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Analysis of MERCATOR data - Part I: variable B stars

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Abstract

We re-classified 31 variable B stars which were observed more than 50 times in the Geneva photometric system with the P7 photometer attached to the MERCATOR telescope (La Palma) during its first 3 years of scientific observations. HD 89688 is a possible β Cephei/slowly pulsating B star hybrid and the main mode of the COROT target HD 180642 shows non-linear effects. The Maia candidates are re-classified as either ellipsoidal variables or spotted stars. Although the mode identification is still ongoing, all the well-identified modes so far have $\ell \leq 2$.

1. Introduction

The MERCATOR telescope is a 1.2-m telescope located on the Roque de los Muchachos observatory on La Palma (Spain). Since the start of scientific observations in spring 2001, this telescope has been intensively used to observe variable B, A and F main sequence stars with the P7 photometer, providing quasi-simultaneous observations in the 7 passbands of the Geneva photometric system. The first results obtained after 18 months of observations were already presented by De Cat et al. (2004) and De Ridder et al. (2004). We now present results after 3 years of collecting data. In Part I (this paper), the analysis of the 9023 datapoints of variable B stars is discussed while Paper II (Cuypers et al., these proceedings) focuses on the analysis of the 5149 datapoints of variable A and F stars.

We here restrict ourselves to the 31 variable B stars which were not included in multi-site campaigns and which were observed at more than 50 epochs. Based on the photometric observations gathered with the satellite mission HIPPARCOS, these objects were previously classified as candidate β Cephei stars (β Ceps; main-sequence B 0–3 stars pulsating in low order, low degree p/g-modes with periods of 3–8 h), slowly pulsating B stars (SPBs; main-sequence B 3–B 9 stars pulsating in high order, low degree g-modes with periods of 0.5–3 d) and Maia stars (Maias; variable main-sequence stars situated between the SPBs and the δ Scuti stars). They are respectively given with squares, triangles and stars in Fig. 1.

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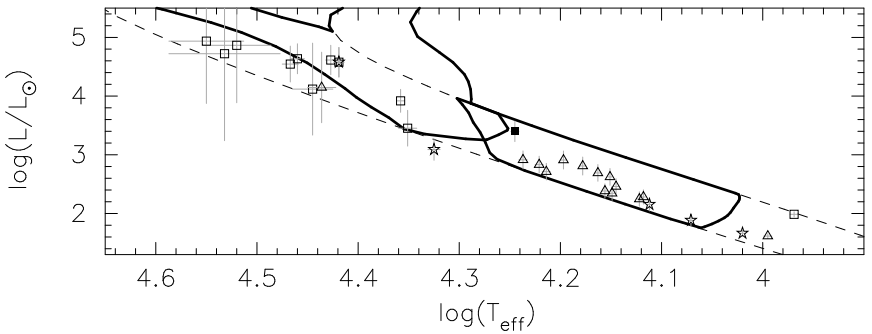

Figure 1: Position in the H-R diagram of the 31 variable B stars discussed in this paper. The candidate β Cephei stars, slowly pulsating B stars and Maia stars are given with squares, triangles and stars respectively. HD 89688 is given with a full symbol. The ZAMS and TAMS are given with dashed lines, and the theoretical instability strips for β Cephei and slowly pulsating B stars, as given by Pamyatnykh (1999), with full lines.

2. Frequency analysis

The time series in the Geneva passbands and colours were both subjected to a detailed frequency analysis with the PDM (Stellingwerf 1978) and Lomb-Scargle (Scargle 1982) methods. Since our ground-based data-sets suffer from strong aliasing, the space-based photometric observations of the HIPPARCOS satellite proved to be very useful to extract the physical frequencies in some cases. Our results enable us to re-classify the stars into the following categories by using the same criteria as De Cat et al. (2004):

- SPBs: 11 multiperiodic (HD 1976, 3379, 21071, 25558, 28114, 28475, 179588, 182255, 191295, 206540, 222555), and 2 monoperiodic (HD 138003, 208057)
- β Ceps: 6 multiperiodic (HD 13745, 13831, 14053, 21803, 180642, 203664)
- Hybrid star: HD 89688
- Spotted stars: HD 46005, 154689, 169820
- Ellipsoidal variables: HD 24094, 112396, 149881, 208727
- Be star: HD 180968
- Constant stars: HD 19374, 214680, 217782

For all the periodograms and phase diagrams, we refer to De Cat et al. (in preparation). For HD 89688, we now have *marginal* evidence for the SPB-like frequency 0.7965(6) d^{-1} (or one of its aliases), while the HIPPARCOS photometry points towards β Cep-like frequency 7.3902(5) d^{-1}. Its position in the H-R diagram is compatible with the classification as a hybrid star (full symbol in Fig. 1). For the multiperiodic COROT target HD 180642, the first mode is a high amplitude mode which shows non-linear effects. We detect up to the second harmonic of $\nu_1 = 5.486971(6)$ d^{-1}, making it only the second β Cep star for which more than one harmonic is observed (Aerts et al., in preparation). Note that for all the Maias, i.e. HD 46005, 154689, 169820, 208727, the observed variations are explained by mechanisms other than pulsations.

3. Mode identification

For the mode identification, we applied the method of the photometric amplitudes (Dupret et al. 2003) in which the observed and theoretical amplitude ratios relative to the amplitude

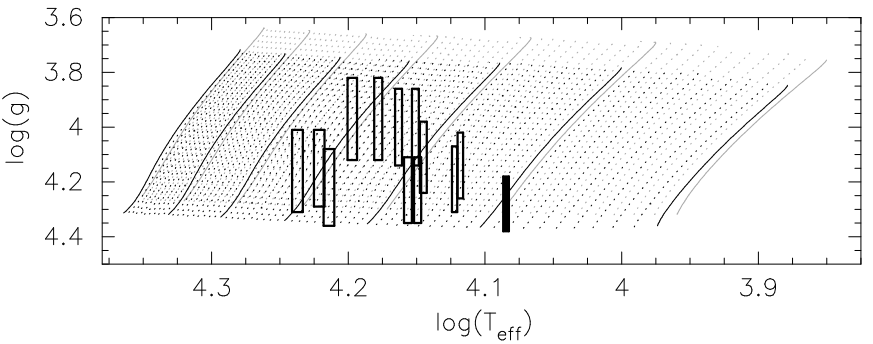

Figure 2: Presentation of the grids of equilibrium models used for the mode identification of the SPBs. The evolution tracks of grid 1 and 2 (see text) with masses between 2–8 $M_{\odot}$ in steps of 0.1 $M_{\odot}$ are respectively given in light and dark grey. The boxes represent the observed error boxes of the 13 SPBs in our sample. The filled box corresponds to HD 179588.

in the U filter are compared. For the SPBs, we confronted the results based on 2 grids of equilibrium models (Fig. 2). Grid 1 consists of models calculated with CLES-013 (written by R. Scuflaire) with an initial mass fraction of metals $Z_0 = 0.020$ and of hydrogen $X_0 = 0.70$, mixing-length $\alpha_{\rm conv} = 1.80$, and the standard metal mixture of Grevesse & Noels (1993). Grid 2 was obtained with CLES-018.2 with the 'new' solar values $Z_0 = 0.015$, $X_0 = 0.71$, $\alpha_{\rm conv} = 1.75$ and the standard metal mixture of Asplund et al. (2005). In both cases, we used the CEFF equation of state (Christensen-Dalsgaard & Däppen 1992) and a Kurucz atmosphere with the junction point at optical depth $\tau = 10$, and we assumed neither convective overshooting nor diffusion. One of the main changes between CLES-013 and CLES-018.2 is the use of the new value of the cross section of $^{14}N(p,\gamma)^{15}O$ recently measured by Formicola et al. (2004). We calculated the non-adiabatic eigenfunctions and eigenfrequencies for g-modes with $\ell \leq 3$ with the code MAD (written by M.-A. Dupret). For each star, we selected the models within the observed error box of $\log(T_{eff})$ and $\log g$ (boxes in Fig. 2), and selected the eigenfrequency which is the closest to the observed frequency to calculate the theoretical amplitude ratios. In Fig. 3, we give a representative example of our results, i.e. for the two main modes of HD 179588. Although there are significant differences in the position and/or the shape of the theoretical curves for the higher degree modes of grid 1 (left) and 2 (right), the identification of the modes remains the same, i.e. $\ell = 1$ or 2 for the mode corresponding to $\nu_1 = 0.856543(15)$ d^{-1} (top), and $\ell = 1$ for the mode corresponding to $\nu_2 = 2.04263(5)$ d^{-1} (bottom). In general, these differences coming from the use of 2 different grids increase for increasing values of the observed frequency. So far, all the well-identified SPB modes have $\ell = 1$ or 2. For the β Ceps, the mode identification is still ongoing.

4. Conclusions

Our photometric survey allowed a significant contribution to the classification of variable B stars. HD 89688 is a possible β Cep/SPB hybrid star and the COROT target HD 180642 is a multiperiodic β Cep star of which the main mode shows non-linear effects (Aerts et al., in preparation). Amongst the 31 targets with a sufficient amount of data, we identified 4 ellipsoidal variables and 4 spotted stars. Their classification should be checked by supplementary spectroscopic observations. The mode identification is still ongoing, but all well-identified

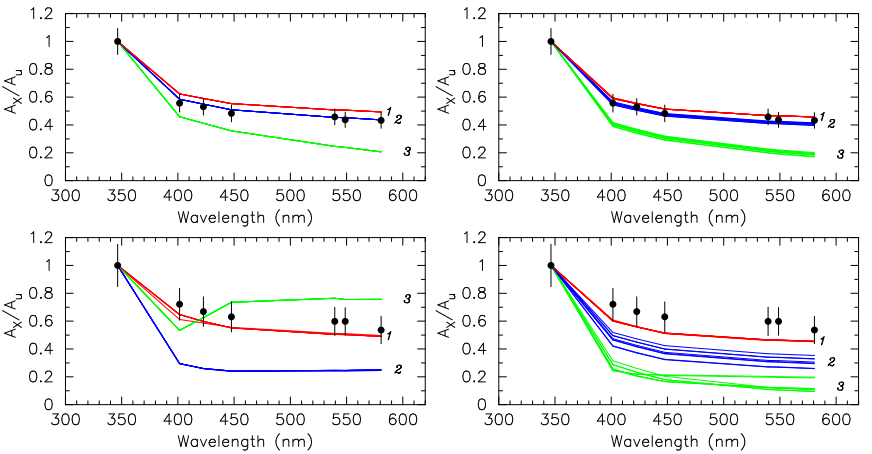

Figure 3: Photometric mode identification for $\nu_1 = 0.856543(15)$ d^{-1} (top) and $\nu_2 = 2.04263(5)$ d^{-1} (bottom) of HD 179588. For each theoretical model within the observed range of $\log(T_{eff})$ and $\log g$, the theoretical amplitude ratios for modes with $\ell = 1$ (full lines), 2 (dashed lines), and 3 (dotted lines) are represented with an individual line. The dots indicate the observed amplitude ratios and their standard error. The left and right panels show the results obtained with grid 1 and 2 respectively (see text).

modes have $\ell \leq 2$ so far.

The final results of our survey will be given by De Cat et al. (in preparation). The MERCATOR observations allow to take the first steps in asteroseismic modeling for two multiperiodic β Cep stars, i.e. HD 203664 (Aerts et al. 2006) and HD 21803 (Saesen et al., in preparation). For 12 Lac and V2052 Oph, the MERCATOR telescope was included in multi-site campaigns. The data of these objects are being analysed by Handler et al. (submitted to MNRAS) and Handler et al. (2006) respectively.

Acknowledgments. This work is based on observations collected with the P7 photometer attached to the MERCATOR telescope (La Palma, Spain). We are very much indebted to all the observers from Leuven University. CA and JC acknowledge support from the Fund for Scientific Research (FWO) - Flanders (Belgium) through project G.0178.02.

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Analysis of MERCATOR data - Part II: variable A & F stars

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Abstract

The results of a frequency analysis of photometric observations of variable A and F stars obtained with the MERCATOR telescope are presented. Already 15 γ Dor stars, including a new one, and 3 δ Scuti stars were analysed in detail. A re-analysis of HIPPARCOS data of these stars was done, as well as a comparison with frequencies found in the literature. Light curve parameters (frequencies, amplitudes and phases) were calculated for the variations in the 7 filters of the Geneva photometric system. The amplitude ratio diagrams of the γ Dor stars are very similar, with only few, but remarkable exceptions.

1. Introduction

The MERCATOR telescope is a 1.2-m telescope located on the Roque de los Muchachos observatory on La Palma (Spain). Since the start of scientific observations in the spring of 2001, this telescope has been intensively used to observe variable B, A and F main sequence stars with the P7 photometer, providing quasi-simultaneous observations in the 7 passbands of the Geneva photometric system. The first results obtained after 18 months of observations were already presented by De Cat et al. (2004) and De Ridder et al. (2004). We now present preliminary results after 3 years of collecting data. In Part I (De Cat et al. these proceedings) the analysis of the observations of the variable B stars is discussed. In Part II (this article) the analysis of variable A and F stars is presented, with emphasis on the pulsating γ Doradus stars, hereafter γ Dor stars (see Henry et al. (2005) for a class description and a recent list).

In total about 30 A and F stars were observed regularly. They were selected because they were already known as γ Dor stars, were flagged as variable in the HIPPARCOS catalogue, and/or were considered good candidate γ Dor stars (Handler 1999; Eyer and Aerts 2000). A few stars from other lists (Henry and Fekel 2002; Koen and Eyer 2002) were added as well. In the mean time, the γ Dor character of most of our targets (apart from a few δ Scuti stars) has been confirmed, and they are already listed as bona fide γ Dor stars by Henry et al. (2005). Hence, the main goal of our observations is to obtain well defined light curve parameters (frequencies, amplitudes, phases) in the 7 colours of the Geneva photometric system for all the observed variable stars. This allows the application of e.g. the method of photometric amplitudes (Dupret et al. 2003) to identify the pulsation modes.

2. Frequency analysis

The time series in the Geneva passbands were subjected to a frequency analysis with a multifrequency least squares method after a first inspection with other methods as PDM

Table 1: Overview of the γ Dor stars observed with the MERCATOR telescope and already analysed in detail (HD = HD number, SP = Spectral Type, N = number of observations used in the analysis, T = total time span of observations (in days), V = magnitude V, σ_v = standard deviation in filter V, N_f = Number of frequencies identified so far)

HD	SP	N	T	V	σ_v	N_f
277	F0	154	1148	8.365	0.022	3
2842	F0V	111	1149	7.987	0.023	3
7169	F2V	104	1149	7.280	0.012	2
23874	F0	93	1045	8.198	0.013	1
69715	F1	67	804	7.174	0.022	2
74504	F0	45	793	8.852	0.026	2
86358	F3V	103	804	6.468	0.015	4
100215	Am	173	838	7.982	0.019	4
105458	F0III	291	983	7.757	0.026	3
108100	F2V	196	980	7.116	0.012	2
113867	F0	167	946	6.825	0.028	3
167858	F2V	62	406	6.620	0.024	3
206043	F2V	89	768	5.765	0.010	3
211699	F0	104	1149	9.132	0.029	2
218396	A5V	103	1151	5.966	0.017	3
221866	F2V	146	1149	7.452	0.018	4

(Stellingwerf 1978) or Lomb-Scargle (Scargle 1982). Since our ground-based data-sets suffer from strong (daily) aliasing, we searched for confirmation of our frequency solution in the space-based photometric observations of the HIPPARCOS satellite. Whenever possible, we compared our results with the results published in the literature.

2.1 γ Doradus stars

In Table 1 we list the γ Dor stars that have a sufficient number of high quality observations (at least 40) spread over a reasonably long interval (minimal 400 days) to allow a meaningful frequency analysis. Observations with a quality flag zero were not included, although for some stars their number is rather high. These observations can still be useful to extract information on multiperiodicity, but this will be elaborated further in a forthcoming paper.

The number of frequencies as given in Table 1 is to be considered as a first estimate. In several cases more frequencies can be identified if a comparison is made with HIPPARCOS and/or other ground-based data. Since this has not yet been done for every star in the list, the number given is a lower limit.

HD 74504 is a new γ Dor star. Koen and Eyer (2002) re-analysed the HIPPARCOS data of this F0 star and found a frequency of 1.9058 d^{-1}. In the MERCATOR data of this star at least two frequencies are identified: 1.9057d^{-1} and 1.8210 d^{-1}. Moreover, since the combination of 1.9058 d^{-1} and 1.8212 d^{-1} is also one of the best two-frequencies solutions in the HIPPARCOS data, we classify this star a bona fide γ Dor star. A candidate for a third frequency in this star is 1.2564 d^{-1}. A diagram with the amplitude ratios normalised to the highest amplitude (i.e. in the filter B1 of the Geneva system) is shown in Fig. 1. The observed 'plateau'-like shape near the B filters is also present in the amplitude ratios of HD 218396. For most of the other γ Dor stars, the amplitude ratio curves resemble those of HD 100215 shown in Fig. 2.

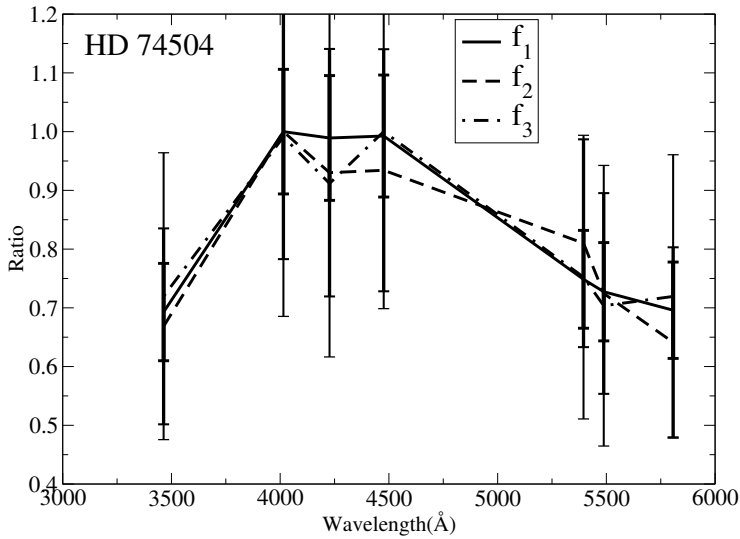

Figure 1: Amplitude ratios (normalised to the amplitude in filter B1 of the Geneva system) for HD 74504.

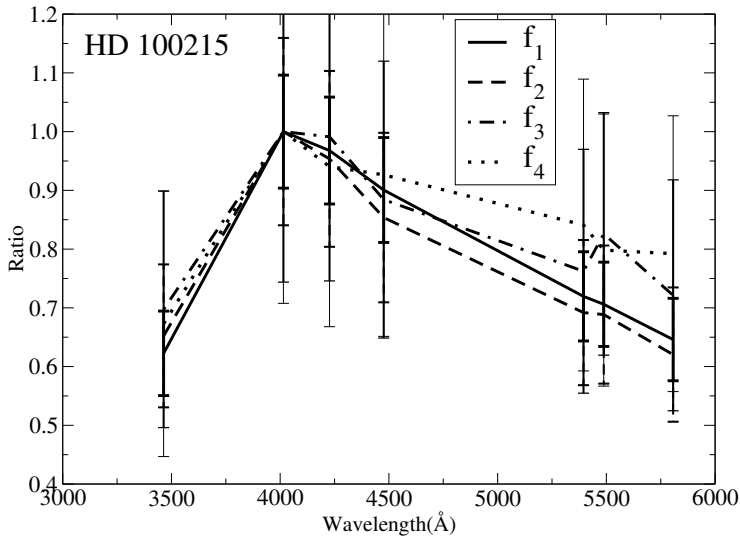

Figure 2: Same as Fig. 1 but for HD 100215.

2.2 δ Scuti stars

The stars HD 94117 (F2, $V = 7.01\,mag$) and HD 104573 (A5, $V = 8.14\,mag$) are most probably δ Scuti stars. HD 94117 was not known as a δ Scuti star and has at least two frequencies: $6.2738\,\mathrm{d}^{-1}$ and $7.9066\,\mathrm{d}^{-1}$. HD 104573 has been presented before (De Ridder et al., 2004).

3. Conclusions

Thanks to the continuous monitoring during several years, well defined and accurate light curve parameters in the 7 filters of the Geneva photometric system were obtained with the MERCATOR telescope. At least one new γ Dor star (HD 74504) had been discovered and also one multiperiodic δ Scuti star (HD 94117) was found.

For about 15 γ Dor stars reliable amplitudes were obtained for their multiperiodic light variations. The graphs with amplitude ratios as a function of wavelength all look very similar, except that in a few cases the amplitudes do no drop off very steep after the B1 filter. The results of a complete analysis of the whole data set will be presented in a forthcoming paper. The mode identification for these stars will start soon.

Acknowledgments. This work is based on observations collected with the P7 photometer attached to the MERCATOR telescope (La Palma, Spain). We are very much indebted to all the observers from Leuven University. We acknowledge support from the Fund for Scientific Research (FWO) - Flanders (Belgium) through project G.0178.02. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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