Ground-based multicolour photometry of NGC 6811

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ABSTRACT

NGC 6811 is one of the four open clusters in the field of view of the Kepler space mission. Among its members there are several known pulsating A-F stars of the Delta Scuti, Gamma Doradus, and hybrid type, which makes this cluster a very interesting object to study its pulsational content.
During the summers of 2013 and 2014 we performed an extensive observational campaign using the 1.5 m telescope at the Sierra Nevada Observatory and multicolour photometry. New pulsating variables candidates were detected in this work. We fulfilled a frequency analysis for the known variables, with very good agreement with previous results. By using Strömgren photometry we were able to obtain the main physical parameters of the stars such as temperature, surface gravity, metallicity and luminosity. We have also determined the corresponding frequency phase-shifts and amplitude ratios between different filters as a first step to identify the pulsational modes of the variables.

1.- Introduction

Variable stars in open clusters are a great tool to test stellar evolution and structure models as they have the advantage that their age, distance, metallicity and reddening can be known with great precision.
NGC 6811 (19 37 17 +46 23 18) is an intermediate age cluster with several known δ Scuti, γ Doradus and hybrid type variables among its members which makes it a very interesting object to study.
This cluster is also in the field of view of the Kepler space mission which provided great precision photometry, in white light, for several of the cluster pulsating stars.
In this work we obtained ground-based multicolour photometry of the cluster, determined its age, reddening and distance module as well as the physical parameters of its members.
We detected all the previously known δ Scuti stars and found two new variables: one δ Scuti and one γ Dor.

Figure 1. Image of NGC 6811 taken with the 1.5 m Telescope of the Sierra Nevada Observatory. The FoV is 7x7 arcminutes.

2.- Observations

Our observations were made at Sierra Nevada Observatory (Granada, Spain) during the summers of 2013 and 2014 (30 nights in total). We used a 1.5 m telescope equipped with a 2048x2048 CCD and Strömgren-Crawford filters (uvbyβ).
We obtained temporal series using v,b and y filters focusing in the A-F members of the cluster aiming to obtain a great precision (S/N ~ 500). We also had a couple of calibration nights in which we took images using the four Strömgren filters plus Hβ in order to get the Strömgren indices and hence be able to calculate the physical properties of the stars in the cluster.
Our main field of observation was a 7x7 arcmin area centred in NGC 6811 (Figure 1) but we also focused our observations in a secondary field for six nights in order to observe all the δ Scuti and γ Doradus previously known in this cluster.
Earlier this year we carried out an additional calibration night using the 0.9 m telescope and a brand new set of Strömgren-Crawford filters.

3.- Data analysis

The images' basic reduction was performed using IRAF. In order to obtain the differential magnitudes we used VAPHOT (Deeg & Doyle 2013). The frequency analysis was made using PERIOD04 (Lenz & Breger 2005).
The dereddening of the stellar parameters was made based on the work of Philip & Egret (1980).
In order to calculate the temperature and surface gravity of the stars we used the NEMO grid of model atmospheres (Heiter et al. 2002). The metallicity calculations were based on Smalley (1993) for spectral types A3-F0 and Nissen (1998) for spectral types F-G.

4. Results

4.1 Cluster Parameters

For NGC 6811 we determined an age of 600 Myrs, a reddening of E(b-y) = 0.06 and a distance module of 10.45 magnitude. These values are in good agreement with the ones found by Luo et al. (2009).

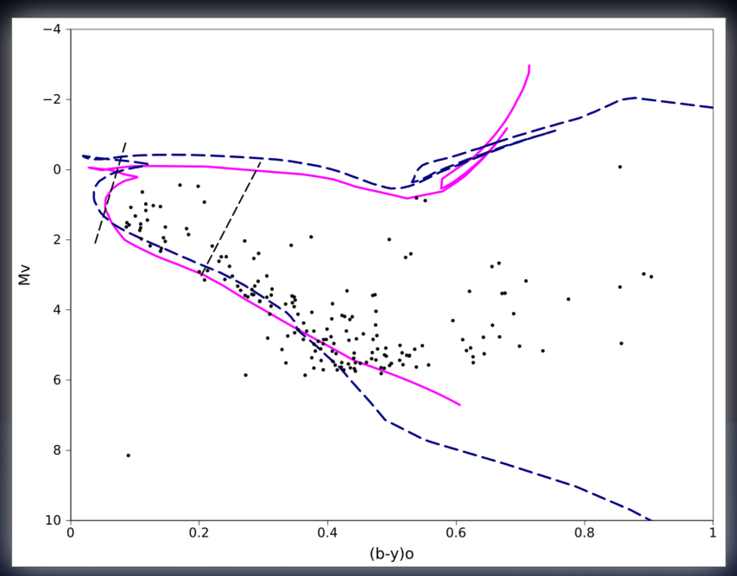

Figure 2. HR diagram for our sample of stars in NGC 6811. The pink solid line is the isochrone of log(t) = 8.75 and solar metallicity (Z = 0.019) from Claret (2004), the dashed blue line is the isochrone of log(t) = 8.75 and solar metallicity from Bressan et al. (2012). The dashed black lines correspond to the blue and red edge of the δ Scuti instability strip from Rodríguez and Breger (2001).

ID	Te	logg	[Me/H]	Mbol	log(Te)	log(L/Lsun)	Spectral Type
1	6860	3.41	0.53	0.86	3.84	1.56	F
2	7640	3.93	0.13	1.66	3.88	1.24	A
3	7710	3.91	−0.09	1.50	3.89	1.30	A
4	7800	4.02	−0.10	1.73	3.89	1.21	A
5	7200	3.73	0.09	1.52	3.86	1.29	A
6	7650	4.13	−0.21	2.20	3.88	1.02	A
7	8070	4.09	0.03	1.65	3.91	1.24	A
8	7630	4.09	0.00	2.11	3.88	1.06	A
9	7400	3.93	−0.08	1.89	3.87	1.14	A
10	7410	3.68	−0.05	1.17	3.87	1.43	A
11	7050	3.91	−0.15	2.06	3.85	1.08	A
12	7860	4.01	−0.03	1.63	3.90	1.25	A
13	7780	4.04	−0.01	1.82	3.89	1.17	A
14	7320	3.54	−0.06	0.85	3.87	1.56	A
15	7700	3.89	−0.16	1.47	3.89	1.31	A
16	6840	4.38	−0.23	3.12	3.83	0.65	F
17	7990	4.13	0.06	1.83	3.90	1.17	A

Table 1. Physical parameters of the δ Scuti a γ Doradus stars found in this work.

In table 1 we present the physical parameters for the δ Scuti and γ Doradus variables found in the cluster as well as their spectral classification. The temperatures, surface gravities and metallicities found this work are in good agreement with the ones found by Huber et al. (2014).

4.2 Variables

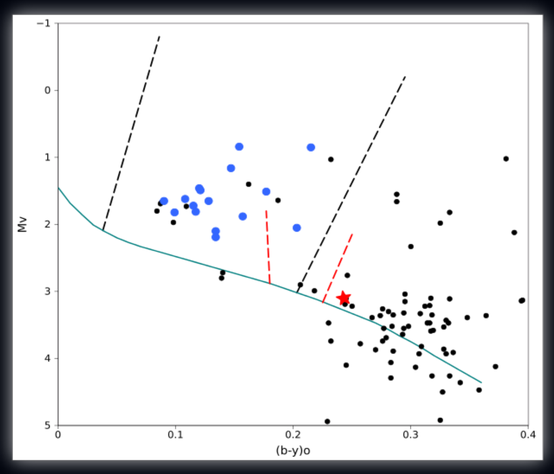

Figure 3. δ Scuti Instability strip from Rodríguez and Breger (2001) (Black dashed lines). The dashed red line denotes the γ Doradus instability strip by Handler & Shobbrook (2002). The blue dots are the δ Scuti variables found in this work and the γ Doradus is represented as a red star.

In figure 3 we can see that all the δ Scuti variables found are inside the instability strip determined by Rodríguez and Breger (2001) as expected. The γ Doradus does not fall between the limits of the instability strip determined by Handler & Shobbrook (2002), although is not uncommon to find γ Dor variables beyond the red edge of this instability strip as can be seen in Uytterhoeven et al. (2011).
According to the membership probabilities determined by Sanders (1971) all the variables found in this work are members of the cluster except ID2.
In table 2 we show the frequency analysis of the δ Scuti and γ Doradus variables. The frequencies found are in good agreement with previous ground-base studies as Luo et al. (2009) and Kepler based studies as Uytterhoeven et al. (2011) and Rodríguez et al. (2016).
We detected all the previously known δ Scuti stars discovered using ground based observations and also all the known δ Scuti discovered using Kepler data, this is the first time that these are detected from the ground and have light curves in multicolour photometry.
We also found to new variables: one δ Scuti and (ID7) and one γ Dor (ID16).
We achieved a very good precision, being able to detect pulsations with amplitudes as low as 0.7 millimagnitudes (ID11).
In every case we verified that the amplitudes in the different filters follow the relation $A_v > A_b > A_y$ consistent with δ Scuti and γ Dor pulsators (Rodríguez 2005).
In figure 4 we present an example of a δ Scuti light curve (ID17) in three different filters (v, b and y).
The decrease in amplitude from the v to the y filter can be visually appreciated.

ID	Frequency (c/d)	Av (mmag)	Phase	S/N
1	F1 9.96	44.0	0.65	37.26
	F2 4.23	19.0	0.69	11.53
	F3 7.45	16.5	0.19	11.07
	F4 5.87	11.3	0.16	8.27
	F5 10.51	6.0	0.19	4.95
2	F1 15.12	22.5	0.55	19.07
	F2 13.71	10.9	0.51	12.34
	F3 11.23	7.1	0.84	8.08
	F4 14.33	5.3	0.03	5.53
	F5 10.81	4.3	0.53	4.57
3	F1 7.84	3.0	0.74	6.77
	F2 7.12	3.0	0.95	5.78
4	F1 10.72	2.6	0.93	11.44
	F2 23.91	2.3	0.17	4.65
	F3 20.57	2.3	0.55	4.34
5	F1 7.43	12.6	0.09	15.36
	F2 7.10	11.0	0.45	13.62
	F3 8.82	7.1	0.72	7.50
	F4 3.42	5.3	0.07	5.92
	F5 8.32	6.2	0.62	6.69
	F6 7.47	5.5	0.37	6.76
	F7 5.99	3.8	0.06	4.80
6	F1 13.50	3.0	0.47	6.40
	F2 26.15	2.2	0.92	8.34
	F3 17.62	2.7	0.89	5.00
	F4 28.45	2.5	0.95	7.45
	F5 31.22	2.1	0.31	5.24
	F6 26.29	2.0	0.39	7.67
7	F1 23.19	2.8	0.83	13.24
	F2 22.97	1.7	0.67	8.10
	F3 23.58	1.7	0.92	7.78
	F4 23.83	0.9	0.13	4.49
8	F1 15.65	5.2	0.39	21.17
	F2 13.30	3.8	0.22	14.47
	F3 30.95	4.3	0.88	12.85
	F4 25.21	3.9	0.05	10.81
	F5 33.68	3.5	0.34	9.04
	F6 11.91	3.4	0.86	12.53
	F7 24.42	2.9	0.56	8.04
	F8 14.95	1.8	0.80	7.11
	F9 13.70	2.0	0.66	7.84
	F10 21.45	1.4	0.77	5.10
	F11 15.06	1.3	0.96	5.51
9	F1 14.60	4.9	0.98	10.24
	F2 14.88	3.3	0.21	7.22
	F3 23.72	3.0	0.70	5.79
	F4 20.24	2.2	0.23	5.91
10	F1 5.13	9.3	0.90	11.02
	F2 7.67	4.0	0.49	5.77
11	F1 12.98	0.7	0.38	4.21
	F2 2.39	0.7	0.49	3.35
12	F1 10.60	3.9	1.00	7.55
	F2 11.10	3.2	0.73	6.05
	F3 16.52	2.8	1.00	5.75
13	F1 27.73	1.2	0.61	3.91
14	F1 12.47	3.8	0.68	5.08
15	F1 18.62	6.6	0.47	26.84
	F2 16.54	3.7	0.31	15.30
	F3 13.96	1.8	0.58	7.23
	F4 20.87	1.5	0.66	4.72
	F5 19.55	1.5	0.50	5.60
	F6 17.58	1.1	0.72	4.59
16	F1 2.28	1.8	0.51	4.69
	F2 2.73	1.5	0.59	3.83
17	F1 19.03	4.1	0.09	11.34
	F2 20.61	4.7	0.60	11.22
	F3 21.62	3.2	0.65	7.70
	F4 18.83	2.0	0.30	5.73

Table 2. Frequency analysis of the δ Scuti and γ Dor variables found in this work.

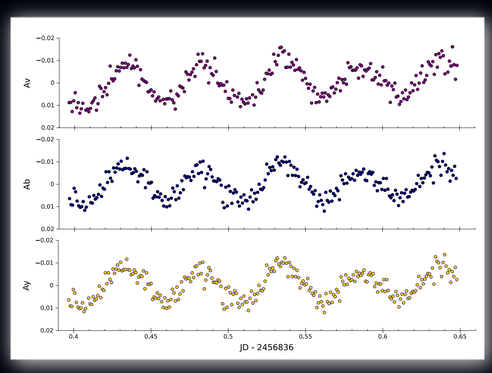

Figure 4. Light curves of ID17 in v, b and y filters.

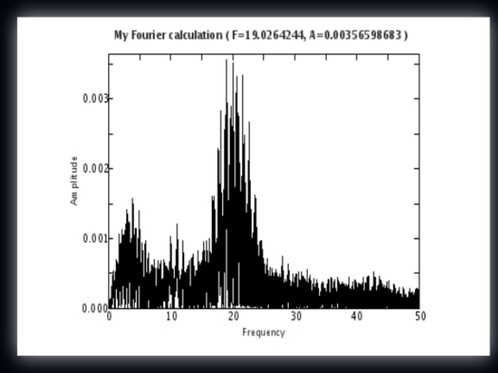

Figure 5. Periodogram of the temporal series of ID17 in the v filter.

5. Conclusions

- We have determined an age of 600 Myrs, E(b-y) = 0.06 and distance module of 10.45 magnitude for NGC 6811.
- We obtained the physical parameters of the cluster stars using Strömgren-Crawford photometry with good agreement with the ones found by Huber et al. (2014).
- In this work we found 16 δ Scuti and one γ Doradus (ID16) variables stars. Twelve δ Scuti stars were previously known from ground-based observations (Luo et al. 2009) and other three were known from Kepler observations (Uytterhoeven et al. 2011), we studied those with multicolour photometry for the first time.
- We found 2 new variables, one δ Scuti and one γ Doradus, which we also confirm with the Kepler data analysis performed by Rodriguez et al. (2016).
- All the variable stars found are members of the cluster according to Sanders (1971) except ID2.
- We achieved a very good precision, finding variability with amplitudes as low as 0.7 millimagnitudes. For every frequency found we verified that the amplitudes in the different filters follow the relation $A_v > A_b > A_y$ characteristic of δ Scuti and γ Doradus pulsations (Rodríguez 2005).

6. References

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Observatorio de Sierra Nevada. Photography courtesy of Alfredo Sota.