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DIVISION G
COMMISSION 35 **STELLAR CONSTITUTION**
CONSTITUTION DES ÉTOILES

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COMMISSION 35 WORKING GROUPS

Div. G / Commission 35 WG	**Active B Stars**
Div. G / Commission 35 WG	**Massive Stars**
Div. G / Commission 35 WG	**Abundances in Red Giants**
Div. G / Commission 35 WG	**Chemically Peculiar and Related Stars**

DECENNIAL ACTIVITY OF COMMISSION 35: 2005-2015

1. Introduction

Commission 35 (C35), "Stellar Constitution", consists of members of the International Astronomical Union whose research spans many aspects of theoretical and observational stellar physics and it is mainly focused on the comprehension of the properties of stars, stellar populations and galaxies. The number of members of C35 increased progressively over the last ten years and currently C35 comprises about 400 members. C35 was part of Division IV (Stars) until 2014 and then became part of Division G (Stars and Stellar Physics), after the main IAU reorganisation in 2015. Four Working Groups have been created over the years under Division IV, initially, and Division G later: WG on Active B Stars, WG on Massive Stars, WG on Abundances in Red Giant and WG on Chemically Peculiar and Related Stars. In the last decade the Commission had 4 presidents, Wojciech Dziembowski (2003-2006), Francesca D'Antona (2006-2009), Corinne Charbonnel (2009-2012) and Marco Limongi (2012-2015), who were assisted by an Organizing Committee (OC), usually composed of about 10 members, all of them elected by the C35 members and holding their positions for three years. The C35 webpage (http://iau-c35.stsci.edu) has been designed and continuously maintained by Claus Leitherer from the Space Telescope Institute, who deserves our special thanks. In addition to the various general information on the Commission structure and activities, it contains links to various resources, of interest for the members, such as stellar models, evolutionary tracks and isochrones, synthetic stellar populations, stellar yields and input physics (equation of state, nuclear cross sections, opacity tables), provided by various groups. The main activity of the C35 OC is that of evaluating, ranking and eventually supporting the proposals for IAU sponsored meetings. In the last decade the Commission has supported several meetings focused on topics more or less relevant to C35. Since the primary aim of this document is to present the main activity of C35 over the last ten years, in the following we present some scientific highlights that emerged from the most relevant IAU Symposia and meetings supported and organized by C35 in the last decade.

2. Summary of the Scientific Highlights

2.1. *IAU Symposium 228: "From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution", Paris, France, May 23 -27, 2005*

The symposium was dedicated to Monique and François Spite with the aim of recognizing their important contributions to the study of chemical abundances of cosmological interest. The various sessions presented a comprehensive overview of the scientific progress in the study of the early production of the chemical elements and their cosmic evolution.

The first session was devoted to the problem of lithium, its abundance in different astronomical objects, its implications for primordial production, and the analysis of the different mechanisms of destruction and synthesis. Special emphasis was placed on departures from the "Spite and Spite" plateau, the behavior of the ^{6}Li, the less abundant and more fragile lithium isotope, and subsequent implications, both cosmological and astrophysical. Remaining sessions were devoted to the evolution and properties of first stars with special emphasis on the properties of the more massive stars and the influence of rotation and stellar winds on their evolution, the properties of the galactic bulge and halo and the properties of metal poor stars. An entire session was also dedicated to supernovae AGB stars and planetary nebulae, their properties and their production of new chemical elements. At this point, it was recognized that our understanding of the chemical evolution of the galaxy was strongly mediated by the parameterized descriptions of the star formation rate, the initial mass function, mixing of the interstellar medium, stellar evolution and so on, in such a way that it could lead to a potentially dangerous situation in which observations could be reproduced just choosing an adequate, but not necessarily correct, choice of parameters. Properties of stellar clusters, both globular and old open clusters, were also considered. Finally, the abundances at large redshifts were examined.

The final result, thanks to the high quality of the data presented in the symposium, together with theoretical interpretations, was an accurate presentation of our current knowledge of the early evolution of chemical elements and a clear description of the problems that still remain.

2.2. *IAU Symposium 234: "Planetary Nebulae in the Galaxy and Beyond", Hawaii, USA, April 3-7, 2006*

Planetary Nebulae (PNe) represent the brief transition between Asymptotic Giant Branch (AGB) stars and White Dwarfs (WDs) and play a key role as multi-wavelength laboratories for developing our understanding of atomic, molecular, dust and plasma processes in diverse astrophysical environments. Important fields of study include

(*a*) The means by which their wonderfully diverse morphologies are obtained, including multi-dimensional shaping mechanisms and the role of a binary companion, magnetic fields and rotation;

(*b*) Their influence on the interstellar media of galaxies, including chemical enrichment;

(*c*) The growing use of their narrow high luminosity emission lines to probe the dynamics and mass distributions of galaxies and the intergalactic media of clusters of galaxies.

The broad meeting themes included Galactic and extra-galactic surveys for planetary nebulae; the evolutionary and structural relationships between asymptotic giant branch stars, post-AGB objects, planetary nebula and white dwarfs; nucleosynthesis and the properties of the central stars, including the role of a binary companion; multi-wavelength properties of the nebulae; atomic processes and nebular chemical abundances; the mechanisms for the formation of nebular structures, including the role of magnetic fields and binaries; and the properties and applications of extragalactic planetary nebulae, which are now being observed out to Coma Cluster distances.

There was intense debate on the following three topics:

(*a*) Are all PN central stars binaries? If so, what are the implications for our understanding of AGB and post-AGB evolution and the origin of the white dwarf population? Targeted surveys of PN central stars would help answer this question by providing statistics (e.g., how many PN central stars are actually binaries?).

(*b*) Do magnetic fields play a dominant role in the origin of observed planetary nebula structures? In contrast to previous meetings, there seemed a near-consensus that magneto-hydrodynamical effects play an essential role in explaining the origin of some observed structures, including bipolarity. Recent direct measurements of magnetic field strengths in the envelopes of AGB stars have helped catalyze this debate. Binary companions may also play an important role in shaping the nebula; again, statistics would help.

(*c*) Deep nebular spectra reveal a host of heavy element optical recombination lines (ORLs), which yield systematically higher ionic abundances than do the forbidden lines from the same ions, which have classically been used to estimate abundances. Is this effect due to temperature fluctuations, such that the ORLs give thecorrect abundances, or do the ORLs originate from cold plasma inclusions in the nebula, so that the forbidden lines give the correct abundances? This debate was not settled and we will expect to hear more on this in coming symposium on PNe.

2.3. *IAU Symposium 239: "Convection in Astrophysics", Prague, Czech Republic, August 21-25, 2006, in the context of the IAU General Assembly*

Thermal convection occurs in most objects that populate our Universe, whenever radiation is not efficient ebough to transport the heat because of the high opacity of the plasma. In astrophysical objects convection involves a wide range of spatial and temporal scales, this is why it is usually called turbulence, which makes it rather difficult to model. For this reason convection remains one of the major uncertainties when modeling stars and planets, and this is partly true also for accretion disks. However, substantial progress has been achieved during the years, both in the numerical simulation of convective regions and in the observation of convective flows by various new techniques.

The main goal of this meeting was to bring together astronomers working in different disciplines: solar physics, stellar physics, planetary physics and accretion discs, to report on the current state of the art in these fields and to encourage interdisciplinary cooperation.

Among the various arguments and techniques covered by the program the most important results that came out of this meeting were the following:

(*a*) Important advances were presented on the observing atmospheric convection in stars and on the helioseismic inferences on subsurface solar convection. In this context, the exciting advances in those years through the use of local helioseismology in probing the dynamics of the outer layers of the Sun were extensively discussed.

(*b*) A new determination of the solar abundances using the results of 3-D hydrodynamic simulations of the solar surface layers has been reported, the new determinations differing considerably from the previously estimated values and having a number of consequences in the context of the stellar astrophysics.

(*c*) New developments were reported on the simulation of convection and in particular gravity waves in planets, and on observations of convection in the giant planets from space missions, and also on of detailed 3-D simulations of convection in brown dwarfs.

(*d*) The role of convection in stars was extensively discussed. More specifically: a) it was reviewed the role of convection and convective overshooting in stellar evolution; b) they were presented impressive results on multidimensional simulations of convection in oxygen burning shell during the late stages of evolution of massive stars; c) it was reported on new results on supersonic convection in red giant stars and d) it was described a new composition gradient driven instability that can lead to mixing in stars.

(*e*) It was reported a recent work on the role of convection in exciting oscillations in stars and in particular on the use of the amplitudes of such oscillations as a probe of turbulent convection.

(*f*) In the context of the interaction between convection and rotation a) it was presented the current sate of knowledge of the rotation of the solar convective zone as derived from helioseismology; b) they were reported recent simulations of convection of a rotating layer and it interaction with magnetic fields and c) it was discussed the role of rotation in the generation of magnetic fields by dynamo action.

2.4. *IAU Symposium 250: "Massive Stars as Cosmic Engines", Kauai, USA, December 10-14, 2007*

The symposium Massive Stars as Cosmic Engines was structured according to the five major science themes of 1 Atmospheres and Winds, 2 Stellar Evolution, 3 Nearby Populations, 4 Feedback, and 5 Early Universe.

The surfaces of OB stars are basically understood, and models and observations agree quite well. Independent atmosphere codes used by different groups give consistent results. We can routinely generate fully blanketed non-LTE models and compare them to observations. This has led to a major revision of the relation between spectral type and effective temperature, the latter being $10-20\%$ lower than previously thought. The ramifications for the ionizing photon output or the bolometric corrections are significant. The long-standing discrepancy between stellar spectroscopic and evolutionary masses still persists, although the new atmospheres with their higher mass-luminosity ratio improve the agreement. While we understand the overall physics and derived parameters of OB stars, the effects of micro- and macro-turbulence, variability, porosity, and wind clumping still pose challenges.

Stellar rotation is a fundamental channel leading to the formation of Wolf-Rayet (W-R) stars. Originally, all W-R stars were suggested to be components of binaries, with orbital forces being responsible for the mass loss. Subsequently, it was recognized that stellar winds in single stars could remove mass as efficiently, and a 2nd W-R channel was established. Now rotation becomes the 3rd channel. At low Z, rotation may even be the dominant formation channel. However, model predictions of stellar evolution must rely on sometimes rather large extrapolations. This is particularly true when it comes to evolution to very low Z.

Binary evolution can play a crucial role for understanding the observed properties of individual stars and of massive populations as a whole. Mass transfer affects evolution in many ways, one of them being increased spin-up and therefore even higher rotation velocity. Could all rapid rotators be binary stars? Population models accounting for binary evolution appear to improve the agreement between predicted and observed stellar number ratios.

30 Doradus used to be the gold standard and Rosetta Stone for studies of massive star clusters. Heavily dust-obscured star clusters in our own Galaxy attracted a lot of

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attention during this meeting as well. Notable examples are the Arches and Quintuplet clusters near the Galactic Center. The Arches cluster is dense and rich enough to allow a full sampling of the IMF well in excess of 100 solar masses if such massive stars existed. However, no stars more massive than about 150 solar masses are found. This is interpreted as a genuine upper limit to the initial mass function.

What is the ionization source of the diffuse ISM? This long-standing open question has been brought back on the agenda owing to the revised relation between stellar spectral type and ionizing photon output. Previously, there seemed to be an excess of photons in HII regions that could leak out and heat the diffuse ISM. The new calibration essentially eliminates this excess, and the ionizing source of the diffuse ISM is again an open issue.

Feedback is fundamental at any redshift and at any time. Molecular hydrogen is the major coolant in the primordial ISM where star formation sets in once the gas has cooled down sufficiently. When the newly formed stars inject wind and SN material, the H2 may be removed, thus effectively curbing the cooling and star formation process. The main epoch of massive galaxy formation is at redshift 2. These galaxies host massive central black holes which can trigger galaxy-wide outflows. The outflows remove material from the galaxy centers, inhibiting further growth. Finally, local starbursts inject matter and energy into the ISM and may eventually pollute the surrounding intergalactic medium.

There is a fairly strong conviction among theorists that the first generation of stars was born with a top-heavy initial mass function. The absence of dust and a higher equilibrium temperature favor higher accretion during the star-formation process. As a result, the characteristic masses of stars are an order of magnitude higher than in the present-day universe, and the masses of the most massive stars may be as high as 500 solar masses. This is a research area that is begging for close collaborations between star formation experts, atmosphere modelers and cosmologists: such extremely massive and hot stars are ideal testbeds for the predictions of, e.g., the ionizing radiation in the extreme UV and the mass loss at zero metallicity.

2.5. *IAU Symposium 252: "The Art of Modeling Stars in the 21st Century", Sanya, China, April 6-11, 2008*

Our knowledge of the Universe is determined by the stars – either by the light they emit or the elements they produce. Stellar modeling thus stands at the heart of modern quantitative astronomy and astrophysics. Stellar models require a detailed understanding of both micro- and macro-physics. This meeting allowed us to consolidate recent advances in both radiative opacities and equations of state. The former now routinely include contributions from dust and molecules, which were ignored until recently. Many groups have provided updated equations of state which are now freely available, and were compared and discussed at this meeting.

One particular area receiving much discussion was multi-dimensional models of stellar atmospheres and their effect on abundance values. The recent determinations of the solar oxygen content were a subject of lively discussion. Although these now place the Sun in agreement with nearby stars and the interstellar medium, the models with lower oxygen no longer produce such good comparisons to helio-seismological observations. Discussion centered on ways to improve this situation, such as helium diffusion in the outer envelope and a possible under-estimate of the solar neon content. Symposium 252 was held in the days before the Kepler satellite, and hence seismology of other stars was in its infancy. Nevertheless substantial work was presented on the PG1159 stars.

The vexed issue of mixing in stars received much attention. It was then, and remains today, one of the areas where the most improvement is needed. Discussions on the extent of overshoot and the borders of convection were presented, as were new 2D and 3D models for the phenomenon. These new models presented in Sanya are part of a push in recent years to heroic multi-dimensional simulations that will eventually push us past the current roadblock that is our lack of understanding of mixing over evolutionary timescales. But other mixing processes were also discussed, such as semiconvection, thermohaline mixing, and of course rotational mixing and the host of new instabilities that this produces. Clearly the old ideas of rigid rotation are simply not valid for most cases. In real stars these various processes combine and compete - the modeling of which seems beyond us at present.

Mass-loss is a crucial phenomenon in the lives of stars, and received appropriate attention. Evidence was presented for the clumpy nature of the mass lost from massive stars, although the origin of these clumps was a mystery. AGB star mass-loss is a complex phenomenon, involving cool stars, dust and molecule formation, and possibly also the formation of planetary nebulae. We heard how spherical PN are a rarity, with the majority being bipolar.

The importance of Super-AGB stars was stressed, and arguably the first modern models were presented in Sanya, together with their associated nucleosynthesis. These stars are not often discussed, but they are likely to outnumber all supernovae.

Although one must understand single star evolution before one can study multiple stars, the meeting discussed many of the phenomena for which binarity is required, and indeed there are many classes of stars which can only exist because of binarity (eg Ba stars, some of the CEMP stars).

2.6. *IAU Symposium 256: "The Magellanic System: Stars, Gas, and Galaxies", Keele, UK, July 28-Aug 1, 2008*

This symposium continued a tradition of decadal IAU-sponsored meetings on the Magellanic Clouds. This is because, as the nearest gas-rich galaxies to the Sun, the Magellanic Clouds offer the greatest detail and depth as well as galaxy-wide views, with most objects at very similar distance. Hence many relations between stellar properties have been discovered first, or at least well calibrated, in samples in the Magellanic Clouds. Henrietta Leavitt's Cepheid period-luminosity relation is an obvious early example, which continues to be calibrated in the Magellanic Clouds to the present day. New observational facilities in the Southern hemisphere or space often quickly turn their eyes on the Magellanic Clouds to show off their power and reveal new information.

From the point of view of stellar constitution, IAU Symposium 256 was interesting for several reasons. One hot topic that had been emerging over the previous few years had been the realization that old globular clusters are not simple stellar populations. Just before IAU Symposium 256, spread in the upper main sequence of massive intermediate-age clusters in the Magellanic Clouds was observed, and the question arose whether this was a sign of extended star formation or a reflection of other physics such as stellar rotation or binarity. This question was not answered at the meeting, and to this day it still is not - although the most recent work clearly casts the extended (or multiple epoch) star formation theory in doubt and solutions may be found in binary and rotation evolution or a combination of both. There clearly remains some homework to do for people working on stellar constitution and evolution.

Other highlights related to stellar constitution that were presented include results from the very recent Spitzer Space Telescope surveys of the LMC and SMC (SAGE) by Margaret Meixner and Karl Gordon (also in the form of two large poster walls), the first results from the OGLE-III variability survey by Igor Soszyński (pulsation being the key to separating stars of different constitution but similar luminosity and temperature), a

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review on stellar sources of X-ray emission by Yaël Nazé, and a review on the metal dependence of young stellar objects by Joana Oliveira.

Separate sessions each with about ten talks addressed the stellar chemical yields and resulting chemical evolution of the Magellanic Clouds, the Magellanic Clouds as laboratories of stellar astrophysics, and the final stages of stellar evolution and feedback. Progress was reported in all of these areas, with more detailed observations of the star formation histories, chemical abundances, and properties of massive star atmospheres, more sophisticated models of stellar evolution as a function of metallicity, and more precise measurements of mass loss (in particular dust production). Keiichi Ohnaka won a poster prize for his pioneering interferometric work resulting in resolving the circumstellar dust shell around the red supergiant WOH G064 in the LMC. But most of the big questions remain. For instance, reconstructing the star formation and chemical enrichment history still relies on assumptions such as an age-metallicity relation (we now know that the LMC and SMC may in fact have exchanged gas and stars multiple times, so a more fundamental approach to incorporating stellar yields from models is required). Stellar models still differ between different groups, and never incorporate all physics at once. And mass-loss rates are still uncertain and cannot be calculated from first principles.

The meeting was attended by 150 scientists from all over the world. Of the 15 invited talks, 8 were presented by women (and 17 out of the 48 contributed talks). The proceedings were dedicated to the memory of Bengt Westerlund who had died shortly before the meeting - he is famous for his work on stellar populations.

2.7. *IAU Symposium 262: "Stellar Populations Planning for the Next Decade", Rio de Janeiro, Brazil, August 3-7, 2009, in the context of the IAU General Assembly*

IAU Symposium 262 was focused on the definition of the state of the art of our understanding of stellar evolution, galaxy formation and galaxy evolution as well as on the legacy of massive surveys covering large portions of the sky such as SDSS, HDF, UDF, GOODS and COSMOS. The meeting offered an interesting opportunity of discussing the newest results, both from the theoretical and the observational point of view, in the various fields of stellar population studies. On the theoretical side, significant new results have been reported on the modeling of thermally pulsating asymptotic giant branch stars as well as of stellar populations with non solar-scaled metal abundance ratios. The implications of these improvements for the interpretation of observations have also been widely discussed.

On the observational side, significant improvements of photometric and spectroscopic studies of resolved stellar populations, both in the Milky Way and in nearby galaxies, have been reported. It has become evident that these studies have reached such a sophisticated level that they can provide, at least in some cases, a detailed reconstruction of the star formation and chemical enrichment histories of the investigated stellar systems. Moreover, the possibility to reconstruct the rest-frame optical spectra of very high redshift galaxies, through their extremely deep infrared spectra, has provided constraints to the hosted stellar populations.

A new aspect of modern research on stellar populations that has been reported at the Symposium is the development of flexible techniques to investigate stellar systems at all redshifts, as motivated by the availability of large databases of observations and theoretical models.

The challenges for the subsequent decade identified at the Symposium were:

(*a*) the development of well-calibrated and extensively tested models over the whole spectral range from ultraviolet to infrared wavelengths, through the modeling of the late

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phases of stellar evolution to almost the same degree of accuracy as for the modeling of main-sequence stars;

(*b*) the progress in modeling stellar populations with non-solar abundances to provide more stringent constraints on galaxy assembly from chemical pattern studies;

(*c*) the exploitation of the new ground-based and space-based facilities to study resolved stellar populations with unprecedented detail and to get images and spectra of the very first stellar populations formed in the far universe.

2.8. *IAU Symposium 265: "Chemical Abundances in the Universe: Connecting First Stars to Planets", Rio de Janeiro, Brazil, August 10-14, 2009, In the context of the IAU General Assembly*

The main goal of this symposium was to provide an updated picture of the origin and evolution of the elements across all of cosmic time.

Big Bang Nucleosynthesis (BBN) was the first discussed topic. It was pointed out that BBN was consistent with the Cosmic Microwave Background (CMB) results and with the observations of ^{2}H, ^{3}He and ^{4}He. The measured abundances of ^{7}Li in the most metal poor stars, on the contrary, did not agree with the CMB predictions. Several explanations were proposed to resolve this tension, among which were some unknown types of mixing or diffusion, responsible for the depletion of ^{7}Li in the atmospheres of the halo stars, or new physical phenomena. The possible detections of ^{6}Li in metal-poor unevolved stars was also proposed as possible clues to solve the ^{7}Li $-$ CMB discrepancy, however it was also pointed out that the quantitative abundances derived for the lithium isotopes strongly depend on highly uncertain input physics like the 3D modeling or non-LTE calculations.

The first stars and their characteristics were another topic of vigorous discussion. It was argued that that the initial mass function of the very first stars had to be very biased towards higher masses due to the lack of cooling processes at zero metallicity and that, perhaps, extremely massive objects were also responsible for the reionization of the Universe. Of equal importance to the masses was the nucleosynthesis occurring in these massive stars as well as their contribution to the early enrichment of the Universe. It was noted that stellar rotation could have important effects on the evolution and nucleosynthesis of primordial stars and therefore that it could have a major effect on the initial phases of chemical enrichment. The idea that very massive stars dominated the early stages of the chemical evolution of the Universe was also reinforced by new observations of carbon enhanced-metal poor (CEMP) stars that confirmed their increasing number with decreasing [Fe/H].

Another important topic of this Symposium concerned the chemical abundances in the high redshift Universe. It was pointed out how a number of high-redshift objects like, e.g., QSOs, Lyman break galaxies, (LBG), damped Lyman-α systems (DLA), Lyman-α forest gas or the ISM within the host galaxies of the gamma-ray bursts (GRB) are providing a wealth of information about the Universe when it was much younger and complement the results from the nearby, very old, low mass stars. They also span very different ranges of gas size, from the very small scales of the QSOs (~ 10 pc) to the increasing sizes provided by the LBGs, the DLAs up to the Lyman-α forest systems, spanning the largest scales ($\sim 10^5$ pc). On interesting results in this context was the evidence that, in many of these systems, the chemical enrichment took place very early in the history of the Universe, at equivalent redshifts $z \sim 9 - 10$.

Other interesting results that came out of this Symposium concerned the abundance patterns in a wide variety of galactic environments, and how the elemental abundance distributions can be used to trace star formation and chemical enrichment histories. A number of results were presented on the abundances observed in a growing variety of galaxies or galactic populations among which the irregular and dwarf galaxies (especially the dwarf spheroidals), the recently (at that time) discovered ultra faint dwarf galaxies, the Galactic halo, the bulge and the Milky Way center and the Omega Centauri tidal stream. It was put in evidence how the abundance patterns of the smaller galaxies differ substantially from the one observed in the Milky Way disk and halo, such a difference providing information on how the star formation and therefore the return of the metal-enriched gas into the local ISM varies in different types of galaxies. Of great interest were the newly discovered ultra faint dwarf galaxies and in particular whether there is any relation between these tiny systems and the Galactic halo.

Special emphasis was placed on the increasingly sophisticated studies of the different components of the MW, in particular the thin disk, the tick disk, the inner and outer halos, the bulge and the galactic center. One of the most interesting results in this context was the evidence that the thick disk and the bulge share the same chemical composition. It was also evident the presence of a substructure of the galactic halo, that is an inner and an outer halo having sizable different abundance patterns. There was a lot of discussion on the need of complex chemical evolution models, including both the chemistry and the dynamics, in order to put all the new available abundance observations from the various different galaxies in a single coherent view. The meeting emphasized the need to take into account processes like infall or outflow, as well as the dynamic interactions between the various parts of the galaxy. Such chemo-dynamical models have been proposed as the only tools being able to improve our interpretations of the observed abundance patterns. Modeling topics also included the s-process in a low-metallicity environment and the thermohaline mixing as a possibile solution to the longstanding ^{3}He problem.

An entire session of this Symposium has been devoted to the topic of the "exoplanets". At that time this topic was a relatively new addition to the field of cosmochemistry but it became an increasingly important one in the following years because of the clear correlations between the likelihood of the presence of large planets and the host-star metallicity. The meeting reviewed the role of the metallicity of the parent star in the process of planet formation in both the gravitational instability model and the core-accretion model. Another aspect of this topic that was discussed was the possible interaction between the parent star and their planetary families, such as ingestion of the planet by its host star, which may influence the stellar composition. Observations of chemical abundances of stars with and without planets have been reviewed and a clear connection between the chemical composition and the planetary architectures has been shown, although the exact connection remained elusive. In this context it was proposed that some Li-rich red giant stars may have accreted, or ingested, large planets, leaving a chemical signature. The possible accretion of chemically fractionated material by our own Sun was the argument of one discussion, with the suggestion that the presence of a solar system-like terrestrial planet family may be imprinted in the abundance pattern of the parent star.

2.9. *IAU Symposium 268: "Light elements in the Universe", Geneva, Switzerland, November 9-13, 2009*

IAU Symposium 268 offered an overview of the most recent observational and theoretical research on the formation and evolution of light elements in the Universe, namely H, He, Li, Be, B with the associated isotopes, that play a key-role in several astrophysical fields. Indeed the interest in these elements connects all the astrophysical communities, as they can provide important clues to understand stellar and ISM structure and evolution, galaxy formation and evolution, Big Bang nucleosynthesis and cosmology. IAU Symposium 268 was an opportunity for astrophysicists from a variety of subfields to

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discuss relevant developments towards our understanding of the light elements and of their role in the above mentioned astrophysical fields.

The meeting reported the striking observational progress achieved thanks to the accurate determination of the baryon density of the Universe by recent cosmic microwave background experiments (e.g. WMAP), which led to an unprecedented precision in the determination of the yields of Standard Big Bang Nucleosynthesis, to be compared with the abundance of light elements observed in low-metallicity environments. At the same time, the advent of a new generation of ground and space based telescopes allowed the observation of light elements in objects previously unreachable, with new intriguing results on their present and past abundances. Multi-fiber instruments allow us to gather a wealth of data in a consistent way but need to be fully understood and interpreted.

On this basis, new theoretical breakthroughs in describing stellar interiors and the chemical evolution of complex systems and the remaining challenges in this field were also addressed at the meeting. Most of these theoretical improvements were achieved thanks to constraints coming from combined observations of light element abundances in various types of stars. Moreover, 3D time-dependent hydrodynamical model atmospheres were developed and have helped provide more reliable surface abundance determinations. Finally, several independent and fully consistent chemical evolution models, able to fit the general trends of Galaxies physical and chemical features, were discussed at the meeting.

The main challenges for the future remained the understanding and detailed reproduction of all light element patterns, their local, short-term variations, as well as their global evolution in the Universe. In this context, the symposium represented a great opportunity to collect inputs and ideas from observers, stellar and galactic physicists, and cosmologists. This occurrence was particularly relevant because the complete understanding of the evolution of the Light Elements in the Universe is a challenging task that requires the exchange of ideas and the collaboration of astrophysicists with observational and theoretical expertise in stellar hydrodynamics and evolution, Galactic and extra-galactic astronomy, and cosmology.

The meeting was timely in view of the launch of Planck, a satellite designed to image Cosmic Background radiation anisotropies, and the HST refurbishing Servicing Mission 4. Moreover, 2009 was the International Year of Astronomy, the 450th anniversary of the University of Geneva, the 175th anniversary of the University of Bern, the 40th anniversary of landing on the Moon, and the 400th anniversary of Galileo's astronomical telescope. Therefore, several public manifestations (public talks, exhibition at the Museum) were organized during the Symposium in connection with all these events.

2.10. *IAU Symposium 272: "Active OB Stars: Structure, Evolution, Mass-Loss, and Critical Limits", Paris, France, July 19-23, 2010*

This symposium focussed on those massive and intermediate-mass hot stars that exhibit strong variability due to mass outflows, rapid rotation, pulsations, magnetism, binarity, radiative instabilities, et cetera. The questions that were identified were summarized by the organizers as follows (selected and paraphrased):

(*a*) what is the role of magnetic field, rotation, metallicity and mass loss in the evolution of OB stars? How do surface abundances evolve?

(*b*) What is the role of magnetic fields, rotation, and pulsations in the activity of OB stars? What is responsible for wind clumping and the formation of a disk or clouds?

(*c*) What is the internal structure of active and critically-rotating OB stars? How is the angular momentum transported? If there is a magnetic field, is it of fossil or dynamo origin?

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(*d*) Under what conditions do active OB stars become Be stars? What causes LBV outbursts? What happens when a star reaches critical rotational velocity?

(*e*) What are the observed properties and statistics and how does observation compare to theory?

The meeting highlighted progress in these areas. For instance, it has recently become possible to measure magnetic fields for larger samples of stars, something that has been difficult and long hampered our knowledge of the effect of magnetic fields. Clumping of winds complicates mass-loss rate determinations; only X-ray measurements are immune to these effects but these kinds of measurements have become possible. Lower metal content seems to result in lower mass-loss rates (of OB stars), larger rotational velocities and more Be stars. The LBV phase may be longer than previously thought, increasing their importance for the mass lost and the formation of Wolf-Rayet stars. Interferometric observations have been able to resolve disks around Be stars. Magnetic Herbig Ae/Be stars are probably the progenitors of Ap/Bp stars. Asteroseismology has started to offer novel constraints on internal mixing processes.

André Maeder conluded the meeting, first referring to Jean-Paul Zahn, who has made enormous contributions to our understanding of mixing within rotating stars but who has sadly passed away earlier this year (2015). Clearly, this area is a full 3D problem, with meridional circulation and horizontal turbulence. It is interesting that Maeder spoke of turbulence because turbulence is scale free, whereas convection for instance has a typical scale. How does a magnetic field affect the transport processes, of angular momentum and of chemicals? The Hunter diagram is emphasized, in which stars display a variety of combinations of rotational velocity and surface abundance anomalies, clearly pointing at a more complicated situation that initially thought (or hoped). Maeder also expressed his surprise that there seems to be no rule for how strong an OB star's magnetic field is, and he recalled Huib Henrichs interesting demonstration that magnetic fields can cause surface nitrogen enhancement even in the absence of rotation (perhaps explaining part of what's going on in the Hunter diagram?). It is also clear that rotation, magnetic fields, surface abundances and mass loss are all interlinked.

While none of the above questions has been fully answered, it can be expected that continued progress be made in all these areas, making for an optimistic future and likely more meetings.

This meeting was attended by 172 scientists from 26 countries.

2.11. *IAU Symposium 283: "Planetary Nebulae: An Eye to the Future", Tenerife, Canary Islands Spain, July 25-29, 2011*

Planetary nebulae (PNe) play a key role in stellar evolution. An important fraction of stellar matter in the Universe, which includes stars in the approximate range of 1 to 8 solar masses, goes through the asymptotic giant branch (AGB) and PN phases near the end of their lives. Observationally, most known PNe are the progeny of stars less than about 4 solar masses. This is because the dynamical PN phase of more massive progenitors is intrinsically very short ($\sim$ 100 years) and also because there are fewer of them in the Galaxy. Stars from the high-mass end are usually observed at the early stages of PN formation, when they appear as embedded AGB stars.

The broad meeting themes included surveys of planetary nebulae, the morphologies, abundances, kinematics and structure of PNe, theoretical evolutionary models of binary and single stars, the central stars of PNe, the population of Galactic, extra-galactic and intra-cluster PNe, and future directions of the field. Some of the most significant highlights of the meeting were:

(*a*) The results from PHAS: the INT/WFC photometric H-alpha survey of the Northern Galactic Plane was completed: 155 new PNe were discovered.

(*b*) "A Kinematic Catalogue of Galactic Planetary Nebulae" that consists of high-resolution spectra of about 600 PN was completed.

(*c*) New results from the HERSCHEL satellite were presented and included observations of large detached shells around AGB stars formed in the interaction of the AGB mass loss with the ISM, and the discovery of water vapor in a C-rich AGB star.

(*d*) New results on the statistics of binary central stars were presented: At least 20% of PNe have close binary pairs that have passed through at least one phase of common envelope evolution. There were also discussions on how well we understand binary evolution and the common envelope phase. New 3D models of the common envelope phase were also presented.

(*e*) Large carbon molecules (fullerenes, C60 and C70) were detected around PNe in the Milky Way and in the Magellanic Clouds. These fullerenes, the biggest molecules known in space, are accompanied by large concentrations of hydrogen, contradicting theories and laboratory experiments, which show that fullerene formation is strongly inhibited by hydrogen. Fullerenes are much more common and abundant in the Universe than initially thought, with important implications for circumstellar and interstellar chemistry and physics. In addition, graphene (planar C24) has been detected for the first time in some PNe with fullerenes.

(*f*) The relationship between uncertainties in atomic data and the resulting uncertainty in derived abundances was heavily debated: How large are the uncertainties in atomic data used for chemical abundance calculations? It seems that no consensus has yet been reached.

(*g*) Abundances of heavy elements in PNe were presented. The elements obtained in PNe (e.g., Zn, Ge, Se, Kr, Xe) are complementary to the elements derived from stellar spectra (e.g., Sr, Y, Rb, Ba) and provide important constraints to mixing in theoretical models of AGB stars. Zn was discussed as an important metallicity diagnostics in PNe, where the iron abundance cannot be reliably determined.

2.12. *IAU Symposium 289: "Advancing the Physics of Cosmic Distances", Beijing, China, August 27-31, 2012, in the context of the IAU General Assembly*

The meeting addressed the physics underlying methods of distance determination, the most recent results were presented and a roadmap for future theoretical and observational advances in the field was provided.

Knowing the distance to an astrophysical object is crucial to undertand it. In the last 10 years unprecedented quality of photometric and spectroscopic data of stars, stellar populations and galaxies have became available thanks to ground-based 8-10 meter-class optical and NIR telescopes (i.e. Keck, VLT, Gemini, Subaru), space observatories (i.e. HST, Herschel, Spitzer, Chancra, XMM-Newton) and the high resolution achieved by radio observations (as VLBA, VERA). In parallel, the improvements on stellar models and numerical simulations allow us to predict observational properties with high accuracy but the comparison with the data is hampered by the lack of precision on the estimated distance to the object. While previous IAU symposia focused on individual aspects of selected methods of distance determination, this Symposium was characterized by its interdisciplinarity, encompassing a broad range of techniques and theories.

A detailed revision of all currently used distance indicators at all scales, from the solar neighborhood to the edge of the Universe, was performed, high-lighting their limitations and ways of improvement. Conclusions were based on the lively debates that follow the scientific contributions presented in 16 review talks, 16 invited talks, 35 contributed talks and 50 posters.

Milestones in the field were discussed, such as the Pleiades distance controversy, the needed refinement of the distance to the Galactic Center, to the LMC, to the Local Group, nearby galaxies, local supercluster and cosmic distances, as well as the used of Cepheids, Miras, RR-Lyrae, planetary nebulae luminosity function cut, red giant branch tip, eclipsing binaries, maser water measurements, Tully-Fisher relation, surface brightness distribution, or Type Ia Supernovae. It was concluded that we are still far from possessing precise distance ladders. Statistical and systematic uncertainties persist even for the nearest and presumably better understood distance methods, as the controversy on the distance to the Pleiades shows. Improvements require a better understanding of the late stages of stellar evolution (i.e. stellar atmospheric and pulsation physics, mass loss, etc., as a function of stellar initial mass and metallicity).

From the observational point of view, the advantages of access to significant amounts of observing time in small telescopes (2-4 m-class) rather than access to the deep universe through extremely large telescope were discussed. At the end, the future looks promising due to facilities as LSST, JWST, SKA, Pan-STARRS or VISTA.

2.13. *IAU Symposium 301: "Precision Asteroseismology", Wrocklaw, Poland, August 19-23, 2013*

This symposium celebrated the scientific opus of Wojtek Dziembowski, one of the world's leaders in the study of solar and stellar pulsations. The meeting was focused on the seismic study of pulsating stars, trying to identify the missing physics to be included in the stellar evolutionary models and how the analysis of stellar pulsation data could improve our models and our understanding.

The program of the Symposium was divided into 7 sessions with a total of 35 invited talks, 28 contributed talks and 75 posters. Each session was accompanied by lively and fruitful discussion, a special session was devoted to honored Wojtek Dziembowski, and two public lectures were organized to disseminate the knowledge about asteroseismology.

Key observational and theoretical problems were addressed. The main theoretical topics discussed were the efficiency of convection and its interaction with pulsation as well as the role of rotation, magnetic fields and element mixing in pulsation excitation. Several fundamental questions were afforded: How to best use the rich but irregular oscillation spectra? How far are we from unravelling the mode-selection mechanism? What is missing from astrophysical opacities? (An announcement of the new opacity bump around log T=5.6 was made at this meeting). Projects for the near future include the potential of asteroseismology to study planet-hosting stars. On the observational side, high quality results were presented from the ground-based surveys OGLE, ASAS and Araucaria, and the space missions MOST, CoRot and Kepler, as well as the preliminary results from two new asteroseismic project, BRITE and SONG.

2.14. *IAU Symposium 307: "New Windows on Massive Stars", Geneva, Switzerland, June 23 – 27, 2014*

The symposium discussed innovative techniques to probe the interior of stars, to constrain the size of their convective cores and the way they rotate in their interiors through asteroseismology, to determine the strength and topology of their surface magnetic fields through spectropolarimetry and to measure the shape and distribution of their circumstellar environments through interferometry. Together with other more classical methods, such as photometry and/or spectroscopy, these techniques have changed our understanding of massive star evolution and showed that beside the initial mass and the metallicity,

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the evolution of massive stars, either single or in close binary systems, may also depend on their axial rotation and on their surface magnetic field.

Stars are three dimensional (3D), turbulent plasma, and much more complex than the simplified one dimensional (1D) models we use for stellar evolution. Computer power is inadequate at present for adequately resolved (i.e., turbulent) 3D simulations of whole stars. This complexity was discussed and examples were shown of how it may be tamed by the use of 3D simulations and Reynolds-Averaged Navier-Stokes (RANS) equations.

Thanks to excited modes, in particular those propagating in the deep interior, the extent of the mixed central region can be constrained by astreoseismology. This region consists of the fully mixed convective core surrounded by an "extra-mixed" region, either fully or partially mixed. The extent of the extra-mixed region can only be reliably determined by asteroseismology provided some rather strong requirements are fulfilled not only on the number of well identified modes but also on the detailed elemental abundances of the observed star.

One of the big issues extensively discussed in this symposium was the treatment of convection in massive stars. However, most stellar evolution codes still compute convective regions in the frame of the local mixing length theory (LMLT) with either the Ledoux or Schwarzschild criterion.

Asteroseismic analyses require fully consistent models, in particular models with correctly located convective boundaries, i.e. satisfying the convection criterion on its convective side. A departure from this requirement leads to too small convective cores and erroneous Brunt-Väisälä frequency distributions, with a possible misleading interpretation of the asteroseismic data.

Asteroseismology and interferometry are highly complementary. Examples are the detection of non-radial pulsations in massive stars and the possibility of demonstrating differential rotation on the surface of Bn stars. The current interferometric facilities, i.e., ESO's Very Large Telescope Interferometer (VLTI)/AMBER, VLTI/MIDI, VLTI/PIONIER and the Center for High Angular Resolution Astronomy (CHARA) array were discussed, together with their current limitations. The forthcoming second-generation VLTI instruments GRAVITY and MATISSE were presented, as well as the FRIEND prototype in the visible spectral domain and an update of the Navy Precision Optical Interferometer (NPOI).

Much of the research performed with today's spectropolarimetric instrumentation has been focused on broadening our understanding of stellar magnetism. Magnetometry relies principally on the use of circular (Stokes V) spectropolarimetry, exploiting the longitudinal Zeeman effect to detect the line-of-sight component of magnetic fields in stellar photospheres. The origin of the magnetic fields of OB stars has been a major driving question during the last decade. Analytic and numerical investigations have demonstrated that stable fossil magnetic field configurations can result naturally in stellar radiative zones from the relaxation of an initially random seed field. Linear polarimetry, primarily in the continuum, has been employed to investigate scattering geometries of circumstellar discs and envelopes, to probe wind structures and oblateness, and to provide independent constraints on the structure of stellar magnetospheres. Linear polarimetry of spectral lines has been exploited to a limited extent, although useful interpretation of those results has often remained an unsolved problem.

2.15. *IAU Symposium 316: "Formation, evolution and survival of massive star clusters", Honolulu, USA, August 11-14, 2015, in the context of the IAU General Assembly*

The interest of the study of massive star clusters is a direct consequence of the connection they provide between the interstellar medium, star formation and evolution, mass and energy feedback to evolution of galaxies, and cosmology. It is widely recognized that these systems are ideal laboratories to probe very localized processes within interstellar gas clouds as well as large-scale dynamics of interstellar matter in interplay with the formation, evolution, and death of stars. They are the key sites of high-mass star formation and they host large numbers of compact and exotic objects that form preferentially in dense environments. They hold clues to how star formation and evolution as well as chemical and dynamical evolution of stellar systems influence each other and vary from one environment to another, from the present to the early Universe. They are the witnesses of the formation, assembly, and evolution of galaxies and of their substructures across time. They play a role in hierarchical cosmology as well as in the reionization of the intergalactic medium.

The purpose of the symposium was to examine the fundamental processes sustaining the formation, evolution, disruption or survival of massive star clusters. With this goal the topics covered were:

(*a*) Origin of giant molecular clouds

(*b*) Physics of massive star cluster formation and its dependence on the environment

(*c*) Initial mass function of star clusters

(*d*) Dynamical and chemical evolution of massive star clusters - Interplay and feedback between ISM, stars, and cluster dynamics

(*e*) Star cluster destruction: infant mortality rates, early destruction, tidal stripping

(*f*) Star formation hierarchy (clustered and triggered star formation) and multiple stellar generations in massive star clusters

(*g*) Stellar populations and time evolution of their characteristics in massive star clusters

(*h*) Contribution to the stellar content of galaxies and their substructures, and tracers of remnant star clusters in galaxies

(*i*) Theoretical simulations of the dynamics of massive star clusters, recent code developments and hardware issue

(*j*) Observational challenges with present and future ground-based telescopes and space missions.

The discovery of multiple stellar populations in Galactic globular clusters, which is now embraced by the community at large, has totally revolutionized the classical picture of these objects and has shed a new light on massive star clusters long thought to be simple systems of coeval stars born out of homogeneous material. This drastic paradigm shift has raised a number of fundamental questions about the physical processes that drive the formation and internal evolution of massive star clusters, on the star cluster initial mass function, and on the contribution of star clusters of various sizes and ages to the general galactic field stellar population and to the reionization of the intergalactic medium at high redshift. This has consequently led to significant investments both on the observational and theoretical sides over the past couple of years in order to understand these very complex objects in a broad astrophysical context.

Among the crucial points that have been addressed during the symposium it is worthwhile mentioning the role of the early dynamical and chemical evolution of star clusters together with stellar feedback on the intracluster medium, along with the connection

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between the detected numbers of exotic objects (millisecond pulsars, cataclysmic variables) and both chemical and dynamical evolution, the combination between multiple population studies and kinematics of single stars as well as various structural parameters for star clusters, and the connection between nuclear star clusters and the globular cluster system of individual galaxies.

3. Concluding remarks

The scientific interest of Commission 35 community certainly spans a range of topics much broader than those presented here and that we could not discuss in detail. However, we think other considerations also should be mentioned.

Several meetings or series of meetings have attempted to cross boundaries between fields or between communities. For instance, in 2008 a meeting was organized in Pasadena on the topic of "Hot and Cool: Bridging the Gap in Stellar Evolution", to bring together communities working mostly on OB-type massive stars and those working on cool stars. Subsequent meetings on massive stars have more prominently included - or even concentrated on - red supergiants. For instance the Paris 2012 meeting devoted to Betelgeuse or Focus Meeting 16 ("Stellar Behemoths: Red Supergiants in the Local Universe") organized by Ben Davies at the IAU General Assembly in 2015. The Vienna group have organized three meetings in their hometown on AGB stars in relation to the galaxies they inhabit, in 2006, 2010 and 2014. And in Budapest in 2016 the 12th edition of the series of "Torino Workshops" on AGB star nucleosynthesis, conceived by Roberto Gallino and Maurizio Busso in 1995, will again bring together experts on nucleosynthesis, meteoritic abundances, and other behavioural aspects of AGB stars. It is hoped that truly inter-disciplinary meetings can bring progress in areas that have long separate; for instance could we make advances in understanding and describing convection by getting together with atmospheric scientists in weather and climate forecasting, or even industrial researchers as well as pure mathematicians?

Another example of interdisciplinary series of meeting is the "Nuclei in the Cosmos" series, which is the formemost bi-annual symposium of nuclear physics, astrophysics, astronomy, cosmo-chemistry and other related fields that started in Wien, Austria, in 1990 and which is, in 2016, in its 14th edition. This symposium aims to survey the recent achievements and exchange expertise and progress in this interdisciplinary field, and it promotes mutual understanding and collaboration over the fields fundamental to solving a range of open questions, from the origin of the elements to stellar, galactic and cosmic evolution.

The Working Group on Abundances in Red Giants has been active under the chairmanship of John Lattanzio. After the editors Thierry Forveille and Claudine Kahane moved on to other things, their AGB Newsletter looked all but doomed, but it was resurrected at Keele University in 2006 by Jacco van Loon (current Chair of the WG) and Albert Zijlstra (University of Manchester), and has since been very healthy and become the Working Group's official communiquè. It will continue to fulfil this role for the revamped Working Group on Red Giants and Supergiants.

If one object deserves to be mentioned in relation to our (mis)understanding of stellar evolution, it is perhaps SN 1987A. Since this surprise explosion of a blue supergiant, and subsequent discovery of a ring of material probably arising from a red supergiant past, it has continued to be monitored and "explained" but there is as yet no consensus even whether it was a single star or a binary. (Selma de Mink has recently emphasized that a significant fraction of all massive stars have been affected - or will be affected - by close binary interaction.) What other systems do we know that will undergo the same fate?

Another fascinating topic worth being mentioned is that of the pre-solar grains. The isolation of surviving pre-solar minerals in primitive meteorites in 1987 heralded the birth of a new branch of astronomy. Holding pieces of stars in our hands enabled us to unleash all the detailed methods available to modern analytical laboratories. For the first time we were able to determine detailed compositional information, including isotopic ratios, for trace elements. These studies have provided new and often unique information on galactic chemical evolution, on nucleosynthesis in a variety of stellar objects, on grain formation in stellar outflows, and on the survival of grains in the interstellar medium, in the solar nebular, and in meteorite parent bodies.

Commission 35 sponsored a Joint Discussion on this topic at the IAU-GA in Prague in 2006. This brought together experts from all relevant areas and was an excellent opportunity to publicize the possibilities of this new science to those who may not be familiar with the recent developments. The papers presented at that meeting illustrate the breadth and depth of information derivable from these laboratory studies. The unprecedented accuracy of the stellar compositions so obtained can provide exquisite tests of our models. Such work has driven a revolution in stellar models and the number of species included in the calculations, because for the first time we have accurate data with which to confront the models.

Such studies have provided strong evidence for the mixing of different nucleosynthesis layers in supernova explosions, and have been used to stimulate re-determinations of nuclear reaction rates, for example. In particular, they offer detailed insights into neutron capture nucleosynthesis, with accurate isotopic ratios for rare elements that are simply impossible to obtain from traditional spectroscopic methods. These studies remain a unique way to determine the detailed composition of stars that are now long gone.

The field of pre-solar grain analysis continues to grow, and Commission 35 is proud to have helped this new science at a critical phase in its development.

The above considerations are presented as a summary of the activities of the Commission in recent years. They illustrate the breadth of applications and physical processes, not to mention specialist instruments and techniques, that are required to contribute to the field of *Stellar Constitution*.