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ZAMS rotational velocities of Be/Oe stars and LGRBs progenitors in the Magellanic Clouds.

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Abstract. The Large and Small Magellanic Clouds are privileged environments to perform tests of theoretical predictions at low metallicity on rotational velocities and stellar evolution. According to theoretical predictions, the rotational velocities of B-type stars are expected to be higher in low metallicity (LMC/SMC) than in high metallicity (MW) environments. To verify the models, we observed 523 B and Be stars with VLT-FLAMES, which form, at the moment, the largest observed sample of this kind of objects in the MCs. We first determined the stellar fundamental parameters and we found that B and Be stars rotate faster in the MCs than in the MW. We also determined the first distribution of the average ZAMS rotational velocities versus the mass of Be stars. These results indicate that the appearance of Be stars is mass-, metallicity-, stellar evolution-, and star-forming region-dependant. Moreover, the recent models of Long Gamma Ray Burst progenitors foresee possible LGRBs progenitors at the SMC's metallicity. We confront these models with the observed (ZAMS rotational velocities, masses) distributions of the fastest rotators (Be and Oe stars) in our sample. Furthermore, we compare the corresponding predicted rates from our study with observed rates of LGRBs.

Keywords. Magellanic Clouds, stars: emission-line, Be, stars: fundamental parameters, gamma rays: theory

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1. Introduction and observations

This document deals with the determination of rotational velocities of B-type stars at different metallicities (MW, LMC, SMC) and their consequences on the stellar evolution in particular for the late stages. A comparison between the results from the observations and theory is also given. To perform this study, thanks to the VLT-FLAMES/GIRAFFE facilities in MEDUSA mode, a large sample of B and Be stars have been observed in the LMC-NGC 2004 and SMC-NGC 330 regions and their surroundings, 176 and 344 hot stars respectively. We used a medium resolution R = 6400 in the blue wavelength range around Hϵ, Hδ, Hγ (LR02) and R = 8600 in the red one around Hα (LR06). Among this sample, 178 Be stars were observed.

2. Rotational velocities vs. metallicity: observations and theory

Using the GIRFIT code (Frémat et al. 2006) we determined the fundamental parameters for each star by fitting observed spectra with theoretical NLTE spectra. The

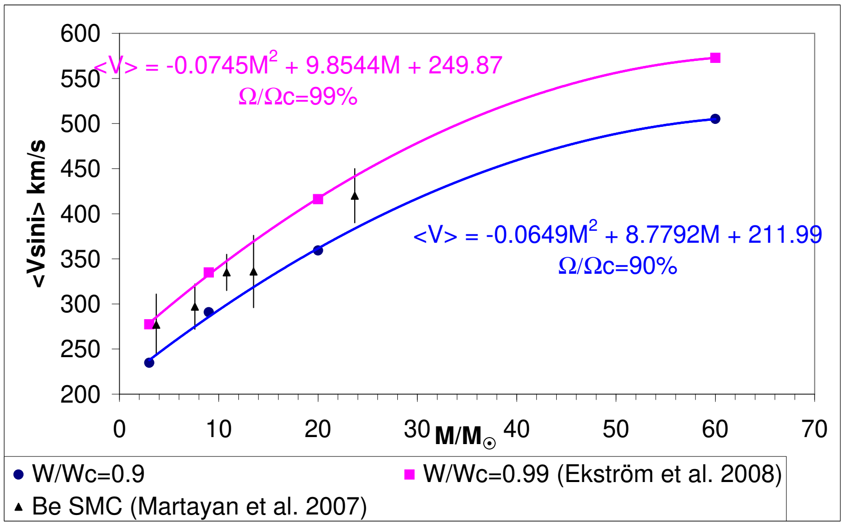

Figure 1. Comparison of average $v \sin i$ distribution for observed Be/Oe stars in the SMC (black points from Martayan et al. 2007) with the theoretical tracks for stars, which display the Be-phenomenon at the SMC metallicity (pink and blue curves are from Ekström et al. 2008).

gravitational darkening effects for fast rotating stars such as Be stars were taken into account thanks to the FASTROT code (Frémat et al. 2005).

Statistically, Martayan et al. (2006, 2007) found that B and Be stars with similar masses and ages rotate faster at low metallicity (in the SMC) than at high metallicity (in the MW). This result was the first confirmation, based on a significantly large star sample, of the theory from Maeder & Meynet (2001) about the behaviour of rotational velocities in respect of the metallicity for main sequence (SMC vs. MW) B and Be stars. Hunter et al. (2008) recently arrived at the same conclusions. Our results in the LMC are in agreement with those of Keller (2004).

More recently, Ekström et al. (2008) published new stellar evolutionary tracks at the SMC metallicity. In Fig. 1, we compare the independent results from Martayan et al. (2007), for which we add the values for the most massive SMC Be stars-late Oe stars, with the results from Ekström et al. (2008) for the $v \sin i$ distributions. As shown, there is a good agreement between the two studies and the theory seems to correctly reproduce the observations.

3. ZAMS rotational velocities

Using the observed values from Martayan et al. (2007) and evolutionary tracks from Schaller et al. (1992, for SMC and MW metallicities) and Charbonnel et al. (1993, for LMC metallicity), Martayan et al. (2007) also determined for the first time the ZAMS rotational velocities of Be stars in the SMC, LMC, and MW. The values for the linear rotational velocities in the MW come from Zorec et al. (2005).

In Fig. 2, we add the ZAMS rotational velocities for massive SMC Be and late Oe stars to the values from Martayan et al. (2007). We fitted 2nd order polynomials through these values. We compared our observational values to Ekström's et al. (2008) theoretical ones. The comparison shows again a good agreement between the theory and observations. The distributions show an increase of $V0_{ZAMS}$ for B stars and late O stars (due to low mass-loss) and a decrease of $V0_{ZAMS}$ for the more massive O stars (in which the stellar

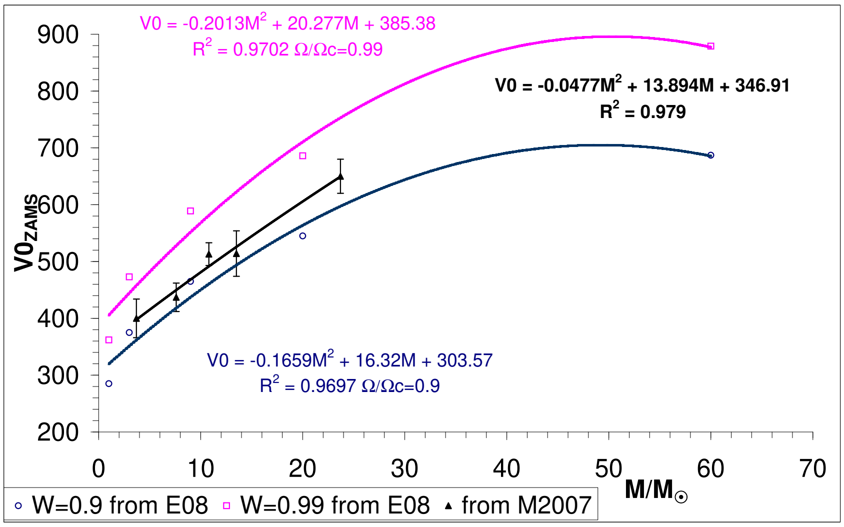

Figure 2. ZAMS rotational velocities distributions for observed Be/Oe stars in the SMC (black points and curve) compared with theoretical distributions from Ekström's et al. (2008).

winds are strong enough to drive strong mass-loss and strong angular momentum-loss). However, we need observations of more massive stars, like O fast rotators stars to better constrain this trend.

4. Stellar evolution and Long Gamma Ray Burst progenitors

The Gamma Ray Bursts are the most energetic events in the universe since the Big Bang. We distinguish two kinds of GRBs, the short and long soft GRBs. It is believed that short LGRBs can be produced by the merging of two compact objects such as neutrons stars in a binary system.

Here we focus on the long soft GRBs. Since the model of the collapsar from Woosley (1993), where LGRBs are produced by the collapse of massive fast rotating stars, the recent developments from Hirschi et al. (2005) or Yoon et al. (2006) predict the ranges of masses and rotational velocities of the LGRBs progenitors as a function of the metallicity. The distributions of ZAMS angular rotational velocities of Be stars in our SMC sample as a function of mass with the predicted area of LGRBs by Yoon et al. (2006) show that most of the massive Be stars and late Oe stars are located in the LGRBs progenitors' area.

However, Hirschi et al. (2005) foresee more LGRB progenitors from massive fast rotators stars than Yoon et al. (2006). As a consequence of these studies, we propose that the most probable LGRB progenitors are the low metallicity (Z of SMC or lower) early Be stars and late Oe stars. Moreover, after the main sequence, these stars must become fast rotating WR stars. To do that, it is necessary that the stars at the end of the main sequence be fast rotators and massive stars. The finding by Martayan et al. (2007) that massive Be stars at low metallicity are in the second part of the MS is an argument that favours this scenario.

5. Be/Oe stars as Long Gamma Ray Burst progenitors: estimated rates

To test our scenario that takes massive Be stars and late Oe stars as progenitors of LGRBS, we determined the corresponding rates of LGRBs it implies. To do that, we use the proportions of SMC Be/Oe stars to B/O stars from Martayan et al. (in this proceedings). We also use the number of B and O stars in the SMC estimated from OGLE catalogues for the whole SMC. We take into account the lifetime of the stars and the angle of γ-ray beams to infer the rates of LGRBs events. We obtain that they range as: 3×10^{-6} to 3×10^{-5} LGRB/year/galaxy.

These rates must be compared with observed rates of LGRBs: from Hirschi et al. (2005, and references therein): 3×10^{-6} to 6×10^{-4} LGRB/year/galaxy, and from Fryer et al. (2007, and references therein) in the local universe (z<1), the values range from: 10^{-6} to 10^{-5} LGRB/year/galaxy.

The rates we estimated are in good agreement with the observed rates of LGRBs and as a consequence, massive Be stars and late Oe stars are then among the most probable candidates of the LGRBs progenitors.

6. Conclusions

The comparisons of rotational velocities distributions of Be stars from our VLT-GIRAFFE observations with theory show good agreements. The results are also similar for the ZAMS rotational velocities, while we added the most massive Be stars to the distributions. From the comparison of stellar evolution models to our observations of SMC Be stars we suggest that the most probable candidate of LGRB progenitors can be the more massive Be stars and late Oe stars. The rates of LGRBs we estimate with the distributions of Be stars at low metallicity are in good agreement with the observed rates of LGRBs in the local universe.

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References

Charbonnel, C., Meynet, G., Maeder, A., et al. 1993, *A&AS* 101, 415
Ekström, S., Meynet, G., Maeder, A., et al. 2008, *A&A* 478, 467
Frémat, Y., Zorec, J., Hubert, A.-M., et al. 2005, *A&A* 440, 305
Frémat, Y., Neiner, C., Hubert, A.-M., et al. 2006, *A&A* 451, 1053
Fryer, C.L., Mazzali, P.A., Prochaska, J. et al. 2007, *PASP* 119, 1211
Hirschi, R., Meynet, G., Maeder, A. 2005, *A&A* 443, 581
Hunter, I., Lennon, D.J., Dufton, P.L, et al. 2008, *A&A* 479, 541
Keller, S.C. 2004, *PASA* 21, 310
Maeder, A., & Meynet, G. 2001, *A&A* 373, 555
Martayan, C., Frémat, Y., Hubert, A.-M., et al. 2006, *A&A* 452, 273
Martayan, C., Frémat, Y., Hubert, A.-M., et al. 2007, *A&A* 462, 683
Schaller, G., Schaerer, D., Meynet, G., et al. 1992, *A&AS* 96, 269
Woosley, S.E. 1993, *ApJ* 405, 273
Yoon, S.-C., Langer, N., & Norman, C. 2006, *A&A* 460, 199
Zorec, J., Frémat, Y., & Cidale, L. 2005, *A&A* 441, 235