Evolution of massive Be and Oe stars at low metallicity towards the Long Gamma Ray bursts*

C. Martayan[1,2], J. Zorec[3], D. Baade[4], Y. Frémat[5], J. Fabregat[6], and S. Ekström[7]

[1] ESO, Alonso de Cordova 3107 Vitacura, Santiago, Chile

[2] GEPI, Observatoire de Paris, place Jules Janssen 92195 Meudon Cedex, France

[3] Institut dAstrophysique de Paris, 98bis boulevard Arago, 75014 Paris, France

[4] ESO, Karl-Schwarschild-Str. 2, Garching bei Muenchen, Germany

[5] Royal Observatory of Belgium, 3 avenue circulaire, 1180 Brussel, Belgium

[6] Observatorio Astronomico de Valencia, 46980 Paterna Valencia, Spain

[7] Geneva Observatory, University of Geneva, Maillettes 51, 1290 Sauverny, Switzerland

Abstract: Several studies have shown recently that at low metallicity B-type stars rotate faster than in environments of high metallicity. This is a typical case in the SMC. As a consequence, it is expected that a larger number of fast rotators is found in the SMC than in the Galaxy, in particular a higher fraction of Be/Oe stars. Using the ESO-WFI in its slitless mode, the data from the SMC open clusters were examined and an occurrence of Be stars 3 to 5 times larger than in the Galaxy was found. The evolution of the angular rotational velocity at different metallicities seems to be the main key to understand the specific behavior and evolution of these stars. According to the results from this WFI study, the observational clues obtained from the SMC WR stars and massive stars, and the theoretical predictions of the characteristics must have the long gamma-ray burst progenitors, we have identified the low metallicity massive Be and Oe stars as potential LGRB progenitors. To this end, the ZAMS rotational velocities of the SMC Be/Oe stars were determined and compared to models. The expected rates and the numbers of LGRB were then calculated and compared to the observed ones. Thus, a high probability was found that low metallicity Be/Oe stars can be LGRB progenitors. In this document, we describe the different steps followed in these studies: determination of the number of Be/Oe stars at different metallicities, identification of the clues that lead to suppose the low metallicity Be/Oe stars as LGRB progenitors, comparison of models with observations.

1 Introduction

Let us recall that a Be star is a non-supergiant B-type star which spectrum has shown at least once emission-lines. Actually a Be stars rotate very fast, in the Galaxy at $\sim$ 85% of the critical rotational velocity. With episodic matter ejection from the central star, a circumstellar decrection disk is formed. This phenomenon is not restricted to B type stars but can also occur in late O and early A stars in the Galaxy. In the first part of this document the metallicity effects on the rotational velocities and on the ratios of Be to B stars are examined.

*Based on ESO runs 069.D-0275(A), 072.D-0245(A) and (C).

The second part of that document deals with the long soft gamma ray bursts (here type 2 bursts) and their possible relationship with the massive Be and Oe stars at low metallicity.

2 Ratios of Be stars with respect to the metallicity

Maeder, Grebel, & Mermilliod (1999) found that the ratio of Be stars to B stars in open clusters seems to increase with the the metallicity decrease. However, only 1 open cluster in the SMC was used. Wisniewski & Bjorkman (2006) found a similar result but the number of open clusters in the SMC/LMC remained small. The strong variation of the Be/B ratio from an open cluster to another prevents definite conclusions from these studies. It was thus needed to increase the samples (much more SMC open clusters) for improving the statistics, for better constraining the freedom degrees such as the age, the metallicity, the density, etc, and for quantifying the trend found with respect to the metallicity.

• **The WFI Hα spectroscopic survey and Be stars ratios**

Observations with the ESO-WFI in its slitless spectroscopic mode (Baade et al. 1999) were carried out on September 25, 2002 with the aim to map the LMC/SMC central parts for detecting the Hα emission-line stars and the Be stars. The WFI was used with a grism and a Hα filter insuring a bandpass of 700nm, a resolving power of 100 adapted to find the emission in the Hα line of Be stars. The exposure time was 600s. In the SMC 14 images and in the LMC 20 images were obtained (see Martayan, Baade & Fabregat 2010). Let us recall that this kind of instrumentation is not sensitive to the diffuse ambient nebulosity and is not sensitive enough to the weak emission, thus only lower estimates of the emission-line stars content can be provided. Finally 3 million spectra were obtained in the SMC (covering 3 square degrees), and 5 million in the LMC. In this first part of their survey, Martayan, Baade & Fabregat (2010) focused in 84 SMC open clusters. Once the emission-line stars and normal stars detected, the stars were classified.

- 1) the astrometry ($\sim$0.5”) was performed with the ASTROM code (Wallace & Gray 2003).

- 2) the WFI stars were cross-matched with Ogle-II photometric catalogues (Udalski et al. 1998). For the stars successfully correlated, the B, V, and I colours were obtained.

- 3) for each open cluster, the E[B-V] and the age were obtained from Pietrzynski & Udalski (1999), then the photometry of the stars was corrected of the reddening.

- 4) the absolute magnitudes of the stars were obtained with the SMC distance modulus (Udalski 2000).

- 5) $\sim$4400 stars in SMC open clusters were classified using the calibration of Lang (2001).

- 6) The SMC data were compared to the results from McSwain & Gies (2005) in the Galaxy.

At that step it is possible to compute the ratios of Be stars to B stars per spectral-type categories, i.e. for example B0e/(B0+B0e), etc, in the SMC and MW. Finally Martayan, Baade & Fabregat (2010) found that **the Be stars are 3 to 5 times more abundant in the SMC (at low metallicity) than in the MW.**

• **Metallicity (Z) and rotational velocities**

Keller (2004), Martayan et al. (2006, 2007), Hunter et al. (2008) found that OBBe stars rotate faster at lower Z. The SMC OBBe stars rotate faster than LMC OBBe stars, which rotate faster than their Galactic counterparts. This is due to a lower mass-loss (the stellar winds are radiatively driven winds, see Bouret et al. 2003, Vink 2007) and lower angular momentum (Ω) loss at lower Z resulting in faster rotation (Maeder & Meynet 2001).

The ZAMS rotational velocities for SMC, LMC, and MW Be stars samples were determined by Martayan et al. (2007). Be stars at their birth rotate faster in the SMC than in the LMC, which rotate faster than in the MW. This is an opacity effect, at lower Z, the radii should be smaller, thus for an identical intial angular momentum, the stars rotate faster.

Theoretical tracks for Be stars at Z_{SMC} from Ekström et al. (2008) fairly agree with the mean Vsini and mean VZAMS of SMC Be stars (see Martayan et al. 2010).

3 Long soft Gamma Ray Bursts and relationship with Be/Oe stars

The gamma ray bursts (GRBs) are the most energetic events since the Big Bang. Among them, 3 classes are distinguished. The type 1 or short GRB (less than 2s) probably resulting of the collapse of 2 compact objects. The type 2 or long GRB (LGRB) is associated to the SNIc and is probably resulting of a massive fast rotating star collapsing in a black hole (Woosley 1993, Fryer 1997). And the rare type 3 pseudo LGRB is not associated to a SN. New theoretical models (Hirschi, Meynet & Maeder 2005, Yoon, Langer & Norman 2006, Georgy et al. 2009) provide some informations about the LGRBs progenitors masses and rotational velocities from the ZAMS at different Z: they must be massive fast rotator at low Z (to avoid too much mass-loss and Ω loss), the H, He envelopes should be lost by fast rotation mixing and/or by a quasi chemically homogeneous evolution (Maeder 1987, Yoon, Langer & Norman 2006; Woosley & Heger 2006), and the stars should have a weak magnetic field.

From the observations point of view, Iwamoto et al. (1998, 2000) found that the massive fast rotating stars are at the origin of the LGRBs. Thöne et al. (2008) found that the LGRB060505 occured in a low-Z galaxy, with high star-formation rate, in a young environment (6 Myr) and from an object about 32 $M_{\odot}$. Campana et al. (2008): the LGRB060218 progenitor had an initial mass of 20 $M_{\odot}$ ($\sim$B0 star), with Z = 0.004 ($\sim Z_{(LMC,SMC)}$). Martins et al. (2009) observed several SMC WR stars whose evolutionary status and chemical properties can be understood if they are fast rotators with a quasi chemically homogeneous evolution.

- **Comparison theory/observations of LGRBs progenitors areas**

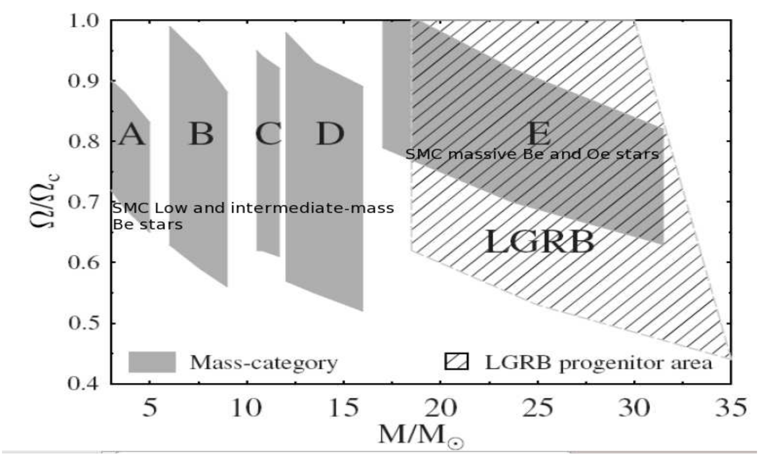

Figure 1: Comparison of LGRBs progenitors area (dashed) at Z_{SMC} at the ZAMS with categories of SMC Be/Oe stars (grey-plain ABCDE areas). This Figure was adapted from Martayan et al. (2010).

One can compare the theoretical models at the ZAMS of Yoon, Langer & Norman (2006), that show areas in rotational velocities vs. the masses for different Z of LGRBs progenitors, with mass-categories of Be/Oe stars. In Fig. 1, such comparison is done using the determined ZAMS rotational velocities for Be stars (ABCD) and for massive Be and Oe stars (E) in the SMC by Martayan et al. (2010).

From observational and theoretical clues it seems that massive fast rotators at low Z, i.e, massive Be and Oe stars could be progenitors of LGRBs. The next sections provide additional tests for supporting this finding, including the predictions of the LGRBs rates and numbers in the local universe.

• **Prediction of the LGRBs rates and numbers from Oe/Be stars populations**

To predict the rates of LGRBs from a well defined population, here the massive Be and Oe stars, different assumptions and computations were performed:

- the SMC is a representative galaxy of the Im.

- The number of OB stars in the SMC was determined using the SMC OGLE-III catalogue that is complete down to B9.

- The corresponding number of Oe/Be stars is determined with the rates from Martayan, Baade & Fabregat (2010).

- The binaries were removed of the sample and the transience of the Be phenomenon was taken into account

- The lifetime of different spectral type stars was taken into account.

This provides the base rate of LGRBs, then the LGRBs beaming angles distribution from Watson et al. (2006) is used. In such case, the average predicted rate is:

R_{pred} LGRBs= (2-5) x 10^{-7} LGRBs/year/galaxy.

These rates should be compared to the observed value:

R_{obs} LGRB $\sim$ (0.2-3) x 10^{-7} LGRBs/year/galaxy (Zhang & Mészáros 2004; Podsiadlowski et al. 2004; Fryer et al. 2007).

One can then predict the number of LGRBs in the local universe, here for a redshift z $\leq$ 0.2 by taking into account that:

- there are 17% of Im for z$<$0.5 (Rocca-Volmerange et al. 2007),

- the number of galaxies with z $\leq$ 0.2 comes from Skrutskie et al. (2006),

- the previous rates are used.

- 11 years are considered from 1998 to 2008, years for which the follow-up of the GRBs is the best (in term of redshift and classification) in the GRBOX survey[1].

In such case the predicted number is **N_{pred} = 3-6 LGRBs** in 11 years at z$\leq$0.2.

The predicted numbers could be compared to the observed number of LGRBs in 11 years at z$\leq$0.2 from the GRBOX survey: **N_{obs} = 8 LGRBs**.

From these different tests and comparisons it seems that the populations of low Z massive Be and Oe stars could play a major role in the explanation of the LGRBs.

4 Remaining questions and conclusion

However, among other there are remaining important questions:

-What is actually the stellar/chemical evolution at low-Z with fast rotation? Some discrepancies between the theory and the observations were found by Hunter et al. (2009).

-The LBV stars could explode in SN without WR phase (Smith et al. 2010), that is not understood by the theory.

[1]http://lyra.berkeley.edu/grbox/grbox.php

- Which observational clue could be found for the chemical evolution? Maybe from the GRB environment according to Woosley & Heger (2006) and Georgy et al. (2009). However, the fast rotating stars such as some SMC massive Be/Oe stars have Vsini $\geq$ 500 km/s, which according to the models could imply a quasi chemically homogeneous evolution.

- Is the SMC really representative of all the Im? Are the proportions Be/Oe similar in all SMC-like galaxies? Bresolin et al. (2007) observed OB stars in IC1613 ($Z_{IC1613} \leq Z_{SMC}$). They found 6 Be stars among the 6 main sequence B stars observed.

- How many LGRBs/SGRBs are not detected by the Gamma Ray observatories?

- There are more LGRBs at high-z. The first stars (very very metal-poor stars) were also probably very fast rotators (like Be/Oe stars?) and thus were probably LGRB progenitors.

References

Baade, D., Meisenheimer, K., Iwert, O., et al. 1999, The Messenger, 95, 15
Bouret, J.-C., Lanz, T., Hillier, D. J., et al. 2003, ApJ, 595, 1182
Bresolin, F., Urbaneja, M., Gieren, W., et al. 2007, ApJ, 671, 2028
Campana, S., Panagia, N., Lazzati, D., et al. 2008, ApJ, 683, L9
Ekström, , S., Meynet, G., Maeder, A., et al. 2008, A&A, 478, 467
Fryer, C. L., Mazzali, P. A., Prochaska, J., et al. 2007, PASP, 119, 1211
Fryer, C., Mazzali, P., Prochaska, J., et al. 2007, PASP, 119, 1211
Georgy, C., Meynet, G., Walder, R., et al. 2009, A&A, 502, 611
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
Hunter, I., Brott, I., Langer, N., et al 2009, A&A, 496, 841
Iwamoto, K., Mazzali, P. A., Nomoto, K., et al. 1998, Nature, 395, 672
Iwamoto, K., Nakamura, T., Nomoto, K., et al. 2000, ApJ, 534, 660
Keller, S. C. 2004, PASA, 21, 310
Lang, K. R. 1992, Astrophysical data, Planets and Stars (New York: Springer Verlag Eds)
Maeder, A. 1987 A&A, 178, 159
Maeder, A., Grebel, E. K., & Mermilliod, J.-C. 1999, A&A, 346, 459
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
Martayan, C., Baade, D. & Fabregat, J. 2010, A&A, 509, A11
Martayan, C., Zorec, J., Frémat, et al. 2010, A&A, 516, A103
Martins, F., Hillier, D. J., Bouret, J. C., et al. 2009, A&A, 495, 257
McSwain, M. V., & Gies, D. R. 2005, ApJS, 161, 118
Pietrzynski, G., & Udalski, A. 1999, Acta Astron., 49, 157
Podsiadlowski, P., Mazzali, P. A., Nomoto, K., et al. 2004, ApJ, 607, L17
Rocca-Volmerange, B., de Lapparent, V., Seymour, N., et al. 2007, A&A, 475, 801
Smith, N., Li, W., Filippenko, A., et al. 2010, MNRAS, in press, arXiv1006.3899
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Thöne, C. C., Fynbo, J. P. U., Östlin, G., et al. 2008, ApJ, 676, 1151
Udalski, A., Szymanski, M., Kubiak, M., et al. 1998, Acta Astron., 48, 147
Udalski, A. 2000, Acta Astron., 50, 279
Vink, J. 2007, AIPC, 948, 389
Wallace, P. T., & Gray, N. 2003, Users guide of ASTROM
Watson, D., Hjorth, J., Jakobsson, P., et al. 2006, A&A, 454, L123
Wisniewski, J. P., & Bjorkman, K. S. 2006, ApJ, 652, 458
Woosley, S.E. 1993, ApJ, 405, 273
Woosley, S. E., & Heger, A. 2006, ApJ, 637, 914
Yoon, S.-C., Langer, N. & Norman, C. 2006, A&A, 460, 199
Zhang, B., & Mészáros, P. 2004, Int. J. Mod. Phys. A, 19, 2385