The spectroscopic multiplicity fraction in a sample of (candidate) hybrid A- and F-type stars from the *Kepler* mission

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Abstract

By means of a long-term spectroscopic study based on multi-epoch, high-resolution spectra for 83 A/F-type candidate hybrid pulsating stars from the *Kepler* mission, we derive a lower estimate of the fraction of hybrid stars that belong to spectroscopic binary and multiple systems. For the first sample (49 hybrid stars), we derived a global spectroscopic multiplicity fraction of 27%. Currently, we are investigating a second sample containing 46 candidate hybrid stars. From a preliminary classification based on 34 hybrid stars, we derive a spectroscopic multiplicity fraction of at least 25%. Spectroscopic observations are still on-going. We furthermore identified several systems for which a combined analysis of Time Delays (TDs) with Radial Velocities (RVs) allows to derive precise orbital elements, accurate mass ratios as well as an identification of the pulsating component(s). For some targets, we also analyse the low-frequency region of the periodograms based on the rich data sets from the *Kepler* mission. *Finally, we present the distribution of the observed orbital periods for the new spectroscopic systems.*

Why is this important?

In a study of 30 candidate SX Phe stars, NE17 found evidence of membership to star systems in one third of the cases. In a previous study, LA18 derived a multiplicity fraction of ~30% in a sample of 49 *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), though Xiong et al. (2016) reported new results. 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). **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 operate (e.g. tidally excited gravity modes).

Spectroscopic observations

Our goal is **to characterize the spectroscopic variability** of an unbiased sample of *Kepler* hybrid (γ Dor - δ Sct) pulsators. We need 4 - 6 observations (at least) to be able to detect binarity or multiplicity at the different time scales, with orbital periods ranging from a few days to several years, and to establish a meaningful classification. We aim to determine the orbits for the systems with good phase coverage. The acquisition of the spectra was and is performed with telescopes equipped with échelle spectrographs at the following sites: HERMES, La Palma, Spain (RA11); ACE spectrograph, Piszkés-tető Observatory, Hungary (DE17); TCES, Thüringer Landessternwarte, Tautenburg, Germany (www.tls-tautenburg.de); OES, Ondřejov Observatory, Czech Republic (Kabáth et al. 2018) and the échelle spectrograph, Observatorio Astronómico Nacional, San Pedro Mártir, México.

The spectroscopic multiplicity fraction

We completed an extensive study of a first sample from the *Kepler* mission (49 A/F-type bona fide hybrid stars and one much cooler hybrid object from Table 3 in UY11). We identified 10 spectroscopic systems (3 single-lined or SB1, 4 double-lined or SB2, 3 triple-lined or SB3) and 3 objects with long-term RV variations (VAR). Two other hybrid stars have a possible companion or shell (CMP). Including the known *Kepler* eclipsing binary, we find a global multiplicity fraction of at least 27% (more probably 30%) (Fig. 1a, part I, LA18). Our second sample of A/F-type candidate hybrid stars is based on a re-analysis of all Kepler targets with T_{eff} in the range 5500-10000 K. It contains 46 poorly-studied hybrid stars satisfying Kp < 10.5 mag (using Simbad, CDS, France). We identified 6 SBs while 6 other targets have a possible companion or shell (CMP). From this, we obtain a spectroscopic multiplicity fraction of ~25% (Fig. 1b, part II) (*Note: this is on-going work*).

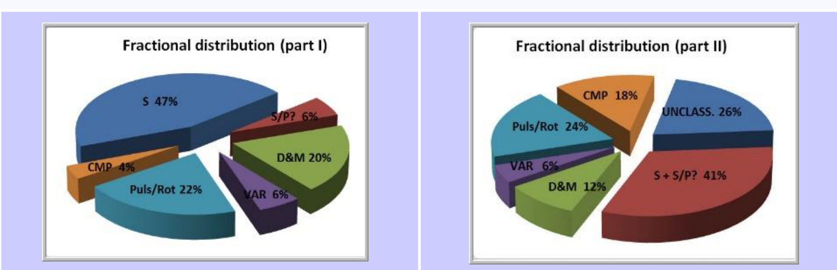

Fig. 1(a-b). Classification results based on 83 A/F-type hybrid pulsators. Classes are S: stable, S/P?: stable or pulsating?, D&M: binary/multiple, CMP: composite, Puls/Rot: pulsating/rotating star, VAR: long-term RV variability.

Acknowledgements

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Individual analyses & results

- 1. **KIC 6381306 (2A7,5/A5,90)**. Whereas multiple frequencies populate the low-frequency region of the periodogram (Fig. 2), we discovered that the dominant low frequency corresponds to the orbital frequency (f_{orb}= 0.256 d^{-1}). This star belongs to a SB3, with orbital periods of 3.91 days and 212.2 ± 0.3 days. This result is essential to understand the stellar pulsations from the periodogram. With T_{eff} = 9000 K (primary), this system lies blueward of the δ Sct instability strip.

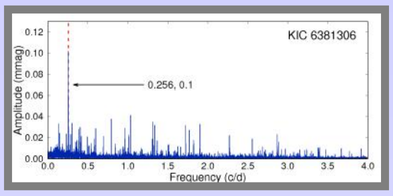

Fig. 2. The [0-4] d^{-1} region of the periodogram of KIC 6381306 (based on *Kepler* data)

- 2. **KIC 6951642 (F0,120)**. This object was classified as a pulsating star with long-term RV variations (Fig. 3). The orbital motion of a binary system induces periodical shifts in the phases of the pulsation frequencies of the pulsating component(s) due to the variable light-travel-time. These shifts correspond to time delays. MU18 computed TDs from nine different modes (e.g. in Fig. 4) showing the same long-term pattern. By combining our RVs and their TDs, they suggested a possible orbital period of ~1900 days. **Extending our spectroscopic observations for the system will enable a refined (RV+TD) analysis in the next years.**

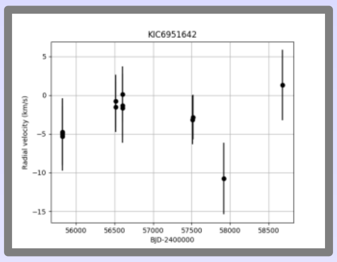

Fig. 3. Radial velocities of KIC 6951642 (with a time span longer than 4 years).

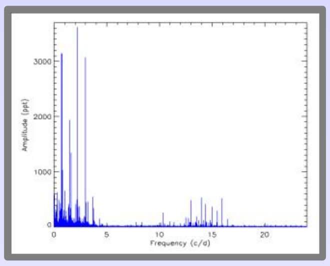

Fig. 4. Periodogram of KIC 6951642 based on the *Kepler* LC data (FP17).

- 3. **KIC 8975515(A8,162/A8,32)**. This object is a SB2 with an orbital period of ~1600 days (f_{orb} = 0.0006 d^{-1}) and consistent TDs. We performed a full frequency-analysis of the *Kepler* LC and SC data, and searched for periodic patterns among the detected *g*- and *p*-modes. In the low-frequency region (a), we detected the period spacings 0.020 ± 0.002 and 0.024 ± 0.002 d. In the high-frequency region (b), we detected 3 doublets and two triplets (incl. 12 modes), for which we derived the mean frequency spacings 0.443 ±0.002 d^{-1} and 1.729±0.053 d^{-1} (Fig. 5). Thus, we find **no obvious connection** between the regular patterns and the orbital frequency.

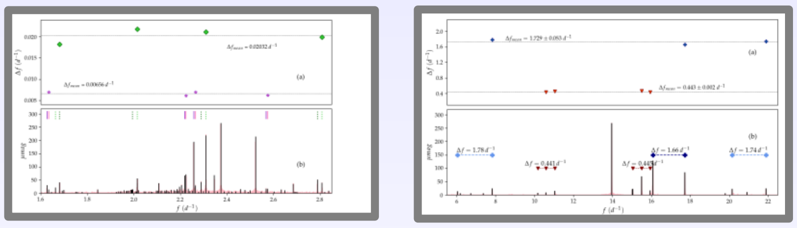

Fig. 5(a-b). Illustration of the regular period and freq. spacings detected in the low- resp. high-frequency regions of the periodogram for KIC 8975515 (Samadi-Ghadim et al., in prep.).

Conclusions

- 1. We find that **at least one out of four** ***Kepler*** **hybrid stars** is part of a binary or a multiple system. The spectroscopic multiplicity fraction derived from these two samples of A/F-type hybrid stars is thus in excellent agreement with Nemec et al. (2017), who found 33% of binary/multiple systems in their sample of SX Phe stars. **For an asteroseismologist, it matters whether the hybrid pulsator is in a binary or multiple system or not.**

- 2. The TDs obtained from the *Kepler* light curves and the RVs obtained from the long-term monitoring provide the long time base needed for an accurate determination of the orbits. This in turn allows **to derive fundamental component properties** (e.g. the mass (function)). In addition, we may identify the pulsating component(s). Armed with this information as well as with improved atmospheric parameters and *v*.sin *i*, our study provides crucial knowledge for a future asteroseismic modelling of several interesting hybrid pulsators.

- 3. **Current & future work**: combined (RV+TD) analyses; frequency-search analyses of *Kepler* data; determination of the total multiplicity fraction & follow-up of very interesting targets.

References

Balona et al. 2015, MNRAS 452, 3073 (BA15)
Balona 2018, MNRAS 476, 4840 (BA18)
Derekas et al. 2017, MNRAS 464, 1553 (DE17)
Fox-Machado & Pérez Pérez 2017, RevMexAA Conf. Ser. 49, 87 (FP17)
Grigahcène et al. 2010, ApJ 713, L192 (GR10)
Lampens et al. 2018, A&A 610, A17 (LA18)
Murphy et al. 2018, MNRAS 474, 4322 (MU18)
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)
Xiong et al. 2016, MNRAS 457, 3163 (XI16)

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