VV124 (UGC4879): a new transitional dwarf galaxy in the periphery of the Local Group

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ABSTRACT
We present the first photometry of individual stars within VV124 (UGC4879) and find that this is the most isolated dwarf galaxy in the periphery of the Local Group. This work is based on imaging and spectroscopic follow-up observations with the 6-m BTA telescope; we resolve VV124 into 1560 stars down to the limiting magnitude levels of $V \simeq 25.6$ and $I \simeq 23.9$. Young blue stellar populations and ionized gas are found near the core, but notably displaced from the centre of the galaxy as traced by dominant evolved red stars. The mean heliocentric radial velocity derived from the spectra of two blue supergiant stars and unresolved continuum sources is $-70 \pm 15$ km s$^{-1}$. The evolved ‘red tangle’ stellar populations, which contain the red giant branch (RGB), are identified at large galactocentric radii. We use the $I$-band luminosity function to determine the distance based on the Tip of RGB method, $1.1 \pm 0.1$ Mpc. This is $\sim 10$ times closer than the values usually assumed in the literature, and we provide revised distance-dependent parameters. From the mean $(V - I)$ colour of the RGB, we estimate the mean metallicity as $[\text{Fe}/\text{H}] \simeq -1.37$ dex. Despite its isolated location, the properties of VV124 are clearly not those of a galaxy in formation, but rather similar to a transitional dIrr/dSph type.

Key words: galaxies: distances and redshifts – galaxies: dwarf – galaxies: individual: VV124 (UGC4879) – Local Group – galaxies: stellar content.

1 INTRODUCTION
The star formation history (SFH) and chemical-enrichment history of the Local Group (LG) galaxies, which can be derived from their resolved stellar populations, directly test cosmological galaxy formation models. However, the dynamical and mass-loss histories of the nearest satellite galaxies are the major uncertainty in understanding their evolution. Tidal stripping and stirring (e.g. Mayer et al. 2006), ram pressure stripping (Blitz & Robishaw 2000), and the local ultraviolet radiation from the primary galaxy (Mayer et al. 2007) all act to remove dark matter and/or baryons from dwarf galaxies, and may induce star formation. Isolated dwarf galaxies are not affected by these environmental effects, and are therefore ideal probes of the basic mechanisms affecting the SFH of a galaxy. Galaxies in the periphery of the LG are particularly valuable in this respect, being the only isolated systems for which detailed information is possible on their complete SFH with the Hubble Space Telescope (HST; Gallart & the LCDID Team 2007). Additionally, these fringe dwarfs are important probes of the dynamical state of the local Universe (van der Marel & Guhathakurta 2008). The purpose of this Letter is to announce the discovery of an additional exceptionally isolated galaxy in the outskirts of the LG.

One of the authors (AIK) noted a discrepancy between the distance based on the adopted radial velocity of VV124 (UGC4879), $V_\text{h} = 600$ km s$^{-1}$, cited in both the NED and HyperLeda data bases, and the galaxy’s apparent resolution into stars on the Sloan DSS images. The bright blue stars are well distinguished near the centre of VV124, while a few dozen fainter red objects can be traced to large galactocentric distances. Assuming that this field population is composed of red giant branch (RGB) and asymptotic giant branch (AGB) stars, we made a preliminary estimation of VV124 distance as $D \lesssim 2$ Mpc.

This object is one of the Vorontsov-Veliaminov galaxies listed in his ‘Atlas and Catalog of Interacting Galaxies’ (Vorontsov-Veliaminov 1959) as a ‘Nest’ type. Later the galaxy was included in Zwicky, Herzog & Wild’s (1966; CGCG264-088) and Nilson’s (1973; UGC4879) galaxy catalogues. The later catalogue noted a presence of ‘several faint very blue condensations superimposed’ in the object, Jansen et al. (2000a) described VV124 as a low-luminosity dwarf that ‘shows the enhanced Balmer
absorption lines and blue continuum of a young ‘post-starburst’ galaxy.

The radial velocity measurement of $v_R = 600 \pm 100$ km s$^{-1}$ for VV124 comes from the first CfA redshift catalogue (Huchra et al. 1983) that was reproduced in the RC3 catalogue with an uncertainty of 50 km s$^{-1}$, and currently cited in both NED and HyperLeda data bases with a note on alternative measurement in UZC (Falco et al. 1999), 62 $\pm$ 99 km s$^{-1}$. The revised 2002 version of UZC$^1$ gives $cz = -44 \pm 69$ km s$^{-1}$, derived via cross-correlation of the spectra obtained using the FAST spectrograph on the 1.5-m Tillinghast telescope. This measurement, however, remained unnoted, and the galaxy was even considered by Azzaro et al. (2006) as a distant companion of NGC 2841, which has a Cepheid distance of $\sim$14 Mpc (Macri et al. 2001; Saha et al. 2006). VV124 is undetected in H$\alpha$ (Schneider et al. 1992), probably due to the survey’s search range, 100–6800 km s$^{-1}$. Another possible reason behind the lack of concerns over the VV124 distance is a relatively high surface brightness, $\mu_{B,P} = 23.55$, for its new distance-corrected luminosity, $M_B = -11.6$ – about 1.5 mag above the value expected from the empirical absolute magnitude versus surface brightness relationship (e.g. Karachentsev et al. 2004). Various optical (Jansen et al. 2000a; Taylor et al. 2005) and near-infrared imaging surveys (Grauer, Rieke & Quillen 2003) aimed at the global photometric parameters and also missed an apparent high degree of VV124 resolution.

2 OBSERVATIONS AND STELLAR PHOTOOMETRY

Follow-up imaging observations of VV124 were obtained on 2008 January 10/11 using the Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations (SCORPIO; Afanasiev & Moiseev 2005) mounted at the prime focus of the 6-m BTA telescope of the Special Astrophysical Observatory (Russia). The detector was an EEV42-40 2048 $\times$ 2048 8 CCD array with a field of view roughly 6 $\times$ 6 arcmin$^2$ and a scale of 0.357 arcsec per 2 $\times$ 2-binned pixel. VV124 was observed with 3 $\times$ 200 and 3 $\times$ 60 s in V and 2 $\times$ 200 and 3 $\times$ 60 s in I broad-band filters close to the standard Johnson–Cousins photometric system. The weather conditions were good, with a stable seeing of 1.0–1.1 arcsec. The primary data reduction was performed using the ESO-MIDAS software package. It included de-biasing, flat-fielding and cosmic-ray hit removal.

Fig. 1 shows a co-added image from these data, exhibiting many resolved stars. The image of the central part of the galaxy obtained by division of I-on-V-band frames is shown in Fig. 2, and it demonstrates a slight asymmetry in the distribution of the blue stars (white in the figure) relative to the red stars, which can be traced to large galactocentric distances.

We performed single-star photometry with DAOPHOT II (Stetson 1998). Because of relatively strong image aberrations of the SCORPIO camera, we carefully selected isolated stars suitable to model the point spread function (PSF), and removed stars from the detection catalogue located in the areas where the PSF reconstruction was inadequate. The absolute photometric calibration of the data was performed using the observations of standard stars from the lists by Landolt (1992) on the same nights. We corrected data for foreground extinction in the direction of VV124 using the values of Schlegel, Finkbeiner & Davis (1998): $A_V = 0.050$ and $A_I =$

1 Available at ftp://cdsarc.u-strasbg.fr/pub/cats/J/PASP/111/438/.

Figure 1. Image covering a 4.1 $\times$ 3.8-arcmin$^2$ region centred on VV124 made from the 6-m telescope data in V band. The histogram equalization technique was applied to enhance image contrast. The north is up, and the east is to the left-hand side.

Figure 2. The distribution of blue (in white) and red stars (in black) in the central 1.5 $\times$ 1.5-arcmin$^2$ area, obtained by division of I-to-V-band images. The lines mark the slit positions for the spectroscopic observations. The red plus sign shows the centre of VV124. Two analysed BSG stars, and an H$\alpha$ region are indicated.

0.029. We did not correct for internal extinction within VV124, but the transparency of the outer field stellar population (the population from which we derive the distance) is high and suggests that the extinction is low at large galactocentric radii.

The colour–magnitude diagram (CMD) of VV124 (Fig. 3) illustrates a stellar mix that is characteristic of the superposition of many stellar generations, and reminiscent of the CMD of a typical galaxy.'
transitional intermediate dIrr/dSph galaxy like Phoenix or LGS3 (Gallart et al. 2004; Gallart & the LCID Team 2007). The ‘blue plume’ at \((V - I) \sim 0\) contains massive blue supergiants (BSGs) and – at fainter magnitudes – main-sequence stars, the ‘red plume’ at \((V - I) \sim 1.5\) contains evolved giants and AGB stars, while the ‘red tail’ extending past \((V - I) > 2\) contains intermediate-mass AGB stars in the thermally pulsing phase, and the concentration of stars below the Tip of the first ascent RGB (TRGB) at \(I \simeq 21.2\) contains low-mass RGB and AGB stars. For reference, we overlay the CMD with the \(Z = 0.001\) BaSTI stellar isochrones (Pietrinferni et al. 2004) assuming the distance derived below. The blue plume is quite scarce, whereas the RGB exhibits a significant width. The stellar crowding and blending, as well as a fluctuation of internal extinction, may dominate these effects. However, based on preliminary artificial star tests, the RGB width exceeds that due to photometric errors, suggesting a possible wide range of stellar metallicities and/or ages.

3 DISTANCE AND METALLICITY

We used our stellar photometry to find the TRGB and to determine the distance and metallicity of VV124 (following Lee, Freedman & Madore 1993). The photometric data of outer stars are preferable to the central high stellar density region since they exhibit much less crowding and fewer AGB stars, which tend to have a stronger concentration towards the centre of irregular galaxies (Tikhonov 2005, 2006). Therefore, for the analysis of the RGB, we exclude the innermost region (Fig. 2) defined by a central circle with a diameter of 90 arcsec that corresponds roughly to 1 scalelength of the AGB star density profile. There are a sufficiently large number of stars detected in the selected area to have \(0.7 < (V - I)_0 < 2.0\). The TRGB was found by applying a Sobel filter to the \(I\)-band luminosity function; it occurs at \(I_0 = 21.17 \pm 0.10\) (indicated in Fig. 3 by a line). In order to estimate the average metallicity of the RGB stars, we measure the colour at half a magnitude below the TRGB, \((V - I)^{\odot}_{\text{RGB}} = 1.43\), corresponding to the \((V - I)^{\odot}_{\text{TRGB}} = 1.63\). Based on the calibration by Lee et al. (1993), we estimated the metallicity of RGB stars of \([\text{Fe}/\text{H}] = -1.37\), and a distance of \(D = 1.1 \pm 0.1\) Mpc.

Note that the result on the metallicity is based on the assumption that the age of the RGB stars is predominantly old, since the calibration of Lee et al. (1993) is based on old Galactic globular clusters; therefore, if the majority of stars are younger than 10–13 Gyr, this metallicity estimation is an upper limit of an intrinsic value.

4 SPECTROSCOPIC OBSERVATIONS

Long-slit spectra of VV124 were obtained with the same 6-m/SCORPIO facility on 2008 February 6/7 in a wavelength range of 4000–5600 Å with a spectral resolution of 5 Å. Two 1-arcsec-wide long slits were placed on two bright blue stars near the centre of the galaxy, marked in Fig. 2 as ‘bl1’ and ‘bl2’. With the VV124 distance of 1.1 Mpc, the scale along the slit corresponds to 5.3 pc arcsec\(^{-1}\). This gives a separation of 111 pc between stars ‘bl1’ and ‘bl2’. Both slits run over the compact H II region, while the second one also includes by chance a high-redshift background galaxy.

The spectral data have been reduced using standard calibration procedures within the IDL environment. The uncertainty of the wavelength calibration is 10 km s\(^{-1}\). However, the final accuracy of the radial velocity measurements was limited by the quality of the spectrum of each of the detected components.

By matching the spectra of the two bright stars with the template spectra from the STELIB stellar library (Le Borgne et al. 2003, http://www.ast.obs-mip.fr/article181.html), we find that both stars are BSGs of spectral type O9.5 for ‘bl1’, and F5Ia (‘bl2’). HD30614 (\(\alpha\) Cam, O9.5Iae) and HD188209 (O9.5Ib) are good matches for the star ‘bl1’, and the spectrum of HD269697 (F5Ia) from the Large Magellanic Cloud is a close match of that of ‘bl2’. From the results of our stellar photometry, we find that ‘bl1’ has \(V = 18.53\) and \((V - I) = -0.13\), while the magnitude and colour of ‘bl2’ are \(V = 17.81\) and \((V - I) = +0.30\). At the TRGB distance modulus of VV124, \((m - M) = 25.21\), this corresponds to deduced absolute magnitudes of \(M_V = -6.73\) and \(-7.45\) for ‘bl1’ and ‘bl2’, respectively.

To measure the radial velocities, we used absorption lines of hydrogen, H\(\delta\), H\(\gamma\) and H\(\beta\), because these are the deepest and most reliable lines for redshift measurements. The heliocentric radial velocity of ‘bl1’ is \(-79 \pm 10\) km s\(^{-1}\), while radial velocity of ‘bl2’ is \(-76 \pm 15\) km s\(^{-1}\).

In addition, we analysed the redshifts of absorption hydrogen lines of the unresolved stellar populations integrated at various areas along the slits. These hydrogen lines are the most prominent details in the spectra of unresolved objects. The mean value of the radial velocity obtained from these spectra, \(-70 \pm 15\) km s\(^{-1}\), is in good agreement with the measured velocities of the two BSGs.

We also found a compact H II region exhibiting faint H\(\beta\) emission (see Fig. 2), as well as an extended region of faint diffuse \([\text{O}\text{III}]\lambda5007, 4959\) emission, located in the western part of the galaxy, traced over 70 pc along the first slit and over 120 pc in the second slit. The emission-line spectrum is roughly consistent.
with the mean radial velocity of the absorption lines.2 We will present a more detailed analysis of the spectroscopic data in a follow-up work.

## 5 RESULTS AND DISCUSSION

The basic parameters of VV124 are presented in Table 1, based on our measurements and data available from the literature. As judged from our distance estimation and new photometric and spectroscopic measurements, VV124 lies at a distance of 1.1 Mpc and appears to be a transitional dIrr/dSph type galaxy: although possessing some young stellar populations the bulk of stars is evolved. Despite its isolated location, and some recent star formation, the properties of VV124 are clearly not those of a galaxy in formation.

VV124 is located 1.1 Mpc from the Milky Way and 1.2 Mpc from M31 – on the periphery of the LG (Fig. 4). Leo A is its nearest neighbour, at a separation of ≈0.5 Mpc. There are only two other galaxies in the LG with similar, although slightly lower, degree of isolation: DDO 210 and SgrDIG, located in the direction opposite to that of VV124. Remarkably, the peculiar radial velocity of these three galaxies, corrected either for the LG rest frame or for the motion within the Local Sheet – following relation (15) from Tully et al. (2008) – is close to zero, −12 < \( V_{\text{LG}} \) < +21 and −3 < \( V_{\text{LSR}} \) < +9 km s\(^{-1}\), confirming that these objects are near the LG turnaround radius. Most importantly, these galaxies are not, and have never been, satellites of either of the dominant members of the LG. Their free-fall time into M31 or the Milky Way is longer than a Hubble time. The exceptional isolation means that these are among the few galaxies in the nearby Universe whose evolution has never been complicated by the local environmental mechanisms. Therefore, these objects are ideal probes of the basic mechanisms affecting the SFH of a galaxy. This would, however, require deeper observations, preferably with \textit{HST}.

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2 Our radial velocity measurements are in agreement with the velocity listed in the latest version of the UZC, and they have been also confirmed after wavelength re-measurements of the original Jansen’s et al. (2000b) spectra (R. Jansen, private communication).
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