

# A VLT/FORS2 spectroscopic survey of individual stars in a transforming dwarf galaxy

G. Battaglia<sup>1,2</sup>, N. Kacharov<sup>3</sup> and M. Rejkuba<sup>4</sup>

<sup>1</sup>Instituto de Astrofísica de Canarias, calle Vía Láctea s/n, E38205 - La Laguna (Tenerife), Spain

<sup>2</sup>Universidad de la Laguna, Dpto. Astrofísica, 38206 La Laguna, Tenerife, Spain  
email: [gbattaglia@iac.es](mailto:gbattaglia@iac.es)

<sup>3</sup>Max Planck Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany

<sup>4</sup>European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany

**Abstract.** Understanding the properties of dwarf galaxies is important not only to put them in their proper cosmological context, but also to understand the formation and evolution of the most common type of galaxies. Dwarf galaxies are divided into two main classes, dwarf irregulars (dIrrs) and dwarf spheroidals (dSphs), which differ from each other mainly because the former are gas-rich objects currently forming stars, while the latter are gas-deficient with no on-going star formation. Transition types (dT) are thought to represent dIs in the process of losing their gas, and can therefore shed light into the possible process of dwarf irregulars (dIrrs) becoming gas-deficient, passively evolving galaxies. Here we present preliminary results from our wide-area VLT/FORS2 MXU spectroscopic survey of the Phoenix dT, from which we obtained line-of-sight velocities and metallicities from the nIR Ca II triplet lines for a large sample of individual Red Giant Branch stars.

**Keywords.** techniques: spectroscopic, stars: abundances, galaxies: dwarf, galaxies: evolution, Local Group

---

## 1. Introduction

As in other galaxy groups, also the dwarf galaxies inhabiting the Local Group can be broadly divided in two categories, late- and early-types, on the basis of the presence or absence of both gas and current star formation, respectively. It is still a question whether these morphological types share similar ancestors and owe their distinct properties at redshift zero to a different evolutionary path, or whether their “destiny” as a late- or early-type system was somewhat imprinted in the conditions at their formation. The fact that Local Group late- and early-type dwarfs share similar scaling relations (see Tolstoy, Hill & Tosi 2009 for a recent review), appear to follow the same stellar mass-metallicity relation (Kirby *et al.* 2013) but inhabit clearly different environments - with late-types found in isolation and early-types in general satellites of the large Local Group spirals - hints to environmental effects being relevant for the evolution of these galaxies.

On the basis of lifetime star formation histories from very deep colour-magnitude diagrams, Gallart *et al.* (2015) propose the existence of two main types of dwarf galaxies: *slow dwarfs*, i.e. those that have formed stars at a relatively low rate for the whole life of the system, and *fast dwarfs*, i.e. those that have experienced most of their star formation activity in the first Gyrs of evolution. Late-type systems map into *slow dwarfs*, but this is not always the case for early-type and *fast-* dwarfs. Gallart *et al.* propose that the two

evolutionary paths are imprinted from the start and related to the environment in which the dwarfs were born.

The spectroscopic study of the evolved stellar component of dwarf galaxies offers a complementary perspective, as for Local Group galaxies it is possible to determine metallicities and line-of-sight velocities for individual stars, and hence study their internal kinematics and metallicity properties in detail and out to large radii. Red giant branch stars are particularly interesting targets, because they probe a very large range of ages, from  $\sim 1.5$  Gyr to the early star formation episodes. Being very luminous, they are within reach of current spectrographs on 8m-10m telescopes for galaxies to within  $\sim 1$  Mpc.

## 2. The data-set

Here we present preliminary results from our VLT/FORS2 MXU spectroscopic survey of RGB stars in the Phoenix transition type (dT). This system is as luminous as a typical “classical” spheroidal, but found at a distance of  $\sim 400$  kpc from the Milky Way, hence it can provide an interesting view of the properties of low mass dwarf galaxies that have mostly evolved in isolation.

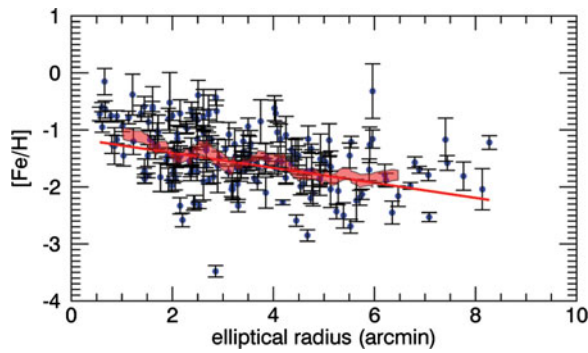
We obtained VLT/FORS2 MXU spectroscopic data for the Phoenix dT in service mode (Programme 083.B-0252; PI: Battaglia). We used the 1028z grism in combination with the OG590+32 order separation filter (wavelength coverage 7730 - 9480 Å); the slits were set to have a width=1” for a final resolving power of  $R \sim 2500$ . We obtained 11 pointings in which we allocated slits to a total of 254 pre-selected red giant branch (RGB;  $I < 21.5$  mag) stars from Battaglia *et al.* (2012) that cover a total area of roughly  $10' \times 20'$  across the field of the galaxy. In addition to these data, we use VLT/FORS2 MXU spectra for 30 stars in a central pointing (Programme 71.B-0516; PI: Cole).

The data reduction and extraction of the spectra was performed with standard IRAF procedures, together with custom made IDL scripts. We extracted line-of-sight velocities ( $v_{l.o.s.}$ ) and equivalent widths (EWs) from the Ca II triplet (CaT) nIR lines. Line-of-sight velocities were obtained by cross-correlating the continuum normalized spectra with a synthetic spectrum derived from a stellar atmospheric model with similar parameters as expected for the Phx targets. The EWs were determined by fitting a Voigt profile and transformed into [Fe/H] using the calibration from Starkenburg *et al.* (2010). The CaT [Fe/H] was validated against two calibrating globular clusters; these were also used to test the accuracy of the  $v_{l.o.s.}$  determination, together to Phx stars overlapping among different masks. The median error in  $v_{l.o.s.}$  is  $8 \text{ km s}^{-1}$ . The sample of probable Phoenix members among the two observing programmes consists of  $\sim 190$  stars, as indicated by the stars’ position on the colour-magnitude-diagram and radial velocity.

## 3. Results

We obtain a systemic l.o.s. velocity equal to  $-21.2 \pm 1.0 \text{ km s}^{-1}$  and a dispersion of  $9.3 \pm 0.7 \text{ km s}^{-1}$ . The systemic velocity is consistent with the determination of  $-13 \pm 9 \text{ km s}^{-1}$  obtained by Irwin & Tolstoy (2002) from a much smaller sample of 7 stars and in excellent agreement with the velocity of the HI cloud ( $-23 \text{ km s}^{-1}$ ) proposed by St-Germain *et al.* (1999) as physically associated to Phoenix.

It is well-known that dwarf galaxies inhabiting dense environments such as within the virial radii of the Milky Way or M31 are devoid of gas, except for relatively massive systems such as e.g. for the Magellanic Clouds or IC 10. The fact that such a small system as Phoenix has been able to form stars until almost present day (Hidalgo *et al.* 2009) and still contains gas, together with its large distance and velocity direction approaching



**Figure 1.** Metallicity versus elliptical radius for the Phoenix probable member stars. The red lines show the running average and the linear fit to the metallicity properties.

the Milky Way ( $v_{\text{GSR}} = -108.6 \pm 1.0 \text{ km s}^{-1}$ ), strongly suggests that Phoenix is still to enter the Milky Way virial radius for the first time and has evolved undisturbed from interactions with large galaxies.

Interestingly, the metallicity properties of this system appear alike to those of similarly luminous dwarf spheroidal galaxies satellites of the Milky Way, which are devoid of gas and are found in a higher density environment. In particular we detect a clear negative, approximately linear  $[\text{Fe}/\text{H}]$  gradient (see Fig. 1), whose slope compares well to those of Milky Way dwarf spheroidal galaxies (e.g. Leaman *et al.* 2013). This finding leads us to speculate that metallicity gradients in these small dwarf galaxies are likely to be driven by internal mechanisms rather than by environmental ones, although this conclusion needs to be put on a more secure foot by similar spectroscopic surveys of larger samples of Local Group dwarf galaxies inhabiting different environments.

The detailed metallicity and kinematic properties of Phoenix from the VLT/FORS2 MXU sample here presented will be discussed in Kacharov *et al.* (in prep.)

## Acknowledgements

We are grateful to A. Cole for useful discussions and for providing the reduced VLT/FORS2 data from program 71.B-0516.

## References

- Battaglia, G., Rejkuba, M., Tolstoy, E., Irwin, M. J., & Beccari, G. 2012, *MNRAS*, 424, 1113  
 Gallart, C., Monelli, M., Mayer, L., *et al.* 2015, *ApJL*, 811, L18  
 Hidalgo, S. L., Aparicio, A., Martínez-Delgado, D., & Gallart, C. 2009, *ApJ*, 705, 704  
 Irwin, M. & Tolstoy, E. 2002, *MNRAS*, 336, 643  
 Kirby, E. N., Cohen, J. G., Guhathakurta, P., *et al.* 2013, *ApJ*, 779, 102  
 Leaman, R., Venn, K. A., Brooks, A. M., *et al.* 2013, *ApJ*, 767, 131  
 Starkenburg, E., Hill, V., Tolstoy, E., *et al.* 2010, *A&A*, 513, A34  
 St-Germain, J., Carignan, C., Côte, S., & Oosterloo, T. 1999, *AJ*, 118, 1235  
 Tolstoy, E., Hill, V., & Tosi, M. 2009, *ARA&A*, 47, 371