The VLT-FLAMES Tarantula Survey

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(Poster contribution)

Abstract. The Tarantula survey is an ESO Large Programme which has obtained multi-epochs spectroscopy of over 800 massive stars in the 30 Dor region in the Large Magelanic Cloud. Here we briefly describe the main drivers of the survey and the observational material derived.

Key words: open clusters and associations: individual: 30 Doradus – stars: early-type – stars: fundamental parameters – binary stars: spectroscopic

Проектът "FLAMES Tarantula"

Невена Маркова и консорциум FLAMES Tarantula, 33 автори

"FLAMES Tarantula" е голям проект на Европейската Южна Обсерватория в рамките на който са получени спектри на над 800 масивни звезди в мъглявината Tarantula (Паяк) от Големия Магеланов Облак. В тази статия излагаме основните цели на проекта и получения наблюдателен материал.

1 Introduction

Despite their scarcity, massive O-type stars and their descendants play an important role in the history of the Universe (from the earliest times to the present day). They are the main engines which drive the chemical and dynamical evolution of galaxies, enriching the interstellar medium with heavy elements, creating H II regions and exploding as supernovae. In the distant Universe, they dominate the integrated UV radiation in young galaxies. Massive stars are potentially also key objects for studying and understanding phenomena such as cosmic re-ionisation and γ-ray bursts.

The VLT-FLAMES survey of Massive stars (FSMS, Evans et al. [2005], Evans et al. [2006] was a European Southern Observatory (ESO) Large Programme which obtained high-resolution spectroscopy of about 700 massive stars from seven cluster fields in the Milky Way and Magellanic Clouds, with the primary objective to study the effects of metallicity on stellar evolution. Some of the key results include: a precise quantification of the theoretically predicted metallicity dependence of the winds from O-type stars (Mokiem et al. [2007]); determinations of chemical abundances in the Clouds (Hunter et al. [2007], Trundle et al. [2007]); first evidence of a metallicity dependence in

the effective temperature of B-type stars at a given spectral type (Trundle et al. [2007]); new insights into the role of rotational mixing in the atmosphere of B-stars (Hunter et al. [2008b], [2009]); and a quantitative verification of the assumption that low metallicity massive stars should rotate faster (Hunter et al. [2008a]). (A summary of the results from the FSMS can be found in Evans et al. [2008])

Building upon the experience gained through the FSMS, the FLAMES consortium initiated a new multi-epoch spectroscopic survey of the Tarantula Nebula in the Large Magellanic Cloud – the VLT-FLAMES Tarantula Survey (P.I. Evans). The Tarantula Nebula (also known as 30 Doradus) is an immense star-forming region at the eastern end of the stellar bar in the LMC, and the most active starburst region in the Local Group. A significant amount of the total energy emitted by the nebula comes from R136, a compact cluster located at its core, thought to host some of the most massive stars known (Crowther et al. [2010]). Due to its proximity, its relatively low reddening, and the favorable inclination of the LMC, the Tarantula Nebula is one of the best laboratories to study the formation and evolution of massive stars.

2   Project aims

A detailed description of the scientific objectives of the project will be provided in the survey overview paper (Evans et al. in preparation); here we briefly comment on three of the main drivers.

Predictions of evolutionary models: Evolutionary models incorporating stellar rotation (Meynet and Maeder [2000]2000, Heger and Langer [2000]) predict significant enhancement of the surface helium and nitrogen abundance in massive O-type stars due to the effects of rotational mixing. The models also predict that stars with initial masses larger than 15 $M_\odot$, will either slow down (at Z=$Z_\odot$) or remain at almost constant rotation rates (at Z lower than $Z_\odot$) throughout their main-sequence (MS) lifetimes, suggesting that massive O-type stars in the Magellanic Clouds should rotate faster than their Galactic counterparts. While some of these predictions have been confirmed by observations, others are not (e.g., Penny and Gies [2009] and references therein). The FLAMES Tarantula Survey aims to investigate the effects of rotation at the high-mass end of the Hertzsprung-Russell (H-R) diagram and, in particular, to test the model predictions with regarding to rotational mixing of core-processed material to the stellar surface.

Massive binaries: If undetected, binarity (multiplicity) can significantly modify the results of spectroscopic and photometric analysis. The fraction of massive binaries in 30 Dor is expected to be large (Bosch et al. [2009]), so to identify and characterize the binaries among the FLAMES sample is a crucial task.

The multi-epoch observation strategy adopted for the survey allows us to obtain clear signatures of short-period binary in the majority of the targets, while also providing information for some of the long-period binaries as well,

This will put robust constraints on the total binary fraction in 30 Dor. Armed with these new data and the results from the model atmosphere analysis we will then be able to test the model predictions of both single-star and binary evolution.

Dynamical mass of R136: The effect of binaries on the dynamical mass estimates of young stellar clusters was highlighted recently by Gieles et al. [2010]. The multi-epoch FLAMES observations will be used to obtain precise radial velocities for our targets in and around R136. We will then determine the velocity dispersion for single massive stars (i.e. excluding the detected binaries) to derive a dynamical mass for the cluster. This will provide an important external estimate to the debate regarding the photometric mass of R136, which hinges on the low-mass form of the initial mass function (Sirianni et al. [2000], Andersen et al. [2009]).

3   Observational material

The Fibre Large Array Multi-Element Spectrograph, FLAMES (Pasquini et al. [2002]), is on UT2/Kueyen of the Very Large Telescope (VLT) at Cerro Paranal. FLAMES can be used to feed two optical spectrographs: the medium-high resolution spectrograph Giraffe, and the high-resolution spectrograph UVES. The Giraffe spectrograph works in combination with three different types of fibre systems - Medusa (single fibres), deployable integral field units (IFUs), and ARGUS (a monolithic central IFU); UVES is fed by only one fibre system attached to its red arm.

The observational strategy of the new survey builds upon the experience gained from the FSMS and includes multi-epoch observations with the Giraffe spectrograph in its Medusa and ARGUS IFU modes, plus using the feed to UVES. The sample comprises $\sim 1\,000$ stars brighter than $V = 17$ mag. (to ensure adequate signal-to-noise, S/N) with no limitation in color (to avoid selection biases and achieve a good representation of the upper part of the H-R diagram). The targets were primarily selected from unpublished imaging of 30 Dor, distributed such they cover its full spatial extent and outwards into the surrounding field stars and other nearby OB associations. The total field spans a diameter of about 20 arcminutes from the center of R136. Observational details are summarized in Table 1. Individual comments on each observational component are outlined below.

MEDUSA observations: The primary dataset for our survey was obtained with the Giraffe spectrograph in the Medusa mode. To build-up the sample, a total of nine Medusa configurations were used[1] Each target was observed at three of the standard Giraffe settings (LR02, LR03 and HR15N), providing a total wavelength coverage from about $4\,000$ to about $5\,000$ Å, plus the region around H_α needed to constrain stellar wind properties.

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[1] Each Medusa configuration allows up to 132 targets (including sky fibres), distributed over a $25'$ field-of-view to be observed simultaneously.

Table 1. Summary of the spectral coverage and resolving power (R) of the FLAMES Tarantula Survey observations.

Mode	Setting	λ-coverage [Å]	R
Medusa	LR02	3960 to 4564	7 000
Medusa	LR03	4499 to 5071	8 500
Medusa	HR15N	6442 to 6817	16 000
ARGUS	LR02	3980 to 4570	10 500)
UVES	Red arm	4175 to 6200	47 000

For detection of massive binaries, each of the Medusa targets was re-observed at three additional epochs using the LR02 setting. The execution of these was constrained such there was a minimum of 28 days between the follow-up epochs. To put constraints on long-period systems, a final epoch was obtained one year later then the main observations. The S/N ratio of the combined Medusa data is greater than 50 for all of the O- and B-type stars.

ARGUS IFU observations: We also employed the Giraffe spectrograph in its ARGUS IFU mode to sample the denser central region in and around R136. Five ARGUS pointings were observed with the LR02 setting, see Table 1. To identify and characterize massive binaries, each ARGUS pointing was observed at five different epochs. Following the Medusa strategy, the first two observations were executed with no time restriction; the second and the third, and third and fourth epochs were separated by a minimum of 28 days; the final observations were obtained about one year later.

UVES observations: In parallel to the ARGUS observations a small sample of 25 stars were observed using the six fibres feeding the red arm of UVES. Twenty of these were in common with the Giraffe-Medusa sample; five are unique.

Complementary observations: To expand our view of the 30 Dor, the Tarantula Survey is supplemented with data from two external sources.

- VLT-SINFONI near-IR spectroscopy: K-band spectroscopy was obtained of the central arcminute around R136 using the SINFONI IFU (P.I. Gräfener). These data will be used to investigate the wind properties and to constrain the clumping factor.
- Faulkes Telescope South observations: As part of the Faulkes off-line queue and also the schools educational programme, there is an on-going monitoring campaign using the Faulkes Telescope South to obtain Bessel B and V, SDSS i', and Pan-STARRS Y observations of many of our FLAMES targets. This will enable more detailed analysis of the binary systems identified via the multi-epoch spectroscopy.

4 Current status

All the observations have been obtained, with a total of about 22 000 spectra collected. The data have been reduced and released to the consortium,

with work now proceeding on multiple strands of research. Based on the reduced spectra from the LR02 settings, and results from a preliminary radial velocity analysis, rough classification of the Medusa targets was performed. The sample comprises approximately 300 O-type stars, 500 B-type stars, 20 WR/slash stars, 90 stars with cooler spectral types (but with radial velocities consistent with their membership of the LMC) and about 100 foreground stars. As a first step towards a more detailed classification, a spectral atlas of Galactic standards has been created using high-resolution spectra of O- and early B-type stars, drawn from both hemispheres and degraded to the resolving power of the FLAMES spectra.

5   Acknowledgements

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Fig. 1. Nevena Markova gives a talk

Fig. 2. Tsvetan Georgiev at the opening of the Conference