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The multiplicity of O-type stars in NGC 2244

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Abstract: The investigation of the multiplicity of massive stars is crucial to determine a robust binary fraction but also for understanding the physical properties of these objects. In this contribution, we will present the main results from our long-term spectroscopic survey devoted to the young open cluster NGC 2244. We discuss the spectral classification, the projected rotational velocity ($v \sin i$) and the multiplicity of O-stars. The stellar and wind parameters of each star, obtained using the CMFGEN atmosphere code, help us to better constrain the individual properties of these objects. Several of these stars were observed by the CoRoT satellite (SRa02) in the Asteroseismology channel. This intensive monitoring and the unprecedented quality of the light curves allow us to shed a new light on these objects.

1 Introduction

O-type stars play a key role in the ecology of galaxies but the knowledge of their formation is still fragmented. In this context, the study of massive stars in clusters is interesting in order to discriminate between the different formation scenarios since they constitute a homogeneous population (same age, distance and chemical composition).

The study of the multiplicity of early-type stars in galactic young open clusters through extensive spectroscopic campaigns unveils an average binary fraction of 0.44±0.05 (Sana & Evans 2011). These investigations led to serious corrections of the binary fractions in the rich-open clusters quoted by Garcìa & Mermilliod (2001). However, numerous observational biases prevent the detection of all spectroscopic binaries such as e.g., a very long-term period, a large mass ratio or too low an inclination (for details, see Sana & Evans 2011, Sana, Gosset, & Evans 2009 or Mahy et al. 2009).

In order to extend these studies, we have undertaken a detailed investigation of the young open cluster NGC 2244, situated in the core of the Rosette Nebula and aged between 2 and 3 Myr (Chen, de Grijs, & Zhao 2007, and references therein). We establish the binary fraction amongst O-type stars in the cluster, present the preliminary wind and stellar parameters of all these stars and summarise the preliminary results of the analysis of the CoRoT data devoted to 4 O-stars in NGC 2244.

2 Spectroscopic campaign

Garcia & Mermilliod (2001) listed 6 O-type stars as belonging to NGC 2244 whilst Ogura & Ishida (1981) reported a seventh O star (HD 258691), fainter than the others ones, and which is located outside of the field of view used by Wang et al. (2008). The question of the membership of this latter is thus open. As a consequence, our multiplicity investigation focused on the same stars as taken into account by Garcia & Mermilliod (2001) to establish the binary fraction of NGC 2244.

Our spectroscopic dataset thus contains a total of 136 spectra for 6 O-type stars. These spectra were taken with different instruments which implies different resolutions. The data were spread over a timescale of 9 years, allowing us to search for the short as well as the long-period binaries. The details and results of the spectroscopic investigation of O-type stars are reported in Mahy et al. (2009).

Among the 6 O-type stars in NGC 2244, only one has been detected, for the first time, as a spectroscopic binary: HD 46149. The signature of the secondary component is clearly visible (see Mahy et al. 2009) and we have estimated its orbital period to be close to 800 days. However, it is difficult to be more accurate because our data do not cover the entire orbital cycle. From the least blended spectrum, we estimated spectral types of O8V and early B (B0–1) for the primary and the secondary, respectively. We also classified HD 46150 as a binary candidate since small variations, at the limit of being significant, have been detected and the Temporal Variance Spectrum (TVS, Fullerton, Gies, & Bolton 1996) exhibited profiles with double or triple peaks. Although HD 46056 and HD 46485 present broad and shallow lines, their line widths did not change as a function of time, supporting the idea that both stars are fast rotators rather than binary systems. In general, the 4 remaining stars, HD 46056, HD 46202, HD 46223 and HD 46485, did not show any significant variations in their radial velocities and were, accordingly, classified as presumably single stars.

The spectroscopic investigation thus reveals a binary fraction of O-type stars in NGC 2244 in the range of 17–33% while the previous estimate (Garcìa & Mermilliod 2001) put this value at 50%, based on a very heterogeneous dataset i.e., radial velocities taken from the literature.

3 Determination of stellar and wind parameters

We have used the CMFGEN atmosphere code (Hillier & Miller 1998) for the analysis of the optical and UV spectra of the 6 O-type stars in NGC 2244. The luminosity was computed supposing a distance of 1.55 kpc for the young open cluster, i.e., the mean value in the range estimated by Hensberge, Pavlovski, & Verschueren (2000). On the one hand, the stellar parameters such as the surface gravity ($\log g$) or the effective temperature ($T_{\rm eff}$) were determined from the optical domain. We used the wings of Balmer absorption lines H_β, H_γ and H_δ as indicators of $\log g$ whilst the classical ratio between the equivalent widths of the He I λ 4471 and He II λ 4542 lines provided a good estimate of the $T_{\rm eff}$. Other lines of He I and He II, such as He I λ 4026, He I λ 5876, He II λ 4200 and He II λ 5412 were used as additional diagnostics to determine $T_{\rm eff}$.

On the other hand, the wind parameters were derived from the IUE spectra. The wind terminal velocity (v_∞) was estimated from the absorption part of the P Cygni lines observed in the UV domain. The UV P Cygni and emission lines also served as main indicators of the mass-loss rate ($\dot{M}$).

The $v \sin i$ were directly estimated by comparison of our synthetic spectra to the observed line profiles. A macroturbulence component has to be introduced to correctly reproduce the line profiles (e.g., for the He I λ 4713, C IV λ 5812 and He I λ 5876 lines).

The preliminary wind and stellar parameters of the 6 O-type stars (Martins et al., in prep) are reported in Table 1. However, the results concerning the secondary component of HD 46149 are uncertain. Indeed, our sample of spectra does not cover the entire orbital cycle, it is thus difficult to correctly disentangle the individual spectra of both components of HD 46149. From these parameters,

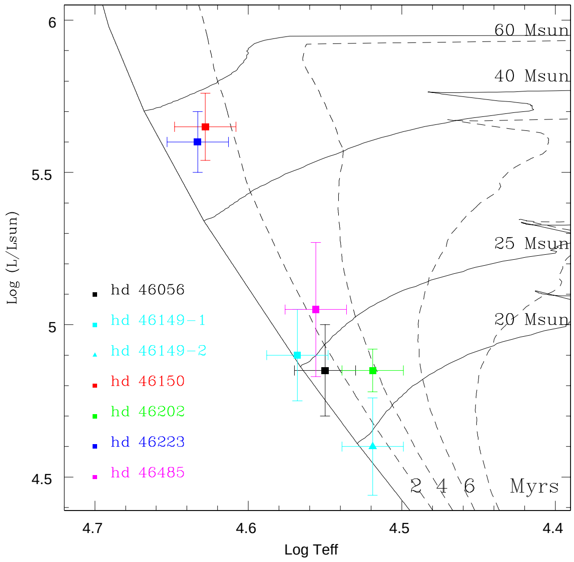

Figure 1: HR diagram showing the position of the O-type stars in NGC 2244. Evolutionary tracks are from Meynet & Maeder (2003) computed with an initial rotational velocity of about 300 km s^{-1}. The dotted lines indicate the isochrones of 2, 4, 6 and 8 Myr.

we put all the stars on a HR diagram (Fig. 1), implying an age of less than 5 Myr for all the O-type stars investigated in Sect. 2. The two hottest stars, HD 46150 and HD 46223, are found to be of the same age (i.e., 0–2 Myr old). A previous study of NGC 2244, by Wang et al. (2008) in the X-ray domain, revealed the existence of X-ray sources, associated to PMS stars, around HD 46150 but not around HD 46223. Two explanations were advanced by these authors. The first one assumes that dynamical interactions in NGC 2244 would be responsible for the ejection of HD 46223 from the central part of the cluster. The second scenario considers that HD 46223 might actually be younger than HD 46150 and would not be part of the same population as the core of the cluster. Our results favor the former explanation based on dynamical interactions inside the cluster since the two hottest stars appear to have a similar age.

Table 1: Preliminary stellar and wind parameters of the 5 O-type stars and both components of HD 46149. The different columns indicate the stars, the spectral type (derived in Mahy et al. 2009), the effective temperature, the luminosity, the surface gravity, the mass-loss rate, the terminal velocity, the projected rotational velocity and the macroturbulence velocity, respectively.

Target	Spectral type	$T_{\rm eff}$ (kK)	$\log(\frac{L}{L_\odot})$	$\log g$	$\log(\dot{M})$ ($M_\odot$ yr^{-1})	v_∞ (km s^{-1})	$v \sin i$ (km s^{-1})	$v_{\rm mac}$ (km s^{-1})
HD 46056	O8V	35.5±2.0	4.85	3.75±0.10	–9.0	1500±100	330	0
HD 46149-A	O8V	37.0±2.0	4.90	4.25±0.10	≤–9.0	1800±100	∼0	24
HD 46149-B	B0–1	33.0±2.0	4.60	3.50±0.10	–	–	100	27
HD 46150	O5.5V	42.5±2.0	5.65	4.00±0.10	–7.2	2800±100	100	37
HD 46202	O9V	33.0±2.0	4.85	4.00±0.10	–8.9	1200±100	20	17
HD 46223	O4((f$^+$)) V	43.0±2.0	5.60	4.00±0.10	–7.2	2800±100	100	32
HD 46485	O8V	36.0±2.0	5.05	3.75±0.10	–8.1	1700±100	300	0

4 The CoRoT photometric data

The CoRoT satellite (Auvergne et al. 2009) has observed 4 O-type stars in NGC 2244 (HD 46149, HD 46150, HD 46202 and HD 46223) during the second short run (SRa02, ~34 days) with the Asteroseismology channel. The sampling of the obtained data is of one point every 32 s, providing light curves of an unprecedented quality.

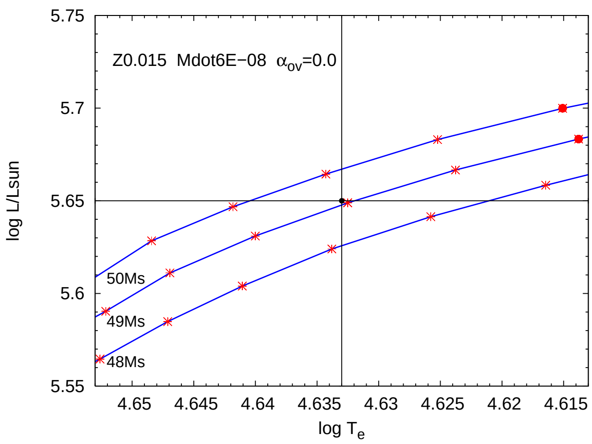

Figure 2: Evolutionary tracks of HD 46223 in the error box computed from the parameters estimated by CMFGEN (Table 1). The red crosses correspond to models computed with ATON and red points correspond to models with excited modes. No overshooting is included in the models.

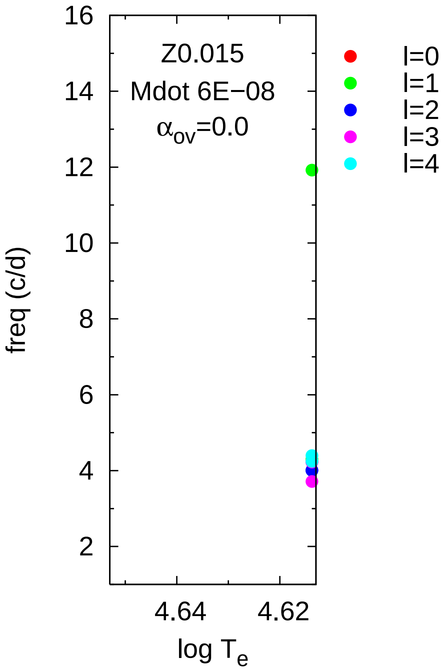

Figure 3: Frequencies computed for the models with excited modes (l) on the tracks of 49 $M_\odot$.

Degroote et al. (2010) claimed the presence of solar-like oscillations in the CoRoT light curve of HD 46149. However, it is currently not possible to attribute these oscillations to the late O-type primary or to the early B-type secondary star of the binary system. Another intensive asteroseismological activity is also detected from the CoRoT light curve of HD 46202 (Briquet et al., in prep).

However, from a general point of view, all O-type stars in the sample observed by CoRoT are affected by the presence of red noise. The parallelism with the helioseismology could indicate that this red noise is linked to something similar to granulation. The work of Cantiello et al. (2009) suggested that a sub-surface convection zone, induced by the iron opacity bump, could affect the stellar surface behaviour through, e.g., the microturbulence or the clumping and could be responsible for the red noise. Furthermore, Belkacem, Dupret, & Noels (2010) suggested that this convection zone could generate stochastically excited oscillations in massive stars.

We have established a first preliminary theoretical asteroseismological analysis of HD 46223. We have determined an error box (Fig. 2) on the HR diagram from the stellar parameters derived with the CMFGEN code (Hillier & Miller 1998, Table 1). Several models have been computed using the ATON evolution code (Ventura, D'Antona, & Mazzitelli 2008) to determine the possible existence of excited modes in this star. Among the 17 different models (red crosses in Fig. 2), computed in the error box, only two present excited modes. If we consider the associated frequencies (Fig. 3), we should detect frequencies close to 4 d^{-1} and 12 d^{-1}. However, no outstanding peak is visible around these frequencies in the semi-amplitude spectrum (Fig. 4) of HD 46223, which implies that this star

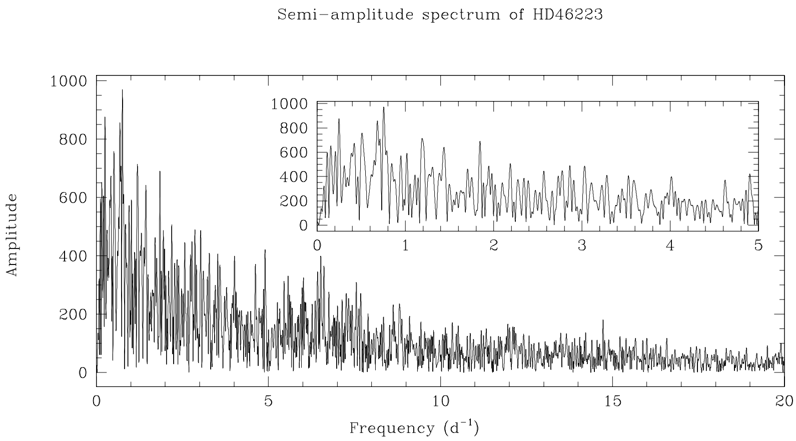

Figure 4: Semi-Amplitude spectrum of the CoRoT light curve of HD 46223 computed with the Heck, Manfroid & Mersch method (Heck, Manfroid, & Mersch 1985; revised by Gosset et al. 2001). The inset shows a zoom-in on the low-frequency domain.

would only be affected by red noise. However, we present here only preliminary results of the analysis of these CoRoT data. A more detailed analysis will be presented in a forthcoming paper (Blomme et al., in prep).

Acknowledgements

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Discussion

W.R. Hamann: I am really excited by your discovery of "red noise" as an indication of granulation on O star surfaces. The iron opacity bump, which is expected from theory to cause an outer convection zone, also plays an important role for initiating radiation-driven winds. Therefore I think that both phenomena - convection and wind initialization - are in fact closely interwoven, although we don't have an idea how this looks like in detail.

S. Heap: How did you distinguish between physical red noise and instrumental red noise?
L. Mahy: We have just assumed that the instrumental noise has to be the same for all the stars in the field of view of the CoRoT satellite. However, all the CoRoT light curves of O stars have a different trend which tends to favor the physical red noise and not an instrumental one.