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The tip-of-the-red-giant-branch distance indicator and the structure of the nearest galaxy groups

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Abstract. The tip of the red giant branch (TRGB) is one of the most accurate distance indicators to galaxies in the Local Universe (for distances up to 8–10 Mpc). A distance accuracy as high as 5% can be achieved with the recently developed maximum-likelihood implementation of the TRGB method and modern calibrations. In this paper, we consider in detail TRGB distance determinations to nearby groups of galaxies (within 8 Mpc). We discuss the photometric accuracy and describe colour–magnitude-diagram features of nearby dwarf galaxies and their influence on the accuracy of distance determination. We have determined accurate structures of the two nearest galaxy groups, M81 and Cen A, using observations of galaxies in these groups with the *Hubble Space Telescope*'s WFPC2 and ACS instruments. The new technique allows us to see new details in the distribution of galaxies in the Canes Venatici I Cloud.

Keywords. galaxies: distances and redshifts, galaxies: dwarf, galaxies: stellar content

1. Introduction

The luminosity of the tip of the red giant branch (TRGB) provides a standard candle that can be used to derive accurate distances to galaxies within 10 Mpc (see, e.g., Karachentsev *et al.* 2006). The TRGB method is comparable in accuracy as a distance indicator to the Cepheid period–luminosity relation (see Makarov *et al.* 2006; and references therein). According to modern stellar evolution theory, the tip of the first-ascent red giant branch marks the violent onset of core-helium burning in low-mass stars. Observationally, this phenomenon causes a distinct and abrupt termination of the bright end of the red-giant-branch luminosity function (LF). This discontinuity is found empirically to be stable at the ~ 0.1 mag level in the I band for ages ranging from 2 to 15 Gyr and for metallicities encompassing the entire range represented by Galactic globular clusters, $-2.1 < [\mathrm{Fe/H}] < -0.7$ dex. Lee *et al.* (1993) defined the position of the TRGB in a reproducible and quantitative manner. They used a standard image-processing edge-detection (ED) algorithm employing the zero-sum Sobel kernel $[-2, 0, +2]$ which, when convolved with the stellar LF, leads to a maximum in its output at the luminosity where the discontinuity in star counts is greatest. The measuring errors for the tip magnitude, I_{TRGB}, were estimated to be typically 0.1–0.2 mag in their study. A disadvantage of the binned approach of Lee *et al.* is that the TRGB solution depends on both the LF's bin size and placement. Sakai *et al.* (1996) modified this method for application using a smoothed, continuous LF. The smoothed I-band LF is obtained by replacing the discretely distributed stellar magnitudes with the corresponding Gaussian functions.

As an alternative, a maximum-likelihood (ML) TRGB detection method was proposed by Méndez *et al.* (2002). The ED algorithms find a maximum of the first derivative of the LF of the stars in the TRGB region, whereas in the ML analysis a predefined LF is fitted to the observed distribution of the stars. Further development of the ML algorithm was introduced by our team (see Makarov *et al.* 2006). The algorithm was optimized by introducing reliable photometric errors and a completeness factor determined using artificial-star experiments. Measuring uncertainties of less than 0.03 mag for the TRGB magnitude were achieved. We also calibrated the TRGB method (Rizzi *et al.* 2007) and obtained new zero points and dependence on metallicity.

2. Structure of nearby galaxy groups

There are a number of galaxy groups in the neighbourhood of our Local Group of galaxies which are highly populated. As usual, each galaxy group contains one or two giant galaxies, which are accompanied by a family of dwarf satellites (cf. the M81 and Centaurus A groups, the IC 342–Maffei galaxy complex). We considered the individual structures of the groups and resolved stellar populations of a number of dwarf satellites. Interestingly, each galaxy group has its own peculiarities, which enables us to investigate dwarf galaxies in very different environments.

2.1. *The Centaurus A group of galaxies*

The mean distance to the Centaurus A (Cen A) group is approximately 3.8 Mpc. The central body, Cen A, is the only giant elliptical galaxy in the nearby Universe (except for the highly obscured galaxy Maffei 1). It has a vast satellite system of dwarf galaxies; most have been observed with the *Hubble Space Telescope*'s ACS and WFPC2 cameras. We measured TRGB distances to the satellites and studied their resolved stellar populations (Karachentsev *et al.* 2007; Makarova *et al.* 2007). Most of the galaxies we studied are dSphs. They exhibit prominent morphological segregation, where dwarf satellites which are situated closer to the gravitational centre do not exhibit any recent star formation and have no gas. The Cen A group looks highly evolved, with signs of metal enrichment in a number of galaxies (see Fig. 1).

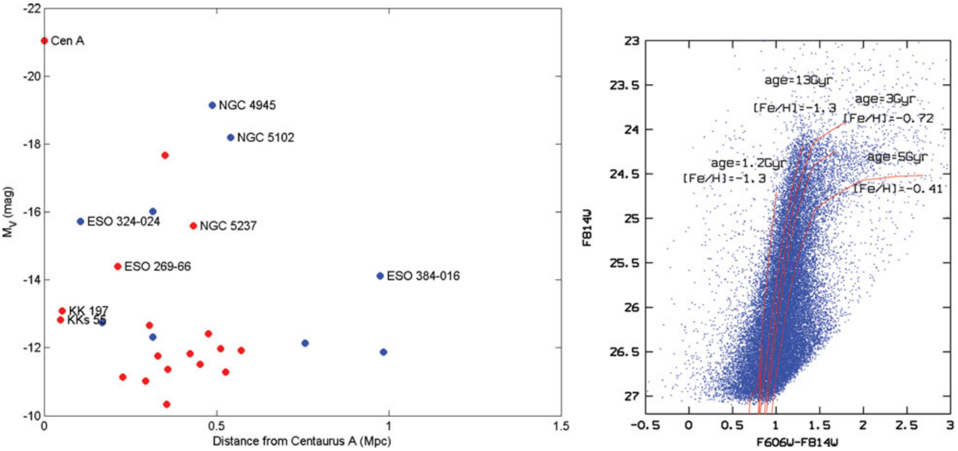

Figure 1. (left) Absolute magnitude versus distance from Cen A for the satellites studied. Dwarf spheroidal galaxies are shown as light (red) points, and dwarf irregulars as dark (blue) points. Note the clear morphological segregation. (right) Colour–magnitude diagram of the KK 197 dwarf speroidal, as an example of a galaxy exhibiting pronounced metal enrichment.

2.2. *The highly isolated dSph KKR 25 at a distance of 1.9 Mpc*

We studied a very interesting example of a highly isolated dwarf, which has no gas and does not show any recent star formation (see Fig. 2; Makarov *et al.* 2012). KKR 25 is located at a great distance from any massive galaxy in the Local Volume, so that it will unlikely have been affected by interactions over the course of its evolution. We can conclude that the evolution of KKR 25 was regulated by star formation in the galaxy itself rather than by its environment, in contrast to the dSphs in the Cen A group.

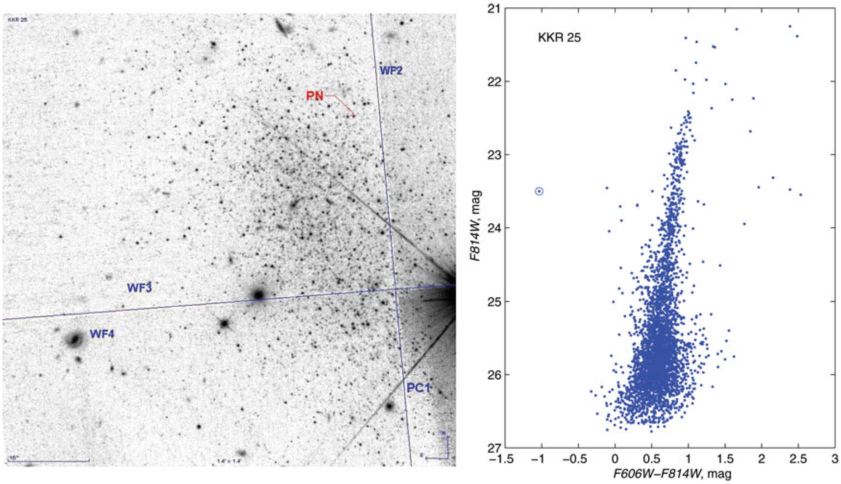

Figure 2. (left) WFPC2 image of KKR 25 and (right) its colour–magnitude diagram. We detected a planetary nebula in the galaxy, identified here by a circle.

2.3. *Tidal dwarfs in the M 81 group*

The mean distance to the M81 group is approximately 3.7 Mpc. The entire central part of the galaxy group is embedded in a huge HI cloud. We studied the resolved stellar populations of four tidal dwarf galaxies within the group (see Fig. 3; Makarova *et al.* 2002). All galaxies show evidence of continuous star formation in the period between ∼20 and 200 Myr in the recent past, and we did not detect any old RGB population. Apparently, these objects are examples of galaxies for which we cannot measure the TRGB distance.

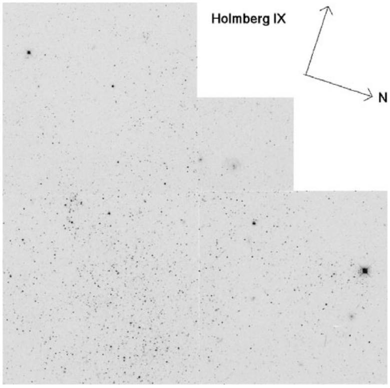

Figure 3. WFPC2 image of Holmberg IX, one of the tidal dwarfs in the M81 group.

2.4. *The CVn* I *Cloud of galaxies*

A prominent concentration of nearby galaxies with radial velocities $v_0 < 500$ km s^{-1} is located in a relatively small volume bounded by right ascension $\alpha = (11.5^{\rm h}, 14.0^{\rm h})$ and declination $\delta = (+20^\circ, +60^\circ)$ in the Canes Venatici constellation. The complex of galaxies is populated mostly by objects of late morphological types. It does not have a common dynamical centre as usually associated with a single luminosity-dominant galaxy. Our recent measurements of the distances to 30 members of the complex allowed us to revise the structure and reliably separate a virialized part of the complex (see Fig. 4).

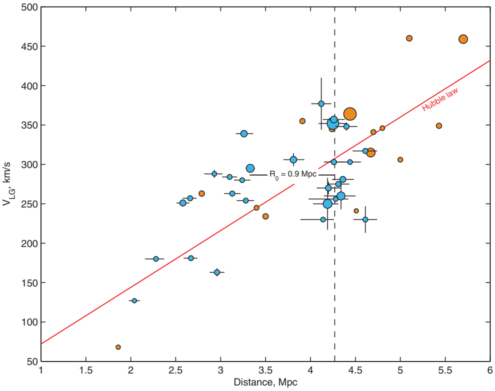

Figure 4. Distance–radial-velocity diagram for the CVn I Cloud complex.

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