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Star clusters and young populations in the dwarf irregular galaxy Leo A

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Abstract. We have studied young stellar populations and star clusters in the dwarf irregular galaxy Leo A using multicolor (B, V, R, I, $H\alpha$) photometry data obtained with the Subaru Suprime-Cam and two-color photometry results measured on archival HST/ACS $F475W$ & $F814W$ frames. The analysis of the main sequence (MS) and blue supergiant (BSG – "blue loop") stars enabled us to study the star formation history in the Leo A galaxy during the last ~200 Myr. Also, we have discovered 5 low-mass ($\lesssim$400 $M_{\odot}$) star clusters within the ACS field. This finding, taking into account a low metallicity environment and a yet-undetected molecular gas in Leo A, constrains star formation efficiency estimates and scenarios. Inside the well known "hole" in the H I column density map (Hunter *et al.* 2012) we found a shock front (prominent in $H\alpha$), implying an unseen progenitor and reminding the "hole" problems widely discussed by Warren *et al.* (2011).

Keywords. galaxies: dwarf, galaxies: individual Leo A, galaxies: star clusters

1. Introduction

Leo A is an isolated dwarf irregular galaxy in the Local Group. It is a gas-rich (Young & Lo 1996; Hunter *et al.* 2012) dark-matter-dominated stellar system (Brown *et al.* 2007; Kirby *et al.* 2017) of low metallicity (van Zee *et al.* 2006; Kirby *et al.* 2017).

The present-day star formation activity is indicated by few H II regions, while the existence of an old stellar population is proved by the detection of RR Lyr stars (Dolphin *et al.* 2002; Bernard *et al.* 2013). Detailed studies of stellar content in Leo A were performed with the Hubble Space Telescope (HST) Wide Field and Planetary Camera 2 (WFPC2) (Tolstoy *et al.* 1998; Schulte-Ladbeck *et al.* 2002) and Advanced Camera for Surveys (ACS) (Cole *et al.* 2007) by the imaging of the central part. The outer parts of the galaxy were studied with the Subaru Suprime-Cam by Vansevičius *et al.* (2004), and with the HST Wide Field Camera 3 (WFC3) by Stonkutė *et al.* (2018).

2. Data

We used the stellar photometry catalog (Stonkutė *et al.* 2014) based on the Subaru Suprime-Cam imaging data of the Leo A galaxy. To study young populations, we selected only bright blue stars in the color-magnitude diagrams (CMDs) shown in Fig. 1: $V < 23$, $B < 23$, $B - V < 0.25$, $V - I < 0.5$. These objects were visually inspected using multicolor Subaru and HST/ACS images.

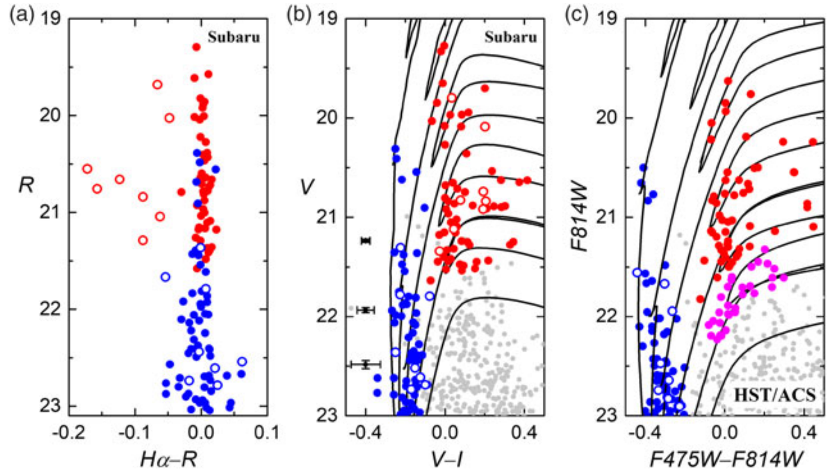

Figure 1. CMDs of the Leo A stars (MS – blue; BSG – red & magenta). a) R, $H\alpha - R$ (Subaru), MS stars located in the H I "hole" (Fig. 2a) are marked with blue open circles, BSG $H\alpha$ emission stars are marked with red open circles. b) V, $V - I$ (Subaru), the PARSEC isochrones (Marigo *et al.* 2017) of 15, 30, 55, 100, & 160 Myr ($Z = 0.0005$) are plotted. c) $F814W$, $F475W - F814W$ (HST/ACS), the isochrones of 15, 30, 55, 100, 160, & 220 Myr ($Z = 0.0005$) are plotted. All isochrones are corrected for the distance modulus of 24.5 (Dolphin *et al.* 2002) and reddened assuming the MW foreground extinction of $A_V = 0.057$, $A_I = 0.031$, $A_{475} = 0.068$, & $A_{814} = 0.032$ (Schlafly & Finkbeiner 2011).

Based on the PARSEC isochrones Marigo *et al.* (2017), we estimate that selected MS stars are younger than ∼30 Myr and BSG star ages are from ∼30 to ∼230 Myr (Fig. 1). We selected the following objects: 88 MS stars, 9 out of them fall into the H I "hole" area (Fig. 2a); 69 BSG stars (Fig. 2b), 8 out of them show $H\alpha$ emission (Fig. 1a); 31 BSG stars from deep HST/ACS photometry data (Figs. 1c and 2c, filled magenta circles).

Additionally, we used the $H\alpha$ (width of the passband ∼20 nm) map made by subtracting a reference frame obtained in the R passband (Fig. 2d and e).

The integrated H I column density map (Hunter *et al.* 2012) was employed for the analysis of young stellar population distributions and for the "hole's" dynamics and morphology study (Fig. 2a-c).

3. Results and Discussion

The analysis of the MS and BSG star distributions enabled us (by assuming there is no star migration across the disk) to visualize the 2D star formation history in the Leo A galaxy over the last ∼200 Myr (Fig. 2). The analysis of young stellar populations within and around the "hole" seen in the H I map revealed a number of interesting features:

• by inspecting the H I column density distribution map, we found that the column density inside the "hole" and in the "hole's" walls comes as 1 to 10; to "inflate" the "hole" of ∼500 pc in size from a single center assuming an average gas velocity dispersion of ∼7 km/s (Hunter *et al.* 2012), it would take ∼40 Myr; therefore, this estimate could be set as an upper age limit of the "hole";

• number densities of stars in the eastern and western parts of the "hole" differ strongly; however, stellar populations of ages from ∼30 to ∼230 Myr are lacking in both parts (Fig. 2a-c);

• regions of star formation seem to avoid the "hole" for ∼200 Myr; the "hole's" western part has started to fill with a new generation of stars only recently (<30 Myr, Fig. 2a) and, probably, this population produces the shock front seen in the $H\alpha$ map (Fig. 2d)

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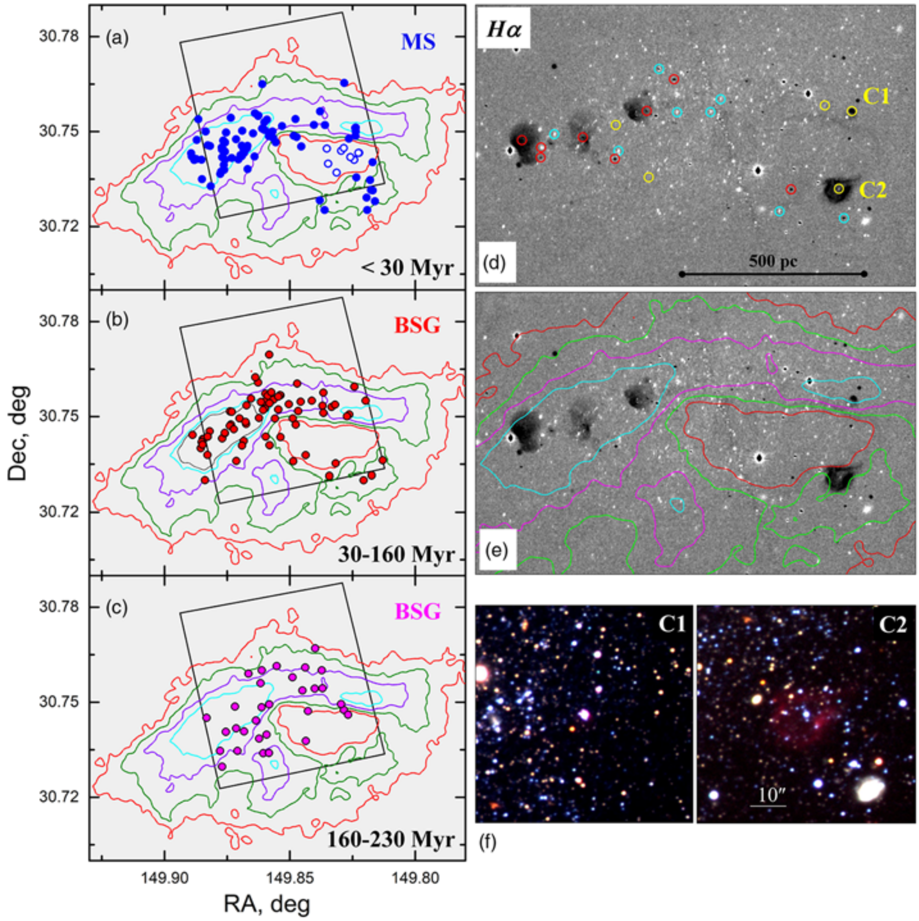

Figure 2. a-c) MS and BSG stars – color coding is the same as in Fig. 1. HST/ACS field is marked in black. H I column density contours (3×10^{20} – red, 5×10^{20} – green, 7×10^{20} – magenta, & 10^{21} – cyan, atoms/cm^2) are shown. d & e) the Subaru Suprime-Cam $H\alpha$ image of the Leo A galaxy. The dark areas correspond to enhanced $H\alpha$ emission, e.g., H II zones. d) discovered star clusters (Fig. 3, yellow open circles), BSG $H\alpha$ emission stars (Fig. 1a, red open circles); BSG stars younger than ∼30 Myr (cyan open circles) are shown. e) H I column density contours are plotted. f) the composite color images ($1' \times 1'$) of star clusters ($H\alpha$ – red, V – green, B – blue). North is up, East is left in all panels.

and induces star formation well ahead of the shock front (∼20 pc); see, e.g., clusters C1 & C2 and stars younger than ∼20 Myr to the South of the cluster C2;

• remarkably, the form of the $H\alpha$ shock front closely resembles the H I column density distribution morphology (Fig. 2e), implying that the western part of the "hole", in principle, could be swept out of H I gas by the young MS stellar population; however, the distribution of MS stars (younger than 30 Myr), projecting onto the H I "hole's" western part, does not resemble its form and there is no increase in the number density of the young MS stars within the H I "hole" (Fig. 2a); therefore, the problem of which objects or processes are responsible for shaping the eastern part of the "hole" remains unsolved.

By employing HST/ACS resolved stellar photometry data, we discovered 5 low-mass ($\lesssim$400 M$_\odot$) star clusters residing in the central part of the Leo A galaxy (Fig. 3). All clusters are distributed around the H I "hole" (Fig. 2d). Note, however, that these clusters

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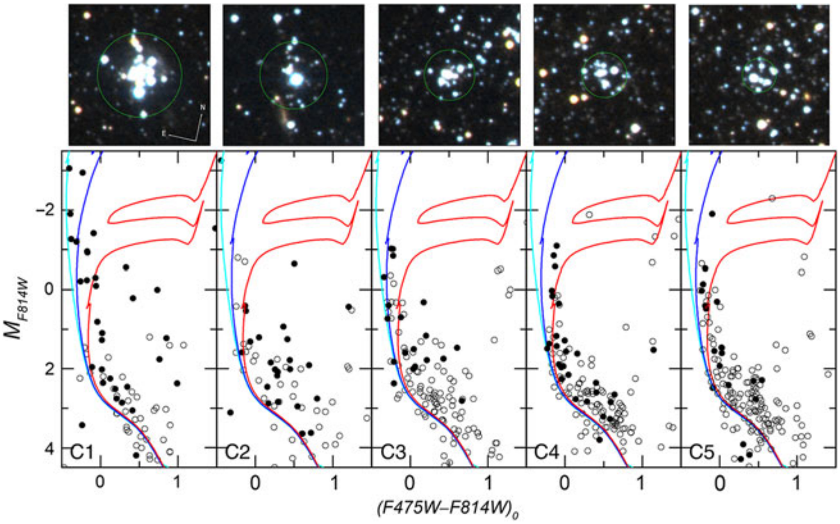

Figure 3. The HST/ACS ($5'' \times 5''$) images and CMDs of the Leo A cluster areas showing the star-like objects residing inside the green circle marking the cluster itself (filled black circles) and star-like objects residing inside the circle of a $2.5''$ radius (open circles). The PARSEC isochrones (Marigo *et al.* 2017) of $Z = 0.0005$ metallicity and ages of 20 (cyan), 100 (blue), and 500 (red) Myr are plotted. Positions of all stars in CMDs are corrected for the distance modulus of 24.5 (Dolphin *et al.* 2002) and dereddened assuming the MW foreground extinction of $A_{475} = 0.068$ & $A_{814} = 0.032$ (Schlafly & Finkbeiner 2011).

are too compact to be resolved on Subaru images. Therefore, for the complete census of star clusters in the Leo A galaxy high quality wide field HST observations are needed.

Also, we discovered 8 BSG stars with enhanced $H\alpha$ emission (Fig. 1a and Fig. 2d), which indicate Be stars in the Leo A galaxy. However, 5 of them are located nearby to H II zones and their $H\alpha$ photometry could be contaminated by a diffuse emission.

Acknowledgements

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