Bulletin de la Société Royale des Sciences de Liège, Vol. 80, 2011, p. 376 - 380

A Project to Study Stellar and Gas Kinematics in 30 Dor with the VLT-FLAMES Tarantula Survey

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Abstract: The VLT-FLAMES Tarantula Survey offers a unique opportunity to study the stellar and gas kinematics of 30 Doradus in the Large Magellanic Cloud (LMC). Using the nebular emission lines in the fibre spectra of ∼1000 stars, we can map the radial velocity structure of ionized gas across the 30 Doradus region, enabling us to study the environment of massive stars. Multi-epoch ARGUS-IFU observations and MEDUSA/UVES fibre spectroscopy in the young massive cluster R136, at the core of 30 Dor, will allow us to quantify the effect of binaries on the velocity dispersion of the cluster. The true velocity dispersion will be measured from the radial velocities of the identified single stars, providing an essential ingredient to estimate the dynamical mass and probe the dynamical state of R136.

1 Introduction

High-quality spectra of large samples of O and B stars over a region more than 200 pc wide in 30 Doradus were obtained as part of the VLT-FLAMES Tarantula Survey (Evans et al. 2010a, Taylor et al. 2011). While it is primarily aimed at understanding the evolution of massive stars via detailed atmospheric analysis, this rich dataset also allows to address many other key questions about these stars and their environment. 30 Doradus is an intricate system and more than just a convenient region to sample a large number of massive stars. As the nearest extragalactic giant H II region, it is an ideal place to study the collective interactions between massive stars and the interstellar medium. The young (∼2 Myr) dense star cluster R136, at its core, is a prime target to better understand the early evolution of young massive clusters (e.g. Portegies Zwart, McMillan & Gieles 2010).

In the following sections, we discuss ongoing efforts to analyze the gas and stellar kinematics in 30 Doradus and how this will improve our knowledge of feedback from massive stars and cluster dynamics.

2 Gas Kinematics in the 30 Doradus region

Nebular spectra have been extracted from the spectra of ∼1000 stars observed across the 30 Dor nebula and region as part of the survey (see Taylor et al. 2011 for a description of the data and fibre positioning). Several key nebular lines are covered (Hα, Hβ, Hγ, Hδ, [O III] 5007, [O III] 4959, [O III] 4363, [N II] 6549, [N II] 6583, [S II] 6717, [S II] 6731, He I 4471, He I 4922, He I 6678). Selected line ratios (corrected for reddening) will be measured to map the nebular gas properties (e.g. temperature, density) across the 30 Doradus nebula and out into the surrounding region, complementing the results obtained by Pellegrini, Baldwin & Ferland (2010) in the central 140×80 pc region of the nebula.

The spectral resolution of our data (R∼10000) is high enough to resolve the nebular line profiles, which are often complex and show multiple components. We fitted the strongest lines with multiple Gaussians (Fig. 1) to determine the radial velocity of the ionized gas. These measurements will be used to analyze the global dynamics of the gas and the associated feedback from stellar winds and supernovae. Previous studies of the kinematics of ionized gas in 30 Doradus, in particular the comprehensive echelle observations of Chu & Kennicutt (1994), have revealed a large number of expanding structures, ranging in size from ∼1 to ∼100 pc and with expansion velocities from about 20 to 300 km s^{-1}. Discrete high-velocity features ($\Delta v > 100$ km s^{-1}), sometimes isolated, have also been found. The high-velocity shells and structures are most likely associated to supernova remnants (SNRs). With the spectral coverage and resolution of the Tarantula Survey data, it will be possible to measure selected line ratios for the high-velocity component alone and see if they resemble those of LMC SNRs (see e.g. Meaburn et al. 2010), providing information on the role of supernovae in shaping the gas kinematics of 30 Dor.

The nebular spectra from the Tarantula Survey are also ideal to study the pervasive broad component (FWHM∼100 km s^{-1}) found by Melnick, Tenorio-Tagle & Terlevich (1999) in their long-slit spectra of the central region of the 30 Dor nebula. Such a broad component has been found in different starburst environments where it has been associated to emission from ionized gas within turbulent mixing layers caused by the impact of winds and radiation (e.g. Westmoquette et al. 2010). Preliminary analysis of the Tarantula Survey spectra shows that including a broad component is generally required in order to obtain a satisfying fit to the nebular line profiles (see Fig. 1).

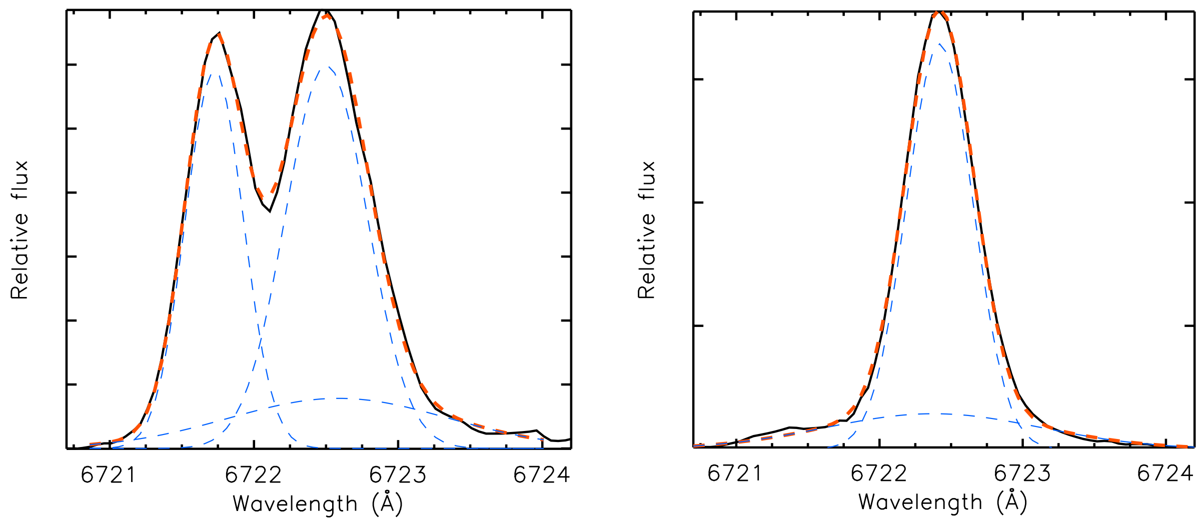

Figure 1: Examples of multiple-Gaussian fits to the [S II] 6717 line profile of two different MEDUSA targets. The fit is shown in red and the contribution of individual components in blue, illustrating the presence of a broad component.

Another application of the gas radial velocity measurements will be to serve as a reference frame to compare to the systemic stellar velocities obtained as part of the survey and see which stars have a discrepant radial velocity compared to the surrounding gas (e.g. Evans et al. 2010b). This is interesting, for example, to see if a star has formed in situ, or if it got to its current location after being ejected by dynamical interactions in a cluster or by the kick from the supernova explosion of a companion.

3 Stellar Kinematics in R136

To investigate the kinematics of stars in and around R136, five dense areas were observed with the ARGUS integral field unit (IFU) mode of FLAMES as part of the Tarantula Survey (see Fig. 2). The five pointings, each covering a $12'' \times 7''$ field of view, are located inside a radius of about 5 pc from the core of R136, with each observed at five different epochs. The observations were performed with the LR02 GIRAFFE setting, resulting in data cubes covering the spectral range from 3960 to 4560 Å with a resolving power of $\sim$10000. Sources were identified by comparison of the collapsed IFU images with the higher resolution HST-WFC3 image. The IFU spaxels are $0.52''$ wide and isolated sources generally extend over a few spaxels. By combining the signal of the appropriate adjacent spaxels, spectra were extracted for 41 sources, in addition to an integrated spectrum of the unresolved core. The typical signal-to-noise ratio of the spectra for a single epoch is around 90. In addition to the ARGUS spectra, it will also be possible to use for this analysis the fibre spectra obtained in the MEDUSA and UVES observing modes (see Taylor et al. 2011) for the targets located near R136. In total, more than 80 stars from the survey will be considered in the analysis of the stellar velocity dispersion of R136.

The mass of a star cluster can either be determined via its integrated luminosity and age-dependent mass-to-light ratio, or alternatively, from a combination of the radius containing half the light and the line of sight velocity dispersion. These quantities are respectively referred to as the photometric mass ($M_{\rm phot}$) and the dynamical mass ($M_{\rm dyn}$), and comparing them for a given cluster is a way to check the assumptions on which both estimates are based (i.e. the IMF for $M_{\rm phot}$ and virial equilibrium for $M_{\rm dyn}$). For example, a value of $M_{\rm dyn}$ that is found to be much larger than $M_{\rm phot}$ could mean that the cluster is not in virial equilibrium and instead dissolving. Such a comparison between $M_{\rm phot}$ and $M_{\rm dyn}$ is therefore useful to probe the dynamical state of clusters. In recent years, many young ($\sim$10 Myr) extra-galactic clusters were found to have $M_{\rm dyn}$ up to about 10 times larger than $M_{\rm phot}$ (e.g. Bastian et al. 2006), suggesting that they might be super-virial following gas expulsion (e.g. Goodwin & Bastian 2006). It was however realized that the dynamical timescale of these clusters is so short that they should have had time to reach a new equilibrium. Gieles, Sana & Portegies Zwart (2010) have shown that the discrepancy between $M_{\rm dyn}$ and $M_{\rm phot}$ in these young clusters can instead be explained by the excess velocity dispersion from the internal orbital motion of binaries. Taking binaries into account is therefore crucial to estimate $M_{\rm dyn}$ properly, and R136 should be no exception as it is young and its light is dominated by massive stars, for which the binary fraction is typically high (e.g. Sana & Evans 2010, Bosch,Terlevich & Terlevich 2009). However, given that the binary fraction of O stars in nearby open clusters is $\sim$50%, we can also expect to have a fair number single stars remaining (see Sana & Evans 2010).

The multi-epoch aspect of the Tarantula Survey makes it possible to disentangle binaries and single stars. The time sampling of the different ARGUS and UVES exposures is very similar to that of the MEDUSA data, with baselines of a few hours/days, $\sim$1 month, and $\sim$1 year. Monte-Carlo simulations of the detection probability as a function of period given the time sampling for one of the MEDUSA fields (e.g. Fig. 2 of Taylor et al. 2011) indicate that the survey should be fairly complete in detecting binaries with orbits of up to tens of days. Assuming a broken Öpik Law for the distribution of periods (see Sana & Evans 2010), the fraction of spectroscopic binaries missed by our

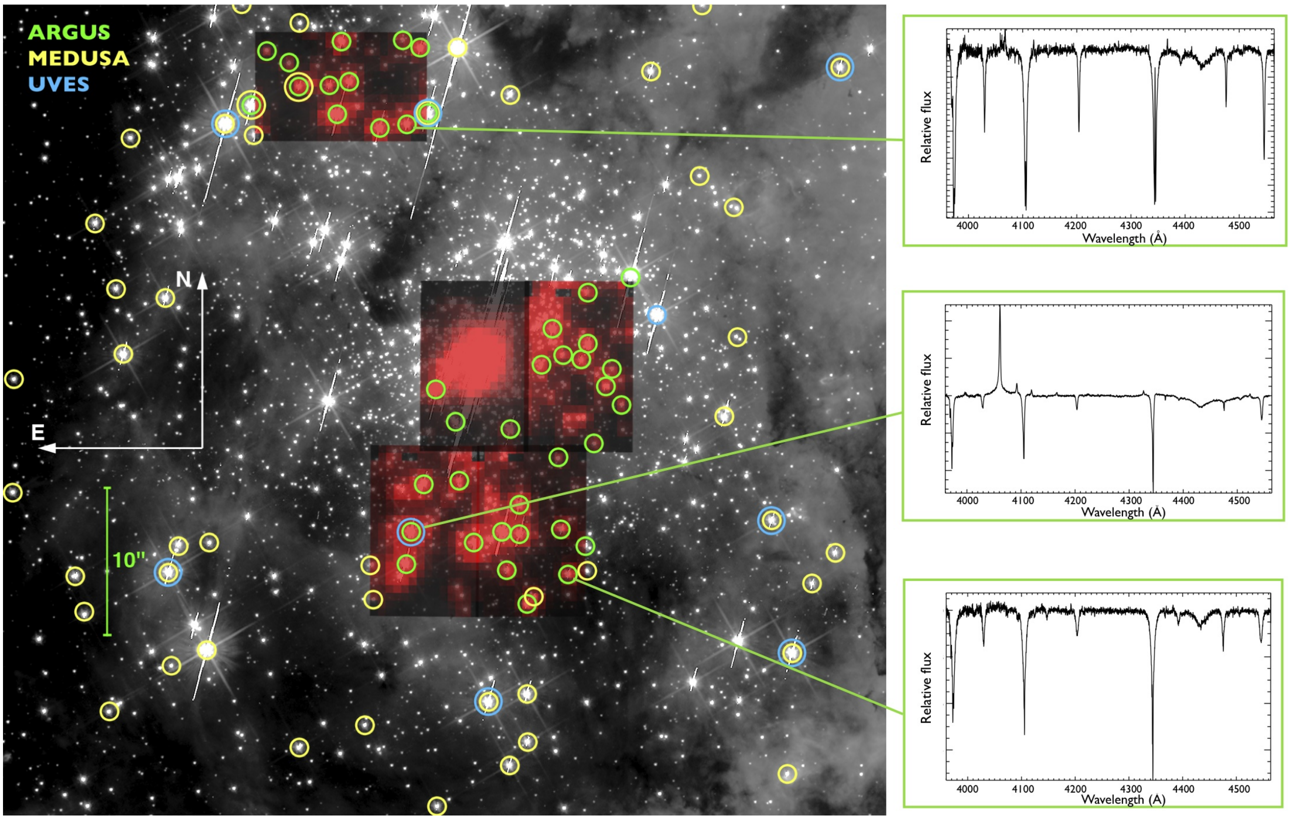

Figure 2: The five ARGUS-IFU pointings from the Tarantula Survey (in red) overlaid on the HST-WFC3 F555W image of the central region of 30 Doradus, with circles showing the distribution of ARGUS, MEDUSA, and UVES targets. Examples of spectra extracted from the ARGUS-IFU cubes are presented for three stars.

time sampling should not be significant. The binaries missed will be those with longer periods, for which the radial velocity amplitude is anyway smaller.

We will be able to quantify the effect of binaries on the measured velocity dispersion of R136. This will provide a clear observational illustration of the contribution of binary motions to the velocity dispersion of a young cluster, and an example to keep in mind when considering measurements of $M_{\rm dyn}$ from integrated light spectroscopy. The remaining single stars will be used to measure the true velocity dispersion of R136, a quantity which will then be essential in future efforts to estimate its dynamical mass and probe the dynamical state of the cluster.

With a resolving power of 10000 and a typical signal-to-noise in excess of 150 (when merging all epochs), our preliminary analysis using Gaussian fitting suggests that we can easily measure the radial velocity of single stars to a precision of a few km s^{-1}, and down to $\sim$1 km s^{-1} for the stars with narrower lines and higher signal-to-noise. These measurements will thus provide a meaningful constraint on the velocity dispersion, which we can expect to be of the order of several km s^{-1}.

4 Conclusion

The VLT-FLAMES Tarantula Survey will enable a detailed study of stellar and gas kinematics in 30 Doradus. Data reduction is now complete, giving us a rich dataset of $\sim$1000 nebular spectra across the region, and multi-epoch spectroscopy of more than 80 stars to analyze the stellar kinematics in R136. Future analysis will include studying feedback from massive stars and supernovae across the broader 30 Doradus region, and measuring the stellar velocity dispersion of R136.

Acknowledgements

V. H.-B. acknowledges support from the Scottish Universities Physics Alliance (SUPA) and the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

Bastian, N., Saglia, R. P., Goudfrooij, P., Kissler-Patig, M., Maraston, C., Schweizer, F., & Zoccali, M. 2006, A&A, 448, 881

Bosch, G., Terlevich, E., & Terlevich, R. 2009, AJ, 137, 3437

Chu, Y.-H., & Kennicutt, R. C., Jr. 1994, ApJ, 425, 720

Evans, C. J., Bastian, N., Beletsky, Y., et al. 2010a, in de Grijs & Lépine, eds, *IAUS266: Star Clusters: Basic Galactic Building Blocks Throughout Time & Space, Cambridge Univ. Press*, p. 35

Evans, C. J., Walborn, N. R., Crowther, P. A., et al. 2010b, ApJ, 715, L74

Gieles, M., Sana, H., & Portegies Zwart, S. F. 2010, MNRAS, 402, 1750

Goodwin, S. P., & Bastian, N. 2006, MNRAS, 373, 752

Meaburn, J., Redman, M. P., Boumis, P., & Harvey, E. 2010, MNRAS, 1206

Melnick, J., Tenorio-Tagle, G., & Terlevich, R. 1999, MNRAS, 302, 677

Pellegrini, E. W., Baldwin, J. A., & Ferland, G. J. 2010, arXiv:1009.4948, Accepted for publication in ApJS

Portegies Zwart, S. F., McMillan, S. L. W., & Gieles, M. 2010, ARA&A, 48, 431

Sana, H. & Evans, C. J., 2010, to appear in Neiner, Wade, Meynet & Peters, eds, *Proc. IAUS272: Active OB Stars: Structure, Evolution, Mass loss & Critical Limits*, Cambridge University Press; arXiv:1009.4197

Taylor, W.D., Evans, C.J., Hénault-Brunet, V., et al. 2011, in Proceedings of the 39th Liège Astrophysical Colloquium, eds. G. Rauw, M. De Becker, Y. Nazé, J.-M. Vreux & P.M. Williams, BSRSL 80, 430

Westmoquette, M. S., Slavin, J. D., Smith, L. J., & Gallagher, J. S., III 2010, MNRAS, 402, 152