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Using δ Cep stars to study northern dwarf irregular galaxies of the Local Group

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Abstract. Dwarf galaxies in the Local Group provide a unique astrophysical laboratory. Despite their proximity some of these systems still lack a reliable distance determination as well as studies of their stellar content and star formation history. We present first results of our survey of variable stars in a sample of six Local Group dwarf irregular galaxies. We describe observational strategies and data reduction, and discuss the lightcurves of newly found and rediscovered δ Cep stars in DDO 216, Leo A and GR8. Based on these data, we present newly derived independent Cepheid distances. Other variable stars found in our survey are discussed in a related article of this volume (Snigula et al.).

Key words. Galaxies: distances – Galaxies: dwarf – Galaxies: individual: Leo A – Galaxies: individual: DDO 216 – Galaxies: individual: GR8 – Cepheids – Local Group

1. Introduction

The main aim of the Wendelstein (WST) monitoring project is to determine numbers and properties of the bright variable stars in six northern dwarf irregular galaxies: LGS 3 (Pisces), UGCA 92 (EGB 0427+63), DDO 69 (Leo A), DDO 155 (GR8), DDO 210 (Aquarius), and DDO 216 (Pegasus). Those will be used to put further constraints on their stellar content, and thus on their evolutionary history, (Snigula et al. 2004,Snigula et al. this volume) and for distance estimates. Here we present the results of our survey for classical Cepheids in Leo A, DDO 216, and GR8. We derive distance moduli and compare them with recently published ones.

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Table 1. Epochs per filter, telescope and object.

	WST		CA		
object	*B*	*R*	*B*	*R*	*I*
Leo A	31	94	13	47	29
DDO 216	17	70	–	2	–
GR8	23	106	14	49	31

2. Observations

The relatively small 0.8 m Wendelstein telescope has the necessary long-term availability for monitoring projects (i.e. 130 clear nights per year, unrestricted access). Although the telescope does not take full advantage of the good ($\ll$ 1”) seeing quality of the site, we regularly obtain images of 1 to 1.5” FWHM

Table 2. Parameters of our δ Cep stars: identifier, position, most significant Lomb period, significance (p-level), flux averaged apparent R-band magnitude, RMS error of R-band magnitude. Error of period $\delta P <$ 0.01d. V01 to V05 = • and V06 to V07 = ▲ in Fig. 2. P01 to P03 = • and P04 to P06 = ▲ in Fig. 3.

Id	RA-2000 [h]	Dec-2000 [deg]	period [d]	significance [p]	$< R_{\bar{f}} >$ [mag]	$\delta < R_{\bar{f}} >$ [mag]
V01	09:59:28.679	+30:44:35.38	6.487	6.93e-10	20.62	0.11
V02	09:59:27.762	+30:44:57.42	1.685	8.78e-03	21.45	0.25
V03	09:59:23.914	+30:45:13.06	3.354	5.86e-04	21.47	0.25
V04	09:59:29.115	+30:43:48.70	2.049	9.80e-03	22.10	0.44
V05	09:59:30.472	+30:44:03.65	1.685	3.43e-05	22.26	0.52
V06	09:59:25.918	+30:44:36.70	1.607	2.61e-04	21.68	0.30
V06*a*			2.630	1.63e-04		
V07	09:59:25.672	+30:44:41.79	1.564	5.47e-04	22.07	0.44
P01	23:28:32.702	+14:45:15.49	3.889	1.31e-02	21.03	0.24
P02	23:28:36.217	+14:44:02.64	3.712	1.06e-02	21.71	0.45
P03	23:28:37.310	+14:43:45.33	2.642	5.07e-03	22.23	0.73
P04	23:28:33.753	+14:44:27.68	3.188	2.93e-02	21.09	0.26
P05	23:28:28.990	+14:44:41.88	1.118	1.75e-02	21.41	0.34
P06	23:28:32.340	+14:44:47.06	8.593	5.99e-02	22.17	0.69
GR8	12:58:41.389	+14:13:09.47	15.436	9.47e-07	21.47	0.07

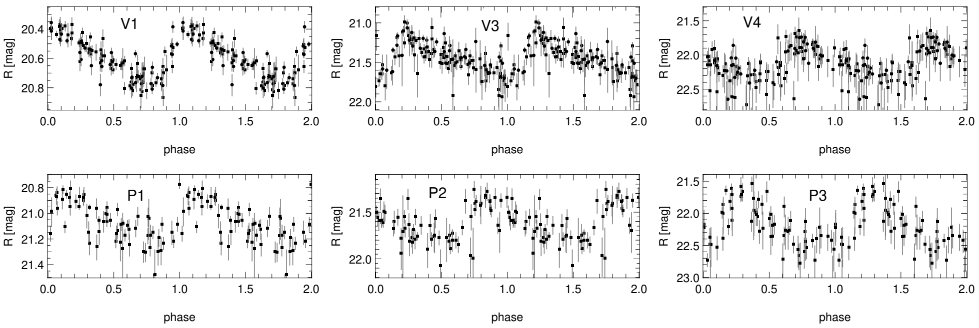

Fig. 1. Phase convolved R-band lightcurves for the δ Cep stars used to derive the distance moduli. ■ = Wendelstein 0.8 m, • = Calar Alto 1.23 m, + = measurements having $S/N < 1$ obtained at either site, all plotted with 1σ error bars. Top: Leo A, bottom: DDO 216.

(Riffeser et al. 2001). The Wendelstein observations, starting with test observations in 1999, sparsely sample a five year interval in R and B filter bands. We added observations in the R, B and I-bands, obtained with the 1.23 m telescope at Calar Alto (CA) observatory (Tab. 1). The Wendelstein data are used to find variable sources and to determine their periodicities, while the CA data, if present, serve as an independent consistency check. The typical limiting magnitude of an individual exposure is about $R \sim 22.5$ ($M_R = -2.0$ for Leo A, $M_R = -2.5$ for DDO 216, $M_R = -4.0$ for GR8, respectively). Thus, we have access to all kinds of red long period variable stars, blue and red irregular variables, and also Novae and Supernovae but so far none of either type of exploding stars were detected. RR Lyr stars are certainly too faint, while classical δ Cep stars are well within the limits of our data. Tab. 1 displays the number of collected and reduced epochs so far. We restrict the results presented in this article to periods of $P < 130$ days, the longest period values known for δ Cep stars.

3. Data Reduction

All images were bias subtracted, flat-fielded, and cleaned of particle events. After an astrometrical alignment signal-to-noise maximising stacks per night were built. For every stack, representing an epoch, a difference image against a common deep reference frame was created applying an implementation (Gössl & Riffeser 2002, 2003) of the Alard algorithm (Alard & Lupton 1998). These difference images were finally convolved with a stellar PSF. Our codes propagate individual pixel errors through every step of the data reduction.

We find variable star candidates by first building a (cumulative) mask frame counting where and how often individual difference frames deviate from zero by at least 1σ (i.e. propagated error). For all candidates indicated by this variability mask, a Lomb (1976) algorithm in the interpretation from Scargle (1982) is used to search for periodic signals.

To get rid of false and problematic classifications we apply rigorous selection criteria. (See detailed discussion in Hopp et al. 2005). Finally we fit the R-band period luminosity relation (PLR) for fundamental mode (FM) LMC Cepheids $M_R = -3.04(\log P - 1.0) - 4.48[\pm 0.25]$ of Madore & Freedman (1991) corrected for galactic extinction following Schlegel et al. (1998) to the remaining candidate(s) of each object. Tab. 2 lists the found δ Cep stars, Fig. 1 and 4 show the lightcurves of all stars used for the distance moduli.

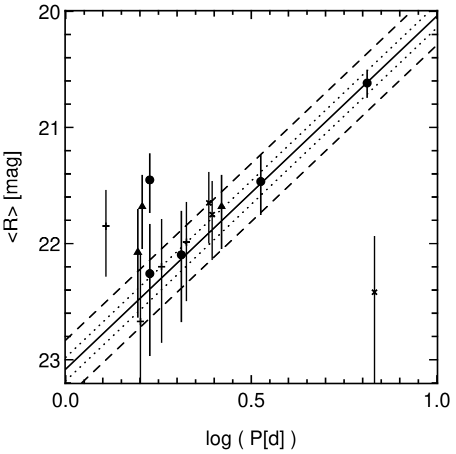

Fig. 2. PLR for Leo A. Solid line: Best fitting R-band PLR for FM LMC Cepheids of V01, V03, and V04 (Tab. 2), extinction corrected by $A_R = 0.055$: $24.47 \pm 0.10 \pm 0.06_{\mathrm{ZP}}$. V02 is disregarded as being brightened by crowding, V05 for being beyond the scope of the applied PLR. Dotted lines: Propagated error of the fit. Dashed lines: Error of the PLR. •▲: δ Cep stars of Tab. 2. +×: Add. δ Cep candidates described in Hopp et al. (2005).

4. Results

4.1. Leo A

For Leo A we find a distance modulus of $m - M = 24.47 \pm 0.10 \pm 0.06_{\mathrm{ZP}}$ (Fig. 2) which is consistent with the findings of Dolphin et al. (2002), Tolstoy et al. (1998), and Schulte-Ladbeck et al. (2002). Dolphin et al. searched for RR Lyr stars in Leo A and derived $m - M = 24.51 \pm 0.12$. Tolstoy et al. used a combination of ground-based and HST data to derive a tip-of-the-red-giant-branch (TRGB) distance of $m-M = 24.5 \pm 0.2$. They also used red clump stars yielding a discrepant $m - M = 24.2 \pm 0.2$. Schulte-Ladbeck et al.'s even deeper HST data allowed the detection of red horizontal branch stars and concluded that they and the TRGB are in better agreement with $m-M = 24.5 \pm 0.2$.

4.2. DDO 216

Fitting the Madore & Freedman FM PLR to P02, P03, and to P01 (the latter with a doubled period, see below) we derive a distance modulus of $m - M = 24.92 \pm 0.20 \pm 0.06_{\mathrm{ZP}}$ (Fig. 3) for the Pegasus dwarf irregular. P01 to P04 are four out of six candidates already independently proposed by Aparicio (1994). He could not provide any period solutions lacking a sufficient number of observed epochs. Using HST imaging data (Gallagher et al. 1998) we find P04 to be artificially brightened by crowding while P01 seems to be pulsating in the 1st overtone mode. We confirm the TRGB distance $m - M = 24.9 \pm 0.1$ of Aparicio.

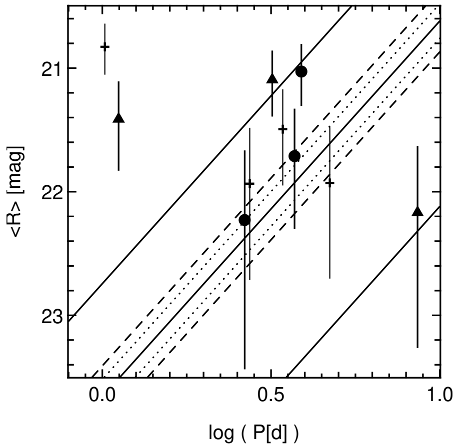

Fig. 3. PLR for DDO 216. Central solid line: The R-band PLR for FM LMC Cepheids extinction corrected by $A_R = 0.176$. Upper solid line: 1st overtone PLR assuming a -0.92 mag offset to the fundamental mode relation. Lower solid line: Type II PLR assuming a +1.5 mag offset to the fundamental mode relation of classical δ Cep stars. Best-fitting PLR of P01, P02, and P03: $24.92 \pm 0.20 \pm 0.06_{\mathrm{ZP}}$. Dotted lines: Propagated error of the fit. Dashed lines: Error of the PLR. •▲: δ Cep stars of Tab. 2. +: Add. δ Cep candidates matching most, but not all of our selection criteria.

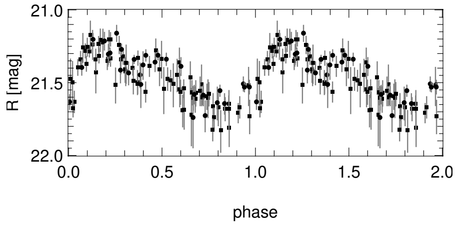

Fig. 4. Phase convolved *R*-band lightcurves for the δ Cep star in GR8. Symbols see caption Fig 1.

4.3. GR 8

In GR8 we only find one δ Cep star with $m_R = 21.47 \pm 0.07$ and $P = 15.44$d (Fig. 4). We derive a distance modulus of $m - M = 26.45 \pm 0.07 \pm 0.06_{\mathrm{ZP}}(\pm 0.25_{\mathrm{PLR}})$ taking into account a galactic extinction of $A_R = 0.07$ (Schlegel et al. 1998). Since this distance is based on a single detection the full intrinsic scatter of the PLR has to be considered as an additional uncertainty. This δ Cep star had already been discovered by Tolstoy et al. (1995) with $m_{<r>} = 22.12$ and $P = 16.166$d. They derived a distance modulus of $m-M = 26.75 \pm 0.35$ which Dohm-Palmer et al. (1998) claim to be consistent with their HST based TRGB observations.

5. Summary

We confirmed by independent discoveries and measurements of δ Cep stars recently derived distance moduli of the three Northern Local Group dwarf irregular galaxies Leo A, DDO 216, and GR8.

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