Astronomy made in Spain

A project of the Spain Astronomical Society (SEA)
to commemorate the International Year of Astronomy 2009

Benjamín Montesinos Comino
Emilio J. Alfaro Navarro

SEA

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First English Edition, 2011

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Publisher: Sociedad Española de Astronomía (SEA)
Design and production: Cyan, Proyectos Editoriales, S.A., Madrid

Index of authors

Preface

This is the English edition of the book "Astronomía made in Spain", an idea that materialized in 2009, the International Year of Astronomy. In order to celebrate that event, the Spanish Astronomical Society (Sociedad Española de Astronomía, SEA) had the idea of publishing a book summarising the history of modern Spanish Astronomy through the personal views of the researches themselves through their discoveries. Papers published in *Nature* and *Science* were chosen as samples of the work that has propelled Astronomy in Spain to the healthy stage we enjoy today. Those two publications were awarded the 2007 Prince of Asturias Prize for Communication and Humanities. As it was expressed in the resolution of the committee: "…both journals represent the most reliable channel of communication that the international scientific community has today for reporting, after a meticulous and impeccable selection process, the most significant research and discoveries in very diverse scientific fields, and at the same time, disseminate the most elevated theories and facts, whilst combining rigour and clarity. *Science* and *Nature* are indispensable sources of information for specialized journalism in every country. For over a century, they have promoted and disseminated mankind's great scientific conquests and thus have brought science closer to life."

We present here 39 conversations with the Spanish astronomers who have published as first authors in *Nature* and *Science* in the last 30 years, until the end of 2009. The same questionnaire was sent to each researcher. They were asked to describe in the simplest possible way the context and scope of their discoveries and also to provide some personal appreciations or anecdotes. When an astronomer had more than one publication, he or she was asked to choose one, or to summarise the results of several or all of them. At the end of each conversation you will find the reference of the paper (or papers) treated in the text. We have placed the contributions in chronological order according to the publication date of the papers, to give a general perspective of the way the different branches have evolved.

You will find very different styles of writing, long texts in some cases and more laconic ones in other occasions, as well as different complexity levels when describing the scientific topics. Corrections and editting of the original texts have been kept to a minimum. The editors are indebted to Susana Cabañero for a very careful translation of the originals in Spanish and to Aprajita Verma for revisions and copyeditting of the translated texts. Each contribution was sent to the corresponding author who made the final “fine tuning” of its contents. We are also grateful to Montserrat Villar, the coordinator of the 2009 International Year of Astronomy Spanish Node, for providing us with finantial support for the translation.

It is always stimulating to read about a historical event when described by a person who *was there.* It is the same in science. There is nothing better than letting people who once made a milestone discovery in their fields describe their experience at first hand.

Benjamín Montesinos Comino
Emilio J. Alfaro Navarro,
on behalf of the Spanish Astronomical Society (SEA)
February 2011

Jordi Isern Vilaboy
Institut de Ciències de l'Espai
(CSIC-IEEC, Barcelona)

What was the problem you had to face?

Type Ia supernova outbursts are the result of the thermonuclear explosion in a white dwarf in a close binary star system. These outbursts are characterised by a very homogeneous maximum luminosity and the correlation between the existing luminosity dispersion and the light curve decline rates. In 1984, it was not yet clear if the nature of these outbursts was thermonuclear or gravitational and the cause of the above mentioned correlation (known as the "Phillips Relation") was unknown.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In this paper we proposed for the first time that thermonuclear supernova outbursts and neutron stars in low-mass X-ray sources could have the same origin, namely, a carbon-oxygen white dwarf.

The difference in behaviour was due to the value of the central density at the moment of ignition and to the changes in chemical composition induced by solidification. If the density was very high (which is the case of initially cold stars), the electronic captures on the ashes could trigger the collapse to a neutron star, while the differences in the chemical composition could change the propagation velocity of the deflagration and explain the small luminosity dispersion at maximum.

Since the paper was published, have there been significant advances in this specific area?

There have been important advances from the observational point of view which have culminated with the discovery, thanks to Type Ia supernovae, of the accelerated expansion of the Universe, but the problem of the residual intrinsic dispersion in the luminosity of Type Ia supernovae at maximum still remains.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The problem mentioned before is part of a more general problem concerning the behaviour of degenerate stellar structures that are responsible for a large number of astrophysical phenomena. The rich and precise astrophysical data we are obtaining currently, and those that will be provided by future telescopes, will allow us to use the stars as large physics laboratories.

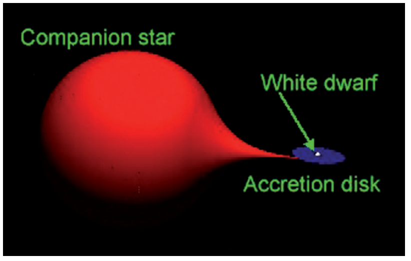

Figure 1. *Type Ia supernova progenitor model. Matter from its companion falls onto the surface of the white dwarf causing the inner regions to become unstable and producing a thermonuclear explosion. Image by Paul Ricker, University of Illinois.*

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

The physics of stellar interiors has been fundamental in my professional career. It determines not only the behaviour of the late evolutionary phases of stars (supernovae and white dwarfs) but also properties of the Galaxy (nucleosynthesis and chemical evolution, fossil stellar populations, etc.). The simplicity of white dwarfs and the paradigm of these degenerate structures, allow us, using them, to define "exotic" physics theories as gravitational constant drifts, axions mass, the neutrino magnetic moment, the existence of monopoles, or the compactification of extra dimensions.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The idea of writing this paper came up during a meal at "Motel Empordà", in Figueres (Alt Empordà), while we were enjoying a roast deer (solid phase) in quince jelly (liquid phase).

Solid white dwarfs as Type I supernova progenitors

J. Isern, J. Labay and R. Canal

1984, Nature, 309, 431

Enrique García-Berro Montilla
Departamento de Física Aplicada
Universidad Politécnica de Cataluña (Barcelona)

What was the problem you had to face?

The evolution of white dwarfs was a problem that gave rise to an important debate in the eighties. It has been known for some time that the evolution of white dwarfs was driven by two important factors. Firstly, it was known that the pressure of a gas of degenerate electrons supports the mechanical structure of white dwarfs. The second fact that was known is that a simple cooling process could describe the evolution of this type of star. Both facts were fully established and widely accepted by the astronomical community. However, we had very few good quality observations of white dwarfs, which made the comparison between the theoretical models and the observations very difficult. In the second half of this decade observational data of better quality were obtained in a systematic and routinely way for a limited number of this type of stars. In particular, precise distances could be obtained for about 200 white dwarfs, which allowed the number of white dwarfs per unit bolometric magnitude and per unit volume to be measured, i.e. the luminosity function of white dwarfs. It was then purely a matter of comparing the theoretical models of white dwarf cooling with the derived luminosity function. The results of this comparison were shown in the paper I published in *Nature.*

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Dense plasma physics predicted that the material of the degenerate core of the white dwarf, composed of carbon and oxygen nuclei, should experience a first-order phase transition at sufficiently low temperatures or, in other words, that the white dwarf's interior should crystallize, with those nuclei forming a crystalline lattice. As a result, an additional energy should be released, the latent heat of crystallization. Some previous studies also showed that it was possible that the chemical composition of the solid phase was different to that of the liquid one. In particular, some theoretical calculations showed that the solid phase should be richer in oxygen. As a result of this and the high gravity of white dwarfs, the central regions of the white dwarf would be oxygen-rich, as the crystallized material is denser than the liquid, which would be carbon-rich. The separation of carbon and oxygen releases additional energy which should be radiated by the white dwarf, therefore altering its cooling rate. This is due to the fact that the material has to be electrically neutral, and therefore, the oxygen-rich solid material carries with it additional electrons, therefore modifying the pressure balance. Our detailed calculations took into account the resulting energetic balance and allowed us to obtain the cooling rate of white dwarfs with high precision.

On the other hand, it was already known before our work that white dwarfs could be used as stellar chronometers. It was speculated that as the evolution of white dwarfs could be considered as a cooling process, and given the very narrow mass distribution of white dwarfs, if we detected the faintest white dwarf in the solar neighbourhood we would be looking at the oldest one and, therefore, knowing its age, we could put a lower limit to the age of the Galaxy. This simple reasoning can be refined using the luminosity function (a statistical measurement). It is well known that the colder an object is, the longer it takes to cool down. In the case of white dwarfs, this means that the fainter a white dwarf is, the longer it takes to decrease its intrinsic brightness. The probability of detecting a white dwarf with a specific luminosity depends mainly on how long it maintains that luminosity. Therefore, the white dwarf luminosity function should be a monotonically increasing function for decreasing luminosities, as low-luminosity white dwarfs take longer to cool. The first observational determinations of the luminosity function confirm this hypothesis. The surprise was that the determinations of the luminosity function, which were published during those years, presented a very sharp decrease at low luminosities, indicating a substantial deficit of these low-luminosity stars. This decrease in the number of white dwarfs was quickly attributed to the finite age of the Galaxy and our models allowed us to determine the age of the Galaxy.

Since the paper was published, have there been significant advances in this specific area?

There have been enormous advances in this area of astronomy. Today, all theoretical models of white dwarf cooling include the phase separation of oxygen and carbon. Besides, as a result of systematic sky coverage (2MASS, SDSS, 2dF…) the number of white dwarfs accessible to high-quality observations has increased outstandingly, going from about 200 white dwarfs to more than 6,000. This has permitted the construction of very precise luminosity functions which allow conclusions about the physical processes that take place in the interior of white dwarfs to be drawn. In particular, about exotic particle emission, like the axion. It is also possible to obtain statistical limits on a hypothesised variation of the universal gravitational constant predicted by some alternative gravitational theories, but which still need to be confirmed. In the near future, ESA's Gaia astrometric satellite will help us to extend the observational data base even more with which it will be possible to precisely measure the stellar formation rate in the solar neighbourhood using the white dwarf luminosity function, among other potential applications. For all this, it will be necessary to improve the models of white dwarf cooling. Future perspectives opening up in this field are therefore very promising.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

One of my fields of work is still the evolution of white dwarfs. The determination of their observational properties and physical characteristics are still today very active research fields. In the next few years, important advances are expected, especially in relation to the pulsational properties of white dwarfs. Some significant advances are also expected in the determination of different populations of white dwarfs (disk and halo). Also, the observations from space platforms will make it possible to obtain very high quality data, both from field white dwarfs and white dwarfs in clusters, either in open or globular clusters. The perspectives in this sense are very wide as it will be possible to compare several methods to determine the age of clusters. Therefore, the theoretical models of the evolutionary properties of white dwarfs is showing notable advances.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Yes. The answer to both questions is positive. I have maintained an active line of research in the field of white dwarfs, which has been extended to other related areas. I have dedicated most of my time to this research field, as I feel very comfortable with it and find it very interesting. Of course, I have also worked in other aspects of astrophysics which have nothing to do with the evolution of white dwarfs. Regarding the question about the influence of this paper on my professional career, I have to say that when I published this paper I did not give it the importance I should have. With time I have developed a different perspective. It should be taken into account that when I published this paper I was in the last stage of my PhD thesis. Now, I value the contribution the paper made as it deserves to be.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Nothing in particular, simply the great moments I had with the co-authors of the paper. The calculations were done with very different resources to the ones available today and, to a large extent, they were the result of scientific discussions and the co-operation and friendship among the authors. Co-operation and friendship that still exist today.

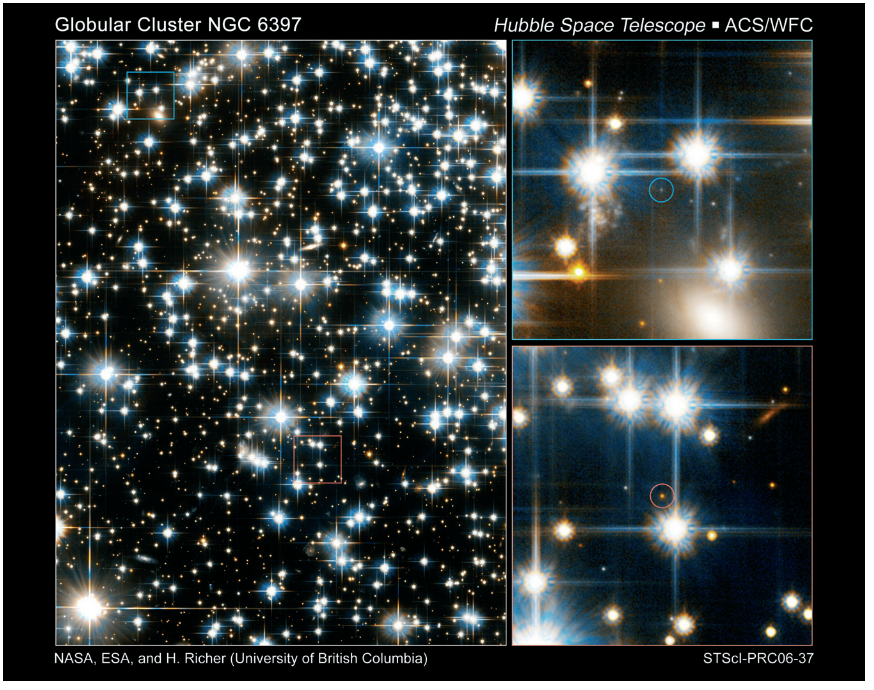

Figure 1. *Image of the globular cluster NGC 6397. The image on the left corresponds to the field observed by the Hubble Space Telescope. The faintest stars in this field are red dwarfs and white dwarfs. The first ones have a magnitude of 26, while the latter have a magnitude of 28. The image at bottom right shows the faintest red dwarf (inside the circle). The image at top right shows one of the faint white dwarfs in the field, the blue star surrounded by a circle. Note the different colours of the stars.*

ADDENDUM: …23 years later

NGC 6791 is an open cluster close to the Sun and very well studied. It has been possible to obtain images of its stars reaching very faint magnitudes, even fainter than those corresponding to the end of the cooling sequence for white dwarfs. In addition, it is a very populated cluster, old and metal rich. It was already known that there was a remarkable discrepancy between the age of the cluster obtained by fitting the main sequence (8×10^9 years) and the one estimated from white dwarfs (6×10^9 years), but there was no plausible hypothesis to account for that difference. An explanation is that, given the high metal abundance of this cluster, one of the products of Helium burning, namely ^{22}He, settles towards the interior of its white dwarfs, releasing gravitational energy. In addition, as we suggested back in 1988, at even lower temperatures, the main components of a typical white dwarf (^{12}C and ^{16}O) crystalize, producing their separation in solid phase, releasing more energy and delaying the cooling of the white dwarf. In our paper published in *Nature* in 2010 (see the reference below) we demonstrate that taking into account the delays induced by both phenomena, the ages -obtained using the methods mentioned above- match each other. In this way we have proved that the mechanism we suggested 23 years ago does actually occur in the dense nuclei of white dwarfs. It was a great pleasure to see that what we proposed was finally confirmed by observations. In opposition to my feelings in 1988, in this case I valued a lot to see our paper published… No doubt, I accumulate 23 more years of experience…

Properties of high-density binary mixtures and the age of the universe from white dwarf stars
E. García-Berro, M. Hernanz, J. Isern and R. Mochkovitch
1988, Nature, 333, 642

A white dwarf cooling age of 8 Gyr for NGC 6791 from physical separation processes
E. García-Berro, S. Torres, L.G. Althaus, I. Renedo, P. Lorén-Aguilar, A.H. Córsico, R.D. Rohrmann, M. Salaris and J. Isern
2010, Nature, 465, 194

David Valls Gabaud
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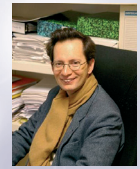

What was the problem you had to face?

The second half of the 1980s marked a milestone in the galaxy formation scene. For the first time, a very detailed theoretical picture was being developed based on just one hypothesis. It was postulated that dark matter, which forms haloes surrounding the observed galaxies, would have a low thermal velocity *(Cold Dark Matter or CDM)* in opposition to the alternative hypothesis according to which dark matter consisted of lighter elementary particles, such as neutrinos. Within this framework, it can be shown that dark matter haloes form in a hierarchical way: The less massive haloes collapse first and start merging with others, forming increasingly larger halos. One of the predictions of this *biased* galaxy formation theory is that the initial galaxies, less massive and therefore less biased with respect to the mean value, should have a very different spatial distribution to that of the brightest and more massive galaxies, much more biased. The object of the test was, therefore, to measure the spatial distribution of the brightest galaxies with respect to the faintest galaxies.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

It was hard to prove this prediction with even the most detailed galaxy catalogues of the time. This situation changed with the galaxy catalogue made by a Harvard CfA team (Huchra, Geller and De Lapparent), which showed for the first time the filaments that characterise the large-scale structure of the Universe. This distribution was roughly the one predicted by this galaxy formation theory, so it was essential that the theory undergo a more detailed testing. Due to the small number of galaxies available (barely more than a thousand, but they revolutionised cosmology) it was very difficult to measure these subtle effects. The first step was to develop a new robust statistical method that enabled the theory to be tested with a relative measurement of the effect instead of trying to measure the effect in an absolute way.

The measurements made in the CfA catalogue delivered amazing results, and so the second step was to analytically calculate the detailed predictions that were feasible within the framework of the galaxy

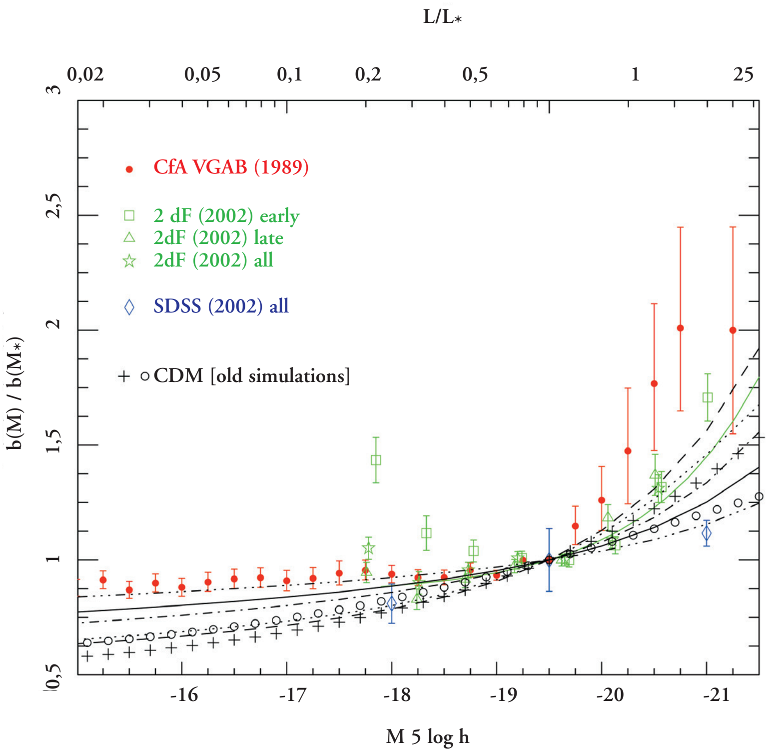

Figure 1. *Variation of the relative bias parameter of galaxies as a function of luminosity (left) and absolute magnitude (bottom). In red, the measurements from the CfA catalogue in 1989. The dashed and continuous lines represent several analytic models of galaxy formation in the CDM paradigm. The crosses and circles are the predictions of numerical simulations with CDM at that time, which were clearly in contradiction with observations. The most recent measurements with much deeper catalogues are shown in green (2dF catalogue) and blue (SDSS catalogue). The present measurements show that the issue is not yet settled. The bias of bright galaxies in the 2dF catalogue is very different from the one in the SDSS catalogue, and some dwarf galaxies seem to have a large bias in the 2dF catalogue but not in the SDSS. The local density of galaxies probably determines the bias, as well as the luminosity of galaxies or the mass of dark matter haloes.*

formation theory. The result was that the measurements were clearly in contradiction to both the refined analytical predictions and the first numerical simulations of large structures. Theory could not explain, in a simple way, the large-scale distribution of brightest galaxies compared to the faintest galaxies, and therefore, it was not possible to understand how galaxies actually formed.

Since the paper was published, have there been significant advances in this specific area?

Yes, as we are living what it is probably the golden age of Cosmology. On the one hand, the theoretical predictions have advanced significantly, partly thanks to large-scale numerical simulations. On the other hand, the spectrographs mounted on large telescopes have enabled more and more detailed and complete catalogues to be made. Just to emphasise the order of magnitude, what took several years of painstaking observations for the CfA team to obtain a thousand galaxy spectra, now can be done in less than an hour of observation at the Very Large Telescope (VLT, ESO, Chile). New catalogues, with nearly a million galaxies, have yielded contradictory results (Figure 1) both between themselves and in comparison to theory. Now we think that the luminosity of galaxies is not uniquely determined by the mass of the dark matter haloes surrounding them, but there are more subtle effects that can have an influence, such as the local density of galaxies. For example, the galaxies in clusters are in denser environments, and this can influence their star formation histories which, in turn, determine the observed luminosities.

What are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

This field of Astronomy continues to be very active, especially because it is necessary to understand in detail the large-scale distribution of galaxies in order to measure the cosmological parameters that describe the Universe as a whole. For instance, there are several projects aimed at measuring baryonic acoustic oscillations, which are a reflection of what happened when the Universe became transparent to photons and at a regime where the bias is supposed to be known and simple. Yet the measures can be affected by the luminosity dependence of galaxy bias, as we have just seen, and these effects may skew the measurements of the cosmological parameters. There is still plenty of work to do with present catalogues in order to understand in detail the characteristics of large-scale galaxy distribution and, therefore, to understand how galaxies form.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Publishing a paper in *Nature* during your thesis is quite exceptional and I was simply lucky to be working in a hot topic with unique tools (advanced statistical methods, analytical calculations in Gaussian random fields) when the first "big" galaxy catalogue was published. The eagerness to work with that catalogue was so strong that some colleagues even scanned the enlarged photocopies of the published figures because the real catalogue would be published much later.

The paper, of course, was very useful to obtain my first postdoctoral contract, but I did not continue working on that topic until a couple of years ago when I wanted to measure the effect in new catalogues, with results which are surprisingly more difficult to interpret. I am taking up this line of work again because of the growing importance of this field for the future measurements of cosmological parameters and also to understand the mechanisms that determine the luminosity of galaxies and the evolution of star formation within them.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

This was the second paper I wrote during my PhD thesis and my first one published in *Nature.* I was not very familiar with the reports sent by referees and it was surprising to receive one very enthusiastic report and another demolishing one. The second referee took a long time to answer and kept sending more and more complicated questions that could not be resolved in the framework of a short *Letter* to *Nature* and which were not related to the topic. In the end, we decided to ask for a third independent referee who had access to all the correspondence. He turned out to be none other than P.J.E. Peebles, who is widely regarded to be one of the founders of modern cosmology, and who sent a highly favourable report while he criticised the second referee. I still keep as a memento the letter that J. Maddox, the mythic editor of *Nature,* sent accepting our paper, apologising for the behaviour of the second referee and guaranteeing us that this person would never be contacted again by *Nature* to referee a paper.

Luminosity segregation as a constraint on the theory of biased galaxy formation
D. Valls-Gabaud, J.-M. Alimi and A. Blanchard
1989, Nature, 341, 215

Xavier Barcons Jáuregui
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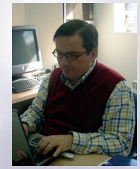


What was the problem you had to face?

Our aim was to try to understand the physical state (temperature, density, homogeneity) of atoms and ions that are thought to be dispersed in between galaxies. It is not expected that 100% of atoms are captured inside galaxies or galaxy clusters during the galaxy formation process thereby predicting the presence of atoms and ions in the intergalactic medium.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

We used three cosmological observables to infer the density and temperature of the intergalactic medium. The first one derives from distant quasar observations, the second and third ones from the observation of all types of extragalactic background light (especially microwaves and X-rays) present in the Universe.

We reached the conclusion that the present temperature of the intergalactic medium would be between 20,000 degrees and about 10 million degrees. This temperature interval was inconsistent with the idea of attributing the origin of energetic X-rays (the cosmic X-ray background), that fill the Universe, to the intergalactic medium, a model we had defended previously. It also rejected one of the cosmic structure formation models at that time, based in big cosmic explosions, which other researchers were putting forward.

Since the paper was published, have there been significant advances in this specific area?

The most significant advances have been achieved during the past decade and, for the time being, they are largely theoretical. Hydrodynamical simulations made in the current cosmological paradigm show that, indeed, half of the atoms in the Universe are in a diffuse phase in the intergalactic medium. They also show that the temperature of this diffuse medium was several hundred thousand degrees when the Universe was one third of its present age, but today it could have a temperature of many million degrees. Finally, the simulations show that the intergalactic medium is likely to be distributed in the form of filaments, similarly to dark matter.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

There is a possibility that the current generation of X-ray space

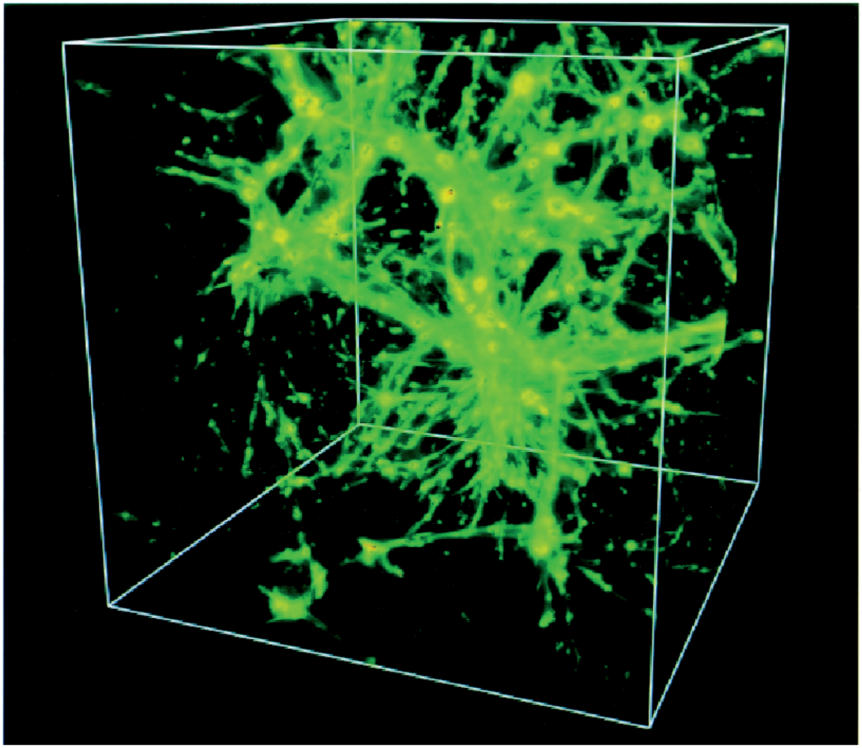


Figure 1. *The figure shows a numerical simulation of how matter is distributed in the integalactic medium in the current universe. The regions with larger densities mark the position of galaxies and clusters of galaxies, but the majority of that medium is too diluted to be seen with the current astronomical instrumentation. An interesting point is that, instead of being uniformly distributed, the intergalactic medium shows a filamentary structure. In that way, if a beam of light from a distant object crossed one of those filaments, the next-generation X-ray telescopes would be able to see the trace of that filament in the light of that far-away source. Figure taken from R. Davé et al. 2001, The Astrophysical Journal, 552, 473.*

observatories detect the first traces (or filaments) of the hot intergalactic medium (temperatures of million degrees), through the fingerprint that highly ionized oxygen atoms would leave in the X-ray light we receive from distant sources, such as quasars or very luminous similar objects. With the aid of Chandra and XMM-Newton missions, we have been searching for these “absorption lines” of six-times-ionized-oxygen that is the state in which it would preferably be, given its temperature, but for the time being there is no clear conclusion. In the best case, these missions would enable us to find only the very first intergalactic medium filaments. However, their study will have to await until the launch of the

International X-ray Observatory (IXO) towards 2020.

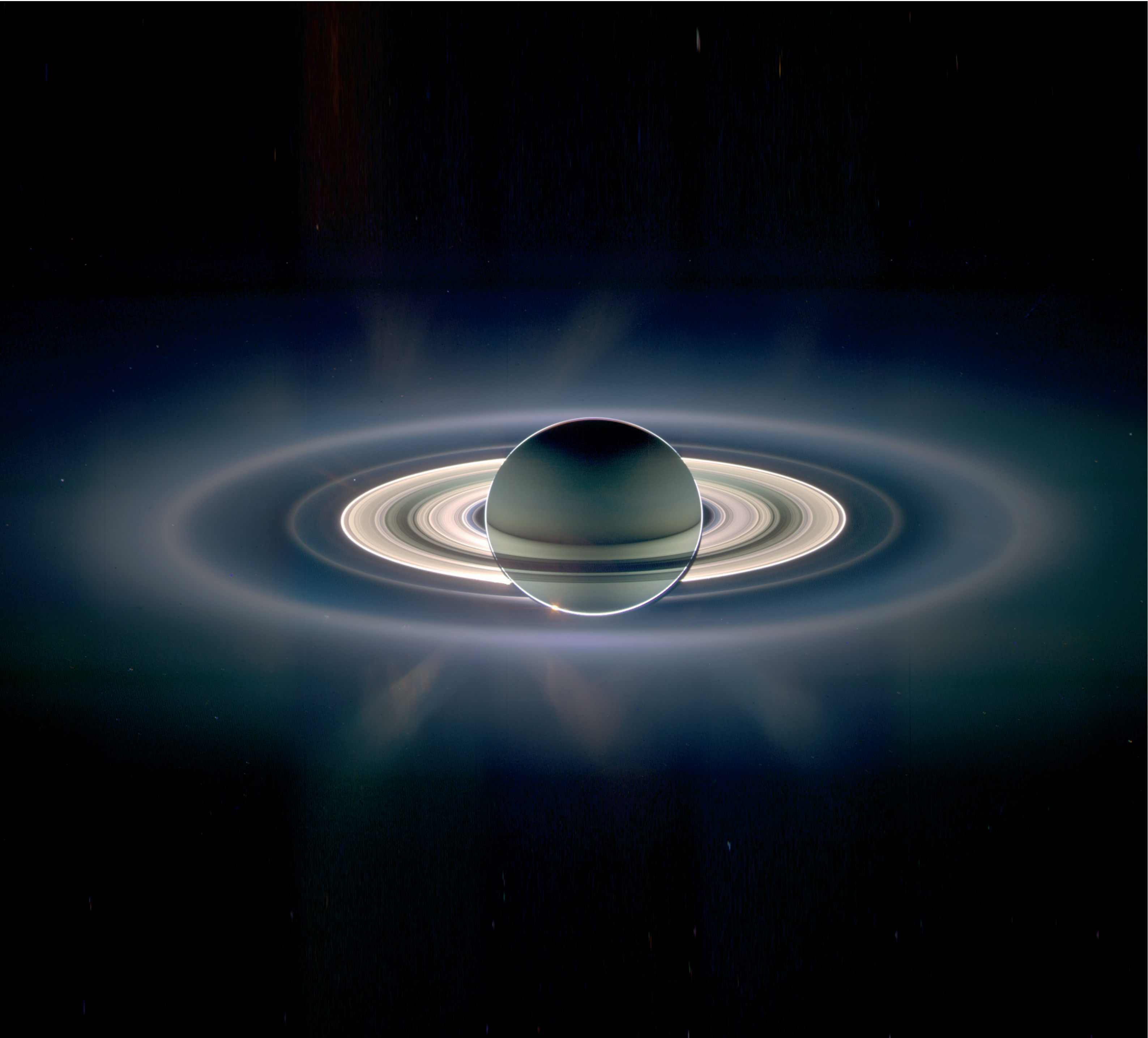
How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

For more than a decade I stopped my research on this topic. From 1997 onwards, I became interested again when I got involved in the scientific definition of the IXO mission (formerly know as XEUS) following a collaboration among the European Space Agency (ESA), the U.S. Space Agency (NASA) and the Japanese Space Agency (JAXA). Together with other colleagues we saw that the combination of a large effective area together with a spectral resolution capability as that of IXO was what was exactly needed to tackle this problem.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

What I am going to tell it is related to a different paper I published in *Nature* with other colleagues *(Extensive dark-matter haloes in low-luminosity galaxies revealed by quasar absorption-lines,* X. Barcons, K.M. Lanzetta, J.K. Webb, 1995, *Nature* 376, 321). This paper mixed two aspects of the study of galaxies that, at least at that time, were regarded as very different: QSO absorption lines caused by neutral gas along the line of sight and galaxy kinematics. Two external referees were assigned, one from each of these communities. Each of them, who had no strong argument against the paper, pretended that the paper had to derive its emphasis towards the field of the other one: It seemed that they did not want intruders. The editor had to intervene and decided to accept the paper. Several years later, one of those referees confessed to me that he was one of them (we had already identified the other one) and he recognized his behaviour with that paper was perhaps not the most constructive one.

The physical state of the intergalactic medium
X. Barcons, A.C. Fabian and M.J. Rees
1991, Nature, 350, 685



Agustín Sánchez Lavega
Departamento de Física Aplicada I
Escuela Técnica Superior de Ingeniería
Universidad del País Vasco, Bilbao

What was the problem you had to face?

When I was 16, I was able to look at the Universe for the first time with a small telescope that I bought with the pocket money I managed to save, and since then this was always the only thing that strongly caught my attention. What were those bright and dark spots that could be seen over the trembling disks of Mars and Jupiter? These and other questions lead me to study the planets, and, in particular, to explore the atmospheres of the giants Jupiter and Saturn. For my PhD thesis I studied the winds of Saturn and especially, the strange and giant storms ("Great White Spots"), rummaging in libraries to collect the scarce data available. There were only four documented events after more that 120 years of observation, and with the information we gathered we created for the first time a dynamical model of the nature of the spots. And, as they are apparently recurrent with Saturn year (30 terrestrial years), we raised the possibility that a new storm would be visible in 1990. It indeed happened, and it was the study of this phenomenon that brought us for the first time to the front page of *Nature*.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Saturn's equatorial storm appeared at the end of September 1990 and it was discovered by a North American amateur astronomer. A few days later, we could observe it in detail with the 1 meter telescope at the Pic du Midi Observatory in the French Pyrenees. We collected an excellent set of multicolour images of the early phases of the storm and its development and evolution for more than a year.

We could measure in detail the storm clouds movements and the planet's equatorial winds. With all these data, and with those obtained later with the Hubble Space Telescope (HST), which had been recently launched at the time, we were able to put a limit to the height of clouds and improve the dynamical model of the storm. We could determine that the giant storm was caused by convection in deep water clouds in Saturn's atmosphere.

Since the paper was published, have there been significant advances in this specific area?

The work published in *Nature* was later the basis of two PhD theses in our research group (and some others in the United States). The published

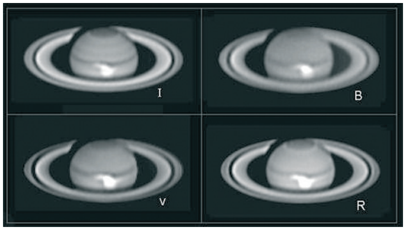


Figure 1. *Images of Saturn's equatorial storm obtained in October 1990 from the Pic du Midi Observatory. The letters on the images correspond to the names given to the different colour filters used.*

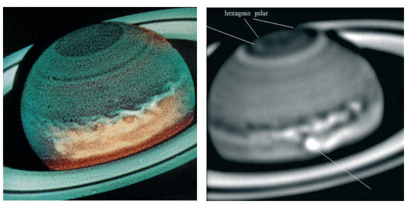
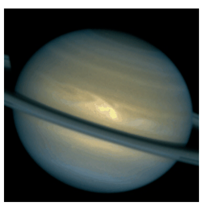


Figure 2. *Images of Saturn in 1990 (above) and 1994 (right) showing the storms (Great White Spots) at those years. The colour images were obtained with the Hubble Space Telescope (HST), and the black-and-white image is from the Pic du Midi Observatory.*



work enabled an advance in the details of the formation of these storms and the structure of the planet's atmosphere. It also happened that a new second storm came up in the equator in 1994, and we published another work in *Science* about it. A paper we wrote some years later in 2003, again occupied the front page of *Nature,* where based on the analysis of HST images we suggested that the apparent change in velocity of Saturn's strong equatorial jet stream could be the result of giant storms. Since then there has been a great advance in the knowledge of this planet and, in particular, its atmosphere, after the Cassini spacecraft entered into orbit in the middle of 2004. Cassini is allowing us to study Saturn's wind system and meteorology. However, there have not yet been any great storms while the spacecraft has been in orbit around the planet…

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

One of the big problems of atmospheric dynamics of giant planets is to know the nature of its multiple and intense winds in the form of jet streams which vary with latitude. We do not know if they are deep and extend down into the interior of Jupiter and Saturn, or if they are a superficial phenomenon and, therefore whether the source of energy is the deposition of solar radiation (which arrives from the top) or the internal energy retained inside the planet after its formation (which flows from beneath). At the beginning of 2008, we got our third front page of *Nature* with a work about Jupiter's intense tropical jet in which we studied the relationship between two strange storms (similar to the ones in Saturn), the planetary disturbance they produced and the depth of the jet stream where they emerged. We think the jet stream is deep. Another fundamental problem is the determination of the water vapour abundance and its spatial and temporal distribution necessary to explain the meteorological phenomena in the atmospheres of these planets.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

There is no doubt that publishing in *Nature* and *Science,* and even more, occupying their front pages, is probably the best showcase of the research that one is carrying out to other scientists in the same field and in related areas, and to the mass media. Our group has been successful in this respect, with six papers in *Nature* (three times at the front page) and another three in *Science.* This has definitely contributed to the public image of this research, both among colleagues and socially through conferences, papers, interviews, etc. This has given us the foundation to extend our research to the atmosphere's of other planets, such as the study of the wind system of Venus using data from the Venus Express spacecraft, and the methane storms on Titan.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I learnt about the eruption of Saturn's equatorial storm in 1990 through a telephone call from the Pic du Midi Observatory at 2 in the morning. I was told it was spectacular and that they were photographing it in detail. The following day I took an 8-inch Celestron telescope and I was observing it with my younger son from a cliff near my house when the storm, like a bright dot, crossed the central meridian of Saturn's disk. I was profoundly impressed! In the following months I was observing with the 1-meter telescope at Pic du Midi in very hard winter conditions and sometimes pointing towards Saturn when it was only 20º above the horizon! In an innocent way, without knowing the consequences it could have, I sent the paper on the storm to *Nature.* The referees received it so enthusiastically (opinions were exchanged by email, which it was not a standard yet) that the editor decided to publish it as a

Figure 3. *Front pages of* Nature, *which correspond to the papers published by the group at the University of the Basque Country about Saturn's storms and Jupiter's tropical jet*

long *Article.* I received the acceptance and the proof-sheet in a long fax, and the additional surprise arrived when we received the journal in the library and saw the storm on the front page. As we did not have enough money to pay the colour copies for the front page, *Nature* kindly sent me two free copies that I still keep with great care. That very Thursday, people from everywhere in the world started to call without stopping to ask about the phenomenon. Congratulations from the Spanish Ministry of Education to National Geographic, from the newspapers to the radio and the television came flooding in. Without seeking or knowing it, we learnt what it means to publish and occupy the front page of *Nature.*

The Great White SPOT and disturbances in Saturn's equatorial atmosphere during 1990
A. Sánchez-Lavega, F. Colas, J. Lecacheux, P. Laques, D. Parker and I. Miyazaki
1991, Nature, 353, 397

Large-scale storms in Saturn's atmosphere during 1994
A. Sánchez-Lavega, J. Lecaheux, J.M. Gómez, F. Colas and 5 co-authors
1996, Science, 271, 631

A strong decrease in Saturn's equatorial jet at cloud level
A. Sánchez-Lavega, S. Pérez-Hoyos, J.F. Rojas, R. Hueso and R.G. French
2003, Nature, 423, 623

Depth of a strong jovian jet from a planetary-scale disturbance driven by storms
A. Sánchez-Lavega, G.S. Orton, R. Hueso, E. García-Melendo and 21 co-authors
2008, Nature, 451, 437

Jorge Casares Velázquez
Instituto de Astrofísica
de Canarias (Tenerife)

What was the problem you had to face?

In the seventies and eighties three X-ray binaries were identified with compact objects more massive than 3 solar masses: Cyg X-1, LMC X-3 and A0620-00. This value is the maximum mass allowed for neutron stars according to standard models and, therefore, these binary systems would be strong candidates to harbour black holes. However, in order to explain the observations, some alternative models were proposed that replace the black hole with two compact stars or new models of "exotic" neutron stars, stable up to 5 solar masses. Then, at the end of the eighties, there was an important astrophysical debate about whether black holes exist. In this context, the detection of a compact star with a mass over 5 solar masses was suggested as the "Holy Grail in the search for black holes"

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In 1992, using the 4.2 m diameter William Herschel Telescope at the Observatorio del Roque de Los Muchachos (La Palma), we managed to detect the companion star of the X-ray source V404 Cyg and study its movement. This star travels faster than 208 km/s and completes its orbit around a compact object in 6.5 days. These numbers imply that it is more massive than 6 solar masses and therefore, that would qualify V404 Cyg as the aforementioned "Holy Grail" of black holes. One could say that our work marked a turning point in the identification of black holes. At present, there is no debate about the existence of black-holes and the word "candidate" has fallen into disuse because all the X-ray sources with dynamic masses over 3 solar masses are now considered real black holes.

Since the paper was published, have there been significant advances in this specific area?

We have moved from having 3 black-hole candidates to 20 confirmed black holes, 17 in our Milky Way, 2 in the Magellanic Clouds and one in the galaxy M33. Fifteen of them have relatively precise masses ranging between 4 and 15 solar masses. Nobody doubts the existence of black holes and they are routinely used to explain observed phenomena in a wide range of astrophysical scales,

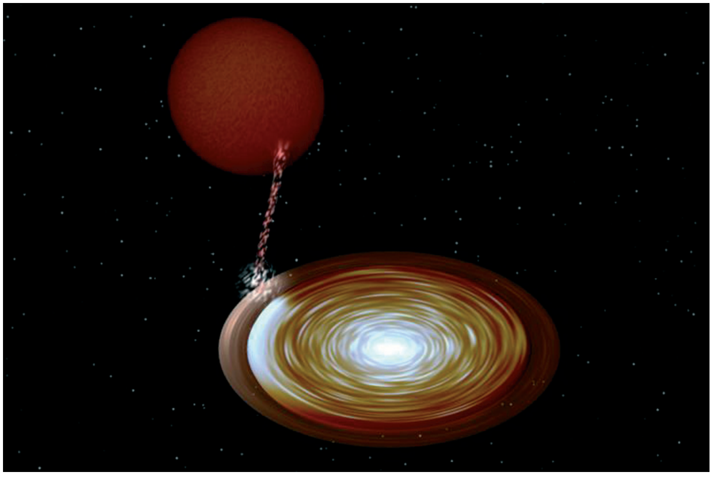


Figure 1. Artist's concept of the X-ray binary V404 Cyg. A 0.7 solar mass star and spectral type K0 orbits around a black hole of 12 solar masses in 6.5 days. Tidal forces deform the companion star and pull off material from its photosphere, which falls towards the black hole forming an accretion disk. Courtesy of Rob Hynes.

from binary systems to active galactic nuclei. One of the recent and most spectacular discoveries has been the demonstration of the presence of a supermassive black hole at the centre of our galaxy Sagittarius A. Using adaptive optics technology with the Very Large Telescope (ESO, Chile), it has been possible to directly measure the orbit of several stars around Sagittarius A. The presence of a supermassive black hole is the only possible explanation for that extremely high concentration of matter in such a small volume.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

In my opinion, there are two fundamental problems in this field: determining the mass spectrum of black holes and the nature of ultraluminous X-ray sources (ULXs). The former has implications in many areas of Astrophysics, such as models for supernova explosions or models of the chemical enrichment of the Galaxy. Unfortunately, our sample of 20 black holes it is too limited to draw conclusions about their mass distribution. This is only the tip of the iceberg of an underlying population that is estimated to comprise several thousand X-ray binaries in a state of "hibernation" (they do not emit X-rays). It is important to discover new X-ray binaries to enlarge the known sample of black holes. The second problem is to resolve whether ULXs, detected in nearby galaxies, contain black holes of 100-1,000 solar masses. In that case, we would be talking about the unknown links between stellar-mass black holes and supermassive black holes in galaxy cores. This demonstration would only be possible through dynamic studies similar to the one we did with V404 Cyg.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

This work has had a decisive influence on my career. It opened the door to a post-doctoral contract at the University of Oxford, where there used to be one of the strongest European groups in X-ray binaries. Since then, I have continued my research in this type of objects. We have revealed the nature of these compact objects with the discovery of four additional black holes with masses over 5 solar masses as well as measuring neutron star masses. We have also developed new techniques to measure masses using fluorescent emission produced by the irradiation of the companion star. I have also dedicated part of my time to study the properties and behaviour of accretion disks at different timescales, from seconds to years.

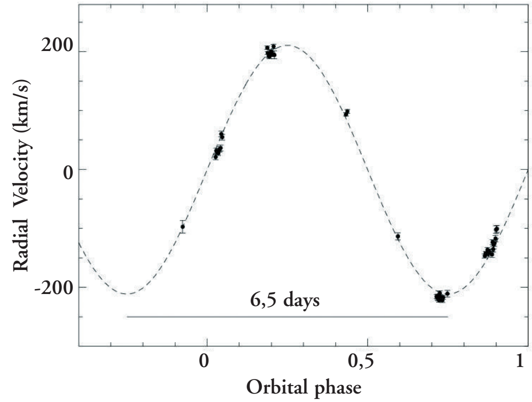


Figure 2. Radial velocity curve of the companion star in V404 Cyg. It shows the radial velocity variation of the K0 star due to the gravitational effect of the black hole.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I discovered the black hole during the last year of my thesis, I had already finished my three-year working contract at IAC and I was unemployed. That event gave rise to sensational news headlines of the type: "Spanish unemployed researcher discovers the first black hole." Also, for some time after the publication of this paper, I received many emails and some manuscripts from different parts of the world asking for my opinion of quite elaborate physical theories or trying to convince me that the Theory of General Relativity was wrong.

A 6.5-day periodicity in the recurrent nova V404 Cygni implying the presence of a black hole
J. Casares, P.A. Charles and T. Naylor
1992, Nature, 355, 614

Eduardo Battaner López
Departamento de Física de la Tierra y del Cosmos
Universidad de Granada

What was the problem you had to face?

Spiral galaxies rotate "too fast" and the rotation does not fall off with distance as occurs with planets. In order to explain this "rotation curve" we resort to the hypothesis that a galaxy has a dark matter halo, which cannot be seen. Dark matter must be some ten times more massive and extend about ten times further than visible matter and its nature is unknown. According to this hypothesis, the most orthodox, we do not know either the mass of the galaxy, or its size or composition.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The rotation of spiral galaxies at large distances from the centre can be derived from kinematic measurements of the galaxy's gas (measured in radio wavelengths). The gas is very ionized. As in laboratory plasma, the movement of this ionized gas modifies the magnetic field and the magnetic field modifies the movement.

We determined that a centripetal magnetic force could explain the rotation. A classical magnetohydrodynamic explanation was used instead of the more exotic ones based on dark matter. The existence of dark matter was not denied, but *it was not* in the galaxies; rather the galaxies were in the dark matter.

Since the paper was published, have there been significant advances in this specific area?

Reactions to this paper were fierce. We had questioned one of the most brilliant hypotheses of modern cosmology. We answered the critics in a more extended paper in a different journal; we wrote an extensive review paper in another one and settled the issue, turning our attention to other research topics.

Since then, there have been important advances. The magnetic field of the Milky Way and other galaxies has been precisely measured. Its distribution is the one that we assumed to explain the rotation. We have just highlighted this in a recent paper.

Despite confirming a prediction made 10 years ago, the dark matter hypothesis still prevails. However, it is acknowledged that the magnetic field cannot be ignored in explanations of the rotation curve of spiral galaxies.

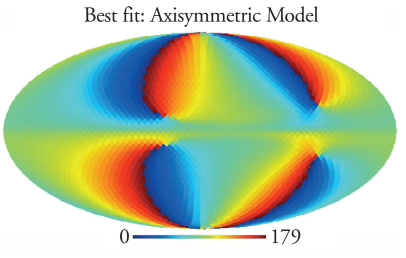


Figure 1. *Predictions of a galactic magnetic field model from Beatriz Ruiz's thesis, directed by J. A. Rubiño and the author.*

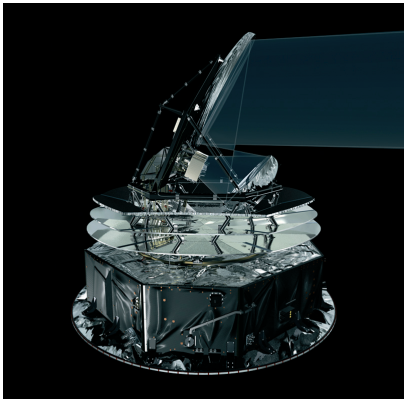


Figure 2. *Image of the Planck observatory, a European Space Agency mission, launched in May 2009, which is allowing us, among other objectives, to gain a deeper knowledge of the magnetic field of our Galaxy.*

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The established hierarchical dark matter models explain many things notably well, but they do not adequately explain the rotation curves of spiral galaxies precisely. The Galaxy's magnetic field is going to be very well determined with two future experiments: Planck (space mission to measure the Cosmic Microwave Background) and the SKA (Square Kilometer Array, a one square kilometre array of radio antennas).

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

As I have already mentioned, I dedicated my attention to other topics. I felt it was better to wait. I have worked in subjects related to magnetism in intergalactic, extragalactic and pre-galactic media. In view of the new measurements of the magnetic field of the Milky Way, we have revisited this area of research recently.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The paper published in *Nature* was signed by Battaner, Garrido, Membrado and Florido. But Garrido, Membrado and Florido were the names of the co-authors; don't think these are undeserved epithets to my person! (Translator's note: Play on words, in Spanish Garrido, Membrado and Florido are surnames but also mean "handsome", "shrewd", and "the elite" or "flowery".)

Magnetic fields as an alternative explanation for the rotation curves of spiral galaxies
E. Battaner, J.L. Garrido, M. Membrado and E. Florido
1992, Nature, 360, 652

Evencio Mediavilla Gradolph
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

Kinematic studies of extended objects, such as galaxies, were done at that time with inappropriate and laborious sequential techniques, such as moving the slit over the object in successive exposures. This method was subject to systematic errors (some very important ones such as differential atmospheric refraction) and to changes in the observational conditions at the time of the exposure (changes of *seeing*, extinction, air mass, etc.). As a result, galaxy velocity maps in the optical were scarce and potentially unreliable.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The solution was to develop a new technique, known as 3D spectroscopy or integral field spectroscopy. This technique decomposes the focal plane into discrete elements (galaxy pieces), transporting and aligning these discrete elements in the spectrograph grating to obtain one spectrum of each surface element of the galaxy. We used optical fibers to make the decomposition, and reformatting of the focal plane. Actually, this solution required a huge amount of laboratory work, building several instruments and prototypes, developing programmes for data reduction and analysis, publishing papers which demonstrated the possibilities of this new, at the time, technique. The publication of the paper about NGC 2237 in the very prestigious journal *Nature* had a demonstrative effect: our instruments and new analysis techniques were innovative and reliable.

Regarding the scientific results, I would like to say that, seen from the present perspective, it was one of the first papers where direct kinematic evidence for galaxy merging were shown, very much in the line of the ideas about the hierarchical formation, although this was not the main approach of the paper.

Since the paper was published, have there been significant advances in this specific area?

At that time, there were three international groups with operational instruments (SILFID, TIGER, HEXAFLEX). The technique belonged to these pioneering groups, of which we were part, and we had to develop every application we needed. Today, almost every telescope is (or is planned to be) equipped with an instrument to perform 3D

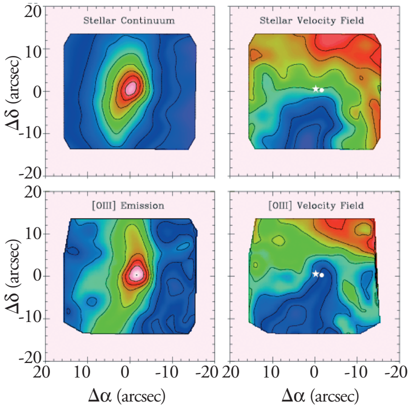


Figure 1. *Velocity and intensity maps of the Seyfert galaxy NGC 5033 obtained with INTEGRAL (it was front page of Astronomy and Astrophysics, vol. 433).*

spectroscopy. For instance, the integral field spectrograph HARMONI has been studied for the E-ELT (European Extremely Large Telescope). We are part of the Spanish contribution to this instrument study.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Actually, 3D spectroscopy has passed from being solely a resource of a very few experts to being a technique widely used, as are CCD imaging or the classical grating spectroscopy. The technique is expected to contribute to making big discoveries in all areas of astrophysics.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Although we have always been very active in this field (now we participate in HARMONI for the E-ELT, as we mentioned above), the truth is that the time when we were starting was very special (the new ideas in the design of the technique could have a global impact).

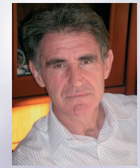
Today, the technique is developed enough and the challenge is to build instruments with better performance. This implies a technological qualification which must be shared by many members of large teams (that I find less motivating).

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The truth is that at that time, our work was a doubly unusual paper for *Nature* as it was based on an instrumental technique, and it was written by a team of solely Spanish researchers.

Evidence for an offset active nucleus in the Seyfert galaxy NGC3227
E. Mediavilla and S. Arribas
1993, Nature, 365, 420

Juan María Marcaide Osoro
Departament d'Astronomia i Astrofísica
Universitat de València



The papers in *Nature* and *Science* in 1995 correspond to two phases of the same research. The first one reports the discovery of the shell-like structure of the radio emission of supernova SN1993J from VLBI observations made on day 239 after explosion, and the second one reports the expansion of that structure over a year -the first supernova expansion "movie" ever. They are complementary.

What was the problem you had to face?

The determination of the emission structure of a radio supernova and its quick temporal evolution, and the comparison of the results with the predictions of the standard model that had been proposed ten years earlier. In other words, our problem was to make the first *movie* of a radio supernova evolution.

We had previously worked, for other purposes, on radio supernovae, but the SN1993J explosion in the galaxy M81 offered a unique opportunity. The emission was relatively strong and the distance to the supernova was relatively small.

We could resolve its spatial structure. We quickly realized that it could be observed for more than a decade and its evolution with time could be accurately determined... a luxury!

What was the solution to this problem and the contribution these papers made to the area of expertise in which it is framed?

International resources to carry out this research were only available in competition for just one instrument (the global Very Long Baseline Interferometry Network, Global VLBI Network). Two large international teams were formed and the competition was fierce. The time allocation committees finally decided to share the resources between the groups in a fair way, each time demanding results to each of the teams. Working from Spain, at the beginning the most difficult thing was to remain in the race without being thrown out. The other team, with more American members (ours was more European rooted, but both had scientists from many countries) was a powerful one. The only way for us to survive was to succeed making the key contributions before them.

We worked hard and were lucky. These papers showed the self-similar evolution of a spherical shell structure. They confirmed the standard model and the scientific contributions were unique. Together with another paper in 1997 where we presented the deceleration of the expansion, they

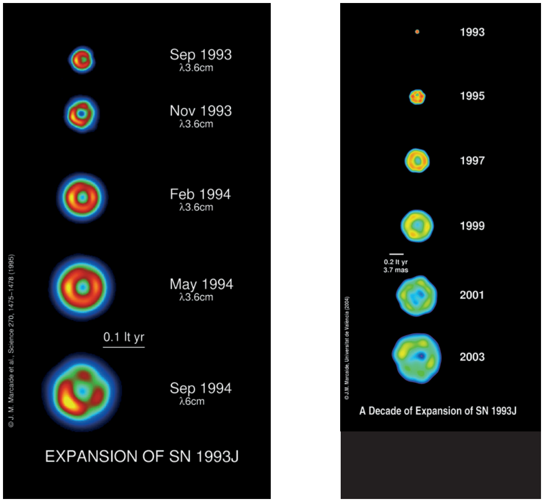


Figure 1. *Evolution of the expansion of supernova SN1993J over a decade.*

were the best contributions in this research field. The other group started to publish their contributions around the year 2000 (some of them contradict our more recent results). Before then, and probably after, we led this research.

Since the papers were published, have there been significant advances in this specific area?

Since then, we have been working tirelessly trying to understand subtle details of the expansion of the supernova. We have also tried to understand how the emission that we observe is generated. We have done more than 30 observations with the Global VLBI Network over 14 years. The other team has done a similar amount. Eventually we have analyzed the whole set of 69 observing epochs.

In my opinion the most significant advance took place when we discovered (published in 2009) that the expansion appears to be slightly different when observed at 6 cm and 18 cm. We found that there are instrumental and physical effects which make the measured expansion to be not exactly the same using 6 cm and 18 cm wavelengths. Nobody had thought of this before. It also showed that the other team may not have performed the analysis correctly as they have not detected this effect. Numerical simulations of the radiosupernova emission, absorption by the ejecta, and instrumental effects are capable of explaining not only the discovery but can also simultaneously (and wonderfully) fit the radio light curves and the VLBI results.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

This field of Astrophysics has a fundamental problem: Radio supernovae explode either too far away or they are not strong enough microwave emitters to be able to study them in detail, despite of using the largest radio telescopes in the world.

Therefore, it has only been possible to study very few supernovae, less than a dozen in total, and none with the detail of SN1993J.

How did they influence your professional career? Have you continued in that line of work? Have they opened new perspectives or later did you dedicate yourself to other topics?

I had previously written scientific contributions in other areas (quasars, active galactic nuclei, graviational lenses, Galactic Centre, astrometry, etc. I had even published in *Nature* and *Science* four times before returning to Spain.) Almost all of these publications had the common denominator of the use of the VLBI technique. This VLBI research on the supernova SN1993J led me towards radio supernovae studies. I am still actively pursuing this type of research.

Do you have any anecdote related to these papers' gestation and publication that you think is worth telling?

Perhaps the best one happened at the very beginning I almost missed all the options to lead this research because for more than a week I did not hear about the SN1993J explosion. I had practically been locked-up at home, for almost a week, correcting from beginning to end the first draft of a PhD thesis of one of my students. I learned about the event when I saw a photograph in *El País* newspaper. I immediately called a Dutch colleague who confirmed to me that radio emission had been detected that very same night in Cambridge. That was our starting point. The fact that the microwave emission is always delayed with respect to the visible emission was very helful for me this time. Well, maybe I took the corrections of that PhD thesis draft too seriously. Naturally, we managed to get the resources because important colleagues fully supported our innitiative. I am very grateful to them. During the gestation and publication no anecdotes happened that are worth mentioning. Perhaps I could mention a little one. Before the image of the supernova expansion came out in *Science,* Sir Martin Rees had already included it in his last book *Gravity's Fatal Attraction* of the collection Scientific American. I had informally passed the image to him during a visit of mine to the Institute of Astronomy in Cambridge, and he asked me then if he could use it (he did not tell me what for). I told him that he could and that I was expecting to see it soon in *Science.* We almost had a *copyright* conflict! Kidding.

Discovery of Shell-Like Radio-Structure in Supernova 1993J
J.M. Marcaide, A. Alberdi, E. Ros, P. Diamond and 19 co-authors
1995, Nature, 373, 44

Expansion of Supernova 1993J
J.M. Marcaide, A. Alberdi, E. Ros, P. Diamond and 11 co-authors
1995, Science, 270, 1475

Vicent Martínez García
Observatori Astronòmic
Universitat de València

What was the problem you had to face?

It is known, since Edwin Hubble's first observations in the thirties, that galaxies are not randomly distributed. Already in the eighties, the first three-dimensional galactic surveys were carried out. That is to say, those, which besides the position of the galaxies in the celestial sphere contain information about their distances (measured from its redshift). These three-dimensional maps of the cosmic macrostructure traced by the distribution of galaxies show a texture characterized by large filaments, galactic clusters and superclusters, flat structures like big walls, which delimit regions apparently empty of luminous matter. This *cosmic web* can be characterized, at scales which are not too large, by its fractal structure. On average, the number of galaxies in a sphere of radius r centred on a given galaxy grows proportionally as r raised to a certain exponent which we call *correlation dimension.* For the distribution of galaxies and a significan range of scales, this dimension is approximately 2, a value that is significantly different from 3 which would be expected for a homogeneous distribution (in that case the number of galaxies would grow proportionally with the volume of the sphere). On the other hand, present cosmology is based in the Cosmological Principle which states that the large-scale Universe must be homogeneous (there are no preferred locations) and isotropic (there are no preferred directions). In this paper we tried to solve the problem of the determination of the scale at which the transition from a fractal regime to a more homogeneous distribution of galaxies in space is observed.

What was the solution to this problem and the contribution these papers made to the area of expertise in which it is framed?

At the time when the 1999 *Science* paper was published there was a certain debate within the scientific community about the fractal nature of galaxy distribution at small scales and the existence of a limit at larger scales. A group of scientists maintained that, with the observational data available, the fractal structure did not seem to break and, therefore, no transition to homogeneity was observed.

The paper proved that, even though galactic surveys were not yet large enough, a gradual transition to a homogeneous distribution of the

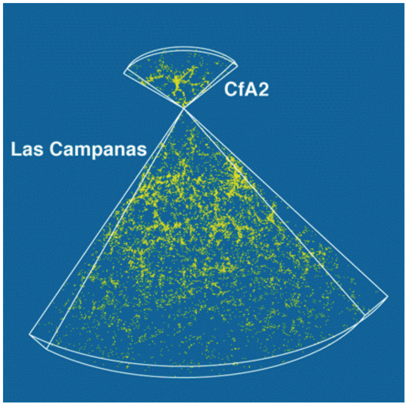


Figure 1. Distribution of galaxies in two sectors of the sky centred on the Earth. The deepest sector (the one below) reaches a distance of 3,000 million light-years. The dots represent the position of 13,000 galaxies. Structures like filaments, walls and voids can be observed in both sectors but the size of these structures is not larger in the deeper slice, as it would be expected in a fractal structure.

luminous matter was already evident at scales of the order of 200 million light-years.

Since the papers were published, have there been significant advances in this specific area?

Certainly, much deeper galactic surveys have been completed since, covering very wide regions of the sky which contain hundreds of thousands of galaxies. The two most important are: The 2-*degree field redshift survey* made with the multi-object spectrograph at the 3.9 m Anglo-Australian telescope and the *Sloan Digital Sky Survey* made with a dedicated 2.5 m telescope in New Mexico. Both galaxy catalogues have been used to corroborate the gradual transition to a more homogeneous distribution at the scales predicted in my paper in *Science.* In fact, if we statistically study the clustering of galaxies by means of a two-point correlation function, the latter shows that the fractal behaviour at small scales disappears at larger ones; it has been even possible to prove the existence of a peak (a small local maximum, called acoustic peak) at scales close to 500 million light-years which agree fairly well with the theories of cosmic structure formation.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

One of the fundamental problems is the precise measurement of the acoustic peak I mentioned in the previous question. The position of this peak determines a characteristic distance whose precise measurement can give very valuable information about the nature of what cosmologists have called *dark energy,* thought to be the dominant component of matter and energy in the Universe (70% would be dark energy) that would be responsible for the acceleration of the cosmic expansion observed today. Projects such as PAU *(Physics of the Accelerating Universe),* with the objective to construct a survey of more than 200 million galaxies using photometric techniques, can contribute to the solution of this enigmatic energy.

Undoubtedly, another fundamental problem would be to know the details of cosmic evolution, in other words, how the distribution of matter at different epochs since its formation gives us information about the physical processes which took place. The ALHAMBRA survey, made with the 3.5 m telescope at Calar Alto, has this scientific objective; it will cover a sky area equivalent to 20 times that of the full Moon, but it will have an unparalleled depth for such a large area.

How did they influence your professional career? Have you continued in that line of work? Have they opened new perspectives or later did you dedicate yourself to other topics?

The 1995 paper in *Science* was the completion of an intensive period of activity that I had started with my thesis. I keep on working on the study of the large-scale structure of the Universe but I have also been interested in other problems such as the extension of dark matter halos surrounding elliptical galaxies, cosmic evolution, the nature of dark energy through the study of baryonic oscillations, the detection and morphological characterisation of larger cosmic structures: filaments and galactic superclusters, etc.

Do you have any anecdote related to these papers' gestation and publication that you think is worth telling?

Yes, I have an interesting one concerning the 1999 paper. The *Science* editor sent, as it always does, the paper to two different referees. Both were very positive but one of them mentioned in his report that *Nature* had recently published a similar paper. One of its authors was the British Royal Astronomer Sir Martin Rees *(The large scale smoothness of the universe,* Wu, Lahav and Rees, 1999, *Nature,* 397, 225). The paper cited my previous works. But due to this fact, the editor of *Science* chose not to publish my new paper in the journal. Of course I accepted the decision, although I thought that my contributions were different and in a sense, more convincing. During those weeks

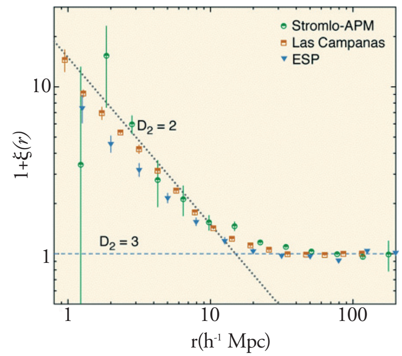


Figure 2. *The correlation function of galaxies for different surveys shows a gradual transition from a fractal regime with a correlation dimension of 2, to a homogeneous distribution with a correlation dimension of 3.*

I was in touch with my British colleague, Professor Peter Coles. When I told him what had happened he asked me a few details, for example the name of the editor who was responsible for the decision. Later, I learnt that he wrote to her, identifying himself as the referee of the paper published in *Nature*, stating that in his opinion, my paper deserved to be published in *Science* because of its contribution to the field. The editor sent Peter Coles' letter to the original referees of my paper asking them to check both and give a considered opinion about publishing my paper in *Science.* Both answers were favourable and, finally, the paper was published.

Multiscaling properties of large scale structure in the Universe
V.J. Martínez, S. Paredes, S. Borgani and P. Coles
1995, Science, 269, 1245

Is the Universe fractal?
V.J. Martínez
1999, Science, 284, 445

Francisco J. Castander Serentill
Institut de Ciències de l'Espai
(CSIC-IEEC, Barcelona)

What was the problem you had to face?

The paper was published in the middle of the nineties. At the time, we already had an idea of how galaxies and galaxy clusters had formed. Galaxy clusters are the largest structures observed and the evolution of their abundance depends considerably on the constituents of the universe, and in particular, on the amount of existing mass. The observational measure of the mass in the universe was one of the most important questions at the time since it is a parameter which determines the geometry and global evolution of the cosmos.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Galaxy clusters, and especially the evolution of their abundance, are fundamental for the study of the universe. Clusters are formed by galaxies, hot gas and dark matter. Traditionally, clusters were detected by searching for overabundance of galaxies, which is not a very reliable method. With the arrival of X-ray satellites it was possible to start detecting clusters through the X-ray emission of the hot gas they contain. The first results showed a fast evolution in the number of clusters, compared with what was expected. Our work was the first to use data from a new X-ray satellite ROSAT, launched in 1990, to study the evolution of cluster abundance. We found that the evolution in the number of clusters was inconsistent with the predictions based solely on gravitation and we highlighted the need to understand the behaviour of hot gas to be able to use clusters for the study of the universe.

Since the paper was published, have there been significant advances in this specific area?

Since our paper was published, this topic has experienced great advances. On the one hand, the ROSAT satellite continued to obtain data and in subsequent years it was possible to analyse many more observations and to increase the number of clusters studied.

Later, in 1999, two new X-ray satellites were launched, XMM-Newton and Chandra, that to date are providing high quality data, which allow us to study in detail galaxy clusters and the evolution of their populations. Together with other cosmological probes like the Cosmic Microwave Background (CMB) and supernovae, the clustering of galaxies allows us to know quite precisely the composition of the universe and its geometry.

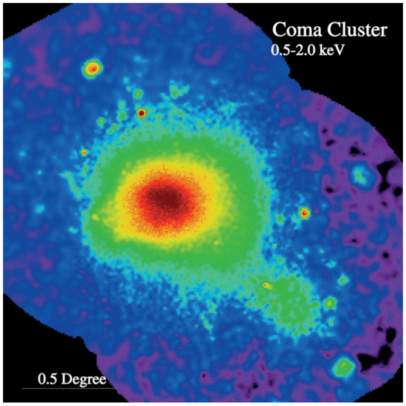


Figure 1. *False-colour image of the X-ray emission from the gas in the Coma galaxy cluster.*

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Today we know that our universe comprises approximately 5% ordinary matter, 20% dark matter and 75% dark energy, which is accelerating the expansion of the universe. Understanding dark matter and dark energy is one of the challenges of modern cosmology. During the last years, large projects are being designed and developed to analyse this problem with different observational techniques. One of them is the study of galaxy clusters. This will be done with images in the visible wavelength range and with hot gas studies in the radio and X-rays. In particular, a new X-ray satellite that will study the evolution of galaxy clusters in more detail is planned to be launched.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I believe that the publication of this paper at the end of my thesis enabled me to successfully obtain post-doctoral positions, especially the first one that allowed me to continue my career in research. Since then, as well as galaxy clusters, I have worked on other topics as the evolution of galaxies, gravitational lensing, the cosmic X-ray background radiation, Gamma-ray bursts, but always with the common aim of understanding the structure and evolution of the Universe. Now, I am involved in large observational cosmology projects to study dark matter and dark energy, using different techniques, including galaxy clusters.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

We wrote this paper during the last year of my PhD in Cambridge. During the phase of external editing, I was doing the compulsory military service. When I did not have to be in barracks, I was going to work at LAEFF (Laboratorio de Astrofísica Espacial y Física Fundamental) in Madrid, to make corrections and modifications to my paper. I have always been grateful to them for their hospitality.

Deficit of distant X-ray-emitting galaxy clusters and implications for cluster evolution
F.J. Castander, R.G. Bower, R.S. Ellis, A. Aragón-Salamanca and 7 co-authors
1995, Nature, 377, 39

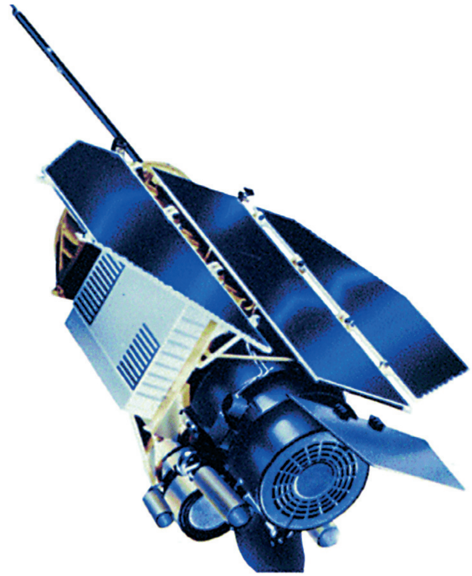


Figure 2. *ROSAT is an acronym for Röentgen Satellite. This space mission provided a fundamental advance in our knowledge of the X-ray sky.*

Rafael Rebolo López
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

Proving the existence of brown dwarfs, intermediate bodies between stars and giant planets. These dwarfs are similar in size to Jupiter, but according to theory, they would be about 10 and 70 times denser.

Already in the 1960s, there was speculation about the existence of these objects; there were several good candidates but none of them was conclusive. We knew that if brown dwarfs were very numerous in the Galaxy they could contribute to dark matter.

This was one of the motivations to search for them. It was also hoped that they had atmospheric characteristics similar to those of giant planets and, therefore, the detection of these characteristics could help us in the direct detection of exoplanets at a time when we did not know if either of these existed.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The paper in *Nature* proved the existence of brown dwarfs in the Pleiades Star Cluster, a region where there had been many searches before but they were unable to reach objects with luminosities and temperatures that are sufficiently low as to conclude that the hydrogen burning limit had been crossed, this is the limit that separates stars from brown dwarfs. Most of the previous searches were done using V and I filters but we decided to use the R and I filters, based on what we expected from the spectral energy distribution of massive brown dwarfs in the cluster. The first object we found with characteristics typical of a brown dwarf, named Teide Pléyades 1, had a spectral energy distribution consistent with a spectral type of M8 and a proper motion consistent with that of the Pleiades stars. Using substellar evolution models, we concluded that their characteristics could only be understood if it was an object with a mass lower than 65 times the mass of Jupiter, that is, a brown dwarf. Based on the statistics that we obtained, we could already state in this work that in the Pleiades cluster there could be hundreds of these objects and thousands of them in the Galaxy.

Since the paper was published, have there been significant advances in this specific area?

There have been enormous advances. Some months later, the discovery and

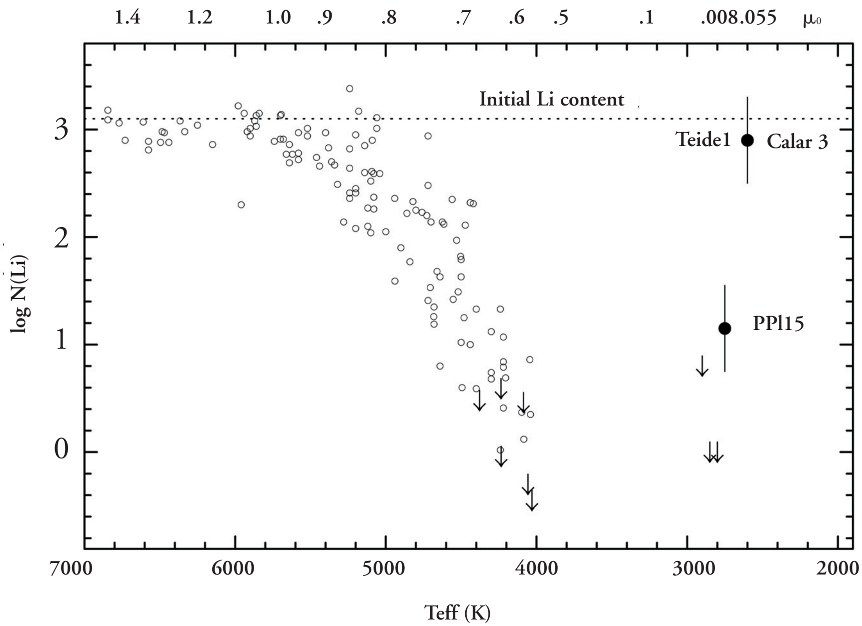


Figure 1. Brown dwarfs Pleiades Teide 1 and Calar 3 (discovered a few months later) have preserved their initial lithium content. Each symbol shows the lithium abundance of an object (in a logarithmic scale) versus the temperature of its atmosphere. It can be seen how the stars of the Pleiades cluster with masses below that of the Sun have depleted their lithium content according to their mass, the smaller the mass the larger the depletion. In the stellar interiors, lithium nuclei are destroyed via proton collisions at a very high temperature and this can be drastic in lower-mass stars. However, it was expected that the brown dwarfs of the cluster had a very different behaviour since they should not reach the necessary temperature for those collisions to break lithium nuclei. Spectroscopic observations carried out with the Keck telescope in November 1995 revealed that both Teide 1 and Calar 3, the least luminous objects found in the Pleiades up to that date, confirmed what was expected for bona fide brown dwarfs.

detection of the next brown dwarf was also published in *Nature*. This was identified as Gl 229 B, in this case the first brown dwarf orbiting a star. Our group identified other similar objects to Teide 1 in the Pleiades. The following year, we already had an indication of the mass function in the cluster that effectively indicated that there were hundreds of these objects in the Pleiades. Presently we know several dozens and more are being discovered. The brown dwarf mass function has been determined today in many clusters and in the solar neighbourhood. The evidence of the existence of thousands of millions of brown dwarfs in the Galaxy is conclusive; there could even be as many as stars.

Our group led the discovery of brown dwarfs with increasingly low masses, detecting the first free-floating planetary-mass objects in stellar clusters like the one in the Sigma Orionis star cluster. We also discovered the second brown dwarf orbiting a star, G 196-3B (published in *Science* in 1998); at that time this object, with a mass 25 times the mass of Jupiter, was the least massive substellar object known.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Establishing how far down the mass function the substellar domain extends, that is, the masses of the smallest objects that result from the fragmentation of the clouds of interstellar material. In other words, are there free-floating super-Jupiters in the interstellar space?

Another problem of great interest is the detection of low-temperature brown dwarfs; there must be hundreds in the solar neighbourhood with atmospheric temperatures between 300 and 500 Kelvin. We haven't discovered them yet. Detecting these objects is an extraordinary challenge, we will learn a lot about atmospheres in a very poorly explored domain which overlaps with the one of planet temperatures like Venus and the Earth.

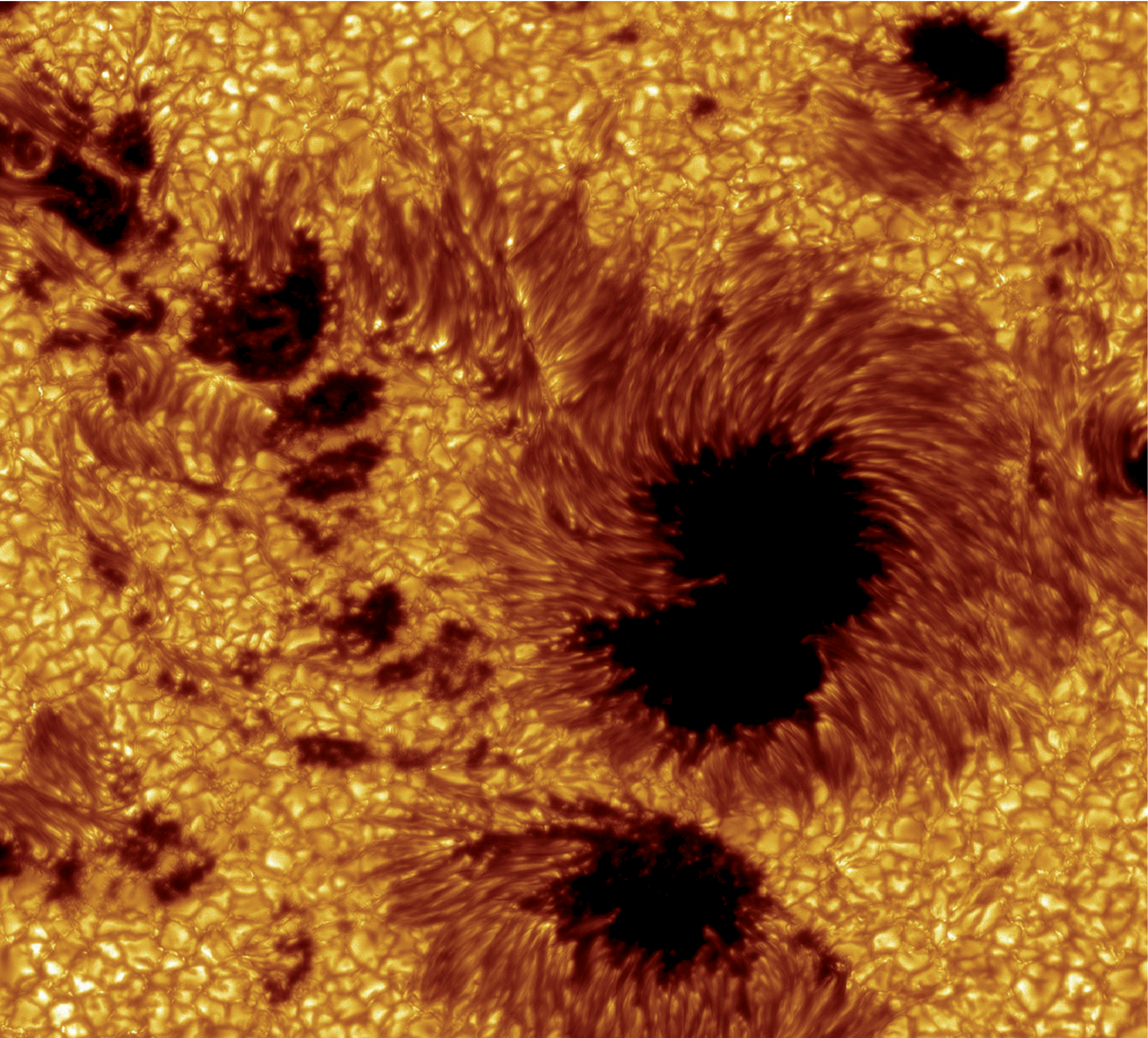
How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

It had an important influence. This work was crucial for the formation of a research group on brown dwarfs at IAC. This group has produced dozens of papers that sum up thousands of citations and it continues to be very active. I am proud that the research of the group members is recognised at an international level. In the last years we are directing our research towards the area of exoplanets with the aim of detecting Earth-like planets around other stars.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

We discovered the object with the 80 cm IAC80 telescope at the beginning of 1994; at the end of that year we were able to obtain the spectrum that confirmed its nature with the 4.2 m William Herschel telescope. We sent the paper for publication to *Nature* in May 1995 and we needed several months to convince the referees that we had discovered a new class of objects. Finally, it was published on 14 September 1995. *Nature* wrote at the front page *"Brown dwarfs exist - official"*.

Discovery of a Brown Dwarf in the Pleiades Star Cluster
R. Rebolo, M.R. Zapatero-Osorio and E.L. Martín
1995, Nature, 377, 129



Carlos Westendorp Plaza
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

Trying to understand the manifestation on the solar surface of the magnetic field generated in the Sun's interior was, and still is, a big challenge. The enigma that we call "sunspots" that was already known in ancient China led us to question our understanding of the "measurement" concept in Physics. There are so many interacting phenomena (plasma, convection movements, richness of the magnetic field structures and all with supersonic velocities of unknown origin and direction) that it is impossible to study one without understanding the whole. Some excellent sunspot observations that provided a lot of detailed information enabled us to take a step forward from the traditional methods. The complex external filamentary structure of the spot, called the *penumbra,* was the area where these phenomena converge and where we were able to obtain new results.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Through the result of Basilio Ruiz Cobo's thesis and his later work, we managed to develop a computer program which is used all over the world. I was very lucky to be able to apply this code to the observations Valentín Martínez Pillet brought from the USA and with Jose Carlos del Toro Iniesta's energy and inspiration, we obtained the first in-depth view of a sunspot in all its splendour. It revealed the complexity of the magnetic field over the solar surface, together with velocities that showed that they followed the magnetic field and looped back down to the Sun's interior. This was expected but no one had been previously able to deduce this from observations until then.

Since the paper was published, have there been significant advances in this specific area?

After consulting experts like Basilio and Valentín, they confirmed that the study of the sunspot penumbra has aroused an enormous interest in recent years. Initially, it was due to the discovery that the bright penumbral filaments present a central darkening (or "dark-core") in 2002, using observations from the new Swedish Solar Tower. Many groups worked on the problem to find a physical explanation for the phenomenon. It was thought to be very closely related to the structure of the filaments and the velocity field which constitutes the

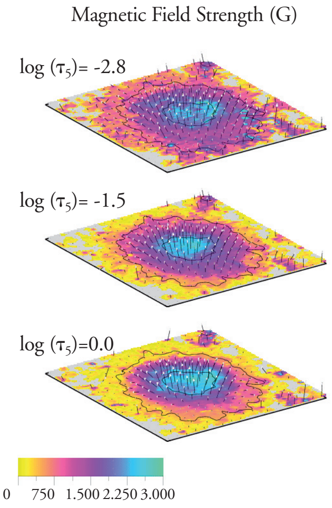


Figure 1. Intensity of the magnetic field, colour coded, for three photospheric layers of a sunspot, from the deepest to the most superficial. The arrows show the magnetic field vector (intensity, zenithal angle and azimuth). The dark lines show the limits the umbra/penumbra and the sunspot with the surrounding Sun in calm.

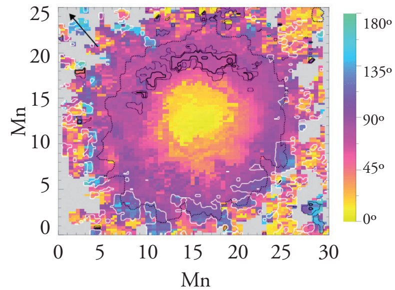


Figure 2. Map of the magnetic field inclination in a typical sunspot (colour coded), close to the centre of the disk (direction indicted by the arrow). Velocities are represented by continuous contour lines (in black towards the observer, in white they move away from the observer). It shows how velocities are detected moving away from the observer before the end of the sunspot (dotted line) and where the field is horizontal or even loops back onto the surface (it shows more than 90º with respect to the horizontal axis).

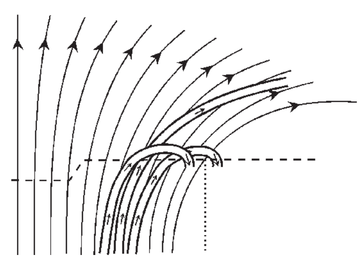


Figure 3. Simplified representation of the suggested structure of the penumbra and the velocity flux (Evershed effect).

so-called *Evershed flow* (named after the discoverer in 1909). Finally, two possible scenarios have prevailed: The *uncombed* scenario in which the Evershed flow is produced through more horizontal tubes and with a weaker field strength embedded in a more vertical and intense field, and the *gappy* scenario, where the bright filaments would be the observational counterpart of convective penetrations in the penumbra. Both models seem to partially explain the observational properties. The uncombed model seems to fit the results on the spectropolarimetric inversions better, with the presence of a non-zero net circular polarisation and with the Evershed flow. The gappy model seems to explain the brightness of the penumbra more easily.

Additionally, the study of the magnetic fields in the moat (the region surrounding the spots) and the plasma velocities in those areas have confirmed the discoveries we published in our paper, in the sense that movements of materials in sea-serpent-like structures are observed, which are nothing more than the extension of penumbral filaments.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The main problems in this field continue to be the clarification of the structure of penumbral filaments and their relationship with both the Evershed flow and the brightness of the penumbra. There is also the question of the MMF *(moving magnetic features)* and their connection with the penumbra and the magnetic flux elimination mechanisms of the spot. We also need to find an explanation for the structure and dynamics of the umbral dots and *umbral flashes,* as well as the distribution of sunspots and the *dynamo mechanism* (oscillation in the Sun's magnetic field).

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I learnt how the efforts of a great and well balanced team can bring a reward, as well as that in science, you need to be good but you also have to seem to be good. Unfortunately, for this you have to publish in magazines where the scientific interest is not the most important thing, as confirmed recently in *Nature* where they do not seem to be interested in Solar Physics because it does not provide them with a high number of citations. It is still a hard work to reach the public, to whom we undoubtedly should dedicate more economical and human resources as it is an inherent part of our work.

The impact of this work also made more difficult the decision I had taken before finishing my thesis to change my career path to my other passion of informatics. Working close to the people who made it possible and knowing that the work is still cited in international conferences and that some of my colleagues are still working on it gives me a great satisfaction.

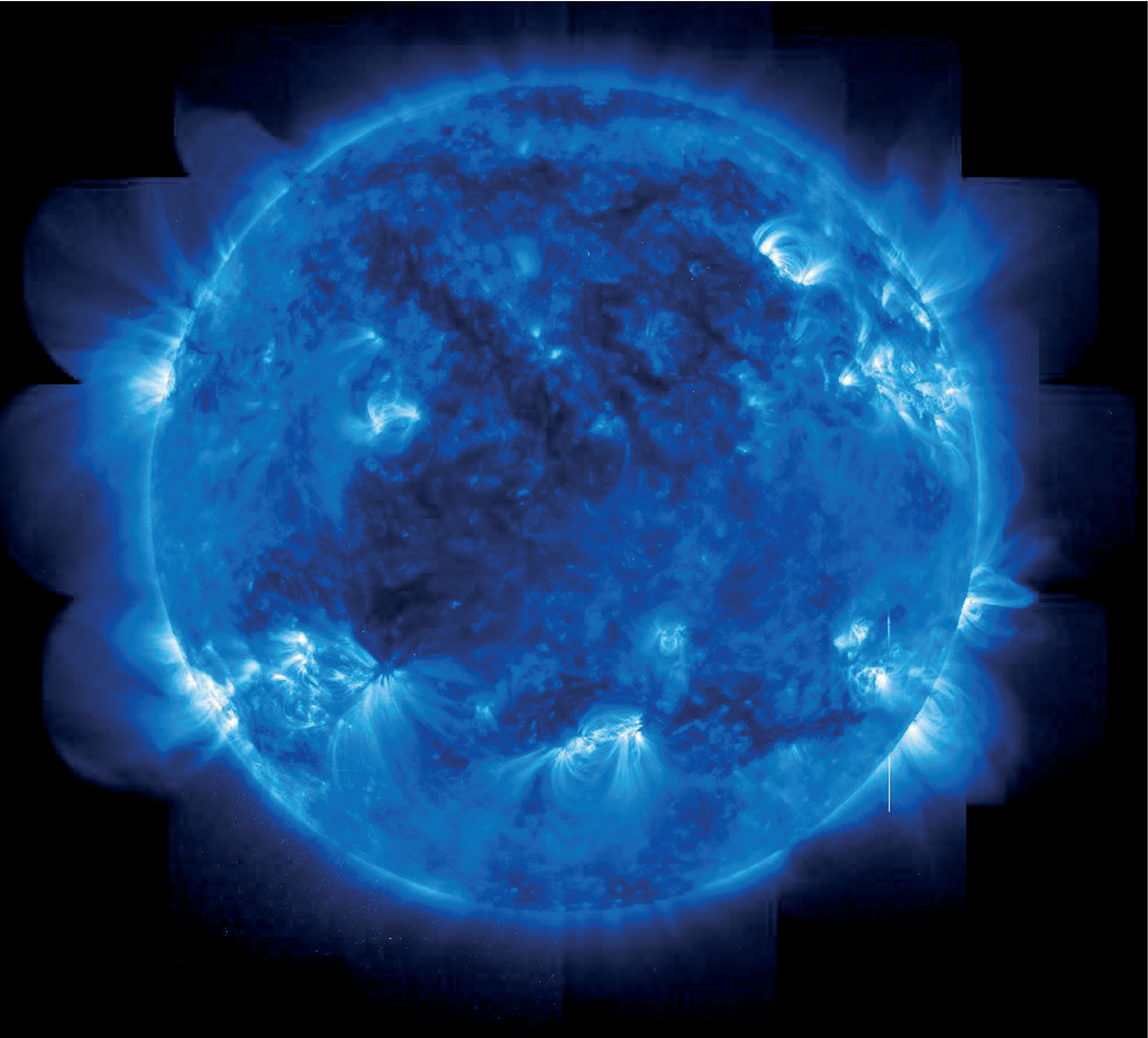
Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Although the results were known by the international scientific community, it was only after the publication of this paper that we were contacted by the mass media. When some of them came to the institute, in front of a TV camera and with a microphone, I had to answer the question: "…but, what have you discovered?" Trying to explain all the work behind a process which took several years, especially taking into account not only the years in which I participated but all the previous work that constituted the base of this result, was a really big challenge. Actually, more than a "discovery", if this result was a milestone (and it seems that time is proving it to be), the important thing is that it represents the success of a good team.

Evidence for a downward mass flux in the penumbral region of a sunspot

C. Westendorp, J.C. Del Toro Iniesta, B. Ruiz Cobo, V. Martínez Pillet, B.W. Lites and A. Skumanish

1997, Nature, 389, 47



Benjamín Montesinos Comino
Centro de Astrobiología (CSIC-INTA, Madrid)

What was the problem you had to face?

In 1909 the British astronomer John Evershed (1864-1956), who was at the Kodaikanal Solar Observatory in India, discovered that the spectral lines originated in the penumbral filaments of sunspots were not at their rest positions but showed a Doppler shift.

The displacement of the spectral lines from their normal positions indicate that the material producing them is moving towards us if the shift is towards the blue, or moving away from us if the shift is towards the red. This phenomenon observed in the filaments was called "Evershed effect" and was interpreted as a mass flow in the penumbra of sunspots, from the regions close to the sunspot umbra (the darker central part) towards the outer parts; this flow is called "Evershed flow".

At the beginning of the nineties there was no satisfactory explanation for this phenomenon, and after some preparatory work, John H. Thomas and I decided to propose a plausible model that explained the observed features of this phenomenon and predicted some others.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The solution to the problem lies in what is known as "siphon flows" in thin magnetic flux tubes. Basically, this model assumes that sunspot penumbral filaments act like magnetic flux tubes which channel gas flows. If the pressure in one of the footpoints of the tube is lower than at the other footpoint, the gas will flow from the regions with higher pressure to the regions with lower pressure. This works in a similar way to when we want to empty a liquid container with a thin tube: to start emptying it out we suck from one end while the other one is submerged in the liquid. This explanation, which seems qualitatively logic and simple, is extremely complicated to manage from the numerical modelling point of view, as it requires the simulation of the various phenomena, stresses, pressures, etc., that a flux tube (the penumbral filament) suffers submerged in a magnetized atmosphere (the magnetic field of the spot). Basically, our work was the first one that managed to successfully explain many of the features of the Evershed flow (velocities, densities, magnetic fields, lengths, shapes and heights of the tubes).

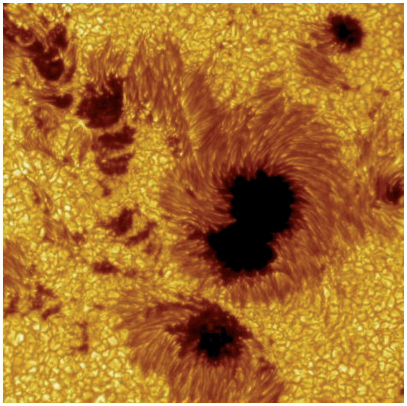


Figure 1. Sunspots showing the umbra and penumbral filaments well differentiated with respect to the photospheric granulation. Courtesy of the Royal Swedish Academy of Sciences.

Since the paper was published, have there been significant advances in this specific area?

In the last decade there have been considerable observational advances which are contributing towards a better knowledge of this phenomenon. One of the fundamental challenges of solar observations is to obtain the best possible spatial resolution, that is, to try to discriminate the properties of a given phenomenon in increasingly small surface elements. Recently, observations of the Evershed effect have been obtained with a resolution of 0.2 arc seconds using the Solar Telescope of the Royal Swedish Academy of Sciences, at the Roque de los Muchachos Observatory, and the Japanese space observatory Hinode has provided data of the small scale structure of this mass flow. From the theoretical point of view there have been advances in the interpretation of the time variations of the Evershed effect: our model is steady, that is, the equations that describe the phenomenon do not depend on time and, in the years following the publication of this paper in *Nature,* several interpretations arose attempting to reproduce the observed timescales in the flow behaviour.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Despite being the closest star to us —or precisely for this reason!— there are many phenomena, not only in the sunspots but globally in the entire Sun, that need a theoretical model which is still incomplete. On the other hand, observations become of increasing better quality and that helps to put strong constraints on the theoretical developments.

In the specific field of sunspots, helioseismology (the study of solar oscillations) is providing data regarding the structure of sunspots below the photosphere and that will help us to better understand the complex energy balance mechanisms.

If we consider the Sun globally, I think there are two intricate and difficult problems, although little by little progress is being made based on the established models: The first one is coronal heating and the second one is the origin of solar cycles. The fact that in both cases three-dimensional models are needed and that they have to include complex magnetohydrodynamic formalisms and nonlinear physics make these problems extremely hard to tackle.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Obviously all the work I did together with Professor Thomas has been very important for my professional career. It opened a new area of research and I learnt a lot, both in the theoretical aspects and in the field of numerical calculations associated with the solution of this problem. After the publication of this paper in *Nature,* which for us really finalised the problem, I have not continued working on this specific issue, but in an area within the so-called "Solar-stellar connection" which is the modelling of the activity cycles observed over the last four decades in about 30 solar-type stars; these cycles are similar to the 11-year cycle of the Sun. Currently, my research is almost centred in the physics of young stars (between 1 to 10 million years) with protoplanetary disks made of gas and dust, and of older main-sequence stars surrounded by debris disks.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I started to work on this area by chance. In 1988 I was working on other issues with a post-doctoral contract at the Physics Department at Oxford University. That year John H. Thomas (Jack), a professor from Rochester University (New York), arrived to join our group for a sabbatical stay. After talking one day, we started to do some simple calculations about the mass flow behaviour in thin magnetic tubes.

From there we started a collaboration, which lasts until today. The simple calculation we performed in 1988 was becoming more and more complicated and culminated in 1997 with the publication of the

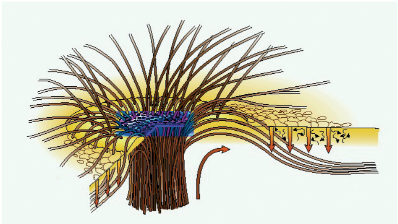


Figure 2. *Sketch of the filamentary structure of a sunspot. The umbra is modelled as a thin magnetic tube bundle and the penumbral filaments are extensions of those tubes which emerge over the photosphere. The Evershed flow would be channelled through those thin filaments.*

paper in *Nature.* As it can be seen, the gestation lasted almost 10 years! I was surprised to be able to publish a paper in *Nature* that was essentially theoretical, although the model was successfully compared to observations. In any case, it gave a satisfactory answer to a problem that had remained unresolved for 90 yeas and perhaps, this was the important fact when the journal accepted this paper.

From the beginning of the collaboration with Jack, I started a friendship with him and his family, which for me is as important as our scientific interaction. I have visited Rochester several times and I have always found hospitality at Thomas' home. I went to visit the Niagara Falls for the first time with them, to buy products to an *Amish* community in the state of New York, I learnt how to sail in a small boat and to water-ski at the Keuka Lake. Jack and his wife have also visited me in Spain and I will not forget their astonishment when they saw the Alhambra, the Alcázar de Sevilla, the Mezquita de Córdoba... and obviously, the Easter processions during a trip to Andalucía in1993.

The Evershed effect in sunspots as a siphon flow along a magnetic flux tube
B. Montesinos and J.H. Thomas
1997, Nature, 390, 485

Ramón Oliver Herrero
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Universitat de les Illes Balears
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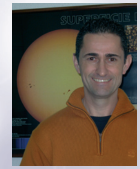


What was the problem you had to face?

Flares are explosive phenomena occurring in the solar atmosphere that release energy and particles which propagate through the interplanetary medium. Particles ejected in very energetic flares reach the Earth producing the Aurora Borealis and causing damage to the electrical equipment onboard satellites orbiting the Earth. Between 1980 and 1984, the Solar Maximum Mission satellite observed that the number of high-energy flares increased every five months, although the mechanism that triggered this periodical increase was unknown. Likewise, this periodicity appeared during the maximum of the solar activity cycle (11-year cycle during which the number of different phenomena such as sunspots or flares varies). Therefore, the problem was: why do high-energy flares show this periodicity? Why does this periodicity coincide with the maximum of solar activity?

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

A previous study on the behaviour of sunspot regions carried out by our group concluded that they also showed a five-month periodicity. Since the area of a sunspot is directly related to the amount of magnetic flux that originates in the Sun's interior and emerges through the surface, the probable cause of the periodic nature of solar flares is the periodic emergence of magnetic flux causing reconnections with the existing one, thus stimulating an increase in the number of flares.

Using *wavelets,* which enable the precise determination of the time and frequency of a phenomenon, we proved unmistakably that during 1980-1984 the periodicity seen in flares was also simultaneously seen in sunspot areas. This work provided the first explanation of the reason for this periodicity, leaving open the question of why the magnetic flux emerged periodically near the solar activity maximum.

Since the paper was published, have there been significant advances in this specific area?

After the publication, we analysed the available data on the photospheric magnetic flux and verified the exact correlation between the periodic impulses of magnetic

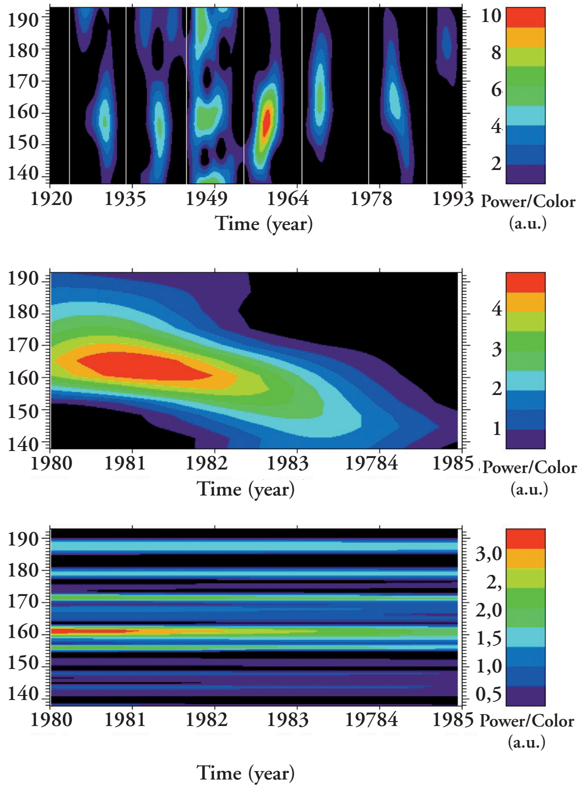


Figure 1. Wavelet analysis of the sunspot area time series. The year is indicated in the horizontal axis and the period in the vertical axis. An intense periodicity in a specific moment of time is shown as a red-colour spot in the corresponding year and period. Upper image: White vertical lines show the solar activity minimum epochs. The 160-day periodicity appears significantly near the maxima of cycles 16 to 21. Middle image: Zoom-in of the period 1980-1985 showing the time interval, around the maximum of cycle 21, where the periodicity is evident. Lower image: Precise determination of the period.

flux and flares, unmistakably confirming their correspondence. This periodicity has also been detected, with more or less intensity, around some of the maxima of the subsequent solar activity cycles. Some theoretical explanations of why the magnetic flux emerges in a periodical way have been proposed but they are not convincing.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The fundamental problem is to obtain a perfect understanding of the way the magnetic flux emerges from the Sun. Presently, and thanks to the availability of supercomputers, numerical codes and visualization tools, it is possible to carry out highly sophisticated numerical simulations to understand the emergence process from the convection zone to the corona.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

After the publication of this paper we have continued working in this and other lines of work. Recently we have obtained some theoretical results which allowed us to explain the periodic emergence of magnetic flux from the *tachocline* (a very thin layer in the Sun's interior which seems to be directly related to the generation of the magnetic field emerging through the photosphere) and why this emergence appears predominantly around the maximum of solar activity.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

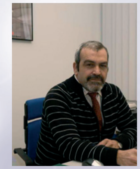
The hypothesis at the basis of our work was formulated around 1990, but the lack or ignorance of a suitable technique, i.e. the *wavelet* analysis, prevented us from testing the veracity of the hypothesis. Finally, in 1998 we were able to use an analysis program based on *wavelets* that allowed us to confirm this hypothesis. We also believe that it was one of the first wavelets analysis applications to a solar physics problem.

Emergence of magnetic flux on the Sun as the cause of a 158- day periodicity in sunspot areas

R. Oliver, J.L. Ballester and F. Baudin

1998, Nature, 394, 552

José Cernicharo Quintanilla
Centro de Astrobiología (CSIC-INTA, Madrid)



What was the problem you had to face?

The interpretation of the formation mechanisms of stars in giant molecular clouds was one of my fields of work when we published the first paper in *Science.* Until that time it was difficul to carry out detailed studies because most of the information on the physical conditions of the gas had been obtained in the milimiter and radio domains. The advent of the Infrared Space Observatory satellite (ISO) allowed us to analyse the fine-structure emission lines from carbon and oxygen and also to obtain data on the emission from dust grains and its distribution in the Trifid nebula. The choice of this object was done according to its size, appropriate for the angular resolution of the instruments on board ISO. The second problem, strongly linked to the first one, was how to access the innermost regions of the star formation clouds. The results to these problems were published in the two *Science* paper of which I was the first author.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Our first surprise during the study of the Trifid was to see that there were a large amount of young objects in the boundary between the ionized and neutral gas, the photodissociation region in astronomical jargon. The data indicated that most likely there were a second and a third generation of less massive stars; this originated the title of the paper "Induced Massive Star Formation in the Trifid Nebula?". The UV light of the central star has photoevaporated the most external layers of the surrounding clouds (the arms of the Trifid) inducing strong pressure and density gradients and a second episode of formation of less massive stars that populate the dark regions of the nebula.

With respect to the second paper, we realized that the bands corresponding to the frozen grains left opened some windows with less absorption in the spectrum. We observed with ISOCAM (one of the instruments of ISO) one of the prototypical regions with embedded young stars, and we managed to see directly the youngest objects through those windows. The title of the paper was "Windows Through the Dusty Disks Surrounding the Youngest Low-Mass Protostellar

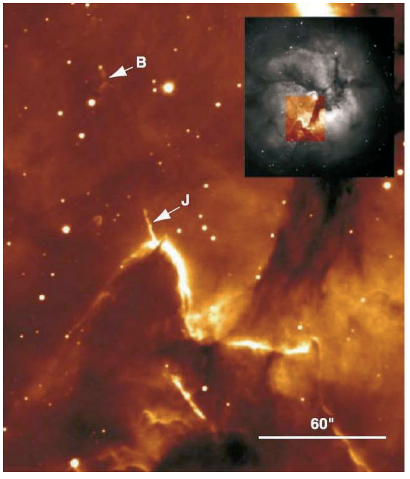


Figure 1. Image of the SW region of the Trifid Nebula taken with a filter that allows us to observed the emission by sulfur atoms singly ionized. The observation was taken with the Nordic Optical Telescope (NOT) at the Observatorio del Roque de los Muchachos (La Palma). With the letter 'J' we have marked the position of the jet emerging from the upper part of the globule. The region marked with 'B' indicates a shock front caused by the jet. In the inset at the top right we show a mosaic of H· images obtained with the IAC80 telescope at the Observatorio del Teide (Tenerife). The mosaic covers the whole nebula and shows in colour the area observed on the NOT.

Objects".The conclusion, confirmed a few years later with Spitzer data, was that even with absorption in the optical larger than 100 magnitudes, it was possible to observe the innermost layers due to the change of the absorption with wavelength. We derived a size of 3-4 AU and a dust temperature of 300-400 K. Most probably we were seeing the surface area of the protoplanetary disk illuminated by the central star.

Since the paper was published, have there been significant advances in this specific area?

The advances have been enormous. The observatory Spitzer started working shortly after our two publications appeared in the journal. Spitzer data are of very high quality and they have shown the complexity of the physical processes involved in the evolution of gas and dust and then in star formation. We still need to study those objects with high angular resolution and a larger sensitivity. In this context, the space observatory Herschel is already making spectacular contributions to the observation of the universe in the far infrared and submillimiter domains. We expect a quantitative step forward because the instruments are much more sensitive than those on ISO and Spitzer, and the telescope has a diameter of 3.5 meters instead of 0.6 and 1.0 meters of those two space platforms.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

My field of interest is molecular astrophysics. The observation of molecules is the only way to determine the physical conditions of the gas and its chemical evolution. The study of star formation must be done in parallel with the study of the surrounding protoplanetary disks. The detection of exoplanets is a fascinating area and in a few years we will have a fairly wide census, including earth-like planets. The study of the evolution of the gas from the diffuse clouds up to its accretion onto the forming —gas or rocky— planets is one of the fundamental problems in this field. Knowing how the chemical composition of the gas changes with time, understanding how the gas is deposited in the dust grains during the first stages of the formation of a star, studyng the chemical processes of the gas occurring in the surface of the grains, its further evaporation and the accretion onto the planetesimal are stories still to be written. We are in a trully exciting time for Astrophysics. Spanish astronomers are very well positioned to participate in this endeavour. The data we have now in our hands are limited and so recent that, as J. Larralde would say, it is not possible even to write a history about any of those topics.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Both! I have continued in this research line, getting more interested in protoplanetary disks, in particular in the chemistry of the gas that undergoes the extreme conditions we find in these objects. I think this is a very exciting field and the new interferometer ALMA will open a completely new and original vision on the evolution of gas from the very first moment of the disk formation up to the formation of the first planetesimals that later will originate the planets. We are currently very limited in sensitivity and angular resolution to understand the subtle chemical processes originating the complexity and the properties of the early planetary atmospheres. My opinion is that ALMA will be a tool that will provide us endless discoveries in the field of star and planet formation. On the other hand, as I said before, the Herschel observatory —of which I am one of the mission scientists— is already flying and their instruments are providing a complementary view to ALMA in the far infrared.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Indeed. Mi interest in the Trifid started during a popular talk in a school in Madrid. I was talking about the interstellar medium and the physical processes occurring when a massive star forms and completely modifies its surroundings. I chose for that an image of the Trifid. In the projection on the screen the image was inverted. In explaining the image I realized of something that I had never seen before, and not only me, but all the astronomers that had been studying this object for more than half a century!. There was a cometary globule, an object under the ultraviolet radiation field from the star that illuminates the nebula; a sort of jet was expelled from the globule, entering the ionized area of the region. I stared silently for about a minute... I had worked before on molecular jets from low-mass stars. When I finished my talk I browse the literature. There were many images of the region, and the jet was apparent in many of them, but nobody said anything about it. The first paper in *Science* is, in part, devoted to that jet, that has been named HH399 afterwards. It is the first totally ionized jet emerging from a low-mas star formed recently. Since then, several more cases have been found and we have published more than ten papers on the Trifid using data from ISO and other observatories.

Induced massive star formation in the Trifid Nebula?
J. Cernicharo, B. Lefloch, P. Cox, D. Cesarsky and six co-authors
1998, Science, 282, 462

Windows through the dusty disks surrounding the youngest low-mass protostellar objects
J. Cernicharo, A. Noriega-Crespo, D. Cesarsky, B. Lefloch and four co-authors
2000, Science, 288, 649

Eduardo Martín Guerrero de Escalante
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

The problem we had to tackle was the characterisation of the properties of the first brown dwarfs of spectral type L in the solar neighbourhood. Brown dwarfs are objects which lie in what we call the "substellar limit", that is, they are not stars because they do not fuse hydrogen as in the Sun.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

For the first time it was possible to obtain images of a binary brown dwarf using the Hubble Space Telescope. It was proven that it is possible to detect the companions of brown dwarfs with sufficient sensitivity to detect planetary mass objects. The first binary system with an L-type companion was discovered.

Since the paper was published, have there been significant advances in this specific area?

Yes, dozens of very low mass binaries have been detected, and even some planetary mass objects. The dynamic masses of several brown dwarfs have been measured. The general multiplicity properties of brown dwarfs, like the frequency of binaries, semi-major axis distribution and the mass ratio, have been studied. These results have been used to restrict the validity of formation scenarios for very low mass objects.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Among the many problems in this hot topic, I would highlight the determination of the mass-luminosity relation for brown dwarfs, the discovery of very low-mass eclipsing binaries and planets orbiting around brown dwarfs.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Yes, it did. I have continued with this line of work, although lately I have been dedicated to other topics.

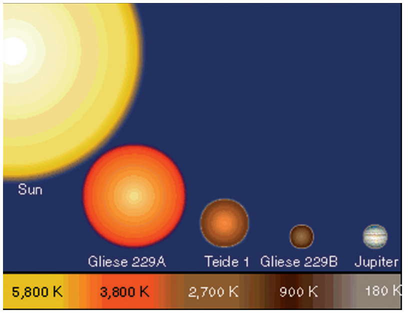


Figure 1. *Comparison of some properties (size, temperature and colours) among the Sun, a white dwarf M (Gliese 229 A), two brown dwarfs (Teide 1 and Gliese 229 B) and Jupiter. Brown dwarfs bridge the mass gap between stars and planets. A substellar object is considered a brown dwarf if its mass is between 0.013 solar masses (13 times the mass of Jupiter) and 0.070 solar masses.*

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The data were obtained using the director's discretionary time on the Hubble Space Telescope. When I saw the first double brown dwarf, the first thing I thought was that the telescope had moved or that I was seeing double. Another brown dwarf was observed that curiously was also a binary (although that was discovered seven years later) but we could not resolve it because its orbit was eccentric.

A Search for Companions to Nearby Brown Dwarfs: The Binary DENIS-P J1228.2-1547
E.L. Martín, W. Brandner and G. Basri
1999, Science, 283, 1718

Alberto J. Castro Tirado
Instituto de Astrofísica de Andalucía (CSIC, Granada)

What was the problem you had to face?

In 1999, the nature and many physical properties of cosmic gamma-ray bursts (GRBs) were still unknown and when the intense burst occurred on January 23 (visible for a few seconds with a simple pair of binoculars) we tried to collect as much data as possible to give the most satisfactory explanation for the observed phenomenon.

We should not forget that the nature of GRBs only started to be clarified some thirty years after their discovery when, in 1997, the X-ray emission that follows the initial higher energy emission (gamma rays) for a few hours (or days in some cases) was detected (the so-called afterglow).

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

A large amount of data was obtained over all the electromagnetic spectrum and with different observational techniques (especially in the optical: photometry, spectroscopy and polarimetry). Three *Letters* in *Science* and one *Article* in *Nature* were published; I was the first author of one of the *Letters* in *Science* and co-author of the others (the three letters were published consecutively in the same issue).

The cosmic cataclysm occurred 9 billion light-years away, implying that it was the most luminous cosmic object in the observed universe to date (night would have turned into day if it would have been in our Galaxy). In our work that was published in *Science* we also found two important results: 1) the evidence of a change in the slope of the light curve in the optical, which we interpreted as the strongest evidence for a collimated jet of material with an aperture angle of a few degrees; and 2) a limit on the degree of linear polarization of 8% in the optical.

Since the paper was published, have there been significant advances in this specific area?

Yes, many. In the field of GRBs there have been many discoveries to date, both in the exploration of long-duration gamma-ray bursts (associated with the gravitational collapse of very massive stars that give rise to the birth of new black holes, confirmed in 2003) and in the short duration GRB population (with the discovery of the first

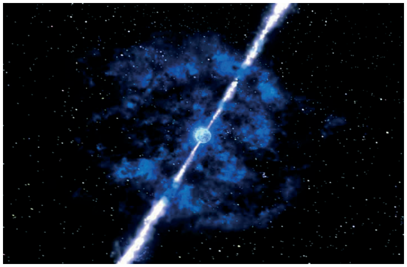
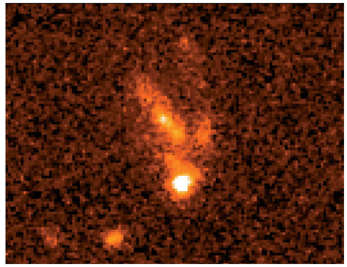
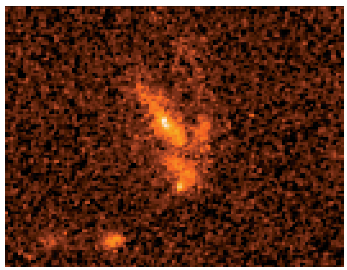


Figure 1. *An artist's concept of the gravitational collapse of a very massive star originating the cosmic gamma-ray burst. Its wavefront reached the "electronic eyes" of the scientific satellites on January 23, 1999, after travelling in space for some 9,000 million years. Courtesy: NASA/Zhang & Woosley.*





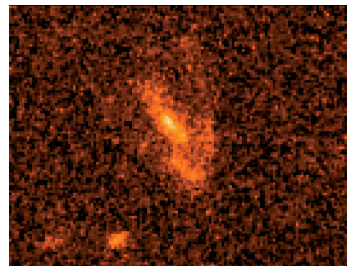


Figure 2. *Images obtained with the Hubble Space Telescope of the optical afterglow emission from GRB 990123 superimposed to the host galaxy (at least two galaxies appear to be interacting 9,000 million light-years away) 23 (left) and 59 (bottom left) days after the burst. Note how in the last image (bottom right), taken a year later, all the residual light from the GRB has disappeared. Courtesy of Fruchter* et al. *(1999).*

examples in 2005.) In fact, since 1997, there must be some thirty papers published in both journals metioned above for all the groups that are working in this field.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The theoretical model, the so-called "Fireball model", used to explain the observed emission after the initial gamma-ray burst, clearly presents some serious limitations in explaining the detailed light curves which are being obtained by multiwavelength observations, such as those obtained with the *SWIFT* satellite. Also the existence of a population of intermediate-duration GRBs with a different physical nature is under debate. Even more uncertain, is a possible dichotomy in the class of short-duration GRBs, such that existing examples would be short class II GRBs, while class I short GRBs would be practically unknown because of the small number of data available. Among the many discoveries to be made are: 1) the detection of GRBs further away than the furthest known objects, which will be related to the first generation of stars created in the Universe; 2) the detection of gravitational waves

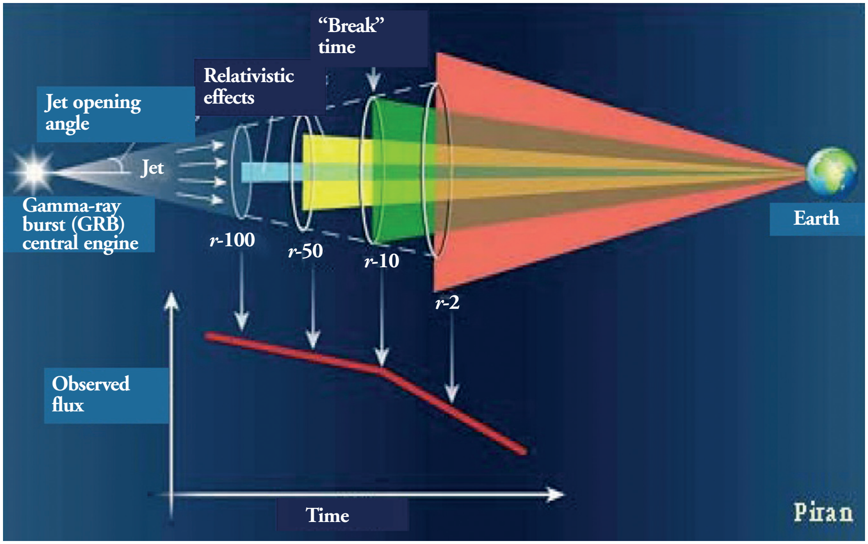


Figure 3. Theoretical interpretation of our observations within a relativistic "fireball model". The change in the slope is observed during the so-called "break" time, when the collimated emission is accelerating (the Lorentz Γ factor decreases) and therefore, the aperture angle of the emission cone increases exceeding the emission cone that we see from the Earth due to the relativistic effect. This results in an "apparent" loss of photons as an observational fact. Adapted from Piran (1999).

coming from the coalescence of neutron star binary systems.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Undoubtedly, these and other publications I have written on the same field (two as a first author in *Science,* one as a first author in *Nature,* and eight more as a co-author in both journals) have contributed to maintain this line of work as the most productive of all the others in which I am involved, to the point that in parallel over the last 15 years I have guided the technological developments in robotic astronomy using ultrasensitive cameras for continuously searching variable objects in the night sky.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Yes, regarding the typical race when two scientific teams have independent data that can yield the same big impact discovery. In this specific case, the team led by Professor S. Kulkarni (Caltech, USA) and the one led by me (I was then working under a contract limited to a specific project at INTA and worked physically at IAA-CSIC). Kulkarni et al. sent their paper to *Nature.* We sent ours to *Science.* There is no doubt that both journals knew about the paper that had been sent to its rival on the same object (GRB 990123). The two months between the phenomenon occurrence and the publication of the results were frenetic, but it was worth the stress. The Spanish team (and *Science*) won the round to the California's powerful team (and *Nature*) by seven days and therefore *Nature* had to advance the press release with the announcement by a week! It was probably, the first time in its long history that *Nature* had to change its policy in this sense…

ADDENDUM: Not everyone follows the same game rules

Some years ago, I received a call from a journalist from *Nature* asking my opinion on a discovery that was going to be published in a paper several weeks later, of which I was not a co-author. He was calling me because I had discovered the object in question in 1992 and this, as it turned out, was going to be announced as the most massive black hole in our Galaxy (to date). Of course, I praised the work done and the importance of the result. However, I had my suspicions, a year before I had collaborated with the scientist (and friend at that time) who was going to be the leader of the mentioned publication in *Nature.* The day following the journalist's phone call, I phoned the head office of the European Space Observatory (ESO) in Munich —the data used for the paper published in *Nature* had been obtained with one of the VLT telescopes (ESO, Chile)— and I asked them for a copy of the observing time request made by the first author of the paper in question, with the "false" excuse that I did not keep a copy of it (obviously they assumed that I was a co-applicant).

As I had mentioned above, a year before we had worked together on the same object using data from ESO, that we were able to obtain because we had previously sent a request for observing time which I had signed as a co-author (at that time Spain was a few years ahead before becoming a full member.) After a few minutes and following my request, I received by fax the full proposal that had been sent, with reference number 65.H-0422. Unfortunately my suspicions were confirmed. My name appeared again as the second co-applicant of the new time request. But this time without my consent! As I was the discoverer of the object in question and the author of several papers on the subject, my name was used without permission in order to obtain time to observe the object with the VLT, which turned out to be a fundamental part of the paper to be published in *Nature.* Logically, I immediately thought of contacting ESO and *Nature* but, in the end, I decided to leave things as they were. Of course, then I contacted the first author of the paper in *Nature* (and ex-friend since then) and immediately rejected any future collaboration with him. And it is like this even now…

Unfortunately, not everybody (neither in science nor in life) follows the same game rules.

Decay of the GRB 990123 Optical Afterglow: Implications for the Fireball Model
A.J. Castro-Tirado, M.R. Zapatero-Osorio, N. Caon, L.M. Cairos and 48 co-authors
1999, Science, 283, 2069

Pere Planesas Bigas
European Southern Observatory (Santiago, Chile)

What was the problem you had to face?

The problem was to determine the quantity, distribution and kinematics of the molecular gas in galaxies located at cosmological distances. Stars are born from this gas, that is why its study is essential to know the star formation history and efficiency in very distant galaxies, which are therefore very young. At that time (1999), it had not been possible to detect molecular gas in any galaxies at redshifts between 1 and 2, in other words, when the Universe was between 1/4 and 1/3 of its present age. The observational problem was the weakness of the emission and the small angular size in which the molecular gas is distributed due to the large distance to these galaxies, which made it impossible to detect them with the telescopes of the time. Our methods proved for the first time the viability of those studies.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The solution was to observe a very particular galaxy, in the sense that there is another very massive galaxy in the line of sight between it and us that acts as a gravitational lens (Figure 1). This gravitational lens was known for its effect on the light emitted by the powerful quasar that resides within the distant background galaxy. This effect, explained by Einstein's general relativity theory, the intervening mass along the line-of-sight causes the radiation emitted by a background or distant quasar to deviate from its normal path, amplifying its brightness and potentially producing several images of the background object. Moreover, when acting on an extended galaxy, gravitational lensing increases its apparent size (Figure 2). Thanks to this effect, the brightness of the molecular gas emission was amplified by the gravitational lens allowing us to detect it and, acting as a "cosmic magnifying glass", increased its apparent size and, therefore, we were able to measure its distribution and kinematics. The latter had not so far been possible for the few galaxies located at even larger distances that had been detected at that time.

Since the paper was published, have there been significant advances in this specific area?

Since then, molecular gas has been detected in three other galaxies located at the same redshift range.

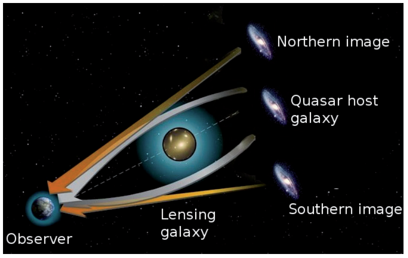


Figure 1. *Explanatory sketch of the gravitational lensing effect. As the observer and both galaxies are aligned, if the intervening galaxy (or galaxy cluster) is massive enough the observer can even see two or more images of the distant galaxy. In our case this galaxy harboured a quasar.*

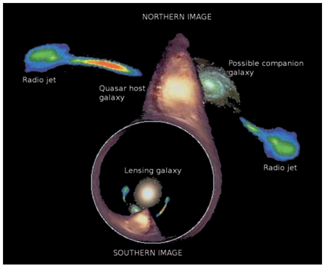


Figure 2. *An artist's concept showing the distortion of a distant galaxy produced by a gravitational lens. The quasar that resides inside this galaxy produces two plasma jets that emit radio waves. The lens duplicates and distorts the image. This is not appreciated in Figure 3, as a quasar is a point-like source, but it is appreciated in the case of a galaxy, an extended source.*

Most molecular gas detections in galaxies at these distances, or even further, have been possible thanks to the presence of an intervening gravitational lens, very often initially unknown. However, the galaxy we detect is similar to the Milky Way, while the other galaxies are less normal, they are richer in molecular gas. The originality of our project was to choose a case in which we knew about the existence and characteristics of a gravitational lens lying between us and the galaxy that harbours the quasar. In fact, the chosen quasar was the one where the gravitational lensing phenomenon was first discovered (20 years before, in 1979) and it is known as the "twin quasar", since its optical image consists of two bright spots (Figure 3).

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

One of the main difficulties in determining the characteristics of galaxies in the early universe is that we do not know their size. This is especially complicated in the case of molecular gas measurements taken with high-frequency radio waves. We can only obtain very detailed information in those cases where a gravitational lens increases its size.

However, this technique has given results in only very few occasions; one of them is the "twin quasar". For it to be really effective, a radio interferometer capable of measuring details much smaller than those measured with present interferometers is needed. Such an interferometer, called ALMA, is currently being built in the Atacama desert at 5000 meters altitude, from where these very difficult observations will be routine in a few years time. At present, I am participating in the construction of this observatory.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

A large amount of my scientific research during the years previous to the publication of this paper was related to the study of luminous and ultraluminous infrared galaxies. These galaxies have bursts of star formation that give rise to hundreds of new stars per year, at a rate a hundred times faster than in our Milky Way.

That paper was my first foray into the study of the distant universe, where other galaxies with high rates of star formation are also detected. Their study can be based on the closer ultraluminous galaxies that I previously studied. Recently, I have participated in the characterisation of dense molecular gas in a galaxy at a redshift of 3.9 (when the Universe was only 10% of its present age). This galaxy harbours one of the most luminous quasars in the Universe and it also experiences amplification due to the gravitational lensing phenomenon.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

One anecdote previous to the publication of the paper is related to the editing process followed by these journals, based on the evaluation of one or more scientists who decide if the paper is suitable for publication in the journal. Such evaluation, which always attempts to be objective, sometimes has editorial biases, as it happened to us when *Nature* rejected our paper, while the other one, *Science,* accepted it immediately.

After this paper's publication, I could see the great interest generated (the news was published in the newspaper El País and in several scientific vulgarization magazines, the Madrid Planetarium invited me for a conference, etc.); the question that aroused the most interest among the people who asked me about the subject was the use of gravitational lenses as an enhancement of the telescope's capability.

GAS-RICH GALAXY PAIR UNVEILED IN THE LENSED QUASAR 0957+561

P. PLANESAS, J. MARTÍN PINTADO, R. NERI AND L. COLINA

1999, SCIENCE, 286, 2493

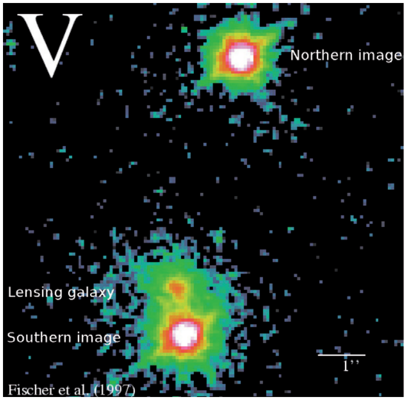
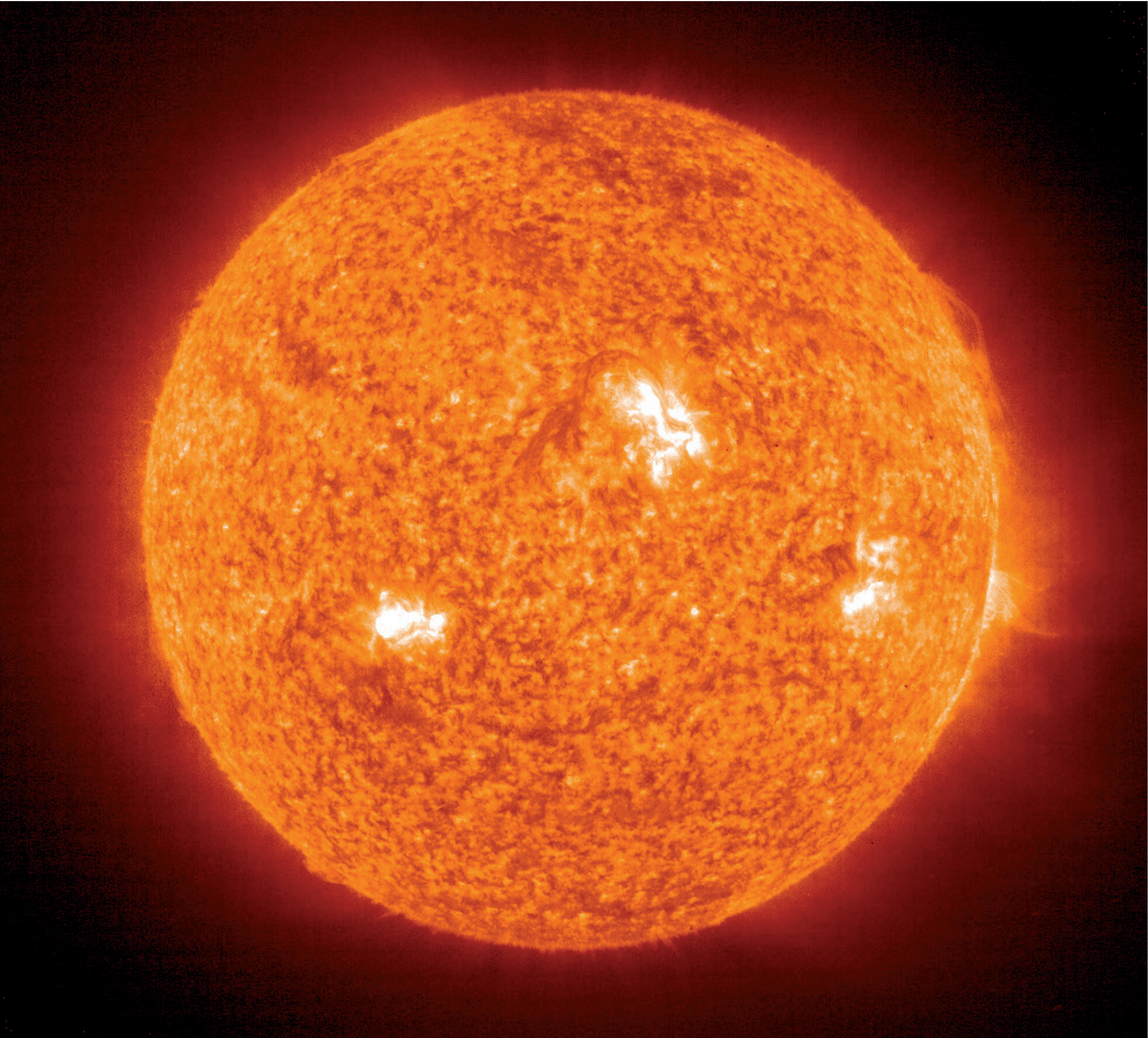


Figure 3. *Optical image of the "twin quasar" QSO 0957+561 showing two point-like images formed by the intervening gravitational lens and a faint image of the galaxy which originates the phenomenon. This is the first case of gravitational lensing discovered and one with one of the largest image separations known (6"). Courtesy of the CASTLES project: http://www.cfa.harvard.edu/castles/*



Héctor Socas Navarro
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

The chromosphere (upper layers of the atmosphere) above sunspots exhibits a very dynamical behaviour, including sudden brightenings with a period of about 3 minutes. These brightenings, called *umbral flashes,* were discovered observationally in the sixties and even now little is known about their physical nature and origin.

The study of these phenomena is very complicated because they take place in highly magnetized environments (sunspots have a magnetic nature) and because in the chromosphere the usual diagnostic techniques are not normally applicable. Also, due to the dynamic character of the *umbral flashes,* follow up data is required on very short timescales and periods to study its nature.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

We approached the problem in two ways, using both observational and analytical advances. On the one hand, we used a new instrumental set for the spectropolarimetric observations in the near infrared, specifically in a spectral range where the chromosphere can be observed. Polarimetry allows us to study the magnetic field and its relation to the observed phenomena, hence its importance in this scenario. This type of observations had not been possible before our work.

The second method was to use a new diagnostic technique which allowed us to make inversions of lines formed outside the local thermodynamical equilibrium. This technique, developed and tested during my thesis, gave us the possibility of relating the observations with the changes taking place in the solar atmosphere.

During the course of our research we had a surprise, since the form of the polarization profiles changed during the *umbral flashes* and became strongly asymmetric. These profiles, which we named as “anomalous”, were too asymmetric to be explained with magnetic field or velocity gradients. The interpretation of these observations led us to the conclusion that those *umbral flashes* worked as a group of *geysers* that ejected jets of hot material to the top layers of the atmosphere. These jets, which reach velocities of about 15 km/s, have a very small horizontal extension (smaller than 1000 km) and go

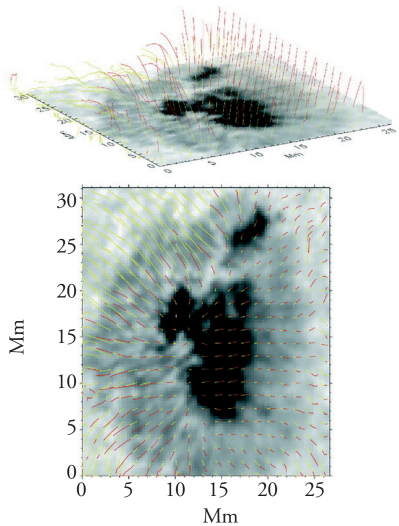


Figure 1. *Image of a sunspot with magnetic field lines that pierce the chromospheric region above the penumbra. The units in the axes are millions of meters.*

through a relatively calm and much colder atmosphere.

Since the paper was published, have there been significant advances in this specific area?

In general, there has been little advance due to the difficulties mentioned above, both in making suitable observations (polarimetry in chromospheric lines) and in the development of the analysis techniques (combination of inversion algorithms with radiative transport outside the local thermodynamic equilibrium). Perhaps the most significant advance is the one presented in a recent publication using high-resolution imaging observations from the Hinode satellite (Socas-Navarro, McIntosh, Centeno, de Wijn and Lites 2008). Unfortunately, Hinode does not allow polarimetric measurements of the chromosphere to be made, but the quality of its high spatial resolution images allows to directly see that there is really a mix of hot and cold material when the umbral flashes occur. Since spectroscopy and polarimetry are not possible, Hinode data do not allow the phenomenon dynamics to be studied but they do confirm the prediction that we had made in our work.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The chromospheres of the Sun and the stars have incomprehensibly high temperatures, and this is one of the major problems in stellar physics today. We think that wave propagation in small vertical magnetic elements and the existence of small-scale reconnection phenomena are the key to this enigma. It is speculated that the umbral flashes could be a large-scale version of what could be happening in continuously all over the Sun to heat the chromosphere. At present, we do not have appropriate tools to investigate these processes, as they take place at very small spatial scales and require the observation of chromospheric lines. In the next decade, with the construction of ATST (Advanced Technology Solar Telescope) and EST (European Solar

Telescope), we hope to be able to make these observations. The development of computational resources will also be important, as 1D (one dimension) models that we use in our research will no longer be suitable outside sunspots. It will be necessary to make inversions with radiative transport in 3D (three dimensions) outside the thermodynamic equilibrium, and this will require supercomputers, to which it is very difficult to have access to.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Generally I have continued working in the field of the chromospheric dynamics but I have not been particularly centred in umbral flashes. Since the publication of this paper, I have published two more (Centeno, Socas-Navarro, Collados and Trujillo Bueno, 2004 and the mentioned Socas-Navarro, McIntosh, Centeno et al. 2008) where other evidence confirming the predictions

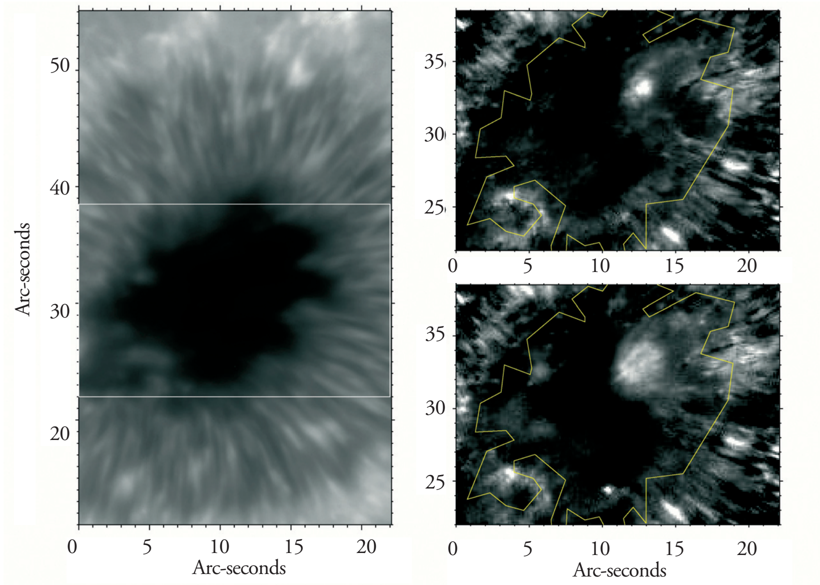


Figure 2. In this sunspot we can see the darker and colder central region (umbra), and the dark and bright penumbral filaments. On the right, the contour plots that limit similar magnetic field values.

of the original paper were presented. I hope that with the development of new solar telescopes it will be possible to make the observations we need to move forward in this field.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The data were obtained with the Gregory Telescope at the Observatorio del Teide, which was already considered obsolete and was about to be closed. In fact, I think that our observations were some of the last made there. It was a very simple instrument and, precisely, because of that simplicity we were able to reconfigure it and build the setting we needed to collect our data. At that time, it was almost impossible to carry out our study with any other telescope. The moral of the story is that the most sophisticated is not always the best. Flexibility is also important because in science it is impossible to foresee all the possible future needs.

Anomalous Polarization Profiles in Sunspots: Possible Origin of Umbral Flashes

H. Socas Navarro, J. Trujillo Bueno and B. Ruiz Cobo

2000, Science, 288, 1398

Vicent Quilis Quilis
Departament d'Astronomia i Astrofísica
Universitat de València

What was the problem you had to face?

The study of the morphological transformation of galaxies is one of the most fascinating topics in astrophysics, and it has crucial implications in the theoretical model that would allow us to understand the formation of structures that build up the Universe. In particular, the so-called Butcher-Oemeler effect, which implies that galaxies in nearby clusters are very different from galaxies in distant clusters, has been known for a long time. With the arrival of the Hubble Space Telescope, we could observe the important difference between galaxy populations in nearby clusters, which are dominated by small spheroidal galaxies (S0) without outstanding features, whereas distant cluster populations are dominated by spiral galaxies. These observations have given rise to many hypotheses on the nature of this effect and more than a thousand papers have been written on the subject but with no clear conclusions. In the year 2000, we still did not understand the reasons behind the large differences between cluster galaxy populations according to their age.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

There were three main hypotheses to explain the origin of S0 galaxies in clusters. The first one pointed to the effects of tidal forces experienced by spiral galaxies when interacting with the structure surrounding them. The second theory referred to the effects of galaxy mergers. And, finally, the third hypothesis suggested that galaxy interactions with cluster environments (the intracluster medium) could cause the aforementioned metamorphosis. Previous studies based on very high resolution N-body simulations had dismissed the first two hypotheses, while some preliminary attempts, with inappropriate techniques, had failed to adequately describe the interactions with the environment.

Our idea was to study, with the latest generation computational techniques, the interaction between spiral galaxies and their environment. In order to do this, we used the cosmological code I developed during my PhD thesis, which was able to precisely describe fundamental phenomena associated with the gaseous components of cosmological structures, such as shockwaves

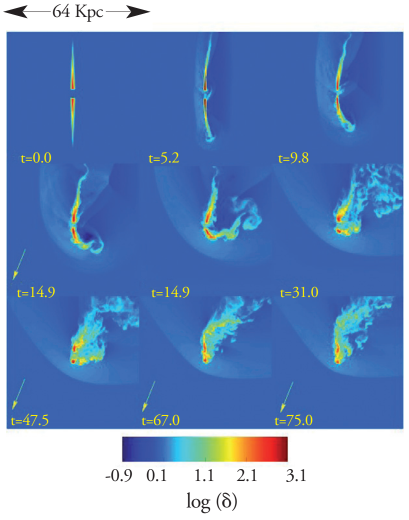


Figure 1. *Temporal evolution of the gaseous disk of a spiral galaxy (viewed edge-on) when interacting with the intracluster medium. After a hundred million years the galaxy has lost almost all its gas and has run out of fuel for star formation. Like the gas, the other galaxy components (not shown in the figure) have also suffered important changes, so that the end of the process is a system with the typical morphology of a S0 Galaxy.*

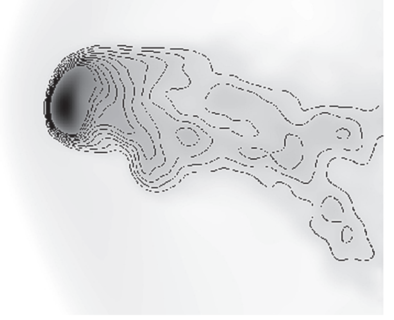


Figure 2. *Synthetic radio map of a spiral galaxy travelling through the intracluster medium. Contour lines represent the emission associated with the gas, while the grey-scale shows the density of that gas. The image shows the compressed contour lines in the direction of motion and the gas tails behind the galaxy. This image can be compared directly with observations.*

and the formation of instabilities and turbulence, to simulate the effects suffered by a typical spiral galaxy when orbiting in the intracluster medium.

The right description of this complex physical scenario permitted us to conclude that the interaction with the intracluster medium transformed, in time scales of hundreds of millions of years, spiral galaxies into spheroidal galaxies (S0) with very low star formation rates.

In order to make these simulations, we used the most powerful computer of that time in the United Kingdom and it took three months of intensive calculations that generated a huge amount of data.

Since the paper was published, have there been significant advances in this specific area?

Since the publication of this paper there have been important advances in this field. Several groups have made similar simulations, with different techniques and higher numerical resolutions, confirming the results presented in our paper. It has also been possible to study the interaction phenomena with the environment in different ranges of the electromagnetic spectrum, thanks to a new generation of observations that have also confirmed our predictions.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The creation of a theoretical-observational framework, which will help us to understand the formation and evolution process of galaxies, is undoubtedly one of the main objectives of modern astrophysics. On a galactic scale, there is an overlap between the influence of the cosmological evolution of the Universe as a whole, and galactic and stellar astrophysics. Therefore, the search of a global paradigm that describes the formation of the large-scale structure and the star formation process in the Universe must entail the understanding of galaxies. In this sense, research aimed towards disentangling all aspects of galaxy evolution, and in particular its morphological transformations, is fundamental for the description of the Universe.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

The publication of this paper has been important in my professional career, as it has become a classical reference in this field. In fact, the interaction mechanism with the intracluster medium is now the accepted explanation of the origin of S0 galaxies in clusters, both by theoretical and observational colleagues.

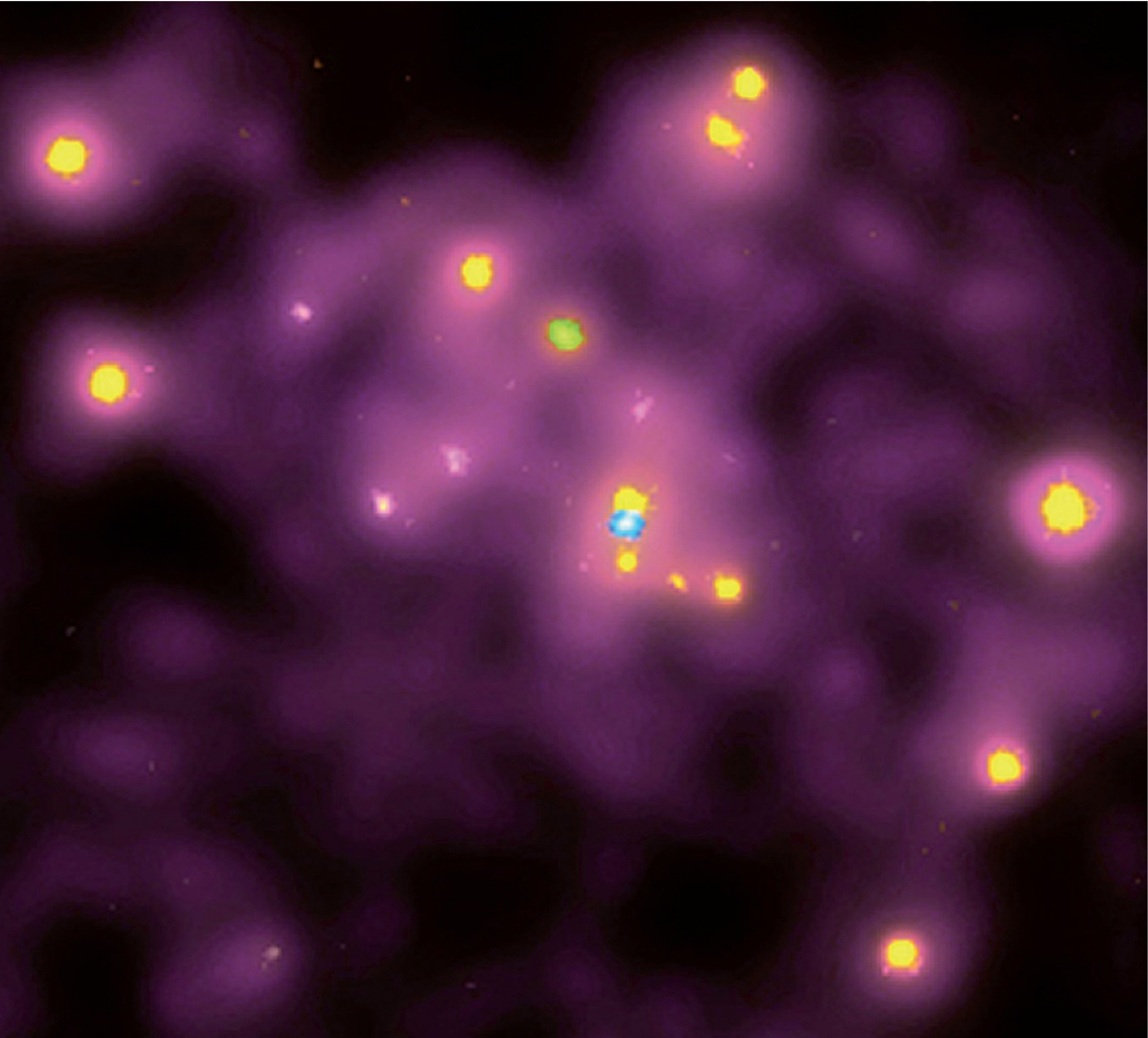
Now I am starting to work on this topic again using new generations of cosmological codes. The basic idea is to form galaxy clusters from cosmological initial conditions but with enough resolution as to describe the galaxies that populate those clusters. In this way, we will be able to follow the evolution of those virtual galaxies and to study all the phases and transformations occurred during their lifetime.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Perhaps the most curious thing was the choice of the title. We wanted a shocking title but we did not agree. One day, taking a coffee, we were joking about making a version of that great classic film: Gone with the wind. After some minutes of hesitation, it was clear that it was going to be the definitive title of our paper.

Another curiousity was the disparity between the reports of the referees. One of them was extremely enthusiastic and was urging us to publish the paper, while the other one, although favourable, had certain doubts and was asking for some additional material. Finally, the latter referee was satisfied with the additional material we provided but it could not appear in the magazine because of a space limitation.

Gone with the wind: the origin of the S0 galaxies in clusters
V. Quilis, B. Moore and R.G. Bower
2000, Science, 288, 1617



Josep María Paredes Poy
Departament d'Astronomia i Meteorologia
Universitat de Barcelona

What was the problem you had to face?

In the nineties the existence of a new type of stellar object in our Galaxy was established: which are X-ray binaries with relativistic jets, also known as microquasars. In these systems, an ordinary star orbits around a neutron star or a black hole, which captures (accretes) mass from the bright companion star and forms an accretion disk. A fraction of the mass accreted is ejected at relativistic velocities in a direction perpendicular to the accretion disk, creating the jets that characterize microquasars.

Just a few more than a dozen microquasars were known and it was important to expand the sample to characterise the observed phenomenology with a broader statistical base.

These microquasars had been discovered as a result of some eruptive episodes detected by X-ray observatories in terrestrial orbit. We decided to look for new microquasars but without having to wait for an eruption that alerted us.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

To identify potential microquasar candidates, we used different catalogues in the optical, radio and X-rays that contain the position and energy emitted by the catalogued sources in the different wavelengths. With the aid of computers, and taking into account relevant properties of microquasars, we carried out a detailed inspection of those astronomical databases, which made it possible to select a short list of candidates.

Subsequent observations with the VLA (Very Large Array) enabled detailed studies of the candidates, and in particular, to improve the position of one of them, especially interesting, LS 5039. To be sure that it was a microquasar we had to prove that it had jets and, for that, we used the VLBA (Very Long Baseline Array) radio interferometer. As we expected, the analysis of the observations showed an elongated and asymmetric structure. It was what we were looking for. In addition, the microquasar position coincided with an unknown very high-energy gamma-ray emission source. We proposed that the new microquasar, LS 5039, was also a gamma-ray emitter. This discovery represented the first observational

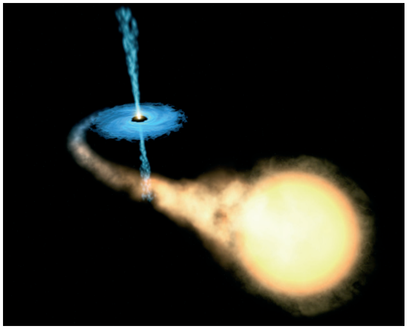


Figure 1. Artist's concept of a binary star system where a black hole captures matter from its companion and ejects part of it in the form of relativistic jets. Credits: ESA, NASA and Félix Mirabel (CEA and CONICET).

evidence that microquasars can also be high-energy gamma sources, and that an important part of the gamma-ray sources not yet identified could be compact extragalactic objects connected with microquasars.

Since the paper was published, have there been significant advances in this specific area?

There have been amazing advances. In 2005, five years after proposing that microquasars are also gamma-ray emitters, the Cherenkov HESS telescope detected LS 5039 in very high energy gamma rays, confirming our discovery and extending the emission energy range of microquasars. In 2006, the Cherenkov MAGIC telescope located on the island of La Palma, detected variable emission from the microquasar LSI+61303 and in the year 2007 it also detected fast variability emission in the microquasar Cygnus X-1, which is the best candidate for harbouring a black hole.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

One of the major problems, which affects both microquasars and quasars, is to know the formation mechanism of relativistic jets and the processes of matter accretion onto the black hole. In the next years, the Fermi gamma-ray satellite, launched in June 2008 by NASA, is expected to detect a large number of sources, and microquasars are probably a fraction of them. This will allow us to study the energetic mechanisms associated with accretion/ejection processes.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Yes, it influenced my career. This discovery made it easier for me to get involved in high-energy Astrophysics. We have broadened the issues we were working on. One of them is related to sources that emit gamma-rays and are not identified due to the poor angular resolution of the observation instrument. We explored the area around the gamma ray source with different instruments (radio telescopes, satellites with X-ray detectors, optical telescopes, the Cherenkov telescope) to identify what object (microquasar, pulsar, galaxy's active nucleus, etc.) is responsible for the gamma ray emission. We also developed theoretical models consistent with the observational data and that make it possible to reasonably explain all the associated phenomenology.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

At the end of 1999, we received the data from our observations with the VLBA. The analysis of these data had to tell us whether we had discovered a new microquasar or not. As we were very anxious to know if the source, LS 5039, showed jets we decided to work during the whole Christmas holidays. And we received our present!

Discovery of a High-Energy Gamma-Ray-Emitting Persistent Microquasar

J.M. Paredes, J. Martí, M. Ribó and M. Massi

2000, Science, 288, 2340

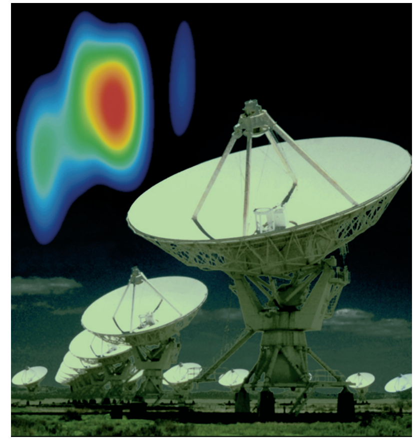


Figure 2. *Composition showing the Very Large Array (VLA), an interferometer located in New Mexico, and the high resolution radio frequency map of the microquasar LS 5039 obtained with the VLA and the VLBA at 6-cm wavelength. The emission is more intense in the central region (nucleus, in red), while the lobules on the left and right sides (jets) are fainter.*

José Luis Ortiz Moreno
Instituto de Astrofísica de Andalucía (CSIC, Granada)

What was the problem you had to face?

I wanted to know the amount of matter that there is in the trans-neptunian belt (the zone beyond Neptune, where Pluto and other bodies lie). I believed that there could be a large amount of it in the form of small frozen bodies, with very volatile ices, and sizes between centimetres and meters. Some of these bodies could reach Jupiter and even reach the Earth or its vicinity (the Moon) but due to their large volatility, if they were on a course to collide with the Earth most likely they would disintegrate very quickly in the atmosphere, and therefore they would not produce the meteors to which we are used.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

I found a way to determine the amount of very volatile matter in the vicinity of the Earth by pointing our telescopes towards the night side of the Moon that is visible from the Earth and searching for flashes of light produced each time a big enough object impacted against that part of the Moon. We knew that when a body collides with another body at enormous speeds, the impacting body vaporizes (it disintegrates in a sort of gas) and emits light during the almost instantaneous process, therefore making it possible to see impacts of very volatile matter. In 1998 we tested the technique, but without success, and proposed that the Leonid meteor shower of 1999 would offer an excellent opportunity to detect, beyond any doubt, impact flashes against the Moon. Finally, this was achieved in November 1999, and in the year 2000 we published our results in the journal *Nature.*

Since the paper was published, have there been significant advances in this specific area?

Yes, soon after we were able to determine the fraction of impact energy that is emitted in the form of visible light in the collision processes with more precision than in our *Nature* paper. And some time later, in 2002, we made the first detection of sporadic impacts (impacts produced by bodies of unknown origin, not associated with meteor showers, which are showers of material of known comets). Sporadic

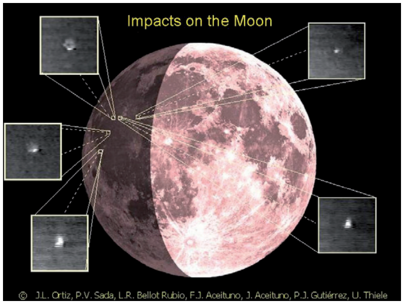


Figure 1. *Synthetic image of the Moon where five real images of impact flashes detected in November 1999 have been superimposed. The brightness of the dark side of the Moon has been artificially enhanced.*

impacts were the ones we were looking for from the beginning and we were able to determine the number of volatile material impacts against the Earth according to their energy. Our preliminary conclusions indicate that three times more material than previously expected arrives and most of it is volatile. Following the success of our pioneering work, NASA established a specific program to make the same measurements we did, starting in 2005.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

This is a very broad and new field, and therefore there are many things to explain and study in depth. Perhaps one of the most important problems is to determine the precise place from where the most volatile material we see impacting against the Moon originates.

Did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I guess that it did influence my career because this type of contributions are very positively evaluated by reviewing panels, and helps in the way that the committees that finance research in Spain are, sometimes, more prone to grant money for projects. After the paper in *Nature,* I obtained my own funding to do this research for the first time. Perhaps it was by chance, perhaps not.... Until that time the work had been done without any specific funding, using other financial resources and funding means where there were none. Even the labour, fundamental for all scientific research, was given by amateur astronomers who did not even belong to a research centre. I continued working on the topic but not as my primary scientific activity because it required much more effort than I could afford with the human and economic resources I had.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

After the publication in *Nature,* the North American astronaut of the Apollo XVII mission and former United States senator from New Mexico, Harrison Schmitt, contacted me to tell me something that happened while he was piloting the Lunar Module in December 1971. Harrison Schmitt, better known as Jack Schmitt, saw a large flash, but the event remained unexplained for a long time. It was thought that a cosmic ray hit his eyeball and I knew this "official" version, but Jack asked me if he could have witnessed an impact of a body on the Moon. Thanks to the data he provided me, I reached the conclusion that he had probably seen an impact from a Geminid shower particle. He was very happy to know that what he had seen was real and not a hallucination, as some people wanted him to believe. Of course, it had nothing to do with aliens.

Many other luminous phenomena that occurred on the Moon, commonly associated with aliens and occultism and called "lunar transient phenomena", have been explained as impact phenomena of interplanetary material against the surface of the Moon and nothing related to aliens.

Optical detection of meteoroidal impacts on the Moon
J.L. Ortiz, P.V. Sada, L.R. Bellot Rubio, F.J. Aceituno, J. Aceituno, P.J. Gutiérrez and U. Thiele
2000, Nature, 405, 921

José Luis Gómez Fernández
Instituto de Astrofísica de Andalucía (CSIC, Granada)

What was the problem you had to face?

Thanks to the start of the commissioning of the Very Long Baseline Array (VLBA) it was possible to make a detailed follow up (with a high spatial and temporal resolution) of a relativistic jet in an *active galactic nucleus* (AGN).

The study, carried out in the radio galaxy 3C120, showed an unusual variation in the hydrodynamics and non thermal emission, consisting of a sudden increase in the emission together with a rotation of the polarization angle.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

These observations were explained as being due to the interaction between the jet and a cloud in the intermediate region between the broad- and *narrow-line* region ((BLR and NLR, respectively).

This made it possible to determine the important role of the surrounding medium in the study of jets in AGN, and on the other hand, the important contribution of the jet itself in the evolution of the galaxy that harbours it (something that is very topical in cosmological simulations today).

Since the paper was published, have there been significant advances in this specific area?

Yes, similar studies on other relativistic *jets* have continued to be done, together with numerical simulations of hydrodynamics and emission, and the role of *feedback* of the *jet* in the galactic evolution, all of these have provided a significant advance in the understanding of relativistic jets.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

What it is still unknown are the processes of jet formation, acceleration and collimation, especially important for the study of AGN, GRBs and microquasars. A second paper in *Nature,* where I appear as a co-author, followed this line of work. In the next years a significant advance in those topics is expected, mostly thanks to the FERMI satellite and to the Japanese VSOP-2 mission.

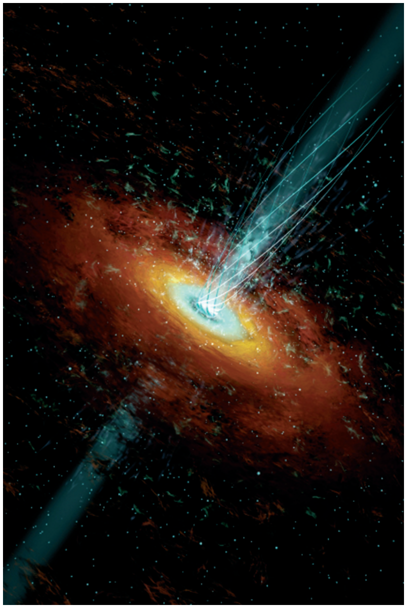


Figure 1. Artist's concept of an active galactic nucleus (AGN) with two relativistic jets perpendicular to the disks.

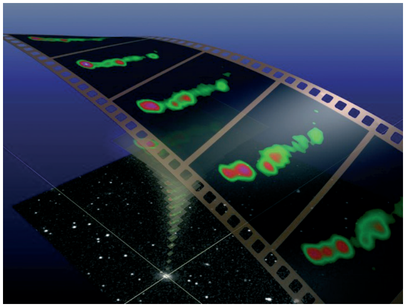


Figure 2. Real images of the radio galaxy 3C 120, over an artist's concept, showing the temporal evolution of the jet.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I have continued my research in this topic.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I do not remember anything special. Perhaps the most surprising thing was the great stir caused by the media. I think that sometimes journalists are so afraid of not echoing something correctly that they can create a big snowball. It was also a time when being Spanish and publishing in *Science* or *Nature* was a big asset. Now I think that is not the case (which can be a sign of "maturity").

Flashing Superluminal Components in the Jet of the Radio Galaxy 3C120
J.L. Gómez, A.P. Marscher, A. Alberdi, S.G. Jorstad and C. García-Miró
2000, Science, 289, 2317

María Rosa Zapatero Osorio
Centro de Astrobiología (CSIC-INTA, Madrid)

What was the problem you had to face?

Are there isolated bodies with masses smaller than 13 times that of Jupiter, in other words, planets that do not orbit any other star? If they exist, what is the ratio of these with respect to other more massive bodies? How did they form so that they are now "isolated"? What are their physical properties?

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

We explored in depth a very young region of the sky, virtually a birthplace of stars and brown dwarfs, well-known by our team: the σ Orionis star cluster, with an age of only 3 million years (more than 1,000 times younger than the Solar System).

Observations were made in the red-visible and near infrared wavelengths, where it is expected that these very low-mass bodies emit most of their energy by gravitational contraction. This survey resulted in the discovery of a relatively high number of "isolated" planetary mass candidate members of the cluster, with masses in the range 5 to 15 times that of Jupiter. In addition, the first spectra of three of these objects were presented, confirming their cold atmosphere.

Since the paper was published, have there been significant advances in this specific area?

Yes, later other research teams have found bodies with similar masses in other young regions of the sky, which show that the formation of these very low-mass objects is common in our Galaxy. Several groups of theoretical scientists are trying to model and understand the formation mechanisms that lead to "isolated planets". Deeper and more recent explorations carried out in the σ Orionis cluster indicate that bodies with masses about 3 times that of Jupiter exist, likely to be bodies with the smallest mass directly "photographed" outside the Solar System.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The formation mechanisms of isolated planets are not known with certainty, although there are several different theoretical works that try to explain their existence in young regions of star formation none

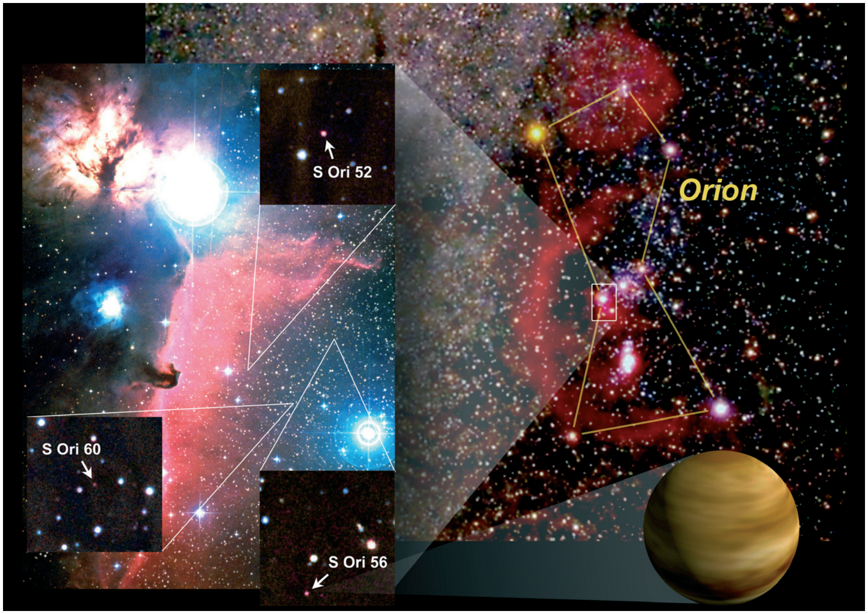


Figure 1. Orion constellation (background image) over which the position of the young star cluster around the Û Orionis star is highlighted (image on the left). Three isolated planets with masses ranging from 5 to 15 times that of Jupiter, which probably belong to the Û Orionis cluster, are marked with arrows. Courtesy of Gabriel Pérez (IAC).

of which are confirmed at this time. A very important piece of information in Astrophysics is the population census of all the bodies (stars, brown dwarfs and planets) that are formed from a molecular cloud. Any model should reproduce the observed relative number of these three types of bodies. Is there a mass limit for the formation of "isolated planets"? If so, what is the limit?

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Yes, I have continued in this line of work.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

There are no anecdotes, except for the great observational effort (the need of nights with good seeing and transparency, data should be very deep), and the satisfaction of the whole team when discovering one candidate and then another, then another and one more candidate after the data reduction.

Discovery of Young, Isolated Planetary Mass Objects in the Û Orionis Star Cluster
M.R. Zapatero-Osorio, V.J.S. Béjar, E.L. Martín, R. Rebolo, D. Barrado and Navascués, C.A. Bailer-Jones and R. Mundt
2000, Science, 290, 103

Garik Israelian
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

When examining the VLT (ESO, Chile) spectra of the star HD 82943 (with a planetary system), we found that they showed the unmistakable fingerprint of lithium-6 (^{6}Li), an isotope of this element which should not appear in a "mature" star like HD 82943, because lithium-6 is extremely "fragile" and, although it can be a part of the primordial material that forms a star, it cannot live for long.

In stars similar to the Sun, any atom of ^{6}Li would disappear during the first million years of the stars lifetime: Strong gas currents would carry ^{6}Li to the inner layers of the star where the temperatures are 5, 10 or 15 million degrees. ^{6}Li can not resist temperatures above 1.5 million degrees; beyond this temperature it is destroyed. Therefore, finding this isotope fingerprints in the spectrum of HD 82943 was a surprise. We calculated that in order to leave such a mark on the spectrum of the star, some 3.2×10^{44} atoms of ^{6}Li would be necessary, an incredible amount. And this was crying out for an explanation.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

As planets are very far from reaching the temperatures of the stars, they can easily preserve the initial amount of this isotope.

Therefore, things would start to make sense and the hypothesis of engulfed planets arises in a natural way: The simplest way to explain the observations is that one or more planets have fallen into the star.

Since the paper was published, have there been significant advances in this specific area?

We have confirmed the presence of ^{6}Li in this star with even better quality spectra. Other groups tried to detect ^{6}Li in other planetary systems. In some cases there are "signs" but there is not a clear detection.

It is a very complicated project and requires a lot of work with very high-quality spectra and very well modelled synthetic spectra.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The two fundamental problems in this field are the identification of weak lines and possible blends with the lithium lines. The convection processes can

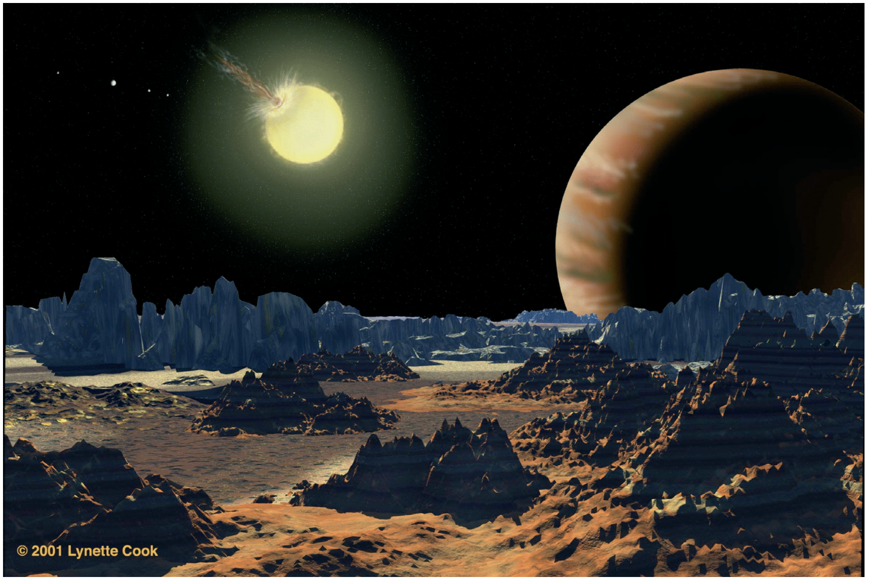


Figure 1. Artist's impression of a planet falling into its star, as seen from a third planet. Courtesy: Lynette Cook.

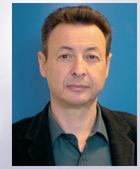
cause asymmetries in the spectral lines and that can therefore affect the detection of the ^{6}Li isotope.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?
Yes, I have continued to work on this topic. We are still analysing the ^{6}Li in the stars with planets. We improved the theoretical lists of spectral lines and also studied the asymmetries of iron lines. We will obtain the first results in a couple of years or so.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?
The news about our discovery had a great impact and was featured in newspapers, on television, radio and the internet.

EVIDENCE FOR PLANET ENGULFMENT BY THE STAR HD 82943
G. ISRAELIAN, N.C. SANTOS, M. MAYOR AND R. REBOLO
2001, NATURE, 411, 163

José María Torrelles Arnedo
Institut de Ciències de l'Espai (CSIC-IEEC, Barcelona)



What was the problem you had to face?

Stars similar to the Sun are formed by an accretion process, whose first stage is the collapse and fragmentation of interstellar clouds of gas and dust. The material accumulates in the centre, forming a "protostar" or stellar embryo. One part of the unused material is ejected at high speeds in the form of jets, while the rest is accumulated around the protostar, forming a rotating disk. Later, the matter from this disk falls into the protostar and this evolves into a star surrounded by a planetary system. However, the birth of stars much more massive than the Sun was, and still is, a mystery in many aspects. Our research group thinks that those stars can be formed by accretion, in a similar way to the less massive stars. In 1997, we observed a massive protostar candidate (15 times the mass of the Sun) in the Cepheus region, which was thought to be surrounded by an accretion disk. We decided to observe this region through the emission of water vapour molecules with the radio telescope system VLBA (Very Long Baseline Array) with the aim of studying the structure and kinematics of the gas in the disk. The VLBA has the capacity to resolve very small details, 200 times better than the Hubble Space Telescope.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

Although the data we obtained were consistent with the presence of a disk around a massive protostar called HW2, our big surprise was to discover a water-vapour spherical bubble expelled by another stellar embryo in the vicinity of HW2. This bubble, ejected 33 years ago, has been expanding through the interstellar medium at a speed of 32,000 km/h, reaching a size of 18,000 million kilometres, comparable to the size of our Solar System, but preserving a perfect spherical form. Up to now it was known that when most stars are born its main feature is that they eject large amounts of matter into the interstellar medium in the form of *jets,* highly collimated and moving at supersonic speeds, in agreement with theoretical predictions.

That is why we were very surprised to find such a perfect expanding spherical bubble, something very difficult to explain from a theoretical perspective. Our contribution was to

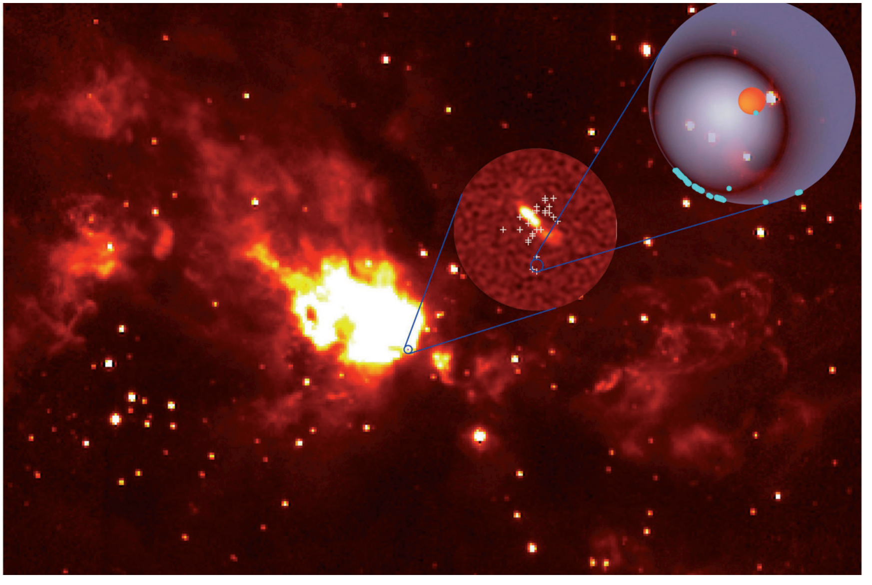


Figure 1. Image of the infrared emission of the gas and dust cloud in the Cepheus constellation, located some 2,000 light years from Earth, where many stars are being born. The first zoom-in of the image shows the detail of one of the stellar embryos (the bright and elongated structure that can be appreciated in the centre), surrounded by strong water vapour emission (indicated with crosses). The second zoom-in of the image (on the right top corner) recreates the location of the enigmatic stellar embryo that has produced a spherical bubble of water vapour around it, which continues expanding after reaching a size similar to our Solar System. The discovery of this bubble has been made using the VLBA radio telescope system at the National Radio Astronomy Observatory (NRAO), observatory that depends on NSF (USA). (Infrared image credit: Klaus-Werner Hodapp).

find, by chance, a new phenomenon that may have to do with an unknown physical process that causes the ejection of matter in a very early stage of the stellar embryo evolution, long before the influence of the protoplanetary disks is evident.

Since the paper was published, have there been significant advances in this specific area?

Our observations and results motivated other research groups to make similar observations of the water-vapour emission in other star forming regions using the VLBA. This instrument, which belongs to the National Radio Astronomy Observatory (USA), is composed of ten radio telescopes (each with a dish 25 meters in diameter): One located in Hawaii, another in St. Croix (U.S. Virgin Islands) and the other eight in the North American continent. The ten radio telescopes are remotely controlled. As a result of those new observations, two additional protostars has been found that eject gas in multiple directions into the interstellar medium, almost isotropically (although the sphere is not as perfect as in the case of the Cepheus region). So far, we know that the water-vapour emission is the product of very violent collisions in the interstellar medium gas.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?
The main problem of this new phenomenon is to explain, from a theoretical point of view, the physical origin of isotropic ejections during the first stages of stellar evolution. So far, we do not have a conclusive answer. In the next few months we are expecting to explain the evolution of the spherical bubble found in the Cepheus region, from its discovery to the present day. In order to do that, we are in the process of analysing new observations made in the region with the VLBA. Very preliminary results indicate that the bubble, although it still preserves some features that we presented in our *Nature* paper, is being dissipating into the interstellar medium.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?
We exploited the potential of the VLBA and its associated reduction software to carry out the observations of the Cepheus region. As a result, all the members of the group that participated in this experiment have the motivation to continue in this line of research, and at present it is one of the priorities of our Spanish research group composed by researches from the Instituto de Astrofísica de Andalucía (CSIC), Universitat de Barcelona, and Institut de Ciències de l'Espai (CSIC).

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?
Perhaps it is not an anecdote, but I do remember the first big surprise when coming across this discovery, which we were not looking for, and the subsequent joy shared by all the members of the team. Undoubtedly, so far this has been the most complex research project I have had the good fortune to be part of with our whole team.

Spherical episodic ejection of material from a young star
J.M. Torrelles, N.A. Patel, J.F. Gómez, P.T.P. Ho, L.F. Rodríguez, G. Anglada, G. Garay, L. Greenhill, S. Curiel and J. Cantó
2001, Nature, 411, 277

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What was the problem you had to face?

Planetary Nebulae (PNe) are formed when the envelope ejected during the earlier red giant phase is ionized by the radiation from the remnant central star. In 1997 we obtained images and analysed spectra of K3-35, an object whose nature was controversial: PN or forming star? Our analysis, published in 1998, conclusively proved that K3-35 is a planetary nebula. This result was not consistent with the existence of water maser emission towards K3-35, as detected by other researchers. Water masers are abundant in red giants but were inconceivable in PNe where the physical conditions for such an emission do not exist. However, the existing observations did not have enough spatial resolution to precisely locate the masers with respect to K3-35.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In 1999 we used the Very Large Array (VLA) to obtain simultaneous data of the water masers and of the radio continuum (which traces the ionized region) in K3-35. This technique allows us a very precise measurement of the relative positions of both emissions. Water masers were indeed associated with K3-35, which became the first PN discovered with water masers. The masers were located in a disk with a radius of 85 AU (1 astronomical unit is equivalent to 150 million kilometres) and, surprisingly, also at a distance of 5,000 AU from the centre, at the tips of two collimated jets. The physical conditions to excite the water maser do not exist at such enormous distances, so we proposed that the jets were involved in the excitation. We also observed OH masers in K3-35. The OH emission at 1,665 MHz was circularly polarized, implying that we had detected a magnetic field in a PN for the first time.

Since the paper was published, have there been significant advances in this specific area?

The existence of PNe with water masers is a fact today. As well as K3-35, our group has detected two other PNe and several PN candidates with water masers. We know that ejections of matter with non spherical geometry, probably in the form of collimated jets, represent a crucial role in the formation of water masers in these objects. We have a basic understanding of how water

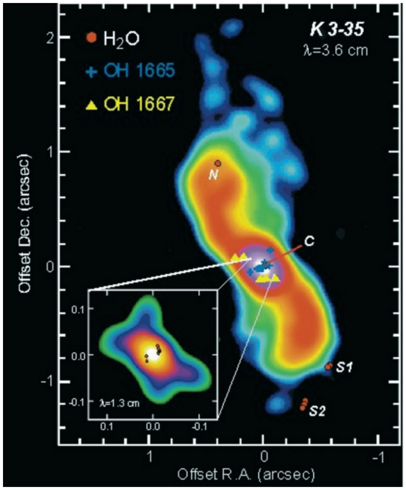


Figure 1. *Water-maser emission and OH maser emission in the planetary nebula K3-35. The colour images represent the radio continuum emission at 3.6 cm (large image) and at 1.3 cm (small image), that trace the ionized region of the object. The reddish region in the image at 3.6 cm represents the collimated bipolar jet of K3-35. The red dots indicate the water maser positions (regions N, C, S1 and S2). The blue crosses indicate the OH maser emission at 1,665 MHz, and the blue triangles indicate the OH maser positions at 1,667 MHz. In the 3.6 cm image, the distance between the N region and the centre of the object is about 5,000 AU. In the 1.3 cm image, the distance between the masers and the centre is about 85 AU.*

masers evolve in these phases of stellar evolution, and there is evidence that these masers are associated with relatively massive stars (about 4-5 solar masses). Magnetic fields have been detected and measured in several PNe, including a very detailed study of K3-35 carried out by our group, and in their central stars. The existence and magnitude of magnetic fields give observational support to theoretical models for the formation of PNe that incorporate magnetic fields.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Nowadays we know that PNe present very complex structures: Non-spherical, multipolar or highly collimated, envelopes and high velocity bipolar jets, in many cases with direction changes and/or several orientations within the same PN. These components cannot be explained with the classical concepts of late stellar evolution and represent a challenge for theoretical models.

We think that, in the formation of PNe, multiple physical factors are involved: Interaction between the winds of the central star, magnetic fields, binary nature of the central star and collimated jets. In the next few years we expect significant advances in our knowledge of the origin of collimated jets, mainly through the study of water masers, in the detection of binary central stars and in the influence of magnetic fields in the formation and evolution of PNe.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Water-maser detection in K3-35 led us (an increasingly large group of researchers) to search for this emission in other PNe. We already know three PNe and have several other PN candidates with water maser emission. We are also searching for and detecting water masers in objects in an evolutionary phase immediately prior to the PN stage.

The relevance of all these objects has led us to observe them in other wavelengths (infrared, optical, X-rays) and with several observational techniques (images, spectra) to obtain more information about their characteristics and properties. K3-35 itself has been the target of many observations, by our group and other groups. We can say that water detection in K3-35 has opened a new research line whose results are building the base of new future projects.

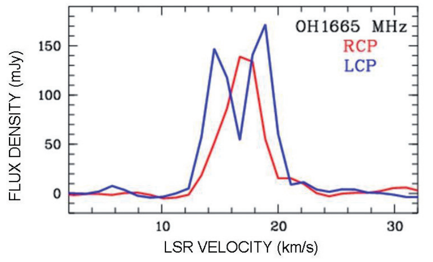
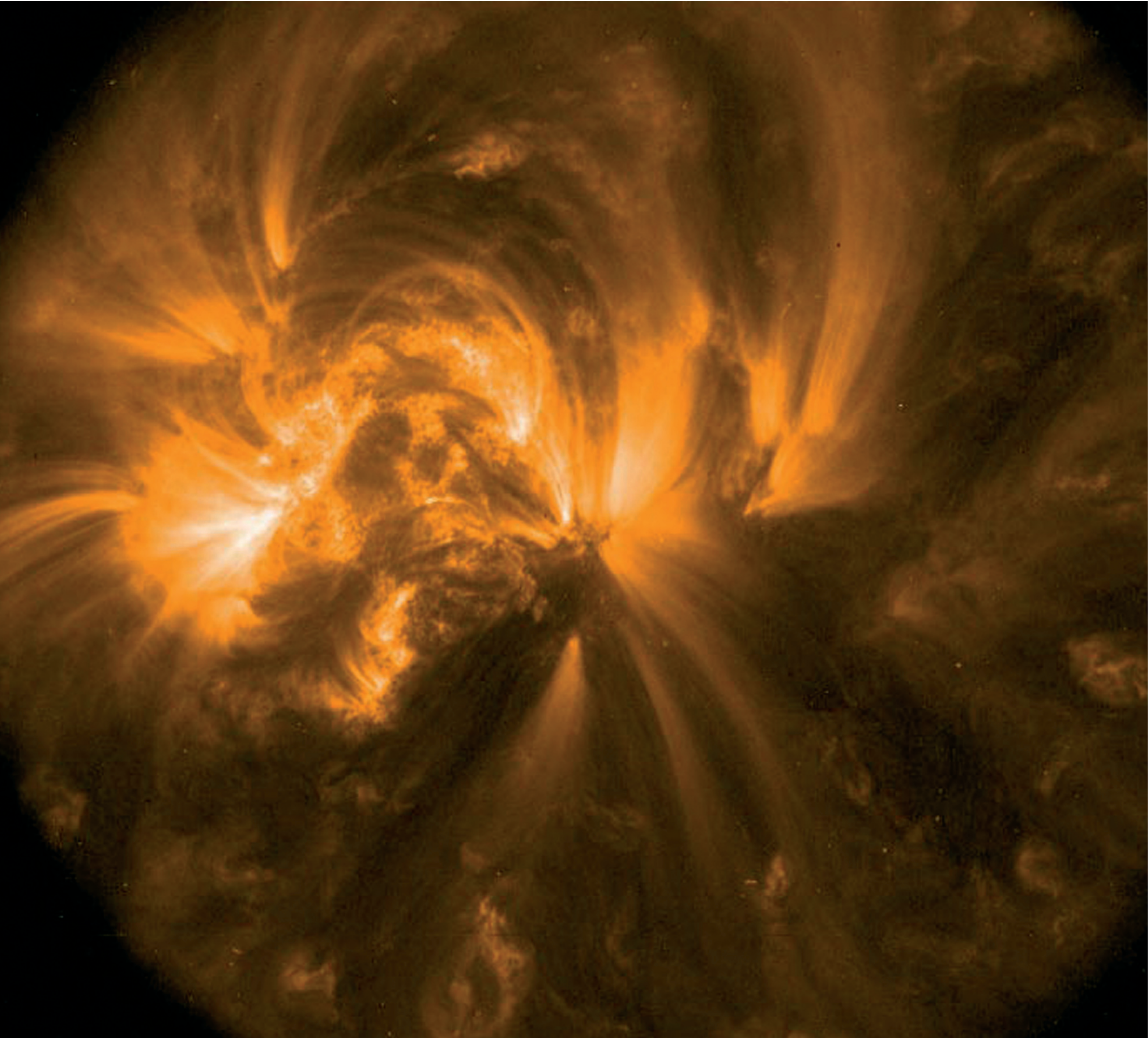


Figure 2. *OH maser emission spectra at 1,665 MHz. The blue spectrum shows the left circular polarized emission (LCP) and the red spectrum shows the right circular polarized emission (RCP). The difference between the two spectra indicates the presence of a magnetic field.*

Water-maser emission from a planetary nebula with a magnetized torus
L.F. Miranda, Y. Gómez, G. Anglada, and J.M. Torrelles
2001, Nature, 414, 284



Javier Trujillo Bueno
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

The problem was the determination of the magnetic field in the solar atmospheric plasma, both in structures embedded in the chromosphere and the corona, and in the apparently non-magnetic regions of the underlying photosphere. For this, it is necessary to measure and interpret the polarization of the sunlight in spectral lines originating in its atmosphere.

The physical mechanism that produces polarization in a spectral line is the Zeeman effect; this effect had been used to carry out most of the research until then. The polarization produced by the Zeeman effect is due to the energy splitting of the upper and/or lower magnetic levels of the spectral line considered. The good news is that the simple detection of polarization due to the Zeeman effect implies the presence of a magnetic field. The bad news is the following: On the one hand, plasma diagnostic techniques based in the polarization of the Zeeman effect are not very practical for the determination of the magnetic field in hot plasmas (like the ones in the Sun's chromosphere and corona) because the larger the thermal broadening of the spectral lines the lower the amplitude of the polarization signal; on the other hand, the Zeeman effect as a plasma diagnostic technique tends to be "blind" to the presence of highly tangled magnetic fields below the resolution element of current telescopes.

In short, the lack of detection of polarization induced by the Zeeman effect does not necessarily imply the absence of magnetic fields in the observed plasma.

What was the solution to this problem and the contribution that your two Nature papers made to the area of expertise in which they are framed?

The solution to the problem of the magnetic field determination in those plasma regions of the solar atmosphere involved the development and application to spectropolarimetric observations of new diagnostic techniques based on the Hanle effect (Figure 1).

The investigation we carried out on the magnetism of the apparently non-magnetic regions of the solar photosphere (Trujillo Bueno, Shchukina and Asensio Ramos 2004) consisted in measuring the linear polarization amplitudes produced by

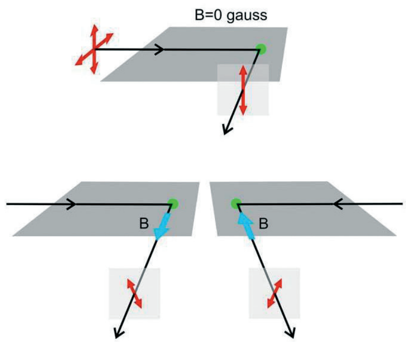


Figure 1. The upper panel shows that light scattering processes by atoms in a stellar atmosphere produce linear polarization in spectral lines. The lower panels indicate that this polarization is modified by the presence of a magnetic field (Hanle effect). For the situations represented in both lower panels, the modification with respect to the non-magnetized case of the upper panel is a decrease in the polarization amplitude and a rotation of the polarization direction. Note that, even for the case where both magnetic polarities of the lower panels are mixed together below the observational resolution limit, we still have a measurable effect as the polarization amplitude of the observed light continues to be lower than that corresponding to the non-magnetized case of the upper panel.

scatterig processes in carefully selected atomic and molecular spectral lines and comparing them with the ones that the Sun would produce if it were not magnetized. The difference between the observed polarization and the polarization corresponding to the non-magnetized case is due to the presence of a "hidden", spatially unresolved magnetic field. We managed to determine its intensity thanks to our numerical simulation of the polarization induced by scattering processes, and its modification by the Hanle effect, in three-dimensional hydrodynamical models of the solar photosphere. The mean magnetic field intensity we derived is very significant (about 100 gauss), and it is much more intense in the intergranular regions than in the granular regions of the solar photosphere. The intensity and ubiquity of this unresolved magnetic field implies that the apparently quiet regions of the solar atmosphere contain an enormous amount of magnetic energy, so large that only a small fraction would be sufficient to balance the radiative energy losses produced in the external regions of the solar atmosphere (the chromosphere and the corona).

In our second publication (Trujillo Bueno et al. 2002) we managed to predict (with calculations based on the quantum theory of polarization) and discover (with observations carried out with the Tenerife Infrared Polarimeter developed by the IAC) the existence of peculiar polarization signals in the spectral lines of the neutral helium triplet at 10830 Angstroms, when observing huge plasma structures of the solar corona (prominences) where it was believed that such a polarization should be insignificant. In particular, we proved that the Hanle effect can be used as a magnetic field diagnostic technique for the whole solar disk and not only in 90º scattering geometry, as was previously thought. We also discovered a new physical mechanism that generates polarization in spectral lines (the selective absorption of polarization states). This is very difficult to study in terrestrial laboratories, as it requires the observation of the light that is partially absorbed by a very-low density and large dimension plasma (Figure 2). Besides, for this to be produced, the atoms in the plasma under study must be excited by anisotropic radiation pumping, something that happens naturally in the external regions of the stellar atmospheres. The importance of this discovery lies in the fact that it enables a reliable study of magnetic fields in the solar chromosphere and corona, as well as in other astrophysical systems such as that of supernova atmospheres. For example, recent applications of our diagnostic technique are making it possible to study the strength and geometry of the magnetic field that confines the plasma of the enormous solar prominences; these prominences usually cause impressive coronal mass ejections that sometimes affect the near-Earth environment.

Since the publication of these two papers, have there been significant advances in this specific area?

Yes, in the first place, today many scientists who work on solar and stellar physics are applying our plasma diagnostic techniques to

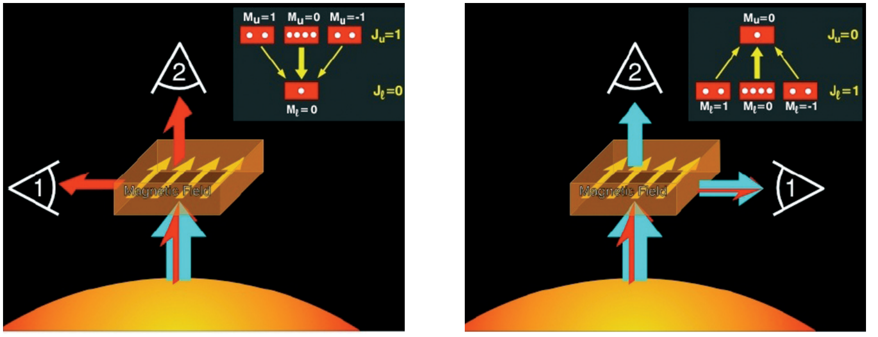


Figure 2. Illustration of the polarization of the emergent spectral line radiation resulting from 90º and forward scattering processes, when these scattering processes take place in an optically thin plasma permeated by a horizontal magnetic field. The left panel refers to a spectral line whose upper level has an angular momentum J(up)=1 and its lower lever J(low)=0, while the right panel corresponds to a line with J(up)=0 and J(low)=1. In each case, the anisotropic illumination of the atoms produces the atomic polarization shown (see the differences among the populations of the three magnetic sublevels in each atomic level with J=1). Therefore, in the left panel the linear polarization observed is due to selective emission of polarization states, while in the right panel the only mechanism in action is selective absorption of polarization states. For this reason, in the right panel, an observer placed at the position (1) sees that light scattered at 90º by an optically thin plasma is not polarized while, at position (2), he/she sees linearly polarized light perpendicular to the magnetic field.

deduce the magnetic field from the observations of the polarization caused by the joint action of the Hanle and Zeeman effects, and this is producing an important advance in our empirical knowledge of the magnetic fields that confine the plasma of the chromospheric and coronal structures. In addition, some space agencies, as the Japanese, are planning a new solar space telescope; one of the two possible options includes sophisticated instruments to observe the polarization signals in spectral lines that we have investigated in our research. Such spectropolarimetric observations would give rise to an unprecedented development in solar and stellar physics.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Regarding telescopes, the main problem lies in that we do not have any large-aperture solar telescope on Earth (for example, with a 4 meter diameter), which is essential for detecting many of those polarization signals with a spatial resolution of 100 km over the solar atmosphere and with a temporal resolution of the order of seconds. Fortunately, several European countries are working together on the design of what could be the European Solar Telescope (EST), although, provided the funding for its construction on one of the observatories in the Canary Islands is obtained, it would not be operational before 10 years from now. Another good piece of news is that, as I mentioned before, the Japanese space agency is very interested in equipping its next solar telescope with new instruments designed to measure the polarization signals resulting from the joint action of the Hanle and Zeeman effects in several spectral lines. In fact, a few months ago, in an important meeting in Tokyo, scientists from all over the world have discussed in depth the two ongoing proposals for such a space telescope known as SOLAR-C.

From the theoretical point of view, including the numerical simulation of the processes of the generation and transfer of polarized radiation in magnetized plasmas, perhaps the main problem is that there are very few scientists working in this fascinating research field, which requires the careful combination of atomic physics, numerical simulation and spectropolarimetric observations with sophisticated instruments.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I think it had a significant influence, although I do not believe that a good paper published in *Nature* or *Science* is better than a good paper published in other journals like The Astrophysical Journal o Astronomy and Astrophysics. Papers published in *Nature* and *Science* are like luxury press releases but not everything a scientist achieves is suitable to be published in those interdisciplinary journals. It is good to publish in them from time to time, provided that they are good papers, also interesting for scientists who work in other disciplines, but the aim should always be to contribute to the development of science and publish the scientific results clearly and rigorously in the optimum journal for each particular research work. Regarding the second question, we continue working with great interest in this line of research but we are trying to facilitate the application of these developments achieved in solar and stellar physics to other fields of Astrophysics.

Selective absorption processes as the origin of puzzling spectral line polarization from the Sun
J. Trujillo Bueno, E. Landi Degl'Innocenti, M. Collados, L. Merenda and R. Manso Sainz.
2002, Nature, 415, 403

A substantial amount of hidden magnetic energy in the quiet Sun
J. Trujillo Bueno, N. Shchukina and A. Asensio Ramos
2004, Nature, 430, 326

Margarita Hernanz Carbó
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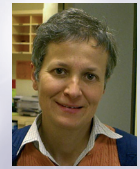
(CSIC-IEEC, Barcelona)



What was the problem you had to face?

Although at first sight all the stars in the sky appear to be unchanging and with a constant brightness, often there are stellar explosions that extremely increase the luminosity of some objects. Nova explosions are an example. They are produced when a white dwarf star accretes hydrogen-rich matter from a close companion star. The progressive accumulation of mass on the surface of the white dwarf ends up provoking the uncontrolled nuclear burning of hydrogen, with the resulting ejection of the envelope of the star at velocities of several hundreds or thousands of km/s, accompanied by a large increase in luminosity. The turn-off of nuclear burning that causes the nova to fade and return to its original state of quiescent mass transfer is relatively unknown and it is only observable in X-rays. This is why we decided to observe the X-ray emission, with the aid of satellites, of some novae after they have exploded.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

X-rays are the only way to study the phases after the nova explosion; once the envelope has been ejected, the hydrogen nuclear burning continues quiescently on the surface of the white dwarf; this keeps the atmosphere very hot and it emits X-rays. The European Space Agency's XMM-Newton (X-ray Multimirror Mission) satellite offers a unique opportunity to study this emission thanks to its large collecting area. Our observations of the nova V2487 Oph, which had exploded in 1998, with the XMM-Newton satellite produced surprising results, as we did not detect the hot atmosphere of the white dwarf but a different kind of X-ray emission, characteristic of the violent fall of matter onto the surface of a white dwarf with an intense magnetic field. Therefore, we deduced that the transfer of matter had been re-established as early as 2.7 years after the explosion.

Since the paper was published, have there been significant advances in this specific area?

Since the year 2002, there have been important advances in the field of X-ray observations, since both XMM-Newton and Chandra satellites have provided new excellent quality data. High-resolution spectra have been obtained, enabling the

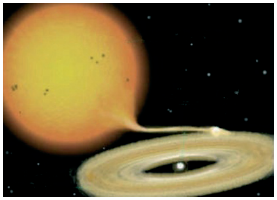


Figure 1. Artist's concept of a white dwarf capturing matter from its companion. The result of this accumulation of matter is a nuclear explosion known as nova.

transfer from the imaging era to the spectroscopy era in the X-rays, as happened decades ago with optical astronomy. Knowing the amount of energy per unit time emitted at each frequency or wavelength, through the study of emission/absorption lines, allows us to study the underlying physical phenomena. In the case of novae, we have an increasing amount of information regarding the very hot atmosphere of the white dwarf and the surrounding material, both the material that is ejected during the explosion and the material that falls onto the white dwarf again, transferred from its companion.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

In the field of stellar explosions, several fundamental problems remain to be solved. On the one hand, theoretical models of the explosion itself still include some simplifications, such as the assumption of spherical symmetry and therefore the resulting one-dimensional calculation, which should be overcome in the near future. Both the constant improvement of computer power and the development of new numerical techniques will make it possible to tackle the explosion phenomenon in three dimensions, with reasonable calculation times. Regarding X-ray observations, the level of detail that is being achieved with X-ray spectrometers on board XMM-Newton and Chandra is a challenge for theoretical interpretation, and more complete X-ray emission models are necessary, including very hot white dwarf atmosphere models and mass accretion models in the presence of intense magnetic fields.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

In my professional career I have continued working in research topics along the path opened by the paper I published in *Science* in 2002. It is known that, in science, a single object does not define a phenomenon, therefore more cases should be found to be able to establish the general or exceptional nature of the event. The X-ray observatory XMM-Newton has allowed us to apply the same study of the fading and subsequent recovery of novae to other objects. So far, we have not found any object of the same type as V2487 Oph, but we have indications that they must exist since we have detected similar objects. In addition, we want to take advantage of future space instruments both in the X- and gamma-ray ranges. In fact, we have become involved in their design to ensure that it will be possible to achieve the best quality science.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The publication of this paper had quite an impact in the media, bigger than usual, because the authors were two women. Although this is something that should not be surprising, it was much highlighted in the media, with sentences like "two women astronomers discover…" The female authorship seemed to be more important than the content of the paper. Besides, it stressed the fact that the authors were my thesis student —Glòria Sala— and me —her thesis director— something that it is actually quite usual in our research field. In brief, there were several interviews about work and family "conciliation", etc., that probably would not have been made if the authors were not women; this shows that we have not yet reached equality.

A Classical Nova, V2487 Oph 1998, Seen in X-rays Before and After Its Explosion
M. Hernanz and G. Sala
2002, Science, 298, 393

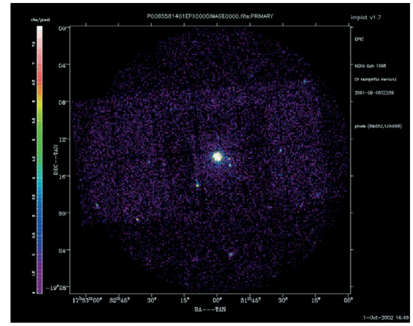
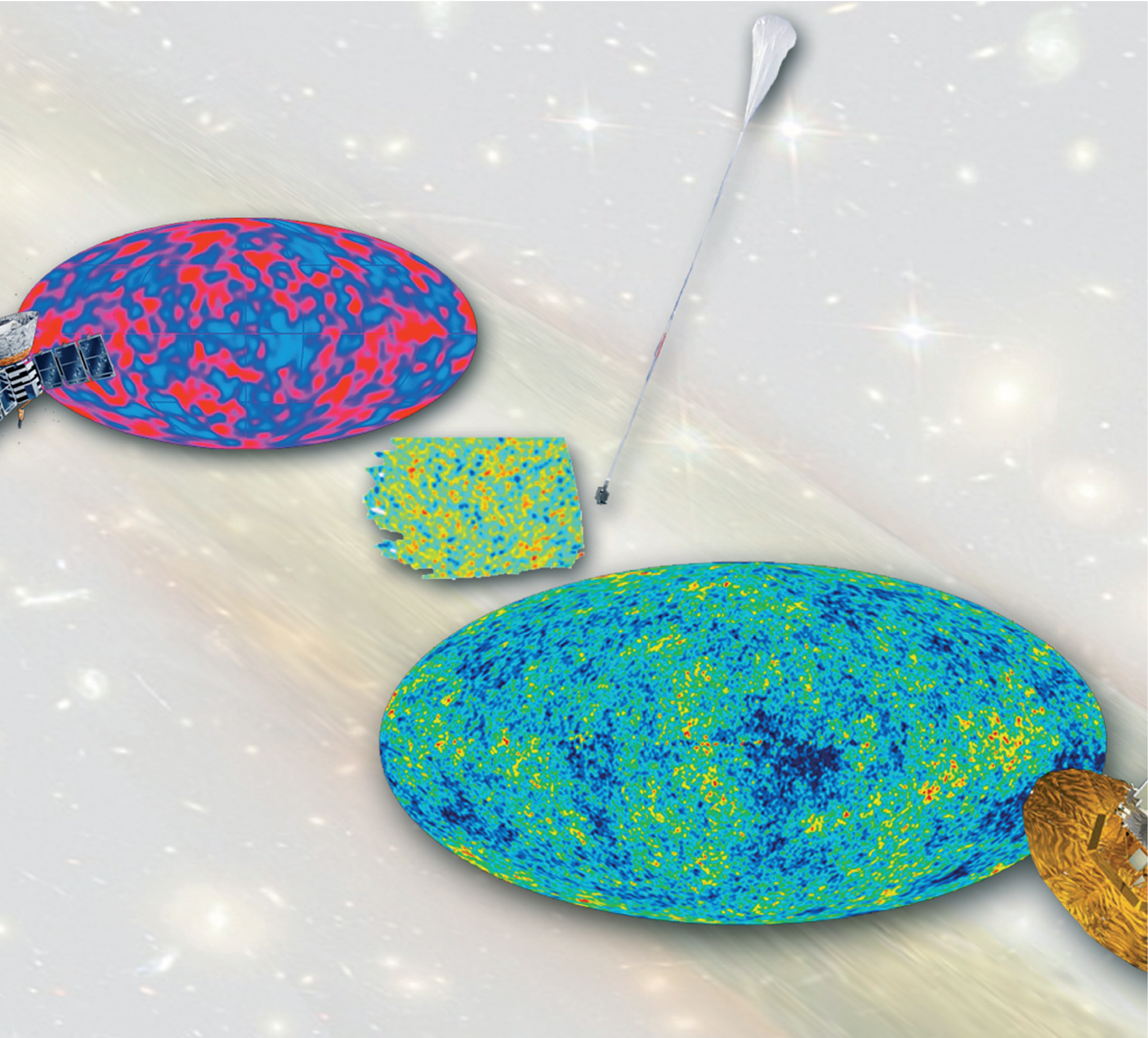


Figure 2. *Image of the Nova Oph 1998 obtained in X-rays with the instrument EPIC on board the XMM-Newton observatory.*



Jordi Miralda Escudé
Institució Catalana de Recerca i Estudis Avançats (ICREA)
Institut d'Estudis Espacials de Catalunya (IEEC, Barcelona)

What was the problem you had to face?

I had to write a paper summarizing the advance in our scientific knowledge about the first stars and galaxies formed in the Universe, and the way they influenced the intergalactic medium.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The contribution was to make a review of the work done until that moment by many scientists and the things we had learnt from different observations.

Since the paper was published, have there been significant advances in this specific area?

Yes, there have been quite a few. One of the most important ones was the increase in the accuracy of the measurement of the opacity of the Universe since the moment the first stars were formed. We can measure the opacity of the Universe towards the furthest radiation that we can observe, that is called the "cosmic background radiation" and it has been filling all the space since the Big Bang. Background radiation started to propagate through space freely when the Universe was 400,000 years old; at that moment the temperature had dropped enough for atoms to start forming for the first time. Before that time, the Universe was opaque, since ionized matter (with atomic nuclei and free electrons) is much more opaque than atomic gases. However, when the first stars and galaxies were formed, matter became ionized again; this is the so-called reionization epoch. When observing the background radiation, we can see the fraction of that radiation that has been absorbed on its way towards the Earth, as the radiation passed through the reionization epoch and was scattered by the ionized matter. This gives the Universe a certain opacity.

The first measurements suggested an opacity of 15%. This seemed to indicate that the first stars had been formed very early compared with theoretical predictions of the structure formation in the Universe, although the measurement error was very high. Subsequent higher precision measurements have indicated that the opacity is about 8%, a value more in agreement with the expectations.

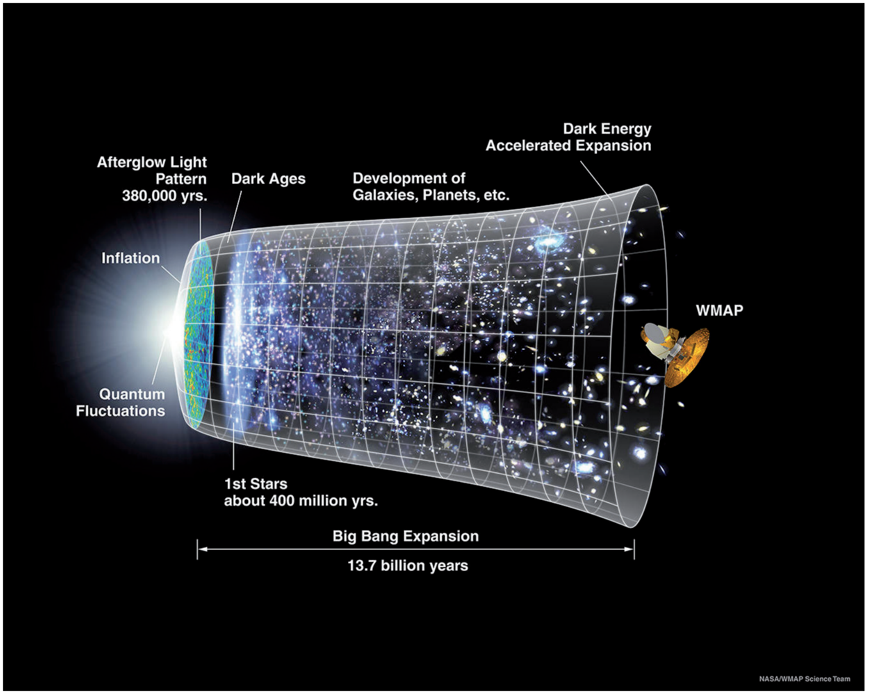


Figure 1. *Sketch of the evolution of the Universe. Courtesy of the WMAP consortium.*

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The problems are to find out what type of stars and galaxies first formed, the age of the Universe when that happened and the type of radiation they emitted that ionized the Universe.

We hope several new discoveries in this field will advance our knowledge during the next decade. Infrared telescopes will allow us to discover increasingly distant galaxies, observed when the age of the Universe was less than 1 billion years and the first galaxies were forming.

We also expect to be able to observe the largest stellar explosions, called gamma-ray bursts, which can also be observed at the largest possible distances due to their incredible luminosity; the detection of these bursts shows the presence of massive stars and allows us to examine the state of the surrounding medium. Another important advance is going to be the probable detection of hydrogen in the 21-cm line from intergalactic atomic matter in the early Universe, at the epoch when the first stars were forming, using radio telescopes observing at very low frequencies. This would represent a great milestone for observational cosmology.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I am still thinking and investigating on this topic but I also work on other issues.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

When I was writing the paper, I was living in the US state of Ohio and I had a Swiss girlfriend who was a professor at the Chinese Literature Department at the University. The subject of my paper was obviously very far from her specialization. However, when the deadline for submitting the paper was only ten days away and I was getting nervous because I had not written anything yet, she gave me an idea on how to start it.

From there, I was able to write the ideas I had in mind very quickly. At the end of the paper I mentioned her name in the acknowledgments. After its publication, I gave her a copy but I think she never realized her name appeared in the acknowledgements of a paper in *Science*.

The Dark Age of the Universe
J. Miralda-Escudé
2003, Science, 300, 1904

Josep Miquel Girart Medina
Institut de Ciències de l'Espai
(CSIC-IEEC, Barcelona)

What was the problem you had to face?

Stars are formed by the collapse (by their own gravity) of giant interstellar clouds of molecular gas and dust particles. These clouds are opaque to visible radiation because of the presence of dust grains. So, if we want to study the star formation we should observe star-forming regions in the infrared or microwave wavelengths. In the last decades, there have been important developments in telescopes and their instrumentation at these wavelengths that have made it possible to achieve great advances in our knowledge of star formation. But there is still a long way to go, and there are many unanswered questions. One of them is: What mechanisms controls the start and subsequent evolution of the collapse of a gas cloud: magnetic fields, turbulence…?

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The interstellar magnetic field can only be studied if it is possible to detect the polarized radiation. The polarized emission is only a small fraction of the total radiation that a telescope receives, which is already very weak, especially at microwave wavelengths! (This is the reason why radio telescopes are usually very large). A decade ago, we made one of the first advances with the BIMA interferometer (Berkeley Illinois Maryland Association, California). At these radio telescopes, we installed a system that detected the polarized emission of dust grains in molecular clouds where stars are forming.

More recently, a polarimeter was installed at the SMA (Submillimeter Array, in Mauna Kea, Hawaii), the first set of antennas that reaches wavelengths below the millimetre range. Taking advantage of the sensitivity of this radio telescope to the radiation generated by interstellar dust, we pointed it towards one of our best candidates: a region where stars like the Sun are forming, which is at a distance of only 1000 light years from the Earth. And we hit the bull's-eye! The images we obtained clearly showed that the collapse of the cloud drags the magnetic field, making it to adopt a shape similar to an hourglass, as predicted by the models that see the magnetic field as the "controller" of the collapse.

Since the paper was published, have there been significant advances in this specific area?

There have been modest advances. Despite the power of the SMA, the

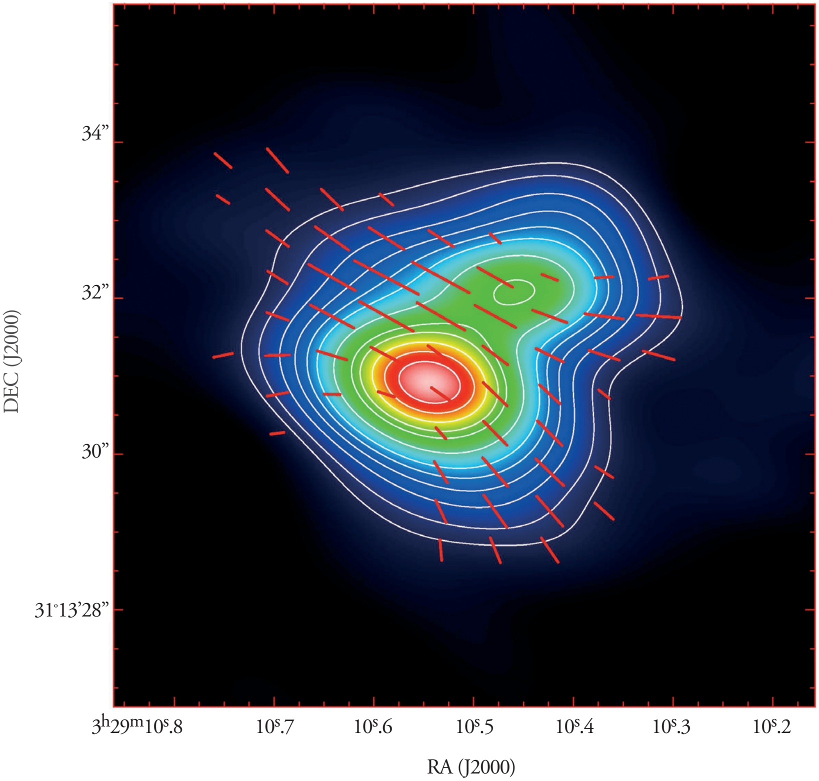


Figure 1. *Image obtained with the SMA at 0.88 mm of the dust emission associated with the region NGC 1333 IRAS 4A, a place where stars like the Sun are forming. The red bars indicate the direction of the magnetic field.*

number of molecular clouds which are bright enough at submillimeter wavelengths is not very large. So the sample of the study is relatively small. But, little by little, I think that in a few years there will be significant advances.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Regarding star formation, there are still plenty of controversial or little-known aspects. One is to know if the more massive stars form in the same way as less massive stars, like the Sun. Another is to know how planets form. The advance in both problems is limited by the enormous difficulty in observing these processes. In this sense, ALMA (Atacama Large Millimetre/submillimiter Array), a new interferometer that is being built in Chile at an altitude of more than 5000 meters above sea level, is going to have a huge impact on the progress of these problems, as well as in many others. There is an important part of the astronomical community that, as we say in

Catalan, *"espera amb candeletes"* ("eagerly awaits") the commissioning of ALMA.

Figure 2. The Submillimeter Array, located atop Mauna Kea in Hawaii, at an altitude of more than 4000 meters.

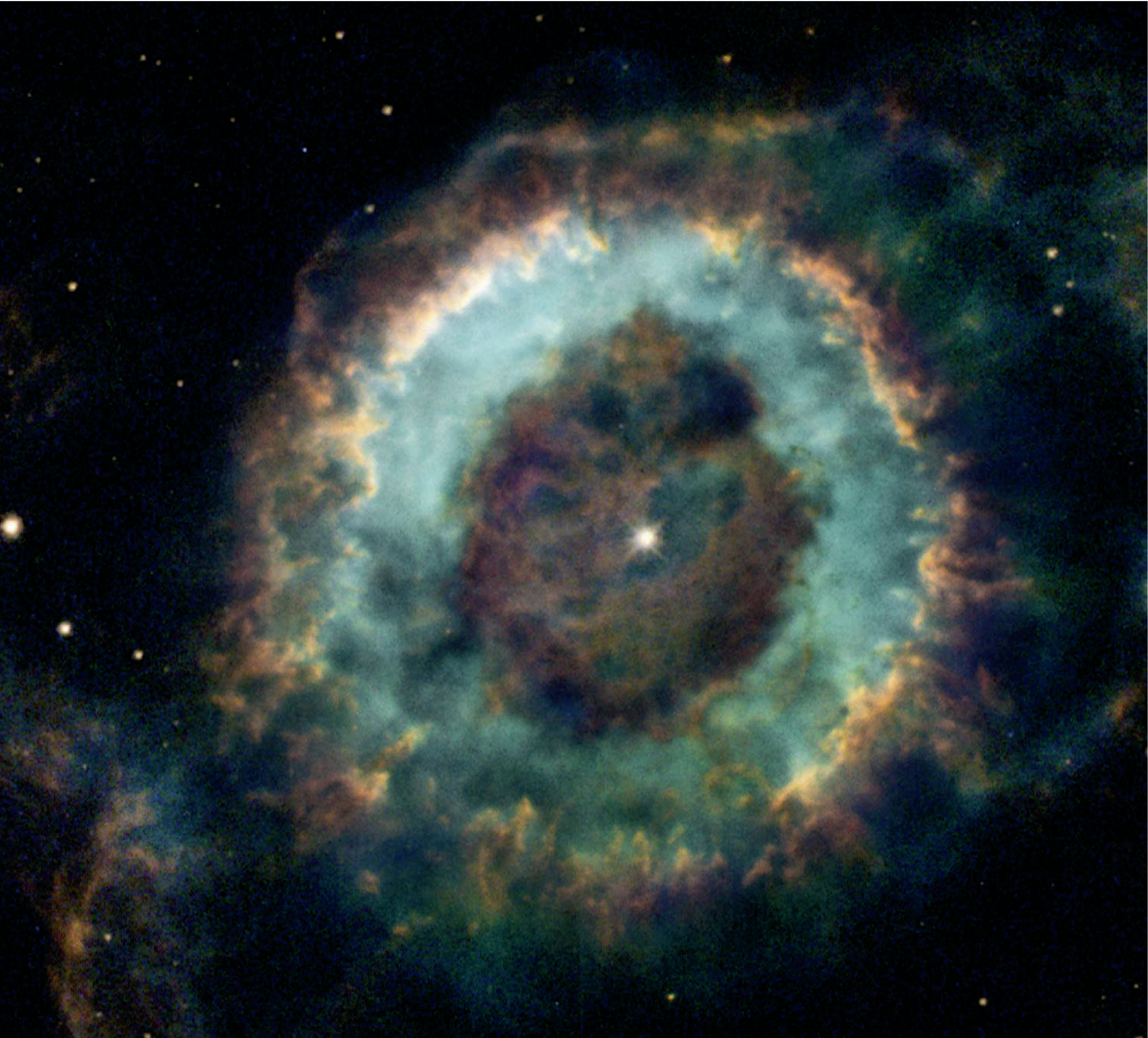
How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

Since we realized the importance of the results, our group has devoted an important part of its research to the study of the magnetic field in molecular clouds, trying to take the most out of the SMA, as well as other instruments which are able to detect the polarized emission of interstellar radiation.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

Our observations were the first made with the SMA polarizing system, so we were the guinea pigs. In Hawaii, I processed the data obtained from the observations with the SMA, in collaboration with my colleague Ramprasad Rao (a Hindu living in Hawaii and working for the SMA). For several reasons we realized that the software designed by the SMA for the processing of data collapsed with our data obtained using the polarizing system. We did not make any progress at all in those days, it was completely frustrating! We had to go back to the past, and use older software that worked very well for BIMA, and adopt some routines to the specifications of the SMA, without being sure that it would actually work. In the end, we managed to do it and when we obtained the first images we immediately realized the importance of the results.

MAGNETIC FIELDS IN THE FORMATION OF SUN-LIKE STARS
J.M. GIRART, R. RAO AND D.P. MARRONE
2006, SCIENCE, 313, 812



Aníbal García Hernández
Instituto de Astrofísica
de Canarias (Tenerife)

What was the problem you had to face?

We wanted to identify, for the first time, the old stars of our Galaxy (Asymptotic Giant Branch or AGB stars) with masses between 4 and 8 times that of the Sun, for studying their chemical composition and the elements produced inside them. This would allow us to observationally prove the theoretical models of the late stages of the life of stars of this type (stellar evolution), as well as the physical mechanisms (stellar nucleosynthesis) that convert them into factories of heavy elements, including some very exotic elements like rubidium, zirconium, barium, strontium, etc. In particular, stellar evolution models predicted more than 40 years ago that this type of stars should produce rubidium (particularly the isotope rubidium-87, ^{87}Rb) in large quantities; however, this had never been observationally confirmed.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

With measurements at radio wavelengths and of their infrared colours we could efficiently isolate the right stars for the first time. The chemical analysis of these stars allowed us to discover that shortly before dying they show an extraordinary amount of rubidium (up to 100-1000 times the amount present in the Sun) on their surface. Although the existence of this type of massive and evolved stars, very enriched in rubidium, had been predicted, as I mentioned above, more than 40 years ago by theoretical models of stellar nucleosynthesis, an observational confirmation had not been obtained to date.

This work has made it possible to study, for the first time, the late stages of the life of the most massive AGB stars. Moreover, these stars contribute significantly to enriching the interstellar medium, therefore it is crucial to understand what happens inside them and the chemical composition of the material returned to the interstellar medium at the end of their lives in order to understand the chemical evolution of our Galaxy.

Since the paper was published, have there been significant advances in this specific area?

The results presented in this paper were not completely explained by the theoretical models available at the time and therefore, this research has

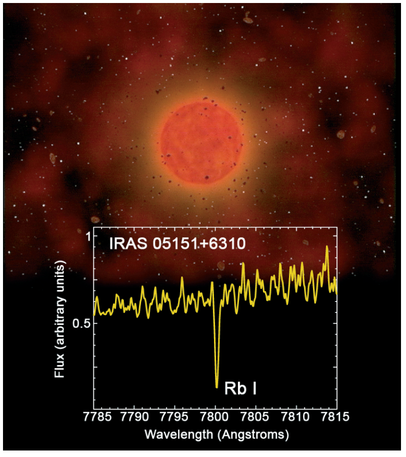


Figure 1. Rubidium is detected as a very intense absorption line at a wavelength of 780 nanometres. This is a spectrum of one of the discovered rubidium-rich stars, superimposed on an artist's impression of an AGB star. Image courtesy of the European Space Agency.

Figure 2. Sketch of the stellar structure of low and intermediate-mass stars (less than 8 times the mass of the Sun) at the end of the AGB phase. Basically, AGB stars are composed of an inert C-O core surrounded by two thin shells rich in helium and hydrogen. On top of this double shell configuration sits a large hydrogen convective envelope. Note that the figure is not to scale and, in particular, the envelope is much larger than the C-O core.

made it possible for the models to be improved so that they can reproduce the observations. These days, the models have been refined and are able to reproduce the observations of rubidium stars. Also, this type of stars could explain the chemical anomalies that are found in the oldest meteorites in the Solar System and, they are starting to be identified in nearby galaxies.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The fundamental problems are related to the faintness of these stars in the visible wavelength range and the improvement of the theoretical models. Although this type of stars are present in almost every galaxy, the large distances to other galaxies make

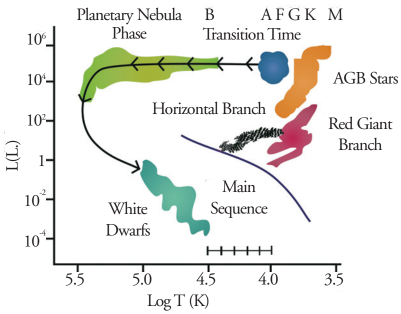


Figure 3. H-R (Hertzsprung-Russell) diagram that shows the stellar luminosity (in solar luminosities) versus temperature (in Kelvin). The main evolutionary phases in the life of a star of low and intermediate-mass (less that 8 times the mass of the Sun) are shown. After the depletion of hydrogen (main sequence) and helium (Red Giant Branch) in their cores, these stars evolve towards the AGB. Finally, they form planetary nebulae and end their lives as white dwarfs.

them very difficult to detect, even using 8-10 meter diameter telescopes. Now that we are able to efficiently isolate the right stars for the first time, it will be possible to detect and study them in the closest galaxies (the so-called galaxies of the Local Group).

In addition, we will also obtain very important information at other wavelengths that will allow us to fine-tune the current theoretical models, something that will help to better understand the late stages of life of these stars

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

This work has allowed me to continue in this line of research since these stars can be studied in other wavelength ranges such as the near-infrared, where we can obtain information on other chemical elements. In addition, the identification of these stars in our Galaxy as well as the study of their chemical composition have opened new research fields like for example, their role in the chemical evolution of other galaxies and the knowledge of the environment where our Solar System formed.

Rubidium-Rich Asymptotic Giant Branch Stars
D. A. García Hernández, P. García Lario, B. Plez, F. D'Antona, A. Manchado and J.M. Trigo Rodríguez
2006, Science, 314, 1751

María Teresa Beltrán Sorolla
INAF-Osservatorio Astrofisico di Arcetri
(Florencia, Italia)

What was the problem you had to face?

The problem was to understand how massive stars form; these are stars with masses 8 times larger than the mass of the Sun. High-mass stars are key ingredients of galaxies, since they control their appearance and evolution, inject energy into the interstellar medium and regulate the star formation rate. Furthermore, they are responsible for the production of heavy elements necessary for life, like oxygen, carbon, calcium or iron. Despite the importance of these stars, very little is known about their formation mechanisms. One of the theories proposes that massive stars form as a result of gravitational collapse, in a similar way to the formation of our Sun; others, however, propose that massive stars form by coalescence of many lower mass stars.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In the low-mass star formation process, infall, outflow and rotation play very important roles. Despite the fact that rotation, outflow and, to a lesser extent, infall, had already been detected in massive star forming regions, they had never been observed simultaneously in the same stellar object before.

In our study we looked for observational evidence of these movements around a very young stellar object in the process of formation called G24.78+0.08 A1, which has a mass of about 20 solar masses. These observations revealed, for the first time, the simultaneous presence of these three basic ingredients in star formation: rotation, infall and outflow. We, therefore, confirmed the prediction of the theory that proposes that massive stars would form in a similar way to the Sun.

Since the paper was published, have there been significant advances in this specific area?

In the last years, evidence of infall had been found in a very limited number of massive stars, but still it is possible to count on the fingers of one hand the massive stars where these three basic elements of star formation have been clearly detected.

As statistics are so poor, it is difficult to derive important parameters in the star formation process, like for example, the accretion rate at which the material is incorporated into the forming star. The fact that there are so few

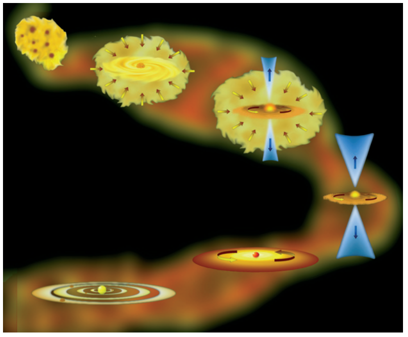


Figure 1. Sketch of star formation. The protostellar cloud collapses and the presence of rotation makes a disk appear. Part of the cloud material is ejected in two outflows perpendicular to the disk, while the material of the disk is accreted by the star.

examples is mainly due to the difficulty to study massive star forming regions, owing to their small number when compared to the number of known low-mass star forming regions, the larger distances to us and the fact that massive star lifetimes are very short.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Our study confirmed that stars up to 20 solar masses could form by accretion or infall of material through a rotating disk around the star. However, it remains to be proved if more massive stars also form in this way. No rotating and infalling disks, as those observed in lower mass stars, have yet been detected towards the most massive stars. For this reason, some theories propose that the most massive stars form by different mechanisms, like for example merging of low-mass stars.

In the next few years there will be advances in this field, with the new facilities already working, like the infrared observatory Herschel and the Gran Telescopio Canarias (GTC), or those that are currently being constructed, such as the antennas of the ALMA interferometer. They will allow us to observe the area immediately surrounding the star and to check if disks exist.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

I have continued with this research line, extending the search of infalling material to other massive stars. Following the hypothesis that massive stars form like low-mass stars, we have started to carry out studies on the importance of the magnetic field. For low-mass stars we know that the magnetic field plays a fundamental role in the formation process but its importance has not yet been proven in the case of massive stars.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The publication of this paper had a great impact worldwide, something that seemed impossible taking into account that it was an Astronomy paper. Out of curiosity, I started to search the internet for papers about our discovery and I found some written in Arab, Chinese, Japanese, Thai, Korean, Finnish, etc., just to cite the most exotic ones. The most curious one was a paper in a Nigerian newspaper where alongside the text there was a photograph of an astronaut doing a space walk. The caption was: "Astronomer working". It is true that we astronomers would like to take a closer look at the objects we study, but for the time being I do not think anyone has gone that far!

Infall of gas as the formation mechanism of stars up to 20 times more massive than the Sun

M.T. Beltrán, R. Cesaroni, C. Codella, L. Testi, R.S. Furuya and L. Olmi

2006, Nature, 443, 427

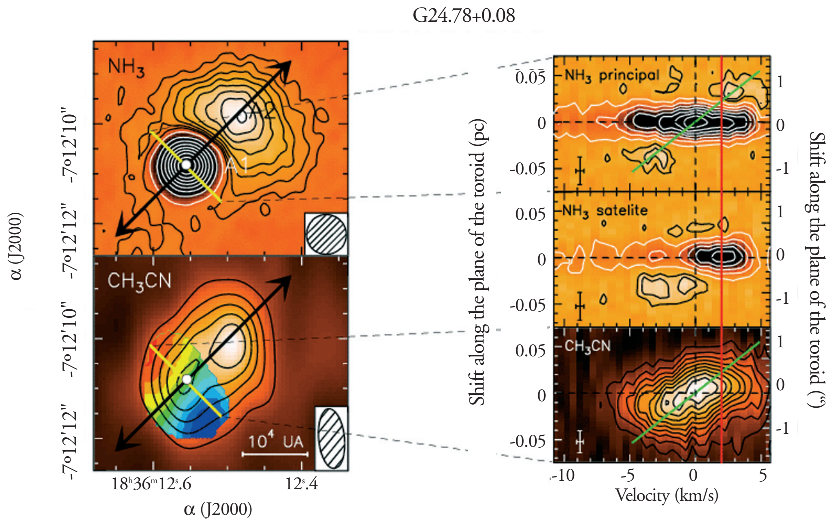
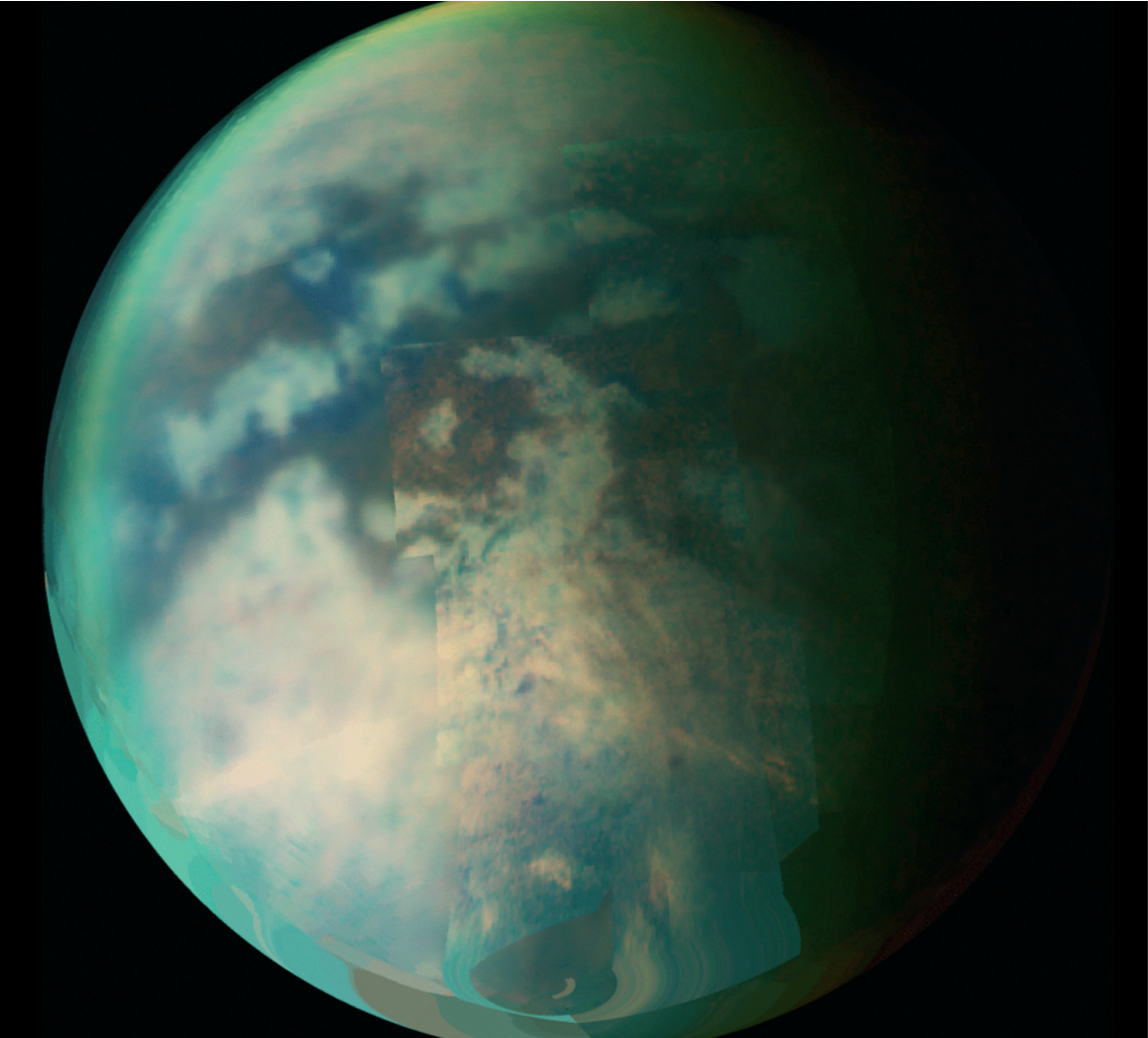


Figure 2. Left panels: Absorption and emission by molecular gas towards the HII region in G24.78+0.08 A1, a massive star in process of formation with spectral type O9.5 and 20 solar masses. The upper panel shows the map of the integrated line emission of NH_3. In the lower panel, the contours indicate the integrated line emission of CH_3CN and the colours the CH_3CN velocity gradient indicative of rotation. Right panels: Velocity field in the massive toroid G24.78+0.08 A1. The upper panel shows the NH_3 main line, the central panel shows the NH_3 satellite line and the lower panel CH_3CN. In the central panel one can clearly see that the absorption peak observed in the NH_3 satellite line is shifted 2 km/s with respect to the stellar velocity, as indicated by the red line. This absorption shift towards positive velocities indicates that the gas, located between the star and the observer, is going away from the observer and moving towards the star, and therefore, infalling onto G24.78+0.08.



Ricardo Hueso Alonso
Departamento de Física Aplicada I
Escuela Técnica Superior de Ingeniería
Universidad del País Vasco, Bilbao

What was the problem you had to face?

In 2005, the European probe Huygens penetrated the atmosphere of Saturn's moon, Titan for the first time. This moon is the only natural satellite with an atmosphere and has a size comparable to that of Mercury. At a vast distance from the Sun, 15,000 million kilometres, its temperature is so low, -180ºC, that the methane in the atmosphere can condense forming clouds, which have been regularly observed from the Earth using large telescopes.

Huygens found a landscape sculpted by watercourses and fluvial structures, a damp surface, although without liquids, and rounded stones as the ones found on a dry riverbed. Both facts suggested that, occasionally, there are intense rainfalls of liquid methane on Titan's surface. Agustín Sánchez-Lavega and I carried out the task of modelling this phenomenon, trying to quantify the amount of methane rain that can fall on Titan's surface.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In the study published in *Nature* we made a three-dimensional numerical model showing how a methane storm can be formed in Titan's atmosphere. The main challenge in this model was to include how the small liquid and frozen methane particles contained in the clouds are formed and how they grow until producing precipitation that reaches the surface. The model itself was an adaptation of previous works carried out by our team on the formation of water storms in the atmospheres of the giant planets Jupiter and Saturn, but accommodating them to the conditions of Titan's atmosphere was a great effort. Our model predicts that, under the right conditions, it is possible to form in Titan convective storms similar to the ones on Earth, but based on the condensation and precipitation of methane. These phenomena can produce a precipitation of about 50-200 litres per square meter in a few hours, comparable to the intense storms which cause local flooding in summer and spring in the Iberian Peninsula.

Since the paper was published, have there been significant advances in this specific area?

Of course. Although the Huygens probe sent data on Titan's surface for

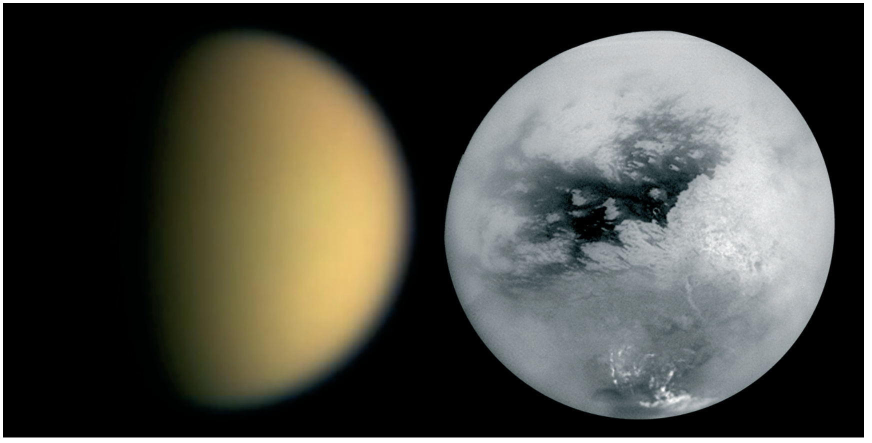


Figure 1. *Titan observed by the Cassini probe. The atmosphere is covered by a permanent haze at high altitude that prevents us from directly observing the surface (left). At certain wavelengths (right) the haze becomes transparent and it is possible to observe the surface and the formation of storms, in this case in the South Polar Region.*

just a short period of time, the American Cassini probe is orbiting Saturn and its moons since 2004, providing new observations of Titan's surface. In particular, its radar has found large lakes in both the northern and southern hemispheres. In addition, Titan is regularly monitored from the Earth using large telescopes and the seasonal cycle of its atmosphere is starting to be understood; an atmosphere governed by a slow rotation and the atmospheric cycle of methane. Several weeks ago we heard that some surface variations in the polar regions have been found after a period of intense storms observed from the Earth, one of the specific predictions of our model. Therefore, a large number of observations are consistent with our results and there has been an advance in global models of Titan's atmosphere that take methane condensation into account.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

The frequency of the storms and their relation with the seasonal cycle of Titan is not understood. The origin of atmospheric methane is not clear either, as it is known that methane is destroyed by solar ultraviolet radiation in the high atmosphere, recombining to form more complex hydrocarbons and dense layers of red haze, which hide the surface. Now we are starting to explore the global influence of storms on the surface using radar observations of regions which are similar to dunes over a large part of the surface of Titan, and large lakes in the polar regions. However, it is not known if the lakes are deep or superficial, nor how much methane or ethane can be stored. Some of these mysteries could be solved with the new Cassini data but many will have to wait for the results of a new probe that has been proposed to the European and US space agencies that would be sent to explore Titan.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

This work was the one and only study to date that I have carried out

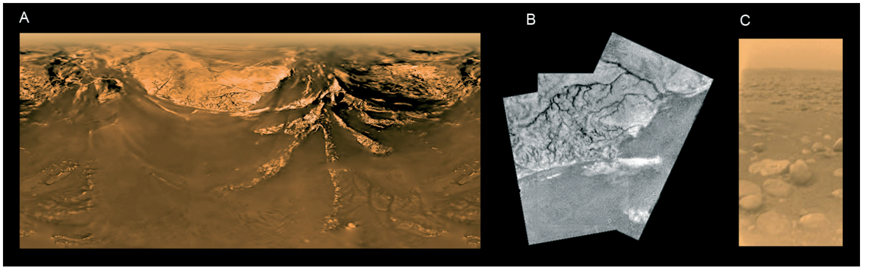


Figure 2. *Observations of Titan's surface made with the Huygens probe; the watercourses and the round form of the surface stones are clearly shown. The surface material is mainly water ice at very low temperature.*

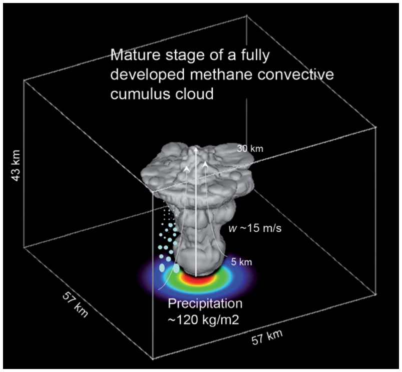


Figure 3. Simulation of a convective storm in Titan with details of the precipitation and vertical velocities developed in this vertical cloud.

on Titan's atmosphere. Although we started this line of research, later we became part of a team that analyses data from the European space mission Venus Express (since the year 2006) and therefore we have not been able to continue with our study of Titan. However, thanks to the study outlined here, I have been consulted by European Space Agency (ESA) and NASA committees about issues related to the design and proposal of new Titan exploration missions. I have also been the scientific referee of papers about Titan's atmosphere. On a more general level, the publication of this paper provided recognition of my research, which motivated me to tackle new scientific objectives more enthusiastically.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

The paper was sent to publication after the summer of 2005, when my postdoctoral fellowship had just finished and I was unemployed and without the right to receive any unemployment compensation after nine years doing research with fellowships. I spent a few months living out of my savings while we polished the last details of this research work, knowing that I had some results that I could not leave in a drawer. Later, I managed to return to the scientific research thanks to a Spanish "Ramón y Cajal" contract. The impact of the paper about the methane storm on Titan attracted significant interest in a wide variety of publications and media.

Methane storms on Saturn's moon Titan
R. Hueso and A. Sánchez-Lavega
2006, Nature, 442, 428

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Service d'Astrophysique
(CEA-Saclay, Francia)

What was the problem you had to face?

The purpose of our study was to detect gravity-oscillation modes (also called *g* modes) in the Sun. Unlike acoustic modes (also called *p* modes) that were detected at the end of the sixties, g modes have remained undetected until now. These waves are important because, unlike *p* modes, they propagate in the radiative zone of the Sun, especially in its core. Therefore their detection will allow us to deepen our knowledge of the structural and dynamic properties of this region, where nuclear reactions take place. The problem we had to face was that in the convective zone of the Sun (the outer 30% of its structure) *g* modes become evanescent, reaching the surface with velocities of the order of 1 mm/s or even lower, so that it has been impossible to detect them until now.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

In order to detect these weak waves, a French-Spanish consortium developed the GOLF instrument (Global Oscillations at Low Frequency) as part of the SoHO (Solar and Heliospheric Observatory) payload, launched on 2nd December 1995. Its main objective was, and still is, the detection of low-frequency acoustic modes and *g* modes. It has been necessary to collect data for 10 years in order to have enough sensitivity to detect those oscillations.

The detection of g modes was done indirectly, studying its asymptotic properties in the Fourier space. In this way we detected the periodicity due to the bipolar modes (l=1) comparing the results with the predictions (see Figure 1). This was the first time that it was possible to prove the existence of *g* modes in the Sun. The work also permitted the rotation rate of the Sun's core to be constrained; it rotates on average about 4 to 5 times faster than the rest of the radiative zone.

Since the paper was published, have there been significant advances in this specific area?

Due to the difficulty of measuring such weak signals on the solar surface and that there is no other instrument able to reach such a high sensitivity, the progress in this field is slow. At present we have extended the calculations using series of data

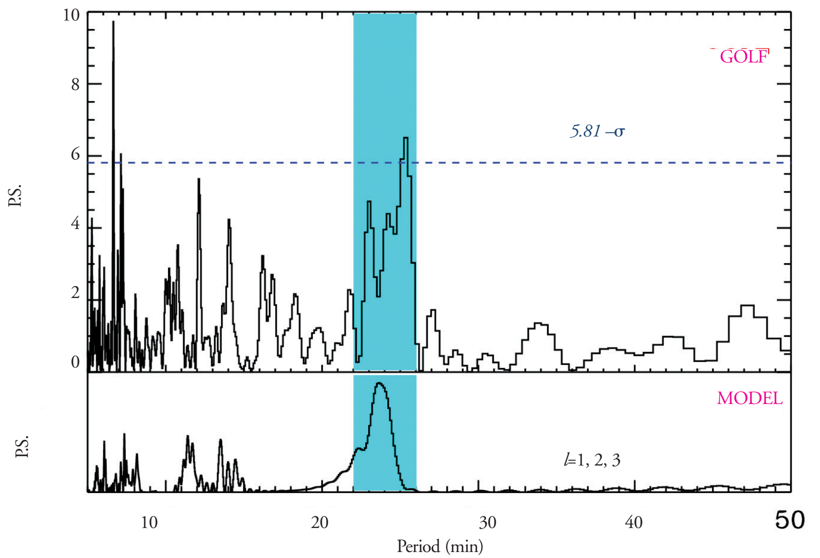


Figure 1. Periodogram (frequency spectrum) of data obtained with the GOLF experiment over a 10 year-period. The main peak corresponds to the periodicity of bipolar gravity modes. The same analysis is shown at the bottom of the figure but using theoretical frequencies for the above modes. The confidence level of the structure found is above 99.97%.

Figure 2. Photo-montage representing the SoHO satellite observing the Sun and a cross section of the Sun showing its convective zone (the outer 30% of its structure) and its radiative zone, where gravity modes propagate (represented by continuous lines). Image courtesy of IAC.

obtained for 14 years (40% more than in the original study) and we have increased the precision of our results. On the other hand, the search of individual *g* modes continues and we are starting to obtain very promising results.

The most important advances have come from theoretical implications resulting from the measurement of the solar core rotation and the verification of new opacity tables, which have been recently measured and present certain inconsistencies with our results. In fact, not long ago, a new opacity table was published which partially solves the problem.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

From an observational point of view, you have to characterize the gravity modes (its amplitudes, frequencies, lifetimes, etc.) precisely and also measure the high-degree *p* modes in order to study the radiative and convective zones of the Sun in depth. This knowledge will help us to understand the structure and dynamics of the internal regions of the Sun as well as the mechanisms that govern the solar magnetism and its cycles that are very poorly understood today. It is well known that these cycles affect the conditions in space (with consequences, for example, in future manned flights to Mars), produce disturbances in satellite connections, and even affect the Earth's climate.

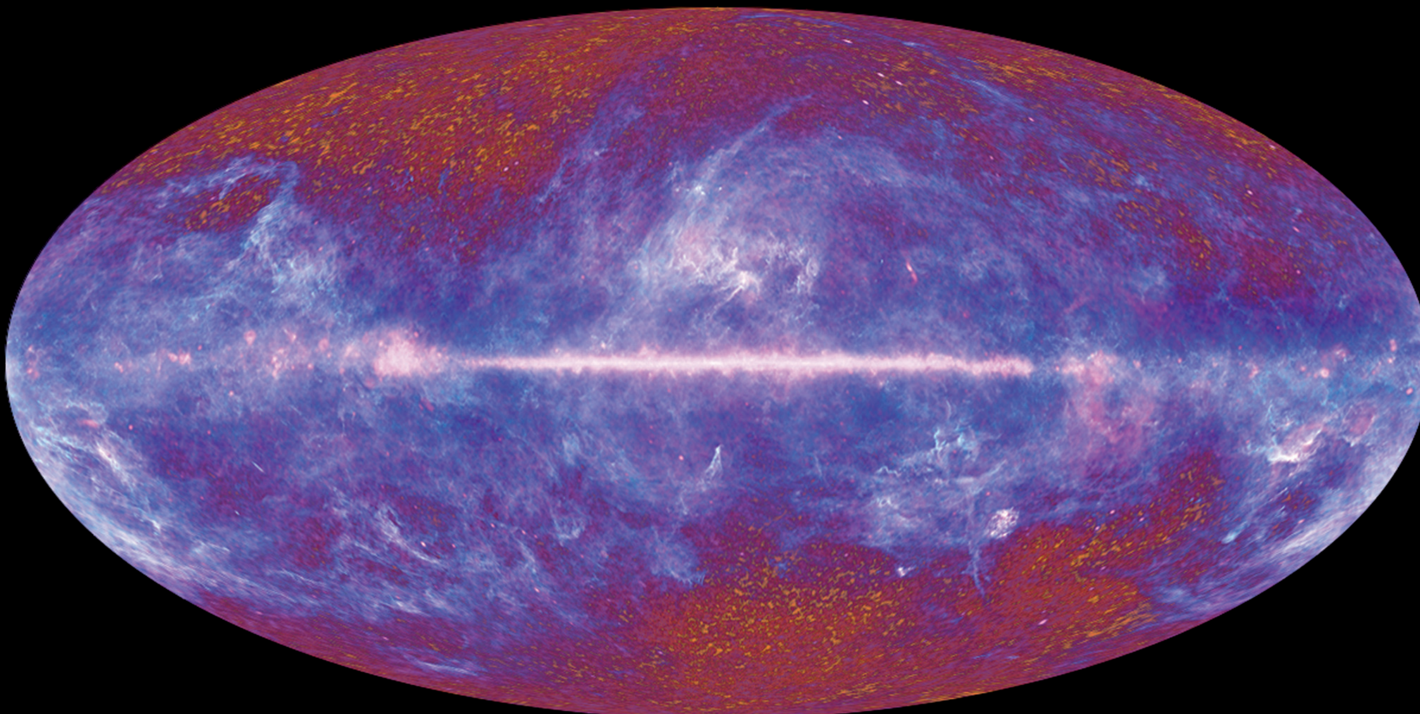
How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

After almost 15 years developing and working with the GOLF instrument, it has been a great satisfaction to be able to measure all the things the instrument was designed and constructed for. Obviously, we have opened a door and the objective is to go through it and go deep into this field that has just been born for solar physicists. At the same time, the techniques used to extract such weak signals can be employed for the study of low signal-to-noise ratio pulsations in other stars. In fact, we were already using these techniques with data from the CoRoT (Convection Rotation and Planetary Transits) and Kepler satellites.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

When this paper was published in *Science* I was visiting the IAC (Instituto de Astrofísica de Canarias) and the mass media showed great interest in this issue and we gave several interviews. One of them was published in the Canary edition of a national newspaper, and on their webpage they included a summary of the interview, in which several members of our team participated. What we could not imagine was that this was the most-read paper during the month of its publication and because of this we were given a commemorative statuette. No one in the team could have imagined that people could show so much interest in a scientific note on the Sun, to the point of it being the most-read paper of the time.

Tracking Solar Gravity Modes: The Dynamics of the Solar Core
R.A. García, S. Turck-Chièze, S.J. Jiménez-Reyes, J. Ballot, P.L. Pallé, A. Eff-Darwich, S. Mathur and J. Provost
2007, Science, 316, 1591



Marcos Cruz Rodríguez
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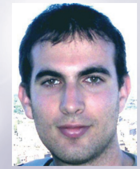

What was the problem you had to face?

In previous papers we analysed the Cosmic Microwave Background radiation data provided by NASA's WMAP satellite, finding an anomaly, namely a large cold spot of unknown origin in the south Galactic hemisphere, with an angular radius of about 5 degrees. This spot was detected by filtering the data with a function called "Spherical Mexican Hat Wavelet". The probability of observing such a spot according to the standard model was only about 1% and the problem was that its origin was unknown.

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

After ruling out in several papers that the spot was due to Galactic contamination or instrumental noise, we decided to check if the spot could have been created by a cosmic defect called a "texture". The theory of cosmic defects predicted a specific pattern, amplitude and size for the spot. Hence we performed a Bayesian analysis in order to prove if the texture hypothesis could explain the data. The result of this analysis was that the spot was indeed consistent with the texture hypothesis. The first detection of a cosmic defect would be a great advance in our understanding of the early Universe and high-energy physics. However, additional analysis is necessary to obtain a definitive confirmation.

Since the paper was published, have there been significant advances in this specific area?

We have recently published a paper comparing three hypotheses to explain the origin of the spot. The probability that the spot had been produced by a void or a large cluster was very low and the hypothesis of the cosmic texture continued to be the most likely. Currently, we are working on an extended all-sky analysis in order to detect additional textures predicted by the theory. However, these textures are harder to detect since their angular size is smaller, and the anisotropies that are not generated by textures have their maximum power at scales between 1 or 2 degrees.

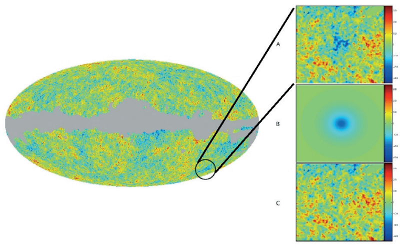

Figure 1. Microwave Cosmic Background radiation measured by NASA's WMAP (left) and an azimuthal projection of a 43º x 43º patch (A), centred at a prominent cold spot detected using spherical wavelets. We show through a Bayesian analysis that the most acceptable hypothesis to explain the spot is a combination of two signals. One due to the cosmic defect, called texture (B) and a Gaussian signal due to the density fluctuations of the early Universe (C).

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

In cosmology we have a standard model, also called "concordant model", that explains reasonably well the observed Universe. However, the big problem of that model is that the nature of about 95% of the content of the Universe is unknown. About 74% of the energy density of the Universe is attributed to a "dark energy" of unknown origin, which would be the responsible for the expansion of the Universe. Most of the remaining energy is in the form of cold dark matter: non-baryonic and non-relativistic matter of unknown composition. Only 4% of the energy in the Universe is accounted for by ordinary baryonic matter. The big challenge of cosmology in the next few years is to discover the nature of dark matter and dark energy.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

We are currently finishing a paper which could confirm our discovery. My professional career has advanced considerably as I defended my thesis some weeks after the publication of the paper and a year later, I signed a contract for a position as Assistant Professor at the University of Cantabria.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I was lucky that the publication of the paper in *Science* coincided with the time when the journals *Science* and *Nature* were bestowed the Prince of Asturias Award, so we were invited for a press conference in Oviedo,

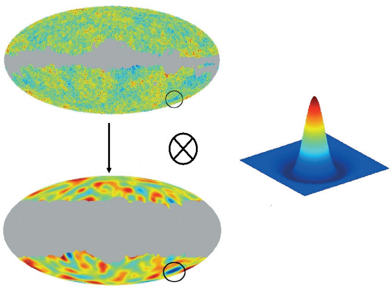

Figure 2. Cosmic Microwave Background radiation data taken by the WMAP (top) are filtered using the Spherical Mexican Hat Wavelet at an angular scale of 5 degrees (right) to reduce noise and other contaminating signals, as well as to amplify the signal to the selected scale. The filtered map (bottom) has less noise and it is possible to see a cold spot in the South Galactic Hemisphere which is more prominent that the others and could be the result of a cosmic effect.

where my grandparents live and I have good friends. The press conference was an interesting experience and I became "famous" for a short time, since I was interviewed by several radio stations and our work was mentioned in the national and international press.

A Cosmic Microwave Background Feature Consistent with a Cosmic Texture
M. Cruz, N. Turok, P. Vielva, E. Martínez-González, and M. Hobson
2007, Science, 318, 1612

Enric Pallé Bago
Instituto de Astrofísica de Canarias (Tenerife)

What was the problem you had to face?

Anyone who has ever stopped to watch the starry sky has wondered if we are alone in the Universe. The past two decades have witnessed the discovery of hundreds of extrasolar planets (planets around other stars). The recent advances in the detection and characterization of those exoplanets makes us think that the answer to that timeless question is now a matter of time.

Although most of the planets detected are gaseous giants, little by little we are very close to be able to detect rocky planets similar to our own Earth. When we will find them, the efforts will concentrate on determining the likely presence of life. More precisely, this was the problem we were considering: What are the characteristics of the light reflected/emitted by the Earth, seen from an astronomical distance? What features can only be attributed to the existence of life?

What was the solution to this problem and the contribution this paper made to the area of expertise in which it is framed?

The solution to this problem was to study the Earth's transmission spectrum during a lunar eclipse. During an eclipse, only the light that passes through the terrestrial atmosphere can reach the darker area of the shadow projected by the Earth over the Moon, the umbra. By studying the threshold light reflected onto the Moon we can recreate the observation of the Earth's transit in front of the Sun.

With these observations we can easily detect the presence of oxygen, water, ozone, carbon dioxide and methane in our atmosphere. Surprisingly, some gases of biological origin as methane (hardly present in our atmosphere), show much more prominent features than those predicted by the models. A scientist who observed us from a distant star would not doubt to identify our planet as a place full of life.

Since the paper was published, have there been significant advances in this specific area?

The study of exoplanets is an incredibly dynamic field; in 2009 there were more that two papers every day. There are more than 500 planets detected and the new discoveries of planets are being announced in scores of papers. So, there are indeed significant advances: Each time smaller and colder planets

Figure 1. *The Moon during an eclipse from the Canary Islands. Photograph courtesy of Daniel López (IAC).*

Figure 2. *An artist's concept of the Earth, seen from the Moon during a lunar eclipse. Photograph courtesy of Gabriel Pérez (IAC).*

are discovered, closer to the habitability zone, and that little by little bring us closer to the detection of Earth-like planets.

Regarding the characterization of the Earth's atmosphere, it is still early to have more papers published about this issue, although our team is already preparing an extension of this study to other parts of the electromagnetic spectrum, especially to the infrared where there are many traces of the main greenhouse effect gases, and also to higher spectral resolutions.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

Presently, the search of exoplanets and the existence of life in the Universe is encountering technical detection limits due to the enormous difference in brightness between these planets and their stars (the Sun is a thousand million times brighter than the Earth), and also the close proximity of both the planet and the star when they are observed at a large distance.

Some instruments designed today will be capable of detecting Earth-like planets; however, we will need a quantitative jump to go from the detection of those planets to the characterisation of their atmospheres. The most promising technique at present is the so-called "differential spectroscopy", possible for those few planets that, because of their orbital geometry, cross in front of their stars. In this sense, our study seems to indicate that the search for life can turn out to be a little easier than it was expected.

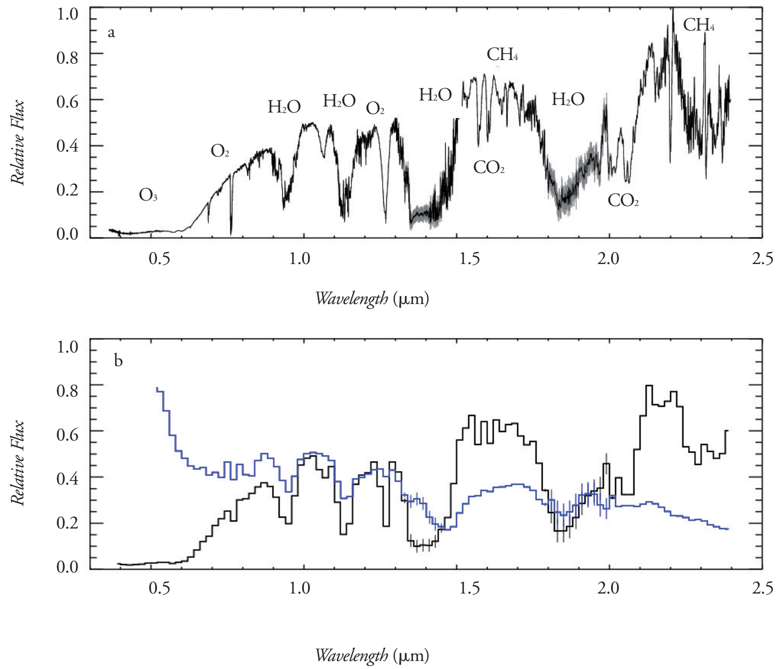

Figure 3. Top figure: The transmission spectrum of the Earth, where some of the major atmospheric constituents are marked. Bottom figure: A comparison between the Earth's transmission (black) and reflection (blue) spectra degenerated to low spectral resolution.

How did it influence your professional career? Have you continued in that line of work? Has it opened new perspectives or later did you dedicate yourself to other topics?

The truth is that it is still too early to say how this has influenced my professional career; it happened just a few months ago. The first time I published in *Science* probably helped me to get my present Ramón y Cajal contract. I would like to think that this new publication will help me to obtain a permanent position (even if we are in a time of crisis). What it is clear is that I am planning to continue with this research line, because as well as being fascinating it seems to have good medium and long term future perspectives.

For the moment, the observations of the Earth and other planets of the Solar System will be our benchmarks in the search for life around other stars in our Galaxy. And despite what one could think, there are still many aspects of our planet that remain to be characterised.

Do you have any anecdote related to this paper's gestation and publication that you think is worth telling?

I remember that, due to the time when it started, we could only observe the second half of the lunar eclipse. At nightfall, the eclipse was already visible to the naked eye but the Moon was still too low over the horizon to be accessible to the telescopes. Therefore, we sat down outdoors to take pictures and to enjoy looking at this spectacular phenomenon.

As soon as the Moon crossed the limit from which we could observe it with the telescope, we started to work. There was no time to loose because lunar eclipses do not happen every day. The first results were already visible in a raw analysis of the data done at the telescope itself and that we discussed before going to bed. It happened to be a great, exciting and enjoyable night.

Earth's transmission spectrum from lunar eclipse observations
E. Pallé, M.R. Zapatero-Osorio, R. Barrena, P. Montañés-Rodríguez and E.L. Martín.
2009, Nature, 459, 814

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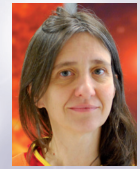

What was the genesis and what are the objectives of the XMM-Newton observatory?

XMM-Newton is a European Space Agency (ESA) mission launched on the 10th December 1999 to observe the sky in X-rays. XMM-Newton's main challenge and objective was to put X-ray astronomy at the same level as astronomy at other wavelengths.

X-ray astronomy has a short history, since the Earth's atmosphere absorbs all X-rays; its study is bound to space telescopes. It was not possible to detect X-rays coming from the Sun until the first balloons or rockets were developed in the fifties. We had to wait until 1962 to see the first cosmic X-rays from an object other than the Sun. In the seventies the first satellites were launched, they detected an increasing number of X-ray sources. It was then understood that there was a need to increase the sensitivity of the instruments and to introduce the capability to obtain spectra, i.e. to separate X-rays according to their energy or "colour". In 1982, a proposal to build a satellite whose "strengths" were precisely these two capabilities was formulated. In 1984, ESA approved the development of the X-ray Multi-Mirror Mission as one of the four cornerstones of its programme "Horizon 2000", designed to bring ESA to the 21st century as one of the world's leaders in space research.

The XMM-Newton Space Observatory was designed to help us to understand the Universe in extreme temperature conditions, as those generated when gas, accelerated to velocities close to that of light, collides with material of the interstellar or intergalactic medium; or in extreme gravity conditions, as those taking place in the vicinity of black holes or neutron stars, very often modified by intense magnetic fields.

XMM-Newton's increased sensitivity to X-rays was achieved by using slightly curved cylindrical mirrors, which are capable of focusing photons that reach the interior at a very small incident angle. Furthermore, many of those cylindrical mirrors were placed one inside the other, as Russian dolls, in order to increase the collecting area. XMM-Newton carries three X-ray telescopes, containing each 58 mirrors of this type. The spectroscopic power was achieved by designing the first reflection gratings which disperse X-ray photons at different angles according to their energy. An optical telescope was built to complete the set, and it was mounted parallel to the X-ray telescopes, thus managing to collect visible or ultraviolet light and X-rays at the same time.

What are the contents of the review paper that youand your colleagues have published in Nature?

Before answering that question I would like to say that XMM-Newton has a “cousin”, born almost at the same time, the NASA’s Chandra satellite. Thanks to their complementary properties, it has been possible to obtain very sharp images and precisely measure the energy of cosmic X-rays. Thus, less than 50 years after the first detection of an extrasolar X-ray source, these two observatories have achieved an increase in sensitivity comparable to that obtained over the last 400 years of optical astronomy, i.e. since Galileo to the present day!

The paper published in *Nature* to celebrate the 10th anniversary of the first observations made by these satellites highlights some of the many discoveries made by XMM-Newton and Chandra that have transformed twenty-first century of astronomy.

The paper includes a sample list of the most important discoveries, although it clearly states that this list is neither objective nor complete or, in other words, that it contains many of the several discoveries but not all of them. The work covers very different aspects: from X-ray production mechanisms in comets or the influence of X-rays in planet formation around young stars to the behaviour in of hot gas jets streaming from galaxies and impacting on the intergalactic medium at high speed and thus regulating the growth of these galaxies, of giant black holes in the galaxy cores and even of the large scale structures of the Universe. In the paper, we explain in detail some of these discoveries. We also explain how XMM-Newton and Chandra have contributed and are still contributing to our understanding of one of the most important mysteries of astronomy today: the nature of dark matter and energy.

Which are the main problems in this area of Astrophysics and what are the expected discoveries in the coming years?

It is difficult to predict the main future discoveries and the impact they may have. We are convinced that an important part of them will come from sky surveys, which are increasingly deeper and cover larger and larger areas. We expect that in the near future XMM-Newton and Chandra will solve some critical issues ranging from the sub-nuclear composition of neutron stars to the large-scale structure of the Universe. Objects as diverse as the highest layers of the Earth’s atmosphere or the nuclei of the youngest galaxies, still undetected because they are extremely distant and therefore very faint, will be studied. We are confident that a detailed census of these objects over the history of the Universe will be done. The intention is to study the regions where stars are being formed, both in the Milky Way and in younger distant galaxies, in order to understand what triggers the bursts of star formation and how these bursts modify the environment, enriching it and injecting energy into the interstellar gas, or, in a similar way, how giant black holes in galaxy clusters inject energy into the intracluster gas.

Surely, some of the discoveries will be done thanks to the cooperation with other telescopes, as for example ESA's Herschel and Planck space missions, launched in May 2009, which will be essential for understanding obscured star formation, in the case of Herschel, or the nature of dark matter and energy, in the case of Planck.

Could you comment on the influence this project has had in your professional career?

My professional career has completely changed since I started to work on the XMM-Newton project. On the one side my work is no longer mainly dedicated to astronomical research but more to provide a service to astronomers, something that despite reducing my scientific "productivity" I have always considered very important. On the other hand, my own research has been increasingly

Figure 1. *Image of Messier 82, a galaxy with intense star formation observed with XMM-Newton in ultraviolet, visible light, and X-rays; the latter are shown mainly in blue colours. Whereas the galactic plane is mainly seen in visible and ultraviolet light, with dark bands owing to dust and bright spots due to the process of star formation, X-rays show two very hot gas cones bursting out from the galactic disk thanks to the boost given by the more massive stars when they explode as supernovas. This image perfectly illustrates the importance of having information in different wavelengths (visible, ultraviolet or X-rays), something which is possible with XMM-Newton. Courtesy: P. Rodríguez-Pascual and ESA.*

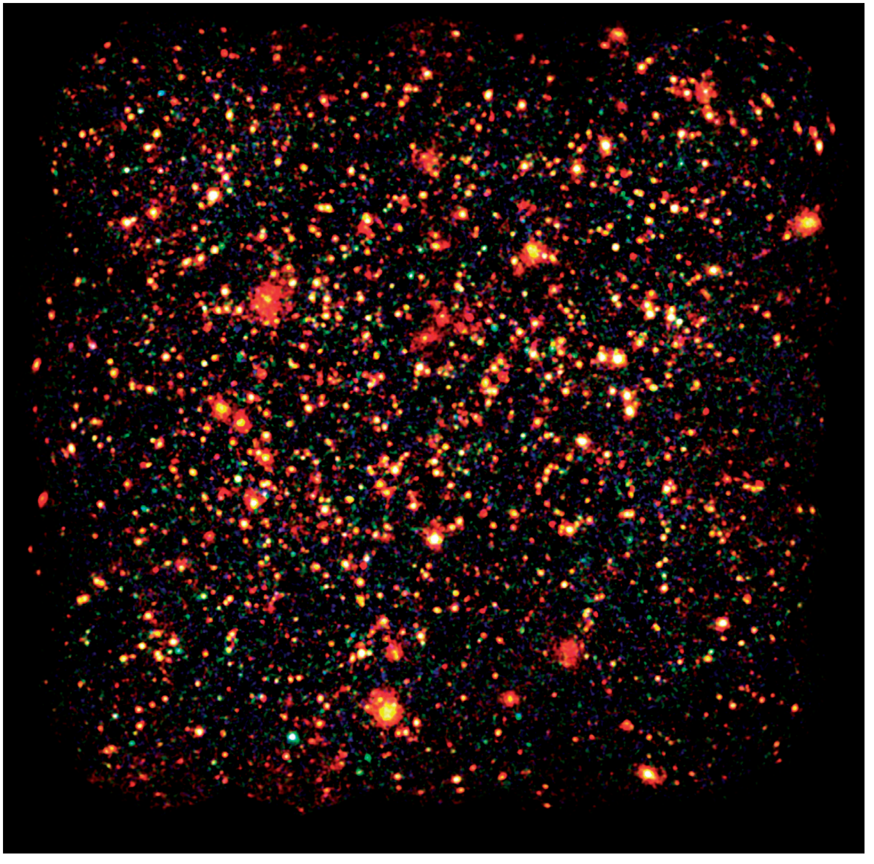

Figure 2. The sky in X-rays: The image shows thousands of X-ray sources in an area of the sky which covers approximately 10 times the area of the full Moon, the XMM-COSMOS field. Red colours show the least energetic X-rays and blue colours show the more energetic ones, with green in the middle. Most of the approximately 2000 colour dots are active nuclei of distant galaxies, while the more than 100 regions, which appear as extended spots correspond to groups of galaxies or galaxy clusters. Courtesy: G.Hasinger, N.Cappelluti, XMM-COSMOS and ESA collaboration.

centered on the analysis and interpretation of X-ray data. What I have kept from previous years working as an astronomer is my interest in active galactic nuclei and its connection with star formation; currently I am studying them mostly in the X-ray band, although I try to maintain an overall view, since they emit radiation in the entire electromagnetic spectral range.

Do you have any anecdote related to this paper's gestation and publication or the events you have lived through in the 10 years of the XMM-Newton project?

Regarding the paper I would like to stress the excellent collaboration with the co-authors who are part of the Chandra team. Together we have tried, and in my opinionsucceeded, to reveal the complementarity and excellence of both observatories.

Regarding the XMM-Newton project, obviously, in more than ten years all kinds of anecdotes have arisen. One of the main landmarks in any space mission is the launch: in a few seconds, the past and the future of nearly a generation of scientists is at a stake. We saw the XMM-Newton launch live, surrounded by colleagues who suffered with nerves and enjoyed the success with us. The next critical step came after a few days: opening the mirror doors and collecting the first data with the instruments, the “first light”. It is amazing to realize how simple things as lifting a lid or opening a camera become very complicated in space, fortunately everything went well!

The most critical event happened in October 2008. For several hours, even days, we thought we had lost the satellite forever. It became “deaf”, “mute” and perhaps “blind”. It stopped sending signals and answering to ours. Where was it? Why wasn't it answering? Luckily, the problem could be solved as soon as it was understood: A switch had got stuck and a very powerful signal had to be sent to move it back to its correct position. The switch reacted to this signal and since then XMM-Newton continues to work perfectly, as before.

On the personal side, I feel privileged to have been able to work on a project as exciting as XMM-Newton and I recognize that I have been a bit lucky because I was “in the right place at the right moment”. But undoubtedly the most important thing has been the privilege of working with people on the project, with people that I value and admire a lot, both professionally and personally. The hardest thing is the powerlessness I feel when I see them fearing for their future. When a space project has been running for a long time, its maintenance becomes increasingly expensive for the space agencies, which have amongst their main goals to develop new technologies together with industry. Although scientists find it very hard to understand the reasoning based on immediate productivity gains, we have no choice but to try to achieve better and better results with fewer resources. Despite the efforts done, jobs seem to be menaced by the need to reduce expenses and even more so in times of crisis. That insecurity is very hard. That is the reason why I would like to thank everyone who continues to work every day, making XMM-Newton to be, and continue to be, a scientific success for many years to come.

The first decade of science with Chandra and XMM-Newton
M. Santos-Lleó, N. Schartel, H. Tananbaum, W. Tucker and M.C. Weisskopf
2009, Nature, 462, 997

The evolution of the expansion of a supernova remnant, detailed monitorings of gamma ray bursts, studies of the storms in Saturn and Jupiter, the first brown dwarf, the confirmation of the presence of black holes in binary stars, models for novae and supernovae, the role of magnetic fields in the rotation pattern of galaxies, sunspots phenomena, the methane cycle in Titan, the impacts of volatile material on the Moon, the discovery of a spherical bubble around a stellar embryo, the description of the intergalactic medium...

These are some of the results we present in 'Astronomy made in Spain', a project of the Spanish Astronomical Society (Sociedad Española de Astronomía, SEA) to commemorate the International Year of Astronomy 2009. This book is a collection of conversations with the Spanish astronomers who have published as first authors a paper -at least- in *Nature* or *Science* in the last 30 years. We would like this legacy paid homage to all Spanish astronomers, stimulated the new generations of students and composed a living history of discoveries told at first hand, without any intermediaries, by the people who made them possible.

Benjamín Montesinos
Emilio J. Alfaro

SEA

EL UNIVERSO
PARA QUE LO DESCUBRAS
MÁS ALLÁ DEL
AÑO INTERNACIONAL DE LA
ASTRONOMÍA