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The VLT-FLAMES Tarantula Survey

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Abstract: The VLT-FLAMES Tarantula Survey is an ESO Large Programme that has provided multi-epoch spectroscopy of over 1000 stars in the 30 Doradus region in the Large Magellanic Cloud. Armed with this unique dataset the assembled consortium is now addressing a broad range of fundamental questions in both stellar and cluster evolution. Here we give an overview of the survey and the observational strategy, which was designed to be very sensitive to massive binaries. We highlight the power of the multi-epoch approach with the discovery of a massive runaway O-type star which appears to be fleeing the core of the Tarantula region.

1 Introduction

The VLT-FLAMES Survey of Massive Stars obtained high-quality spectroscopy of ∼750 massive stars in fields centered on clusters in the Galaxy and the Magellanic Clouds (Evans et al. 2005, 2006). Key results from the project included evidence of the predicted dependence of stellar mass-loss rates on metallicity in O-type stars (Mokiem et al. 2007), and new insights into the role of rotational mixing in B-type stars (Hunter et al. 2008).

This second incarnation of the FLAMES consortium is now focussed on the oft-studied 30 Doradus region, also known as the Tarantula nebula. This is the largest nearby massive 'starburst' region, providing an excellent environment to study the physical properties and evolution of O- and early B-type stars. A broader range of scientific motivations will be discussed in the survey overview paper (Evans et al. in preparation), here we briefly describe two of the primary objectives.

- *The role of rotational mixing in O-type stars:* From analysis of B-type stars from the previous FLAMES survey, Hunter et al. (2008, 2009) found that the surface nitrogen abundances were not as well correlated with stellar rotational velocities as one might expect; work is still underway to reconcile these results with theory. One of the prime motivations for a large sample of high-quality spectroscopy of O-type stars is to undertake a similar analysis of nitrogen (and carbon/oxygen abundances where possible) to test the predictions of evolutionary models. Until now we also have lacked the theoretical tools for such a large-scale analysis but, as described by Puls, Sundqvist & Rivero González (2011), work has been underway to include transitions from N III and N IV in the FASTWIND model atmosphere code (Puls et al. 2005)[1].

- *Detection and characterization of massive binaries:* There is increasing evidence that a significant number of massive stars are in binary systems. This has been observed in various clusters, both in the Galaxy and Magellanic Clouds, with an average binary fraction of 0.44 ± 0.05 from published studies of cluster populations (Sana & Evans 2011). To gain a true understanding of the evolution of massive-star populations, the effects of binarity need to be fully included in our theoretical models of stellar evolution. Identification of binaries is also important in the context of correct estimates of cluster velocity dispersions (e.g. Bosch, Terlevich & Terlevich 2009; Gieles, Sana & Portegies Zwart, 2010).

Other objectives include determining the evolutionary connections between the different subtypes of evolved O-type stars, dynamical measurements in the regions around R136 at the core of 30 Doradus, studying the feedback to the interstellar medium from stellar winds and the ionizing fluxes of the cluster stars, and investigating the dynamics of the associated nebular gas.

2 Observational data

FLAMES is a highly versatile multi-object instrument on UT2 of the VLT (Pasquini et al. 2002). The primary dataset for the Tarantula Survey was obtained with the Medusa mode of FLAMES, which uses deployable fibres to obtain simultaneous observations of up to 132 targets across a $25'$ field-of-view; the fibres (each $1''.2$ on the sky) feed the light from each target to the Giraffe spectrograph.

The Medusa observations comprise spectroscopy of exactly 1000 stars, which were selected from unpublished imaging of 30 Dor taken with ESO's Wide-Field Imager on the 2.2m telescope at La Silla. The targets were selected to sample not just the inner regions of the cluster, but also to extend out into the surrounding field stars and some of the nearby smaller associations/clusters, as shown in Figure 1. To avoid possible selection biases, no colour cuts were made, but a limiting magnitude was applied ($V < 17$, to ensure adequate signal-to-noise, S/N).

A total of nine fibre configurations (fields 'A' through to 'I') were used to build-up the sample of 1000 stars. Each target was observed at three of the standard Giraffe wavelength settings (LR02, LR03 and HR15N, as summarised in Table 1) thus providing coverage of the classical blue region used in the analysis of massive stars, combined with higher resolution observations of Hα, which provides a diagnostic of the intensity of the stellar winds. Each observation consisted of a pair of back-to-back exposures, with three pairs of observations at the LR02 and LR03 settings, and two pairs at HR15N, thus ensuring sufficient S/N ($\geq$50) in the combined spectra.

Table 1: Observational details of the Medusa component of the Tarantula Survey.

Setting	Wavelength	R	Exposures
LR02	3980-4525 Å	6500	$6 \times (2 \times 1815$s)
LR03	4505-5050 Å	7500	$3 \times (2 \times 1815$s)
HR15N	6470-6790 Å	17000	$2 \times (2 \times 2265$s)

[1]For completeness we note that the CMFGEN code (Hillier & Miller 1998) includes models for the nitrogen ions, but is less well suited for analysis of large samples such as the new dataset from the Tarantula Survey.

2.1 Multi-epoch strategy

Three pairs of the LR02 exposures were obtained with no strong time constraints – in practise, these were often obtained consecutively, or on sequential nights. For detection of massive binaries, a further three pairs of LR02 exposures were obtained. The fourth and fifth epochs were constrained such that a minimum of 28 days had expired since the previous LR02 observation, while the final (sixth) epoch was obtained in the equivalent observing season one year later.

From the methods presented by Sana, Gosset & Evans (2009), it is possible to calculate the probabilities of detecting a binary companion around a star as a function of the orbital period, based on the time sampling of the observations. This is shown for one of the fields from the Tarantula survey in Figure 2. The black line shows the detection probabilities for the first five epochs, with the red line demonstrating how inclusion of the sixth, delayed, epoch significantly increases the chance for detecting binaries with periods greater than 100 days. The survey should be fairly complete for orbits of tens of days. Quantifying the potential selection biases is a critical component of the work to inform the binarity results from the survey.

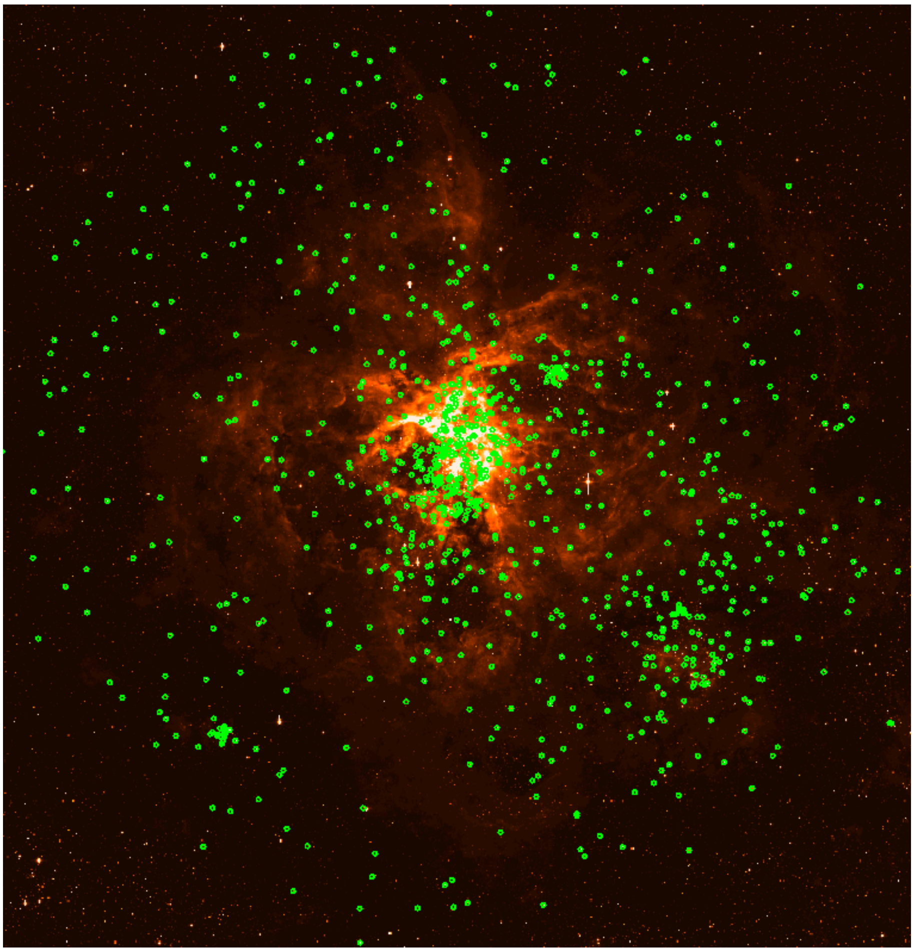

Figure 1: Positions of the FLAMES targets overlaid on a V-band mosaic from the Wide-Field Imager on the 2.2 m telescope at La Silla.

2.2 Spectral content

From the reduced LR02 frames and a first-pass analysis of the radial velocities, it has been possible to make an initial classification of all the Medusa objects. The sample contains around 300 O-type stars,

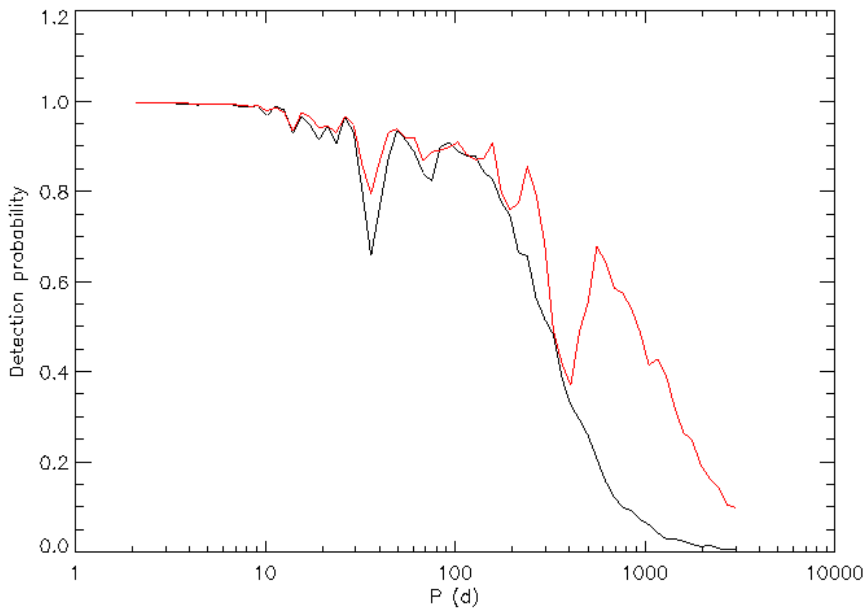

Figure 2: Detection probability of binary systems with different orbital periods given the observed time-sampling of one of the Tarantula fibre configurations. The black line shows the sensitivity for the first five LR02 observations, with the red line indicating the increased sensitivity to longer orbits given by inclusion of the sixth, delayed observation.

towards 500 B-type stars (also of significant interest in terms of multiplicity, chemical composition and the effects of rotational mixing), ~20 Wolf-Rayet or 'slash' Of/WN emission-line stars, ~90 cool-type (A-M) stars with radial velocities consistent with them being LMC members, and just over 100 foreground stars (rejected employing a radial velocity threshold of $\leq 100\,\mathrm{km\,s^{-1}}$).

2.3 Additional data

To expand our view of the 30 Dor stellar populations the survey also employs other modes of FLAMES, as well as being supplemented by other external sources:

- *ARGUS observations of R136:* Five ARGUS pointings were used to target the denser central regions in and around R136. For a fuller description of this aspect of the observing campaign, see Hénault-Brunet et al. (2011).
- *UVES observations:* In parallel to the ARGUS observations, a total of 25 stars were observed using the fibre-feed to the red arm of UVES. The λ5200 Å setting was used, which delivers a spectral resolving power of 47000. Of these 25 targets, five are unique to the UVES data, with the remaining 20 providing complementary information to targets also observed with Giraffe.
- *VLT-SINFONI K-band spectroscopy:* SINFONI has been used in a separate programme (PI: Gräfener) to obtain near-IR spectroscopy of the central arcminute around R136.
- *Faulkes Telescope South photometric monitoring:* Fields matched to our survey areas are being observed in the offline queue by the Faulkes telescope at Siding Spring, providing long-term photometric follow-up in the Bessel BV, SDSS i' and Pan-STARRS Y bands.

3 A massive runaway star from 30 Dor

On the western edge of the FLAMES field is the massive star #016 (numbered in the sequence of the FLAMES targets). Previous spectroscopy with the 2-degree Field (2dF) instrument at the Anglo-Australian Telescope had revealed this star as an O2-type star, with a radial velocity which is discrepant from its surroundings by $\sim 85\text{kms}^{-1}$. Given its early spectral type, magnitude and location, the star was observed as one of the Servicing Mission Observy Verification targets of the *Hubble Space Telescope* Cosmic Origins Spectrograph (COS). Analysis of the P Cygni profiles in the UV spectrum from COS yielded an estimate of the terminal wind velocity of $3450 \pm 50\text{kms}^{-1}$, one of the fastest winds observed for an O-type star (Evans et al. 2010).

The FLAMES observations showed no significant variation in the radial velocity and, using the methods discussed above, it was possible to rule out a massive binary companion to a confidence of 98%. Therefore, its highly discrepant velocity appears real, suggesting that the object has been kicked out the central regions of the cluster in the relatively recent past.

4 Current status

All the observations have been taken and the data have been reduced and released to the consortium. Work has begun in earnest towards the first papers, including classification of the different spectra, analysis of stellar radial velocities/binarity, and analysis of the nebular gas profiles.

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