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PRESENTACIÓN MURAL

Unveiling the evolutionary phase of B[e] supergiants

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Abstract. We obtained medium resolution K-band spectra for two B[e] supergiants and one yellow hypergiant (YHG) in the Large Magellanic Cloud (LMC) and found that the spectra of all three stars show enhanced ^{13}CO band emission, in agreement with theoretical predictions for evolved massive stars. Our preliminary results for the two B[e]SGs seem to indicate that one is a pre-RSG star while the other is in a post-RSG phase.

Resumen. Determinamos la abundancia de ^{13}C en el medio circunestelar de dos estrellas B[e] supergigantes y una hipergigante amarilla en la Nube Mayor de Magallanes usando espectros infrarrojos de resolución media en la banda K. Los espectros de las tres estrellas observadas muestran una emisión intensificada en la banda de ^{13}CO que concuerda con las predicciones teóricas para estrellas masivas evolucionadas. Los resultados preliminares para las dos B[e] supergigantes parecen indicar que una de ellas es pre-RSG mientras que la otra está en la fase de post-RSG.

1. Introduction

B[e] supergiants (B[e]SGs) are evolved, massive and luminous B-type stars which are surrounded by disks or rings that have formed from an equatorially enhanced mass-loss event. These disks are cool and dense enough for efficient molecule and dust formation. Both can be observed by their emission in either molecular bands like the CO bands or by their continuum emission in terms of a strong infrared excess, respectively. Although studied in great detail, the evolutionary phase of B[e]SGs remains unclear. Did they just leave the main sequence evolving towards the red supergiant (RSG) phase, or are they already post RSG stars? Recent theoretical investigations have shown that the atmospheres and hence the winds of massive, post-main sequence stars will be strongly enriched in the isotope ^{13}C. This isotope thus seems to be a perfect age indicator for massive evolved stars.

2. How to unveil the age of a massive star hidden in its dense circumstellar material?

The chemical surface composition changes during stellar evolution. Thus, a proper abundance analysis of the surface composition usually allows to determine the age of a star. However, many evolved massive stars are embedded and hidden in their dense, circumstellar winds hampering a proper study of their surface composition.

Stellar evolution models (Meynet & Maeder 2005) predict ^{13}C enrichment at the surface of the stars over their lifetime (Fig.1). Transport of ^{13}C via stellar wind leads to the enrichment of the circumstellar material. Then, detection, in particular in the K-band, of enhanced ^{13}CO emission from the dense circumstellar environments such as B[e]SGs' disks will allow for an unambiguous age determination.

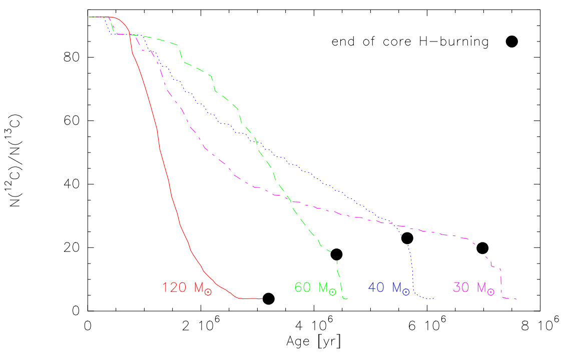

Figure 1. Ratio of ^{12}C/^{13}C surface abundance with stellar lifetime. Models by Meynet & Maeder (2005) for LMC metallicity include the effects of rotation.

3. Observations and modeling results

To trace the amount of ^{13}C in the circumstellar environment of evolved massive stars, we obtained medium resolution K-band spectra with VLT-SINFONI (1.95-2.45 μm, $R \approx 4000$, S/N≈ 500) for two B[e]SGs and one yellow hypergiant (YHG) in the Large Magellanic Cloud (LMC). The stellar parameters of the observed targets are listed in Table 1 and the spectra are shown in the left panel of Fig.2.

Object	$T_{\rm eff}$ [K]	R_* [$R_\odot$]	$M_{\rm ini}$ [$M_\odot$]	Type	Ref.
LHA 120-S 12	23 000	30	$\sim$ 25	Sg	(1)
LHA 120-S 73	12 000	125	25-30	Sg	(2)
HD 269953	5 500	605	$\sim$ 30	YHG	(3)

Table 1. Stellar parameters for the targets. References are: (1) Zickgraf et al. (1986), (2) Stahl et al. (1983), (3) McGregor et al. (1988)

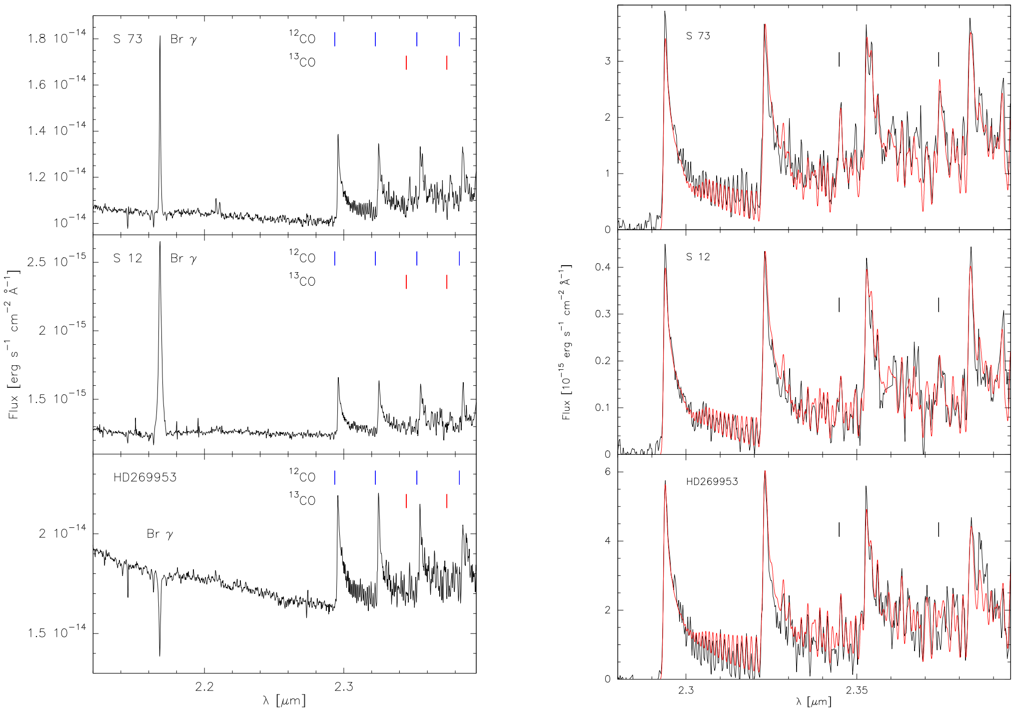

Figure 2. *Left:* K-band spectra of the two LMC B[e]SG stars and the YHG star with identifications for the Brγ line and prominent CO band heads. *Right:* Model spectra (red) overplotted on the observed, extinction corrected and continuum subtracted spectra (black). The ticks mark the identification of the ^{13}CO band heads.

All three stars clearly show the ^{13}CO band emission, whose strength implies a strong enhancement of ^{13}C, in agreement with theoretical predictions. Model computations of the synthetic CO band spectra follow the approach of Kraus et al. (2000). For all three stars we assumed a pole-on orientation of the circumstellar disk or ring, but for the YHG a spherical shell might be more appropriate. The parameters obtained for the best-fitting spectra (right panel of Fig. 2) are listed in Table 2.

Object	$T_{\rm CO}$ [K]	$N_{\rm CO}$ [10^{21} cm^{-2}]	^{12}C/^{13}C	$A_{\rm CO}\cos i$ [AU^2]	Ref.
LHA 120-S 12	2800 ± 500	2.5 ± 0.5	20 ± 2	2.6 ± 0.2	(4)
LHA 120-S 73	2800 ± 500	3.5 ± 0.5	9 ± 1	21.0 ± 0.3	(4)
HD 269953	2300 ± 500	2.0 ± 0.5	15 ± 2	67.5 ± 1.0	(5)

Table 2. Best-fitting model parameters for the targets. References are: (4) Liermann et al. (2010), (5) Muratore et al. (in prep.).

4. Results and outlook

- The detection of enhanced ^{13}CO emission from the two studied B[e]SGs is the first ever direct confirmation of the evolved nature of B[e]SGs in the LMC (Liermann et al. 2010).
- The CO emitting areas projected to the line of sight, $A_{\rm CO} \cos i$, listed in Table 2, constrain the CO region for the B[e]SGs to a narrow ring region.
- The apparent deficiency in CO gas hotter than $\sim$2800 K suggests that there is no CO gas closer to the star. This requires a detached ring of material rather than a disk. Similar results have recently been found for the SMC B[e]SG star LHA 115-S 65 (Kraus et al. 2010).
- The approximately equal initial mass of the stars allows to place them on the same evolutionary track. In Fig. 3 we show the evolutionary track of a rotating 30 $M_\odot$ star model at LMC metallicity (Meynet & Maeder 2005). Interestingly, according to the determined ^{12}C/^{13}C ratios, B[e] supergiants could be pre- as well as post-RSGs. To confirm these findings, studies on a larger sample (Muratore et al. in prep.) are of vital importance.

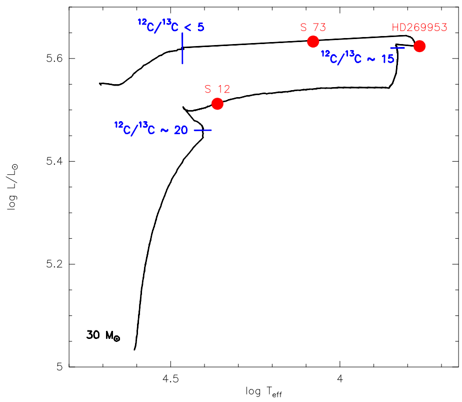

Figure 3. Location of our sample stars in the evolution according to the determined ^{12}C/^{13}C (red dots). Blue ticks mark the onset of different ^{12}C/^{13}C ratio regimes.

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