SUMMARY TALK: WHAT IS HAPPENING TO MASSIVE STARS IN GALAXIES?

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ABSTRACT. Highlights of the IAU Symposium 116 are reviewed. Some of the general themes running through the meeting are identified. These include:i) the fruitful interaction between observation, laboratory work and theory. ii) the need for understanding and, if possible, correcting for the effects of incompleteness and bias in observing lists. iii) the importance of the Magellanic Clouds, as the nearest independently evolving stellar systems, in the study of massive star formation and evolution in galaxies.

It can be hard sometimes, to make our colleagues believe that gatherings at places as beautiful as Porto Heli can serve a useful purpose. Yet, by getting together at the right location for a week-long interchange of ideas, results and information, we can set the stage for new and often pivotal advances in a subject. As we listened to the papers during the last week, many of us felt that this was indeed a good time for a symposium about luminous stars and associations in galaxies. If one were to choose a major theme of our meeting it might well have been the fruitful interaction between observation, laboratory work and theory at this present stage of our understanding. The recent burst of progress has come from a confluence of these three streams, each itself newly enriched by significant new advances. First, we now have at hand an impressive array of new instrumentation on our telescopes which allows observers to measure basic parameters for stars in external galaxies to a precision hitherto unavailable. Second, there has been a lot of new laboratory work, both in the measurement of atomic data and in the development of new techniques for the measurement and analysis of the raw observational material. Third, but of equal significance, there have been advances in theory, helped on by the enormous increase in computing power which has arrived on the scene. In the future we all look forward to the Hubble Space Telescope. Many here have already tasted what is to come from their experience with

C. W. H. De Loore et al. (eds.), Luminous Stars and Associations in Galaxies, 523–528.

IUE. A still greater advance in computing power will follow from the appearance of supercomputer facilities which will not only allow theoreticians to carry out numerical calculations previously thought impossible but will also enable observers to handle promptly the huge data blocks which come out of modern digital recording devices.

Kudritzki and Hummer got our symposium off to a good start in telling us about the resolution of some inconsistent basic data for the brightest O star, ζ Pup. This was achieved by careful attention to the combined effects of electron scattering, gravity and helium abundance. In this first talk, the term windblanketing came up, a term new to many of us but one which has turned out to be very important owing to the dominating effect which strong stellar winds and subsequent mass loss seem to have in the evolution of early-type stars. Kudritzki pointed out that a consistent theory of stellar winds is still necessary. Improvements, such as the taking into account of the finite size of the stellar disk, are now possible with increased computing power. Some of the strongest constraints on models presently come from the observed CNO abundances.

One thing that was missing at this meeting, to which we were all looking forward, was the cheerful, rational presence of Katy Garmany. Peter Conti filled in by telling us about her recent work on the Initial Mass Function (IMF) for massive stars in the Galaxy and the Magellanic Clouds. There continues to be some debate about completeness at the faint end of the solar-neighborhood O star sample. One of us (JAG) continues to worry about how many late O and early B-type stars might still be hidden from visual observation by their placental dust clouds. The weaker radiation pressure of these stars might not allow them to disrupt their surrounding clouds as rapidly as the early O stars and could lead to a skewing of the IMF. Garmany, Conti and Massey have embarked on a major project to extend the study to the Large and Small Magellanic Clouds. This requires good quality spectra of every O star candidate and good atmospheric models to analyse them. The paper by Gehren et al. also gave an excellent discussion of these needs.

Allan Sandage treated us to a masterly survey showing the power of luminous stars as distance indicators. We all saw how the bold approaches initiated by Hubble have succeeded in a way that would have amazed him. Distance calibrations of the first 3 blue and red stars in a galaxy (á statistical procedure urged in a poster paper by Laura Greggio) have been performed using Cepheid distances for 16 nearby galaxies including Sextans A and B and the WLM system. The ultimate aim is not only to fix the Universal distance scale but to map the local velocity perturbations. Some of this will have to wait for the revolution brought about by Space Telescope but much can be done from the ground. Sandage pointed out that the discovery and prompt follow-up of supernova of type I, for example, and their subsequent folding into the distance calibration has become a major observational challenge. Later in the week, in another invited talk, Craig Wheeler enlarged on

the astrophysical opportunities which currently exist in supernova research.

Roberta Humphreys presented a paper about cooler supergiants as crucial signposts in the life cycles of massive stars. New results have been obtained for a number of galaxies including M31, M81, M101 and NGC 2403. Here, another theme of the meeting became prominent. This is the importance of understanding bias and selection effects and, as well, completeness in forming our lists of stars. Interloping foreground stars must be removed from our lists ruthlessly! This can be done either from the measurement of proper motions or from spectroscopic criteria such as those outlined in the paper by Graham and Humphreys. Completeness in our lists of Galactic red supergiants is being improved by work such as that reported by MacConnell et al. Wendy Freedman gave us a grand talk about the stellar luminosity function with results for several external galaxies. She showed how the huge data sets obtained from CCDs and automatic measuring machines could be handled to give results of high statistical weight. In a related paper Tom Manley demonstrated the promise and potential of the Minnesota Automatic Plate Scanner, while John Hoessel's talk on Friday illustrated further the capabilities of CCD detectors for studies of this type as applied to dwarf galaxies.

Poster papers in many ways represented the core of the new results at the meeting. We had a rich array over our four days at Porto Heli. Two papers on the massive G-type hypergiant HD 217476 by Smolinski et al. and by Zsoldos introduced us to the photometric and spectroscopic complexity of this star. De Jager et al. showed that the rate of stellar mass loss depends almost entirely on effective temperature and luminosity for stars of types O through M. Only WR and C stars do not seem to fit. Among the other papers, the Magellanic Clouds were well represented. Two surveys of emission line stars were presented by Azzopardi and Meyssonnier (SMC) and Bohannan (LMC). Dubois showed us that there are still problems in the use of hydrogen lines as distance indicators for the blue supergiants in the SMC. Chiosi's group applied state-of-the-art theory to the interpretation of color-magnitude diagrams. The new evolutionary tracks not only provide a better morphological fit for intermediate age clusters in the LMC but support a distance modulus close to $18^{m}.6$ rather than the smaller values which have recently been suggested by Aaronson and others.

Nolan Walborn's paper was officially concerned with the broad topic of spectral morphology of O stars but it was made especially memorable by his review of the stellar populations associated with the core object R136a in the 30 Dor complex of the LMC. There has been a substantial advance in the imagery and detailed spectroscopy of this object. Particularly impressive is the new holographic speckle interferometry which has been carried out by Weigelt and Baier. This shows that R136a has 8 stellar components, the three most luminous of which are similar in brightness. There are now 28 resolved stars in what was originally labelled as the star R136. In its immediate surroundings,

numerous early O and WR stars have been found which can easily account for the ionization of the 30 Dor nebula. There now seems no identifiable core object which could conceivably have a mass higher than about 250 solar masses. The poster paper by Lortet et al. further emphasized that there are many bright unresolved multiple systems in the Magellanic Clouds which are only now being identified as such.

"How massive can a stable star be?" was the question addressed on Tuesday morning by Immo Appenzeller "and what are the main sources of instability?" He considered the equilibrium states of stellar models and the effects on these of various perturbations. Vibrational instability is potentially one of the more effective ones but it is thermal instability which ultimately plays the most important role because of the strong temperature dependence of the interior nuclear reactions. 90 M⊙ seems to be an upper limit for a stable star on the zero-age main sequence but a star with a mass up to 200 M⊙, while unstable, could evolve quickly into an observable, almost stable, post-main sequence object. Shock wave induced mass ejection seems to rule out as violently unstable any stars as massive as 1000 M⊙. Observations of stars near the upper mass limit were reviewed by Bernard Wolf and Henny Lamers. Between them, they covered S Dor, Hubble-Sandage and P Cyg stars. During the outburst states we generally see an accentuated rate of mass loss up probably by a factor of 100 from that observed in the quiescent stage. Observed velocities are not high but most of the significant mass loss in the star's lifetime occurs during these events. Interestingly, their bolometric magnitude is probably not changing much. It is mostly just a redistribution of the total stellar flux which gives rise to the optical variability.

On Tuesday afternoon, Peter Conti brought us up to date on the astrophysical parameters of Wolf Rayet stars. Especially timely was his discussion based on eclipsing binary studies of an upward revision in the effective temperatures of these stars to about 100,000K. An investigation of V444 Cyg reported by Pauldrach et al. reached similar conclusions. Conti also noted that the effect of back-scattering from stellar winds, discussed by Kudritzki, would be very important in WR atmospheres. He presented new radio-derived mass loss rates by Abbott. These showed a good correlation between $\dot{M}$ and M indicating like several other papers at this meeting that mass loss is radiatively driven. Finally Conti addressed the question of the WR/O star number ratio and showed how the new tracks by Maeder result in greatly improved theoretical and observational accord. Phil Massey spoke about the use of WR stars as tracers of the massive star population in nearby galaxies. He stressed the observational difficulty of isolating a sample of unevolved O stars using photometry alone. WR stars, on the other hand, are easily detected and very effectively trace concentrations of massive stars in a galaxy. He reviewed the various techniques for discovering WR stars emphasizing the problems of bias and completeness. Neither the WR density or the WC/WN number ratio appears to be a function of metallicity alone and it may be necessary to invoke IMF variations between galaxies. Finally, a preliminary survey of M31

for WR stars by Armandroff, Massey and Conti was summarised. Another recent survey of M31 reported by Shara and Moffat has produced quite a different result which can probably be attributed to varying degrees of completeness at small equivalent widths. Moffat, however, argued in discussion that the two surveys were complementary. The Shara and Moffat survey might be less complete but it does cover the whole galaxy. Armandroff et al.'s survey may be biased by the small size of the areas searched.

Thursday morning brought a related theoretical session. Maeder emphasized how mass loss determines the course of evolution through the WR phase. Mass loss may have little effect on the central regions of the star but it radically changes the abundances at the stellar surface. Rotational mixing can lead to material diffusion and may be the agent for producing massive, nitrogen-rich blue straggler stars, such as those observed in Per OB1. Sreenivasan and Wilson demonstrated how spinning models also lead to the prediction of high effective temperatures for WR stars. Bert de Loore and colleagues presented a comprehensive review, with new numerical results, of the evolution of massive binary stars. A large number of evolutionary possibilities exist depending on whether mass is lost or accreted through Roche lobe overflow or through stellar winds. Wolf Rayet stars can be produced in both ways depending on the circumstances. Cases relevant to the formation of X-ray binaries have been investigated and were reported by Hellings.

Chiosi's review concentrated on recent improvements to the theoretical models of massive star evolution, especially those incorporating convective overshooting. He showed how convective overshooting can reconcile the distribution of stars on the AGB with turnoff ages for Magellanic Cloud clusters. This can prove important for studies of the brightest stars in these clusters such as those reported at this meeting by the Kontizases and co-workers. Further application of convective overshooting, this time to the upper mass limit for stars undergoing the He flash, was presented by Bressan and Bertelli . Chiosi also reminded us of the importance of stochastic effects in determining the integrated colors of a star cluster.

Joe Silk gave us a view into the likely processes of massive star formation. He favored the concept of fragmentary molecularclouds being swept up into giant molecular clouds through galactic density waves. Star formation is probably bimodal. An extended period of low-mass star formation precedes the eventual triggering of massive star birth which, by heating the environment, suppresses star formation almost completely for a while. This talk led naturally to the observational papers by Michael Rosa and Paul Hodge in the afternoon. Rosa considered the stellar knots within giant HII regions in external galaxies where a large fraction of the most massive stars are usually found. Since individual stars generally can no longer be resolved the interpretation of the observations is far from simple. To discriminate between age and IMF effects, for example, observations must be made in the far

UV as well as in the optical and infrared. Wolf Rayet stars make a substantial contribution to the observed spectrum which often shows strong variations over distances of only 1". New observations were reported of stellar knots in M101, NGC 55 and NGC 5128. Wolf Rayet features have been identified here and as well, at the sites of 3 supernovae in M83. Paul Hodge described to us the many difficulties in defining stellar associations in nearby galaxies. Here, bias problems again become substantial and consequently, integrated magnitude measurements of stellar associations are probably not good distance indicators. Nevertheless, it does seem that the size or mass distribution of associations cannot be very different from one galaxy to another. Hodge showed part of his new atlas of stellar associations in the Small Magellanic Cloud. New surveys of M31 and M33 were also displayed by Nikolov, Ivanov and collaborators at this time.

While consensus and agreement were reached in several problem areas at this meeting, new questions arose and we are all going to be kept busy in the future searching for their solution. Some flavor of this activity in the field came through after Rosa's paper on Thursday when a spirited discussion ensued on which type of Wolf Rayet stars one would expect to see in the cores of giant extragalactic HII regions. Theorists, for the most part, felt that young clusters of massive stars should contain mostly WC stars, since these are thought to originate from more massive progenitors than WNs. Walborn, on the other hand, stated that in the 30 Dor complex, WR stars are mostly of WN type and that a previous study by Roberts had found that Galactic associations contain mainly WN types. Massey countered that the Roberts study was based on data of 1950s vintage: more complete surveys are now available and, in M33 at least, WC stars are as common as WN stars in the large OB associations. Conti pointed out that, although we know that all WC stars have gone through a WN stage, it is not at all clear that all WN stars continue on to become WCs and that the relative lifetimes are very uncertain. Someone asked Rosa just how he expected to form stars in these HII region cores. Rosa didn't know; another symposium in 3-6 years time might be necessary to answer this one.

Peter Conti was clearly thinking aloud already of possibilities. "A meeting in Java, perhaps?" he suggested.