University of Groningen

An optical velocity for the Phoenix dwarf galaxy

Irwin, Mike; Tolstoy, Eline

Published in:
Monthly Notices of the Royal Astronomical Society

DOI:
10.1046/j.1365-8711.2002.05802.x

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2002

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Irwin, M., & Tolstoy, E. (2002). An optical velocity for the Phoenix dwarf galaxy. *Monthly Notices of the Royal Astronomical Society*, *336*(2), 643-648. https://doi.org/10.1046/j.1365-8711.2002.05802.x

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 25-08-2022

Mon. Not. R. Astron. Soc. **336,** 643–648 (2002)

An optical velocity for the Phoenix dwarf galaxy

Mike Irwin[1★] and Eline Tolstoy[2★]

[1]*Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA*
[2]*Kapteyn Institute, University of Groningen, PO Box 800, 9700AV Groningen, the Netherlands*

Accepted 2002 June 19. Received 2002 June 19; in original form 2002 January 9

ABSTRACT

We present the results of a Very Large Telescope observing programme carried out in service mode using FORS1 on ANTU in long-slit mode to determine the optical velocities of nearby low surface brightness galaxies. As part of our programme of service observations we obtained long-slit spectra of several members of the Phoenix dwarf galaxy from which we derive an optical heliocentric radial velocity of -13 ± 9 km s^{-1}. This agrees very well with the velocity of the most promising of the H I clouds seen around Phoenix, which has a heliocentric velocity of -23 km s^{-1}, but is significantly different from the recently published optical heliocentric velocity of Phoenix of -52 ± 6 km s^{-1} by Gallart et al.

Key words: galaxies: individual: Phoenix – galaxies: kinematics and dynamics – Local Group.

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018

1 INTRODUCTION

Dynamical measurements of outlying Local Group galaxies are crucial for constraining both the age and the total mass of the Local Group and for probing the nature of the intrinsic dark matter within the galaxies. A necessary part of this process involves investigating the link between possible H I detections, the optical components of the galaxies and the relevance of these detections to the recent star formation history of the system. Optical velocities determine whether observations of H I gas in and around these systems are the result of gas associated with these galaxies, a chance superposition with high-velocity H I clouds, outlying components of the Magellanic Stream or just Galactic foreground contamination.

Phoenix is a member of the Local Group, lying approximately 450 kpc from our Galaxy (Ortolani & Gratton 1988) in a fairly isolated location on the opposite side of the Galaxy from the Andromeda subsystem (see Table 1). It is possibly one of the most distant of the satellites of our Galaxy, or perhaps a free-floating outlying Local Group object. It appears to be a galaxy in transition between a dwarf irregular (dI) and a dwarf spheroidal (dSph) system, having had both a recent burst of star formation and a plausible detection of $\approx 10^5$ M$_\odot$ of H I. The H I gas has been detected close to the position of Phoenix at several different locations, and velocities ($v_\odot = 56$, 120 km s^{-1}, Carignan, Demers & Côte 1991; $v_\odot = -23$ km s^{-1}, Oosterloo, Da Costa & Staveley-Smith 1996; and from mosaic mapping using the Australia Telescope Compact Array at $v_\odot = -23$, 7, 59, 140 km s^{-1}, St-Gérmain et al. 1999). Owing to the superior resolution/sensitivity we adopt the latter measurements as defining the possible H I-associated gas throughout the remainder of this paper.

The H I complex at $v_\odot = 140$ km s^{-1} is thought to be an outlying component of the Magellanic Stream, which passes close to the line of sight of Phoenix, while the component at $v_\odot = 7$ km s^{-1} is undoubtedly Galactic in origin. This leaves two remaining H I components that may be associated with Phoenix. The more compact of the H I clouds at $v_\odot = -23$ km s^{-1} is centred approximately 5 arcmin to the southwest of the optical centre of Phoenix and overlaps the optical image. This is within a distance of approximately 650 pc if it lies at the same distance as Phoenix, and partially covers the optical image, which is approximately 1 kpc in size. The component with $v_\odot = 59$ km s^{-1} is much more extended, fragments into four substructures, and is located significantly further to the south of the optical centre. From the H I morphology and dynamics, while it is unclear whether or not the 59 km s^{-1} component is, or perhaps was in the past, associated with Phoenix, the evidence for the -23 km s^{-1} system is more compelling. The derived H I mass of $\approx 10^5$ M$_\odot$ is comparable to that found in the Sculptor dwarf spheroidal and in the dwarf irregular/dwarf spheroidal transition object LGS 3 (Young & Lo 1997). Furthermore, as St-Gérmain et al. point out, the H I velocity field of the -23 km s^{-1} component shows clear evidence of a velocity gradient, indicating either rotation or ejection from Phoenix.

The resolved stellar population of Phoenix has been studied in some detail (Ortolani & Gratton 1988; van de Rydt, Demers & Kunkel 1991; Held, Saviane & Momany 1999; Martínez-Delgado, Gallart & Aparicio 1999; Holtzmann, Smith & Grillmair 2000). Phoenix has obviously experienced recent star formation as can be seen from the sprinkling of blue stars across the field. They are concentrated in 'associations' near the centre of the galaxy and elongated in the direction of the H I cloud at -23 km s^{-1}. This recent 'episode' of star formation has been quantified by Held et al. (1999) to have started at least 0.6 Gyr ago, but accounts for less than 6 per cent of the *V*-band luminosity of Phoenix and

★E-mail: mike@ast.cam.ac.uk (MI); etolstoy@astro.rug.nl (ET)

© 2002 RAS

Table 1. Phoenix.

Object	RA (J2000) Dec.	Distance (kpc)	M_V	Type	Ref
Phoenix	01 51 06 − 44 26 42	445 ± 30	−10.1	dIrr/dSph	Ortolani & Gratton (1988) van de Rydt et al. (1991)

0.2 per cent of the mass. This is thus broadly consistent with the comprehensive modelling of the central region of Phoenix based on *Hubble Space Telescope* (*HST*) data by Holtzmann et al. (2000). They found that star formation has been roughly continuous over the lifetime of Phoenix, with no obvious evidence for strongly episodic star formation, although a mildly varying star formation rate can fit the data.

Recently, in an attempt to probe the optical–H I link further, Gallart et al. (2001) published the first optical radial velocity study of a sample of 31 individual stars in Phoenix using Very Large Telescope (VLT)/FORS1 in MOS mode. Studying the blue end of the optical spectra in the range ≈3500–6000 Å, which encompasses the Mgb absorption complex, they determined a mean value of $v_{\odot} = -52 \pm 6$ km s^{-1}. There is quite a large offset between this optical measurement and the most likely H I gas velocity component at −23 km s^{-1}. Gallart et al. interpret this difference as either being caused by ejection of gas arising from supernovae from the most recent burst of star formation in Phoenix approximately 100 Myr ago, or as a consequence of ram pressure stripping by a hot intergalactic medium within the Local Group.

The putative association of the H I gas with the optical galaxy is quite a crucial measurement, not only because of the direct coupling of the (potentially) recently expelled gas, but also because of the unique position of Phoenix in the Local Group as potentially (by far) the furthest outlying satellite of the Galaxy. At a Galactocentric distance of ≈450 kpc, Phoenix could have unprecedented leverage in constraining the mass of the Galactic Halo out to 450 kpc.

As part of a long-term VLT service programme to measure the radial velocities of several outlying Local Group satellites we recently acquired some service observations of Phoenix and decided that it was worth reinvestigating the optical–H I connection with an additional optical velocity measurement. In this paper we therefore present the results of VLT/FORS1 long-slit observations of Phoenix in the spectral region centred on the Ca II near-infrared triplet. The slit position was aligned with seven stars bright enough to derive radial velocities from. Although this is a much smaller number of stars than observed by Gallart et al. each spectrum is of sufficiently high signal-to-noise (S/N) ratio (≈10:1 per continuum Å) to derive an accurate velocity measurement.

2 OBSERVATIONS

The observations were obtained in service mode, with UT1/FORS1 in the Long-Slit Spectroscopy (LSS) instrument set-up on the nights of 2000 October 5–6 and 2000 December 31 to 2001 January 1 (see Table 2). The FORS1 long slit spans 6.8 arcmin and was used with a slit width of 1 arcsec and the GRIS-600I+15 grism along with the OG590 order-sorting filter, to cover the Ca II triplet wavelength region with as high a resolution as possible. With this setting the pixel sampling is close to 1 Å pixel^{-1} and the resolution, as estimated from measuring the full width at half maximum of a series of unresolved night sky lines, is in the range 3.5–4 Å, over the wavelength range 7050–9150 Å. This is the maximum resolution that can be obtained with FORS1 without resorting to a narrower slit. Although this is a wavelength range at which the FORS1 CCD (Tektronix) has reduced sensitivity it is where the red giant stars we were aiming to detect are brightest. The Ca II triplet is also a useful unblended feature to accurately measure radial velocities (e.g. Hargreaves et al. 1994) and there are abundant narrow sky lines in this region for wavelength calibration and/or spectrograph flexure monitoring.

Our observation request consisted of a single slit position, or in ESO parlance a single observation block (OB). The data were taken in photometric or thin cirrus conditions with a dark sky (moon phase 0.3) and generally in subarc-second seeing conditions (see Table 2). The OB was made up of a target observation in conjunction with a sequence of radial velocity standards (both individual K-giants and bright globular clusters, see Table 3). The K-giant radial velocity standards provided the basic velocity standardization in addition to Ca II triplet template spectra for comparison with the lower S/N ratio dwarf galaxy spectra. By observing bright globular clusters with known radial velocities we further sought to test our methodology with data more closely resembling the primary targets. A useful by-product of this is additional template spectra to cross-correlate with the main target objects.

We determined the position of the slit on the galaxy accurately by using previous FORS1 imaging of this object (Tolstoy et al. 2000), in which we tried to hit as many bright giant branch stars, which are likely to be members of Phoenix, as possible.

Table 2. The observations.

Date	Begin UT	Object	Exp time (s)	Air mass	Seeing (arcsec)	Comments
2000 Oct 6	00:33	HD 203638	1	1.01	0.85	Photometric
	00:46	Pal 12	250	1.02	0.60	
2001 Jan 1	00:34	HD 8779	1	1.15	1.02	Thin cirrus
	01:00	HD 8779	1	1.20	0.95	
	01:12	Phoenix-1	1000	1.13	1.13	Variable seeing
	01:30	Phoenix-2	1000	1.14	0.97	
	01:48	Phoenix-3	1000	1.20	1.03	
	02:11	HD 8779	1	1.46	0.79	

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018

Table 3. The calibrators.

Object	Class	V	$v_\odot$ (km s^{-1})	Ref
Pal 12	Cluster	11.99	+27.8	Harris (1996)
HD 203638	K0 III	5.77	+21.9	
HD 8779	gK0	6.41	−5.0	
HD 107328	K1 III	4.96	+35.7	RV calibrator

3 DATA REDUCTION AND CALIBRATION

As described in Tolstoy & Irwin (2000), we did not use the basic daytime calibrations provided for UT1+FORS1 observations to either flat-field or wavelength calibrate the data. As before we made use of archive broad *I*-band filter twilight flat-field frames to create a master flat-field frame, and we used the plentiful night-sky lines in this spectral region to wavelength calibrate the data. The two-dimensional non-linear wavelength distortion of the long-slit data was again found to be stable, enabling us to make use of the same two-dimensional wavelength calibration of all the data for a given night. This allows us to correct the distortion of the radial velocity standards, which lack significant sky-lines because of their short exposure times. After extracting all the spectra, cross-correlation of either contemporaneously extracted sky spectra or atmospheric absorption features in the object spectra were used to correct for shifts in the zero-point of the wavelength calibration caused by spectrograph flexure or miscentring of objects in the slit. All of our calibration and data reduction was carried out using the IRAF package.

The observation of the Phoenix dwarf spheroidal galaxy consisted of 3×1000 s exposures. There were no measurable internal shifts found for frames within a sequence, so these were averaged with *k*-sigma clipping used to eliminate cosmic ray events. Full two-dimensional wavelength calibration, using the night sky lines, was then perfomed on the combined data. The globular cluster observation was an integration of 250 s, which was treated in the same way as the target galaxy observations.

The position of the slit across the central region of Phoenix, taken from the FIMS file used to prepare the OBs, is shown in Fig. 1. Also marked are the seven stars clearly detected in the Phoenix spectra. The position of all the resolved objects detected in the Phoenix long-slit spectra are plotted on the colour–magnitude diagram (CMD) of Phoenix (from Tolstoy et al. 2000) in Fig. 2. From their location on the CMD, and also their position on the slit, virtually all of the stars are high probability members of Phoenix. Three stars (1058, 899 and 496) are likely to be red giant branch (RGB) members, star 845 is probably on the asymptotic giant branch (AGB), whereas 1274 and 1328 could be evolved blue loop main-sequence stars. However, 1328 and 1274 (and also 773) lie in crowded regions, and could easily be RGB stars with contaminating flux from a nearby object affecting their photometry. The identification of all the resolved objects in the slit and their location on the CMD provides an excellent independent corroboration of the optical velocity determinations. However, we also note that stars 1328, 773 and 1274 also lie in a region of the CMD where there is a higher probability of foreground contamination.

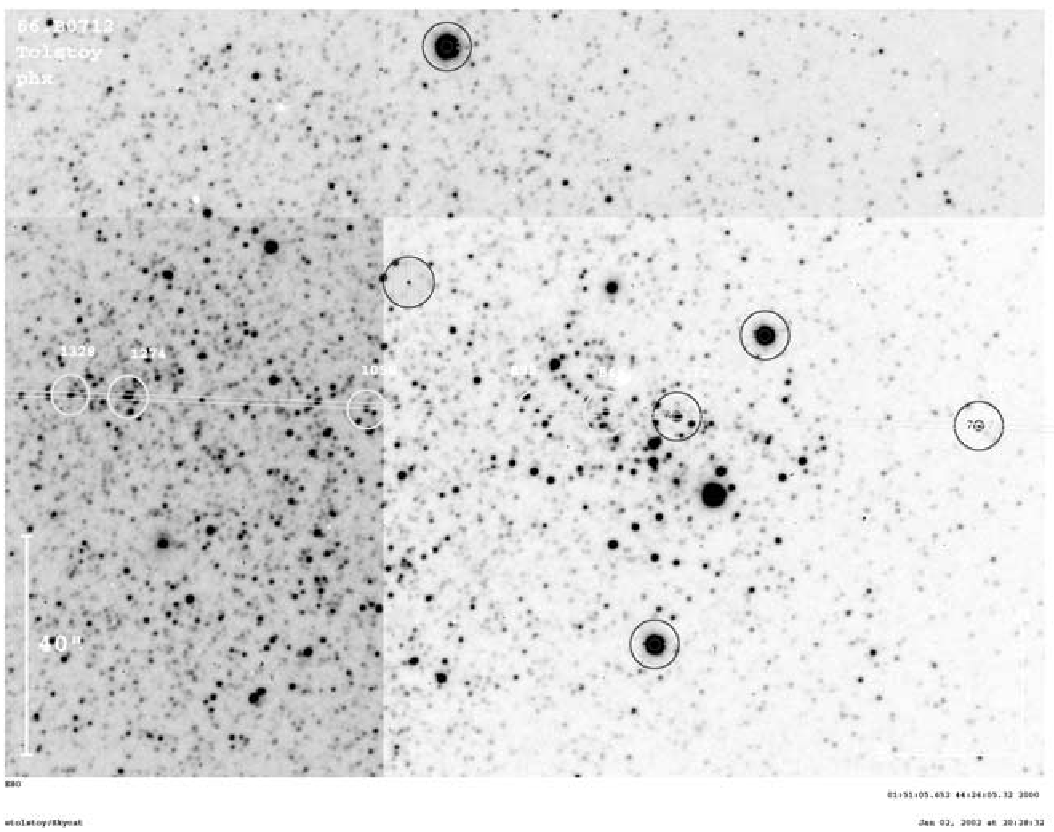

Figure 1. The central 4 arcmin of the Phoenix dwarf galaxy with the adopted slit position marked. North is up and east to the left. This diagram comes from the FIMS observation preparation tool output. The image is a 600-s *B*-band observation made with FORS1 in 1999 August. Marked on the image are the seven stars identified in our long-slit spectrum for which reliable individual spectra could be usefully extracted.

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018

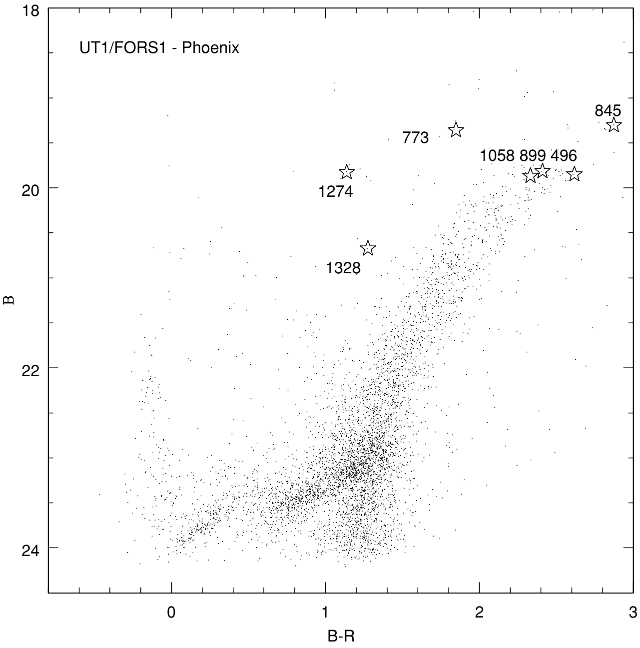

Figure 2. A Phoenix (R, $B - R$) colour–magnitude diagram from VLT data taken in 1999 August (Tolstoy et al. 2000). Plotted as star symbols are objects in the slit for which we could extract individual spectra. The labels correspond to those in Fig. 1 and also in Table 4.

With the usual caveats of over interpretation of posterior statistics we can make an estimate of the likelihood of foreground contamination as follows. Phoenix is at very high Galactic latitude, $b = -68.°9$, which together with a Galactic longitude of $l = 272.°2$ suggests that the contamination by foreground stars in likely to be very low. The radial velocity distribution of potential Galactic foreground contaminants comes from K and M dwarfs in the thin disc, thick disc and halo. In this direction the velocity dispersion of foreground stars is dominated by the σ_W component, which has a value of $\approx$20, 40 and 100 km s^{-1} for thin disc, thick disc and halo stars, respectively (e.g. Carney, Latham & Laird 1989; Mihalas & Binney 1981). The heliocentric velocity offset of the foreground components owing to the relative solar motion is $\approx$11, 25 and 90 km s^{-1}, respectively. All of these populations are potential contaminants, but the positive systemic velocities (and to some extent the large velocity dispersions) mitigate against significant pollution. Further constraints come from the spatial density. The Phoenix CMD was constructed over a region 7×7 arcmin^2 in size and over the total magnitude and colour range of the spectroscopic observations ($18.5 < R < 21$ and $1.0 < B - R < 3.0$), has 380 stellar objects detected. Of these approximately 90–95 per cent are expected to be stars in Phoenix (e.g. Ratnatunga & Bahcall 1985), leaving some 20–30 stars as potential foreground contamination. The long slit used in the FORS1 observations covers 0.2 per cent of this area, therefore the expected number of random contaminating foreground stars in the slit is less than 0.1 over this magnitude and colour range. However, given that we did some prior selection of brighter stars in the above magnitude colour range by aligning the slit to include three relatively bright objects, it is possible that one or more of these selected brighter objects could be a foreground object. Since the expected heliocentric radial velocity of Phoenix is low, contamination by say a single disc foreground K/M dwarf (the most likely contaminant) will be both difficult to spot, but conversely would also have relatively little impact on the derived systemic velocity. We discuss this issue further in Section 5.

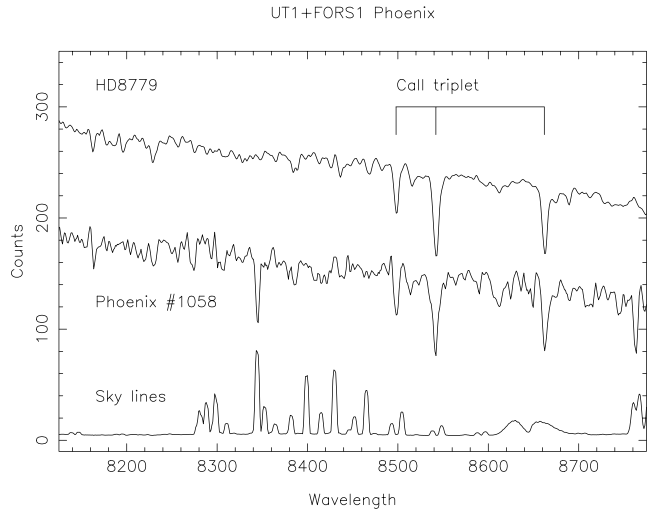

Figure 3. The spectrum of star no 1058 (in observed counts) compared with the spectrum of one of the observations of the radial velocity standard HD 8779 (scaled down by a factor of 250 and shifted vertically for ease of reference). Also plotted for comparison is a sky spectrum (scaled down by a factor of 40) illustrating the potential problems of residual sky line contamination on the spectrum of the target. A three-point linear box-car filter was used to smooth the template and target spectra for plotting purposes. The example night sky spectrum is unsmoothed. Despite the brightness of the night sky lines, the extracted target spectrum has a clearly visible Ca II triplet.

4 EXTRACTING AND WAVELENGTH CALIBRATING THE SPECTRA

For the globular clusters and dSphs, image sections summed along the spatial axis were used to identify resolved stellar or background galaxy images, in the slit and also to define the underlying unresolved background of the dwarf spheroidal galaxy for spectroscopic extraction. Spectra for these objects plus the integrated background were then extracted in the usual manner, taking care to optimize the region chosen to represent the local sky. The computed sky spectrum was also extracted contemporaneously for later use in checking the wavelength solution systematics (see Fig. 3). For the radial velocity standards and also the target objects in the long slit, contributions to systematics from slit centring is also an issue that limits the achieved final accuracy. This is reflected in the scatter ($\sigma_v \sim 5$ km s^{-1}) of the derived velocities for the standards in Table 4, which is dominated by slit-centring errors and limited by the accuracy of post-reduction corrections based on atmospheric absorption lines. The details are identical to those described in Tolstoy & Irwin (2000).

Wavelength calibration was primarily based on one of the central sky spectra taken from the Phoenix data. All of the remaining extracted one-dimensional sky spectra for cluster calibration and target objects were then cross-correlated against the reference image sky spectrum, to adjust the zero-point of the wavelength solution. This enables us to monitor the stability of the wavelength solution and hence determine and track any flexure of the spectrograph. The cross-correlation of sky lines within a single two-dimensional frame gives negligible velocity shifts of $\pm$1–2 km s^{-1}, which is comparable to the juxtaposition of the wavelength calibration errors and correlation-function estimation errors. Sky lines are generally not visible in the standard star spectra so the wavelength zero-point here was checked using the main atmospheric absorption A-band.

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018

Table 4. Individual velocity results.

Object	$v_{\odot}$ (km s^{-1})	rms error (km s^{-1})	Comment
HD 203638	+28.6	±2.5	Systematic errors
HD 8779-1	−8.9	±3.0	caused by flexure and
HD 8779-2	+2.7	±2.4	slit centring are
HD 8779-3	+3.7	±2.5	typically ±5–10 km s^{-1}
Pal 12-1	+26.6	±2.2	
Pal 12-2	+26.1	±3.8	
Pal 12-3	+28.8	±3.9	
Pal 12-4	−24.9	±5.2	Probably a non-member
Phoenix-773	−8.9	±3.0	the most likely
Phoenix-496	−22.4	±2.5	systemic H I velocity is
Phoenix-845	−26.8	±3.5	$v_{\odot} = -23$ km s^{-1}
Phoenix-1058	−3.6	±3.9	
Phoenix-899	+8.8	±5.8	
Phoenix-1274	−31.4	±11.0	
Phoenix-1328	−9.3	±10.0	

The radial velocity primary reference standard used was based on previous observations of HD 107328 from Tolstoy & Irwin (2000).
The rms errors were estimated directly from the centroiding of a general Gaussian fit to the primary cross-correlation peak.
Continuum signal-to-noise ratio was typically in the range 5–10 pixel^{-1} in the Ca II triplet region.

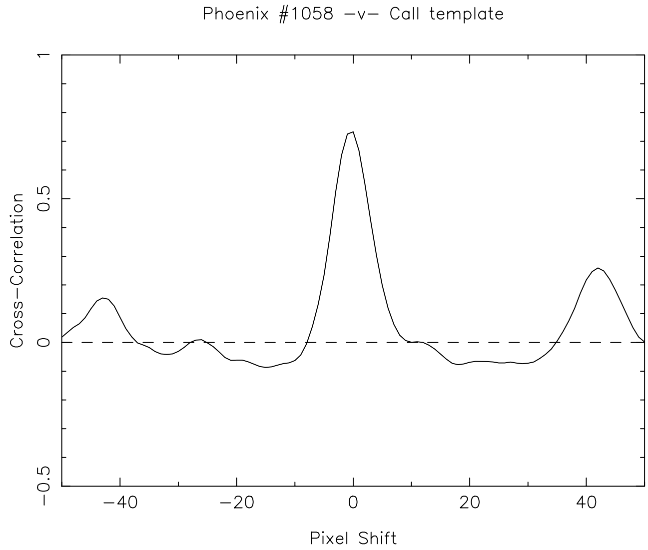

Figure 4. The normalized cross-correlation of the Phoenix spectrum for star no 1058 shown in Fig. 3, against a template spectrum constructed from an observation of HD8779. Prior to cross-correlation, both spectra are continuum-corrected and then the template spectrum is set to zero for all regions outside of the ≈10 Å zone for each of the Ca II absorption lines. No template, flexure or heliocentric corrections have been made for this plot.

Since we had previous observations taken with a similar setup (Tolstoy & Irwin 2000) we could make further use of our earlier cluster and standard star observations to standardize the velocity determinations. After applying all the various checks on the wavelength calibration we estimate that the final systematics of the wavelength solution are in the range 5–10 km s^{-1}, and are mainly dominated by corrections for slit-centring errors. These are comparable to the rms errors, dominated by photon noise, in the cross-correlation of the fainter target objects, but are more than adequate for the current goal.

5 DETERMINING THE RADIAL VELOCITIES

The main advantages of using the Ca II triplet region for radial velocity determination are threefold: the relative brightness and uniformity of the continuum flux from K-giants; the narrowness ≈3 Å of the three Gaussian-like Ca II absorption features; and the abundance of narrow night sky lines for wavelength calibration. Although at first sight the latter might seem a significant drawback too, in practice the velocity template spectrum is only 'active' over the narrow regions of ≈10 Å centred on each of the triplet lines. This minimizes the influence of the, on average, relatively bright sky and means that in practice it is feasible to measure reliable cross-correlations several magnitudes below the average sky level in this region.

For all the globular cluster and dSph observations, individual resolved objects were extracted separately in an attempt to identify system members and possible foreground stars, or even background galaxy, interlopers. Radial velocities were measured for all the spectra, as previously described by Tolstoy & Irwin (2000), using the standard Fourier cross-correlation package in IRAF, FXCOR, after suitable continuum removal and apodizing of the target objects. The template function consisted of the spectrum of a bright radial velocity standard with the continuum fitted and removed to give a mean level of zero for the continuum. All regions outside of the Ca II triplet lines in the template were then identically set to zero, leaving 'active' only the narrow region of ≈10 Å centred on each of the three absorption components.

An example of the results for Phoenix is shown in Fig. 4 where the Ca II triplet is clearly visible in the target spectrum. The measured radial velocities are then corrected for: the template radial velocity offset; the topocentric correction to a heliocentric system; and for flexure/slit miscentring. The final results for the individual objects extracted from the spectra are listed in Table 4, including Phoenix, the radial velocity standards and the globular cluster Pal 12.

Virtually all of the extracted spectra for Phoenix have radial velocities that are consistent with membership given the likely (unknown) optical velocity dispersion of ≈10 km s^{-1}. The range of observed velocities in the seven stars is from −31 to +9 km s^{-1} with a mean of −13.4 km s^{-1}, which compares favourably with the H I velocity of −23 km s^{-1}. The error in the estimate is dominated by a combination of systematic residuals, random photon noise errors and the velocity dispersion of the dwarf. Combining these error estimates leads to a standard error in the derived mean velocity of around ±9 km s^{-1}. It is interesting to note that the formal rms dispersion about the mean for the seven stars is $\sigma = 14.2$ km s^{-1}. Therefore, purely on kinematic grounds, it is difficult to rule out a modest disc contamination since the expected mean radial velocity for disc stars is +11 km s^{-1} in this direction, with a dispersion of ±20 km s^{-1}. However, as noted earlier, the converse is also true, in that contamination by one or two disc stars have little impact on the derived systemic velocity of the dwarf. As noted in Section 3. the most likely foreground contaminants are the three relatively bright stars (773, 496, 1274) used for selecting the most favourable slit location. Of these, 496, lies on the RGB and is therefore unlikely to be foreground. In the worst-case scenario, if the other two stars are foreground, excluding them shifts the derived optical radial velocity by +3 km s^{-1}, which is a negligible change relative to the inherent measuring errors of ±9 km s^{-1}.

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018

6 DISCUSSION

Our determination of the optical velocity for Phoenix of -13 ± 9 km s^{-1} closely matches the most likely H I velocity for this galaxy of -23 km s^{-1} derived by St-Gérmain et al. (1999). In a recent review of the impact of the VLT on Local Group galaxies, Held (2001) quotes recent UVES measurements of giant stars in the Phoenix galaxy that agree to within a few km s^{-1} of the neutral gas velocity. It is difficult to directly reconcile these much smaller negative optical radial velocities with the -52 ± 6 km s^{-1} recently determined by Gallart et al. (2001).

It is highly unlikely that Galactic foreground contamination could have affected any of the optical results significantly and the H I gas velocity result of -23 km s^{-1} seems convincingly secure as argued by St-Gérmain et al. (1999). There is also unlikely to be contamination of our results from the two main tidal streams enveloping our Galaxy: the Magellanic stream and the Sagittarius dwarf tidal stream. The Magellanic stream is predominantly gas with no unambiguous detection of a stellar component yet reported. Therefore, while the Magellanic stream can contaminate the gas distribution in the Phoenix direction, it is unlikely to contribute to contamination of the optical velocities. Likewise, pollution by the Sagittarius dwarf tidal stream is also highly unlikely since the projection of its current orbit does not pass close to the line of sight to Phoenix.

The gradient in the distribution of young stars in Phoenix (e.g. Ortolani & Gratton 1988; Martínez-Delgado et al. 1999) suggests that the recent star formation has been moving from east to west across the central component of Phoenix in a manner consistent with self-propagating star formation theories. The youngest stars are thus spatially overlapping the position of the H I cloud at -23 km s^{-1} (as originally pointed out by Young & Lo 1997). The relative position and velocity of this cloud combined with the evidence of recent star formation provides evidence that a burst of star formation can disrupt and potentially blow out gas from the centre of a dwarf galaxy, inhibiting further star formation (e.g. Dekel & Silk 1986; Mac Low & Ferrara 1999), although it is not the only possible explanation for what is seen (cf. ram pressure stripping scenarios as in Gallart et al. 2001).

However, we can conclude that our results in conjunction with those of Held (2001) unequivocally show that modest amounts ($\approx 10^5$ M$_\odot$) of H I gas are associated with the Phoenix dwarf galaxy, albeit somewhat offset from the optical centre of the galaxy.

ACKNOWLEDGMENTS

This work is based on observations collected at the European Southern Observatory, Chile, in service mode, proposal number 66.B-0712(A). These data were taken in service mode, and we thank the Paranal Science Operations Staff for their efforts. ET gratefully acknowledges support from a fellowship of the Royal Netherlands Academy of Arts and Sciences and support from a Visitor Grant at the Institute of Astronomy, Cambridge. IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

REFERENCES

Carignan C., Demers S., Côte S., 1991, ApJ, 381, 13
Carney B.W., Latham D.W., Laird J.B., 1989, AJ, 97, 423
Dekel A., Silk J., 1986, ApJ, 303, 39
Gallart C., Martínez-Delgado D., Gómez-Flechoso M.A., Mateo M., 2001, AJ, 121, 2572
Hargreaves J.C., Gilmore G., Irwin M.J., Carter D., 1994, MNRAS, 269, 957
Harris W.E., 1996, AJ, 112, 1487
Held E.V., 2001, in Bergeron J., Monnet G., eds, Proc. ESO Workshop Scientific Drivers for ESO Future VLT/VLTI Instrumentation. Springer-Verlag, Berlin, in press (astro-ph/0109548)
Held E.V., Saviane I., Momany Y., 1999, A&A, 345, 747
Holtzmann J.A., Smith G.H., Grillmair C., 2000, AJ, 120, 3060
Mac Low M.-M., Ferrara A., 1999, ApJ, 513, 142
Martínez-Delgado D., Gallart C., Aparicio A., 1999, AJ, 118, 862
Mihalas D., Binney J., 1981, Galactic Astronomy. Freeman, San Francisco, CA
Oosterloo T., Da Costa G.S., Staveley-Smith L., 1996, AJ, 112, 1969
Ortolani S., Gratton R.G., 1988, PASP, 100, 1405
Ratnatunga K., Bahcall J.N., 1985, ApJS, 59, 63
St-Gérmain J., Carignan C., Côte S., Oosterloo T., 1999, AJ, 118, 1235
Tolstoy E., Irwin M.J., 2000, MNRAS, 318, 1241
Tolstoy E., Gallagher J.S., Greggio L., Tosi M., De Marchi G., Romaniello M., Minniti D., Zijlstra A.A., 2000, ESO Messenger, 99, 16
van de Rydt F., Demers S., Kunkel W.E., 1991, AJ, 102, 130
Young L.M., Lo K.Y., 1997, ApJ, 490, 710

This paper has been typeset from a TEX/LATEX file prepared by the author.

Downloaded from https://academic.oup.com/mnras/article-abstract/336/2/643/1160987 by University of Groningen user on 17 December 2018