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Observational results for northern and southern (candidate) γ Doradus stars

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Abstract. We report on observational results obtained for 78 objects originally classified as bona-fide or candidate γ Doradus stars. For the southern objects, we gathered echelle spectra with the CORALIE spectrograph attached to the Euler telescope in 1998–2003 and/or Johnson-Cousins B, V, I_c observations with the MODULAR photometer attached to the 0.5-m SAAO telescope in 1999–2000. For the northern objects, we obtained Geneva $U, B, B_1, B_2, V, V_1, G$ observations with the P7 photometer attached to the 1.2-m Mercator telescope in 2001–2004. At least 15 of our objects are binaries, of which 7 are new. For 6 binaries, we determined the orbit for the first time. At least 17 objects show profile variations and at least 12 objects are multiperiodic photometric variables. Our results allow us to upgrade 11 objects to bona-fide γ Doradus stars and to downgrade 8 objects to constant up to the current detection limits. Mode identification is still ongoing, but so far, only $\ell = 1$ and 2 modes have been identified.

Key words. Stars: variables: general – Stars: oscillations – Line: profiles

1. Introduction

γ Doradus (γ Dor) stars are variable late A- to early F-type stars situated along the main-sequence. Their observed multi-periodic variations with typical periods between 0.5 and 3 days are attributed to non-radial g-modes driven by a flux blocking mechanism at the base of the convective envelope (e.g. Dupret et al. 2004). Currently, there are 54 bona-fide, 104 candidate and 15 rejected γ Dor stars known (Handler 2002; Henry & Fekel 2002, 2003; Fekel & Henry 2003; Mathias et al. 2004; Henry & Fekel 2005; Henry et al. 2005). We contribute to the observational effort which is made in recent years to classify γ Doradus stars in order to further constrain both their characteristics and their instability strip in the HR diagram.

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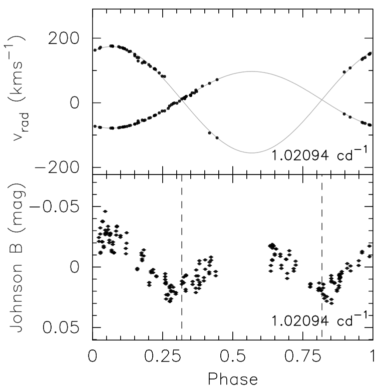

Fig. 1. Phase diagram of the radial velocity $v_{\rm rad}$ (top) and the Johnson B measurements (bottom) of HD 81421 with the orbital frequency as given in the bottom right corner. The reference epoch is HJD 2450000. The dashed lines in the bottom left panel denote the phase at which $v_{\rm rad} = v_\gamma$.

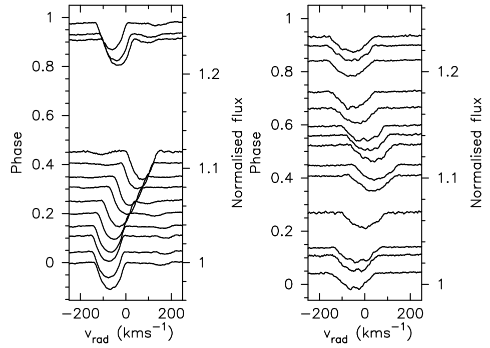

Fig. 2. Selection of observed cross-correlation profiles are shown as a function of orbital phase for HD 81421 (left) and HD 209295 (right).

2. Data

For a sample of 36 southern objects, we gathered a total of 620 echelle spectra during 28 weeks in 1998–2003 with the CORALIE spectrograph attached to the 1.2-m Euler telescope (La Silla, Chile). We cross-correlated them with the standard template of an F0-type star to derive accurate radial velocities. For another sample of 37 southern objects, of which 28 are in common with the spectroscopic survey, we obtained a total of 3913 photometric observations in the Johnson-Cousins B, V, I_c filters during 15 weeks in 1999–2000 with the 0.5-m SAAO telescope (Sutherland, South-Africa). For a sample of 36 northern objects, we obtained a total of 3878 photometric observations in the Geneva $U, B, B_1, B_2, V, V_1, G$ filters during more than 80 weeks in 2001–2004 with the 1.2-m MERCATOR telescope (La Palma, Spain).

3. Orbital variations

At least 15 of our 36 spectroscopic targets are binaries, giving a binarity rate of $> 40\%$. We detected 7 new binaries and 11 double-lined systems. For 9 binaries, we determined the orbit, including 4 ellipsoidal variables. HD 81421 is one of them, which was classified as a monoperiodic γ Dor star before (Martín et al. 2003). However, the photometric period turns out to be half of the orbital period. As shown on Fig.1, the phases of minimum light coincide with the phases of γ velocity at the epoch of our data. For this object, there is no evidence for pulsations since no intrinsic variations are observed in the cross-correlation profiles (CCPs; Fig.2, left). For the other 5 binaries with a known orbit, none of the known photometric periods is connected to the orbital period. We classify them as binaries with a (candidate) γ Dor component. One of them is HD 209295, for which we confirm 4 of the known frequencies in the cross-correlation profile variations (CPVs; Fig.2, right). For the remaining 6 binaries, our current data-set can only be used to estimate the time-scale of the orbit.

4. Intrinsic variations

For 17 of our 36 spectroscopic targets (i.e. $\sim$45%), CPVs are observed (cfr. Fig. 2, right panel). For 8 objects, the main spectroscopic period clearly coincides with the main period known from the HIPPARCOS photometry. However, for some of them, there is no evidence for the same period in our Johnson data. For 4 objects, none of the known periods from photometry is present in the observed spectroscopic variations. One of them is γ Dor itself, for which we find a δ Scuti period instead

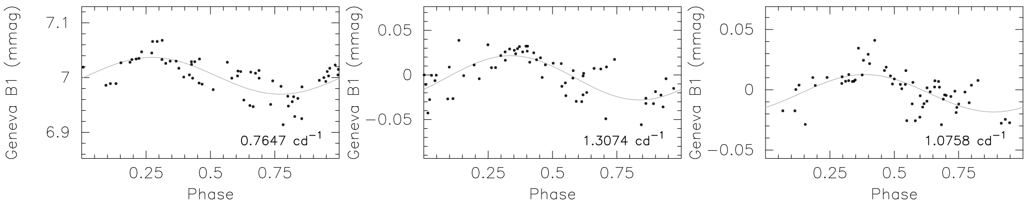

Fig. 4. Phase plots with f_1 (left), f_2 (middle) and f_3 (right) of HD 167858. The reference epoch is HJD 2450000.

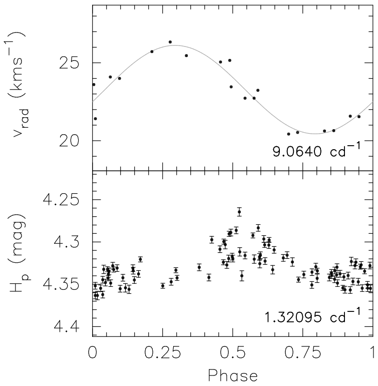

Fig. 3. Phase diagram of the best frequency found in the radial velocity v_{rad} (top) and the main frequency in the HIPPARCOS data (bottom) of γ Dor. The reference epoch is HJD 2450000.

(Fig. 3). Clearly, more data is needed to confirm or reject this result. For the remaining 5 objects showing CPVs, our current data-set is insufficient to check the consistency between the spectroscopic and photometric variations.

Multiperiodicity is another indication of pulsation. At least 12 of our objects show multiperiodic variations in spectroscopy and/or photometry. In Fig. 4, phase-diagrams with $f_1 = 0.7647$ c d^{-1}, $f_2 = 1.3074$ c d^{-1} and $f_3 = 1.0758$ c d^{-1} of HD 167858 are given. f_3 was not known before.

By using these criteria in combination with information found in the literature, we upgrade 11 objects to bona-fide γ Dor stars. On the other hand, 8 objects are downgraded to rejected γ Dor star because we see neither intrinsic CPVs nor periodic variations in photometry (see Table 1).

5. Mode identification

For the mode identification, the method of the photometric amplitude ratios is used (Dupret et al. 2003). For 14 objects with more than 100 Geneva datapoints, the amplitudes of the variations with the observed frequencies were calculated. Since the amplitudes in the B_1 filter are generally the biggest, we used this filter as a reference to calculate the observed amplitude ratios and compare them with theoretical amplitude ratios. The latter are obtained by performing non-adiabatic pulsation calculations with the code MAD, which was recently upgraded to take time-dependent convection into account (written by M.-A. Dupret), on equilibrium models calculated with the evolution code CLES (written by R. Scuflaire). A representative example is given in Fig. 5, in which we show the results for HD 167858 (see example Sect. 4). In this case, the observed amplitude ratios are best fitted with an $\ell = 2$,1 and 1 mode for f_1, f_2 and f_3 respectively. Although the mode identifcation and the subsequent modelling is still ongoing (De Ridder & Dupret, in preparation), we only identified $\ell = 1$ and 2 modes so far.

6. Conclusions and future prospects

A summary of our main results is given in Table 1 where the stars with a changed orbital and/or variability classification are listed. The full results of the CORALIE, MODULAR and P7 observations are given by De Cat et al. (submitted to A&A), Eyer et al. (in preparation) and Cuypers et al. (in preparation). Because the exploitation of dynamical information can give additional and independent constraints on physical properties of the components, we will

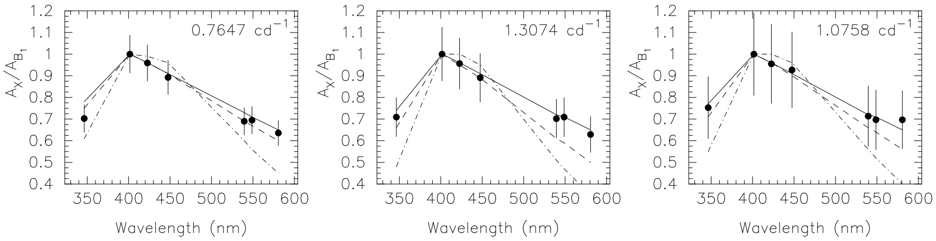

Fig. 5. Comparison of the observed amplitude ratios (filled circles with error bars) and theoretical amplitude ratios for $\ell = 1$ (full line), 2 (dashed line) and 3 (dashed-dotted line) modes for f_1 (left), f_2 (middle) and f_3 (right) of HD 167858.

Table 1. Overview of the obital and variability classification of the 11 upgraded bona-fide and 8 downgraded rejected γ Dor stars, the 7 new binaries (underlined), the 6 binaries with new orbits (indicated with *), the 10 detected double-lined systems (*italics*) and the 3 suspected binaries.

	bona-fide	candidate	rejected
single	HD 14940, HD 40745, HD 41448, HD 112685, HD 135825, HD 149989, HD 187025, HD 216910, HD 218225, HD 211699		HD 7455, HD 22001, HD 33262
suspect		HD 111829, HD 26298	*HD 27604*
SB1		HD 126516*	HD 85964*
SB2	*HD 34025**	HD 10167*, *HD 27377*[1], *HD 35416* *HD 111709*[1,2], *HD 147787*, *HD 214291**	*HD 5590*, *HD 8393*, *HD 81421**

[1] ellipsoidal variability instead of pulsation can not be ruled out
[2] shows cross-correlation profile variations but was classified as chemically peculiar star before

give priority to binaries with a bona-fide or candidate γ Dor star in future investigations.

Acknowledgements. This work is based on observations collected with the CORALIE spectrograph, MODULAR photometer and P7 photometer respectively attached to the Euler Telescope (La Silla, Chile), the 0.5-m SAAO telescope (Sutherland, South-Africa), and the Mercator telescope (La Palma, Spain). We are very much indebted to all the observers. We acknowledge support from the Fund of Scientific Research (FWO) - Flanders (Belgium) through project G.0178.02.

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