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A Search for Massive Pulsators in Cygnus OB2 Association

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Abstract. Preliminary results of a photometric search for massive pulsators in the Cygnus OB2 association are presented. There is no clear evidence for β Cephei-type pulsations in any of the O-type stars in the searched area, but two β Cephei candidates are found among the early B-type members of the association. Their location in the H-R diagram and the periods are discussed in the frame of the predicted instability strip for this type of variable.

1. The background

Theory predicts that the β Cephei-type instability for photometrically observed ($l \leq 2$) modes begins at about 7 $M_{\odot}$ and extends up to the most massive O-type stars with no high-mass limit of the instability domain. The position of the blue edge of the instability strip depends mainly on the metallicity; the larger the metallicity, the wider is the instability strip (see Pamyatnykh, these proceedings). The red edge extends well beyond the TAMS, but because evolution is very fast at post main-sequence phases, the possibility of observing any star at this stage of evolution is very small.

Do the observations match the predicted instability strip? The situation in the lower part of the instability strip is quite satisfactory. We do observe β Cephei stars there. The coolest of them have spectral types B2.5, which agrees quite well with the predicted low-mass limit of the instability strip. Near 10 $M_{\odot}$ the theoretical strip extends down to the ZAMS line. We could expect, therefore, that at least some β Cephei stars would be luminosity class V objects; this is indeed observed. Going towards higher masses, the agreement becomes worse because the observed instability strip has a clear observational high-mass limit corresponding roughly to a B0 spectral type and a mass of about 16 $M_{\odot}$. The picture has only one exception: an O-type β Cephei star HD 34656 (Fullerton et al. 1991). The apparent lack of massive and luminous β Cephei stars which are predicted by the theory needs an explanation.

Certainly, there are selection effects which, at least partially, could explain the disagreement. The more massive the star, the faster its evolution, and it is not easy to catch such a star crossing the instability strip. Moreover, the massive stars are much less abundant than the less massive ones. We have to remember also that the instability strip was calculated in the frame of the linear theory, and therefore we do not know whether the amplitudes in the entire predicted instability strip reach the detection threshold.

In order to verify whether the lack of β Cephei stars in the O-type star domain is due to selection effects or has a physical reason, we started a new photometric CCD search among O-type stars. The Cygnus OB2 association was chosen as a target as it contains a large number of massive stars. Moreover, the association is very compact and therefore suitable for CCD observations. The observed field contained 15 known O-type stars (including four supergiants) and many early B-type stars.

2. The equipment

The equipment we used consists of a 60-cm reflector, equipped with a CCD camera, an autoguider, Johnson BVRI filters, and a set of two Hα filters.

3. Introducing Cygnus OB2 association

The Cygnus OB2 association is located behind the Great Cygnus Rift, the matter of which causes very large and variable reddening across the cluster. The E(B-V) colour excess for association members ranges from 1.4 to 2.3 mag, which corresponds to the total absorption in V of the order of 4 to 7 mag. The true distance modulus is about 11.2 mag, which corresponds to the distance of about 1.7 kpc. Because stars as young as O3 are observed in Cygnus OB2, the association is probably younger than 3 Myr.

We were not able to cover the whole association with our detector. Therefore, we chose three adjacent fields with the largest number of known and probable O- and B-type stars, selected using the UBV photometry of Massey & Thompson (1991). The middle field was centered at the trapezium system ADS 14000, known also as star number 8 from Münsch & Morgan (1953). The three fields covered approximately a $6' \times 12'$ rectangle in the sky. In these fields we recorded 455 stars. All were checked for variability. Due to severe reddening, we used the infrared Cousins I filter for most observations. About 500 search frames in the I band were taken during 21 observing nights, spanning a 44-day interval. Moreover, we took about 80 frames in the V and R bands, as well as single frames through B and Hα filters.

4. The results

In all fields, we found about 25 variables. The detailed analysis of their variability will be published elsewhere. The results for O-type stars are summarized in Table 1. The detection threshold of variations of O-type stars in our search is of the order of 3–5 mmag, depending on the star's brightness. There are several O-type variables, including two supergiants. Most of them are microvariables with semi-amplitudes of the order of a few mmag. For some of them, the variations seem to be periodic, but because the periods (or quasi-periods) are of the order of days, we cannot be sure they are coherent on a longer time-scale. In this respect, our results are similar to those of Balona (1992), although the percentage of constant stars in our sample is larger. One O-type star appears to be an eclipsing binary. None of the O-type stars exhibit short-period variations typical for β Cephei stars.

Table 1. Variability among O-type stars in Cygnus OB2 association.

MT[a] number	Spectral type	V mag.	Comments on variability
457	O3 If	10.54	VARIABLE, P > 15 d?
431	O5 If	10.79	VARIABLE, P = 1.22 or 5.56 d?
483	O5 If	10.17	Constant.
465	O5.5 I(f)	9.12	Constant.
417 A	O4 III(f)	12.09	Constant.
462	O6.5 III(f)	10.41	Constant.
448	O6 V((f))	13.54	VARIABLE, P = 3.15 d?
480	O7.5 V	11.87	Constant.
455	O8 V	12.89	Constant.
390	O8 V	12.90	VARIABLE, irregular?
485	O8 V	12.07	Constant.
507	O8.5 V	12.68	Constant.
473	O8.5 V	12.02	Constant.
421	O9.5 V	13.02	ECLIPSING VARIABLE, P = 4.16 d.
470	O9.5 V	12.52	Constant.

[a]MT is the number from Massey & Thompson (1991).

Two short-period variables were, however, found among early B-type stars of the association. The first one is MT 487. It has a semi-amplitude of about 17 mmag in the I band. The I-filter data folded with the period of 0.25388 d are shown in Fig. 1. We do not know the spectral type of this star, but its position in the two-colour diagram corresponds to a highly-reddened early B star. The light-curve is slightly non-sinusoidal. No other period with semi-amplitude larger than 3 mmag was detected.

The other β Cephei candidate, MT 522, has a smaller semi-amplitude of about 4 mmag in the I band. The periodogram of our I-filter data clearly shows the presence of a periodicity of 0.21213 d, typical for a β Cephei star. There is an ambiguity in the value of the true period, because the peak corresponding to the alias period, 0.1751 d, is almost equally high. The phase diagram for the I-filter data is shown in Fig. 1.

5. Discussion

In general, our observations are consistent with the present predictions of the theory. As was already pointed out by Balona et al. (1997), the isochrones for ages shorter than about 7 Myr intersect the instability region twice: in the lower part of the instability strip, for masses of about 9-10 $M_{\odot}$, and then again for very massive stars, in the O-type star domain. In the case of Cygnus OB2, which is believed to be younger than 3 Myr, the late and mid-O stars lie outside the instability region. It could then happen that none of the observed O-type stars fall in the region where short-period variations in O-type stars are predicted.

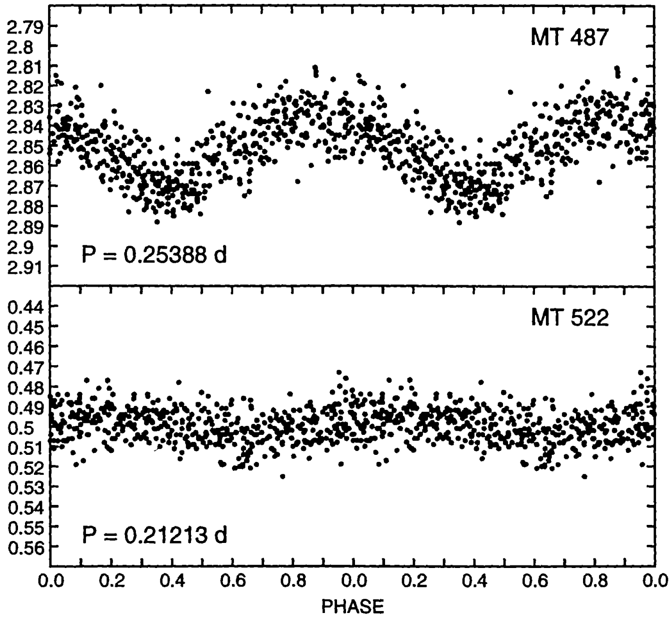

Figure 1. Phase diagrams for the differential I-filter data of the two β Cephei candidates, MT 487 (top panel) and MT 522 (bottom panel). The data were folded with periods shown in corresponding panels. Phase 0.0 was chosen arbitrarily. The ordinate is in mag.

This is difficult to verify since owing to calibration inaccuracies, it is extremely difficult to locate a given O-type star in the theoretical H-R diagram.

The problem with our β Cephei candidates is different. If they were of the same age as the whole association, i.e. less than about 3 Myr, their pulsation periods should amount to about 0.1 d, much less than observed. In order to match the observed and predicted periods, the age of the stars should be increased to at least 5 Myr. This, however, implies non-coeval star formation in the association, which seems to be quite possible. Note that Massey & Thompson (1991) already suggested non-coeval star formation in Cygnus OB2 association.

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