Detection of rapid differential rotation in the Gamma Doradus star KIC 8197761

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ABSTRACT

A search for planetary transits among stars in the lower part of the classical instability strip in short-cadence *Kepler* data revealed KIC 8197761 as the best candidate. The detected periodic dimmings with a period of 9.87 d and an amplitude of about 6 mmag are however due to grazing transits of an M dwarf star. Our analysis of the γ Doradus pulsation implies an internal rotation period of 300 d, whereas the measured v sin i is consistent with the hypothesis of the envelope rotation period - 30 times faster than in the stellar interior - being synchronized with the binary orbit.

KIC 8197761

KIC 8197761 is a γ Doradus pulsator showing periodic dimmings. It is located in the field of the open cluster NGC 6866, but it is not a cluster member. Sowicka et al. (in prep.) showed that an M dwarf star is responsible for visible eclipses.

Variability content of the light curve

The Fourier spectrum is shown in Fig. 2. Several hundreds of frequencies are present in the frequency range from 0.1 to 5 c/d. Interestingly, several of the dominant oscillations are part of multiplets (mostly triplets, sometimes doublets) equally spaced in frequency, and are often the centroid frequencies. We determine the weighted mean frequency spacing of these multiplets: $\mathbf{f_{sp}}$ **= 0.001659(15) c/d.**

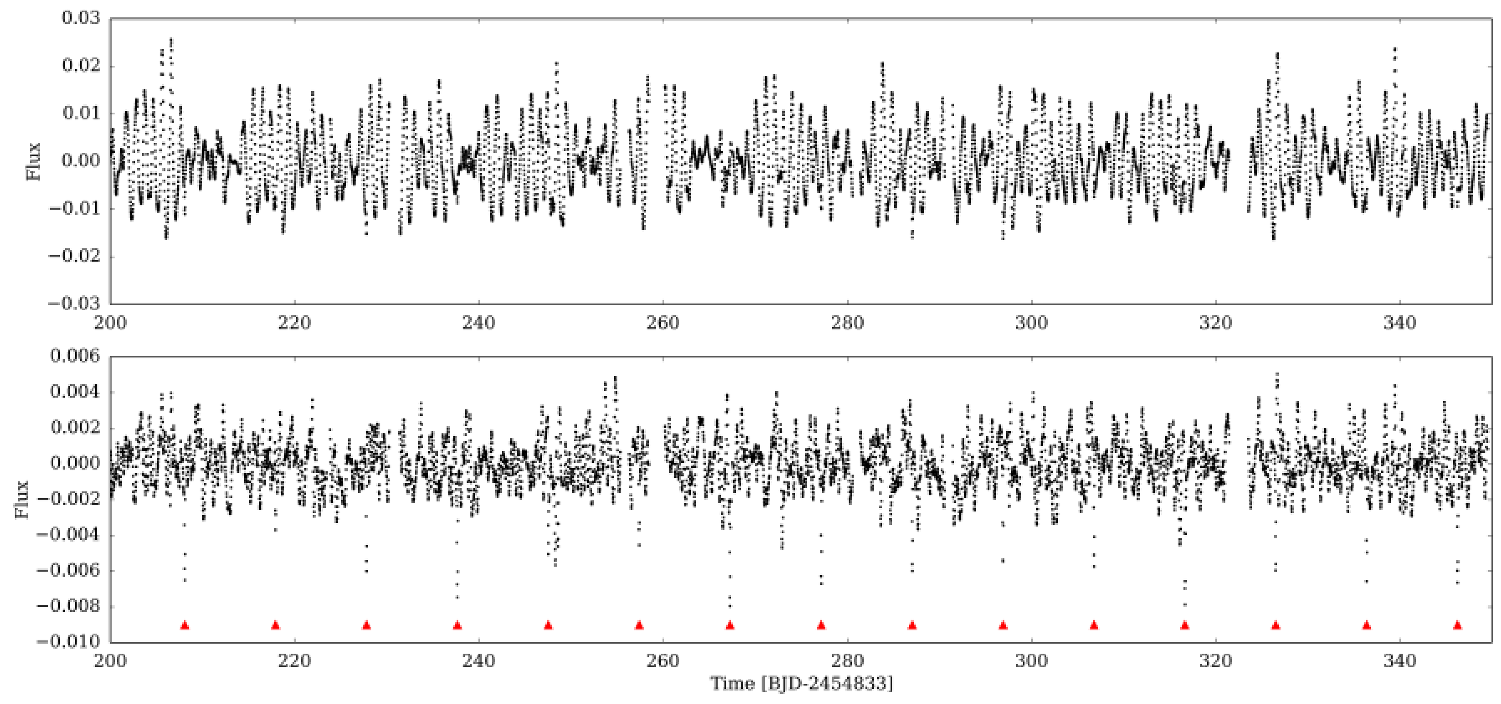

Fig. 1

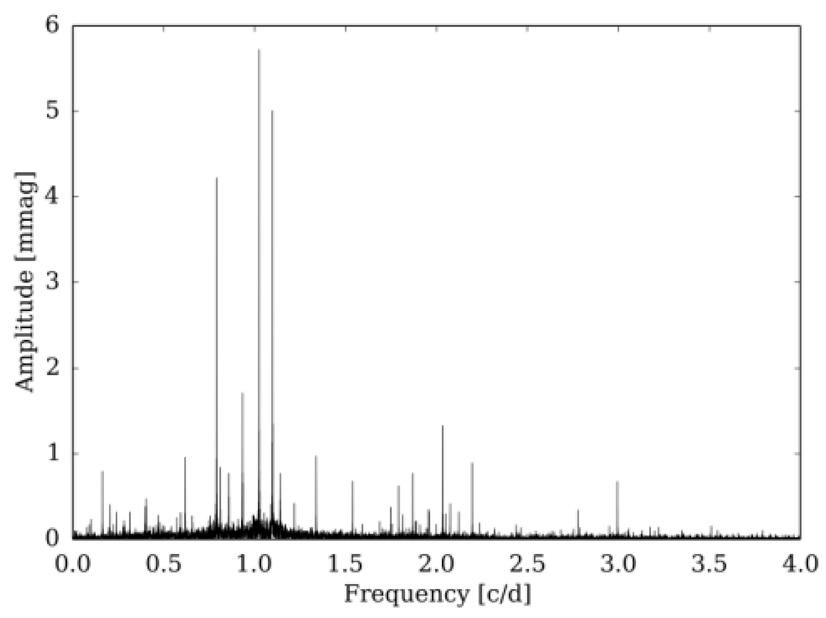

Fig. 2

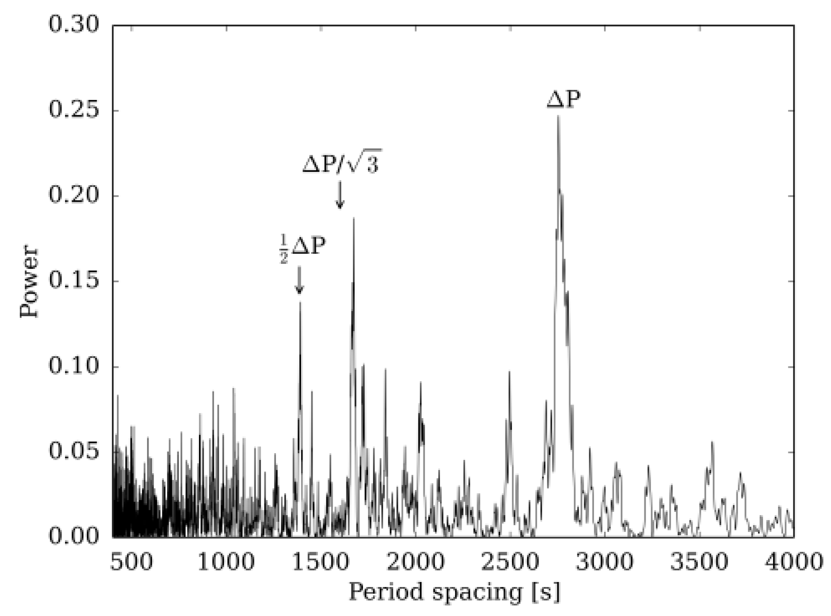

Fig. 3

Fig. 1 upper panel shows a portion of Kepler LC observations, where multi-periodic γ Doradus pulsations are clearly visible. The lower panel shows the same portion of data after removal of some part of pulsation – eclipses became visible and are indicated by triangles. Fig. 2 shows periodogram of Q0-Q17 Kepler LC observations. Fig. 3 shows the spectral window of the period spectrum of KIC 8197761. A mean period spacing around 2770 s and its first harmonic are indicated.

Asteroseismology

As we classified KIC 8197761 as a γ Doradus pulsator, the pulsational signals are likely gravity modes of the same spherical degree l split by rotation. Asymptotic pulsation theory (e.g., Tassoul 1980) predicts that such modes with consecutive radial overtones should be equally spaced in period. Equal spacings of signals within data sets can be revealed by computing their spectral window which is shown in Fig. 3.

This analysis suggests the presence of a mean period spacing of 2770 ± 40 s, with a second possibility for a mean period spacing of 1670 ± 20 s. This is interesting, as the mean period spacings of high-order gravity modes such as excited in γ Doradus stars should relate as $\Delta P_{l=1}/\Delta P_{l=2}=\sqrt{3}$ (Unno et al. 1989). , and that is not the case. The ratio of these two potential mean period spacings is 1.66 ± 0.04, almost 2σ from the asymptotic value.

An Echelle Diagram with respect to the 2770 s mean period spacing, is shown in Fig. 4. The signals that are components of multiplets with equal frequency splittings roughly fall onto a vertical sequence. The two signals that do not are in fact combination frequencies. Therefore, we conclude that the equally-split frequency multiplet structures with periods between 0.7-1.7 d are indeed due to g modes of the same l. Because

1) the multiplets have a maximum number of three members, 2) the mean l=1 period spacing of ZAMS models of γ Doradus stars is about 3000 s, and 3) geometrical cancellation over the visible stellar disk (Dziembowski 1977) favours the observations of l=1 modes in comparison to higher l, we identify these multiplets as rotationally split l=1 modes.

The l=1 multiplets do not fall onto an exact vertical ridge in the Echelle Diagram; some "wavy" structure is superposed. This is an effect of mode trapping, caused by the sharper density gradients in the stellar interior as the object evolves, and can be taken advantage of to constrain its evolutionary state (see, e.g., Saio et al. 2015 and van Reeth et al. 2015 for examples).

With the rotational splitting of f_{sp} = 0.001659(15) c/d, for l=1 P_{rot}= 301 ± 3 d in the asymptotic limit. An initial attempt of more detailed asteroseismic modelling did not bear fruit (H. Saio, private communication).

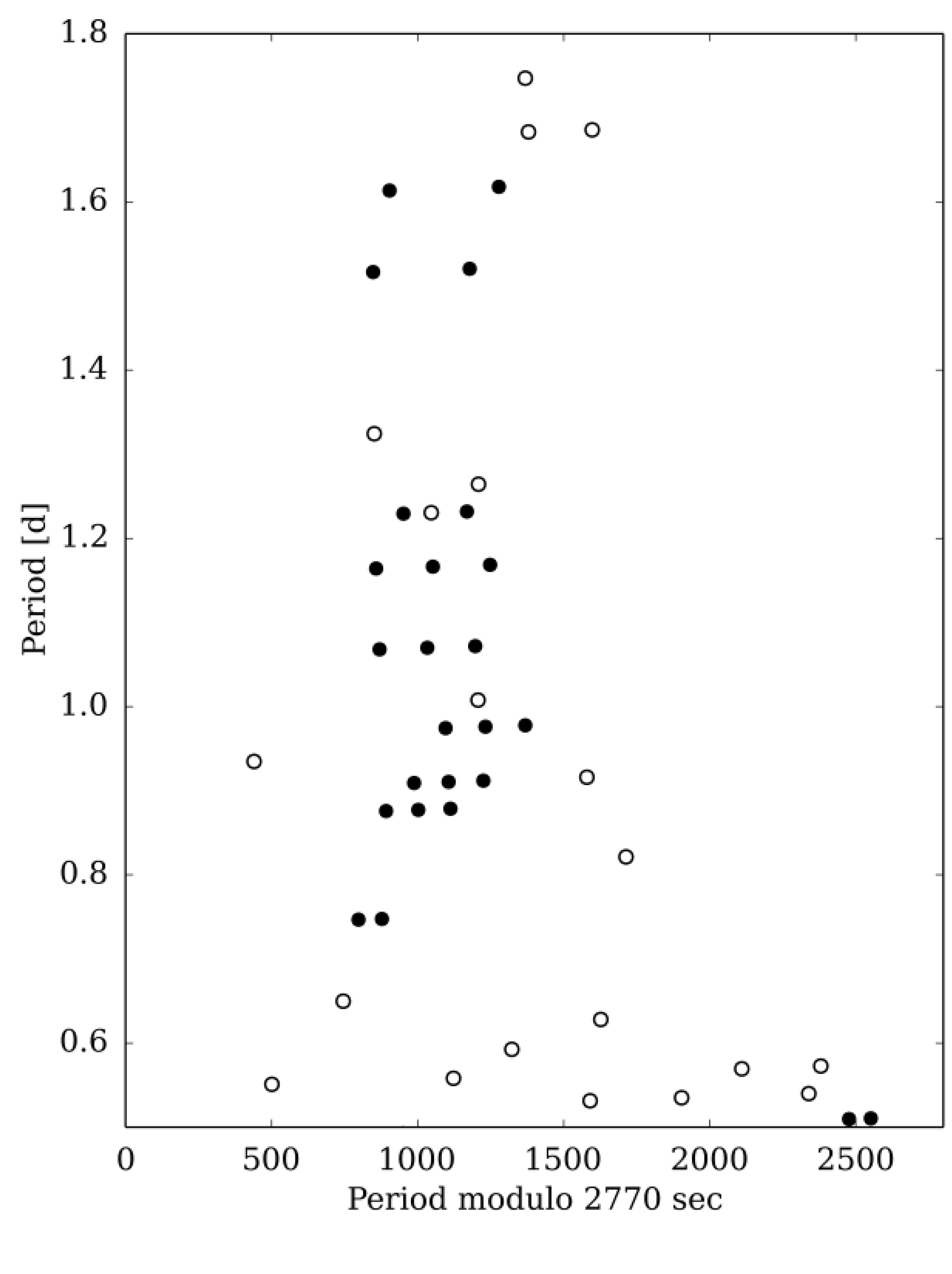

Fig. 4

Echelle diagram of the pulsation periods. Full circles – components of multiplets with equal frequency splittings, open circles – the remaining signals.

Spectroscopy

We also determined the projected rotational velocity of KIC 8197761 from 13 spectra obtained with the 1.2-m Mercator Telescope and HERMES spectrograph to be v sin i = 9 ± 1 km/s. Given the stellar radius of 1.717 $R_\odot$, a rotation period P_{rot} < 10.9 d follows. This is an interesting result. First, it is markedly different from the rotation periods of the star photometrically determined by Nielsen et al. 2013 and Reinhold et al. 2013. This discrepancy is easily explained: both authors identified one of the stellar pulsation periods as a rotational signal. Second, and more interestingly, the (surface) rotation period determined by us is very close to the system's orbital period, but markedly different from the rotation period determined from the frequency splittings of the g-mode pulsations. It is therefore quite possible that the rotation of the envelope of KIC 8197761 is synchronized with the orbit, whereas the stellar core rotates 30 times slower than that.

Conclusions

A careful examination of the pulsational signals of KIC 8197761 revealed the presence of an equal frequency splitting of f_{sp} = 0.001659(15) c/d within some modes of oscillation. We find that these modes are rotationally split l=1 g modes of high radial order. The rotation period obtained using f_{sp} and in asymptotic limit is P_{rot}=301 ± 3 d. On one hand, such a period is very long for a star as hot as a γ Doradus star. On the other hand, it just is such slow rotation that favours the detection of rotational splitting signals. An attempt to perform asteroseismic modelling (H. Saio, private communication) did not bear fruit.

We also performed a spectroscopic analysis of KIC 8197761. Our 13 spectra obtained with HERMES on the 1.2-m Mercator Telescope show radial velocity variations with an amplitude of 19.75 ± 0.32 km/s, and allowed the determination of v sin i = 9 ± 1km/s. The latter suggests that the surface rotation of the star is synchronized with the orbital period, although the stellar core rotates much slower.

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