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

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Abstract

We monitored an ensemble of 50 candidate hybrid A/F-type stars from the *Kepler* mission with the HERMES spectrograph attached to the Mercator telescope over a period of four years. For each target, we obtained radial velocities, improved or new atmospheric properties ($T_{\rm eff}$, log g, v sin i), and a classification in terms of multiplicity, pulsation and/or fast rotation (LA18). Recently, a sample of 40 additional candidate hybrid A- and F-type stars from the *Kepler* mission has been identified as an extension of the first survey. High-resolution spectra of the hybrid candidate stars are systematically collected with small and medium-sized telescopes. Furthermore, by combining the radial velocities with the time delays obtained via the study of the pulsation frequencies during the four years of *Kepler* photometry, we obtained accurate orbits for a number of new stellar systems with good radial velocity coverage.

Astrophysical rationale

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 an (in some cases unexplained) 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 explained from a theoretical point-of-view (GR10, BA15). 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 (RS03, BA18). For an asteroseismologist, it matters whether the hybrid pulsator is in a binary or multiple system or not.

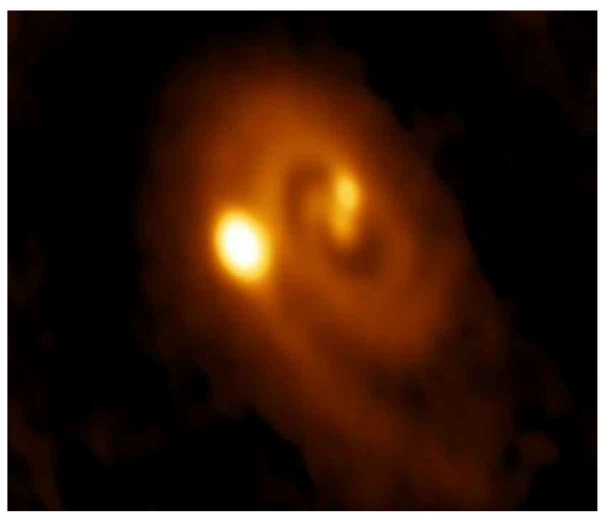

Fig. 1. The mechanisms of stellar formation explain why a vast majority of stars belongs to double and multiple star systems (Tobin, Univ. Oklahoma/Leiden et al.) © B. Saxton, ALMA (ESO/NAOJ/NRAO), NRAO/AUI/NSF

Instruments and spectroscopic observations

The acquisition of the high-resolution spectra over a few years is/will be performed with échelle spectrographs located in different observatories: the HERMES spectrograph at La Palma, Spain (RA11), the ACE spectrograph at Piszkés-tető Observatory, Hungary (DE17), and the spectrograph of the Thüringer Landessternwarte, Tautenburg, Germany (www.tls-tautenburg.de).

Fig.2. The Mercator telescope is located at the observatory Roque de los Muchachos, La Palma (Canary Islands, Spain). Equipped with HERMES, it offers high-efficiency and high-resolution spectroscopy to all the partners of the HERMES Consortium.

The first survey

In the first survey, we performed a multi-epoch spectroscopic study of 49 A/F-type candidate hybrid stars and one target classified as δ Scuti star from the *Kepler* mission (cf. Table 3 in UY11). We classified our targets on the basis of their (constant vs variable) behaviour in radial velocity 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 computed orbital solutions for seven systems. Interestingly, we found a fraction of 27% of spectroscopic binarity/multiplicity among our sample of candidate hybrid stars (LA18), in agreement with Nemec et al. (2017) who found 33% of binary/multiple systems in their sample of SX Phe stars.

References

Balona et al. 2015, MNRAS 452, 3073 (BA15)
Balona 2018, MNRAS 476, 4840 (BA18)
Derekas et al. 2017, MNRAS 464, 1553 (DE17)
Grigahcène et al. 2010, ApJ 713, L192 (GR10)
Lampens et al. 2018, A&A 610, A17 (LA18)
Nemec et al. 2017, MNRAS 466, 1290 (NE17)
Raskin et al. 2011, A&A 526, A69 (RA11)
Reyniers & Smeyers 2003, A&A 404, 1051 (RS03)
Uytterhoeven et al. 2011, A&A 534, A125 (UY11)

Previous and new targets

- 1. The hybrid pulsator 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. 3). The star belongs to a triple system (SB3), with orbital periods of 3.91 days (f = 0.256 d^{-1} for the inner orbit) and 212.2 ± 0.3 days (outer orbit). This identification is a valuable piece of information in order to determine & understand the physical content of the stellar pulsations from the periodogram.

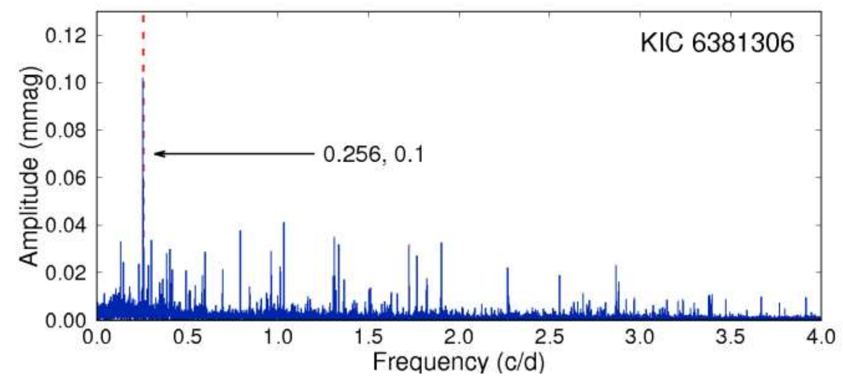

Fig3. The [0-4] d^{-1} region of the periodogram of KIC 6381306 (based on *Kepler* data)

- 2. The hybrid pulsator 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 are the time delays. KIC 4480321 is a triple system (SB3) with orbital periods of 9.166 days (inner orbit) and 2385 ± 11 days (outer orbit). We detected a long-term variation of the time delays. Since the radial velocity is the derivative of the time delay, a combined analysis of the photometric time delays with the radial velocities is feasible and advantageous (Fig. 4).

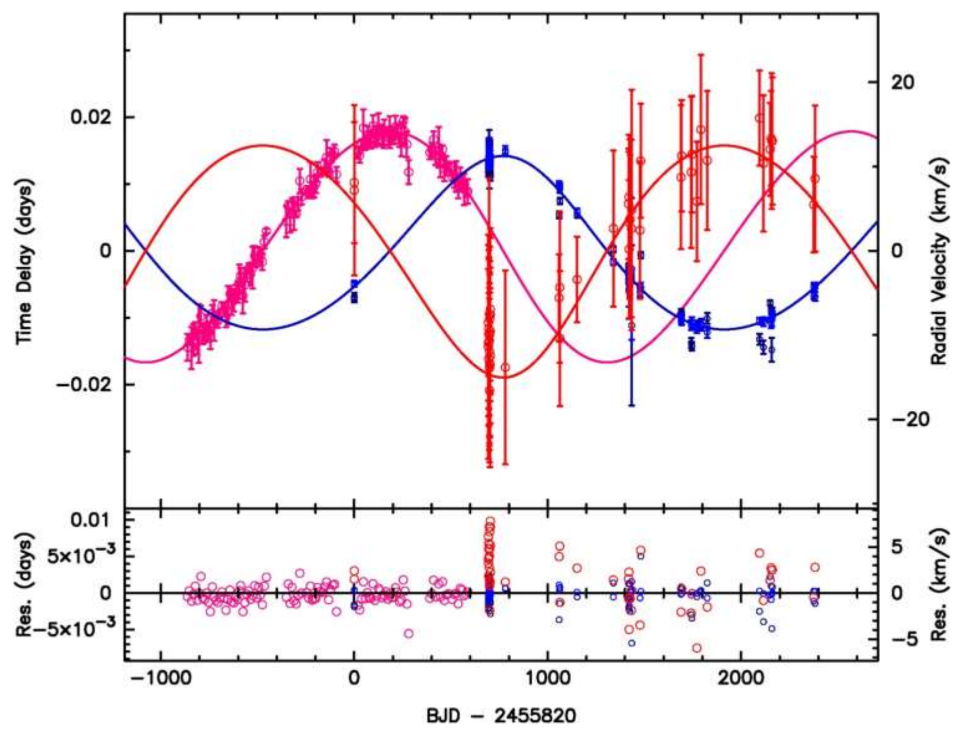

Fig. 4. A powerful combination: photometric time delays and radial velocities (KIC 4480321). The time delays (in pink) and the radial velocities (comp. C in red; comp. A & B in blue) are overlaid with the orbital solution (solid lines).

- 3. The new sample of A/F-type candidate hybrid stars is based on a re-analysis of all *Kepler* targets with $T_{\rm eff}$ in the range [5500-10000] K. After pre-processing and computing of the Fourier-transform, their light curves and Fourier transforms were visually inspected. All the objects showing at least 2-3 independent, significant peaks in the [0-10] d^{-1} and in the [larger than 10] d^{-1} frequency ranges were selected. The final step consisted in i) applying the magnitude limit of Kp < 10.5 mag, ii) removal of objects from the first sample and iii) removal of (well) studied stars (cf. Simbad). Our new sample contains 40 cand. hybrid stars.

Objectives & Summary

- 1. The goal is to characterize the spectroscopic variability of a large sample of *Kepler* hybrid (γ Dor - δ Sct/δ Sct - γ Dor) pulsators. We need 4-5 observations at least (Fig. 5) to be able to detect binarity/multiplicity at very different orbital periods, up to a few years, and to establish a meaningful classification/interpretation. We also aim to determine the orbital periods and solutions for the new binary and multiple systems with sufficient and good phase coverage.

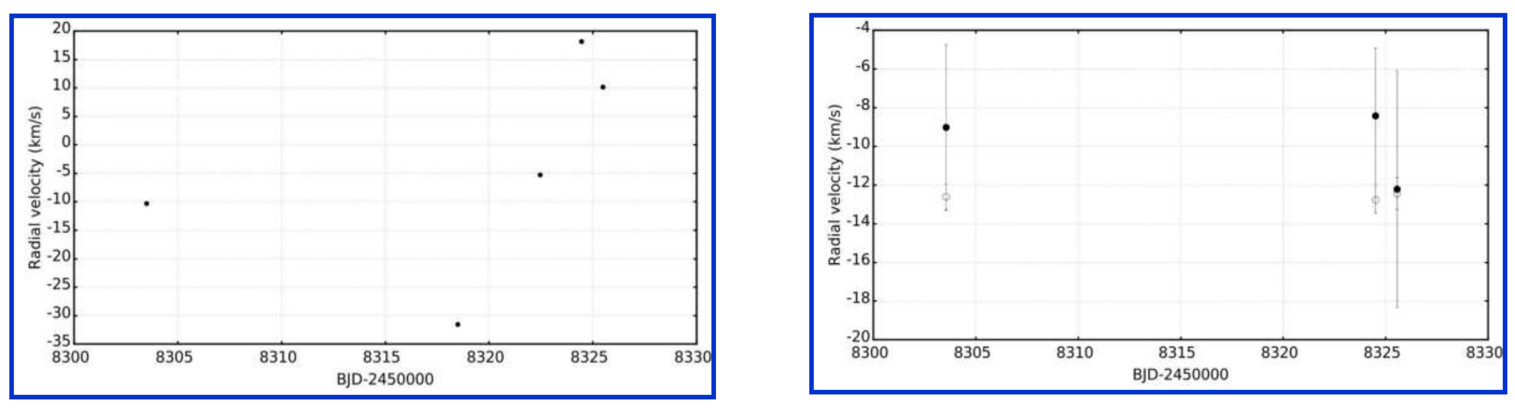

Fig. 5. Measurements of the radial velocity for 2 new *Kepler* hybrid stars

- 2. 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. In addition, we may be able to identify the pulsating component(s).These in turn allow to derive the fundamental properties of the components (such as the mass or mass function). Together with the improved atmospheric parameters and v sin i, our study provides basic knowledge for a future asteroseismic modelling of these interesting pulsators.

- 3. A full and accurate characterization of the hybrid pulsators is necessary in order to distinguish between the genuine hybrid cases and those where other mechanisms operate (including also tidally excited gravity modes).

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