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Puzzling Low-Frequency Variations in the δ Scuti-type *Kepler* Star KIC 5988140 (HD 188774)

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Abstract. At first sight, the *Kepler* data of the A-type star KIC 5988140 mimics the light curve of an eclipsing binary system with a superposed short-period variability of type δ Scuti. It was attributed by the *Kepler Asteroseismology Consortium* (KASC) to the working group "Binary and Multiple Stars", where we picked it up. We used the high-quality space photometry supplemented by recent high-resolution spectra to investigate the cause of the variability of this late A-type object. We considered three different possible scenarios: (1) binarity, (2) co-existence of γ Doradus and δ Scuti pulsations (the hybrid case) and (3) rotation of the stellar surface with an asymmetric intensity distribution (i.e. rotational modulation). We confirm the presence of various pressure modes of type δ Scuti. However, none of the previous scenarios is capable of reproducing all of the observed characteristics of the variations. Thus, the cause of the remaining light and radial velocity variations remains presently unexplained by any of the considered physical processes.

1. Introduction

The near-continuous time series of the National Aeronautics and Space Administration (NASA) space mission *Kepler* allow in-depth asteroseismic studies of unprecedented detail (Jenkins et al. 2010; Chaplin et al. 2011). A remarkable result is the detection of a large number of hybrid stars among the pulsating A- and F-type stars (Grigahcène et al. 2010; Uytterhoeven et al. 2011). We selected the *Kepler* target KIC 5988140, of *Kepler* magnitude 8.852, for a follow-up study as this late A-type star was classified as a binary system with a δ Scuti (Sct) component star by Uytterhoeven et al. (2011). Its light curve is illustrated in Fig. 1. Also note that some 12% of their sample objects were classified as a binary or a multiple system.

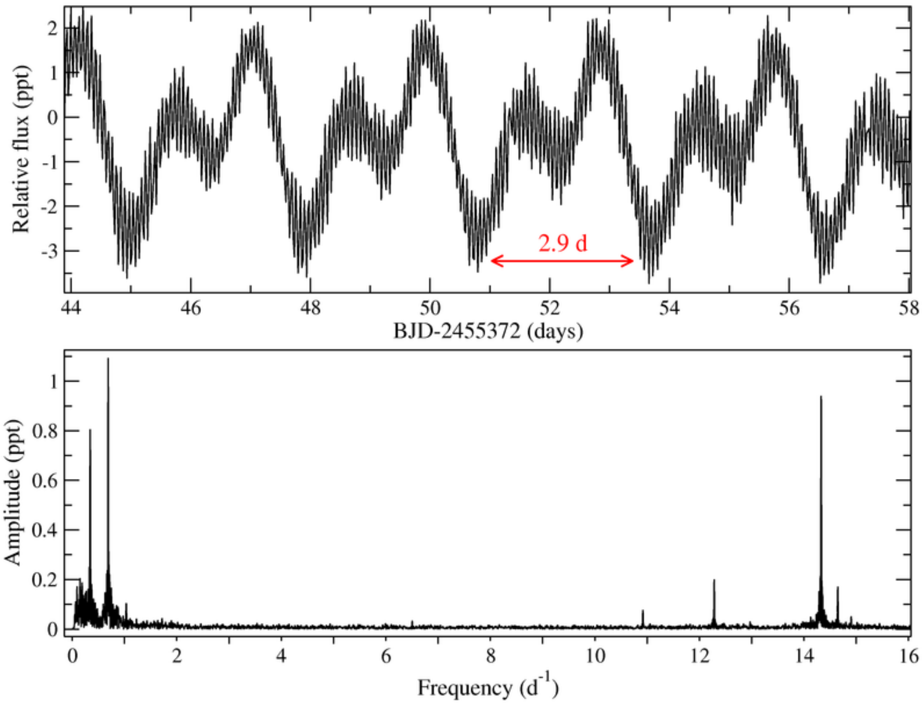

Figure 1. Portion of the *Kepler* light curve covering a 14-day period of quarter Q6 (top) and amplitude spectrum of the entire Q6 data string (bottom).

2. Spectroscopy

We acquired twenty-nine high-resolution spectra in the range 380 – 900 nm with the HERMES spectrograph (Raskin et al. 2011) attached to the 1.2-m Mercator telescope (La Palma, Spain) and eleven spectra in the range 472 – 740 nm with the Coudé-Echelle spectrograph equipping the 2-m TLS-telescope (Thüringer Landessternwarte Tautenburg, Germany). The cross-correlation technique was used to estimate radial velocities (RVs) from the individual spectra. The spectra were next shifted in wavelength according to their RVs and co-added to create a mean spectrum. Using a grid of synthetic spectra calculated with SynthV (Tsymbal 1996) and atmosphere models computed following Shulyak et al. (2004), we derived the best-fit atmospheric parameters: $T_{\rm eff}$ = 7600 K, $\log g$ = 3.4, [M/H]= −0.3 dex and $v \sin i$ = 52 ± 1.5 km s^{-1}.

3. Photometry

We processed the *Kepler* Long-Cadence data from seven quarters (i.e. Q0-Q2, Q4-Q6, Q8) using a pack of Fortran routines which remove the jumps between the quarters and the drifts in an automatic way (courtesy of L. A. Balona). A total of 20668 useful measurements were frequency-analyzed using Period04 (Lenz & Breger 2005). In the frequency range $0-5\,\mathrm{d}^{-1}$, two major peaks (corresponding to $P_1 = P_2/2 = 1.4535$ and $P_2 = 2.9071$ days) were found. Other harmonic terms such as $P_2/3$, $P_2/4$ and $P_2/5$ were also detected. In the range $10-24\,\mathrm{d}^{-1}$, the detection of nine additional significant frequencies corresponding to periods of about $1-2$ hours carries the signature of δ Sct-type pulsation. The radial velocity curve (Fig. 2, top) and *Kepler* light curve pre-whitened for all but the frequencies corresponding to P_2 and its harmonics (Fig. 2, bottom) show a similar double-wave pattern but are not quite in anti-phase as the moments of minimum radial velocity precede the moments of maximum light by ~ 0.1 period.

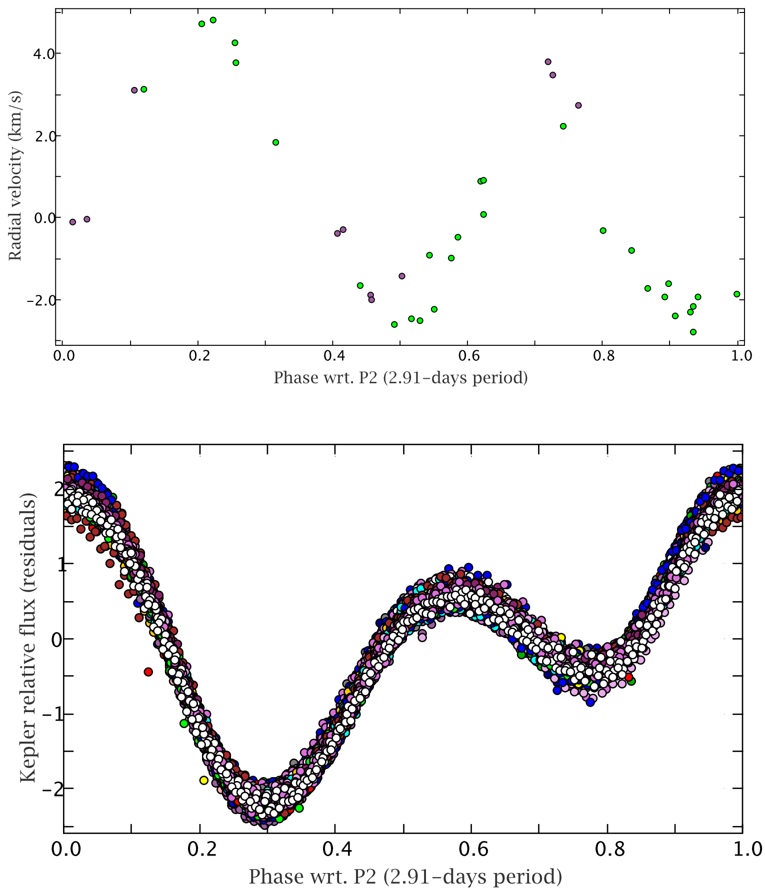

Figure 2. *Top:* Radial velocity curve based on TLS (purple symbols) and HERMES spectra (green), phased with respect to the longer period $P_2 = 2.9071$ days. *Bottom:* 'Basic' *Kepler* light curve pre-whitened for the signal of all detected frequencies except for that of P_2 and its harmonics, phased according to the same ephemeris.

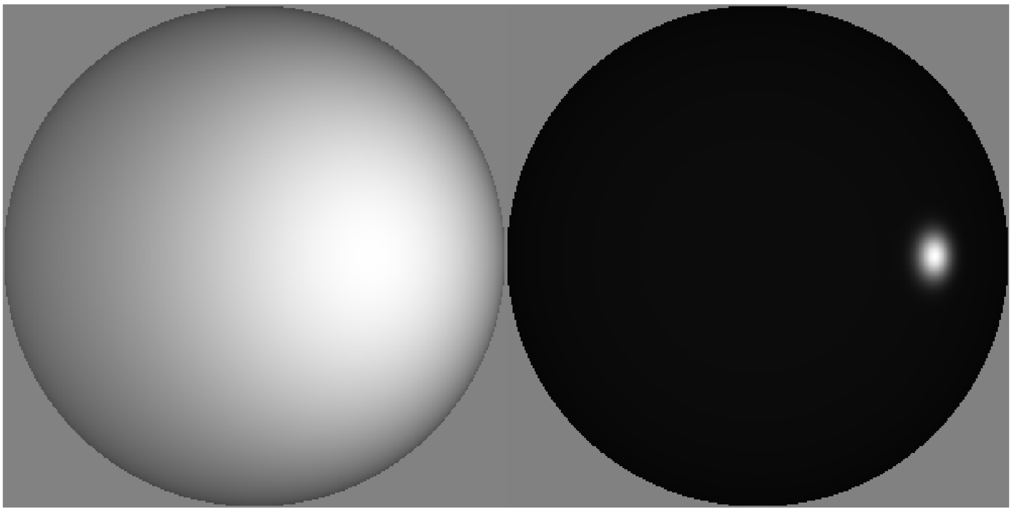

Figure 3. Two (limit) models of a spotted surface shown for the same rotation phase: Model A (left) has two spots of size equal to the stellar radius while Model B (right) has two small spots of very high contrast.

4. Possible scenarios

4.1. Binarity

Is KIC 5988140 a binary? Although there is a strict 1:2 ratio between the two most dominant frequencies (e.g. ellipsoidal distortion coupled to reflection effects), we can rule out the explanation of binarity because the RV curve shows a double-wave pattern, and the phase relationship between both curves is *incompatible* with orbital motion.

4.2. Rotation

Could it be rotational modulation? The stellar surface may present an asymmetric intensity distribution caused by either spots or very high rotation. The presence of multiple harmonics and the expected value of 50° for the inclination angle (assuming that P_2 is the rotation period) are supportive arguments. We used two simple but qualitatively relevant models of a surface with two symmetrically located spots to represent as closely as possible the shape of the observed RV curve (Fig. 3). The predicted total light amplitude is of the order of 20% in both cases. However, this is 40 times larger than the observed peak-to-peak amplitude (the *Kepler* light curve has a total amplitude of only 5 ppt). Critical rotation as e.g. in the case of Altair (Peterson et al. 2006), which has a chromospherically active equatorial band, is very unlikely in this case.

4.3. Pulsation

Is KIC 5988140 a γ Dor – δ Sct hybrid? The surprisingly small light-to-velocity amplitude ratio also pleads against the model of pulsation of type γ Dor. The exact ratio 1:2 between the two frequencies in the low-frequency regime, the presence of multiple harmonics as well as the fact that the phase relation between the phased RVs and the *Kepler* light curve is atypical, do not favour the interpretation in terms of pulsation (i.e. gravity modes as in γ Dor stars).

5. Conclusion

Currently, we do not understand all the observed frequencies which are responsible for the light and RV variations occurring in the δ Scuti star KIC 5988140. The RVs folded on the period of 2.9071 days show a double-wave pattern, which was also detected in the cleaned, so-called 'basic' *Kepler* light curve (Lampens et al. 2013). That a harmonic of the stellar rotation period has the highest amplitude in the RV data, was already observed in an early-type spotted star, namely HR 7224 (Lehmann et al. 2006).

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