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Distance moduli of open cluster NGC 6819 from Red Giant Clump stars

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HIGHLIGHTS

- We study open cluster NGC 6819 using data from *Kepler* space mission.
- Data of Red Giant Clump stars are used to derive distance moduli of NGC 6819.
- Reddening adopted for the whole cluster and individual Red Giant Clump stars.
- Distance moduli obtained with Red Giant Clump stars are in agreement with other methods.
- Red Giant Clump stars can be used as 'distance candles' for open cluster NGC 6819.

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ABSTRACT

In this paper we study *Kepler* open cluster NGC 6819 using *Kepler* data of Red Giant Clump (RGC) single member (SM) stars. The *Kepler* data spans a period of 4 years starting in 2009. In particular, we derive distance moduli for each individual RGC star, from which we get the mean distance modulus of $\mu_0 = 11.520 \pm 0.105$ mag for the cluster when we use reddening from the *Kepler* Input Catalogue (KIC) for each RGC star. A value of $\mu_0 = 11.747 \pm 0.086$ mag is obtained when uniform reddening value $E(B-V) = 0.15$ is used for the cluster. The values of μ_0 obtained with RGC stars are in agreement with the values in the literature with other methods. We report for the case of *Kepler* open cluster NGC 6819 that RGC stars can be used as 'distance candles' as has been done in the literature with other open clusters.

1. Introduction

Distance is a fundamental basic parameter in stellar astrophysics and astrophysics in general. Stars which are members of the cluster are useful in the determination of distance modulus of the cluster. Distance modulus, μ, is the difference between the apparent magnitude (m) and the absolute magnitude (M) of a star: $\mu = m - M$. Absolute magnitude is the apparent magnitude that a star would have if it were 10 parsecs away from Earth. Due to the fact that the apparent magnitude in most cases has to be corrected for reddening, it is commonly written as $\mu_0 = m_0 - M$ or $(m-M)_0$.

NGC 6819 is an open cluster centered at RA = 19:41:18, Dec = 40:11:12. It is a moderately old cluster with age of $\approx$ 2.5 Gyr (Rosvick and Vandenberg, 1998; Kalirai et al., 2001; Basu et al., 2011; Balona et al., 2013) and near-solar or slightly super-solar metallicity ([Fe/H]= $+0.09 \pm 0.03$; Bragaglia et al., 2001). Rosvick and Vandenberg (1998) obtained a distance modulus of $\mu_0 = V_0 - M_V = 12.36$ mag and a reddening of $E(B-V) = 0.16$ from *BV* photometry and main-sequence fitting. Kalirai et al. (2001) used *BV* photometry and derived a distance modulus $\mu_0 = 12.30 \pm 0.12$ mag and a reddening of $E(B-V) = 0.10$. Balona et al. (2013) used asteroseismic method to calculate the cluster distance modulus $(m-M)_0 \approx 12.2 \pm 0.06$ mag with reddening of $E(B-V) = 0.15$ and metallicity of [Fe/H]= +0.09 dex from the Red Giant (RG) stars showing solar-like oscillations. Recently, Wu et al. (2014) derived a distance modulus of 11.88 ± 0.14 mag using asteroseismic method from the data of red giant branch stars. Hole et al. (2009) obtained photometry and radial velocities for 1207 stars in the field of the cluster from which they determined 480 cluster members. They also obtained 24 Red Giant Clump candidates in NGC 6819. Red Giant Clump (RGC) stars are important in an open cluster because they have roughly the same luminosities which means that they are useful in the determination of cluster distance and reddening as was first advocated for by Cannon (1970). Red clump stars have been useful in the determination of distance moduli of clusters such as NGC 6791 (Harris and Canterna, 1981; Anthony-Twarog, 1984; Zurek et al., 1993; Garnavich et al., 1994; Carney et al., 2005). Wu et al. (2014)

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Table 1
A list of RGC stars in the field of NGC 6819. The columns are: the *Kepler* Input Catalogue number – KIC, WIYN OPEN CLUSTER STUDY – WOCS, membership – Mem, the frequency of maximum amplitude, ν_{max}, the large frequency separation, $\Delta\nu$, estimated effective temperature, T_{eff} and luminosity ($\log L/L_\odot$) calculated from solar-like oscillations.

KIC	WOCS	Mem	$\nu_{max}(\mu\text{Hz})$	$\Delta\nu(\mu\text{Hz})$	T_{eff}/K	$\log L/L_\odot$
5024327	011002	SM	44.022	4.704	4675	1.6692
5024967	006009	SM	45.066	4.716	4657	1.6768
5111949	004011	SM	46.234	4.791	4723	1.7022
5112373	005005	SM	44.885	4.588	4673	1.7287
5112491	010002	SM	40.981	4.649	4680	1.6302
5112730	004005	SM	39.768	4.534	4646	1.6310
5112938	002006	SM	43.724	4.736	4667	1.6480
5200152	003021	SM	43.195	4.671	4751	1.7002
5112387	003007	SM	43.123	4.681	4682	1.6631
5112467	006003	SM	45.367	4.730	4664	1.6807

give a summary of distance modulus determination of NGC 6819 (their Table 1) using different approaches such as asteroseismology (Basu et al., 2011; Miglio et al., 2012; Balona et al., 2013), binaries (Talamantes et al., 2010; Sandquist et al., 2013; Jeffries et al., 2013), isochrone (Kalirai et al., 2001; Hole et al., 2009). It is clear that RGC stars have not been used for distance modulus determination in the case of NGC 6819. RGC stars have a helium-burning core surrounded by a hydrogen-burning shell (Cannon, 1970).

The aim of this paper is to derive the distance moduli of *Kepler* open cluster NGC 6819 from RGC stars. No distance modulus studies have been carried out using clump stars for the case of NGC 6819 according to the current available literature. Red clump stars have been used in other cluster as 'standard candles' (Gao and Chen, 2012; Garnavich et al., 1994). We aim to do this by adopting reddening for (i) the whole cluster and (ii) individual RGC stars.

2. Data

The data of RGC in this study were obtained with NASA's *Kepler*. 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. We use the public available *Kepler* data (Q0 – Q16) in this study, where Q stands for quarters referring to the interval in which the data are downloaded after certain time interval, i.e., Q0 is a 10-d commissioning run. The light-curve files of the stars contain simple aperture photometry (SAP) flux and a more processed version of SAP with artifact mitigation included, i.e., presearch data conditioning (PDC) flux. Jumps between quarters were calculated. We identify ν_{max} from the periodogram (Fig. 1) and calculate $\Delta\nu$ using autocorelation as shown in Table 1. In determining distance moduli, we selected stars that are single members (SM) of the cluster according to Hole et al. (2009). Preference was also given to stars that were not marked by Corsaro et al. (2012) as outliers, misclassified CMD or evolved. We omitted stars listed as discrepant by Balona et al. (2013). In addition, the classification of the stars as RGC were also based on the measurement of median gravity-mode period spacings, ΔP (Corsaro et al., 2012), and all our samples/targets (RGC) are those used by Abedigamba et al. (2015) in the study of mass loss in the red giant branch. The effective temperature for each star was estimated using the color-temperature calibrations following the method of Ramírez and Meléndez (2005). We used the $(V-K)$ color with the V values obtained from Hole et al. (2009) and the K values from the 2MASS catalog (Skrutskie et al., 2006). The adopted metallicity used in obtaining T_{eff} in this work are those in Bragaglia et al. (2001). For each of the selected stars in

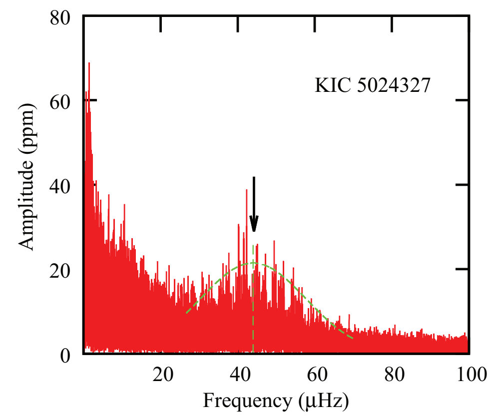

Fig. 1. The periodogram of one of the RGC stars KIC KIC5024327. The arrow shows the location of the frequency of the maximum amplitude, ν_{max}.

Table 1, ν_{max} and $\Delta\nu$ have been used together with the estimate for T_{eff} to obtain $\log L/L_\odot$ using Eq. (1).

3. Luminosity determination

The luminosity 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):

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

where the solar value for the frequency of maximum amplitude is $\nu_{max\odot} = 3120\ \mu\text{Hz}$ (Kallinger et al., 2010), $M/M_\odot$, $R/R_\odot$ and $T_{eff}/T_{eff\odot}$ is the stellar mass, radius and effective temperature relative to the Sun respectively. 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 $\Delta\nu_\odot = 134.88\ \mu\text{Hz}$ (Kallinger et al., 2010). With ν_{max} and $\Delta\nu$ in μHz, Balona et al. (2013) obtained:

$$\log L/L_\odot = -17.274 + 5\log T_{eff} + 2\log \nu_{max} - 4\log \Delta\nu. \quad (1)$$

We apply Eq. (1) in this study to determine the luminosities of the RGC stars in the work as shown in Table 1.

4. Method

4.1. Distance determination

In this section we outline how the distance moduli of the cluster were calculated from the distance moduli of the RGC stars. Only clump stars are used in this case because they are useful in the determination of cluster distances, reddening, and to investigate mass loss & internal mixing in evolving stars as first pointed out by Cannon (1970). This is done in several steps. The first step was to convert the KIC *griz* to standard Sloan Digital Sky Survey (SDSS) *griz* using the following equation given by Pinsonneault et al. (2012) as:

$$g_{SDSS} = g_{KIC} + 0.0921(g-r)_{KIC} - 0.0985,$$