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Local Group evolved stellar populations in the near infrared.

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Abstract. We present JHK observations of Leo I and Leo II dwarf spheroidal galaxies obtained with the WFCAM@UKIRT. The wide field of view and the good photometric quality of the camera led to the first high-precision NIR photometric catalogue obtained so far for these two galaxies. With high-precision photometry we could isolate the foreground Galactic population and disentangle oxygen- and carbon-rich AGB stars. Our data are compared with predictions of the most recent theoretical AGB models.

1. Introduction

The advent of modern near-infrared (IR) imagers with wide field of view, both in operation (WFCAM, WIRCAM, HAWK-I) or forthcoming (VISTA) is making near-IR photometry a reliable tool to study stellar populations. In addition, next generation instrumentation such as the James Webb Space Telescope and adaptive optics at the VLT and ELT will operate in the near-IR domain. These will allow high precision photometry of resolved stars in distant galaxies, out to the Virgo and Fornax clusters, and possibly beyond.

In last years we have started to study Local Group (LG) dwarf galaxies in the near-IR (Gullieuszik et al. 2007a,b). From near-IR photometry of red giant branch (RGB) stars in LG galaxies it is possible to derive accurate measure of the distance and metallicity.

Even more importantly, the near-IR is the best spectral range to study asymptotic giant branch (AGB) stars. Cool AGB stars emit most of their flux at near-IR wavelengths. Further, the most evolved AGB stars are enshrouded in a dusty envelope produced by stellar winds and can be detected only in the near-IR. Another important aspect is the contribution of AGB stars to the light coming from unresolved distant galaxies, which can be dominant for systems with an intermediate age stellar population. Therefore, AGB stars play a key role in the understanding of the properties of stellar populations in the high-redshift universe (e.g., van der Wel et al. 2006)

Here we present our recent results on Leo I and Leo II dwarf spheroidal (dSph) galaxies, the most distant and isolated satellites of

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our Galaxy. Leo I and Leo II have quite different stellar content. The stellar populations of Leo I are predominantly of intermediate age (Gallart et al. 1999), although an old stellar component is also present, witnessed by RR Lyrae variable stars (Held et al. 2001). The stars in Leo II are on average older, with a mean age of 9 Gyr (Mighell & Rich 1996).

2. Data reduction

We obtained JHK_s imaging of Leo I and Leo II with the new wide-field camera WFCAM mounted at the UKIRT at Mauna Kea (Hawaii) in April 2005. WFCAM is composed by four detectors. Since the field of view of each detector (13.′65) is comparable with the tidal radius of our target galaxies, we considered only the chip where our target galaxies were centred and another one to estimate of contribution of the foreground stars.

Raw data were reduced using the WFCAM pipeline, provided by the VISTA Data Flow System Project (Dye et al. 2006). The final products of the pipeline are the "Leavstack" frames with a spatial resolution of 0.″2 pixel^{-1} which is twice that of the original raw images. These are also astrometrically calibrated using the 2MASS point source catalogue (PSC) (Skrutskie et al. 2006) as a reference. The final absolute systematic accuracy is 0.″1.

Point-spread function (PSF) photometry was performed using DAOPHOT and ALLFRAME programs (Stetson 1987, 1994). Instrumental magnitudes were calibrated on the 2MASS system by applying the colour terms between WFCAM and 2MASS systems derived by Dye et al. (2006) and matching our uncalibrated photometric catalogue with the 2MASS PSC (Skrutskie et al. 2006). The median zero point difference was then applied. The uncertainties on our absolute photometric calibration is 0.06 in the J, H, and K_s bands.

Finally, WFCAM near-IR photometry was combined with optical B and V band photometry obtained by our group with the EMMI camera mounted at the NTT at ESO/La Silla (Held et al. 2000).

Photometric errors and completeness of our photometry were evaluated from artificial star experiments. The completeness factor is greater than 50% for magnitudes brighter than $K_s \simeq 20$. All our results are based on the photometry of stars brighter than $K_s \simeq 18$, for which we have a completeness factor $\simeq 100\%$ and photometric errors smaller than 0.02 mag.

In Fig. 1 we show the near-IR colour-magnitude diagrams of Leo I and Leo II. Both diagrams show a well populated RGB down to $K_s \approx 20$. The RGB tip (TRGB) is clearly noticed at $K_s \approx 16$. The location of the RGB is well described by theoretical isochrones with ages 6 and 10 Gyr for Leo I and Leo II, respectively, and metallicity between $Z = 0.001$ and $Z = 0.0004$. The most notable feature, especially in Leo I, is the extended sequence of upper-AGB stars above the TRGB. For Leo I, the sequence shows a red tail (made of carbon stars) extending up to $J - K_s \approx 3.5$. We confirm the presence of very red, probably dust-enshrouded, AGB stars (Menzies et al. 2002). The population of red AGB stars is quite small in Leo II, in agreement with the lower rate of star formation at intermediate ages. These diagrams underline the importance of near-IR observations for selecting and studying an unbiased sample of intermediate-age AGB stars. The most luminous objects in the K_s band become increasingly fainter at bluer wavelengths, and barely detectable in the blue band.

3. Distance and metallicity

The large colour baseline and photometric accuracy make it possible to derive accurate distance and metallicity measurements for Leo I and Leo II. The distance was obtained from the magnitude of the TRGB in the three JHK_s bands following the method fully described by Gullieuszik et al. (2007a). We adopted the calibration based on Galactic globular clusters (GCs) from Valenti et al. (2004).

We took into account the star formation history (SFH) of Leo I by calculating the correction to the TRGB magnitude obtained from the Valenti et al. (2004) calibration, using synthetic colour-magnitude diagrams. Our final measure of the distance to Leo I is $(m - M)_0 = 21.04 \pm 0.11$, which is in perfect agreement with the value $(m - M)_0 = 22.02 \pm 0.13$ found by

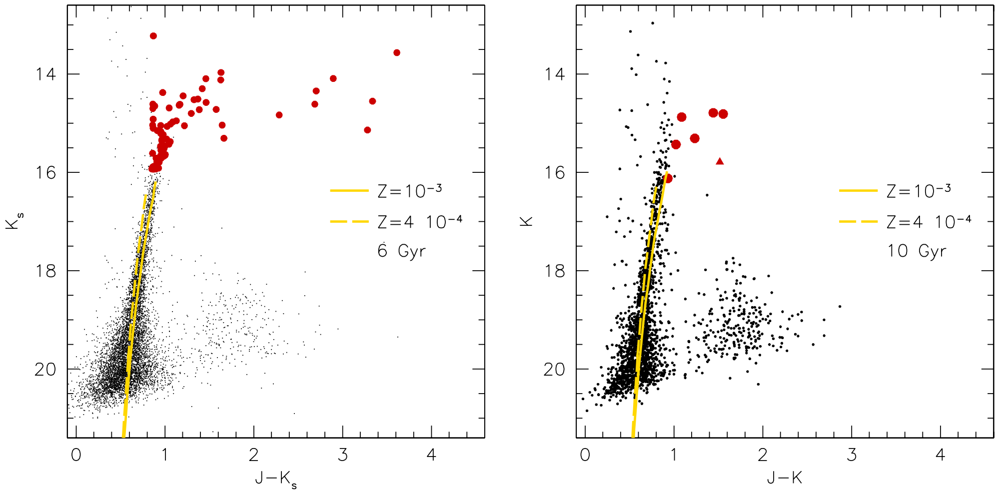

Fig. 1. Near-IR colour-magnitude diagrams of Leo I (*left*) and Leo II (*right*). Stars brighter than $K = 16$, mostly belonging to the upper AGB, are shown as *filled circles*. Also shown are theoretical isochrones with ages close to the average age of the stellar populations in each galaxy, and two different metallicities (Girardi et al. 2000).

Bellazzini et al. (2004) from the I magnitude of the TRGB.

Leo II is dominated by old stellar populations and in this case no population correction is required. We found a distance to Leo II $(m-M)_0 = 21.68 \pm 0.11$. This is an intermediate value between the "short" distance $(m-M)_0 = 21.55$ derived by Mighell & Rich (1996) from the V band magnitude of the horizontal branch and the "long" distance $(m-M)_0 = 21.84 \pm 0.13$ derived by Bellazzini et al. (2005) from the I magnitude of the TRGB.

Metallicities of individual RGB stars were derived comparing their $V - K_s$ colour with a suitable interpolation of RGB lines of GCs from Valenti et al. (2004). Also in this case we had to apply a population correction based on theoretical isochrones, assuming a mean age of 4.5 and 9 Gyr for Leo I and Leo II, respectively. The method is fully described by Gullieuszik et al. (2007a), while a detailed description of our results will be presented in forthcoming papers. Our estimate for the mean metallicity is [M/H] = −1.31 for Leo I and [M/H] = −1.64 for Leo II, which are in full agreement with recent spectroscopic results (Bosler et al. 2007; Koch et al. 2007a,b)

4. AGB stars

4.1. Selection criteria

Near-IR colours, and in particular the $(J - H)$ vs $(J - K_s)$ two-colours diagram, can be efficiently used to discriminate dwarf and giant stars (see, e.g., Bessell & Brett 1988). This can be used to isolate the contaminating Milky Way dwarf star population from the giant stars population of our target galaxies. In Fig. 2 we show the near-IR two colours diagram of Leo I stars brighter than the TRGB. Using the sequences defined by Bessell & Brett (1988) for dwarf and giant stars and similar diagrams obtained for other LG galaxies (e.g Nikolaev & Weinberg 2000; Cioni et al. 2004), we can conclude that stars in boxes 2 and 3 are Milky Way dwarf stars. Stars in box 1 are O-rich AGB stars belonging to Leo I while box 4 is populated by Leo I AGB carbon stars. We identified 31 O-rich and 35 C-rich AGB stars in Leo I. The same selection was made for Leo II, where we identified 14 O-rich and 5 C-rich AGB stars. The reliability of our method is proved by the fact that we correctly classified all C-stars previously identified spectroscopically (Azzopardi et al. 1985, 1986) or

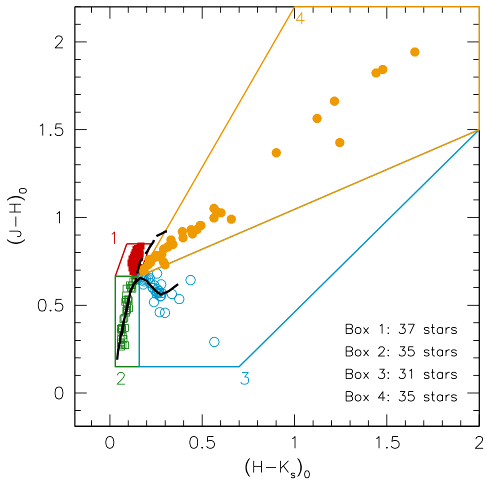

Fig. 2. The two-colour diagram of Leo I stars brighter than the TRGB. The evolved giant and main-sequence dwarf stars loci are shown with dashed and solid lines, following Bessell & Brett (1988). Stars in box 1 are O-rich AGB stars, while stars in box 4 are C-rich AGB stars. Boxes 2 and 3 are populated by foreground Milky Way dwarf stars.

with the narrow-band photometric technique (Demers & Battinelli 2002).

4.2. Comparison with theoretical models

Such complete catalogues of AGB stars in nearby galaxies are rare. The best such data are those for the LMC and SMC, fully sampled in the JHK_s bands of DENIS and 2MASS (see Nikolaev & Weinberg 2000; Cioni et al. 2004). Compared to these galaxies, Leo I and Leo II are more metal-poor, providing us with a unique opportunity to test present-day AGB models at low metallicities.

We proceed to a comparison of Leo I and Leo II data with the recent set of TP-AGB evolutionary tracks from Marigo & Girardi (2007). Combined with the Girardi et al. (2000) tracks for the pre-TP-AGB, these models are used as input for the TRILEGAL population synthesis code (Girardi et al. 2005).

For Leo I we considered the SFH obtained by Dolphin et al. (2005), while for Leo II we used the SFH obtained by Dolphin et al. (2005) and Rizzi et al. (2007, in prep.). Below we briefly present our preliminary results.

In Leo II we identified 15 and 5 O-rich and C-rich AGB stars. Using the Rizzi et al (2007) SFH our simulations predict 23.3 ± 4.3 O-rich stars, and 1.9 ± 1.4 C-stars. The agreement is poor for both types of stars. When the Dolphin et al. (2005) SFH is adopted, the number of predicted O-rich and C stars are 17.6 ± 3.3 and 4.3 ± 1.8, which are in better agreement with observation, within the 1σ error. We compared also the luminosity functions of AGB stars with those predicted by our models. The predicted magnitudes are too bright, both for O-rich and C-stars. A simple way of reducing the number of bright AGB stars in our simulations would be that of depleting the star formation rate at intermediate age. However, a depletion of the intermediate-age stellar population would also cause an overall reduction of the predicted number of C-stars, leading to a worse agreement in the number counts previously discussed. Other possible sources of discrepancies will be discussed together with a more detailed presentation of our results in a forthcoming paper.

Leo I hosts a more numerous population of AGB stars. We classified 37 O-rich stars and 35 C-stars. Adopting the Dolphin et al. (2005) SFH, we predict 64.4 ± 8.2 O-rich stars and 68.9±8.7 C-stars. There is an excess in the predicted number of AGB stars by a factor ∼ 2. This could be related to the SFH derived by Dolphin et al. (2005), which presents a burst of star formation at 2.5 Gyr. We are still working on this discrepancy, analyzing also alternative SFHs. Another interesting aspect to be taken into account is the presence of population gradients. Dolphin et al. (2005) obtained the SFH from WFPC2/HST data, which cover only the central region of Leo I (∼ 2′). In most LG dSphs the fraction of intermediate and young stars increase towards the center. If this would be true also in Leo I, the SFH obtained for the inner region would not be the same as at a larger radial distance, and the variation would be in the direction of a better agreement between simulations and observational data. So far there are no indications for a population gradient in Leo I (see e.g., Koch et al. 2007b, and refs therein), but since this is a key point of our analysis and the lack of a population gradient in Leo I is an exception among LG dSphs, we are still investigating this issue.

We note that the theoretical models of AGB stars used in our analysis are calibrated on Magellanic Clouds data. These are metal-rich systems and some of the inconsistencies found in this work may be due to the extrapolation of the models at lower metallicity. As a consequence, our data will be useful to calibrate AGB models in low-metallicity systems.

References

Azzopardi, M., Lequeux, J., & Westerlund, B. E. 1985, A&A, 144, 388

Azzopardi, M., Lequeux, J., & Westerlund, B. E. 1986, A&A, 161, 232

Bellazzini, M., Gennari, N., & Ferraro, F. R. 2005, MNRAS, 360, 185

Bellazzini, M., Gennari, N., Ferraro, F. R., & Sollima, A. 2004, MNRAS, 354, 708

Bessell, M. S. & Brett, J. M. 1988, PASP, 100, 1134

Bosler, T. L., Smecker-Hane, T. A., & Stetson, P. B. 2007, MNRAS, 378, 318

Cioni, M. R. L., Habing, H. J., Loup, C., Epchtein, N., & Deul, E. 2004, The Messenger, 115, 22

Demers, S. & Battinelli, P. 2002, AJ, 123, 238

Dolphin, A. E., Weisz, D. R., Skillman, E. D., & Holtzman, J. A. 2005, in "Resolved Stellar Populations", astro-ph/05060

Dye, S., Warren, S. J., Hambly, N. C., et al. 2006, MNRAS, 372, 1227

Gallart, C., Freedman, W. L., Aparicio, A., Bertelli, G., & Chiosi, C. 1999, AJ, 118, 2245

Girardi, L., Bressan, A., Bertelli, G., & Chiosi, C. 2000, A&AS, 141, 371

Girardi, L., Groenewegen, M. A. T., Hatziminaoglou, E., & da Costa, L. 2005, A&A, 436, 895

Gullieuszik, M., Held, E. V., Rizzi, L., et al. 2007a, A&A, 467, 1025

Gullieuszik, M., Rejkuba, M., Cioni, M. R., Habing, H. J., & Held, E. 2007b, A&A accepted, arXiv:0709.0918

Held, E. V., Clementini, G., Rizzi, L., et al. 2001, ApJ, 562, L39

Held, E. V., Saviane, I., Momany, Y., & Carraro, G. 2000, ApJ, 530, L85

Koch, A., Grebel, E. K., Kleyna, J. T., et al. 2007a, AJ, 133, 270

Koch, A., Wilkinson, M. I., Kleyna, J. T., et al. 2007b, ApJ, 657, 241

Marigo, P. & Girardi, L. 2007, A&A, 469, 239

Menzies, J., Feast, M., Tanabé, T., Whitelock, P., & Nakada, Y. 2002, MNRAS, 335, 923

Mighell, K. J. & Rich, R. M. 1996, AJ, 111, 777

Nikolaev, S. & Weinberg, M. D. 2000, ApJ, 542, 804

Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163

Stetson, P. B. 1987, PASP, 99, 191

Stetson, P. B. 1994, PASP, 106, 250

Valenti, E., Ferraro, F. R., & Origlia, L. 2004, MNRAS, 354, 815

van der Wel, A., Franx, M., van Dokkum, P. G., et al. 2006, ApJ, 636, L21