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KIC 8263801: A clump star in the *Kepler* open cluster NGC 6866 field?

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HIGHLIGHTS

- We study solar-like oscillations in red giant stars in the field of open cluster NGC 6866 using data from *Kepler* space mission.
- Search for red clump stars amongst red giants stars are made.
- Convincing echelle diagram constructed for KIC 8263801.
- Gravity-mode period spacings calculated for KIC 8263801.
- KIC 8263801 is a secondary red clump burning helium in a non degenerate core.

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ABSTRACT

In this paper we study the field of *Kepler* open cluster NGC 6866 using the data obtained from *Kepler* mission collected for a period of 4 years. We search for the red clump (RC) stars amongst the red giant (RG) stars showing solar-like oscillations using median gravity-mode period spacings (ΔP). We find a RG star KIC 8263801 having median gravity-mode period spacing 173.7 ± 6.4 s. We claim based on the median gravity-mode period spacing that KIC 8263801 is a secondary red clump (SRC) star which is massive enough to have ignited Helium burning in a non degenerate core. In the literature, no classification for KIC 8263801 has been provided. This is the first time that a star located in the field of NGC 6866 is classified in this manner.

1. Introduction

The *Kepler* mission has been helpful in the study of solar-like oscillations in Red Giant (RG) stars. *Kepler* field has four open clusters, NGC 6866 is one of the clusters and the youngest (age 0.65 Gyr). It is the least studied cluster amongst the four *Kepler* open clusters. It is centered at (RA = 20:03:55, Dec. = +44:09:30; l = 79°.560, b = +6°.839) and with a main-sequence turn-off spectral type of about A3. NGC 6866 is roughly located in the direction of solar apex (the point towards which the Sun is moving) which means that all stars (members and non-members) have similar proper motion. Therefore, one cannot use proper motion to discriminate between members and non-members. No radial velocity measurements for stars located in the field of NGC 6866 are available to help in discriminating between members and non-members. The only method left in discriminating between members and non-members in the field of NGC 6866 is the photometric distance method. However, with only a single method one cannot be quite sure of the membership.

Molenda-Żakowicz et al. (2009) searched the cluster for variables and discovered three δ Scuti and two γ Doradus stars. They also found that most of the stars were placed on the main sequence and that the red giant clump were not visible. Loktin et al. (1994) derived [Fe/H] = +0.10 from photometry and obtained an age = 0.66 Gyr. Gunes et al. (2012) found the age value of 0.8 ± 0.1 Gyr, while Joshi et al. (2012) estimated the age from the color-magnitude diagram using the theoretical isochrones of solar metallicity and found an age ∼ 0.63 Gyr. Balona et al. (2013a) estimated the age of *Kepler* open cluster NGC 6866 to be 0.65 ± 0.1 Gyr with isochrones of solar composition. Kharchenko et al. (2005) obtained an age of 0.5 Gyr using isochrone-based procedure. Joshi et al. (2012) obtained UBVRI photometry and time series photometry of several stars in NGC 6866. In fact, they discovered 19 additional new variables that included δ Scuti and γ Doradus stars. Joshi et al. (2012) also found a distance modulus of ∼ 11.84 mag. Another distance modulus calculation of NGC 6866 was performed by Gunes et al. (2012) who found a value of 11.08 using decontamination techniques. According to Hekker et al. (2011a), no red giants have been observed in NGC 6866, however the study carried out by Balona et al. (2013a) on the field of *Kepler* open cluster NGC 6866 reveals that there are 23 Red Giants (RG) with solar-like oscillations. Balona et al. (2013a) used photometric distance method to claim that 5 RG stars out of the 23 RG with solar-like oscillations are members of the *Kepler* open cluster NGC 6866. They made comparison between the photometric distance of each of the star with the one of the cluster.

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The aim of this paper is to survey the field of *Kepler* open cluster NGC 6866 for clump stars amongst the red giant stars showing solar-like oscillations by constructing echelle diagrams and measuring median gravity period separations. Recently, RC stars have been used in the study of mass loss (Abedigamba et al., 2015; Miglio et al., 2012). Therefore, knowing which stars are RC in the fields and clusters are important in broadening our understanding of mass loss in RG stars. In addition, this will help to improve our knowledge of the stages of stellar evolution of RG stars in the field of *Kepler* open cluster NGC 6866.

2. Data

The data of RG with solar-like oscillations in this study were obtained with NASA's *Kepler*. There are more than 13 000 red giants with solar-like oscillations observed with *Kepler* (Stello et al., 2013). The NASA *Kepler* was successfully launched in 2009 March into earth-trailing orbit Borucki et al. (2009). The *Kepler* mission has been important in the study of stellar pulsation. This mission has observed the light variations of over 150 000 stars in a large field of 105-square degrees in the direction of Cygnus and Lyra. Most of the observations are obtained using an exposure time of about 30 min (long-cadence mode), but a few thousand stars have also been observed with an exposure time of about 1 min (short-cadence mode). The *Kepler* magnitudes are in the range $6.3 < \mathrm{Kp} < 18.4$ and effective temperatures $3200 < T_{\mathrm{eff}} < 10,000$ K. *Kepler* studies of pulsating red giants in these clusters allow independent estimates of mass, radius and surface gravity of each star.

We use the public available *Kepler* data (Q0 - Q16) 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. For each star in the field of NGC 6866, Balona et al. (2013a) visually examined the periodogram and attached a variability class, guided by the location of the star in the HR diagram. Solar-like oscillators were classified based on the nature of the periodogram with characteristic Gaussian like envelope, from which RG stars with solar-like oscillations were identified based on their location in the HR diagram. We search for the RGC stars amongst the RG stars identified by Balona et al. (2013a) using the following procedures (i) correcting for *Kepler* photometry, (ii) calculating the periodogram, (iii) identifying solar-like observed frequencies, (iv) identifying ν_{max} and calculating $\Delta\nu$ using autocorellation, (v) constructing echelle diagrams, (vi) measuring median gravity-mode period spacings (ΔP) where possible. A total of 23 stars in NGC 6866 were identified by Balona et al. (2013a) using visual inspections of the light curves and periodograms as stars with solar-like oscillations. We used all the 23 RG stars in this study to determine the population of the RC stars.

3. Mass and radius determination

The mass and radius of a star with solar-like oscillation can be determined from a measurement of the frequency of maximum amplitude ν_{max} and the large separation if the effective temperature is known. The ν_{max} is related to the acoustic cut-off frequency of the star and physical parameters (Kjeldsen and Bedding, 1995):

$$\nu_{\mathrm{max}} \approx \nu_{\mathrm{max}\odot} \frac{M/M_{\odot}}{(R/R_{\odot})^2\sqrt{T_{\mathrm{eff}}/T_{\mathrm{eff}\odot}}},$$

where the solar value for the frequency of maximum amplitude is $\nu_{\mathrm{max}\odot} = 3120\ \mu$ Hz Kallinger et al. (2010), $M/M_{\odot}$, $R/R_{\odot}$ and $T_{\mathrm{eff}}/T_{\mathrm{eff}\odot}$ is the stellar mass, radius and effective temperature relative to the Sun. The frequency separation between successive overtone (separation between peaks of the comb) is a very important parameter. Acoustic modes tend to form equally-spaced frequency structures consisting of modes of the same spherical harmonic degree, *l*, but of successive overtones, *n*. The large separation, $\Delta\nu$, is the separation between successive overtones and depends on mean density of the star:

$$\Delta\nu \approx \Delta\nu_{\odot}\sqrt{\frac{M/M_{\odot}}{(R/R_{\odot})^3}},$$

where $\Delta\nu_{\odot} = 134.88\ \mu$Hz (Kallinger et al., 2010). With ν_{max} and $\Delta\nu$ in μHz, Balona et al. (2013b) obtained:

$$\log M/M_{\odot} = -7.6056 + \tfrac{3}{2}\log T_{\mathrm{eff}} + 3\log\nu_{\mathrm{max}} - 4\log\Delta\nu, \quad (1)$$

$$\log R/R_{\odot} = -1.1151 + \tfrac{1}{2}\log T_{\mathrm{eff}} + \log\nu_{\mathrm{max}} - 2\log\Delta\nu, \quad (2)$$

$$\log L/L_{\odot} = -17.274 + 5\log T_{\mathrm{eff}} + 2\log\nu_{\mathrm{max}} - 4\log\Delta\nu. \quad (3)$$

We apply Eqs. (1)–(3) in this study to determine the masses, radii and luminosities of the stars in the work. We are aware that one can also calculate the masses and radii of red giant stars showing solar-like oscillations using grid-based analysis techniques which depends on stellar age and chemical composition (Gai et al., 2011). Hekker et al. (2011b) used both direct and grid-based method in characterising RG stars in the public *Kepler* data and both methods produced similar results showing the different population of stars.

4. Results

4.1. Using echelle diagram to separate out different modes

The echelle diagram was first introduced by Grec et al. (1983) in the study of the Sun. It involves dividing the power spectrum into equal segments of length $\Delta\nu$ and stacking them one above the other so that modes with a given degree align vertically in ridges. Any departures from regularity are clearly visible as curvature in the echelle diagram (Bedding, 2014). The echelle diagrams have been widely used in the study of RC and red giant branch (RGB) stars (Bedding et al., 2011; Beck et al., 2011; Corsaro et al., 2012). To construct an echelle diagram, one needs to smooth the periodogram (Fig. 1, top panel) such that the observed frequencies are properly identified. We used this procedure; (i) Smooth the periodogram by applying a running mean method (Fig. 1, bottom panel). Smoothing the periodogram eliminates the many close frequencies, giving rise to a single

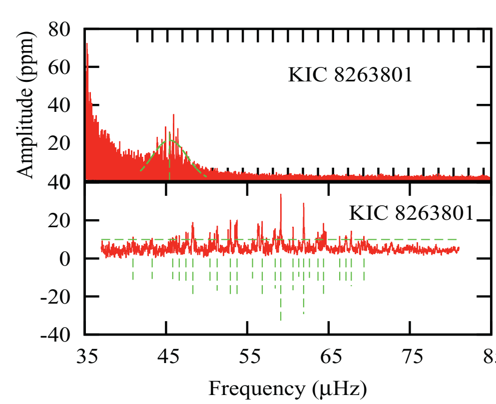

Fig. 1. Top: The periodogram of KIC 8263801 obtained after correcting for the drifts and jumps in the the raw (uncorrected) light curves of the stars (top panel). Comb-like structures which are typical characteristics of stars with solar-like oscillations are clearly seen in the periodogram. The location of the frequency of the maximum amplitude gives what is known as the ν_{max}. Bottom: Smoothed periodograms showing observed frequencies extracted from the periodograms in the top panel. We used running mean approach to smoothen the periodogram. The horizontal line is the noise level limit.