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A YOUNG STAR CLUSTER IN THE LEO A GALAXY

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Abstract. We report a serendipitous discovery of a star cluster in the dwarf irregular galaxy Leo A. Young age (∼28 Myr) and low mass (∼510 $M_\odot$) estimates are based on the isochrone fit assuming a metallicity derived for H II regions ($Z = 0.0007$). The color-magnitude diagrams of the stars, located in and around the cluster area, and the results of aperture photometry of the cluster itself are presented.

Key words: galaxies: dwarf, irregular – galaxies: individual (Leo A) – galaxies: star clusters

1. INTRODUCTION

Leo A (DDO 69) is an apparently isolated dwarf irregular galaxy in the Local Group. It is an extremely gas-rich (Young & Lo 1996), dark matter dominated stellar system (Brown et al. 2007) of low stellar mass (Cole et al. 2007) and low metallicity (van Zee et al. 2006). It consists of multiple stellar populations of ages ranging from ∼10 Myr to ∼10 Gyr (Cole et al. 2007, and references therein). The present-day star formation activity is traced by H II regions, while the existence of old stellar population is proven by the detection of RR Lyr stars (Dolphin et al. 2002).

Extensive studies of the stellar content in Leo A were performed with the *Hubble Space Telescope* (HST) *Wide Field Planetary Camera 2* (WFPC2) (Tolstoy et al. 1998; Schulte-Ladbeck et al. 2002) and *Advanced Camera for Surveys* (ACS) (Cole et al. 2007) by imaging the central part. The outer parts of the galaxy were studied by Vansevičius et al. (2004) and Stonkutė et al. (2014).

We report a discovery of a star cluster, Leo A-C1 (Fig. 1), in the deep HST/ACS images (Cole et al. 2007). The cluster is located at R.A. $= 9^{\rm h}59^{\rm m}16.513^{\rm s}$, Dec. $= +30^\circ44'58.43''$ (J2000.0). Previous Leo A studies did not report any cluster in this dwarf galaxy.

In Section 2 we provide details of data reduction. The derived cluster parameters and a brief discussion are presented in Section 3.

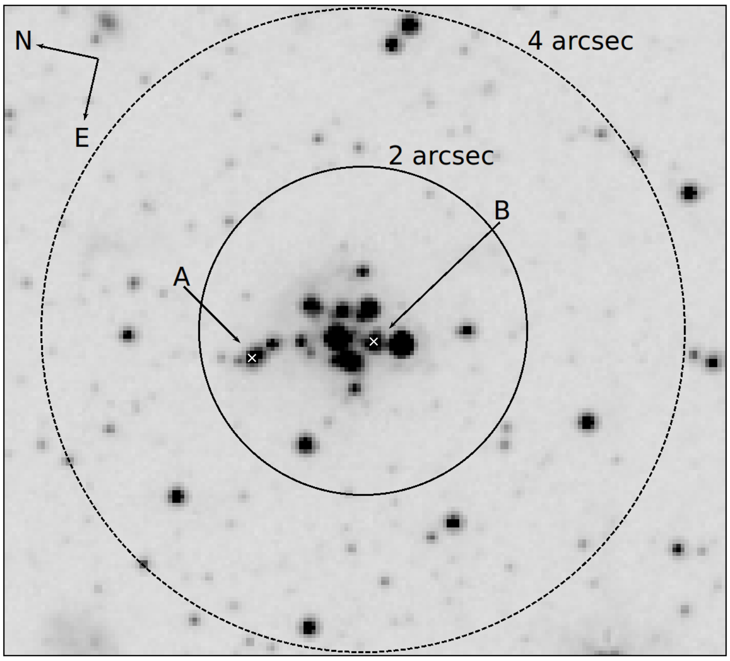

Fig. 1. HST/ACS F814W-band image of the star cluster Leo A-C1. The circles indicate radii of 2″(solid line) and 4″(dashed line), marking the cluster and the comparison field areas, respectively.

2. DATA REDUCTIONS

Photometric data of the star cluster Leo A-C1 were measured using ACS frames from the project LCID (Local Cosmology from Isolated Dwarfs project)[1], see Cole et al. (2007) for observation details. For the photometry we used combined (median) frames made out of eight individual drizzled frames for each pass-band (F475W and F814W).

We employed the DAOPHOT (Stetson 1987) program set implemented in the IRAF software package (Tody 1993) for crowded-field stellar PSF (point spread function) photometry, and the aperture photometry package for the integrated cluster photometry.

The photometric calibration was performed by transforming instrumental magnitudes to the VEGAMAG system using the WFC and HRC Zeropoints Calculator[2]. The accuracy of our photometric data is $\sim$0.03 mag at the bright end for both pass-bands, and reaches $\sim$0.1 mag at $m_{814} \sim 27$ and $m_{475} \sim 28.5$.

The star cluster Leo A-C1 is located in an area free of star-forming regions. Therefore, we assumed that its colors are contaminated only by the Milky Way (MW) foreground extinction, and we de-reddened the stellar photometry data using extinction estimates provided by Cole et al. (2007), $A_{475} = 0.078$ and $A_{814} = 0.039$ mag.

[1] http://www.iac.es/proyecto/LCID

[2] http://www.stsci.edu/hst/acs/analysis/zeropoints

Table 1. Aperture photometry data of Leo A-C1.

r [$r_{\rm H}$]	m_{814}	$m_{475} - m_{814}$
1	20.60	-0.17
2	20.07	-0.17
3	19.95	-0.15
4	19.86	-0.13

Note. A circular aperture radius, r, is given in units of the cluster's half-light radius, $r_{\rm H} = 0.47''$. Photometric data are de-reddened, taking into account the foreground MW extinction, $A_{475} = 0.078$ and $A_{814} = 0.039$ mag (Cole et al. 2007).

3. RESULTS AND DISCUSSION

3.1. Integrated cluster parameters

The determination of an accurate center of the well-resolved cluster is a sensitive procedure in constructing the surface brightness profile. In the central part of Leo A-C1, luminous stars are distributed slightly asymmetrically (see Fig. 1), therefore, the location of the center was derived by fitting the luminosity-weighted and spatially-smoothed surface brightness profiles in the area $2.5'' \times 2.5''$.

Leo A-C1 exhibits round isophotes at large radii, suggesting that the mass distribution is in general spherical – hence we used circular apertures for the construction of surface brightness and integrated luminosity profiles, by integrating in $0.05''$ wide annuli up to the $3.0''$ radius.

The sky background was determined in a circular annulus centered on the cluster and spanning the radial range from $2''$ to $3''$. The correct sky background subtraction is critical in determining the shape of the surface brightness profile in the cluster's outer region (for detailed discussion, see Hill & Zaritsky 2006), therefore, systematic sky background subtraction errors were evaluated by constructing the cluster photometric profiles with various estimates of the sky background. However, the shift of the sky background zone to the positions $1.8 - 2.8''$ and $2.2 - 3.2''$ led to insignificant changes in half-light radius: $r_{\rm H} = (0.47 \pm 0.01)''$. The half-light radius is equal to $0.47''$in both pass-bands (F475W and F814W).

The integrated magnitudes and color indices, derived trough circular apertures of radii $(1 - 4) \times r_{\rm H}$, are listed in Table 1. An apparent radial color gradient is due to the very red object, most probably a foreground MW dwarf star, projected on the cluster's area (marked A in Fig. 1 and Fig. 2a).

3.2. Color-magnitude diagram

The color-magnitude diagram (CMD) within a region of $2''$ radius, centered on the star cluster Leo A-C1, is dominated by the main sequence stars, see Fig. 2a. In order to derive the cluster's age we used isochrones of $Z = 0.0007$ metallicity, based on the oxygen abundance ($12 + \log(O/H) = 7.38$) determined by van Zee et al. (2006). We computed the metallicity of the Leo A galaxy, taking into account the Sun's oxygen abundance $12 + \log(O/H) = 8.69$ (Asplund et al. 2009). Note, however, that the young age derived for the cluster, 28 Myr, is insensitive to the

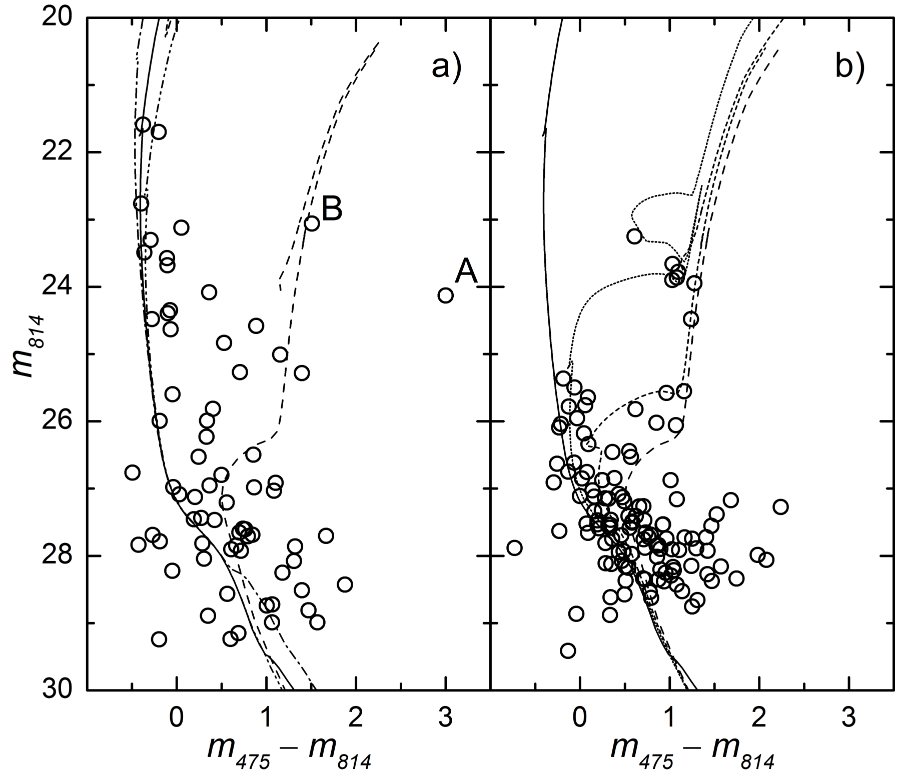

Fig. 2. The color-magnitude diagrams of the stellar-like objects residing in the regions: a) inside the circle of $r \leq 2''$ from the Leo A-C1 cluster's center (see Fig. 1); b) in the circular annulus centered on the Leo A-C1 cluster and spanning the radial range from $2''$ to $4''$. The PARSEC isochrones (release v1.2S, Bressan et al. 2012, Chen et al. 2014, Tang et al. 2014, Chen et al. 2015; http://stev.oapd.inaf.it/cmd) of metallicity $Z = 0.0007$ are shown for ages of: a) 14 Myr (dash dot line), 28 Myr (solid), 56 Myr (dash dot dot), and 5 Gyr (dash); b) 28 Myr (solid line), 708 Myr (dot), 2.5 Gyr (short dash), and 5 Gyr (long dash). All isochrones are shifted by a distance modulus of 24.5 mag (Dolphin et al. 2002). The stars are de-reddened according to the foreground MW extinction $A_{475} = 0.078$ and $A_{814} = 0.039$ mag (Cole et al. 2007).

assumed metalicity.

The isochrones in Fig. 2 are shifted adopting the Leo A distance modulus 24.5 mag (Dolphin et al. 2002). The stars are de-reddened taking into account only the foreground MW extinction, $A_{475} = 0.078$ and $A_{814} = 0.039$ mag (Cole et al. 2007).

The object marked B (Fig. 1 and Fig. 2a) is most probably a red giant star within the Leo A galaxy. The estimated probability was based on the even distribution of such kind of stars (a total number of 36) measured across the $12 \times 22''$ field studied. It was estimated that $\sim$1.7 red giant stars, on average, could fall within the cluster area.

The comparison field was selected in a circular annulus centered on the cluster and spanning the radial range from $2''$ to $4''$ (Fig. 1). The CMD of the comparison field is dominated by the main sequence and red giant stars, which are older than the cluster (Fig. 2b).

Based on 12 cluster stars, located on or near the main sequence (Fig. 2a, in the magnitude range $m_{814} = 21.5 - 25.0$), the mass of the cluster was derived to be equal to $(510 \pm 150)\, M_{\odot}$. For the determination of the cluster's mass the following assumptions were made: the cluster's age is 28 Myr; metallicity $Z = 0.0007$; the stellar mass range is from 0.08 to 30 $M_{\odot}$; the initial mass function is from Kroupa et al. (2002). Finally, the average number of post main sequence stars equal to $\sim$0.4 was estimated, which is in agreement with the fact, that such stars are absent in the cluster Leo A-C1.

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