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New red giant star in the *Kepler* open cluster NGC 6819

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ABSTRACT

A recent study indicated that 39 red giant stars showing solar-like oscillations were discovered in the field of *Kepler*open cluster NGC 6819. The study was based on photometric distance estimates of 27 stars out of the 39. Using photometric method alone may not be adequate to confirm the membership of these stars. The stars were not previously known in literature to belong to the open cluster NGC 6819. In this study, *Kepler* data was used to study the membership of the 27 stars. A plot of apparent magnitude as a function of the large frequency separation, supplemented with the proper motion and radial velocity values from literature revealed KIC 5112840 to lie on the same plane with the well known members of the cluster. Echelle diagram was constructed, and the median gravity-mode period spacings (ΔP) calculated for KIC 5112840. A value of ΔP = 66.3 s was obtained, thus placing the red giant star KIC 5112840 on the Red Giant Branch stage of evolution. Our evolutionary status result using the approach in this paper is in agreement with what is in the available literature.

1. Introduction

Red-giant stars show rich spectra of solar-like oscillation excited and intrinsically damped by turbulence in the outer layers of the convective envelopes (Chaplin and Miglio, 2013). This near-surface convection triggers solar-like oscillations of stars characterized by variations in amplitude, frequencies and mode lifetimes.

Balona et al. (2013) studied stars in the *Kepler* open cluster NGC 6819 and discovered by independent visual inspection of the periodogram and light curves 39 candidate solar-like stars not previously mentioned in the literature (their table 3). They estimated the distance moduli for 27 individual candidate solar-like pulsators by using a fixed reddening E(B-V) = 0.15 and compared the distribution with that of the stars with known solar-like pulsators in *Kepler* open cluster NGC 6819. However, the fact that the distance moduli of some of the candidate solar-like oscillators agree well with that of the cluster members, one can also presume that mass motions in the atmosphere of red giants may change their radial velocity and thus change the membership criterion (Balona et al., 2013).

Cluster membership is crucial to draw meaningful conclusions from the analysis of stars in a cluster. Star clusters share common properties (distance, age, proper motions and radial velocities). The study of these properties in a group of stars allows us to evaluate their cluster membership.

Stello et al. (2011) found that stars located in cluster NGC 6819 lie on a straight line on K mag versus large frequency seperation ($\Delta\nu$) diagram. The advantage of using K mag versus $\Delta\nu$ is that it provides a direct observational way of comparing the candidate red giants with the known members of the clusters. $\Delta\nu$ is not affected by reddening and K mag is used as a relative distance proxy. This is an alternative way of distinguishing between cluster stars and field stars.

The *Kepler* mission has been helpful in the study of solar-like oscillations in Red Giant (RG) stars. NGC 6819 is one of the four open clusters in the *Kepler* field of view. It is located in the galactic plane, with Right Ascension of 19 hr 39 min 36 s and Declination of $+40^{o}\ 04'$. It has an age of 2.5 Gyr (Basu et al., 2011) and super-solar metallicty of [Fe/H] = $+0.09 \pm 0.03$ (Bragaglia et al., 2001) and reddening of 0.15. The cluster has an average mass of $1.68 \pm 0.03\ M_\odot$ (Basu et al., 2011; Corsaro et al., 2012) and distance modulus of 12.20 ± 0.06 mag (Balona et al., 2013). The cluster average radial velocity is 2.34 ± 0.05 km s^{-1} (Hole et al., 2009). It consists of several eclipsing binaries, stars with solar-like oscillations, three γ Dor variables, blue stragglers, rotational variable stars and seven δ Scuti stars (Christensen-Dalsgaard et al., 2007; García et al., 2011; Balona et al., 2013).

In this paper we use Sloan *griz* photometry of the stars from the *Kepler* Input Catalogue - KIC and time-series photometry from the *Kepler* public archives to study the field of the open cluster NGC 6819, the data are available at the Mikulski Archive for Space Telescopes (MAST)[1]. In particular, we study the 27 candidate red giant (RG) stars showing solar-like oscillations in NGC 6819 which Balona et al. (2013) identified by visual inspection of light curves and periodogram in which they were able to estimate the distance moduli. The aim is to (i) distinguish between the members and non-members using magnitude versus $\Delta\nu$ method, (ii) study the evolutionary stages of the member stars by determining whether they are RGB or RGC based on the magnitude versus $\Delta\nu$ analysis.

[1] http://archive.stsci.edu/kepler/

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The paper is organised as follows: Section 2 presents the data and methods used. Section 3 is the membership and evolutionary status. Section 4 is the conclusions.

2. Data and methods

The data used in this study were obtained with NASA's *Kepler*. The NASA *Kepler* was successfully launched in 2009 March into earth-trailing orbit and has proved to be extremely important for studying stellar pulsations (Borucki et al., 2009). The mission has covered a wide field of 105-square degrees observing the light variations of over 150 000 stars in the direction of Cygnus and Lyra. *Kepler* data is sorted in either Long Cadence (LC) data or Short Cadence (SC) data. In LC data, up to 270 exposures are summed to give data points for every 29.422 minutes whereas, in SC 9 exposures giving one data point every after 58.848 seconds (Murphy, 2012). The LC data involves collection of collateral data continously while the SC collects only data for collateral pixels that project on the SC aperture (Gilliland et al., 2010). The LC data has advantages over the SC data of having high signal to noise ratio (S/N) and caters for the blank regions of the field of view (FOV). This is done by the presence of 4464 pixels on each LC channel (Gilliland et al., 2010). Characteristics of SC data are described in (Gilliland et al., 2010), while Jenkins et al. (2010) describe the characteristics of LC data.

We use the public available *Kepler* data (Q0 - Q17) in this study, where Q stands for quarters refering to the interval in which the data are downloaded after certain time interval, i.e., Q0 is a 10-d commissioning run. We use the stars selected in the KIC within a radius of 10 arcmin of the cluster centre. The light-curve files of the stars contain simple aperture photometry (SAP) flux and a more processed version of SAP with artefact mitigation included, i.e., presearch data conditioning (PDC) flux. Jumps between quarters were calculated. The resulting corrected data were used to calculate periodograms. The *Kepler* star identification numbers for red giant stars that were studied in this work were obtained from Balona et al. (2013). There are 39 candidate red giant stars identified in the *Kepler* open cluster NGC 6819 (Balona et al., 2013).

2.1. The physical stellar parameters

The stellar physical parameters frequency of maximum amplitude, $\nu_{\max}$ and the large frequency separation, $\Delta\nu$ were obtained as in Balona et al. (2013). The effective temperature was obtained following the approach in Ramírez and Meléndez (2005). This method uses color-temperature calibrations since it gives a close relationship between effective temperature, $T_{\rm eff}$ and (V - K) color. The *V* magnitude values that were used were obtained from (Hole et al., 2009) and the *K* magnitude values from the 2MASS catalog (Skrutskie et al., 2006) whereas the metallicity in Bragaglia et al. (2001) was adopted. The physical parameters were used in Section 3.1 and 3.2.

3. Membership and evolutionary status

We discuss a number of criteria that were followed in determining the membership of these candidate red giant stars in the *Kepler* open cluster NGC 6819. These were, determination of variation of magnitude with $\Delta\nu$, establishing an evolutionary track and finally determination of gravity modes to ascertain the membership of the target stars.

3.1. Variation of K and V Magnitude with $\Delta\nu$

The values of $\nu_{\max}$ for the 27 target stars were needed to plot a graph of magnitude versus $\Delta\nu$. These were obtained from the periodograms and compared with the values in Table 3 of Balona et al. (2013). The 27 target stars were plotted together with the known members as shown in Fig. 1. Only 10 stars (KIC 4936463, 4937236, 5023379, 5024322, 5025021, 5025472, 5111655, 5112118, 5112840 and 5113644) were observed to fall on the same plane with the known members from the K-magnitude versus $\Delta\nu$ diagram. On the V-magnitude versus $\Delta\nu$ diagram (see right panel Fig. 1), 9 stars (KIC 4936463, 5023379, 5024322, 5025021, 5025472, 5025895, 5112118, 5112840 and 5113644) were observed to fall on the same plane with the known members.

However, when we checked the membership probabilities in radial velocity (Milliman et al., 2014) and in proper motion (Platais et al., 2013) for each target stars (Table 1), most of the stars have low membership probabilities from radial velocities. We found that only KIC 5112840 which is a binary has radial velocity and proper motions in agreement with the mean values of the cluster. In addition, KIC 5112840 falls on the same plane with the members on the magnitude - $\Delta\nu$ diagram. There are 3 other stars with a high probability from proper motions but their radial velocity by Milliman et al. (2014) indicate they are not members.

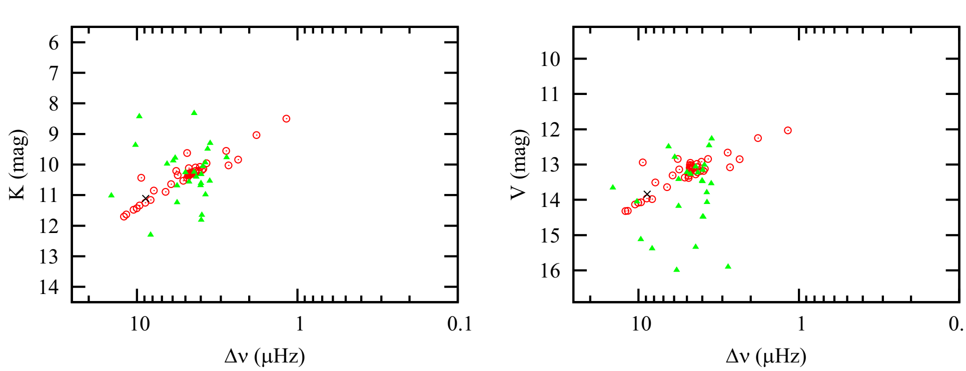

Fig. 1. Left: K-magnitude versus $\Delta\nu$ diagram. Right: V-magnitude versus $\Delta\nu$ diagram. In both Figures, the open circles indicate known members of the cluster (Corsaro et al., 2012; Stello et al., 2011). All the triangles indicate the 27 red giant stars with photometric distance estimates (Balona et al., 2013). Symbol **X** is the location of star KIC 5112840. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
A list of proper motions in Right Ascension (pmRA), in Declination (pmDec), radial velocities (RV) and the probabilities in radial velocities, P(RV) and probabilities in proper motions, P(pm) assigned by Milliman et al. (2014) and Platais et al. (2013) for the 11 candidates. The last column shows the unreddened distance moduli, μ_o from Balona et al. (2013).

KIC	WOCS	pmRA (mas/yr)	pmDec (mas/yr)	RV (km/s)	P(RV)%	P(pm)%	μ_o (mag)
4936463	005019	− 0.47 ± 0.46	− 1.10 ± 0.65	− 4.394 ± 0.11	0	92	12.46
4937236	044015	− 1.82 ± 0.65	− 3.33 ± 0.65	− 15.763 ± 1.00	0	0	12.44
5023379	004019	8.01 ± 0.65	6.60 ± 0.08	− 39.562 ± 0.19	0	0	12.03
5024322	006011	0.31 ± 0.18	− 0.41 ± 0.22	11.141 ± 0.16	0	99	12.28
5025021	004010	2.18 ± 0.13	− 0.61 ± 0.16	37.956 ± 0.11	0	2	11.85
5025472	003017	− 1.22 ± 0.48	− 0.29 ± 0.43	− 23.459 ± 0.40	0	95	11.99
5025895	015024	6.15 ± 0.85	6.43 ± 0.12	− 24.334 ± 0.23	0	0	10.04
5111655	003020	− 0.25 ± 0.22	4.45 ± 0.19	− 13.225 ± 0.18	0	0	11.99
5112118	005009	8.56 ± 0.28	5.51 ± 0.11	− 27.244 ± 0.23	0	0	12.02
5112840	006006	− 0.96 ± 0.21	− 0.08 ± 0.17	0.005 ± 0.37	76	89	12.10
5113644	004020	− 0.24 ± 0.31	− 2.35 ± 0.49	− 86.470 ± 0.17	0	1	12.16

3.2. Evolutionary status

Using the effective temperature, large frequency separation ($\Delta\nu$) and frequency of maximum amplitude ($\nu_{\max}$), we calculated the luminosity of KIC 5112840 using $\log L/L_{\odot} = -17.274 + 5\log T_{\text{eff}} + 2\log \nu_{\max} - 4\log \Delta\nu$ (Balona et al., 2013). With the parameters of KIC 5112840: $\nu_{\max} = 109.6$ μHz, $\Delta\nu = 8.83$ μHz, $T_{\text{eff}} = 4736$ K, we obtained $\log L/L_{\odot} = 1.40$. We used the values of $\log L/L_{\odot}$ and T_{eff} of KIC 5112840 to place it in the HR diagram. It is found that KIC 5112840 occupies the same region with the known red giant stars. An echelle diagram was constructed for KIC 5112840. Following the approach in Abedigamba (2016), we smoothened the periodogram in order to properly extract the observed frequencies. The extracted observed frequencies, with the corresponding amplitudes, are shown in Table 2. The graph of the observed frequency (ν) as a function of ν modulus $\Delta\nu$ gives the echelle diagram (Fig. 2). The period spacings (ΔP) for KIC 5112840 was obtained using the approach presented in Abedigamba (2016). We convert the observed frequencies of $l = 1$ to the period (P) and then calculate the period spacings in either ascending or decending order. For a star in question, the main period spacing considered corresponds to the largest number of modes. For the case of KIC 5112840, (ΔP) = 66.3 s is obtained.

The ΔP index as a function of large frequency separation ($\Delta\nu$) was used to deduce the evolutionary status of KIC 5112840. As pointed out by Bedding et al. (2011) in their Fig. 3 (top panel), if a star has ΔP < 100 s it is on the red giant branch (RGB), while stars with ΔP ~ 100 - 300 s are in the red clump (RC) stage of evolution. The ΔP of this star was found to be 66.3 s and thus KIC 5112840 is on the RGB stage of evolution.

4. Conclusions

The probabilities from proper motions and radial velocity indicate that KIC 5112840 has values which are in agreement with the mean values for the cluster members. The variation of magnitude with the large frequency separation revealed that KIC 5112840 was located on the same plane as the well known members of the cluster. The values of the calculated luminosity and effective temperature places KIC 5112840 in the region occupied by the RGB/RGC. An echelle diagram was constructed to confirm the status of the star KIC 5112840, from which the median gravity-mode period spacing, ΔP = 66.3 s was obtained, thus placing the red giant star KIC 5112840 on the Red Giant Branch stage of evolution. Our evolutionary status result using the approach in this paper is in agreement with what is on SIMBAD Astronomical Database. Therefore, we can conclude that the star KIC 5112840 is a RGB member of NGC 6819.

Table 2
The extracted frequencies (i.e., ν, ν modulus $\Delta\nu$ and the amplitudes) for the star KIC 5112840.

ν mod $\Delta\nu$ (μHz)	ν (μHz)	Amplitudes (ppt)
1.797	107.63	2.00
1.680	116.34	1.94
6.294	112.13	1.73
0.491	115.15	1.67
6.018	103.03	1.52
1.652	98.67	1.42
5.475	111.31	1.38
0.599	106.43	1.38
6.809	112.64	1.34
1.732	125.21	1.32
0.628	97.64	1.32
6.810	103.83	1.31
6.456	121.11	1.31
1.902	90.10	1.25
7.087	86.46	1.23
5.735	120.39	1.12
6.131	94.33	1.09
2.149	81.52	1.08
5.184	102.20	0.98
7.937	104.95	0.96
0.675	124.15	0.94
4.448	127.92	0.93
7.445	122.10	0.89

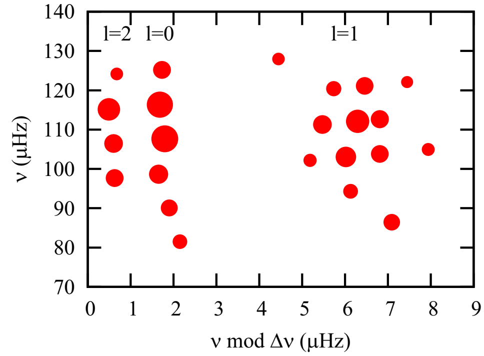

Fig. 2. Echelle diagram for KIC 5112840 star which was constructed using the extracted observed frequencies and the large frequency separation. Vertical points running parallel and closer together are the $l = 0$ and $l = 2$ modes while points scattered and far away from the two parallel lines are the $l = 1$ mixed modes. The larger the circle, the higher the amplitude.

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