Stellar pulsation and rotation in NGC6811

E. Rodríguez[1], S. Ocando[1], M.J. López-González[1], S. Martín-Ruiz[1]

[1]Instituto de Astrofísica de Andalucía, CSIC, P.O. Box 3004, E-18080 Granada, Spain

Abstract

We present the results of the frequency analysis for a selected sample of pulsating δ Sct- and γ Dor-type stars in the field of the open cluster NGC 6811 which have been observed in short-cadence (SC) mode by the Kepler satellite. In all cases, the resulting frequency spectra are very complex, especially when the dominant pulsation is that of the δ Sct type, that is, short-period pulsations corresponding to excited pressure (p) modes. In all cases, the δ Sct stars are shown to be essentially δ Sct/γ Dor hybrid pulsators. However, the opposite seems not to be true. We also find that the δ Sct-type peaks commonly are not stable in amplitude. Many of the main peaks significantly change their amplitudes over relatively short time scales. For a large percentage of pulsators in our sample we also find that the variability shown in the light curves is not produced by a single cause, but a combination of various sources: δ Sct- and γ Dor-type pulsations together with rotational modulation produced by starspots in the surfaces of these stars. This is an indication of stellar activity in the surfaces of these relatively hot stars of spectral type A(-F). Sometimes, activity dominates the luminosity variations in various pulsating stars in our sample. Eclipsing binarity is also detected in a few cases. Flares are also detected in one of the δ Sct-type pulsators. This is an indication of unusual strong activity for this kind of hot stars.

Introduction

NGC 6811 is one of the four open clusters in the field of view of the Kepler space mission. This cluster contains many classical main-sequence pulsators of the δ Sct- (short periods, roughly P≤0.3d, pressure ***p*** modes excited) and γ Dor-type (longer periods, roughly 0.5d≤P≤3d, gravity *g* modes). The Kepler database offers an unique opportunity to study in depth this large and homogeneus sample of pulsating stars concerning their pulsational content and temporal evolution of the excited modes, for stars with similar properties as age and metallicity (Rodríguez et al. 2016).

Method.

We have considered the stars observed in SC mode by the Kepler satellite in the field of NGC 6811 within a distance from the cluster centre d< 7.0 arcmin (Ocando et al. 2016). In total, the sample consists of 36 stars. A frequency investigation has been performed for each of them. Those targets found as pulsators of the δ Sct- or γ Dor-type have been investigated in more depth to study its pulsational content. All of them with more than one month of Kepler SC observations have also been investigated for possible amplitude variability of the main pulsational periodicities.

ID	WEBDA	K_p (mag)	d (arcmin)	Mem	Q	N	Type(1)	Source	log T_e	log $L/L_\odot$	Type(2)	Amp. variab.?
02	489	11.02	11.5(B)	M	2.1,3.2,5 6,11,13	14	δ Sct(V6)/SB1?	1,3	3.837	0.836	δ Sct/γ Dor	Yes
03	26	11.41	4.3	M	2.3	1	δ Sct	2	3.893	1.642	δ Sct/γ Dor	–
05	18	12.07	4.4	M	2.3,5,8.1 8.3,9-11	15	δ Sct(V1)	1,2	3.868	1.180	δ Sct/γ Dor	Yes
08	31	13.24	2.7	M	1.3	1	γ Dor/Rot	2,4	3.863	0.831	Rot/γ Dor	–
11	70	10.85	4.5	M	2.1,5-6	7	δ Sct(V3)	1,2	3.859	0.737	δ Sct/γ Dor/Rot	Yes
12	4	12.94	0.8	M	4.2,5-6	7	δ Sct(V12)	1	3.879	1.311	δ Sct/γ Dor	Yes
14	5	12.21	0.1	M	4.1	1	-		3.901	1.140	Ecl/δ Sct/Rot/γ Dor	–
17	53	12.57	3.5	M	4.1,5-6	7	δ Sct(V10)	1,2	3.892	1.048	δ Sct/γ Dor	Yes
18	43	12.36	1.1	NM	4.1	1	-		3.850	1.097	δ Sct/Rot/γ Dor	–
19	42	12.66	1.2	NM	4.2,5-6	7	δ Sct(V14)	1	3.834	0.994	δ Sct/Rot/Ecl/γ Dor	Yes?
20	39	11.50	1.3	NM	3.2,5-6	7	δ Sct(V4)	1,2	3.891	2.004	δ Sct/γ Dor	Yes
21	54	12.26	4.0	M	4.1	1	δ Sct/γ Do	2,3	3.860	0.930	δ Sct/γ Dor	–
24	44	11.78	1.9	M	3.2,5-6	7	δ Sct(V11)	1	3.888	1.063	δ Sct/Rot/γ Dor	Yes
27	49	12.44	3.0	M	4.1	1	δ Sct/γ Do	2	3.900	1.350	δ Sct/γ Dor	–
28	113	11.50	4.8	M	1.3,5,7-11	19	δ Sct(V5)	1,2,3	3.883	1.603	δ Sct/γ Dor/Rot	Yes
31	230	12.67	7.9(B)	M	4.2	1	γ Dor/Rot	2,4	3.847	0.824	Rot/γ Dor	–
33	33	11.88	2.6	M	3.2,5-6	7	δ Sct(V13)	1,3	3.900	1.611	δ Sct/γ Dor/Rot	Yes
35	36	13.26	0.9	NM	2.1	1	-		3.828	0.954	γ Dor/Rot	–
36	47	10.86	1.5	M	2.3,5-10	19	δ Sct(V2)	1	3.872	1.373	Rot/δ Sct/γ Dor/Fla	Yes

Table 1. δ Sct- and γ Dor-type pulsators in the field of the open cluster NGC6811 using the Kepler SC database. ID: identication number in our sample; WEBDA: WEBDA identication; d: distance (arcmin) from the cluster centre; Mem: membership of cluster using the bibliography; Q, N: quarters and number of available months with Kepler SC observations; Type(1), source: variability type in the bibliography and sources (Vxx: variable detected by Luo et al. 2009; SB1: single-line spectroscopic binary); Type(2): variability type resulting in this work, in order of decreasing amplitude (Rot: rotation; Ecl: eclipsing binary; Fla: flares); the last column means "Amplitude variability" detected in the main peaks. Temperatures and luminosities are from Huber et al. 2014. The sources are: 1) Luo et al. (2009), 2) Uytterhoeven et al. (2011), 3) Molenda-Zakowicz et al. (2014), 4) Reinhold et al. (2013).

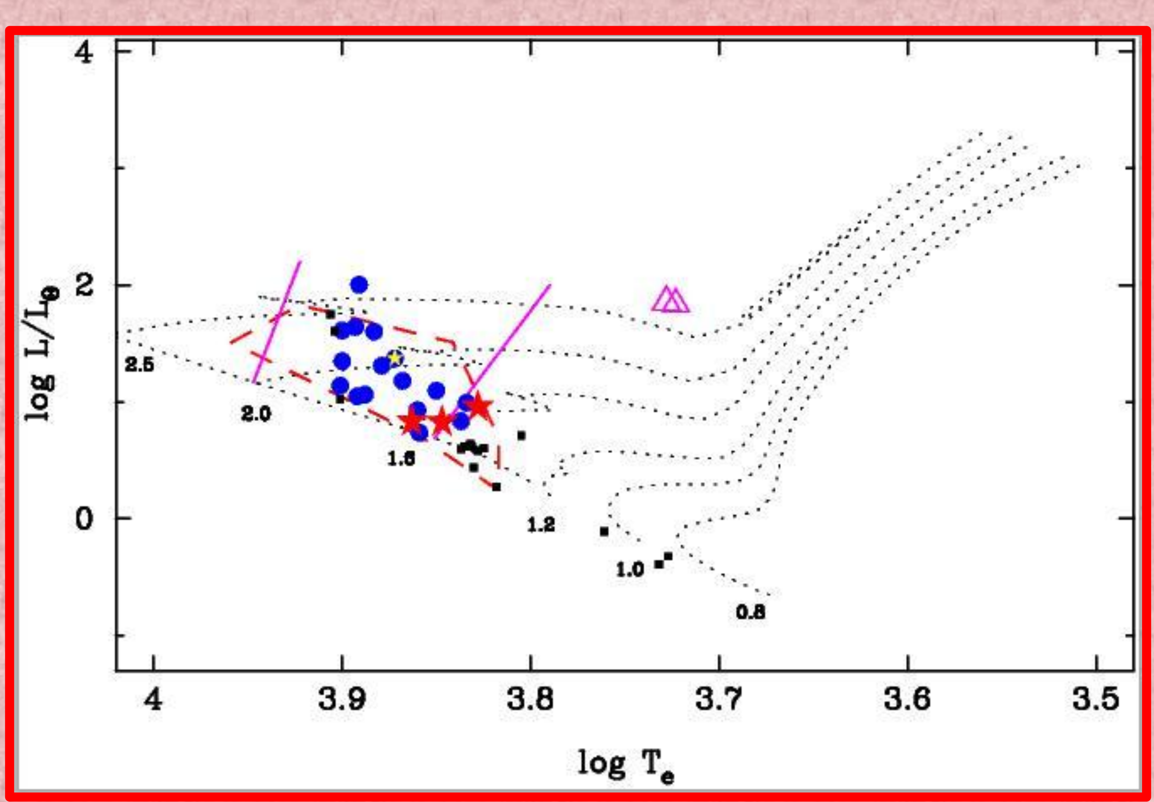

Figure 1. HR diagram for our sample of stars in NGC 6811. The evolutionary tracks with indicated solar masses are from Claret (2004). The ground-based observational borders of the δ Sct instability strip (pink solid lines) are from Rodríguez & Breger (2001). The trapezoidal region shows the general location of the Kepler δ Sct pulsators (Balona & Dziembowski, 2011). Our sample of stars (36 objects) are shown by individual marks: δ Sct stars (16 objects) as blue filled circles, γ Dor stars (3) as red filled stars, red giants with solar-like oscillations (2) as pink empty triangles and the remaining stars, in all cases showing rotational modulation (starspots) (15), as small black squares. A δ Sct-type pulsator showing flares is marked with a yellow filled star.

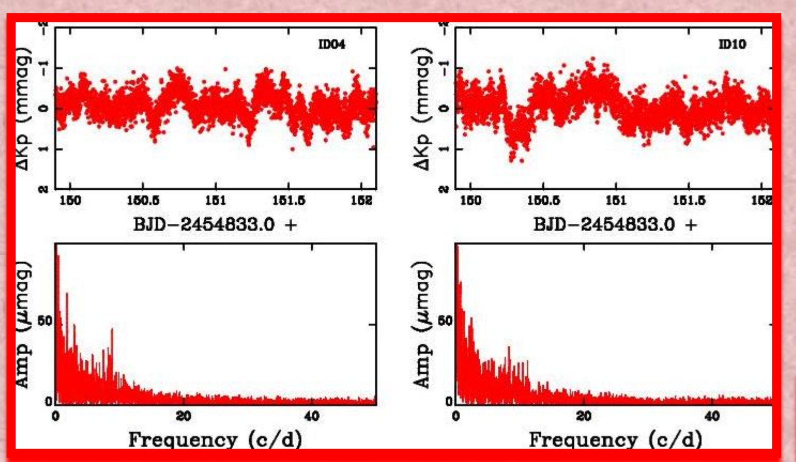

Figure 2. The two red-giant stars (ID04 and ID10) showing solar-like oscillations in our sample. Top panels: light curves obtained from one month of available measurements in SC mode. Bottom panels: the resulting periodograms.

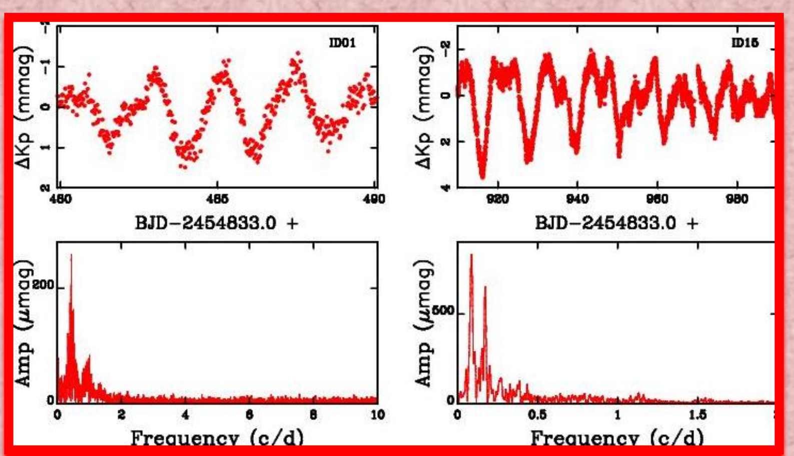

Figure 3. Two examples of stars in our sample showing rotational modulation produced by starspots. Top panels: light curves obtained from one full quarter (3 months) of available measurements in LC mode. Bottom panels: the resulting periodograms.

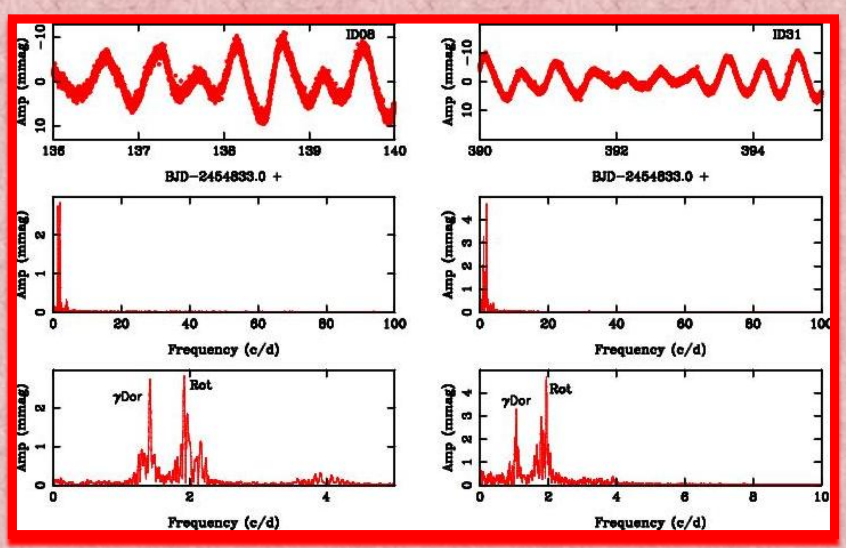

Figure 4. Two examples of γ Dor-type pulsating stars. Top panels: light curves obtained from one month of available measurements in SC mode. Middle panels: resulting periodograms. Bottom panels: zoom to the periodograms in the regions of interest. As can be seen, the peaks due to rotation are the dominant ones in both cases.

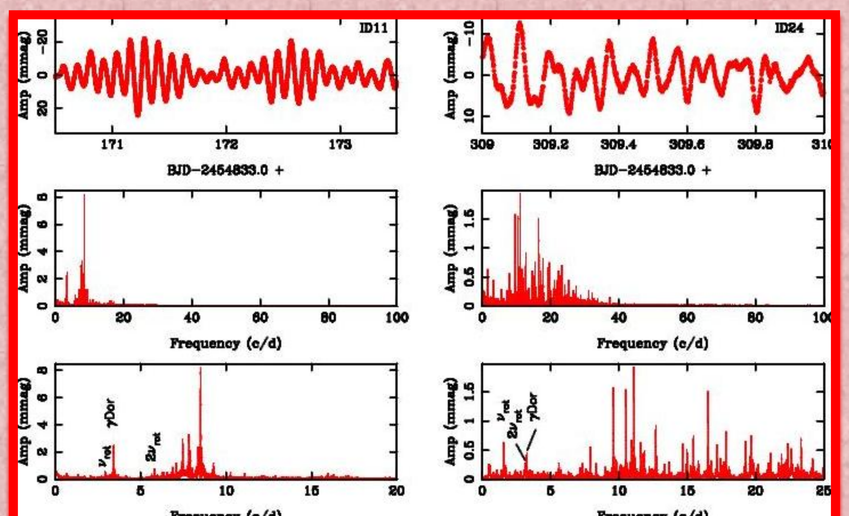

Figure 5. Two examples in which the δ Sct-type pulsations are the dominant. Panels are as in Fig. 4. As can be seen, peaks due to γ Dor-like pulsations and rotational modulation are detected in the low-frequency region in both cases.

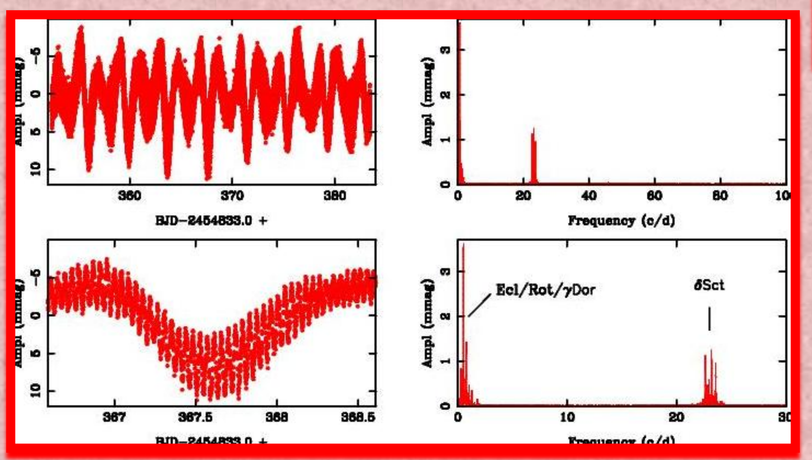

Figure 6. The variable star ID14 (Ecl/δSct/Rot/γDor). Left panels: light curves showing the dominant variability (4days) as due to a eclipsing binarity (top panel) and a secondary and much shorter period (1h) due to δ Sct-type pulsations. Right panels: resulting periodograms. As shown, the peaks in the low-frequency domain are due to binarity, rotation and γDor-type pulsations.

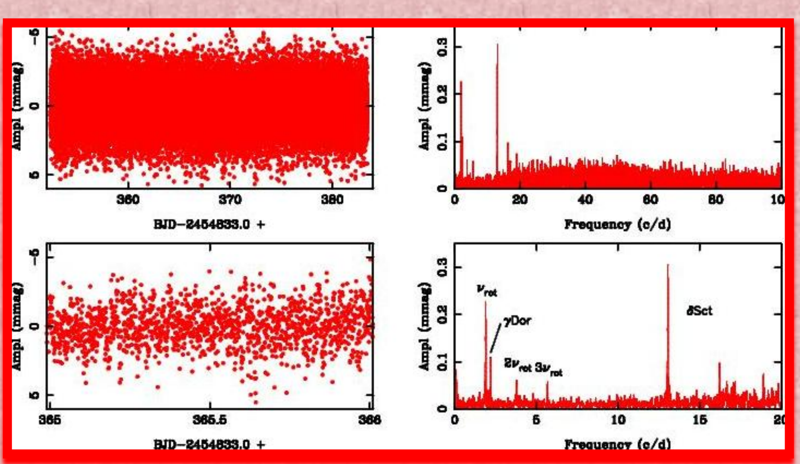

Figure 7. The variable star ID18 (δSct/Rot/γDor). Left panels: light curves showing the full timeseries (one month of SC observations) (top panel) or only one day (bottom panel). The periodicities are so small that it is not possible to see them directly from the light curves. Right panels: resulting periodograms. As shown, the main peak is of the δ Sct type with an amplitude of only 0.3 mmag. The peaks due to rotation and γ Dor-type pulsations are also clearly visible in thelow-frequency region.

Results.

Our analysis reveals all the objects in the sample as variable: 21 are pulsating stars (16 are δ Sct-type pulsators, 3 γ Dor-type and 2 red-giant stars with solar-like (S-L) oscillations). The 15 remaining stars are variable due to rotational modulation produced by starspots (see Fig. 1). This means that activity in the stellar surface is taking place, even for the hotter stars in the sample.

The results for the stars found as δ Sct- or γ Dor-type pulsators are listed in Table 1. The main conclusions can be summarised as:

1) In all cases, the resulting frequency spectra are very complex, especially when the dominant pulsations are those of the δ Sct type. Moreover, stars with very similar parameters (age, metallicity, and HR location) show very different frequency patterns.

2) In all cases, the δ Sct stars are shown to be essentially δ Sct/ γ Dor hybrid pulsators. However, the opposite seems not to be true (see Fig. 4).

3) We find that the δ Sct-type peaks commonly are not stable in amplitude. We detect that an important number of the main peaks signicantly change their amplitudes over relatively short time scales (see Fig. 8).

4) We detect the stellar rotational periods for a signicant percentage of objects in our sample (more than 70% in the total sample and about 50% of the δ Sct-type pulsators). This is an indication of stellar activity in the surfaces of these stars of spectral type A(-F). Sometimes, activity dominates the luminosity variations in various of the main-sequence pulsating stars.

5) Flares have been also detected in one of the δ Sct-type pulsators. This is an indication of unusual strong activity for this kind of hot stars.

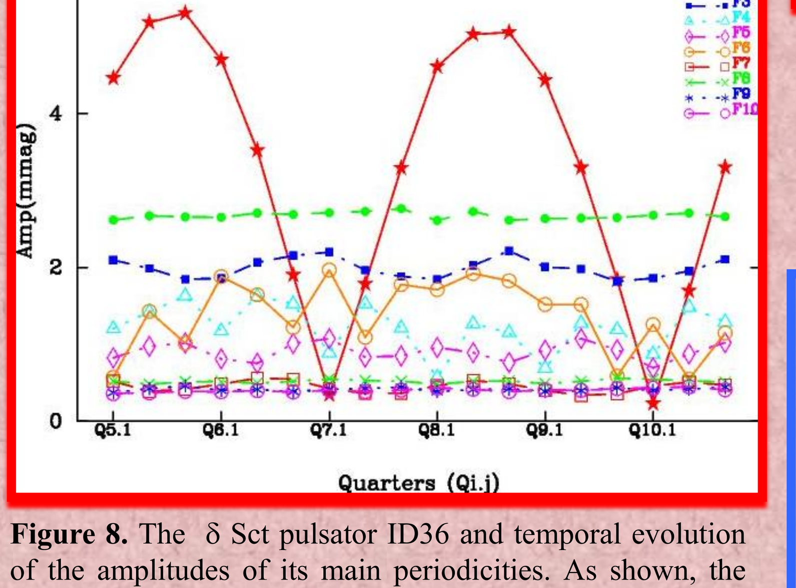

Figure 8. The δ Sct pulsator ID36 and temporal evolution of the amplitudes of its main periodicities. As shown, the four main independent pulsational modes (F1, F3, F4 and F7) show periodic amplitude variability with time. In each of the four cases we find that the amplitude variations are produced by extremely close-frequency pairs.

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