timescales of collapse and star formation in the fragments left behind than on the duration of the collapse of the gas that formed the early flattened components of the Milky Way.

However, confidence that age is the sole second parameter of HB morphology has waxed and waned throughout the years; other possible contributors to the variance in HB morphology that have been suggested include cluster density, rotation, alpha-capture element abundances, oxygen abundances affecting mass loss rates, helium abundance and "deep mixing" of helium in highly convective stars, helium core mass at helium flash, and even the possibility of differences in the amount of swallowed up planets. One of the most exciting developments in the era of CCD photometry is our ability not only to photometer a number of cluster main sequences, but also to discern subtle differences in the shape of main sequence and red giant branch distributions that are the hallmarks of small age differences. Assuming a predominant contribution by age to the second parameter effect, the latest work seems to maintain that about a 3 Gyr age spread does exist in the halo cluster system, but this is still highly debated and the spread may be as low as 1 Gyr, depending on the stellar evolution model used for comparison. Interestingly, several of the second parameter (younger?) halo clusters appear to be associated kinematically with the satellite dwarf galaxies of the Milky Way. This suggests that the Milky Way may have accumulated such clusters through accretion processes - that is, through processes similar to those envisioned by Searle & Zinn.

Information on the timescale for the collapse of the protogalactic cloud that led to the bulk of the Milky Way, a process envisioned, for example, in the landmark Eggen, Lynden-Bell and Sandage paper of 1962, may be encoded in the properties of less remote, more flattened, old components that have been hypothesized to have formed early on. These components - the "lower halo" and the "thick disk" or "Intermediate Population II" - may actually be parts of a continuum of old populations formed during the primordial collapse. The associated globular clusters may be the so-called "disk" and "old halo" clusters, which, at present, indicate little age spread, although much more work is needed here."

Could the primordial matter, origin of the most ancient globular clusters, be chemically enriched by the nucleosynthesis of a previous star population?

"It has been theorized that stars may have formed in the early universe, before the era of galaxy formation, at redshifts higher than z = 1000. The Jeans mass at these times may have limited the mass function of "Population III" stars to masses larger than about 10 to 100 solar masses or so (a limit not yet certain), so these stars would have quickly evolved to supernovae and would have had a chance to dump their nucleosynthetic yield of heavy elements to pre-galactic gas. These first generation stars may have contaminated the primordial Big Bang nucleosynthesis yields with heavy elements to about one ten thousandth of the solar level. Interestingly, this is about the lower bound on metallicities seen in Galactic field star surveys, but two orders of magnitude less than the lower limit of enrichment in Galactic globular clusters."

In relation to the topic of this School, which is at present the most interesting problem in your research?

"I am particularly intrigued by the possibility of gathering a detailed picture of the evolution of the Milky Way by tracing - via chemical and spatio-kinematical data - some clusters back to their site of origin in dwarf galaxies. We see that, for example, the Sagittarius dwarf galaxy is in the process of 'donating' its family of globular clusters to the Milky Way cluster retinue. It is unlikely that this process is unique, and there must exist some present Milky Way globulars that were originally part of smaller galactic subsystems that may or may not have yet totally succumbed to accretion processes by the Milky Way."

PROFILE

STEVEN R. MAJEWSKI, a native of Chicago, received a BA with honors from Northwestern University in 1983, with majors in physics, mathematics, and integrated science. Since his graduate work at the University of Chicago's Yerkes Observatory, from which he received his Ph.D. in 1991, his research has concentrated on the evolution of galaxies and stellar populations, both from the perspective of studying extragalactic systems to high redshifts as well as through detailed study of the spatial, kinematical and abundance distributions of populations in the Milky Way and its satellite system.

In 1990 Majewski began postgraduate work, first as a Carnegie Fellow and then as a Hubble Fellow, at the Carnegie Observatories in Pasadena, CA. He is grateful to maintain connection with the Observatories as a Visiting Associate.

Since 1995, he has been on the astronomy faculty at the University of Virginia where his research group focuses on astrometry, photometry and spectroscopy of stellar systems in the Milky Way. One goal of the research is to understand the history of satellite mergers with the Milky Way. Soon the Virginia group hopes to turn some attention to preparatory science for the Space Interferometry Mission, which will be launched into orbit in 2005. In 1997 Majewski was awarded a David and Lucile Packard Foundation Fellowship and a National Science Foundation Career Award.

Course: STAR CLUSTERS AS A TEST FOR STELLAR EVOLUTION

Prof. Vittorio Castellani
Astronomical Observatory of Capodimonte
ITALY

THE AGES OF CLUSTERS

After much hard work over the last few decades, astronomers today know that globular clusters are among the oldest objects in the Universe, containing as they do some of the oldest stars. Their pronounced spherical shape indicates that they hardly rotate. What is more, their masses, luminosities and radii are more or less the same, wherever they are located. This means that they were born more or less in the same way, and at approximately the same stage of the expansion of the Universe. Since they are not rotating, they must have formed from gas clouds having little or no angular momentum, and that they could be the result of the gravitational fragmentation of still un-ionized primordial gas in expansion. By comparing their colour-magnitude diagrams with calculations based on stellar evolutionary theory it is possible to determine the ages of these objects, which are key elements in the study of the origin and evolution of the galaxies.

What do you think are the most important contributions of the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"One has to bear in mind that each globular cluster represents a snapshot which memorize for us an instant of the evolution of matter in galaxies and, more in general, in the Universe. When interpreting observations in terms of globular cluster age and chemical compositions we are mapping the history of matter in our Galaxies as well as in other galaxies. Each cluster tell us that so many years ago in that galactic location there was a cloud of gas with such a distribution of nuclear species. It follows that globulars represent the most desirable milestones for that 'archaeology' of the Universe which is among the most fascinating objectives of astrophysics. The study of globular clusters will give us key information on the early evolution of spyral galaxies, as our own Galaxy, and on the evolution of galactic halos. They will probably give even more information on the history of both elliptical and dwarf irregular galaxies, mapping over a larger range the evolution of matter in these objects. As a byproduct, the age and composition of globular is already giving severe constraints on cosmological models."

How old are the globular clusters? By how much do you expect this age to vary?

"For galactic globulars, the best guess is now around 11 Gyr and, in my feeling, I will be surprised if this evaluation will be moved by more than ±2 Gyr. It appears to me that this is probably the age when globulars begun to appear everywhere in the Universe."

"FOR GALACTIC GLOBULARS, THE BEST GUESS IS NOW AROUND 11 GYR AND, IN MY FEELING, I WILL BE SURPRISED IF THIS EVALUATION WILL BE MOVED BY MORE THAN ±2 GYR. IT APPEARS TO ME THAT THIS IS PROBABLY THE AGE WHEN GLOBULARS BEGUN TO APPEAR EVERYWHERE IN THE UNIVERSE."

What are the most relevant uncertainties in the branch of physics related to the theories of stellar evolution? What effects might these uncertainties have on our understanding of stellar evolution?

"There are two different kinds of uncertainties, the ones connected with macroscopic mechanisms, the others with our knowledge of fundamental physics. Among the first ones one has convection, element sedimentation, mss loss and model atmospheres. As for the fundamental physics there are uncertainties on the three basic ingredients affecting every stellar model, namely the Equation of State, the radiactive opacities and the energy generation. Moreover we have further uncertainties on the additional physics affecting post Main Sequence stars, i.e., electron conduction and neutrino cooling. As a result, I guess that we are hardly predict the magnitude of a star better than ±0.1 mag. From my point of view we are facing an extraordinary qualitative success of theories but, at the same time, strong difficulties in giving firm quantitative predictions."

In relation to the subject of this Winter School, what is the most interesting problem in your present research?

"With my working group we are approaching several interesting problems, like the use of the cooling sequence of cluster White Dwarfs as a clock marking the cluster age, or the use of He burning clumps in not-too-old clusters as standard candles. However, the most relevant investigation in progress is probably the match between evolutionary models and pulsational theories, to predict the observational features of variables stars, adding further invaluable constraints to the information that one derives from the CM diagram."

PROFILE

VITTORIO CASTELLANI was born on 13 March 1937. He graduated in Physics at the University "La Sapienza" in Rome, with a thesis on "annichilation e+e- in the Frascati storage ring AdA". Shortly after the thesis he joined in Frascati the astrophysics group of proof. Livio Gratton, where four young people (he, V. Caloi, C. Firmani and Z. Renzin) decided to start from the ground an activity in theoretical stellar models. Just at that time he fell in love with globular clusters, looking at the impressive structure of these wonderful stellar systems.
All along the years, the investigation of Pop. II (and Pop. III) stars has remained the main target of the investigations he has developed with a growing group of students and coworkers. Today one finds that these investigations have covered all the evolutionary phases expected in globular clusters, from the very low mass MS stars to the final stage of cooling White Dwarfs, with several relevant outcomes. More recently, these investigations have been also extended to metal rich and supermetal rich stars, disclosing some unexpected and relevant evolutionary features.
One has finally to quote the several papers devoted to the problem of solar (and stellar) neutrinos and Solar Standard Models.
In 1980 he was appointed to the Chair of Astrophysics at the University "La Sapienza", passing afterwards to the Chairs of Theoretical Astrophysics and, recently, of Stellar Physics at the University of Pisa.
He has written two books (in italian) "An introduction to nuclear astrophysics" and "Stellar Astrophysics". Beside this activity, he has been engaged in the investigation of natural and artificial undergrounds, participating in several missions (Moroccan Sahara, Greece, Central Anatolia, West China... and Antarctica) mainly for archaeological pourposes. On this subject he is author of several papers and of a book (The civilization of water) now appearing in Italy and which is being translated into English.
He has been President of the Italian Astronomical Society and of the Italian Spaelological Society, Director of the Laboratory for Space Astrophysics (Frascati), of the Teramo Astronomical Observatory and of the Institute of Astronomy of Pisa University.
Like Galileo, he is a member of the Accademia Nazionale dei Lincei.

Vittorio Castellani

Course: CHEMICAL ABUNDANCES OF STARS IN GLOBULAR CLUSTERS. EARLY NUCLEOSYNTHESIS

Prof. Raffaele Gratton
Astronomical Observatory of Padua
ITALY

REFERENCE METALS

The metal content of a star is an indication of its age. When they are formed stars "feed" on the material of their surroundings; when a star is "metal poor" it is considered to be old since it has been formed in a medium unenriched by supernova ejecta from stars of earlier generations. To determine the metallicity of an object and its abundance of heavy elements, astronomers normally use hydrogen as a reference element, although they also have recourse to iron. By studying the ratio of heavier elements, such as calcium and oxygen, with respect to the metallicity of the object valuable information can be obtained concerning the enrichment of the interstellar medium, which in turn aids the study of the physical processes that might have occurred in the galaxy hosting the object. It is precisely at this point that globular clusters reveal themselves as ideal locations for such investigations, because they provide homogenous samples of more or less metal-poor stars, as explained during the Winter School by Professor Raffaele Gratton of the Astronomical Observatory of Padua (Italy).

"CLUSTERS ARE THE BEST APPROXIMATION TO PURE (SINGLE AGE, SINGLE CHEMICAL COMPOSITION) STELLAR POPULATIONS: THEY THEN PROVIDE INVALUABLE TESTS FOR STELLAR EVOLUTION."

What do you think are the most important contributions of the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"Perhaps the most important data concern ages of globular clusters, since they are the oldest individual objects that may be dated with some accuracy, and the provide a stringent lower limit to the age of the Universe. The age dispersion and distribution provide important test for the epoch and the mechanisms of galaxy formation. Clusters are the best approximation to pure (single age, single chemical composition) stellar populations: they then provide invaluable tests for stellar evolution. They are dense stellar systems, providing basic comparisons for our understanding of the dynamics of dense stellar environments and even on formation and evolution of stars in dense environments. They are rather bright objects, that may be observed at large distances, and may then be used as standard candles."

What is the minimum age dispersion in globular clusters? Is it correlated with their physical features? What kind of information does it provide in regard to the duration to the collapse of the protogalactic cloud?

"If I understand correctly, this question is about the cluster-to-cluster age spread. About twelve years ago, Sergio Ortolani and myself (and nearly at the same time Peter Stetson too) found that Pal 12 is significantly younger than the bulk of the globular clusters, with an age about 2/3 that of 47 Tuc. This was the first clear evidence breaking the Sandage, Eggen & Lynden-Bell paradigma of very fast formation of the galactic halo (although an alternative scenario was proposed earlier by Searle and Zinn). A few other clusters were later found to be young. However, on the whole they are a small minority. Recently, it has been shown that most (and perhaps all) of these clusters were likely accreted from dwarf satellites of the Milky Way. On the other hand, there is a lively debate about the spread of ages for the bulk of galactic globular clusters."

What is the reason for the absence, in our Milky Way, of clusters of metallicity [Fe/H]<-3 in other galaxies?

"The absence of very metal-poor clusters is sometimes considered as an evidence that clusters formed their own metals: a single 20 Mo SN would eject enough metals to pollute a 10^5 Mo proto-cluster at [Fe/H]<-3; as noticed by Andy McWilliam, this is likely related to the observed cosmic scatter in the abundances of the n-capture elements below [Fe/H]<-2. However, several years ago Vittorio Castellani observed that if the fraction of stars with meatllicity below a given value of Z is roughly proportional to Z (a quite reasonable assumption) we should expect less than cluster whose metallicity is less than a thousandth of that of the Sun, since there are les than 200 clusters in the galaxy. So maybe there is nothing special in the absence of clusters with [Fe/H]<-3."

In relation to the topic of this school, which is at present the most interesting problem in your research?

"The distance scale for both population I and II objects. This exemplified by the case of the LMC, where values of the true distance modulus ranging from 18.09 to 18.70 have been proposed in the last year: the shortest value has been obtained by application of the "red giant clump" method by Udalski et al., while the longest has been obtained by Feast and Catchpole using Cepheids. Furthermore there are a number of determinations spread over this broad range. Personally, I obtained two values of 18.60 and 18.37 using the subdwarf fitting method and the absolute magnitude of the horizontal branch respectively. Still both results are based on Hipparcos parallaxes of local calibrations. This range in distances implies an enormous range in ages or globular clusters (from about 11 to more than 20 Gyrs)."

Raffaele Gratton

PROFILE

RAFFAELE GRATTON was born in La Plata (Argentina), on November 21, 1956. Italian, he studied at University "La Sapienza" in Rome where he got his Degree in 1979. He worked at Cerro Tololo Inter-American Observatory, La Serena, Chile, 1980-1981, Asiago Astrophysical Observatory, Italy, 1981-1984 Astronomer; Rome Astronomical Observatory, Italy, 1984-1989, and he is presently Associate Astronomer at Padua Astronomical Observatory, Italy. Gratton is an observational astronomer, but he is now working also on technological aspects (spectrograph design and construction). His speciality is abundance analysis, and his main area of interest are globular clusters and chemical evolution of the Galaxy. He also works on surface abundances as signatures of stellar evolution. Gratton is PI of the High Resolution Spectrograph for the Galileo National Telescope, under construction at the Roque de Los Muchachos Observatory (La Palma).

Course: STELLAR DYNAMICS IN GLOBULAR CLUSTERS

Prof. Rebecca A. W. Elson
Institute of Astronomy, Cambridge
UNITED KINGDOM

THE EVOLUTION OF GALAXIES

A typical globular cluster contains from a hundred thousand to a million stars bound together by the gravitational force they exert on one another. The density of stars in a cluster increases as we approach the centre, where it can reach values thousands of times greater than the density of stars in the solar neighbourhood. The clusters associated with our Galaxy are spherically distributed about the Galactic Centre, in the direction of Sagittarius, at about 8 kiloparsecs from the Sun. About two hundred are known and each one moves in an elongated orbit with a period of revolution of about two hundred million years that takes it through the Galactic plane twice each revolution. These crossings raise gravitational tides within the clusters, which lose some of their outer stars to the Galaxy. The orbital velocity of a cluster can be derived from the total mass of its host galaxy and its distance from the centre of the galaxy. The dynamics of globular clusters provides one of the most reliable means of studying the evolution and structure of galaxies.

Globular Cluster NGC 1818, in the Large Magellanic Cloud.

What do you think are the most important contributions of the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"The globular clusters in the halo of our Galaxy give us the strictest lower limit on the age of the Universe. Globular clusters in our own and other galaxies provide a unique opportunity to study the early stages of evolution in galaxies of various types. They are also ideal laboratories for testing theories of stellar evolution, of the dynamical evolution of large-N self-gravitating systems, and for quantifying the stellar initial mass function, and investigating its universality. This last issue is crucial for interpreting the integrated light of distant galaxies and drawing conclusions about the star formation history of the Universe"

How old are the globular clusters? By how much do you expect this age to vary?

"The terms 'globular' and 'open' clusters were coined to distinguish ancient, rich clusters in the halo of our Galaxy, from the sparser, younger clusters in the disk. It has become apparent that these categories are not altogether appropriate for the cluster systems of other galaxies. The Large Magellanic Cloud, for example, contains clusters rich enough to merit the description 'globular', but not necessarily ancient. Massive star clusters have also been observed forming in mergers of distant galaxies. I would therefore say a globular cluster can be any age! Recent results using Hipparcos parallaxes find an allowable range of ages for the oldest globular clusters of 9.5 – 13.9 Gyr, with a most probable value around 11.8 Gyr."

Taking into account the results of dynamic models in regard to the survival of clusters in different environments, would it be possible to obtain information, or an indication, of these systems' ages, from the present population of their clusters?

"It would be difficult to estimate the ages of globular cluster systems from assessments of their survival rates. There are many unknowns, including the cluster orbits, the kind of dynamical stresses they would have encountered as the galaxy was forming, the initial range of masses and densities of the clusters, and their efficiency of formation from their progenitor clouds. It would be easier to turn the question around and, using the relatively accurate ages measured for globular clusters in our own Galaxy, for example, place constraints on the kinds of disruptive processes they could have been subjected to, and survived, in their lifetimes."

In relation to the subject of this Winter School, what is the most interesting problem in your present research?

"Globular cluster systems in elliptical galaxies appear to have colour distributions that vary significantly from galaxy to galaxy. Some have only blue, or metal poor clusters, while others have both metal poor an metal rich populations. Such bimodality may be the result of mergers or of a multi-phase collapse of the parent galaxy, and contains important clues about the early stages of galaxy formation. Accurate photometry for more systems is needed to form a more complete picture, and this is one of the goals of my current research. A second question my research addresses is the universality of the stellar initial mass function (IMF). Large Magellanic Cloud clusters provide an ideal laboratory for exploring this, and I am leading a large HST project to determine deep IMFS in 8 clusters with a wide range of ages and central densities."

"A GLOBULAR CLUSTER CAN BE ANY AGE! RECENT RESULTS USING HIPPARCOS PARALLAXES FIND AN ALLOWABLE RANGE OF AGES FOR THE OLDEST GLOBULAR CLUSTERS OF 9.5 – 13.9 GYR, WITH A MOST PROBABLE VALUE AROUND 11.8 GYR."

PROFILE

*REBECCA A. W. ELSON was born in Montreal (Canada) on 2 January 1960.
She now lives in the United Kingdom but retains double Canadian and American nationality.
After graduating in Astronomy at Smith College (USA), she obtained a master's degree at the University of British Columbia (Canada) and concluded her work on dynamical friction models.
In 1986 she completed her doctorate at the Institute of Astronomy (Cambridge), the subject of her thesis being the structure and evolution of rich stellar clusters in the Large Magellanic Cloud, a topic on which she continued to work during her stay as a postdoc at the Institute of Advanced Studies, Princeton, New Jersey (USA).
From 1989 onwards, her work has centred more on the formation and early evolution stellar clusters. During 1989-90 she gave a course at Harvard University on "Science and Ethics".
Since 1991, she has been an Associate Postdoctoral Researcher at the Institute of Astronomy, Cambridge (United Kingdom), working mainly with Hubble Space Telescope data in various projects related to galactic and extragalactic stellar populations, globular clusters and globular cluster systems.*

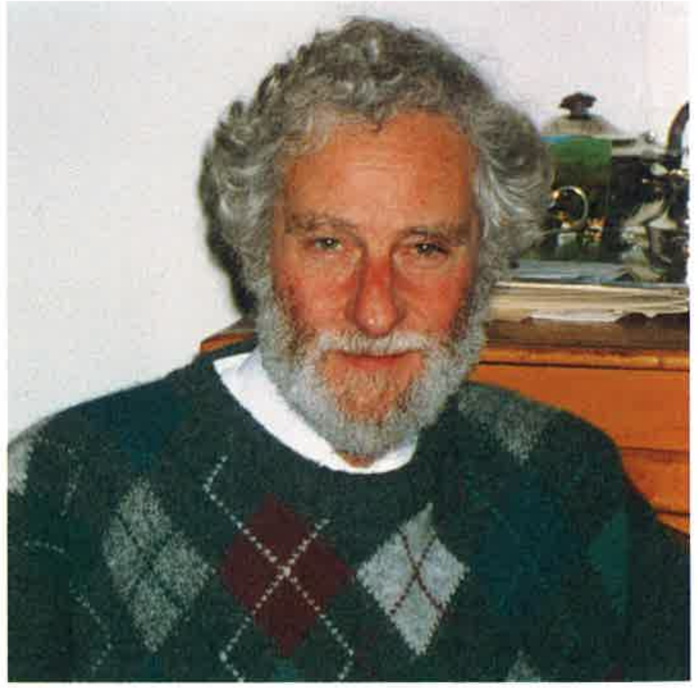
Rebecca A. W. Elson

Course: VARIABLE STARS IN GLOBULAR CLUSTERS

Prof. Michael W. Feast
University of Cape Town
SOUTH AFRICA

HIPPARCOS AND THE NEW DISTANCE SCALE

Hipparchus of Nicaea (II Century BC) catalogued 850 stars. The precision of his measurements allowed him to discover the retrograde motion of the celestial sphere known as "precession of the equinoxes". In August 1989 the European Space Agency launched an astrometric satellite christened with the rather forced acronym HIPPARCOS (from *HIgh Precision PARallax COllecting Satellite*) in homage to the Greek astronomer. The new HIPPARCOS Catalogue contains the positions, parallaxes and proper motions of 120000 stars, with a hitherto unprecedented degree of precision that correct previous values by at least 10 per cent. Professor Michael W. Feast of the University of Cape Town (South Africa) presented results on the distance scale obtained from the data of this satellite at the III meeting of the Spanish Astronomical Society. According to this investigator, thanks to the parallaxes of variable stars obtained with HIPPARCOS, it has been possible to estimate the distances to globular clusters with greater accuracy than ever before. These distance calculations are of vital importance for establishing the ages of globular clusters - they are as old as their respective galaxies - and, in turn, the age of the Universe. Accuracy is of the utmost importance in this case: 'a change in distance of 10 per cent changes the age by 20 per cent', observes Feast.



Michael W. Feast

What do you think are the most important contributions of the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"Globular clusters have been of immense importance for our understanding of the Universe. Attempts to understand the first colour-magnitude diagrams of globular clusters led to the currently accepted theory of stellar evolution. In this theory stars stay most of their lives on the main sequence and then involve through the following sequence; giant branch, horizontal branch, AGB, post-AGB, planetary nebula and white dwarf. These early c-m diagrams changed our whole concept of stellar evolution. Furthermore the realisation that globular cluster stars were both old and metal-poor was a major indicator that most elements other than hydrogen and helium have been manufactured inside stars through the life-time of the Universe rather than all being produced in an initial big-bang as was at one time suspected."

Do you think that the surveys devoted to globular clusters contribute relevant restrictions to basic cosmological questions such as, for example, the age of the Universe?

"Detailed studies of globular clusters both observationally and theoretically are of the utmost importance for our estimation of the age of the utmost importance for our estimation of the age of the oldest stars. These ages obviously set a lower limit to the age of the Universe. The quest to determine the age of globular clusters has driven observers to obtain photometry and spectroscopy of cluster stars of ever increasing accuracy. In the course of this work a great deal has been, and still is being, learned about he processes of stellar evolution, the dredging up of nuclear-processed material form the interior of the star to the surface etc."

To what extent have HIPPARCOS parallaxes had an impact on the distance scale based on variables?

"HIPPARCOS parallaxes of nearby subdwarf stars can be compared with the subdwarf main-sequence in globular clusters to provide much better estimates of cluster distances than was possible previously. These distances are of vital importance for several reasons. For instance when comparing observations of a cluster distance. The derived age is very sensitive to the adopted distance. A change in distance of 10 per cent changes the age by about 20 per cent. It seems likely that the uncertainties in the post-HIPPARCOS ages of clusters will be due more to uncertainties in the theory of stellar evolution than uncertainties in the distances."

In relation to the subject of this Winter School, what is the most interesting problem in your present research?

"A particularly intringuing problem is the following. There appears (at least at first sight) to be a discrepancy between the absolute magnitudes of RR Lyrae variables in globular clusters and those in the general field of the galactic halo. The luminosities of RR Lyraes in clusters are derived via the cluster distances which are based on HIPPARCOS parallaxes of nearby subdwarfs. The luminosities of RR Lyrae variables in the general halo field are derived from a statistical parallax analysis. It is not yet certain that this difference is real. If it is, it will have important implications of the use of RR Lyrae stars as distance indicators to nearby galaxies. It will also indicate that the field and cluster RR Lyraes (of the same overall metallicity) are different from each other in some way, perhaps in the relative abundances of different elements in their atmosphere."

"THE REALISATION THAT GLOBULAR CLUSTER STARS WERE BOTH OLD AND METAL-POOR WAS A MAJOR INDICATOR THAT MOST ELEMENTS OTHER THAN HYDROGEN AND HELIUM HAVE BEEN MANUFACTURED INSIDE STARS THROUGH THE LIFE-TIME OF THE UNIVERSE RATHER THAN ALL BEING PRODUCED IN AN INITIAL BIG-BANG AS WAS AT ONE TIME SUSPECTED."

PROFILE

MICHAEL W. FEAST was born in England and obtained a PhD in physics from Imperial College (London). He then spent two years as a post-doctoral fellow working with G. Herzberg at the National Research Council of Canada in Ottawa. All his research work up to that time had been in laboratory studies of molecular spectra.
In 1952 he moved to the Radcliffe Observatory Pretoria, South Africa. This Observatory had at that time the largest telescope in the southern hemisphere (1.9m). The work there was mainly spectroscopy and centred on studies of the structure of our Galaxy and the Magellanic Clouds as well as astrophysical studies of objects of particular interest including the globular cluster 47 Tuc which was quickly shown to be unusual and is now the prototype of metal-rich globular clusters.
In 1974 Feast moved to Cape Town where the old Royal Observatory became the headquarters of the South African Astronomical Observatory (SAAO) and the 1.9m reflector was moved to the SAAO station at Sutherland. He was director of the SAAO from 1976 to 1992 and from 1983 an honorary professor in the University of Cape Town where he continues his research. Much of his recent work has been on the use of variable stars to establish distance scales and in studies of galactic structure, the Magellanic Clouds and stellar evolution.

Course: X-RAY SOURCES IN GLOBULAR CLUSTERS

Prof. Ramón Canal
University of Barcelona
SPAIN

GLOBULAR CLUSTERS IN X-RAYS

The stars in globular clusters spend much of their time describing mutually crossing orbits. When two stars approach each other closely enough their mutual gravitational pull perturbs their orbits causing them either eventually to escape from the cluster or to plunge inwards to the centre. There are between ten thousand and a million stars in a globular cluster; these tend to agglomerate towards the centre, where the stellar density can reach thousands of stars per cubic parsec. Consequently, collisions between stars are fairly common and give rise to binary systems. These stellar systems comprise an old, highly evolved star with a young companion revolving around it at a relatively short distance, both moving as a single body inside the cluster, in the same way that the Earth and Moon form a system in orbit around the Sun. It is these binary systems that are responsible for the X-ray emission observed in globular clusters which, as Professor Ramón Canal of the University of Barcelona explains, are more abundant in globulars than in the rest of the Galaxy, a possible indication that the process of their formation is different inside globular clusters.

Why are certain X-ray sources more abundant in globular clusters? Could the primordial material from which the earliest globular clusters formed have been chemically enriched by nucleosynthesis in a previous generation of stars?

"IT IS BECOMING MORE AND MORE EVIDENT THAT THE FORMATION OF STARS PRECEDED THAT OF THE GALAXIES. FOR THEIR PART, GLOBULAR CLUSTERS COULD BE THE 'FOSSILS' OF THE FIRST STRUCTURES TO HOST STAR FORMATION."

"X-ray binary sources associated with low-mass stars are more abundant in globular clusters than in the rest of the Galaxy. This seems to indicate that the process of their formation has been different there: the high star density within globular clusters would favour the capture by isolated neutron stars (arising from the gravitational collapse and subsequent explosion of massive stars) of low-mass main-sequence stars into close-proximity orbits; this in turn would make possible the accretion of matter from the outer layers of the companion on to the surface of the neutron star. Very short period (thousandths of a second) pulsars are also very common in globular clusters. This would be consistent with the notion that they are descended from a proportion of these low-mass X-ray binary sources: the accretion of matter from the companion, often already 'evaporated', is what would have accelerated the rotation of the pulsar.

"It is becoming more and more evident that the formation of stars preceded that of the galaxies. For their part, globular clusters could be the 'fossils' of the first structures to host star formation. There is also evidence of a wide range of ages and metallicities for the globular clusters of our Galaxy. It is possible, therefore, that even the most primitive clusters (whose metallicities, although very low, are nevertheless not zero) had already been enriched through the nucleosynthesis of an even earlier generation of stars."

What would you say are the most significant findings of globular cluster research for our present understanding of the Universe? What kind of fundamental information can be derived solely from studying globular clusters?

"The globular clusters of our Galaxy are perhaps the most accessible window on to the history of the early Universe, despite the ambiguities that remain with respect to their role in galaxy formation. Their ages set the highest known lower limit to the age of the Universe, although it is expected that for a while yet there will still be an uncertainty of the order of a couple of thousand million years that effectively increase the ages of the globular clusters."

Is there really a conflict between the estimate of the age of the oldest globular clusters and the age of the Universe derived from recent measurements of the Hubble constant?

"Age estimates of the oldest globular clusters are being revised downwards, but there is conflict only when we assum a critical density Universe whose rate of expansion is gradually decreasing and tending asymptotically to zero. If, as observations of distant thermonuclear supernovae seem to suggest, the expansion is accelerating rather than braking (with a vacuum energy contribution equivalent to a non-zero cosmological constant), the age of the Universe could well be some 14500 million years and there would be no conflict."

What at the moment is the most interesting problem in your research with regard to the Winter School?

"On the one hand, the possibility of forming pair of low-mass neutron stars from the gravitational collapse of white dwarfs (something that Evry Schatzman and I suggested almost 25 years ago) continues to intrigue me. On the other, we are re-evaluating, on the basis of stellar population synthesis, the various routes to arrive at the forming binary systems with neutron stars, both in globular clusters and in other regions of our Galaxy."

"THE POSSIBILITY OF FORMING PAIR OF LOW-MASS NEUTRON STARS FROM THE GRAVITATIONAL COLLAPSE OF WHITE DWARFS (SOMETHING THAT EVRY SCHATZMAN AND I SUGGESTED ALMOST 25 YEARS AGO) CONTINUES TO INTRIGUE ME."

PROFILE

Born on 20 April 1943, RAMÓN CANAL MASGORET graduated in Physical Sciences at the University of Barcelona in 1965, where he obtained his doctorate in 1973 with a thesis directed by Evry Schatzman and Juan J. Orus.
He was Profesor Agregado *(assistant lecturer) at the University of Barcelona (1979-82) and Professor at the University of Granada (1992-97) before occupying the chair in Astrophysics in the Physics Faculty of the University of Barcelona. He has also been associated with the Paris Institute of Astrophysics, where he worked for five years, the University of Chicago (1982-84), where he taught stellar evolution and supernovae, and the Max-Planck Intitute for Astrophysics (1985-91), where his work was dedicated to collapsed stars, supernovae and nucleosynthesis.*
A pioneer of astrophysics in Spain, Ramón Canal participated in the I National Assembly of Astronomy and Astrophysics, celebrated in 1975 at Puerto de la Cruz (Tenerife), the first such meeting ever held in Spain.
He has directed seven doctoral theses and 14 master's dissertations. Among his former students are a number of university professors (for example, Teodoro Roca, Professor of Astrophysics at the University of La Laguna and IAC researcher), CSIC researchers, and university lecturers.
A referee of mainstream scientific journals such as Astrophysical Journal *and* Astronomy and Astrophysics, *he has over a thousand citations in the scientific literature.*
He has been a member of the time allocation committee for the IUE (International Ultraviolet Explorer) *of the European Space Agency (1982-85), a member of the IAC's* CAT *(Telescope Time Allocation Committe) for the Canarian Observatories (1984-86), Director of the Department of Astronomy and Metrology of the University of Barcelona (1987-94), serving member and President of the Advisory Committee (Mathematics and Physics) of the Spanish Advisory Commission for Research Activities, and a member (since 1992) of the World Institute of Science.*
Ramón Canal was a founder member and the first President of the Spanish Astronomical Society (1992-96).

Ramón Canal

Course: GLOBULAR CLUSTERS IN GALAXIES

Prof. William E. Harris
MacMaster University
CANADA

EXTRAGALACTIC CLUSTERS

Globular clusters have been observed in all types of galaxies of practically all sizes, with the possible exception of the smallest dwarfs. In the case of the Milky Way, the clusters are spherically distributed about the Galactic Centre, where they are more densely distributed than in the outer regions of the Galaxy. Investigation of globular clusters has improved our knowledge of the structure of the Galaxy, the first stages of its formation and its chemical evolution, besides providing a huge impulse to the theory of stellar evolution. Observations of this kind of object in other galaxies is of equally great interest; highly significant similarities and differences between the globular clusters of our own and other galaxies, such as Andromeda or the Magellanic Clouds, have been established, as explained by Professor William Harris of MacMaster University, Canada.

William E. Harris

"WE THINK THAT ALL LARGE GALAXIES HAVE OLD-HALO GLOBULAR CLUSTERS, AND SO FAR, ALL THE OBSERVATIONS SUPPORT THIS IDEA. IN FACT, A GALAXY HAS TO BE VERY SMALL — AT THE LOWER END OF THE DWARF SEQUENCE — TO HAVE NONE AT ALL. GLOBULAR CLUSTERS DO INDEED SEEM TO REPRESENT A COMMON THEME IN THE EARLY HISTORY OF GALAXY FORMATION."

What do you think are the most important contributions of the study of globular clusters to our knowledge of the Universe? What type of key information may be found when studying globular clusters exclusively?

"We can now look back over an entire century of astrophysics research. When we do that, I think the biggest long-range impact from the study of globular clusters has been in our understanding of the evolution of stars. In the first half of the century, the construction of stellar structure theory was strongly driven by the challenge presented by globular clusters: what were their stars? How massive, how old, how metal-poor, and how did they evolve? This pioneering work culminated in the early 1950's, when there was an amazing convergence of theory with observation: it became possible simultaneously to detect the main-sequence turnoff in nearby globulars, and also to construct believable models that described the entire hydrogen-burning lifetime of a low-mass star. That work showed beyond a doubt that the universe had to be many Gigayears old, and that the earliest stars formed from pristine metal-poor material. These sweeping conclusions could not have come from any other type of object except the globular clusters! In more modern times, with the advent of high-speed computing, CCD detectors, and ultra-deep imaging from space, we have tremendously refined the whole grand drama of stellar evolution. It's very fitting that, as the century (and millenium!) is drawing to an end, we are pushing to reach the end of the white-dwarf sequence — the very last evolutionary stage for globular cluster stars."

Do you think that the surveys devoted to globular clusters contribute relevant restrictions to basic cosmological questions such as, for example, the age of the Universe?

"The age calibrations for the globular clusters in the Milky Way still provide us with the strongest limit we have to the age of the Universe. 30 years ago, we did not know this quantity to a factor of two; now, we are arguing over differences of 25 percent. On the observational side, still better answers are going to depend on calibrating distances and metallicities to a few percent accuracy. On the theoretical side, we have to settle a long list of remaining uncertainties such as the degree of mixing and semiconvection, opacities and reaction rates, and the amount of helium diffusion."

Is it possible to observe globular clusters in other galaxies? In all of them? To what distance are globular clusters visible? What differentiates the globular clusters of our Milky Way from those in other galaxies? What kind of information do the globular clusters of other galaxies provide?

"We think that all large galaxies have old-halo globular clusters, and so far, all the observations support this idea. In fact, a galaxy has to be very small — at the lower end of the dwarf sequence — to have none at all. Globular clusters do indeed seem to represent a common theme in the early history of galaxy formation. Modern imaging technology makes it easy to find the brightest globular clusters in quite remote galaxies; the current distance 'record' was set a few years ago for the central cD galaxy in Abell 2107 at a redshift of 12600 Km/s (or about 180 Megaparsecs if H=70), in which my colleagues and I detected the brightest globular clusters.

Individually, the globular clusters in other galaxies are surprisingly similar to the ones in our Milky Way in their range of luminosities, metallicities, and (apparently) in their formation history. However, there are striking differences as well, such as in total numbers – some cD galaxies may have 20,000 clusters compared with the 150 or so in our Galaxy. The way in which clusters are distributed in metallicity – the relative numbers at high and low [Fe/H] – also differ between otherwise similar galaxies in ways that are not yet understood."

In relation to the subject of this Winter School, what is the most interesting problem in your present research?

"The most challenging problem is unquestionably to understand how globular clusters form. We know that they can be built in all kinds of conditions: within isolated dwarfs, in starbursts, in the halos of giant galaxies, in mergers between existing galaxies. All that we need, apparently, is a sufficiently large supply of gas collected together. But what governs the way that this gas turns itself into gravitationally bound systems of stars? What determines their near-universal formation efficiency of about 0.2%? What processes fix the mass distributions function, which again has a near-universal shape? These are large questions which have only the vaguest first order answers at the present time?"

Globular cluster in a distant galaxy.

PROFILE

WILLIAM E. HARRIS was born November 28, 1947 in Edmonton, Canada. As an undergraduate, he studied mathematics at the University of Alberta and graduated there in 1969. Graduate school followed at the University of Toronto, with a Master's degree in theoretical astrophysics in 1970 and PhD in astronomy in 1974, on "Globular Clusters in the Local Group Galaxies". After spending two years at Yale as a postdoctoral fellow, he moved to a faculty position at McMaster University in Hamilton, where he has been happy to stay conducting his teaching and research. As a graduate student, he developed a fascination with globular clusters and their place in galactic structure and galactic history which has lasted ever since. "No other subject in modern astrophysics has such a long history, or has re-invented itself so many times through technological advances and unexpected discoveries." Most of his current research is aimed at understanding the characteristics of globular cluster systems in giant elliptical galaxies, and at the ages and formation histories of globular clusters and their role in the earliest stages of galaxies. Harris has found it a "terrific experience" to use telescopes all around the world during the period of rapid growth of astronomy beginning in the early 1970's and continuing into today's large-telescope era. He has chaired time allocation panels for the CFHT and HST, and was recently President of the Canadian Astronomical Society. In his free time, he enjoys choir singing (definitely as a bass), tennis in the summer, and in the winter the ice sport of curling — a strange and unique game invented long ago in Scotland but now played more in Canada than anywhere else.

What key problems remain in our present knowledge of globular clusters? Which do you consider to be the most important one? To what extent may the new instruments for observation, especially the GTC (*Gran Telescopio Canarias*) contribute to the solving of these problems?

UNCERTAINTIES CONCERNING GLOBULAR CLUSTERS

"WHAT WE NEED NOW IS A SOLID DATABASE OF CM DIAGRAMS OF GALACTIC GLOBULARS, AS ONE CAN OBTAIN WITH A GOOD TELESCOPE AND WITH A SOLID AND REPEATABLE OBSERVING (AND REDUCING) PROCEDURE."

R. ELSON:

"A key outstanding problem regarding globular clusters is understanding how they form. This would be give us important insight into the early stages of galaxy formation. While the oldest globular clusters have 'erased' their initial conditions through dynamical evolution, there are massive LMC clusters young enough to preserve information about their formation process. Observations of their stellar content and dynamical state will allow us to determine things like the timescale for star formation in the progenitor cloud, the extent of primordial mass segregation, and so on. In the coming decades new telescopes and instrumentation will let us push deeper down the cluster's mass functions and further into their crowded cores, just as HST has allowed us to do this decade."

V. CASTELLANI:

"In my feeling we are too often in the situation of attempting to give quantitative results on the basis of rather uncertain observational data, as given by different authors with different telescopes, different calibrations an so on. What we needed now is a solid database of CM diagrams of galactic globulars, as one can obtain with a good telescope and with a solid and repeatable observing (and reducing) procedure. This alone can be solve many open questions such as the relative ages of clusters, or cluster age as the second parameter governing the HB features. Much more in general, I would suggest that when dealing with the request for quantitative results, as we actually do, one should start to consider errors. The large amount of astrophysics given without errors is a curious anomaly in the more general field of current physics."

M. FEAST:

One of the key problems in globular cluster research is to obtain very accurate and detailed measurements of chemical abundances at all phases of evolution in a cluster. This will indicate how surface abundance changes (or does not change) with evolutionary state. Abundance ratios of unstable (radioactive elements would enable ages to be estimated for comparison with ages derived from evolutionary considerations. Such a comparison would be very important in telling us whether our age determinations are satisfactory or not. Measurements of this kind require telescopes of very great light gathering power. Thus I would expect that this would be an area in which the Gran Telescopio Canarias could make a major contribution."

W. E. HARRIS:

"Many of the uncertainties surrounding the distances and ages of globular clusters boil down to understanding their chemical compositions in much more detail. For that, we need high-resolution spectra of lots of stars, and this is where the new large telescopes come in. For clusters in other galaxies, large samples of high-quality velocities will allow us to study the dynamics of the halo. In a broader sense, however, the biggest outstanding problem is to understand how clusters form. For this, we need modelling which employs gas dynamics at many scales, as well as star formation theory, in far greater detail than we have on hand today."

I. KING:

"Better understanding of what the initial mass functions were, and how and why they have changed. Also, better understanding of chemical composition and where it came from. With a big telescope, any number may play this game."

R. GRATTON:

"I think the key issue is the second parameter. The Yale group strongly support age as second parameter; however, other "second" parameters are also needed to explain observations. There are a number of likely related effects, ranging already mentioned the discrepancies between different distance scales: here the main uncertainties are related to possible scale errors in colours (due to reddening and colour transformations) and metallicity. While photometry in cluster crowded fields is certainly done better using HST, there are several crucial spectroscopic observations to be done with ground-based 8 meter class telescopes like abundance analysis of main sequence stars or estimates of rotational velocities and of reddening.

S. MAJEWSKI:

"Globular clusters are an important rung in the 'cosmic distance ladder' and yet cluster distances are still subject to large systematic uncertanties. These uncertainties, in turn, impact a host of other issues. For example, to achieve 10% precision in absolute age dating a cluster requires that it's distance be known to 5% accuracy. In the next few decades, however, new generations of astrometric telescopes, like the Space Interferometry Mission and GAIA, will hopefully follow the success of the HIPPARCOS mission and will deliver trigonometric parallaxes - the most direct and reliable way to obtain distances - for all of the Galactic globular clusters. This will truly be an important achievement, since we cannot yet determine a parallax for a single globular cluster! Only a few nearby OPEN clusters have been studied in this way, and even here the results remain controversial.

While trigonometric parallaxes will be obtained for Galactic clusters, it will also be possible in future decades to use large space-based and adaptive optics-corrected ground-based telescopes to obtain color-magnitude diagrams for, and spectra of stars in, increasingly distant extragalactic globular clusters. By comparing the Galactic and extragalactic clusters, the entire distance scale will be improved. In addition more direct comparisons of the chemodynamical properties of Galactic and extragalactic cluster systems will be possible, with great promise for understanding the pathways of galactic evolution. Finally, large telescopes will enable us to obtain color-magnitude diagrams of Galactic clusters down to the level of the white dwarf sequence, so that the stellar evolution timescales used to age date clusters may be compared to the ages derived from white dwarf cooling theory. This technique is now in its infancy with Space Telescope data."

R. CANAL:

"I think the most important problem relating to globular clusters concerns their role in the formation of galaxies. Are we dealing with condensations of matter that preceded and gave rise to the galaxies, or did the globulars form later? Were they contained in haloes of dark matter that fused to form galactic haloes? I believe that the new methods of observation will, over the following decades, bring to bear the necessary data for answering these questions. Already we can detect and investigate globular clusters in fairly remote galaxies. As we probe greater distances, from the present Universe to the epoch of galaxy formation, it will become possible to trace the history of the clusters, to see whether they appear only in galaxies below a given redshift or whether, to the contrary, their presence extends beyond galaxies with morphologies similar to those of the present."

"AS WE PROBE GREATER DISTANCES, FROM THE PRESENT UNIVERSE TO THE EPOCH OF GALAXY FORMATION, IT WILL BECOME POSSIBLE TO TRACE THE HISTORY OF THE CLUSTERS, TO SEE WHETHER THEY APPEAR ONLY IN GALAXIES BELOW A GIVEN REDSHIFT OR WHETHER, TO THE CONTRARY, THEIR PRESENCE EXTENDS BEYOND GALAXIES WITH MORPHOLOGIES SIMILAR TO THOSE OF THE PRESENT."

What would the sky look like if observed from a planet of a globular cluster star? Would this be feasible?

PLANETS IN GLOBULAR CLUSTERS

"IN HIGH-METALLICITY CLUSTERS SUCH AS MANY OF THE ONES IN THE GALACTIC BULGE, BIG TERRESTRIAL PLANETS SHOULD BE ABLE TO FORM."

R.ELSON:

"Densities in the cores of globular clusters range from 10^3-10^4 solar masses per pc^3. Thus, while we have a few stars within 1 pc of the Sun, in the centre of a globular cluster, there would be thousands. The sky would be spectacular indeed, but there would be a high price to pay. Sigurdsson (1992, ApJL 399, L95) discusses ways of forming planetary systems in globular clusters, as well as the prospects for them surviving disruption by close encounters with other stars. He concludes that in the core of an average cluster like 47 Tuc, a planet at 1 AU would survive for only a few hundred million years – an order of magnitude less than the time it took us to involve.

V. CASTELLANI:

"Let me hope to be in a planet at the very periphery of a cluster, out in the galactic halo. If the axis of the ecliptic is not directed toward the clusters, or few months we will have a rather normal, though rather desert sky, possibly with the view of the whole Galaxy over our heads. However, for the restant time the sky would be dominated by the cluster. At a distance of 100 pc from the cluster centre a giant stars in the centre will appear of about m_V=2. One can estimate that an old cluster of 10^5 stars have an absolute V magnitude of the order of m_V=-9. Assuming this light coming from the central region one finds a total magnitude m_V=-4., that is about 10^{-8} of the flux we receive from the Sun, much fainter than the moonlight which reaches m_V=-13. Thus one concludes that at such a distance the cluster will appear in the night sky quite impressive, but without dramatic consequences. However, in the centre of a dense cluster the stellar density can be as high as 10^4 stars for cubic parsec. If a planet can survive the close encounters with the surrounding stars, then one expects in the sky several thousands of stars even much brighter than m_V=1, against 12 in our sky. Note that we will have, in mean, about 10 stars nearer tan 0.1 pc-Even if dealing., as most probable, with solar type MS stars, they will each be brighter than m_V=-5: really a hell of stars. It would be quite interesting to investigate the mythology of people on similar planets!"

M. FEAST:

"I think this depends on which cluster you chose to live in and whereabouts in the cluster. The centres of some clusters are pretty crowded with stars. Even away form the cluster centre there would probably be some pretty bright stars in the sky but one might live confortably round a sun there and it would certainly be a wonderful place from which to do research on globular clusters! One might however conclude that all globulars were like the one that one was living in, and that would, we know, be quite wrong."

W. E. HARRIS:

"Could we expect to find Earth-type planets (big things with rocky/metallic compositions) around globular cluster stars?

In very low-metallicity clusters, probably not; we'd end up with Moon-sized planets at best, after boiling away all the gas; and these little things would not hold on to their atmospheres long enough for life to develop. But in high-metallicity clusters such as many of the ones in the Galactic bulge, big terrestrial planets should be able to form. However, then we need to ask where in the cluster we should look! The central parsec or so, with its frequent star-star interactions, would be a very dangerous environment for planets, which would be removed by tidal encounters. So we'll have to stay a few parsecs out form the cluster centre, and hope that our star doesn't have a plunging orbit that would take it through the core every few million years.

Then what would the night sky look like from our hypothetical planet? The core of the cluster would look like a huge nest of multicolored jewels, several degrees across on the sky and almost as bright in total as the full Moon. Inside the core, the main-sequence turnoff stars would be easily visible to the eye as 4[th] to 5[th] magnitude – thousands of them sitting on top of the diffuse light of the still fainter stars. But the real spectable would belong to the hundreds of horizontal-branch stars, each as bright as Spica or Altair; and best of all the additional hundreds of yellow and red giants, each shining as brightly as Venus of Jupiter. We should even be able to see the core in the daytime! Scattered more thinly across the sky – but still adding up to thousands of stars visible to the eye – would be the rest of the cluster. And, let's not forget the Galactic bulge! We are closer to it now, and it is less obscured by dust clouds in the disk, so it would be hanging (somewhere!) in the night sky, again about as bright as the full Moon but much more diffuse. The rest of the Milky Way would stretch across the sky brighter than we see it from Earth.

All in all, a dramatic place to live! The astronomers there must be a happy crowd. And of course, it may be even more fun for us to speculate about how this view of the sky would affect the mythology, religion, and cultural history of any civilisation there.

Isaac Asimov gave a vivid – an mostly correct – answer to this question about half a century ago in one of his fiction pieces called "Nightfall", probably the most famous science-fiction short story ever written."

I. KING:

"Countless bright stars. But of course you couldn't go there."

R. GRATTON:

"Roughly, stellar density in a globular cluster core is 10^5 stars per pc^3. About 2% of these stars are giants. On average the closest star is at 0.02 pc (4000 astronomic unit), and the closest giant (the brightest star) at 0.08 pc. The brightest star (but the local "Sun") have typically an apparent magnitude of m_V=-10 (or like), and there would be a few thousands of stars brighter than m_V=-5. Sky would be very bright, but no more than at full moon. Extended planetary systems are unlikely to exist in the cluster cores, but since a significant fraction of primordial binaries is present in the outer regions, also planetary systems may be present there (albeit the effect of the low metallicity on planet formation is unclear)."

S. MAJEWSKI:

"It would look very different indeed! Of course, it would depend a bit on where in the cluster the home star would be when you looked, but in a typical place you would see a sky dominated by hundreds of thousands of yellow to red giant stars, with a few, less bright blue stars (some variable as RR Lyrae type stars) sprinkled in. In a big cluster, you could have a thousand of these stars brighter than apparent magnitude -5 (brighter than Venus) and with the closest as bright as apparent magnitude -10!. Interestingly, the most nearby giant stars would be some 10 arcseconds across — resolvable with a small telescope or binoculars. As you move to the outskirts of the cluster, the distribution of stars would concentrate to one direction of the sky. The 47 Tucans would probably conclude that the universe was 10 parsecs across!

Still, it is not clear whether planets could form in low metallicity systems typical of the Galactic globular cluster system. Even gaseous, Jovian planets are thought to condense around rocky cores. Maybe some of the disk clusters like 47 Tuc might be enriched sufficiently for planet formation."

R. CANAL:

"If we were to find ourselves on a planet going round a star inside a globular cluster, how the sky looked would depend on how near we were to the centre of the cluster. Close to the centre, the sky would appear to us to be completely covered in stars, in all directions; at the edge of the cluster, however, depending on the rotational axis of the planet, either an entire hemisphere or a wide stretch of sky, depending on the season of the year would reveal an enormous density of of stars. It looks as though the regions of greatest star density, in the centre of the globular clusters, conditions are not favourable for the formation of planets: tidal forces due to nearby stars would tend to pull apart any possible protoplanetary discs. However, given the detection of planets surrounding such hostile objects as pulsars, I wouldn't care to discard their existence out of hand."

"THE CORE OF THE CLUSTER WOULD LOOK LIKE A HUGE NEST OF MULTICOLORED JEWELS, SEVERAL DEGREES ACRESS ON THE SKY AND ALMOST AS BRIGHT IN TOTAL AS THE FULL MOON."

"ASTRONOMY'S MAIN ACHIEVEMENT OVER ITS LONG HISTORY HAS BEEN TO PUT US IN OR PLACE: FIRST, REMOVING THE EARTH FROM THE CENTRE OF THE UNIVERSE, THEN THE SUN, THE SOLAR SYSTEM, THE GALAXY ITSELF, AND FINALLY SWEEPING AWAY THE CONCEPT OF A CENTRE ALTOGETHER."

"THE ESSENCE OF SCIENTIFIC WORK IS THAT MOST MAJOR ADVANCES TAKE US IN QUITE UNEXPECTED DIRECTIONS AND I WOULD ANTICIPATE THAT TO BE THE CASE IN THE NEXT CENTURY."

We are about to enter the XXI century, or the third millennium; what do you think will be contribution of astrophysics to mankind during the next few decades?

USEFUL ASTROPHYSICS FOR THE FUTURE

R. ELSON:

"Astronomy's main achievement over its long history has been to put us in or place: first, removing the Earth from the centre of the Universe, then the Sun, the solar system, the Galaxy itself, and finally sweeping away the concept of a centre altogether. Similarly, timescales in the Universe have gone from something inconceivably vast. Ever more exotic objects and processes have been discovered, and the conditions required to give rise to us are now understood to be almost impossibly stringent. These discoveries hold a great fascination in our society, fuelling art, music, and poetry.

Astronomy's greatest contribution in coming decades may simply stem from its capacity to stir the imagination of an increasingly jaded and materialistic culture."

V. CASTELLANI:

"Astrophysics has already given a good job, giving to mankind an understandable picture of the sky and a general overview on the evolutionary history of the Universe. This is slowly producing great effects on the psychology of human beings. During the next few decades astrophysics will probably cooperate with basic physics and cosmology to reveal still unsuspected features of such evolution, but the big step has been already done!"

M. FEAST:

"The essence of scientific work is that most major advances take us in quite unexpected directions and I would anticipate that to be the case in the next century. These advances have often led directly or indirectly to important practical applications. After all it was the puzzle of how the sun produced its energy that led to the idea of nuclear power. We cannot be sure what the future advances in astrophysics will be. However we can certain that training in astrophysics will, if properly conducted, equip young people with the necessary technical skills and the powers of reasoning scientifically which will enable them to make important contributions not only in astronomy but in many walks of life in the next century."

W. E. HARRIS:

"In the broadest sense, the next millennium will not be any different from the previous three, four, or ten. Astronomy gives humans a unique window on the physical universe. We learn to look upward instead of just at each other. We learn that the cosmos is indescribably large and that we are connected to it in unexpected ways. We learn that there are marvellous things out there – black holes, galaxies, an entire cosmic history – that we would have no conception of if we just studied what we see around us on the Earth. These things are a marvellous learning experience for any thinking person, and any society. A willingness to explore these ideas is one of the things that makes any society worth living in.

What about the next decades in particular? I think it is likely that we will finally be able to fill in some of the very big remaining 'gaps' in our knowledge of cosmic history – how the gas emerging from the post-recombination epoch turns itself into stars and galaxies; what are the values of the big cosmological numbers such as omega and lambda; and better ideas about the elusive dark matter. And maybe – although I think is a very long shot – the SETI experiments will succeed. If that happens, it will change human society in ways we can't even imagine.

In some sense, there have to be 'ultimate' limits to what astronomy, or any other science, can accomplish. We are finite beings, and there are many fundamental questions that we can state but are unable to answer. And beyond that, there must be levels of questions that we are not even smart enough to state. (Could a cat ask what causes the Sun to rise, or what the stars are?) But we are still very far from any such limits. We need no worry about running out of ideas yet!"

I. KING:

"It will be foolish to try to guess."

R. GRATTON:

"A part from timely prediction of catastrophic impacts (now a fashionable subject for fiction), I think the most interesting topic for common people may be the discovery of planets apt to host life. Various techniques have been developed to search extra-solar planets, and a few successful hits were made. We now know about ten such objects, ranging from exotic objects like planets around pulsars (likely not a pleasant place for life), to more familiar Jupiter-like systems. Within a couple of decades, direct imaging of some of these systems will be possible through interferometric techniques. Of course, there is a big step from finding planets apt for life, and to find extra-terrestrial life, but this is a first step."

S. MAJEWSKI:

"Astronomy has grown from roots put down in very practical application - timekeeping and navigation being the two most obvious. Many of these applications are still important. The hyper-accurate rotation of pulsars, for example, will probably be harnessed for time-keeping purposes. Navigation can and will fix itself to an astrometric "zero point" of distant celestial objects (indeed, the plaques on the Pioneer spacecraft shows the location of our Sun with respect to the nearest pulsars) – ultimately to the most distant quasars. Astronomical navigation and time-keeping will grow in importance as the space age progresses.

Astronomy shares needs and drives technological developments with a number of fields that require cutting-edge imaging, image processing, modelling of extreme physical environments, high speed computing, etc. Some of these applications happen to be military in nature (satellite surveillance, guidance systems, simulations of explosions, etc.) but civilian applications abound: monitoring the Earth's surface from satellites, measuring changes in the global climate, thermal infrared and x-ray imaging, even developing new materials for industrial application. A new, more direct use of astronomy lies in the ability more practically to detect potentially planet-threatening events - nearby supernovae, nearby gamma ray bursts, solar flares - as well as the recent favourite of Hollywood, the danger of comet and asteroid impacts.

Of course, there is always the touchy-feely answer that astronomy reveals our origins and our place in the Universe. The great astronomical advances of the twentieth century have been in understanding the origin of the universe and structures within it. The next century, even the next decade, bring the promise of great achievements in understanding more personal factors, such as the origin of life in the universe. We are already finding planets around other stars, and there is a surge of interest in understanding potential biochemical processes in extraterretrial contexts. Apart from the possibility that biochemistry happens on other worlds, there is also the exciting possibility that exobiology may have had great bearing on the origin of life in the primordial environment of the earth. I can't think of a more profound contribution of astronomy to mankind than to fill in the missing details that link human origins to the stars."

R.CANAL:

"I think the main contribution of Astrophysics to humanity in the coming decades should be, quite apart from its purely stimulating role and its use as a testbench for various kinds of innovative technologies, to provide us with a rational and coherent picture of the Universe with which to bolster our confidence that scientific analysis and the disinterested combination of efforts (at least to a certain point) will be able to tackle the most pressing issues facing humanity."

"A NEW, MORE DIRECT USE OF ASTRONOMY LIES IN THE ABILITY MORE PRACTICALLY TO DETECT POTENTIALLY PLANET-THREATENING EVENTS - NEARBY SUPERNOVAE, NEARBY GAMMA RAY BURSTS, SOLAR FLARES - AS WELL AS THE RECENT FAVOURITE OF HOLLYWOOD, THE DANGER OF COMET AND ASTEROID IMPACTS."

LECTURERS AT THE "CANARY ISLANDS WINTER SCHOOLS OF ASTROPHYSICS"

I. Solar Physics (1989)

- OSCAR VON DER LÜHE (Institute of Astronomy, Zürich, Switzerland)
- EGIDIO LANDI ((Institute of Astronomy, Florence, Italy)
- DOUGLAS O. GOUGH (Institute of Astronomy, Cambridge, United Kingdom)
- GÖRAM SCHARMER (Stockholm Observatory, Sweden)
- HUBERTUS WÖHL (Kiepenheuer Institute. Freiburg, Germany)
- PIERRE MEIN (Observatory of Meudon, France)

II. Physical and Observational Cosmology(1990)

- VALODIO N. LUKASH (Space Research Institute, Moscow, Russia)
- HUBERT REEVES (CEN Saclay, France)
- BERNARD E. PAGEL (NORDITA, Copenhagen, Denmark)
- ANTHONY N. LASENBY (Cavendish Laboratory, Cambridge, United Kingdom)
- JOSE LUIS SANZ (University of Cantabria, Spain)
- BERNARD JONES (University of Sussex, United Kingdom)
- JAAN EINASTO (Astrophysical Observatory, Tartu, Estonia)
- ANDREAS G. TAMMANN (University of Basle, Switzerland)

III. Star Formation in Stellar Systems(1991)

- PETER BODENHEIMER (Lick Observatory, California, USA)
- RICHARD B. LARSON (Yale University, USA)
- I. FELIX MIRABEL (CEN Saclay, France)
- DEIDRE HUNTER (Lowell Observatory, Arizona, USA)
- ROBERT KENNICUT (Steward Observatory, Arizona, USA)
- JORGE MELNICK (ESO, Chile)
- BRUCE ELMEGREEN (IBM, USA)
- JOSE FRANCO (UNAM, Mexico)

IV. Infrared Astronomy (1992)

- ROBERT D. JOSEPH (University of Hawaii, USA)
- CHARLES M. TELESCO (NASA-MSFC, Alabama, USA)
- ERIC E. BECKLIN (University of California, Los Angeles, USA)
- GERARD F. GILMORE (Institute of Astronomy, Cambridge, United Kingdom)
- FRANCESCO PALLA (Astrophysical Observatory, Arcetri, Italy)
- STUART R. POTTASCH (University of Groningen, The Netherlands)
- IAN S. McLEAN (University of California, Los Angeles, USA)
- THIJS DE GRAAUW (University of Groningen, The Netherlands)
- N. CHANDRA WICKRAMASINGHE (University of Wales, Cardiff, United Kingdom)

V. The Formation of Galaxies (1993)

- SIMON D. M. WHITE (Institute of Astronomy, Cambridge, United Kingdom)
- DONALD LYNDEN-BELL (Institute of Astronomy, Cambridge, United Kingdom)
- PAUL W. HODGE (University of Washington, USA)
- BERNARD E. J. PAGEL (NORDITA, Copenhagen, Denmark)
- TIM DE ZEEUW (University of Leiden, The Netherlands)
- FRANÇOISE COMBES (DEMIRM, Observatory of Meudon, France)
- JOSHUA E. BARNES (University of Hawaii, USA)
- MARTIN J. REES (Institute of Astronomy, Cambridge, United Kingdom)

VI. The Structure of the Sun (1994)

- JOHN N. BAHCALL (Institute for Advanced Study. Princeton, New Jersey, USA)
- TIMOTHY M. BROWN (High Altitude Observatory, NCAR, Boulder, Colorado, USA)
- JORGEN CHRISTENSEN-DALSGAARD (Institute of Physics and Astronomy, University of Århus, Denmark)
- DOUGLAS O. GOUGH (Institute of Astronomy, Cambridge, United Kingdom)
- JEFFREY R. KUHN (National Solar Observatory, Sacramento Peak, New Mexico, USA)
- JOHN W. LEIBACHER (National Solar Observatory, Tucson, Arizona, USA)
- EUGENE N. PARKER (Enrico Fermi Institute, University of Chicago, Illinois, USA)
- YUTAKA UCHIDA (University of Tokio, Japan)

VII. Instrumentation for Large Telescopes: a Course for Astronomers (1995)

- JACQUES M. BECKERS (National Solar Observatory, NSO-NOAO, USA)
- DAVID GRAY (University of Western Ontario, Canada)
- MICHAEL IRWIN (Royal Greenwich Observatory, Cambridge, United Kingdom)
- BARBARA JONES (Center for Astrophysics and Space Sciences, University of California San Diego, La Jolla, USA)
- IAN S. McLEAN (University of California, Los Angeles, USA)
- RICHARD PUETTER (Center for Astrophysics and Space Sciences, University of California, San Diego, La Jolla, USA)
- SPERELLO DI SEREGO ALIGHIERI (Arcetri Astrophysical Observatory, Florence, Italy)
- KEITH TAYLOR (Anglo-Australian Observatory, Epping Laboratory, Australia)

VIII. Stellar Astrophysics for the Local Group: a First Step to the Universe (1996)

- ROLF P. KUDRITZKI (University of Munich, Germany)
-CLAUS LEITHERER (Space Telescope Science Institute, Baltimore, USA)
- PHILIP MASSEY (Kitt Peak National Observatory, Tucson, USA)
- BARRY F. MADORE (Extragalactic Database Infrared Processing and Analysis Center (IPAC), NASA/JPL & Caltech, Pasadena, USA)
- GARY DA COSTA (University of Australia, Camberra, Australia)
- CESARE CHIOSI (University of Padua, Italy)
- MARIO L. MATEO (University of Michigan, USA)
- EVAN SKILLMAN (University of Minnesota, USA)

IX. Astrophysics with Large Databases in the Internet Age (1997)

- GEORGE K. MILEY (Leiden Observatory, Países Bajos)
- HEINZ ANDERNACH (University of Guanajuato, Mexico)
- CHARLES TELESCO (University of Florida, USA)
- DEBORAH LEVINE (ESA, Villafranca del Castilo, Madrid, Spain)
- PIERO BENVENUTI (ST-SCF, Munich, Germany)
- DANIEL GOLOMBEK (Space Telescope Institute, Baltimore, EEUU)
- ANDREW C. FABIAN (Institute of Astronomy, Cambridge, Unnited Kingdom)
- HERMANN BRUNNER (Institute of Astrophysics, Postdam, Germany)

OTHER EVENTS

Tuesday 17th:	*Visit to the Instituto de Astrofísica in La Laguna. Welcoming reception at the IAC*
Thursday 19th:	*Working visit to the Roque de los Muchachos Observatory (La Palma)*
Sunday 22nd:	*Working visit to the Teide Observatory (Tenerife)*
Tuesday 24th:	*Visit to the Monje Winelodges*
Thursday 26th:	*Official closing dinner*

PUBLICATIONS

PUBLISHED VOLUMES

CANARY ISLANDS WINTER SCHOOLS OF ASTROPHYSICS

Cambridge University Press has published the following volumes on previous Winter Schools. The volume for last year's Winter School, *Astrophysics with Large Databases in the Internet Age*, is at the printers and will be available shortly.

1. *Solar Observations: Techniques and interpretation*
F. SÁNCHEZ, M. COLLADOS y M. VÁZQUEZ.

2. *Observational and Physical Cosmology*
F. SÁNCHEZ, M. COLLADOS y R. REBOLO.

3. *Star Formation in Stellar Systems*
G. TENORIO-TAGLE, M. PRIETO y F. SÁNCHEZ.

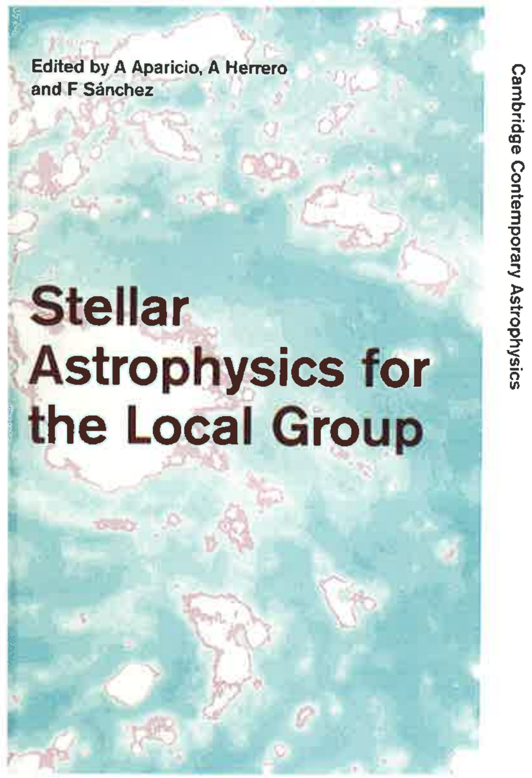
4. *Infrared Astronomy*
A. MAMPASO, M. PRIETO y F. SÁNCHEZ.

5. *The Formation and Evolution of Galaxies*
C. MUÑOZ-TUÑÓN y F. SÁNCHEZ.

6. *The Structure of the Sun*
T. ROCA-CORTÉS y F. SÁNCHEZ.

7. *Instrumentation for Large Telescopes*
J.M. RODRÍGUEZ-ESPINOSA, A. HERRERO y F. SÁNCHEZ.

8. *Stellar Astrophysics for the Local Group*
A. APARICIO, A. HERRERO y F. SÁNCHEZ

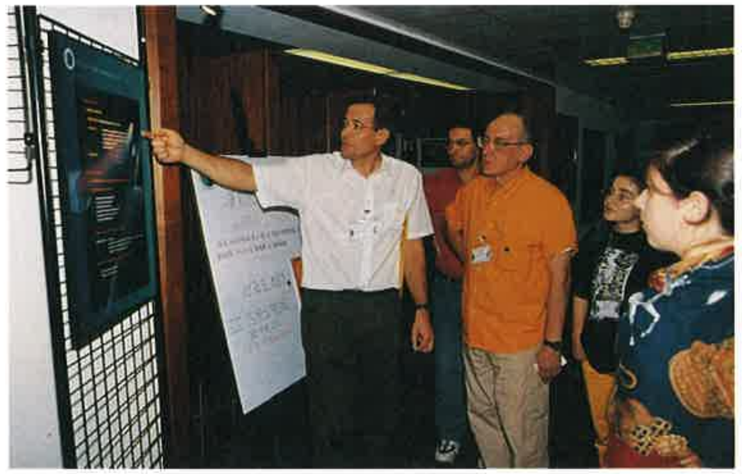


Front page of the latest volume published by Cambridge University Press and devoted to the 1996 Canary Islands Winter School of Astrophysics, on Stellar Astrophysics for the Local Group: A First Step to the Universe.

X CANARY ISLANDS WINTER SCHOOL OF ASTROPHYSICS

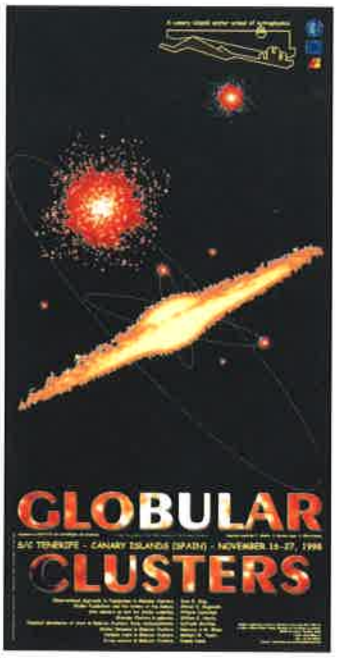
"GLOBULAR CLUSTERS"

SNAPSHOTS



PARTICIPANTS IN THE X CANARY ISLANDS WINTER SCHOOL OF ASTROPHYSICS

Participants in the X Canary Islands Winter School of Astrophysics.



Poster advertising the X Canary Islands Winter School of Astrophysics.

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