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The massive stellar population of IC 10

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Abstract. Using photometric data available in the literature we want to identify the massive stars members of the metal-poor irregular galaxy IC 10 and the clusters and associations that they form. The census of the clusters and associations of these objects is needed to provide information about age and environment on this galaxy that is apparently going through a starburst phase.

Keywords. stars: early-type, galaxies: irregular, stellar population, starburst

1. Introduction

IC 10 is a metal-poor (Z $\sim$ 0.36 Z_{SUN}, Garnett (1990)) dwarf irregular galaxy of the Local Group. It lies at a low galactic latitude (l = 119° .0, b = −3° .3), which makes reddening to this object intense and very uncertain. According to Kim *et al.* (2009) IC 10 is at a distance around 0.7-0.8 Mpc. IC 10 also shows a high star formation rate and a huge number of Wolf-Rayet stars per unit luminosity (Massey & Armandroff 1995). All characteristics suggest that IC 10 is experiencing an intense and very recent burst of star formation. OB associations are an ideal laboratory to study the evolution of massive stars because of their expected small age spread and homogeneous chemical composition. In this work we produce a catalog of OB associations in IC 10, so that the impact of low metallicity on the evolution of massive stars can be evaluated in subsequent follow-up studies.

2. Selection of objects

A catalog of UBVRI magnitudes of stellar-like objects in a region $\sim$ 30 arc min. wide around IC 10 was presented by Massey *et al.* (2007) (LGGS catalog). The original catalog contains 20663 sources, but only 8173 of them have detections in the U-, B- and V-band simultaneously and $(U-B)$ and $(B-V)$ errors $\leqslant$ 0.05. Following Garcia *et al.* (2009), candidate blue massive stars were chosen from their reddening-free Q parameter (Q $= (U-B) - 0.72 \times (B-V)$) that overcomes the problem of uncertain extinction towards the line of sight. We select objects with Q $\leqslant -0.5$ that corresponds to stars hotter than B5. We found that most of these blue objects are indeed over the optical image of the galaxy, but many others lie at great angular distance from it. If these objects are not IC 10 members they can be hot stellar objects from our own galaxy and therefore the contamination of local sources in the final list could be large.

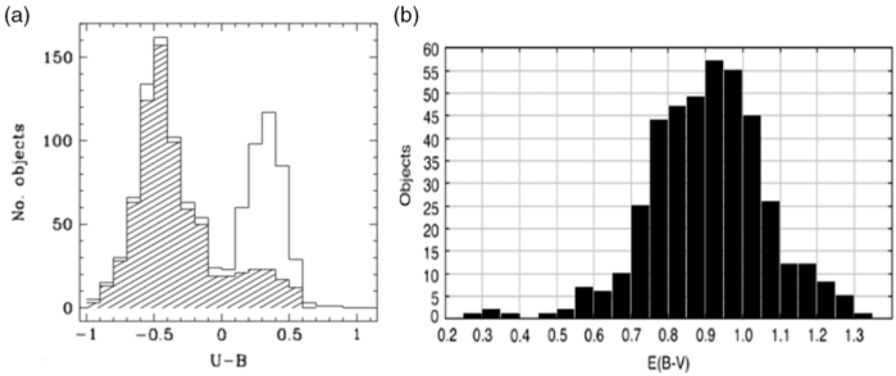

Figure 1. a.- Distribution of $(U-B)$ color of the objects with -1. $\leqslant$ Q $\leqslant$ -0.5 from the Massey et al. (2007) catalog of stellar objects around IC 10 (hollow histogram). The filled histogram correspond to those objects that are inside a region of 5 arc min around the center of the galaxy. In order to minimize the contamination by Galactic objects in the list of IC 10 candidate massive stars, we chose objects with the Q $\leqslant$ -0.5, -1.0, $\leqslant$ $(U-B)$ $\leqslant$ 0.0 and in a region of 5 arc min diameter around the center of IC 10. b.- Distribution of the color excess E(B-V) of the candidate blue massive stars of IC 10.

In order to separate the local objects from the IC 10 objects we present the histogram of $(U-B)$ color of the Q-selected objects in Fig. 1a. (hollow histogram). We found that the distribution is bimodal with two peaks centered at -0.5 and 0.4. The shaded histogram corresponds to objects within a circular region of 5 arc min diameter around the center of IC 10. Most objects with distances larger than 2.5 arc min belong to the $(U-B) = 0.4$ peak, whereas the overwhelming majority of objects close to IC 10 have $(U-B)$ colors between 0.0 and -1.0. Thus, we add $0.0 \leqslant (U-B) \leqslant -1.0$ as a criteria to select candidate massive stars. We identify 529 objects within 2.5 arc min from the centre of IC 10.

3. OB Associations

Following the identification technique presented by Bartinelli 1991 we use a code, based on the friends-of-friends algorithm, to find OB associations in IC 10. This code is the same used by Garcia *et al.* (2009) in their search of OB associations in IC 1613. In order to find the maximum distance (Ds) between stars to be considered members of the same association, we run the code with different Ds (from 1 to 9 arc sec) and look for that distance that returns the greatest number of associations. For n = 2 and n=3 (where n is the minimum number of members a group must enclose to be considered an association) Ds distance is 4 arc sec. This clustering does not guarantee that the groups found are indeed OB associations (i.e. nearly coeval group of OB stars). To discriminate those clusters formed by random overlapping stars we need another criteria, for example the extinction of the stars.

4. Extinction towards IC 10 and color-magnitude diagrams of the groups

Following the recipe from Massey *et al.* 2000 we calculate the intrinsic color $(B-V)_0 = 0.317 \times \mathrm{Q} - 0.005$, for objects with $-1.0 \leqslant \mathrm{Q} \leqslant -0.5$. This recipe was parametrized using models calculated with the ATLAS9 code with $\mathrm{Z} = 0.8\, \mathrm{Z}_{SUN}$. With these and the $(B-V)$ observed color we can calculate the color excess of the objects. In figure 1b we present the histogram of the distribution of $E(B-V)$. The color excess distribution runs from $E(B-V)$ around 0.5 to 1.3, with the majority of objects between 0.7 and 1.1 and a peak

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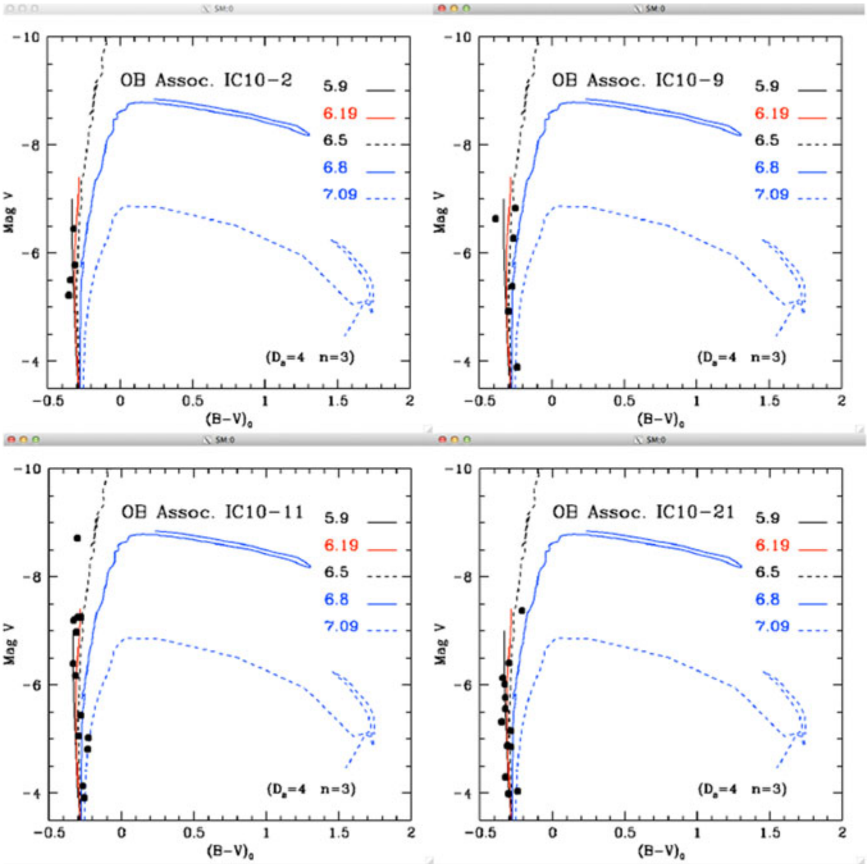

Figure 2. Reddening-corrected color magnitude diagrams of 4 candidate OB associations in IC 10. The isochrone tracks are from Lejeune & Schaerer (2001) and were calculated for a metallicity Z = 0.2 Z_{SUN}. The different tracks have log(Age) = 5.9, 6.19, 6.50, 6.80 and 7.09.

at 0.9 - 1.0. There are 4 objects with $E(B-V) < 0.5$, a value too low to be produced by the extinction of the Milky Way in the direction of IC 10. These low values can be the result of photometric errors or they may be Galactic objects in the direction to IC 10 that we do not filter out properly.

It is possible to calculate the absolute V magnitude M_V of the OB stars assuming that the relation between the color excess $(E(B-V))$ and the visual extinction (A_V) is the same as in the Galaxy $(A_V = 3.1 \times E(B-V))$, and adopting the distance module $(m_V - M_V)$ to IC 10 of 24.27 (Kim *et al.* 2009). With M_V and the intrinsic color $(B-V)_0$ we can create the reddening-corrected color-magnitude diagram of the candidate clusters found and confirm that they are indeed coeval. In figure 2 we present 4 examples, and contrast them against the isochrones from Lejeune & Schaerer (2001). The groups shown in figure 2 have log(Age) = 6.19, 6.84, 6.76 and 6.82, all of them younger than 10 Myr.

5. Comparison against the population of IC 1613

IC 1613 is a dIrr galaxy of the Local Group that is also forming stars, is located at a distance similar to IC 10 $(m_V - M_V = 24.27$, Dolphin *et al.* 2001) and has low foreground extinction $(E(B-V) = 0.02$, Lee *et al.* 1993). We use the photometric catalog by Garcia *et al.* (2009) to compare the population of candidate massive stars of both galaxies. We compare the histogram distribution of the Q parameter of the stars in

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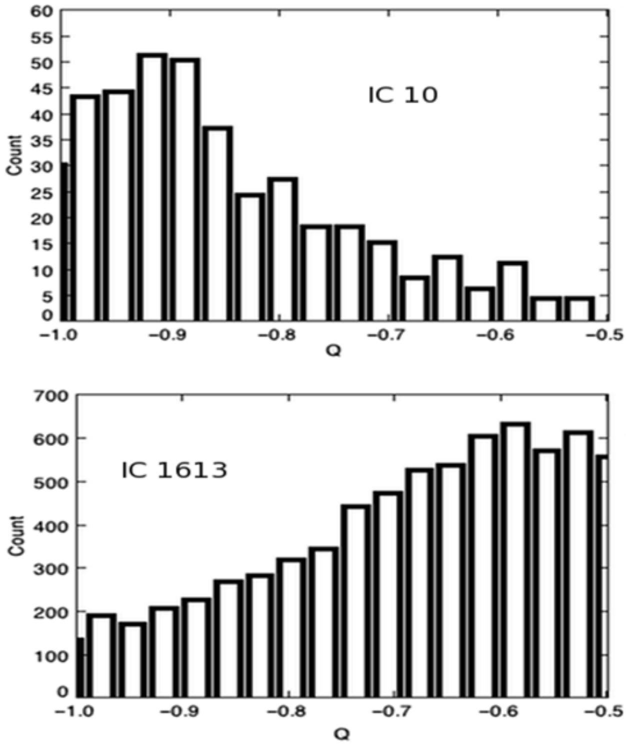

Figure 3. Q-values of the candidate blue massive stars in IC 10 and IC 1613. Pending simulations to assess how the photometric bias against faint/undetected objects in the U-band affects this distribution, the figure suggests that the starburst event in IC 10 promotes the production of hotter, more massive stars.

IC 10 and in IC 1613, in Fig. 3. in Garcia *et al.* (2010), we showed that there is a strong correlation of the Q-parameter with spectral type and effective temperature (T_{eff}) from O5 to B5-types and Q < -0.4; stars with earlier spectral types (and higher T_{eff}) have more negative values of Q. We find that IC 10 has an excess of massive stars, where as the opposite is found in IC 1613.

This result is similar to that presented by Motte *et al.* 2018 on the core mass function (CMF) of the galactic active star-forming region W43-MM1. If the initial mass function (IMF) of IC 10 is the same as the CMF in starburst regions, then we expect that there would be an excess of massive stars similar to the excess found in 30 Dor by Schneider *et al.* (2018). This could be also the origin of the WR super population found in IC 10. A deeper discussion of these results will be presented in Corral *et al.* 2019.

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