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MASSIVE STARS: FROM THE VLT TO THE ELT

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RESUMEN

Nuestro conocimiento de las estrellas masivas ha aumentado significativamente en los últimos 30 años gracias a las nuevas instalaciones y tecnologías. En esta contribución presento un gran *survey* de estrellas masivas que se ha realizado recientemente mediante el uso de VLT-FLAMES, mostrando los campos observados y remarcando la fracción de estrellas binarias que se ha encontrado. Estos datos se han utilizado para la primera comprobación empírica de la dependencia de la intensidad de los vientos estelares con la metalicidad, encontrándose un buen acuerdo con la teoría – un resultado de gran importancia para los modelos de evolución estelar, que se utilizan para la interpretación de cúmulos lejanos, *starburst* y galaxias con formación estelar. Dando un paso más, comentaré como en la actualidad se están dedicando grandes esfuerzos al avance de los planes de actuación y desarrollo de los Telescopios de Gran Tamaño, que serán una realidad en un futuro próximo; este hecho nos ofrecerá una posibilidad más que interesante para obtener observaciones con resolución espacial de estrellas masivas más allá del Grupo Local.

ABSTRACT

New facilities and technologies have advanced our understanding of massive stars significantly over the past 30 years. Here I introduce a new large survey of massive stars using VLT-FLAMES, noting the target fields and observed binary fractions. These data have been used for the first empirical test of the metallicity dependence of the intensity of stellar winds, finding good agreement with theory – an important result for the evolutionary models that are used to interpret distant clusters, starbursts, and star-forming galaxies. Looking ahead, plans for future Extremely Large Telescopes (ELTs) are now undergoing significant development, and offer the exciting prospect of observing spatially-resolved massive stars well beyond the Local Group.

Key Words: galaxies: magellanic clouds — instrumentation — stars: early type

1. INTRODUCTION

An excellent example of the progress enabled by new observing capabilities is afforded by our knowledge of the stellar content of NGC 346 – the largest H II region in the Small Magellanic Cloud (SMC).

The first photometric study of NGC 346 was published by Niemela et al. (1986) using data from the 1 m Yale telescope at the Cerro Tololo Inter-American Observatory (CTIO). This paper also presented spectroscopy of some of the brighter members, building on the pioneering work of Walborn (1978). In the following years, 4 m class telescopes were used to investigate the cluster initial mass function (Massey et al. 1989), and to obtain high-resolution echelle spectra for detailed atmospheric analysis (Kudritzki et al. 1989; Walborn et al. 2000; Bouret et al. 2003). More recently, the images of the cluster from the *Hubble Space Telescope* Advanced Camera for Surveys (e.g. Sabbi et al. 2007) offer a dramatic illustration of the current 'state-of-the-art'.

Understanding the role of environment and metallicity on the evolution of massive stars has been a key topic for the past two decades. However, until now, we have lacked the facilities to obtain large, homogenous sets of observations (in a sensible allocation of telescope time) to provide robust empirical constraints to evolutionary models. The delivery of the Fibre Large Array Multi-Element Spectrograph (FLAMES) to the Very Large Telescope (VLT) was the catalyst for such a survey – to address questions such as the metallicity dependence of stellar rotational velocities and wind mass-loss rates.

2. THE VLT-FLAMES SURVEY

The FLAMES survey of massive stars has observed over 800 targets in 7 fields, centered on stellar clusters in the Galaxy and SMC/LMC, as listed in Table 1; the inclusion of NGC 346 was an obvious choice. The full content of the survey has been presented by Evans et al. (2005, 2006).

Our observations provide lower limits to the binary fraction of the O- and early B-type targets, finding ∼25% in NGC 346 and ∼35% in N11. Although the programme was not originally concerned

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TABLE 1

SUMMARY OF VLT-FLAMES FIELDS

	'Young' clusters (<5 Myrs)	'Old' clusters (10-20 Myr)
Milky Way	NGC 6611	NGC 3293 & 4755
LMC	N11	NGC 2004
SMC	NGC 346	NGC 330

with binary detection, the FLAMES spectra are of sufficient quality that the nature and properties of many of the newly discovered systems can be determined. Specific systems will be the subject of future papers, and we are seeking further monitoring of our fields to better constrain the binary fraction.

The first science papers from the survey have now been published, presenting analyses of the O- and early B-type spectra (Mokiem et al. 2006, 2007; Hunter et al. 2007). One of our primary motivations for the FLAMES survey was to test the theoretical prediction that wind mass-loss rates are dependent on metallicity (Kudritzki et al. 1987; Vink et al. 2001). Figure 1 shows the wind momentum – luminosity relations (WLR) obtained from our LMC and SMC targets, compared with those from contemporary Galactic results. This is the first comprehensive empirical test of the metallicity dependence. For luminosities greater than $\sim 10^{5.2}\ L_{\odot}$, the relative offsets between different metallicity regimes are in good agreement with theory.

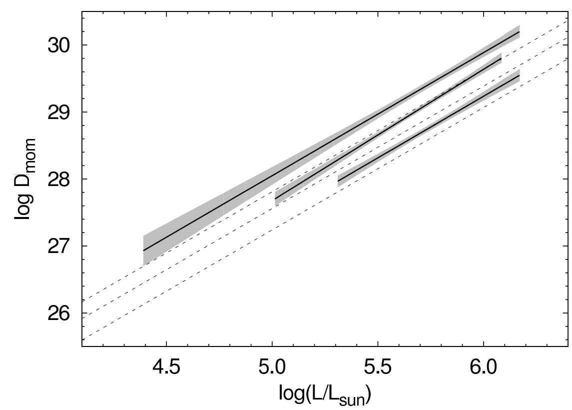

Fig. 1. The observed wind momentum – luminosity relations (solid lines) compared with theoretical predictions (Vink et al. 2001; dotted lines). The top, middle and bottom lines correspond, respectively, to Galactic, LMC and SMC results (Mokiem et al., submitted).

3. ELT SCIENCE CASE

With instruments such as the FOcal-Reducer low-dispersion Spectrograph (FORS) on the VLT, detailed analysis of stars in galaxies at 1–2 Mpc is currently possible (e.g. Urbaneja et al. 2003; Evans et al. 2007). But ideally we want to reach out to more distant systems (thereby sampling different environments – elliptical galaxies, lower metallicities etc.), or we need spectral resolutions that are greater than those available from FORS.

Moving into 2007, the European Southern Observatory (ESO) is starting a full phase A design of its Extremely Large Telescope (ELT). The current baseline reference design is a 42 m primary, with a novel 5 mirror solution that provides correction for ground-layer atmospheric turbulence as its minimum operating mode. An ELT will allow us to observe the resolved massive-star populations in a wide range of systems beyond the Local Group, exploring chemical abundances, stellar kinematics and so on. An ELT will also be able to probe distant clusters and starbursts at new levels of detail to study their initial mass functions and kinematic structure.

There will be many exciting new opportunities in the ELT era, but it is worth noting for our community that the most significant observational advances will almost certainly arise in the near-infrared (because of the demands of adaptive optics). To fully exploit an ELT, a large effort will be required to develop further diagnostic tools in this wavelength region – both in terms of atomic data (e.g. Przybilla 2005), and comparison studies in the Milky Way and Magellanic Clouds.

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DISCUSSION

P. Massey - This is a beautiful survey, but I always get nervous when I'm using fiber devices as the nebular subtraction is never very good. Have you done some comparisons with long-slit spectra of the same objects to see how robust your results are?
C. Evans - These methods are obviously complementary. Comparisons in NGC 6611 showed good agreement. In the clouds we did some tests using both raw and sky subtracted spectra and checked that as well – for the majority of our LMC stars the nebular contamination is not that significant.
H. Zinnecker - I want to reemphasize your last point that much of our massive stars analysed are based on optical astronomy, while it is clear (in view of adaptive optics working best in the near-infrared) that the future of massive stars research is in the near infrared!
C. Evans - I agree! But I'm also very keen to try to at least push down to the I band so that you open up to the calcium triplet for kinematics and metallicity estimates.
H. Zinnecker - For the 30% binary frequencies that you quote for N11 and NGC 346, can you clarify to which limiting period you data are sensitive?
C. Evans - Most of these have periods of a few days. The Flames-Giraffe spectrograph is very stable and there is some evidence for some stars having long periods ($\sim$ 100 days), but of course we need to follow these up to confirm this and to explore their characteristics.
M. Nieva - (a) What is the S/N ratio for your spectra? (b) Which is the ratio of fast rotating stars?
C. Evans - (a) The S/N ratio ranges from around 200 for the brightest stars down to around 50 for the faintest stars in the faintest field. (b) The fraction of very fast rotators is relatively small, although there are many B-type stars that are rotating quickly enough that they are difficult to analyse. We've analysed the narrow-lined stars first, now we're thinking about the faster rotators.

Several "generations" of Virpi's students.