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Massive Be and Oe stars at low metallicity and long gamma ray bursts

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Abstract. According to recent theoretical studies, the progenitors of Long Gamma Ray Bursts should be very fast rotating stars, massive enough but not so for collapsing into a black hole. In addition, recent observations seem to show that stars of about 20 solar masses could be at the origin of LGRBs. At low metallicity B-type stars rotate faster than at higher metallicity. We found with the ESO-WFI an occurrence of Be/Oe stars, that are quasi critical rotators, 3 to 5 times larger in the SMC than in the Galaxy. According to our results, and using observational clues on the SMC WR stars, as well as the theoretical predictions of the characteristics must have the LGRB progenitors, we have identified the low metallicity massive Be/Oe stars as potential LGRB progenitors. To support this identification, the expected rates and the numbers of LGRB were then calculated and compared to the observed ones: 3 to 6 LGRBs were found in the local universe in 11 years while 8 were actually observed.

Key words. Gamma rays: bursts – Stars: early-type – Stars: emission-line, Be – Galaxies: Magellanic Clouds – Stars: evolution

1. Introduction

The first section of this document deals with the Be phenomenon, their rates, their rotational velocities in low metallicity environment. The second section deals with the long gamma ray burst or type 2 bursts and their links with the massive Be and Oe stars at low metallicity, according to the last theoretical developments and observational facts.

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2. Be stars in low metallicity environment

The Be-phenomenon concerns the main sequence OBA-type stars, which spectrum has displayed at least once in its life emission lines mainly in the hydrogen. These lines come from a rotationally supported circumstellar disk formed by matter ejections of the central star. Some information regarding the Be phenomenon can be found in Porter & Rivinius (2003). Nowadays, we know that Be stars are rotating very fast, very close to their critical rotational velocity but it is not clear whether an additional mechanism is needed for ejecting the matter. It was also reported that the Be-phenomenon seems to depend on the metallicity too (Maeder et al. 1999) and evolutionary status (e.g., Fabregat & Torrejón 2000; Martayan et al. 2007). A possibility for investigating these effects is the study of open clusters. In the Milky Way a reference study is the one by McSwain & Gies (2005).

2.1. Ratios of Be stars at low metallicity

Maeder et al. (1999) and Wisniewski et al. (2007) found that the number of Be stars by open clusters seems to increase with the decrease of the environment metallicity. However, the number of stars and open clusters used is relatively small and it was necessary to improve the statistics by increasing the number of clusters, to quantify and compare the trends/ratios between the Small Magellanic Cloud (a low metallicity galaxy) and the Milky Way. Martayan et al. (2010) did a spectroscopic survey of the SMC with the aim to find the emission-line stars and the Oe/Be/Ae stars. The ESO WFI (Baade et al. 1999) in its slitless mode was used and about 3 million spectra were obtained. The spectra of 4300 stars in SMC open clusters were extracted, analyzed, and the emission line stars found (for more details see Martayan et al. (2008, 2010)). Then by cross-correlation with the OGLE catalogues (Udalski et al. 2008) the stars were classified in spectral type. With the freedom degrees constrained (age, metallicity, etc) the rates of Be stars to B type stars per spectral-type category were computed in the SMC and in the Galaxy with data of McSwain & Gies (2005). The comparison of the Be to B stars per spectral type category rates is shown in Fig. 1.

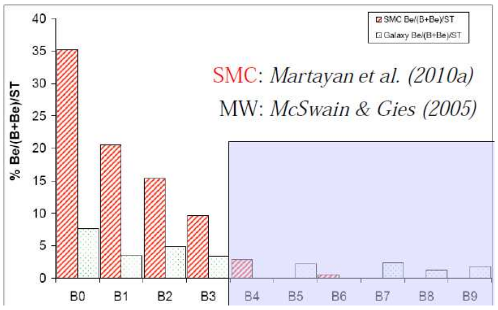

Fig. 1. Ratios of Be stars to all B-type stars per spectral type categories. The SMC sample is only complete till B3 spectral type. The SMC ratios are compared to those from McSwain & Gies (2005) in the Milky Way.

The SMC sample is complete till spectral type B3. For spectral type ranging from B0 to B3 the rates in Fig. 1 indicate that there are 3 to 5 times more Be stars in low metallicity environment than in our Galaxy.

2.2. rotational velocities at low metallicity

As shown in Sect. 2.1, the occurrence of the Be phenomenon is larger in lower metallicity environment. It is explained by the fact that at lower metallicity O, B, A, and Be stars rotate faster than their counterparts in higher metallicity environment (Keller 2004; Martayan et al. 2006, 2007; Hunter et al. 2008). It is due to their lower mass-loss at low metallicity (Bouret et al. 2003; Vink 2007) that implies a lower angular momentum loss (Maeder & Meynet 2001).

With FLAMES observations Martayan et al. (2007) determined the rotational velocities of SMC Be, B stars. They also determined their ZAMS rotational velocities taking into account the fast rotation effects such as the gravitational darkening (Frémat et al. 2005; Zorec et al. 2005). The ZAMS rotational velocities of SMC Be stars are compared with theoretical models from Ekström et al. (2008) in Fig.

2. Their models seem to be able to reproduce properly the observations.

One can also note that SMC Be stars at their birth rotate very fast, with ZAMS rotational velocities exceeding 550 kms^{-1}for the most massive of them. However, for such very fast rotators, the stellar evolution could be modified and instead of following a classical stellar evolution they could follow a quasi chemically homogeneous evolutionary as described in Brott et al. (2011). In Fig. 2, a box with dashed lines shows the predicted area of stars following this quasi chemically homogeneous evolution.

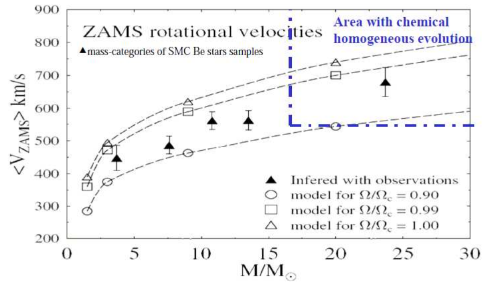

Fig. 2. ZAMS rotational velocities of SMC Be and Oe stars compared to theoretical curves from the models of Ekström et al. (2008). In addition a box shows the location of stars that according to the theory (Brott et al. 2011) can follow the quasi chemically homogeneous evolution.

Therefore one can conclude that the massive Be and early Oe in low metallicity environment such as the SMC could follow the chemically homogeneous evolution. It is worth to notice that Martins et al. (2009) found SMC WR with properties that could be explained only from the chemically homogeneous evolution.

3. LGRBs and Oe/Be stars

This section deals with the type 2 burst also called long soft gamma ray burst (LGRB) because they are longer than 1-3s. Woosley (1993) proposed to explain the LGRB, the model of a massive fast rotating star collapsing into a black-hole during SNIb,c explosion. The energy for the explosion is provided by the potential energy of the matter falling onto the collapsed stellar core. This remaining energy will not accrete onto the black hole that implies for the infalling matter to have enough angular momentum to remain in a disk before accretion.

3.1. Observational and theoretical facts

Iwamoto et al. (1998, 2000) support the idea that massive fast rotating stars are at the origin of the LGRBs. Thöne et al. (2008) found that the LGRB GRB060505 is hosted in a low-metallicity galaxy, with a high star-formation rate. The LGRB came from a young environment (6 Myears) and from an object having about 32 $M_\odot$. Campana et al. (2008) found that the LGRB060218 progenitor had an initial mass of 20 $M_\odot$.

Theoretically, the rotation seems to be a key point to understand the appearance of GRBs (Woosley 1993; Hirschi et al. 2005; Fryer et al. 2007). To keep a large amount of angular momentum up to the last evolutionary phases before the collapse, GRBs progenitors should be massive objects with low initial metallicities. According to Yoon et al. (2006) WR stars with metallicities $Z \lesssim 0.002$ can be progenitors of GRBs.

Due to fast rotation and the rotational mixing of chemical elements, massive stars can undergo quasi-chemically homogeneous evolution to end up as helium WR stars satisfying the requirements for the collapsar scenario (Yoon et al. 2006). Yoon et al. (2006) have calculated diagrams of LGRBs progenitors at different metallicities (including the SMC one) as a function of their ZAMS rotational velocities and masses for magnetized massive stars following the quasi-chemically homogeneous evolution.

From their models, at low metallicity the WR phenomenon can appear in stars having lower masses than those in the Milky Way. We recall the observations by Martins et al. (2009) of several SMC WR stars, whose evolutionary status and chemical properties can be understood if they are fast rotators following this quasi-chemically homogeneous evolution.

According to the different criteria shown by the observations and the theory, the stars must be massive or of intermediate mass, fast rotator, formed in low metallicity environments. Complying with these criteria and the diagrams of LGRB progenitors massive SMC Be and Oe stars could become WR star and give a LGRB.

3.2. Predicted rates of LGRBs from Oe/Be populations

For testing the hypothesis of the SMC massive Be and Oe stars as LGRB progenitors, one can predict the rates of LGRBs based on that specific stellar population. One can use the SMC as a test-bed galaxy, the number of OB stars is determined with the OGLE catalogues. Then the number of the SMC Be/Oe stars is determined through the rates shown in Sect. 2.1, for more details, see also Martayan et al. (2010).

A base rate of LGRB/year is then obtained. However the gamma rays are strongly collimated. One has to take into account the beaming angle to compute the probability to see a GRB.

The table 1 gives the LGRB base rates and the LGRB rates depending on the beaming angle considered and for different mass category of stars (from B2e to O8e). According to the mass calibration of Huang & Gies (2006) the stars of spectral type B0 and higher (masses above 20 $M_{\odot}$) should be considered here.

However, one can take into account the LGRB phenomenon beaming angle distribution (Watson et al. 2006) instead of discrete angle values. In such case, one can get: $N^{\rm pred}_{\rm LGRB} \sim (2 - 5) \times 10^{-7}$ LGRBs/yr/galaxy that can be compared to the observed rate of LGRB: $N^{\rm obs}_{\rm LGRB} \sim (0.2 - 3) \times 10^{-7}$ LGRBs/yr/galaxy (Podsiadlowski et al. 2004; Zhang & Mészáros 2004).

3.3. Predicted number of LGRBs in the local universe

Another possibility is to predict the number of LGRBs in the local universe, i. e, at redshift$\leq$0.2 for which the galaxy catalogue of Skrutskie et al. (2006) is complete. Up to redshift 0.5 the number of Im is about 17% (Rocca-Volmerange et al. 2007).

One can get the predicted number of LGRBs in the local universe during 11 years (between 1998 and 2008) using the previous predicted rates of LGRBs. The result is shown in table 2 for numbers by mass category and discrete values of beaming angles.

Ditto, one can also use the beaming angle distribution, in such case the predicted numbers of LGRBs are: $N^{\rm pred}_{\rm LGRB} \sim 3 - 6$ LGRBs (for mass categories starting from B0e to O8e). This number could be compared to the observed number of LGRBs in the local universe in 11 years with data of the the GRBox from the University of California at Berkeley[1] for years between 1998 and 2008, there are 8 LGRBs.

Therefore there is a relatively good agreement between our predictions and the observed rates/numbers of LGRBs in the local universe.

3.4. Binaries

Malesani et al. (this volume) report that several LGRBs occasionally occurred in “high” metallicity environment. If confirmed it indicates that the usual models of LGRBs, which need low metallicity environment cannot handle them. Therefore, the binary models of LGRB creation (Cantiello et al. 2007) could be of interest too. Considering too the binary system as potential progenitor of LGRB, one could multiply the rates we estimated above by 1/0.7, which gives a number of 9 LGRBs in the local universe (to be compared with the 8 LGRBs actually observed).

3.5. Other biases

Other possible biases than the binaries could be taken into account such as the missed GRBs by the satellites, the obscured GRBs not detected as GRB, etc. On the other side, one could also take into account the effect of the very fast rotating non emission line star, the so called Bn stars on the statistics. For more details, the

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

Table 1. Predicted LGRB rates

Mass category	LGRB base rate	Proba 5deg	Proba 10deg	Proba 15deg
B2e to O8e	3.9-4.8 $\times 10^{-4}$	2.5-3.1 $\times 10^{-7}$	1.0-1.2 $\times 10^{-7}$	2.3-2.8 $\times 10^{-6}$
B1e to O8e	2.6-3.0 $\times 10^{-4}$	1.7-1.9 $\times 10^{-7}$	6.7-7.7 $\times 10^{-7}$	1.5-1.7 $\times 10^{-6}$
B0e to O8e	1.7-1.8 $\times 10^{-4}$	1.1-1.2 $\times 10^{-7}$	4.4-4.6 $\times 10^{-7}$	0.98-1.0 $\times 10^{-6}$
O9e to O8e	5.3-6.2 $\times 10^{-5}$	3.4-4.0 $\times 10^{-8}$	1.4-1.6 $\times 10^{-7}$	3.1-3.6 $\times 10^{-7}$
O8e	2.4-2.8 $\times 10^{-5}$	1.6-1.8 $\times 10^{-8}$	6.2-7.2 $\times 10^{-8}$	1.4-1.6 $\times 10^{-7}$

Table 2. Predicted LGRB numbers in 11 years in the local universe (redshift≤0.2).

Mass category	Number for angle=5°	Number for angle=10°	Number for angle=15°
B2e to O8e	3-4	11-14	25-31
B1e to O8e	2-2	7-9	16-19
B0e to O8e	1-1	5-5	11-11
O9e to O8e	0-0	2-2	3-4
O8e	0-0	1-1	2-2

reader could consult the paper by Martayan et al. (2010).

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