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Variability of B and Be stars in the LMC/SMC: binaries and pulsations.

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Abstract. To study the variability of the 523 B and Be stars observed in the Magellanic clouds with the VLT-FLAMES, we cross-matched the stars of our sample with the photometric database MACHO, which provides for each star an 8 years lightcurve. We searched for long, medium, and short-term periodicity and found the eclipsing binaries in our sample. For these stars, combining, spectroscopy and photometry, we were able to provide information on several systems of stars (systemic velocities, ratios of masses, etc). We also present the ratios of B-binaries to B-non binaries in the LMC/SMC in comparison with the MW. Note that this ratio is also an important issue to understand the mechanism of star-formation at low metallicity. We also found the first multiperiodic B and Be stars in the SMC, in particular the first SMC Beta Cep and SPB, while, according to the models, pulsations were not foreseen in low metallicity environments, i.e. typically in the SMC. Our results show that the instability strips are shifted towards higher temperatures in comparison with the Milky Way' strips of pulsating B-type stars. By the fact that we found more pulsating Be stars than pulsating B stars in the SMC, it seems that the fast rotation favours the presence of pulsations. However, the ratio of pulsating B-type stars to "non"-pulsating B-type stars at low metallicity is lower than at high metallicity.

Keywords. Magellanic Clouds, stars: early-type, stars: emission-line, Be, binaries: eclipsing, stars: oscillations,

1. Introduction and observations

To investigate the B-type star populations in the Magellanic Clouds, VLT-FLAMES observations of a large sample of B and Be stars were obtained in the LMC-NGC2004 (176 stars) and SMC-NGC330 (344 stars) regions and their surroundings. We used a medium resolution R = 6400 in the blue wavelength range around Hγ (LR02) and R = 8600 in the red one around Hα (LR06). Among this sample 178 Be stars were observed. We cross-correlated the coordinates of observed stars with the MACHO photometric database. We obtained the lightcurves for the main part of stars of our sample in order to search their long-, medium-, and short-term variability/periodicity due to potential binarity or pulsations. The time span of MACHO lightcurves is large enough to provide a very high frequency resolution in the spectral analysis and allows us to distinguish between very close frequencies.

2. Binaries

2.1. *Spectroscopic and eclipsing binaries in the Magellanic Clouds*

Blue spectra of B and Be stars in the LMC were obtained 4 days before red ones and it was therefore possible to study the variation of the radial velocities and to detect spectroscopic binaries. Despite the small number of spectra for each object it was possible to estimate the mass ratio and the systemic velocity for some binaries (see Martayan et al. 2006a). By cross correlation with the MACHO and OGLE databases we detected 19 photometric binaries. Among them 14 are new photometric binaries (5 in the LMC, 9 in the SMC). Among the 19 photometric binaries, 6 are also spectroscopic binaries (5 in the LMC, 1 in the SMC) and 2 others are Be stars (2 in the SMC). For the eclipsing binaries, the orbital period was determined with an accuracy better than 0.001 d.

2.2. *Details about LMC and SMC binaries*

Thanks to observations with the VLT-GIRAFFE spectrograph, we found 23 new binary systems among the B stars of our sample in the LMC (see Martayan et al 2006a). The orbital periods were found thanks to the MACHO data. In the SMC, contrary to the LMC, spectra in the blue and red wavelengths were obtained the same night and we cannot study the variation of radial velocity. We found 13 eclipsing binaries. Their periods range from 0.664 d to 455 d with most common values around 2 d. All the periods and details are provided in Martayan et al. (2007b). Finally we found 5% of binaries among B-type stars in the SMC, 12% in the LMC, while in the MW, this ratio is 30% (Porter & Rivinius 2003). However, the detectability of binaries in the LMC/SMC is limited and then the ratios given here are certainly lower limits. Note that McSwain & Gies (2005) suggested that 75% of MW Be stars can be binaries. The identified binaries from our sample with more complete observations of the radial velocity variation should be used for testing/constraining the input parameters of stellar evolution models in low metallicity environments, in particular the stellar radii.

3. Pulsating B and Be stars

3.1. *Pulsating B and Be stars in the LMC/SMC (low metallicity)*

A significant fraction of main-sequence B type stars are variable. The B main sequence is populated by 2 classes of pulsators: the Beta Cephei stars (Stankov & Handler 2005) and the Slowly Pulsating B stars (de Cat 2002). The pulsations are due to the κ-mechanism acting in the partial ionisation zones of the iron-group elements. Be stars are non-supergiant B stars whose spectrum has displayed at least once emission lines mainly in the Balmer series. Emission lines come from a circumstellar disk created by episodic matter ejections from the central star. Be stars are also known as fast rotator stars. In the MW, they display short-term variations like Beta Cep or SPB stars. The κ-mechanism depends on the abundance of iron-group elements, and hence the respective instability strips have a great dependence on the metallicity of the stellar environment. Pamyatnykh (1999) showed that the Beta Cep and SPB instability strips disappear at $Z < 0.01$ and $Z < 0.006$ respectively. The LMC metallicity is $Z = 0.007$ and the SMC one is $Z = 0.002$ (see Maeder et al. 1999, and references therein). Therefore it is expected to find a very low occurrence of Beta Cep and SPB pulsators in the LMC and no pulsator type in the SMC. Previous spectroscopic study of Baade et al. (2002) failed to find variability in two Be stars, while Balona (1992) found monoperiodic variable B-type stars in low metallicity environment. We downloaded MACHO lightcurves for LMC and SMC B and Be stars from the samples of Martayan et al. (2006a, 2007b). We searched then for

Table 1.

	MW	LMC	SMC
Metallicity Z	0.020	0.007	0.002
Stellar radii	decrease	with	Z
Linear rotational velocities	increase	with	Z
Critical rotational velocities	increase	with	Z
Ω/Ω_c (B stars) %	40	37	58
Pulsating B stars %	16	7	5
Ω/Ω_c (Be stars) %	80−88	85	95
Pulsating Be stars %	74	15	25

pulsations with these lightcurves. The fundamental parameters based on VLT-FLAMES spectra provided by these authors and corrected from the fast rotation effects for Be stars (see Martayan et al. 2006b, 2007a) are used. We found several B and Be stars with short-period variability. Many of the short-period variables were found to be multiperiodic and some of them show a beating due to close frequencies. We recall that this result was not expected at this low metallicity by the theory. We propose an observational instability strip in the SMC, which is shifted towards higher temperatures than in the MW. We also propose the hottest pulsating star in our sample as a Beta Cep variable. The results for the MW pulsating stars come from Gutiérrez-Soto et al. (2007). The results presented here are detailed in Diago et al. (2008).

3.2. *Ratios of pulsating B and Be stars vs. the metallicity and rotational velocities*

In Table 1, for each galaxy, we provide the metallicity of the environment, the rates of pulsating B or Be stars, and also their ratios of angular velocities to breakup velocities (Ω/Ω_c), which come from Martayan et al. (2007a, LMC and SMC), for the MW: Frémat et al. (2005), Porter (1996), Chauville et al. (2001), and Stepien (2002). When the metallicity decreases the radii of the stars decrease (see Maeder & Meynet 2001). At the opposite, the linear rotational velocities of stars increase (due to lower angular momentum loss due to lower mass-loss at low metallicity) and due to the combination of this increase with the decrease of the radii, the critical rotational velocities also increase. The evolution of the Ω/Ω_c is due to the combination of these different effects. Finally, we note:

(*a*) a decrease of the rates of pulsating B stars with decreasing metallicity as expected by the theory.

(*b*) More pulsating Be stars than pulsating B stars at similar metallicity, which seems to indicate that the fast rotation in Be stars plays a role in the appearance of pulsations.

(*c*) A decrease of the rates of pulsating Be stars between the MW and the LMC, which corresponds to a metallicity effect.

(*d*) An increase of the rates of pulsating Be stars between the LMC and the SMC while the metallicity decreases. This may be explained by the fact that SMC Be stars rotate faster ($\Omega/\Omega_c \sim 95\%$) than their counterparts in the LMC/MW ($\Omega/\Omega_c \sim 85\%$).

(*e*) There is a similar trend in Ω/Ω_c for B stars, but their ratios are always lower than the minimal ratio from which the fast rotation effects ($\Omega/\Omega_c \sim 70\%$) on the stars are not negligible (see for example Frémat et al. 2005). It explains why there is an effect of the fast rotation between the LMC and SMC for Be stars and not for B stars.

4. Conclusion

Our results provide new informations and constraints for the models about the pulsation theory at low metallicity. They seem to indicate an enhancement of the non-radial pulsations due to the high rotation rates. As a consequence, due to the rotational mixing, are the fast rotators (Be stars) enriched in metals? To confirm and enlarge our results, we need first to increase the samples by using WFI-spectroscopic samples of Be stars in the LMC/SMC; second to determine the chemical abundances of the stars by using high resolution spectra from VLT: UVES, X-Shooter; third to test the decrease of the stellar radii by using observations of binaries at different metallicities, fourth to analyse the COROT lightcurves of MW B and Be stars, which could help to understand the mechanisms at the origin of pulsations and the Be phenomenon.

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References

Baade, D., Rivinius, T., Stefl, S., et al. 2002, *A&A* 383, 31
Balona, L.A. 1992, *MNRAS* 356, 425
Chauville, J., Zorec, J., Ballereau, D., et al. 2001, *A&A* 378, 861
de Cat, P. 2002, *ASPC* 259, 196
Diago, P.D., Gutiérrez-Soto, J., Fabregat, J., and al. 2008, *A&A* 480, 179
Frémat, Y., Zorec, J., Hubert, A.-M., et al. 2005, *A&A* 440, 305
Gutiérrez-Soto, J., Fabregat, J., Suso, J., et al. 2007, *A&A* 476, 927
Maeder, A., Grebel, E.K., & Mermilliod, J.-C. 1999, *A&A*, 346, 459
Maeder, A., & Meynet, G. 2001, *A&A* 373, 555
Martayan, C., Hubert, A.-M., Floquet, M., et al. 2006a, *A&A* 445, 931
Martayan, C., Frémat, Y., Hubert, A.-M., et al. 2006b, *A&A* 452, 273
Martayan, C. Frémat, Y., Hubert, A.-M., et al. 2007a, *A&A*, 462, 683
Martayan, C., Floquet, M., Hubert, A.-M., et al. 2007b, *A&A* 472, 577
McSwain, M.V., & Gies, D.R. 2005, *ApJS*, 161, 118
Pamyatnykh, A.A. 1999, *AcA* 49, 119
Porter, J.M. 1996, *MNRAS* 280, 31
Porter, J.M., & Rivinius, T. 2003, *A&A*, 115, 1153
Stankov, A. & Handler, G. 2005, *ApJS* 158, 193
Stepien, K. 2002, *A&A* 383, 218