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Searching for Be Stars in the Open Cluster NGC 663

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Abstract. With the Palomar Transient Factory Survey, we report Be stars candidates in the open cluster NGC 663, determined by Hα photometry which is to initiating a program to search for emission stars in clusters of different ages. We affirm the membership of these candidate by 2MASS magnitudes and colors, and by proper motions. Through the verifications, one known Be stars was ruled out because its inconsistent proper motions, and four new Be stars were discovered. More emission-line sources were also discovered, including non-member Be stars, dwarfs, and giants.

1. Introduction

The main issue of a single Be star is the lack of age signature. On the contrary, we can study the Be stars in a sample of clusters with different age. However, an open cluster is consist of uncompleted sample of Be stars due to two reasons: (1) a thorough survey for emission-line stars is exhausting because a close cluster cover a extensive sky area, (2) photometric and spectroscopic variability are seen in Be stars. To investigate the Be star phenomena (e.g., fast rotation correlate with massive stellar evolution), we proposed an a pilot program to search Be stars in open clusters with a wide field coverage of the Palomar Transient Factory (PTF) project. In this work, we present a methodology of emission-line stars identification. The young open cluster NGC 663 is a well-known cluster containing a significant number of Be stars. This cluster is our first target with an age of 31 Mys and at a distance 2.1 kpc (Kharchenko et al. 2013).

2. The Search Region Around NGC 663

We determine an appropriate region for NGC 663 to include all possible members with a radial density profile (Figure 1). The stars are chosen from 2MASS point sources with S/N $\geq$ 10 in all J, H, K_s bands and with proper motions (PMs) uncertainties < 5.0 mas yr^{-1}. A 3σ diameter of $\sim 30'$ is determined by the best half-Gaussian fitting. Chen et al. (2004) suggested that open clusters often have irregular morphology during their either the interior relaxation process or

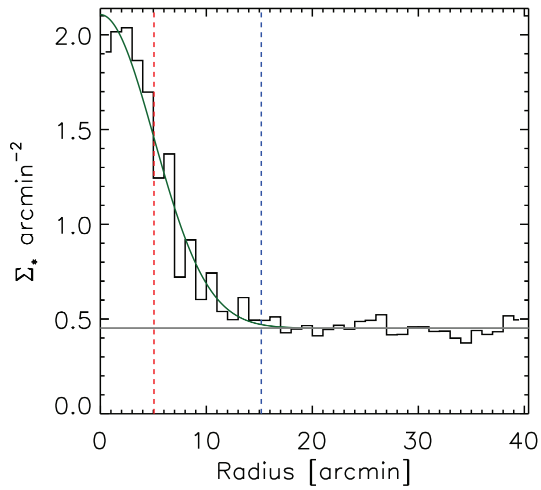

Figure 1. (Left): Radial density profile for NGC 663. The grey horizontal line illustrates the background density. The green curve indicates the best Gaussian fitting results. Red and blue vertical lines show the width of the curve with 1σ and 3σ, respectively.

the Galactic exterior perturbation. To cover all possible candidates and known Be stars, we therefore adopted a box with the side of 40′as the field of NGC 663.

3. Hα Photometry and Emission-Line Candidates

As shown in the left panel of Figure 2, one can see that most stars with large r−Hα are possible emission-line stars, under the assumption that most of the stars in the field show neither Hα in emission nor in absorption. The candidates with r−Hα > $2\sigma_p$ in each 0.5 mag bin were selected. The photometric scattering σ_p is the error propagated of photometric and systematic errors. The photometric error is the weighted error of r−Hα values for stars within the 0.5 mag bin while the systematic errors are the standard deviation of r−Hα values for stars within the same bin. In total, we identify 42 Hα emission candidates. Six known Be stars are not selected by our method, including PKK1, PKK2, PKK3, GG99, G32, and L613. We compare their r−Hα values with the Hα equivalent widths (EW(Hα)) adopted from Mathew & Subramaniam (2011), as seen in the right panel of Figure 2. Our results of r−Hα values are consistent with the earlier EW(Hα) measurement.

4. Identification of Membership

With photometric and kinematic method, we determine the memberships of NGC 663. As illustrated in Figure 3 (left), we first select stars near a isochrone (Girardi et al. 2002) of ~ 31 Myr (Pandey et al. 2005) located at 2.1 kpc (Kharchenko et al. 2013) with E(B−V) of 0.7 mag. The photometric members are identified by an extensive selected region with $J - K_s$ ~ 1.2 mag, because a Be star could have extraordinarily large infrared excess with $J - H$ and $H - K_s$ both greater than 0.6 mag (Lee & Chen 2011). And then we identify the kinematic membership with PMs. The average PM of NGC 663 is ($\mu_\alpha = -0.80, \mu_\delta = -2.43$) mas/yr with standard deviations $\sigma_{\mu\alpha}$ ~3.58 mas yr^{-1} and $\sigma_{\mu\delta}$ ~ 3.41 mas yr^{-1}. As shown in Figure 3 (right), we adopt a 2-sigma

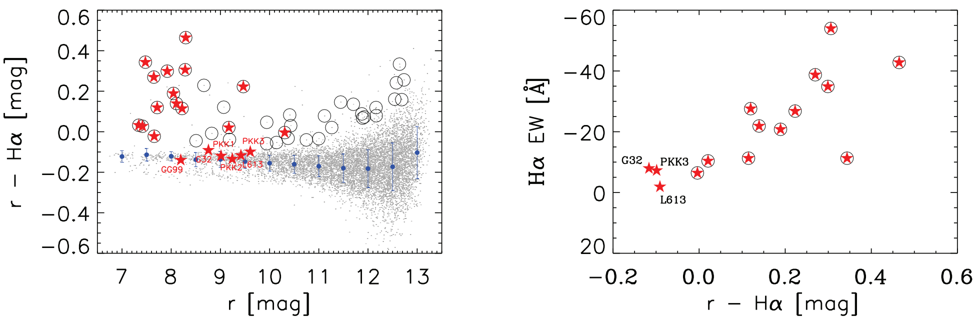

Figure 2. (Left): PTF magnitudes of r−Hα vs. r. Grey dots: all stars within the field of $2^\circ \times 1^\circ$. Blue filled circles represent mean values of r−Hα values within each 0.5 mag r-band bin. Open circles: emission-line candidates; red pentagrams: known Be stars in NGC 663. The symbols with numbers are ID numbers of four newly found Be stars. (Right): EW(Hα) versus r−Hα, in the same format as left figure. There is a positive correlation between the EW(Hα) and r−Hα values.

region (σ_μ = 4.94 mas/yr) approach to determine the kinematic members. Finally, we verify 959 member stars in total with color-magnitude and PM analysis. Among these, 23 stars are identified to be members and with Hα emission.

Figure 4 is the $J - H$ vs. $H - K_s$ color-color diagram. We define a grey-dashed region including 99% of Be stars (Zhang et al. 2005). Therefore, we suggest the emission-line stars in this region as Be stars, so there are 19 Be stars in NGC 663. Among them, 15 stars are formerly list of known Be stars. Therefore, four new Be stars were discovered (ID number: 12, 35, 39, and 41) in NGC 663. Besides, one known Be star SAN 28 was excluded because of its inconsistent PM ($\mu_\alpha = -16.07 \pm 3.95, \mu_\delta = -34.09 \pm 3.95$ mas yr^{-1}) with that of NGC 663.

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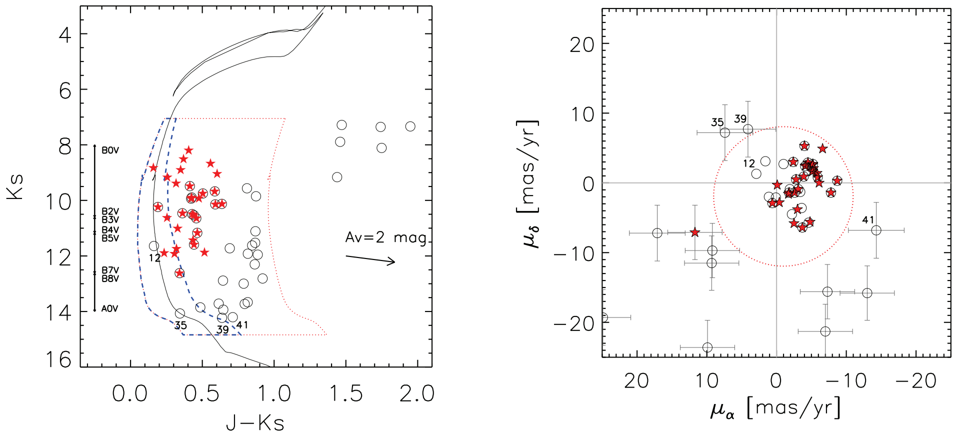

Figure 3. Symbols are same as Figure 2. (Left): 2MASS color–magnitude diagram in the cluster region. The black solid line represents the post-main-sequence isochrone. The objects within the blue-dashed zone are selected as photometric members, including non-emission-line stars. A wide red-dashed zone is for selection of emission-line candidates. (Right): Stellar PMs of known Be stars and emission-line candidates toward NGC 663. The red- dashed circle shows the probable PM range for membership.

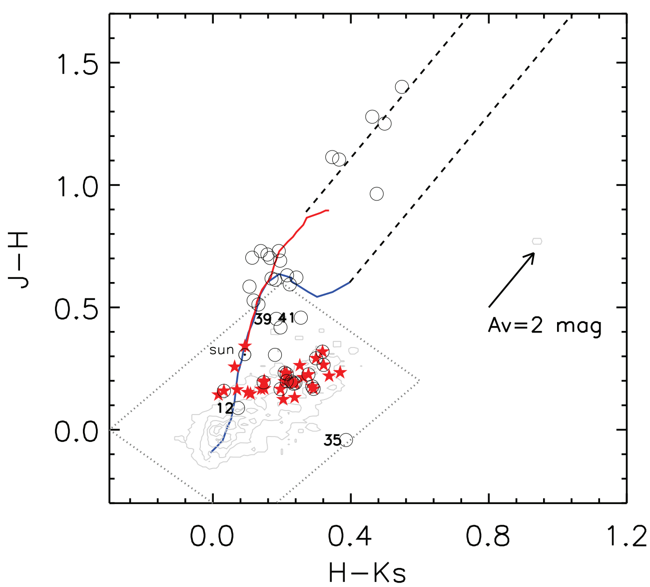

Figure 4. 2MASS color–color diagram in the cluster region, in the same format as Figure 1. The red and blue curves are the giant and dwarf loci (Bessell & Brett 1988). The arrow is the reddening direction (Rieke & Lebofsky 1985) for typical Galactic interstellar extinction (R_V = 3.1), and the dashed lines encompass the region of reddened giants and dwarfs. The grey contours show known Be stars distribution. We assume all possible Be stars in the dashed box.