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

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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 form the WFI study, the observational clues drawn from the WR stars and other massive stars in the SMC, and relying on the model predictions regarding the characteristics that LGRBs-progenitors should have on the ZAMS, we concluded that low metallicity Oe/Be stars are potential progenitors of LGRBs. 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 Be stars rotate very fast, in the Galaxy between 60 to 85% of the critical rotational velocity depending on their spectral type (Cranmer 2005; Huang, Gies & McSwain 2010). A similar result is found in the Magellanic Clouds (Martayan et al. 2006, 2007), where Be stars rotate in the LMC between 75 to 85% and in the SMC between 77 to 95% of the critical rotational velocity. With episodic matter ejection from the central star, a circumstellar decretion 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

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

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.

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 as metallicity decreases. 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 7.4nm, a resolving power of 130 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 on 84 SMC open clusters. Once the emission-line stars and normal stars detected, the $\sim$4400 stars in SMC open clusters were classified in spectral types using the calibration of Lang (2001). In the SMC sample, the spectral type classification was possible from early O stars to late A stars in the main sequence for normal stars, while for Be stars it was mainly possible from O8e to B3e stars. For more details about the intermediate steps, see Martayan, Baade & Fabregat (2010). 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.**

Studies by McSwain & Gies (2005) and Martayan, Baade & Fabregat (2010) are single-epoch surveys and in both cases, some Be stars in B phase were missed. According to McSwain & Gies (2008) 25 to 50% may go undetected in a single spectroscopic observation in the MW. Bonanos et al. (2010) showed that in the SMC, Be stars are also transient and they found that the ratio of early-Be stars to B stars in open clusters is about 32% (vs. 35% found by Martayan, Baade & Fabregat 2010).

• 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 $V\ \sin i$ and mean V_{ZAMS} 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. Type 1 or short GRB (less than 2s) probably resulting from the collapse of 2 compact objects. Type 2 or long GRB (LGRB) is associated with the SNIc and is probably due to a massive fast rotating star that collapses into a black hole (Woosley 1993, Fryer 1997). The rare type 3, or 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 information on the properties of LGRBs progenitors in the ZAMS: they must be massive fast rotators with low metallicity (Z) and weak magnetic field, in order to avoid huge mass- and angular momentum-losses. Thanks to an effective mixing unleashed by the fast rotation, these model-stars undergo a quasi chemically homogeneous evolution (Maeder 1987, Yoon et al. 2006; Woosley & Heger 2006).

Iwamoto et al. (1998, 2000) have found observationally that massive fast rotating stars are at the origin of the LGRBs. Thöne et al. (2008) found that the LGRB060505 was due to a $32M_{\odot}$ hosted in a low-Z galaxy having a high star-formation rate and a young environment (6 Myr). Campana et al. (2008) conclude that the LGRB060218 progenitor had an initial mass of $20M_{\odot}$, 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 undergoing quasi chemically homogeneous evolution.

• **Comparison of theoretical LGRBs-progenitor areas with observations**

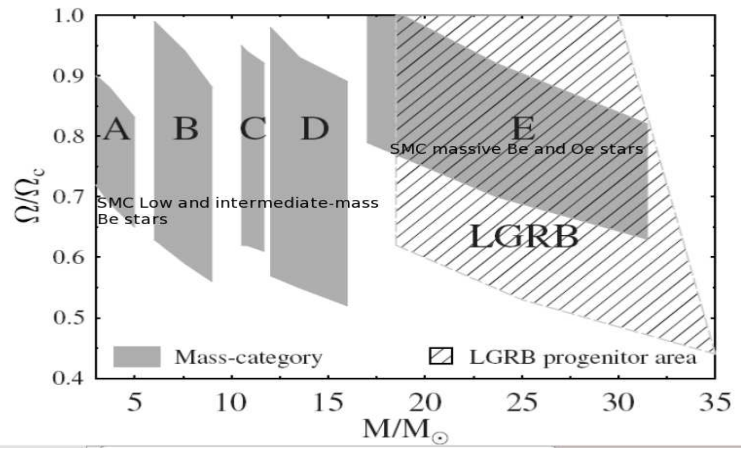

Figure 1: Comparison of LGRBs progenitors area (dashed) at Z_{SMC} at the ZAMS with categories of SMC Be/Oe stars (grey-plain ABCDE areas). This Figure was adapted from Martayan et al. (2010).

The models by Yoon et al. (2006) predict $(\Omega/\Omega_c, M/M_{\odot})-$parameter domains that massive stars of low Z should have in the ZAMS to be progenitors of LGRBs. In Fig. 1 we compare them with the ZAMS-parameter-domains (ABCDE) of Oe/Be stars in the SMC derived by Martayan et al. (2010). The overlapping of the theoretical LGRBs-progenitor area with the observational E-zone suggests that only massive Oe/Be stars with low Z could be progenitors of LGRBs. The rates of LGRB events based on the Oe/Be hypothesis also support this possibility:

• **Predicted LGRBs rates from the counting of Oe/Be stars with low Z**

The prediction of the number of LGRBs events is based on the following assumptions and treatments:

1) the SMC is a representative galaxy of Im type, which all are of low Z;

2) the fraction of Oe/Be stars over all O/B stars in each of them is the one determined by Martayan et al. (2010) for the SMC;

3) the total number N_{tot} of massive Oe/Be stars in the SMC is estimated from the counting carried out in the SMC OGLE-III catalogue, which is complete down to B9 spectral type;

4) binaries are removed from N_{tot} and the fraction of transient Oe/Be phenomena is taken into account;

5) the yearly base-rate of LGRBs events is obtained using N_{tot} and the rotation- and mass-dependent stellar evolutionary lifetime;

6) the observed rate at Earth is estimated using the LGRBs beaming angles distribution from Watson et al. (2006). This leads to the following average predicted LGRBs per year and average galaxy:

R_{pred}(LGRBs) = $(2-5)\times 10^{-7}$ **LGRBs/year/galaxy**,

which has to be compared with the observed rate:

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

Then, one can predict the number of LGRBs events seen in the local universe based on the massive Oe/Be hypothesis by:

1) limiting the estimates to the redshift $z \leq 0.2$, where there are 17% of Im galaxies (Rocca-Volmerange et al. 2007);

2) taking into account the total number of galaxies with $z \leq 0.2$ determined by Skrutskie et al. (2006);

3) considering the above obtained $R_{pred}(LGRBs)$ rate.

Thus, we infer that in 11 years in $z \leq 0.2$ one should have had:

N_{pred} = 3-6 LGRBs,

while from 1998 to 2008 in $z \leq 0.2$ the GRBOX survey[1] has registered:

N_{obs} = 8 LGRBs.

From the above comparison of ZAMS parameters and predicted LGRBs rates, it can be concluded that massive Oe/Be with low Z can be a major link in the explanation chain of LGRBs.

4 Other issues and redshift evolution

In the plot above on the LGRB phenomenon still there are some open questions:

- The theory of stellar evolution with chemical mixing triggered by fast rotation at low-Z still conflicts with observations (Hunter et al. 2009).

- SN explosions of LBV stars without a WR phase (Smith et al. 2010) are not understood by the theory.

- Can GRB environments provide hints on the chemical evolution of fast rotators (Woosley & Heger 2006, Georgy et al. 2009), knowing that according to theory some SMC massive Be/Oe stars with $V sini \sim 500$ km/s should display characteristics of chemically homogeneous evolution ?

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

- Is the SMC fully representative of all Im, and its frequency of Be/Oe similar in all of them (Bresolin et al. 2007)?

- Are the surveys and counts of LGRB/SGRB events complete?

Finally, one can expect that at high redshift stars were extremely metal-poor and probably very fast rotators, like Be/Oe stars but also of other spectral types. Thus with the redshift the number of LGRBs should increase significantly as the number of LGRB progenitors should increase too (Martayan et al. 2010, and references therein).

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Discussion

L. Oskinova: Is there evidence for circumstellar disks from afterglow observations?
C. Martayan: I am not a specialist of that topic but I do not think that there is an observational proof of the existence of circumstellar disks in GRB residual environment. Maybe the current XSHOOTER programs could bring some clues on it.
S. Owocki: Be disks are close to the star and relatively low mass, and so I expect they would be destroyed upon the SN shock breakout, without much evidence in the overall light curve.
C. Martayan: I agree, but I also expect that the circumstellar disk created during the MS by classical Be stars is destroyed in the post-MS phases.