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Radial velocity monitoring of (candidate) hybrid A- and F-type stars from the *Kepler* mission

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Abstract

An ensemble of 50 candidate hybrid A/F-type stars from the *Kepler* mission was monitored during four years with the Hermes spectrograph attached to the Mercator telescope. From this survey, we obtained new radial velocities, new or improved atmospheric properties ($T_{\rm eff}$, $\log g$, $v \sin i$), and classified all our targets in terms of evidence for multiplicity, pulsation and/or fast rotation. An extension of 40 new candidate hybrid A- and F-type stars from the *Kepler* mission has been recently defined for a second survey to be performed under similar conditions. The new high-resolution spectra will be obtained with various small and medium-sized telescopes. For a number of newly detected stellar systems with good radial velocity coverage, we computed much improved orbits by combining the radial velocities with the time delays obtained via the monitoring of the pulsation frequencies during the four years of *Kepler* photometry.

1 Introduction

In a spectroscopic study of 30 candidate SX Phe stars, Nemec *et al.* (2017) found evidence of radial velocity variability for approximately half of the sample, as well as of membership to star systems in one third of the cases. In a previous study, Lampens *et al.* (2018) derived a multiplicity fraction of about 30% in a sample of 50 *Kepler* candidate hybrid pulsators. At first sight, this observed fraction is not different from other studied samples. So, why is it important to find out whether a hybrid pulsator belongs to a binary or multiple system or not? First, the origin of the detected low frequencies can be very diverse: the presence of the low frequencies could be due to a(n) (sometimes not yet understood) excitation mechanism, rotational variability (caused by spots), plain binarity (e.g. a γ Dor star with a δ Scuti pulsator), ellipsoidal variability (caused by tidal distortion) or tidal excitation in a close binary system (caused by tidal interaction in combination with resonance effects). The hotter hybrid pulsators are not predicted from a theoretical point-of-view (Grigahcène *et al.*, 2010; Balona *et al.*, 2015). Secondly, in the case of a pulsator in a system for which tidal forces are important, the pulsations will be affected by the tides and changes may occur with respect to the mode amplitudes, phases and/or the frequencies and their spacings (Reyniers & Smeyers, 2003; Balona, 2018). For an asteroseismologist, it matters whether the (hybrid) pulsator is in a binary or multiple system or not.

2 Method

We use the technique of the radial velocity measurement. The acquisition of the high-resolution spectra over a few years is performed with échelle spectrographs located in different observatories: the Hermes spectrograph at La Palma, Spain (Raskin *et al.*, 2011), the ACE spectrograph at Piszkès-tetö Observatory, Hungary (Derekas *et al.*, 2017), the TCES (Tautenburg Coudé Echelle Spectrograph) of the Thüringer Landessternwarte, Tautenburg, Germany (www.tls-tautenburg.de) and the OES (Ondřejov Echelle Spectrograph) of the Ondřejov Observatory, Czech Republic (Koubský *et al.* (2004); Kabáth et al. 2018, in preparation).

In the first survey, we performed a multi-epoch spectroscopic study of 49 A/F-type candidate hybrid stars and one extra target classified as δ Scuti star from the *Kepler* mission (cf. Table 3 in Uytterhoeven *et al.*, 2011). We classified our targets on the basis of their (constant versus variable) behaviour in radial velocity (RV) and the shape of the cross-correlation functions over a period of four years. Both short- and long-period systems were found, i.e. 4 single-lined (SB1), 4 double-lined (SB2) and 3 triple-lined (SB3) systems. We derived ten orbital solutions for seven new systems. Interestingly, we found a fraction of 27% of spectroscopic binarity/multiplicity among our sample of candidate hybrid stars (Lampens *et al.*, 2018). This is in full agreement with Nemec *et al.* (2017) who found 33% of binary and multiple systems in their sample of SX Phe stars. In addition, we performed a search for time-delay variations based on the *Kepler* data and detected variability of the time delays in nine cases, six of which are also spectroscopic systems.

To define a new sample of A/F-type candidate hybrid stars, we re-analysed all the *Kepler* targets with $T_{\rm eff}$ in the range [5 500-10 000] K. After pre-processing and computing of the Fourier transform (Sódor, Bognár & Skarka, in preparation), their light curves and Fourier transforms were visually inspected. All the objects showing at least 2-3 significant and independent peaks in the [0-10] d^{-1} and in the [> 10] d^{-1} frequency ranges were selected. The final step consisted in i) applying the magnitude criterion of Kp < 10.5 mag, ii) removal of objects from the first sample and iii) removal of (already) studied stars (using the reference list of the Simbad database). The second sample contains 40 candidate hybrid stars.

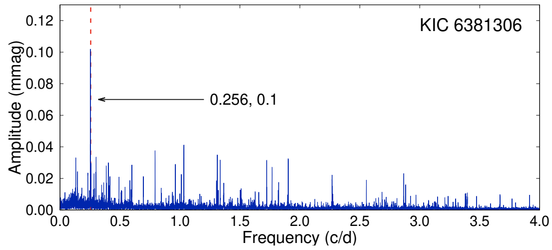

Figure 1: The [0-4] d^{-1} region of the periodogram of KIC 6381306 (based on the *Kepler* data).

3 Some recent results and figures

The hybrid pulsator and triple system KIC 6381306. Whereas multiple frequencies populate the low-frequency region of the periodogram, we found that the most dominant frequency in this region corresponds to the orbital frequency (Fig. 1). The star belongs to a triple system (SB3), with orbital periods of 3.911 days (f = 0.256 d^{-1} for the inner orbit) and 212.2 $\pm$ 0.3 days (for the outer orbit). This identification confirms the presence of additional frequencies in this case, and is a valuable piece of information in order to determine and understand the physical content of the periodogram (including the pulsation frequencies).

The hybrid pulsator and triple system KIC 4480321. The orbital motion of a binary system with a pulsating component induces periodical changes in the pulsation frequencies due to the variable light-travel time. Hence, the phases of the (pulsation) frequencies shift over the orbit. These shifts correspond to the time delays. KIC 4480321 is a triple system (SB3) with orbital periods of 9.166 days (for the inner orbit) and 2385 $\pm$ 11 days (for the outer orbit). We detected a long-term variation of the time delays. Since the radial velocity is given by the (time) derivative of the time delays, a combined analysis of the photometric time delays with the radial velocities is both feasible and promising. An illustration of the power of such an analysis is demonstrated in Fig. 2. Both the time delays and the radial velocities are plotted. The shape of the time-delay curve resembles that of the radial velocity, though with an apparently larger eccentricity and periastron longitude (Irwin, 1952). For more information on this technique, see, for example, the papers by Murphy & Shibahashi (2015) and Shibahashi *et al.* (2016). The advantages of such analysis are obvious. On the one hand, we may derive a far better determination of the mass ratio if the pulsating component is an intermediate or rapid rotator; on the other hand, we may identify the source of the pulsations by comparing the solutions where the time delays are associated to each individual RV curve. The improved (outer) orbital parameters will be published in a forthcoming paper.

4 Objectives and conclusion

- Our first objective is to characterize the spectroscopic variability of a large sample of *Kepler* hybrid (γ Dor - δ Sct/δ Sct - γ Dor) pulsators. We need 4-6 observations at least to be able to detect the presence of the companion(s) (or to present evidence for binarity or multiplicity) at different orbital periods ranging from a few days up to a few years, and to establish a meaningful classification and interpretation of the observed changes (see e.g. the new detections illustrated by Figs. 3 and 4). We also aim to determine the orbital periods and solutions for the (new) binary and multiple systems based on well-sampled phase curves.

- The photometric time delays obtained from the *Kepler* light curves in combination with the radial velocities obtained from the long-term monitoring from the ground provide the long time base needed for an accurate determination of the orbital parameters. These in turn allow to derive the fundamental properties of the components (such as the mass or the mass function). In addition, we may be able to identify the pulsating component(s).

- Together with the improved atmospheric parameters and $v \sin i$, our study provides fundamental knowledge for an asteroseismic modelling of these intriguing pulsators. With such complementary information, detailed Fourier analyses of the *Kepler* light curves of (some of) the newly reported systems are required (foreseen). A full and accurate characterization of the hybrid pulsators is necessary in order to distinguish between the genuine hybrid stars and those where other mechanisms (might) operate (including the eccentric systems with tidally excited gravity modes).

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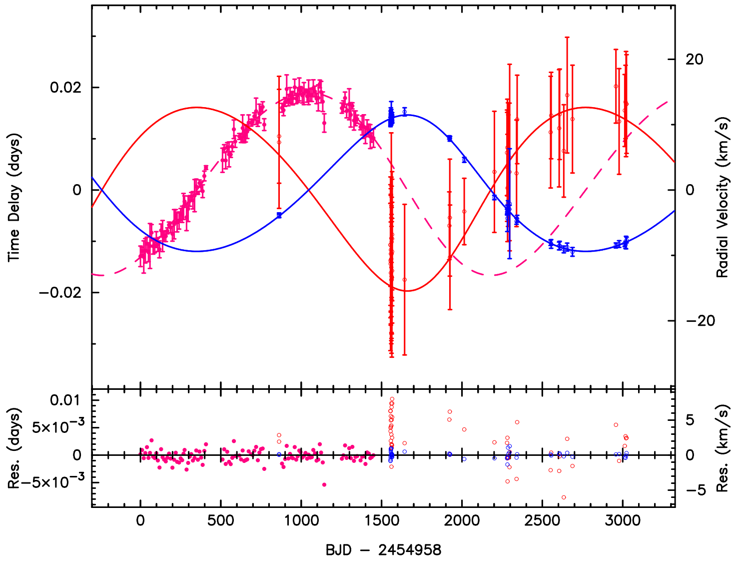

Figure 2: Combined solution based on the time delays from the *Kepler* photometry and the HERMES radial velocities. The time delays (pink symbols) and the radial velocities (red symbols for component C; blue symbols for components A and B (corrected)) are overlaid with the AB-C orbital solution (solid lines).

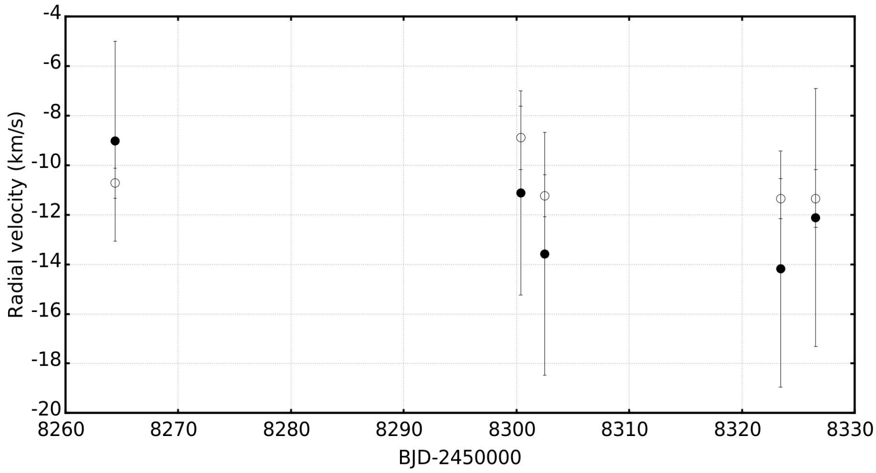

Figure 3: Detection of the variable radial velocity of the *Kepler* hybrid target KIC 1571152. Filled symbols refer to the primary component. Unfilled symbols refer to the secondary component. An uncertainty is attached to each value.

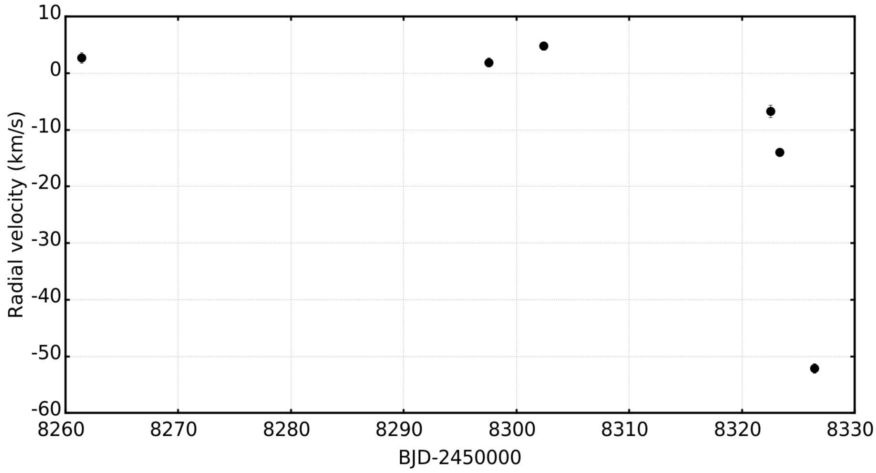

Figure 4: Detection of the variable radial velocity of the *Kepler* hybrid target KIC 6279848. Filled symbols refer to the primary component. The uncertainties are hardly detectable (order of the symbol's size).