Dwarf galaxies in the Local Group: the VLT perspective

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Abstract. Recent results on the evolution of Local Group dwarf galaxies obtained from VLT imaging and spectroscopy are briefly reviewed, and prospects for dwarf galaxy research at the VLT are discussed in the light of the current and forthcoming instrumentation. Some aspects of future instrument developments, such as deep wide-field imaging at both optical and near-infrared wavelengths, that may be of advantage for research on the evolution of dwarf galaxies, are briefly discussed.

1 Introduction

Understanding the origin and evolution of dwarf galaxies and their luminosity and mass distributions may have important consequences in modern observational cosmology. While dwarf galaxies are difficult to study even at moderate redshifts, especially those without active star formation, both star-forming and quiescent dwarfs can be studied with considerable detail in the Local Group (LG). Dwarf galaxies in the LG are close enough that the process of star formation, their dynamical evolution and the interplay between stars and interstellar medium can be studied in detail. By analyzing their color-magnitude diagrams one can derive star formation histories and reconstruct their evolution at look-back times comparable to the age of the universe. However, sound knowledge of the age-metallicity relation is required to obtain reliable determination of the star formation history. Spectroscopy is therefore needed to add essential information to constrain the chemical enrichment histories.

This contribution will focus on studies of stellar populations and kinematics of resolved Local Group galaxies. I briefly review the work done so far at the VLT, and discuss the prospect for dwarf galaxy research at the VLT in the light of the existing and forthcoming instrumentation. Some ideas for future VLT instruments are also presented.

2 Dwarf galaxy evolution with the VLT

2.1 Optical imaging

Studies of resolved dwarf galaxies in the last decade, using both HST and ground based instrumentation, have provided a complex picture of their star formation histories. Star formation can proceed either in distinct episodes, as in the case...
Fig. 1. The \( V, (B - V) \) color-magnitude diagram of the Phoenix dwarf, observed with FORS1 at the VLT of Carina \[11\], or at a nearly continuous rate, as in the case of Fornax (e.g., \[16\], and references therein).

Deep color-magnitude diagrams of LG dwarfs obtained with FORS1/2 indicate that VLT images taken in excellent seeing can indeed be complementary to space observations \[15,19,9\]. As an example, Fig. 1 shows our observations of the dSph/dIrr galaxy Phoenix. The main advantage of VLT imaging over HST/WFPC2 is represented by the larger field, allowing us to detect extended halos of red giant stars around dwarf galaxies, to trace the populations gradients of stars in several age bins, and to map the physical association between star formation and the interstellar medium. In the outer regions, the surface density of stars (“crowding”) is relatively low, so the limiting magnitude is less subject to confusion than in the inner regions, and the benefits of a larger collecting power may largely balance the negative effects of a broader point spread function. A further advantage of a large field is the possibility to conduct efficient searches for variable objects by using a suitable time series strategy. This approach has been employed by our group, using VLT and other ESO telescopes, to study the RR Lyrae variables in LG dwarfs as tracers of the oldest stellar populations \[10\].
The need for deep, wide-field optical imaging of nearby galaxies will be largely met by VIMOS, planned for operation in 2002. While the advent of ACS aboard HST will re-confirm the advantage of space observations for studying distant LG galaxies, the large field of VIMOS will be essential to obtain deep, spatially resolved views of the stellar populations in dwarf galaxies out to 200–300 Kpc from the Milky Way, although it will face the competition with larger prime-focus CCD mosaics being built at 10m-class telescopes.

2.2 Near-infrared imaging

The recent results obtained for the Magellanic Clouds and the Sagittarius dSph using DENIS and 2MASS data have confirmed the scientific potential of near-infrared photometry for studying the evolved stellar populations in nearby galaxies. The near-infrared magnitudes and colors are more directly amenable to the fundamental quantities – luminosity and \( T_{\text{eff}} \) – of the stars that build up dwarf galaxies (e.g., [3]). Thus, near-infrared imaging can play an impor-
tant, yet little exploited role in studying old and intermediate age stars in LG dwarfs. The red giant branch of Milky Way satellite dwarfs is within reach of modern near-IR imaging detectors at 4m-class telescopes, including the future mosaic of VISTA. Figure 2 shows a new view of the RGB/AGB population in Leo I from our NTT/SOFI survey of evolved stellar populations in nearby dwarf spheroidals. The use of the $K$ band allowed us to detect some very reddened luminous stars, hidden at optical wavelengths, possibly obscured AGB stars (cf. [14]).

On the other hand, a 10m-class telescope is needed to sample the relatively bright upper-AGB population in more distant LG galaxies, and to observe red clump and subgiant branch stars in nearby dSph. Beyond the Milky Way environment, most Local Group dwarfs have distance moduli about 24–25 mag, which implies $K = 18–19$ for their RGB tips. Although ISAAC offers adequate sensitivity, its small field of view is not ideally matched to the large projected tidal radii of LG dwarfs (see [12]).

In the next future, NIRMOS will provide imaging over a $14 \times 16$ arcmin$^2$ field in the $J$ and $H$ bands. However, the $K$ band is important in discriminating between carbon- and oxygen-rich stars, and locate them in the theoretical HR diagram [7]. Thus, only a fully cryogenic wide-field near-IR mosaic at the VLT, with sensitivity extended to the thermal near-IR wavelengths, would enable deep, wide field infrared surveys of stellar populations in Local Group galaxies, in particular of their evolved, intermediate-age RGB/AGB populations and young red supergiants. In that it would be complementary to NGST, which will give superior results for the inner regions of distant dwarfs at the edge of the LG and beyond.

2.3 Spectroscopy

Stellar abundances Tracing the chemical enrichment history of dwarf galaxies from color-magnitude diagrams alone is a very difficult task, because of the ambiguity between the effects of a young age and low metallicity (the so-called “age-metallicity degeneracy”). Direct abundance measurements are the best way to reconstruct the stellar metallicity distributions in nearby galaxies and model their chemical evolution.

Measurements of individual stellar abundances are now feasible at 10-m class telescopes (e.g., [17]). High-resolution abundance analysis yields information on the pattern of individual elements, which is directly related to the star formation history of the galaxy. Abundance measurements have been obtained at the VLT for a few red giant stars in Sagittarius [8], using UVES commissioning data. Similarly to other dSph [17], the Sagittarius dSph does not appear to be enhanced in the $\alpha$-elements. Luminous blue supergiants have also been observed in star-forming dwarf galaxies out to relatively large distances. Element abundances of O and other $\alpha$-elements, Fe-peak and s-process elements have been measured for A-type supergiants in NGC 6822 [21] using UVES.

In the near future, FLAMES will allow us to investigate the abundance patterns of elements in hundreds of stars in nearby dwarfs, although detailed abun-
dance analysis will be possible only for the brightest red giants in the nearby Milky Way satellites.

For this reason, intermediate resolution spectroscopy at the VLT will also play an important role in deriving metallicity distributions of stars in distant LG dwarfs. FORS1 spectroscopy in the Ca II triplet region has recently been employed to measure metallicity distributions of stars in Sculptor, Fornax, and in the dIrr NGC 6822 \[20\]. These results confirmed that the colors of the stars are not always representative of their metal content, since they also reflect variable Ca/Fe ratios and an age spread.

**Radial velocities and internal kinematics** Precise measurements of the systemic radial velocities allow us to investigate the dynamics and mass of the Local Group, and to establish for some galaxies the physical association of gas and stars. Radial velocities of stars in the Antlia and Phoenix dwarfs have been obtained by \[18\] and \[8\], respectively. While low-resolution spectroscopy can give useful information, the most compelling information on the star and gas dynamics is provided by high resolution spectroscopy. Recent UVES measurements of giant stars in the Phoenix galaxy (Fig. 3) reveal that the stars and the neutral gas have the same velocity within 2–3 km s\(^{-1}\).
However, the most fundamental questions concern the internal dynamics of dSph galaxies. What is the distribution of mass in dwarf spheroidal galaxies? Is a dark halo needed to explain the observed velocity dispersions? These questions not only bear on the formation of low-mass galaxies, but also on their evolution (e.g., their ability to retain gas against the energetic outflows of supernova explosions). Many studies have been devoted to measuring the internal velocity dispersion of dSph galaxies (e.g., [5]; see [12] for a review).

High resolution spectroscopy of large stellar samples in dSph’s will be a major science objective for FLAMES. Spectroscopy out to several core radii will be used to derive velocity dispersion profiles, detect possible rotation, and model the mass distribution in dwarf spheroidals. To this purpose, a project aimed at investigating the internal kinematics and mass-to-light ratios of nearby and distant dwarfs using the VLT has recently been undertaken by our group.

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