# A Slitless Spectroscopic Survey for Hα-emitting Stars in the Magellanic Clouds

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**The slitless-spectroscopy mode of the Wide Field Imager was used for a comprehensive survey of the Magellanic Clouds to detect stars exhibiting Hα line emission. A total of eight million spectra were recorded. Analysis of 84 open star clusters in the Small Magellanic Cloud confirms that the fraction of extremely rapidly rotating Be stars increases with decreasing metallicity. The very large database also enables other aspects of the complex interplay of early-type stars with stellar evolution, metallicity, mass loss and rapid rotation to be examined.**

## The Be star phenomenon

Be stars are B-type stars that have been observed to exhibit Hα in emission at least once. They rotate so close to the break-up velocity that some relatively minor extra kick in velocity, for example by non-radial pulsation, magnetic flares, or in an eccentric binary orbit, can make the star lose matter that then forms a circumstellar disc. The Hα line emission resulting from the recombination of the gas, which is ionised by the hot central star, is strongly broadened by the rapid rotation of the disc. The effects of rotation still pose a challenge to stellar evolution models, and mass loss from early-type stars has a strong impact on the chemical and dynamical evolution of their host galaxies. Therefore, Be stars are prominent astrophysical reference laboratories.

The evolutionary phase(s) during which this Be phenomenon occurs, as well as the mechanism(s) over and above rotation that cause the mass loss, are not strongly constrained by observations. Therefore, a broad survey of Be stars in both open clusters and the field is important. The multitude of stellar emission-line objects and the ability to suppress confusion with other classes of objects by means of simple colour–magnitude diagrams provides many more suitable target fields in the Magellanic Clouds than the Galaxy, where distance moduli are extremely difficult to determine. At least as valuable, from a diagnostic point of view, is the lower metallicity ($Z_{SMC} \approx 0.1\ Z_{\odot}$ and $Z_{LMC} \approx 0.4\ Z_{\odot}$), which places such studies into a wider perspective of stellar evolution and rotation.

In fact, Martayan et al. (2006, 2007) and Hunter et al. (2008) have already found that OB and A-type stars rotate faster at low metallicity than at high metallicity. This can be understood as the result of radiatively-driven winds being weaker at lower metallicity and removing less angular momentum. If there are fewer metals, the fraction of the stellar radiation that can be absorbed by them is lower, and the resulting reduced effective radiation pressure leads to weaker winds and mass loss. Since ultra-fast rotation seems to play a dominant role in Be stars, the frequency of Be stars should increase with decreasing metallicity. Some preliminary empirical evidence has already been reported by Maeder et al. (1999). However, this work only rests on a small number of open clusters. A broader survey is desirable to disentangle the partially overlapping effects of rotation and evolution that can lead to wrong conclusions.

## Spectro-tiling the Magellanic Clouds with the Wide Field Imager

Even after careful pre-selection of candidate objects, any attempt to obtain fairly complete coverage of the Magellanic Clouds with conventional multi-object spectroscopy techniques is hopeless in view of the large amount of telescope time required. Moreover, the widespread diffuse background emission in the Magellanic Clouds would require slits to be used in order to identify objects with intrinsic line emission, thereby eliminating fibre-fed spectrographs that do not have integral field units, and so much reducing the achievable multiplex.

By contrast, a slitless spectrograph delivers spectra of all sufficiently bright sources and the entire background area so that these problems do not arise (cf. Figure 1). However, in crowded areas spectra will overlap and a narrowband filter may be needed to reduce the length of the spectra. For the same reason, the spectral resolution must be low. If the field of view is large and the objects stand out well above the background flux, then the multiplex of a slitless spectrograph is unrivalled.

At ESO, the grism mode of the Wide Field Imager (WFI; Baade et al., 1999) attached to the 2.2-metre MPG/ESO telescope at La Silla offered such observing opportunities. It could utilise about 75% of the direct imaging field of view of 34 × 33 arcmin$^2$ so that, with 14 and 20 pointings, a good coverage of the main areas of the Small Magellanic Cloud (SMC) and Large Magellanic Cloud (LMC), respectively, could be achieved (see Figure 2). In the SMC, the mean Hα width for Be stars is about 5 nm (range, 0.5–7 nm) thus corresponding to a nominal resolution of 5.1 nm at Hα (or $R$ = 128), very well matched to the resolving power of 130 with the R50 grism. Since even the Hα lines of Be stars remain just unresolved, the detection sensitivity is maximised. A filter of 7.4-nm bandpass, roughly centred on Hα, was inserted into the beam in order to limit the length of the spectra and, thereby, their crowding.

The observations were carried out on 25 and 26 September 2002. Due to poor weather the second night was only partly useful. The typical exposure times were 600 seconds, thus allowing the detection of main sequence stars up to type F. The seeing was about 1.1 arcseconds. No direct images were taken due to bad weather although this was foreseen. The main disadvantages of the absence of direct images are: the difficulty of obtaining accurate astrometry, so the astrometric calculations had to be based on the centre of the spectra; the absence of corresponding photometry on the same date (to mitigate the variability typical of Be stars), which helps in the classification of the stars.

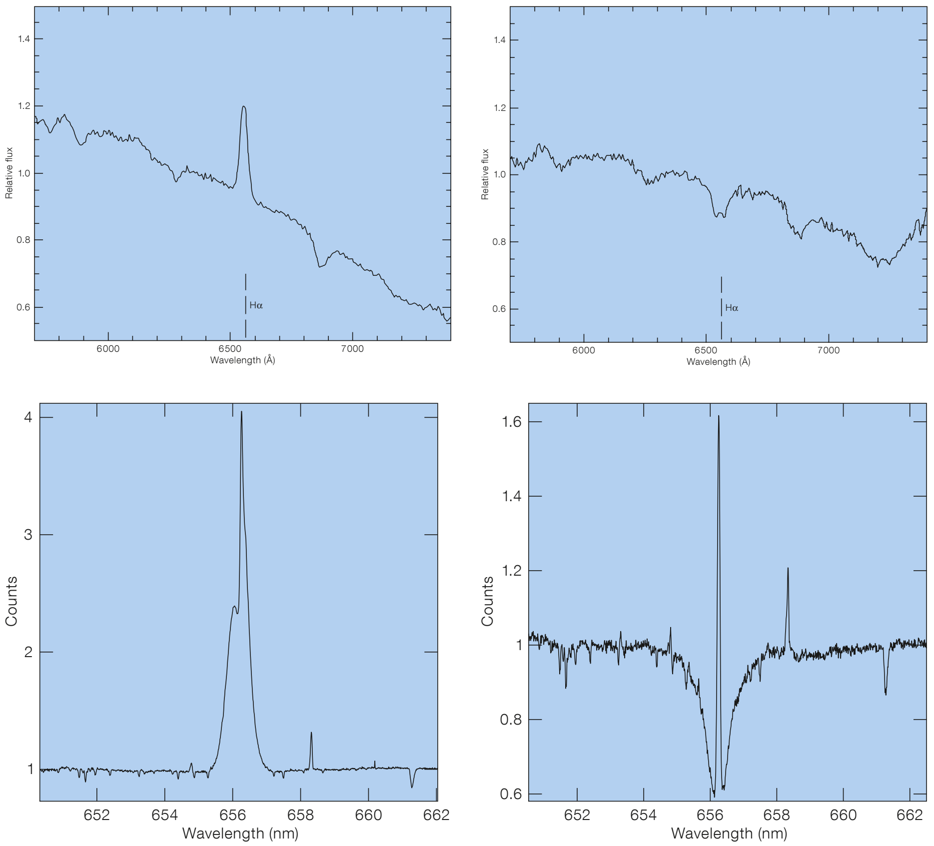


Figure 1. Comparison of the spectra of two Galactic stars (left and right) observed, in Hα, with a slit (lower left) and the FLAMES–GIRAFFE spectrograph (lower right) and with the WFI in slitless mode (left and right upper). The star shown left has a circumstellar disc, while the star at right only happens to lie in an area with diffuse nebular line emission. While the circumstellar emission (left) is found with both instruments, only the slit spectrum (lower right) includes a strong emission line from the large-scale diffuse nebulosity. On account of the lack of spatial resolution across the single fibre, it is not possible to decide whether or not the emission line is intrinsic to the star (lower right). Only the slitless spectrum (upper right) reveals that the line emission is not associated with the object. These two Galactic stars from the open cluster NGC 6611 were observed with a broader WFI filter than the one used for the Magellanic Clouds.

## Extraction and analysis of the WFI slitless spectra

In total, the raw data include spectra of about three million sources in the SMC and roughly five million sources in the LMC. Thanks to a special adaption of the SExtractor code (Bertin & Arnouts, 1996) the detection and extraction of the spectra could be performed fully automatically. With the help of an initial astrometric solution, spectral order –1 was identified; subsequently this order alone was used for analysis.

The very difficult (out-of-focus) point spread function (cf. Martayan et al., 2010) rendered various neural network codes unable to find emission-line objects with acceptable failure rates. Therefore, we developed the IDL code Album, which computes a regional average spectrum and subtracts it from each extracted source, satisfying a number of quality criteria (tilt angle of the spectrum, distortion, etc). In the resulting difference spectra, the Hα line emission stands out fairly prominently. Therefore, the difference spectra were arranged in a photo-album-like fashion, making the detection by eye, even of a large number of line emission sources, quite manageable.

For each extracted source, astrometry was performed with the ASTROM package of Wallace & Gray (2003), assigning the source coordinates to the centre of the spectrum. The achieved accuracy of about 0.5–1 arcseconds was sufficient to cross-identify the WFI sources with photometric catalogues such as OGLE. Using additional calibrations, the OGLE photometry was converted into approximate spectral types so that the detected emission-line sources could be classified.

The reliability of the detection process was verified by means of higher resolution FLAMES spectra of 31 emission-line sources in the field of the SMC open cluster NGC 330, of which 28 are classical Be stars, while the other three are of a different nature (planetary nebula, B[e] star and supergiant). Up to a *V* magnitude of 16.5, line emission above 100 nm equivalent width or with a peak intensity higher than twice the ambient continuum level, was successfully detected in the WFI spectra. Thus completeness of the compiled Be-star catalogue begins to fail at a spectral type of B3.

## Results

The SMC database includes 84 open clusters. The combined colour–magnitude diagram of the stars classified with the WFI is presented in Figure 3, distinguishing stars with and without Hα line emission. The comparison in Figure 4 of the fraction of emission-line stars per spectral sub-type between the Galaxy (McSwain & Gies, 2005) and the SMC shows a clear overfrequency by up to a factor of five of Be stars at low metallicity. Further analysis suggests that this result can no longer be dominated by evolutionary differences. Therefore, the expectation is confirmed that, because low metallicity stars lose less angular momentum through their radiatively-driven winds, and thus, on average, rotate more rapidly, Be stars are more abundant in

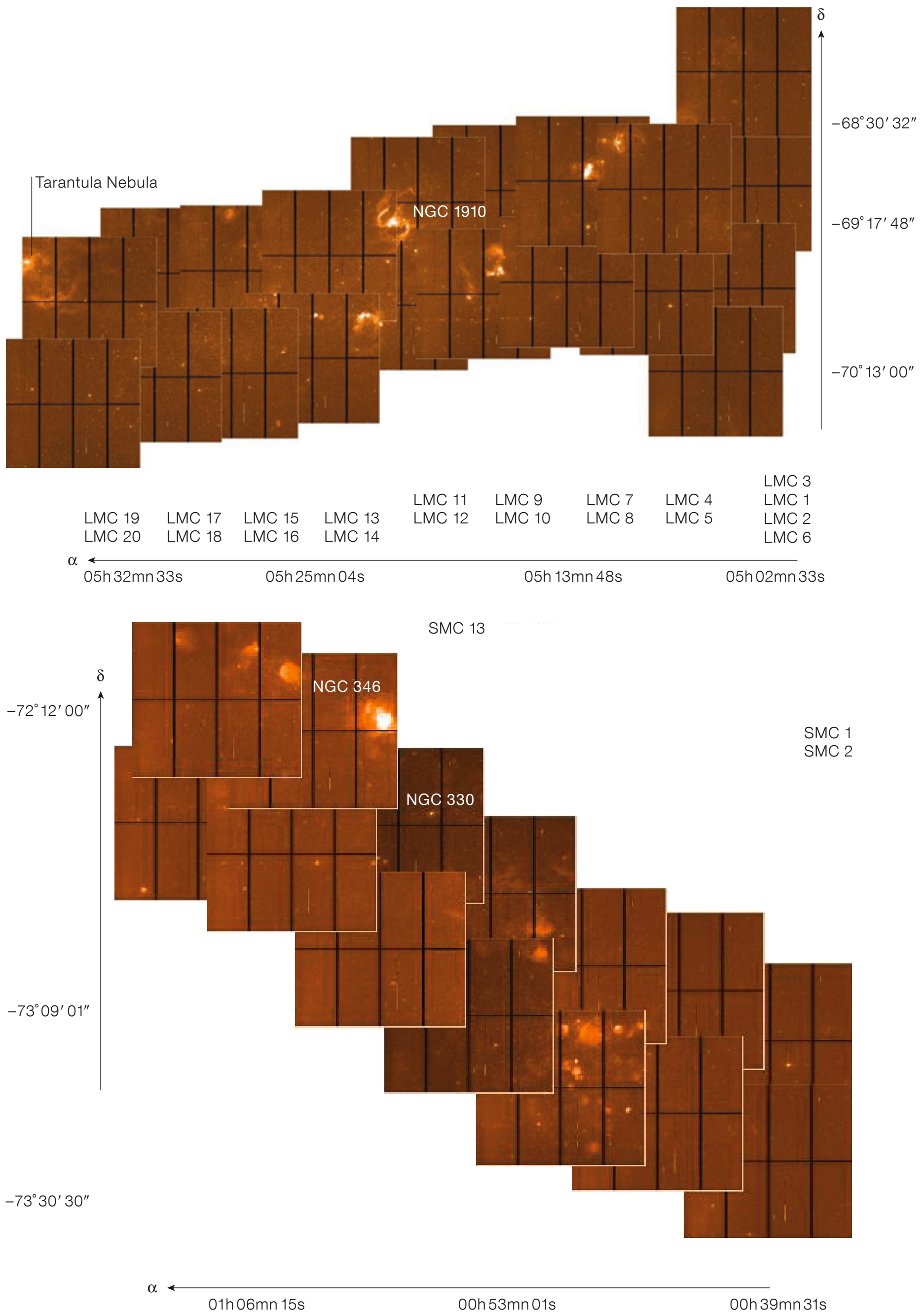


Figure 2. The spatial coverage achieved with the WFI slitless survey of the LMC (top) and SMC (bottom) is shown. Each pointing is named (LMC 1–20 and SMC 1–14) and several SMC clusters are indicated. In the LMC, the nebulosity at the centre hosts the LBV star S Doradus, and the nebulosity at the left is part of the Tarantula Nebula.

the SMC than in the Galaxy. Extrapolated to the extremely low metallicity of first generation stars, this result suggests that, in the early Universe, rapid rotation and the Be phenomenon were probably more common. Such stars may also be related to the predecessors of gamma-ray bursters, which may require very rapid rotation to develop an accretion disc that controls the formation of polar jets.

In both the Galaxy and the SMC, the variation of the fraction of Be stars with spectral type is about the same and, therefore, does not depend on metallicity. From the distribution with cluster age it is apparent that the Be phenomenon is strongest in the latter half of the main sequence phase. Accordingly, some B-type stars acquire Be characteristics only during their main sequence evolution. But others are already formed as Be stars. Probably, the evolution of the fractional critical rotation rate $\Omega/\Omega_c$ is the key parameter governing these differences. Due to the metallicity dependence of mass loss, the evolution of $\Omega/\Omega_c$, too, depends on metallicity. However, this dependency is different for different mass ranges, requiring a large database for its observational analysis.

The WFI slitless Hα survey is not restricted to open clusters. In the 4.5 % of the SMC field area analysed so far, 477 emission-line objects were found. This suggests that the complete survey will identify 4–6 times as many emission-line objects as the previous most complete survey (Meysonnier & Azzopardi, 1993), which was still based on photographic data. As the result, several of the currently less populous classes of emission-line objects will grow to statistically meaningful numbers. Among the young stars, there will also be quite a few Herbig Ae/Be stars.

Inclusion also of the LMC data will extend the parameter space of the Be-star sample towards both intermediate metallicity as well as young stellar ages. This will form an excellent basis for an in-depth spectral analysis of selected targets and areas at higher resolution with FLAMES on the VLT. The results will highlight the metallicity-dependent effect of rapid rotation on the evolution of early-type stars. Most notably, the evolution of $\Omega/\Omega_c$ should become traceable from observations.


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### References


Baade, D. et al. 1999, The Messenger, 95, 15
Bertin, E. & Arnouts, S. 1996, A&AS, 117, 393
Meyssonnier, N. & Azzopardi, M. 1993, A&AS, 102, 451
Hunter, I. et al. 2008, A&A, 479, 541
Maeder, A., Grebel, E. K. & Mermilliod, J.-C. 1999, A&A, 346, 459
Martayan, C. et al. 2006, A&A, 452, 273
Martayan, C. et al. 2007, A&A, 462, 683
Martayan, C., Baade, D. & Fabregat, J. 2010, A&A, 509, A11
McSwain, M. V. & Gies, D. R. 2005, ApJS, 161, 118
Wallace, P. T. & Gray, N. 2003, ASTROM User Guide


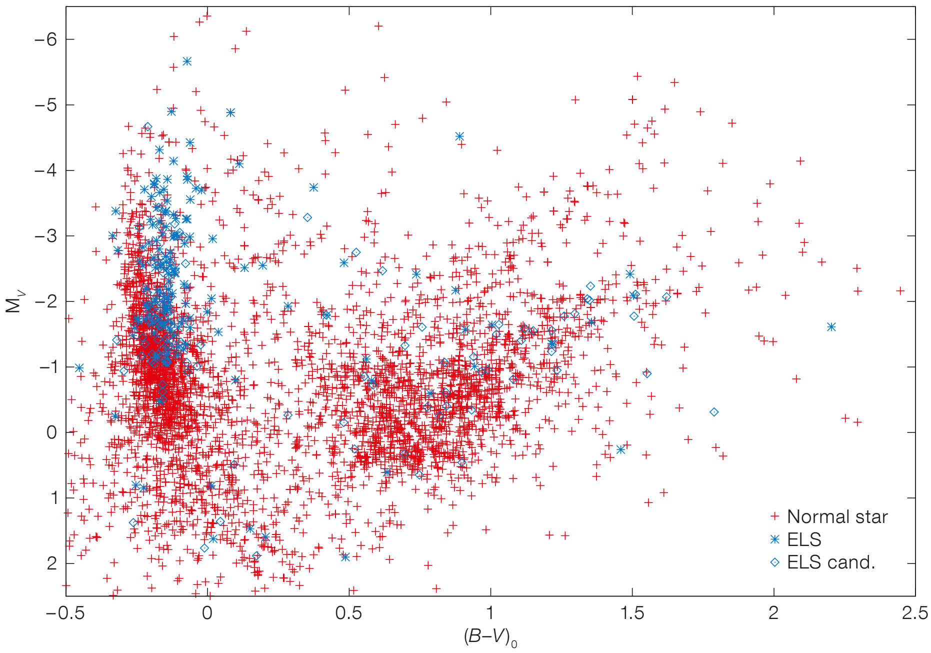


Figure 3. Absolute *V* magnitude versus de-reddened colour $(B-V)_0$ for the full WFI sample of 4437 stars observed in 84 SMC open clusters. Blue asterisks mark emission-line stars, blue diamonds denote candidate emission-line stars, and red plus signs identify normal stars.

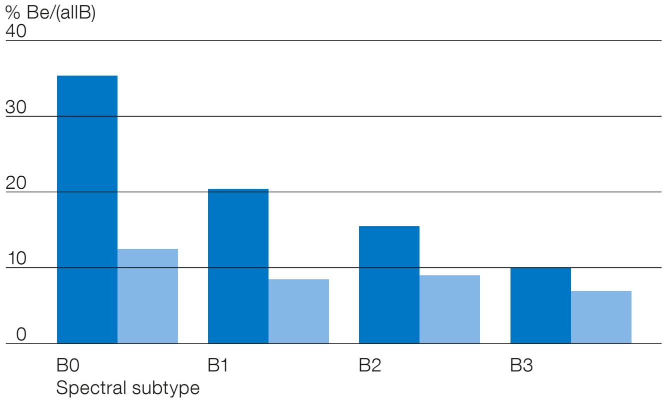


Figure 4. Percentage per spectral subtype of Be stars among all B-type stars. Dark blue left bars are for the SMC (Martayan et al., 2010), and light blue right bars present the Galactic data (McSwain & Gies, 2005). The WFI sample is incomplete for stars with spectral type B3 and later.