1. Introduction

Dwarf irregular galaxies are assumed to be simple gas-rich stellar systems, presumably the “building blocks” of large galaxies (Tosi 2003). An analysis of these systems, which are likely built up solely through self-enrichment, could provide insight into the early star formation history in the Universe.

Leo A (Fig. 1) is an isolated dwarf irregular galaxy in the Local Group. Ages of the stellar populations in Leo A range from ~10 Myr to ~10 Gyr. A large stellar halo (up to the deprojected distance of ~1.7 kpc) was discovered based on Subaru wide-field photometry of red giant branch stars.

Methods. We analysed HST WFC3 archive observation data in the field that is partly located beyond the previously known limits of the Leo A galaxy. We performed photometry of star-like objects in the F475W and F814W passbands and studied the spatial distribution of the Leo A stars below the horizontal branch.

Results. We report a discovery of stellar halo populations (subgiants and faint red giants) in the Leo A galaxy extending up to ~2.3 kpc deprojected distance from the galaxy centre. Analysis of the colour-magnitude diagram suggests old (~5 Gyr) stellar populations of very low metallicity (Z ~ 0.0001).

Key words. galaxies: dwarf – galaxies: stellar content – galaxies: individual: Leo A (DDO 69)
2. Observations and data reductions

We used HST WFC3 F475W and F814W passband observation data of the Leo A galaxy obtained for the HST Proper Motion Collaboration (HSTPMC) program – Mass of the Local Group from Proper Motions of Distant Dwarf Galaxies (the HST proposal GO 12273, the principal investigator Roeland P. van der Marel) during the HST cycle 18 on December 28, 2011, in parallel field WFC3/UVIS.

The WFC3/UVIS camera was pointed ~6’ away (N-W) from the Leo A galaxy centre in the outer halo (Fig. 1). A total exposure time of 5408 and 5282 seconds was obtained in passbands F475W and F814W, respectively. The archival data were downloaded from the Mikulski Archive for Space Telescopes (MAST). We retrieved bias-subtracted, flat-fielded, charge transfer efficiency (CTE) corrected WFC3/UVIS F160W images produced by the STScI On-The-Fly-Reprocessing (OTFR) pipeline OPUS versions 2016_2, which used CALWF3 version 3.4.

To perform stellar photometry, we used the software package DOLPHOT 2.0 (Dolphin 2000, and many unpublished updates). We followed the recommended preprocessing steps and the photometry recipe provided in the manual for the WFC3 module (version April 17, 2016). We used DrizzlePac 2.1.6 (default parameter values) to create clean, deep-drizzled reference frames for object detection and coordinate transformations from four sub-exposures in each of the F475W and F814W passbands. This also allowed us to flag the cosmic rays in the individual F160W images and update data quality images.

The HST WFC3/UVIS field is located at the uncrowded outskirts of the Leo A galaxy. Therefore, we used values of DOLPHOT parameters recommended in the WFC3 manual for uncrowded fields: the FitSky parameter was set to 1, which means the sky fitting in an annulus around each star (R_{inner} = 15, R_{outer} = 35 pixels) and point-spread function (PSF) fitting inside a radius of R_{pert} = 4 pixels.

DOLPHOT determines magnitudes, magnitude errors, object fit, and shape parameters in individual F160W frames, and then combines them for each filter. To combine the magnitudes, we set a parameter Flagmask = 7, which means that only measurements with error flags equal to zero were used.

Numerous extended objects in the WFC3 field can hamper the photometry of nearby stars, therefore setting the DOLPHOT parameter Force1 = 0 could result in a false cleaning of actual stars from the photometric catalogue. Since the CMD is needed to be as complete as possible for our study, we set the parameter Force1 = 1, which forced all detected sources to be fitted as stars. This resulted in a strongly contaminated CMD, as hot pixles and extended objects were also measured as single stars.

The output photometry file had measurements of more than 60,000 objects. In order to discard non-point sources and measurements of artefacts, the photometry catalogue was cleaned. We rejected objects that had measurements in only one filter or had a measured DOLPHOT photometry magnitude error.

Fig. 1. Subaru Suprime-Cam B-passband image of the Leo A galaxy (Stonkute et al. 2014). The ellipses (semi-minor to semi-major axis ratio: b/a = 0.6; PA = 114°) of 8’ and 10’ along the semi-major axis, centred at α = 9h59m24s, δ = +30°44′47″ (J2000), are shown. The HST fields, marked white (ACS) and black (WFC3), are taken from the HST Proposal 12273 by Roeland van der Marel (https://archive.stsci.edu/proposal_search.php?mission=hst&id=12273). The RR Lyr stars discovered by Dolphin et al. (2002) and Bernard et al. (2013) are marked by white open circles. North is up, east is left.

Fig. 2. AST results in the F475W and F814W HST WFC3 passbands. Panels a and b: grey dots show the sharpness of the AST stars; filled (star-like objects) and open (extended objects) circles show the sharpness of the real measured objects. Panels c and d: grey dots indicate the difference of recovered and input magnitudes of the AST stars; black lines indicate average photometric errors provided by DOLPHOT for real objects. Results in panels a-d are shown vs. recovered and measured magnitudes. Derived photometry completeness estimates in the F475W and F814W passbands are shown in panels e and f vs. input magnitudes, respectively.
3. Results and discussion

The first step of the stellar population analysis within the observed field was to pre-select probable stars out of the 756 measured objects. In order to clean out the stellar population from extended objects, we used the sharpness\(F_{814W}\) vs. sharpness\(F_{475W}\) diagram (Fig. 3) that was constructed for the AST and real stars. Following the DOLPHOT prescription (Dolphin 2000, see Eq. (14)), we rejected diffuse sources that have overly negative sharpness in both passbands and are therefore likely background galaxies or unresolved blends of stars. We determined limiting criteria for star selection based on sharpness vs. magnitude diagrams (Fig. 2a and b) of real and AST stars by taking a 3\(σ\) criterion of sharpness scatter of the measured objects at \(F_{475W} = 27.0\) and \(F_{814W} = 25.5\), where the scatter of the AST star sharpness starts to overlap with the sharpness of objects that can be recognized by eye (sharpness\(F_{457W}\) > −0.099; sharpness\(F_{814W}\) > −0.078). Additionally, we cut out a corner with a straight line connecting the points sharpness\(F_{457W}\) = −0.099, sharpness\(F_{814W}\) = 0.0 and sharpness\(F_{457W}\) = 0.0, and sharpness\(F_{814W}\) = −0.078 (Fig. 3). As a result of this selection, we ended up with 128 probable star-like objects. However, some of these objects could still be unresolved galaxies, mainly the so-called “faint blue galaxies” that are abundant below \(F_{814W} = 25\) (Ellis 1997), Leo A blue stragglers (Momany 2015), or MW white dwarfs.

The colour-magnitude diagrams of the 128 star-like objects selected in the studied field are shown in Fig. 4. The PARSEC isochrone (Bressan et al. 2012) of 7 Gyr age and \(Z = 0.0001\) metallicity (the blue line) is plotted in all panels. Additionally, we plot (a) photometric AST star scatter limits (based on Fig. 2c and d), shown by cyan and red lines, as well as the lower limit of the MW foreground star distribution derived from the Besançon models, shown with the grey dashed line; (b) isochrones of 5 and 10 Gyr (\(Z = 0.0001\)) shown with cyan and red lines, respectively; and (c) an isochrone of 7 Gyr and \(Z = 0.0006\) shown with the red line.
of up to a 100 kpc distance. Based on the synthetic CMD of MW stars, we assume that the star-like objects in Fig. 4 that are redder than $F475W - F814W \sim 2.0$ mainly belong to the MW galaxy.

For the analysis we selected only star-like objects with a high photometric accuracy, $F814W < 27$. In order to trace stellar populations in the Leo A outer regions, we decided to employ RGB as well as horizontal and subgiant branch stars. From the isochrone of 7 Gyr age and $Z = 0.0001$ metallicity, we estimated an expected number ratio of stars along these sequences in the magnitude ranges of $24.5 < F814W < 27.0$ and $20.5 < F814W < 24.5$ and found a very good agreement with the observed star number ratio. This test suggested that the overdensity of stars along the isochrone seen in the CMD (Fig. 4) can be attributed to the Leo A galaxy stellar population.

In Fig. 5 the filled circles mark the objects that are probable Leo A members (blue), probable MW stars (red), probable compact faint blue galaxies, Leo A blue stragglers, or MW white dwarfs (cyan). Open grey circles mark faint star-like objects that were not used for the analysis.

![Fig. 5. CMDs of star-like objects in the studied field.](image)

A distribution of star-like objects in the studied field is shown in Fig. 6. Segments of the ellipses (green) centred on Leo A of $a = 8'$ and $10'$ ($b/a = 0.6; PA = 114^\circ$) are overplotted. North-east directions are shown by white arrows.

![Fig. 6. Distribution of star-like objects in the studied field.](image)

4. Conclusions

We have performed photometry in the HST WFC3 field, which is located at the very outskirts of the Leo A galaxy and discovered that its stellar halo extends far beyond the previously known limits (Vansevičius et al. 2004). We stress, however, that the presence of a candidate RR Lyr star located at a distance of 5.9' from the galaxy centre (Dolphin et al. 2002) also provides evidence for a large halo of Leo A.

The detection of the outer halo stellar populations is based on the CMD analysis below the horizontal branch. We can currently assume that the semi-major axis of the stellar halo is $a \sim 2.3$ kpc ($a \sim 10', b/a = 0.6$). In order to establish the edge of the Leo A halo more clearly, we need to study a much larger field or to obtain accurate photometry for objects of $F814W > 27$. However, even a small single HST WFC3 field that includes subgiant stars suggests the galaxy size (stellar component) to be larger by about one-third than previously estimated. Based on the CMD fit with isochrones (Bressan et al. 2012), we find old ($>5$ Gyr) stellar populations of very low metallicity ($Z \sim 0.0001$). However,
to strengthen this conclusion, extremely deep, currently not feasible spectroscopic observations are needed.

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References

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