Report on the ESO Workshop

The Deaths of Stars and the Lives of Galaxies

held at ESO Vitacura, Santiago, Chile, 8–12 April 2013

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This five-day meeting was attended by about 100 astronomers and consisted of 16 invited and 26 contributed talks and more than 40 posters, still leaving ample time for discussions and social activities. A brief overview of the topics is presented, from mass loss in low- and high-mass stars and the ubiquitous importance of binaries, to the influence of this ejected material on galaxy evolution.

AGB and planetary nebulae

The workshop started with a review of the life of solar-like stars by Amanda Karakas, with an emphasis on the asymptotic giant branch (AGB) phase, when stars lose most of their envelope mass in a series of episodic thermal pulses. These thermal pulses (TPs), which each last only a couple of hundred years and are separated by some hundred thousand years, increase the carbon content of the envelope, and only a few TPs are required to make a solar-like star appear as C-rich (C/O > 1). This enrichment in carbon alters the stellar opacity, but this was only very recently taken into account in stellar evolution models, leading to a decrease in the time spent on the AGB and of the possible number of TPs. As the TPs are responsible for the final amount of chemical elements produced (and expelled into the interstellar medium), knowing how many happen before the AGB star evolves to become a white dwarf (WD) is crucial, but also extremely dependent on the assumed mass-loss rate, whose exact mechanism is still far from being understood.

The situation is yet more complicated, as shown by Falk Herwig in his review on the role that hydrodynamic mixing processes, which are closely related to the convection and nuclear reaction rate uncertainties, play in predictions of the evolution and nucleosynthetic yields of AGB stars. He also talked about the role of rotation in AGB stars, and how it may be best investigated in interacting binaries, such as the post-merger evolution of coalescing He+CO WDs and other sources similar to Sakurai's object. Binaries are also useful to explain the formation of planetary nebulae (PNe), as Orsola de Marco explained. The problem is to understand how the spherical mass-loss on the AGB can produce the collimated outflows seen in many PNe (Figure 2). Magnetic fields alone cannot do the trick — an additional source of angular momentum is needed — so that the most natural explanation is that PNe contain a close or wide binary system. This has now been verified in many cases. The remaining problem is how to go from the known ~ 30 % binary fraction of solar-like stars to the apparent ~ 80 % binary fraction in PNe. This, perhaps, implying that single stars do not form PNe at all! A series of talks by the PN group in ESO Chile (Henri Boffin, Dave Jones, Amy Tyndall) presented further developments along these lines, including the discovery of PNe in which there was a clear proof of mass transfer between the two components of the system, as well as showing that the jets observed in the PNe always precede the formation of the PN itself.

Novae

Close binaries containing a white dwarf were the topic of the next session, and Claus Tappert reviewed our current knowledge of novae. A nova eruption is a thermonuclear runaway on the surface of the white dwarf component in a close binary system known as a cataclysmic variable (CV). During this event a certain fraction of the previously accreted matter is ejected as a shell, thus enriching the interstellar medium (ISM) with nuclear processed material. Due to the considerable increase in brightness during the eruption, novae are observable in other galaxies, which makes them attractive as distance indicators. The class of novae may not be very homogeneous, however. Nova eruptions are the primary mechanism for mass loss in CVs, and as such they may well prevent the formation of Type Ia supernovae (SNe) via the single-degenerate mechanism since they prevent the white dwarf from reaching the Chandrasekhar mass limit. Olivier Chesneau showed how adaptive optics and optical interferometry can be used to study interacting binaries in detail, while Ken Shen and Ashley Ruiter presented models of the formation of Type Ia SNe,

Figure 1. The participants at the workshop in the grounds of ESO Vitacura.

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Figure 2. The amazing bipolar planetary nebula Fleming 1 was shown by several speakers at the workshop.

either via double detonations or white dwarf mergers.

Nebular abundances

Returning to the topic of PNe, Denise Gonçalves provided an overview of the determination of nebular abundances, and in particular, on the improvements that have been achieved recently. Abundances in PNe are particularly relevant to provide information about low-to-intermediate mass stellar nucleosynthesis, while at the same time, PNe archive progenitor abundances of α elements. To derive nebular abundances, two methods are widely used: the empirical ionisation correction factor (ICF) method and photoionisation model fitting. The former is often the only one used, and despite severe shortcomings, can provide reasonable results, even though it is advisable to extend the wavelength range used as much as possible. The second method uses empirical abundances as the input for photoionisation model fitting, that is, the abundances are varied until the predicted line ratios (and emission line maps if available) match the observations. Unfortunately, abundances are not necessarily better determined from the model-fitting method, but it can provide more accurate ICFs than using the simple formulae in the literature. To apply one of these methods, a wide range of software exists, such as nebular, *ELSA, 2D_Neb, NEAT, PyNeb, CLOUDY* and *MOCASSIN*. ESO Fellow Lizette Guzman-Ramirez used VISIR to observe a sample of PNe that show evidence of mixed chemistry with emission from both silicate dust and polycyclic aromatic hydrocarbons. The mixed-chemistry phenomenon is apparently best explained through hydrocarbon chemistry in an ultraviolet-irradiated, dense torus. This highlights the need to consider carefully the shape of the PNe when determining nebular abundances.

From massive stars … to PNe again

The second day of the meeting dealt with more massive objects, starting with a review of the evolution of massive stars by Georges Meynet. Massive stars form only a very small fraction of all stars produced in a given stellar generation, but nevertheless are of great importance: if only 0.3% of all stars have masses above 8 $M_\odot$, they contain 14% of all the mass, and almost half of that is returned to the host galaxy in the form of processed material with huge amounts of kinetic energy and on very short timescales. Nor can binarity be ignored, as the most recent censuses show that the binary fraction of massive stars is more than 50%, or even 70% in some cases. Apart from mass transfer and drastic evolution, binarity can imply tidal effects that lead to extra mixing inside the stars. It is also likely that binaries produce 50% of all existing Wolf–Rayet (WR) stars.

Massive stars will explode as supernovae and/or gamma-ray bursts, and the study of these explosions can reveal much about stellar evolution. Jose Groh stressed the fact that in some very rare cases, such as SN 2008bk, we are lucky enough to have an image of the progenitor before it exploded, showing that it was an ~ 8 $M_\odot$ star. The case of SN 2009ip is even stranger as this object underwent several outbursts in a few years, before actually exploding in 2012. The progenitor in this case is thought to be a luminous blue variable (i.e. not unlike η Carinae) with a mass of about 50–90 $M_\odot$.

Nathan Smith made the link between massive stars and planetary nebulae, presenting the similarities and dissimilarities in the morphology of these two kinds of objects (Figure 3). Cool hypergiants with large circumstellar envelopes, such as the "Rotten Egg Nebula", are the massive analogues of OH/IR stars (i.e. embedded AGB stars), while rings are seen in both PNe (e.g., the Necklace Nebula) and massive stars (SN 1987A is a fine example), and there are also clear resemblances between some PNe such as Hubble 5 or the Ant Nebula (Mz 3) and some of the most massive stars such as η Carinae. These bipolar outflows may in fact represent evidence of explosive events also taking place in PNe. On the other hand, while PNe often present jets, these are missing from massive stars. All circumstellar shells, around PNe or massive stars, suffer the effects of ionisation, photoevaporation, shocks, winds and explosions. As such, the wind interaction mechanism for explaining PNe might be too naïve in many cases.

Making stars explode

Going further in the evolution of massive stars, Hans-Thomas Janka presented the state of the art in explosion models, highlighting the importance of neutrino heating as the trigger for core-collapse supernovae and the need to use 3D simulations — not only in explosion simulations, but also for the proper initial conditions inside the progenitor. 3D simulations are very time-consuming, however, and require CPU power that is hardly available yet. Nevertheless the few 3D simulations that do exist clearly show different results than in 2D — models exploding in 2D don't necessarily do so in 3D, but at the current state of the art, it is not clear if this is just a resolution issue. This is most relevant as it seems that hydrodynamical instabilities are critical to trigger the final explosion, and

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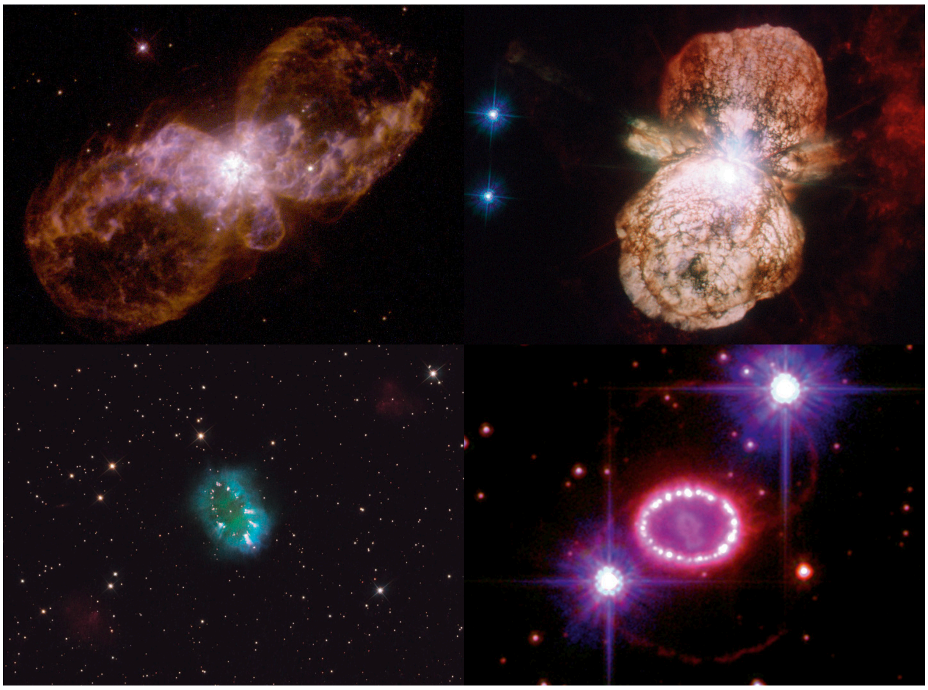

Figure 3. The striking similarities between the planetary nebula Hubble 5 (upper left) and Eta Carinae (upper right) on one hand, and the ring inside the Necklace Nebula (lower left) and around SN 1987A (lower right), on the other hand, potentially illustrate that similar phenomena are at play in solar-like and massive stars.

much emphasis is now given to the standing accretion shock instability. While it appears that although neutrino-driven explosions may explain supernovae with energy below 2×10^{51} ergs, hypernovae with higher energies seem to require a different, as yet unknown, mechanism.

Bernhard Müller and Bronson Messer presented further multi-dimensional explosion models of core-collapse supernovae, including the effect of general relativity, and the resulting astronomical signatures, such as the nucleosynthetic yields and gravitational waves. It was emphasised that only by comparing theory with observations will we see whether we understand the underlying physics. Takashi Moriya and Filomena Bufano presented observations of different flavours of Type II supernovae.

Letting the dust settle

On the third day Isabelle Cherchneff reviewed dust, which is ubiquitous in the Universe and impacts the physics and chemistry of many environments, such as the winds of evolved stars, the formation of planets in protostellar discs and the synthesis of complex organic molecules in molecular clouds. Large dust masses have been inferred in primitive galaxies and are indicative of efficient production in the early Universe, despite the very low metallicity and short timescales involved. A wealth of observational data exists on this key component of the Universe, but the chemical nature of dust, its synthesis in stellar media and the dust yields produced by stars are still very poorly understood. Dust formation requires high gas temperatures and densities to persist for a long enough period of time, and the best loci seem to be the shocked circumstellar environments around evolved stars, i.e. AGB stars, supernova remnants, C-rich WR stars and RCrB stars. The main outcome of Cherchneff’s talk was that no satisfactory model of dust formation in an evolved circumstellar environments currently exists, and the only way out may be to use a chemical kinetic approach.

Mikako Matsuura then provided a review of recent observational studies of dust in planetary nebulae and supernovae, and how they could impact the morphology, spectral appearance of nebulae and ambient interstellar media. Dust is not only produced in stars, but it can also play a crucial role in their further evolution, such as the case of AGB stars, where dust is considered to be the main driving mechanism for the mass loss. Apart from AGB, supernovae also appear to be a major source of dust production. The Atacama Large Millimeter/submillimeter Array (ALMA), for example, has confirmed the presence and location of a vast amount of cold dust in SN 1987A, most likely produced in the ejecta, while the small amount of dust measured in the ring comes from the progenitor. Several talks covered various aspects of dust production: crystalline silicates around oxygen-rich AGB stars (Olivia Jones), metallicity effects in globular clusters and dwarf spheroidals (Eric Lagadec), in the Crab Nebula (Patrick Owen) and in a binary merger V1309 Sco (Christine Nicholls).

Astrosphere, astrosphere!

The next day, after an inspiring free afternoon where most participants went on a vineyard tour (Figure 4), Nick Cox devoted his presentation to astrospheres. When stars plough through space at supersonic speeds, the interaction between their stellar winds and the surrounding medium can give rise to spectacular bowshocks or pile-ups, collectively known as astrospheres. Although the underlying physics is equivalent, the sizes, shapes and properties of these bowshocks can vary drastically for different types of stars or different conditions of the ISM. Even binarity or internal stellar processes can be decisive in shaping the observed interaction regions. The scale of such astrospheres can vary between a couple of hundred astronomical units for G stars such as the Sun to several parsecs for young, hot stars. Betelgeuse is a very nice example as it shows several arcs in the direction of motion, due to the expelled wind that interacts with and sweeps up the surrounding ISM. Other examples are runaway OB stars, Mira variables or R Hya stars, but recent observations with Herschel have shown a whole new population of objects displaying signs of inter-

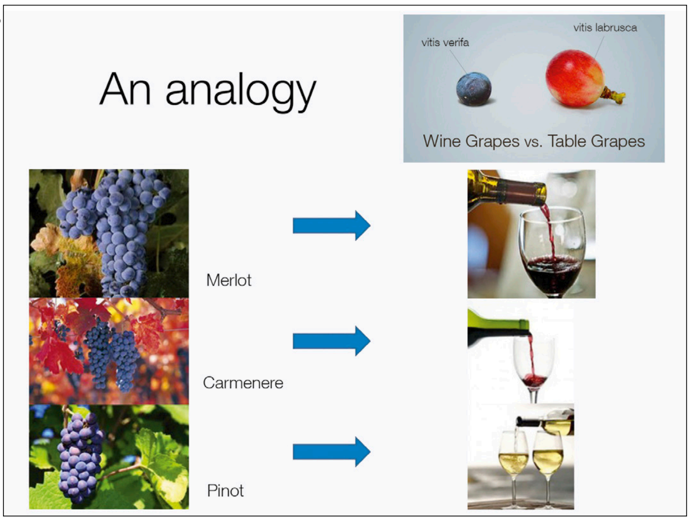

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Figure 4. A perfect example of the blend between scientific and social activities. The vineyard tour on Wednesday afternoon provided a nice analogy to show how similar grapes produce rather different wines, in the same way that similar binary systems may explain the great diversity in Type Ia SNe.

action, allowing classification among those showing fermata, eye, ring or irregular shapes. A new branch of astrophysics is in the making here!

Moving to yet higher mass, Paul Crowther discussed evidence for and against the existence of very massive stars, i.e. stars more than 100 $M_\odot$ in young massive clusters. Such massive stars are thought to have existed as Population III stars when they exploded as pair supernovae, producing vast amounts (several solar masses) of nickel and other elements, and thereby playing an important role in the early chemical enrichment of galaxies. However, they also seem to belong to some young massive clusters, such as the Arches, R136, Trumpler 14 or NGC 3603. Resolution is key to finding such stars, as the literature contains several examples of claims for the existence of very massive stars that turned out to be unresolved clusters, such as R136a. Very massive stars appear to belong preferentially to binary systems, which is a bonus when deriving current masses without depending on models: an example is the eclipsing binary NGC 3603-A1, whose components of 116 ± 31 $M_\odot$ and 89 ± 16 $M_\odot$ orbit each other in four days. Eta Carinae is another well-known example of a binary containing a very massive star, with a current mass of 120 $M_\odot$, but a probable initial mass as high as 200 $M_\odot$. For some of the stars in R136, the initial mass lies in the range 165 to 320 $M_\odot$. Such stars will explode as highly luminous pair-instability supernovae, leaving no remnant, and could explain some observations, such as SN 2007bi.

Galactic enrichment

Another important aspect by which stars contribute to their local environment is through their nucleosynthesis, and Francesca Matteucci discussed the chemical evolution of galaxies. All the basic ingredients needed to build galactic chemical models were presented, as well as the role of supernovae and their nucleosynthesis. Comparisons between model results and observations impose constraints on SN progenitors, stellar nucleosynthesis and galaxy formation processes. Alan Alves-Brito presented the different chemical enrichment timescales associated to the death of massive and low-mass stars in M22 and, ultimately, in the Galaxy. While Giovanni Carraro discussed the contribution to the integrated ultraviolet spectrum of the metal-rich old open cluster NGC 6791 from stars in late stages of stellar evolution: WDs, extreme horizontal branch stars and hot sub-dwarfs.

It was then time to leave the Galaxy and look at a broader view of the interplay between stars and galaxies in the Universe. Magda Arnaboldi presented the latest results on planetary nebula populations in external galaxies. Indeed, because of their bright emission in the [O III] 5007Å line, PNe are detected and studied in galaxies out to 100 Mpc. Based on simple considerations, the peak flux of PNe should decrease with time, but this is contrary to the observations that the peak flux of PNe in galaxies is constant, and may, once again, point to the important role that binaries play in PN formation. Despite the fact that their formation is still far from understood, PNe can be used as important empirical tracers of galaxies and used as distance estimators. Warren Reid showed how PNe are now being used to map the outer kinematic structure of the Large Magellanic Cloud to refine the warps, velocity structures and system rotation uncovered in the inner regions.

Sundar Srinivasan discussed the computation of luminosities and dust injection rates for the entire mass-losing evolved stellar population in the Large Magellanic Cloud. Stacey Habergham described the use of the statistical distributions of the different subtypes of core-collapse supernovae to probe the host star formation properties. The results show: an excess of stripped-envelope SNe in the central regions of disturbed hosts; statistically different distributions of SNIb and SNIc in undisturbed hosts; different distributions of SNIc and SNIIn, both of which are thought to have the highest mass progenitor stars; and an interesting distribution of SNIIn across their host galaxies.

Paradigm shifts and angular momentum

On the last day of the conference, Bruno Leibundgut presented a review of Type Ia SNe as distance indicators. He stressed that it is time to give up some cherished paradigms. Perhaps the most important of which is that Type Ia SNe are not standard candles; in fact, they are not even "standardisable", even though it may be possible to normalise some of them to a common peak luminosity. Type Ia SNe present large variations in luminosity, light-curve shapes, colours, spectral evolution, and even polarimetry. This diversity is such that it is now important to mention which kind of Type Ia SNe is being referred to, as there are clearly several families. The second paradigm to abandon is that Type Ia SNe do not all come from Chandrasekhar-mass white dwarfs. The diversity of Type Ia's shows that trying to find a single formation channel or explosion mechanism may be a utopian endeavour. However Type Ia SNe are still very good distance indicators and as such have led to the best determination of the Hubble constant, and have helped to confirm the existence of dark energy. Further progress in this area will require good data at $z > 1$, but mostly more infrared data at $z > 0.5$. It is nevertheless rather annoying that the origin of such important objects is still unknown.

The state of our current knowledge was summarised in the final talk of the conference by Noam Soker: "If WDs knew theory, they would not have exploded as SN Ia". Soker stressed that the main open questions in stellar evolution are related to angular momentum (AM) evolution, as AM is crucial both at the birth and at the death of stars. In this regard, the most important source of AM is either the contraction of a cloud/envelope — important during birth and core collapse SNe — or a binary companion (including brown dwarfs and planets). Binarity seemed to be a major ingredient to the many topics discussed during the workshop, and is perhaps the underlying *fil rouge*.

Most of the workshop talks are available on the meeting webpage[1].

Acknowledgements

It is a pleasure to thank all the speakers, and more particularly the invited ones, for highly inspiring talks that allowed us to fulfil the aim of this cross-disciplinary workshop to bring together specialists in quite different areas and have them share their expertise. Many thanks also to all the participants and we apologise that the lack of space did not allow us to discuss the numerous and very interesting posters that were presented. We would also like to warmly thank Maria Eugenia Gomez, Paulina Jirón, Amy Tyndall and Catherine McEvoy for their enthusiastic and efficient logistical help in making this workshop a success.

Links

[1] Workshop web page: http://www.eso.org/sci/meetings/2013/dslg2013/program.html

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ESO's Early Seeing Expedition to South Africa

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Site-testing for a joint European observatory in the south began in the 1950s in South Africa, following the declaration of the intent to build a large optical telescope in the southern hemisphere. First hand reflections of one of the early site-testing teams working in South Africa, based at the Boyden Station, are described. Practical problems related to seeing measurement and site assessment are discussed.

The long-term result of the meeting of leading European astronomers with Walter Baade in Leiden in 1953 was the foundation of ESO in 1962. One of its immediate consequences, however, was the decision to send an expedition to South Africa with the aim of finding a suitable place for a large astronomical observatory. The foundation and early history of ESO have been described by Blaauw (1991) and in the more recent history in Madsen (2012). This article recalls an aspect only touched on in Blaauw's monograph (p. 23).

I joined the South African seeing expedition in November 1956 when I had just finished my Staatsexamen fur das Höhere Lehramt with a thesis on cosmology with Prof. Otto Heckmann at Hamburg as advisor. At that time the plans for the European Southern Observatory were still very informal, and nothing had been definitely decided yet. Not even the name of the enterprise was definite, and we were known at the time by the garage that serviced the expedition cars as "Joint European".

Observing conditions in South Africa

At that time very little was known about seeing and seeing conditions in South Africa, only that the number of clear nights in that country was much larger than in Europe and several observatories had been established there: the Cape Observatory at Cape Town; the Radcliffe Observatory with a 74-inch telescope at Pretoria; and the Boyden Observatory with a 60-inch telescope at Bloemfontein. The seeing expedition had the task of finding a fully satisfactory place for a modern observatory, but it was not clear what the meteorological conditions were that had to be fulfilled to meet the request.

The climate of South Africa is divided into two different regimes: in the southern part there is a Mediterranean-type climate with winter rain, and the more northern subtropical region has rain in the summer season. Therefore it was decided to split the expedition into two groups; one was to investigate the winter rain region, the other the summer rain region further north. Both regions have a large number of clear nights when compared to European conditions.

The group that worked in the south (under J. Dommanget) chose Oudtshoorn as their headquarters, while the other group (under H. Elsässer) selected Boyden Station near Bloemfontein. Starting from