The RR Lyrae Distance to the Draco Dwarf Spheroidal Galaxy

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ABSTRACT

We present the first CCD variability study of the Draco dwarf spheroidal galaxy. The data were obtained with the FLWO 1.2 m telescope on 22 nights, over a period of 10 months, covering a $22' \times 22'$ field centered at $\alpha = 17\!:\!19\!:\!57.5, \delta = 57\!:\!50\!:\!05$, J2000.0. The analysis of the BVI images produced 163 variable stars, 146 of which were RR Lyrae: 123 RRab, 16 RRc, 6 RRd and one RR12. The other variables include a SX Phe star, four anomalous Cepheids and a field eclipsing binary. Using the short distance scale statistical parallax calibration of Gould & Popowski and 94 RRab stars from our field, we obtain a distance modulus of $(\mathrm{m-M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag for Draco, corresponding to a distance of 75.8 $\pm 0.7\,(\mathrm{stat}) \pm 5.4\,(\mathrm{syst})$ kpc. By comparing the spread in magnitudes of RRab stars in B, V and I, we find no evidence for internal dust in the Draco dwarf spheroidal galaxy.

The catalog of all variables, as well as their photometry and finding charts, is available electronically via `anonymous ftp` and the `World Wide Web`. The complete set of the CCD frames is available upon request.

Subject headings: Local Group — distance scale — galaxies: dwarf — galaxies: individual (Draco dSph, UGC 10822)

1. Introduction

Dwarf spheroidal (dSph) galaxies are probably the most common types of galaxies in the present-day Universe. They are metal poor galaxies with a metallicity $Z < 0.001$ (Mateo 1998), which resembles that found in galactic globular clusters. Most dSph galaxies show evidence for multiple star-formation episodes, having populations of different ages. There are very few, namely Tucana, Draco and possibly Ursa Minor, that host a single stellar population older than 10 Gyr (see Dall'Ora et al. 2003, and references therein).

The Draco dSph galaxy, a companion to the Milky Way, was discovered by Wilson (1955) and was first observed by Baade & Swope (1961) for variables. They found 261 variables in their $24' \times 24'$ field, but only measured 137 for magnitudes. Of these, 133 were RR Lyrae variables, which they used to derive the distance to the galaxy. There have not been any recent variability studies of Draco, except for the survey by Kinemuchi et al. (2002) which is currently underway. The lack of high quality CCD observations of the RR Lyrae in Draco dSph motivated us to do this project.

However, several studies of Draco's stellar population have been conducted and for these CCD photometry has been obtained. Grillmair et al. (1998) present the CMD diagram obtained from observations with the *Hubble Space Telescope (HST)* and confirm that star formation in Draco was primarily single-epoch and that Draco is very similar to the globular clusters M68 and M92, but 1.6 Gyr older. It has a luminosity of $2 \times 10^5\,\mathrm{L}_\odot$, which places it among the least luminous galaxies known. Bellazzini et al. (2002) have done a comparative study of the Draco and Ursa Minor dSph galaxies with new V, I photometry. Recently, Rave et al. (2003) have released a catalog of photometry of $\sim 5,600$ stars in Draco. They find 142 candidate variables from their colors, using photometry from five catalogs. However, a uniform dataset taken with the same instrument would be more reliable for finding RR Lyrae and obtaining accurate photometry and periods for them.

In this paper, we present a catalog of variable stars found in Draco dSph. The paper is organized as follows: §2 provides a description of the observations; the data reduction procedure, calibration and astrometry is outlined in §3; the catalog of variable stars is presented in §4. In §5 we determine the distance to Draco and in §6 we summarize our results.

2. Observations

The observations of the Draco dSph were made with the 1.2m telescope at the Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona, between August 19th, 1998 and June 20th, 1999, over 22 nights. We used the "4Shooter" camera (Szentgyorgyi et al. 2003), with 4 thinned and AR-coated Loral 2048^2 pixel CCDs. The pixels are 15 microns in size and map to $0.33''$ per pixel on the focal plane, making each image $11'$ on the side. The camera was centered at $\alpha = 17{:}19{:}57.5, \delta = 57{:}50{:}05$, J2000.0. The data consists of 148×600 s exposures in the V filter, 44×900 s exposures in the B filter and 47×600 s exposures in the I filter. The median value of the seeing in V was $2.0''$. The field was observed through airmasses ranging from 1.12 to 1.55, with the median being 1.19. The completeness of our photometry starts to drop rapidly at about 22.5 in I and 23 mag in V and B. The CCDs saturate for stars brighter than 14 in I, 15 in V and 15.5 mag in B. On one photometric night of the run, several images of standard Landolt (1992) fields were taken.

3. Data Reduction, Calibration and Astrometry

Preliminary processing of the data was performed with standard routines in the IRAF [1] CCDPROC package. The differential photometry for the variable stars was extracted using the ISIS image subtraction package (Alard & Lupton 1998; Alard 2000) from the V-band data. The DAOPHOT/ALLSTAR package (Stetson 1987) was used for the conversion into magnitudes. Mochejska et al. (2001) describe the procedure in detail.

On August 31st, 1998, we observed 2 sets of 3 Landolt (1992) fields in the BVI filters at air masses ranging from 1.18 to 1.99. The transformation from the instrumental to the standard system was derived for each chip in the following form:

$$
\begin{aligned}
b &= B + \chi_{\rm b} + \xi_{\rm b} \cdot ({\rm B-V}) + \kappa_{\rm b} \cdot {\rm X} \\
v &= V + \chi_{\rm v1} + \xi_{\rm v1} \cdot ({\rm B-V}) + \kappa_{\rm v1} \cdot {\rm X} \\
v &= V + \chi_{\rm v2} + \xi_{\rm v2} \cdot ({\rm V-I}) + \kappa_{\rm v2} \cdot {\rm X} \\
i &= I + \chi_{\rm i} + \xi_{\rm i} \cdot ({\rm V-I}) + \kappa_{\rm i} \cdot {\rm X}
\end{aligned}
$$

where lowercase letters correspond to the instrumental magnitudes, uppercase letters to standard magnitudes, X is the airmass, χ is the zeropoint, ξ the color and κ the airmass coefficient. Since most of the color coefficients are small, we used $B-V=V-I=1$ when transforming the magnitudes of our stars. Note that the B-band coefficients are larger, therefore our B magnitudes for red stars may be off by 0.1 mag or 0.2 mag (in chip 2), in the worst case.

Stetson (2000) has calibrated ~ 400 stars in the Draco dSph as secondary standards. In chips 3 and 4, where our overlap was large, we normalized to his photometry using the

[1]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 NSF.

brightest 80 stars (to 19.5 mag) and 66 stars (to 20th mag) respectively to determine the offsets in V. The difference between his photometry and ours in these chips was 0.04 and 0.02 mag. In chips 1 and 2 the overlap was too small for a meaningful comparison, thus we kept our own photometry. We then compared our normalized V photometry in chips 3 and 4 with the photometry of Grillmair et al. (1998) from the *HST*. For 100 stars down to 19 mag, the differences between their photometry and ours were 0.06 and 0.03 mag. Bellazzini et al. (2002) have obtained (V, I) photometry of the field and the agreement with our photometry is good, the largest offset being 0.07 mag in chip 3, V-band.

Equatorial coordinates were determined for the V star list. The transformation from rectangular to equatorial coordinates was derived using for chips 1-4: 174, 146, 400 and 282 transformation stars respectively with $V < 20$ from the USNO-A2.0 (Monet 1996) catalog. The median difference between the catalog and the computed coordinates for the transformation stars was $0.''3$ in RA and $0.''3$ in Dec. We also compared the astrometry to Stetson's catalog and found 18, 4, 272 and 151 matches for chips 1-4, having a median offset $< 0.''2$. We use these derived J2000.0 equatorial coordinates to name the variables in the format: Draco*hhmmss.s*+*ddmmss.s*. The first three fields (*hhmmss.s*) correspond to RA expressed in hours, the last three (*ddmmss.s*) to Dec, expressed in degrees, separated by the declination sign.

4. Results

Our search for variables in our field in Draco produced 163 stars, 136 of which were previously identified by Baade & Swope (1961). The remaining 27 are new discoveries. Of these 163 stars, 146 are RR Lyrae, 4 are anomalous Cepheids and the remaining 13 are other long period or non-periodic variables. We found a new field eclipsing binary and a SX Phe star among these. Of the 146 RR Lyrae, 123 are fundamental mode pulsators (RRab), 16 are first overtone pulsators (RRc), 6 are double-mode pulsators (RRd) and one is pulsating in the first and second overtone (RR12). Figures 1, 2 and 3 show typical light curves of RR Lyrae and other variables found in Draco. Tables 1 and 2 present coordinates, periods, intensity averaged BVI magnitudes, V-band amplitudes, the type of variable and the corresponding name given in Baade & Swope (1961). Stars exhibiting the Blazhko effect are also marked. The catalog of all variables, as well as their BVI photometry and V finding charts, is available electronically via `anonymous ftp`[2] and the `World Wide Web`[3]. The complete set of

[2]On `cfa-ftp.harvard.edu`, in `pub/kstanek/DIRECT/Draco`

[3]`http://cfa-www.harvard.edu/~kstanek/DIRECT/Draco`

the CCD frames is available upon request.

We used the multiharmonic analysis of variance technique (Schwarzenberg-Czerny 1996) to search the light curves for periodicity. Additionally, Fourier series were fit to the RR Lyrae light curves phased to the period determined earlier and parameters such as the amplitude of the variation and amplitude and phase of each harmonic were calculated. We searched for multiperiod variables by subtracting the first three harmonics of the Fourier series from the phased light curves and then repeating the period search. We then redetermined secondary periods for the 6 double mode (RRd) stars found by Nemec (1985) in the data of Baade & Swope (1961), by searching the periodogram where the second period was expected.

Baade & Swope (1961) do not find any red irregular or long period variables in their data, with the exception of BS-203, a bright blue variable with a period of ~ 3 years. We observed all of their "special variables" except for BS-138. The only significant difference in these is that the period we find for BS-134 is 0.592 days, not 1.458 days, which agrees with Nemec (1985) who realanyzed the data of Baade & Swope (1961). The periods we calculated for variables also found by Baade & Swope (1961) are very similar in most cases. The cases that differ are marked with an asterisk in Table 1. As a result some stars are classified differently from Baade & Swope (1961). BS-97, BS-121, BS-173 and BS-145 are all RRc stars and BS-190, BS-169, BS-143, BS-72, BS-11, BS-112 are RRd stars. We did not find variables BS-10, BS-31, BS-111 and BS-195 due to the proximity of highly saturated stars.

We present a histogram of the 139 RRab and RRc Lyrae in Draco, with 0.02 day bins in Figure 4. Both components of the double-mode stars are also plotted (in black). The median period for RRab stars is 0.617 days and for RRc stars is 0.392 days, which places the Draco dSph between Oosterhoff type I (~ 0.55 days) and type II (~ 0.65 days) clusters, similarly to other dSph (Dall'Ora et al. 2003). In Figure 5 we present a color magnitude diagram (CMD) of stars in Draco. Circles represent RR Lyrae, squares are anomalous Cepheids and triangles are other variables. Among these other variables is the long period blue variable BS-203, a foreground 0.24 day eclipsing binary, and a multimode SX Phe star which is pulsating in three modes, with periods 0.068, 0.073 and 0.079 days. The period-amplitude diagram for the 146 RR Lyrae in Draco is shown in Figure 6. Circles represent RRab stars, triangles RRc stars and squares RRd stars, for which both periods are plotted.

5. Distance to Draco dSph

The distance to the Draco dSph galaxy has been estimated by several authors. Baade & Swope (1961) obtained a distance of $d = 99$ kpc assuming an absolute magnitude of $M_B = 0.5$ mag for RR Lyrae; Nemec (1985) obtained $d = 84 \pm 12$ kpc using RRd stars found by reanalyzing the data of Baade & Swope (1961); Aparicio et al. (2001) obtained $d = 80 \pm 7$ kpc by the magnitude of the horizontal branch at the RR Lyrae instability strip; Bellazzini et al. (2002) obtained $d = 92.9 \pm 6$ kpc by fitting template cluster horizontal branches.

We use the short distance scale statistical parallax calibration of Gould & Popowski (1998), which is a robust method of measuring the absolute magnitude of RR Lyrae stars. They find

$$\mathrm{M_V} = 0.77 \pm 0.13, \tag{1}$$

at $\langle[\mathrm{Fe/H}]\rangle = -1.60$, for a sample of 147 halo RR Lyrae stars with high-quality proper motions from the *Hipparcos* (European Space Agency 1997) and Lick NPM1 (Klemola, Hanson & Jones 1993) surveys. Shetrone et al. (2001) find $\langle[\mathrm{Fe/H}]\rangle = -2.00 \pm 0.21$ in Draco dSph from high resolution spectroscopy of 6 red giants in the galaxy. Lehnert et al. (1992) also found a metallicity of $\langle[\mathrm{Fe/H}]\rangle = -1.9$, $\sigma = 0.4$, from spectra of 14 giants. The abundances seem to fall into two groups, one with an average [Ca, Mg/H] near -1.6 ± 0.2 and the other -2.3 ± 0.2. We adopt the value $\langle[\mathrm{Fe/H}]\rangle = -2.00$ (also quoted in Mateo 1998) for our distance determination. The metallicity correction is derived from the slope of the luminosity-metallicity relation for RR Lyrae, which lies between 0.2 (Chaboyer 1999) and 0.3 (Sandage 1993). Using 0.2 for the value of the slope and 0.4 dex for the difference in metallicity of Draco dSph from galactic RR Lyrae, we find $M_V = 0.69$ for the RR Lyrae in Draco dSph.

Draco dSph is located at Galactic coordinates $l = 86.^{\circ}37, b = 34.^{\circ}72$. To remove the effects of the Galactic interstellar extinction we used the reddening map of Schlegel et al. (1998) which yields $E(B-V) = 0.027$ mag. This corresponds to expected values of Galactic extinction of $A_I = 0.053$, $A_V = 0.091$, $A_B = 0.118$ mag, using the extinction corrections of Cardelli et al. (1989) as prescribed in Schlegel et al. (1998).

For the distance determination we only used the RRab stars found in chips 3 and 4, which are normalized to the photometry of Stetson (2000). There are 94 such stars in our data. The remaining RRab stars from chip 1 and 2 are not included in this list. We fit a Gaussian to a histogram of these 94 stars, using 0.03 mag bins and found $\langle \mathrm{m_V} \rangle = 20.18 \pm 0.02$, $\sigma = 0.08$, as shown in Figure 7. This value is in agreement with the value of Aparicio et al. (2001) for the horizontal branch at the RR Lyrae instability strip, 20.2 ± 0.1 mag, and with the value of Bellazzini et al. (2002) of 20.30 ± 0.12 mag, obtained by fitting to the template cluster M68. Our measurement implies a distance modulus of $\mathrm{m_V} - \mathrm{M_V} = 19.49$ mag. Correcting for extinction gives a true distance modulus of $(\mathrm{m} - \mathrm{M})_0 = 19.40$ mag and a distance of 75.8 kpc to Draco dSph.

The systematic errors are 0.06 mag in A_V, 0.03 mag in photometry, 0.13 mag in the calibration method and 0.04 mag in metallicity. The error in the reddening from Schlegel et al. (1998) is 0.02 mag, which corresponds to 0.06 mag in A_V, and the error in metallicity is calculated from a conservative error of 0.1 in the slope of the luminosity-metallicity relation times 0.4 dex, the metallicity difference. Adding the systematic errors in quadrature gives a conservative total estimate of 0.15 mag, which is dominated by the calibration error. We consider the effects of internal extinction to be negligible from a comparison of the spread in magnitudes of RRab stars in different filters. Similarly to Figure 7 for V with $\sigma = 0.08$, the spread in magnitudes of RRab stars in B and I are $\sigma = 0.10$ and 0.12, respectively. Thus we find no evidence for internal dust in the Draco dSph galaxy.

The statistical error is 0.02 mag, which leads to a true distance modulus of $(\mathrm{m} - \mathrm{M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag, corresponding to a distance of $75.8 \pm 0.7\,(\mathrm{stat}) \pm 5.4\,(\mathrm{syst})$ kpc.

6. Conclusions

We have presented the results of the first CCD variability study in the Draco dSph galaxy since Baade & Swope (1961). Our search produced 163 variable stars, 146 of which are RR Lyrae, 4 are anomalous Cepheids, 1 is a field eclipsing binary, 1 a SX Phe star and 11 are other types of variables. We have used the short distance scale statistical parallax calibration of Gould & Popowski (1998) for 94 RRab in our field and obtained a distance modulus of $(\mathrm{m} - \mathrm{M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag. By comparing the spread in magnitudes of RRab stars in different filters, we find no evidence for internal dust in the Draco dSph galaxy.

The catalog of all variables, as well as their photometry and finding charts, is available electronically via `anonymous ftp` and the `World Wide Web`. The complete set of the CCD frames is available upon request.

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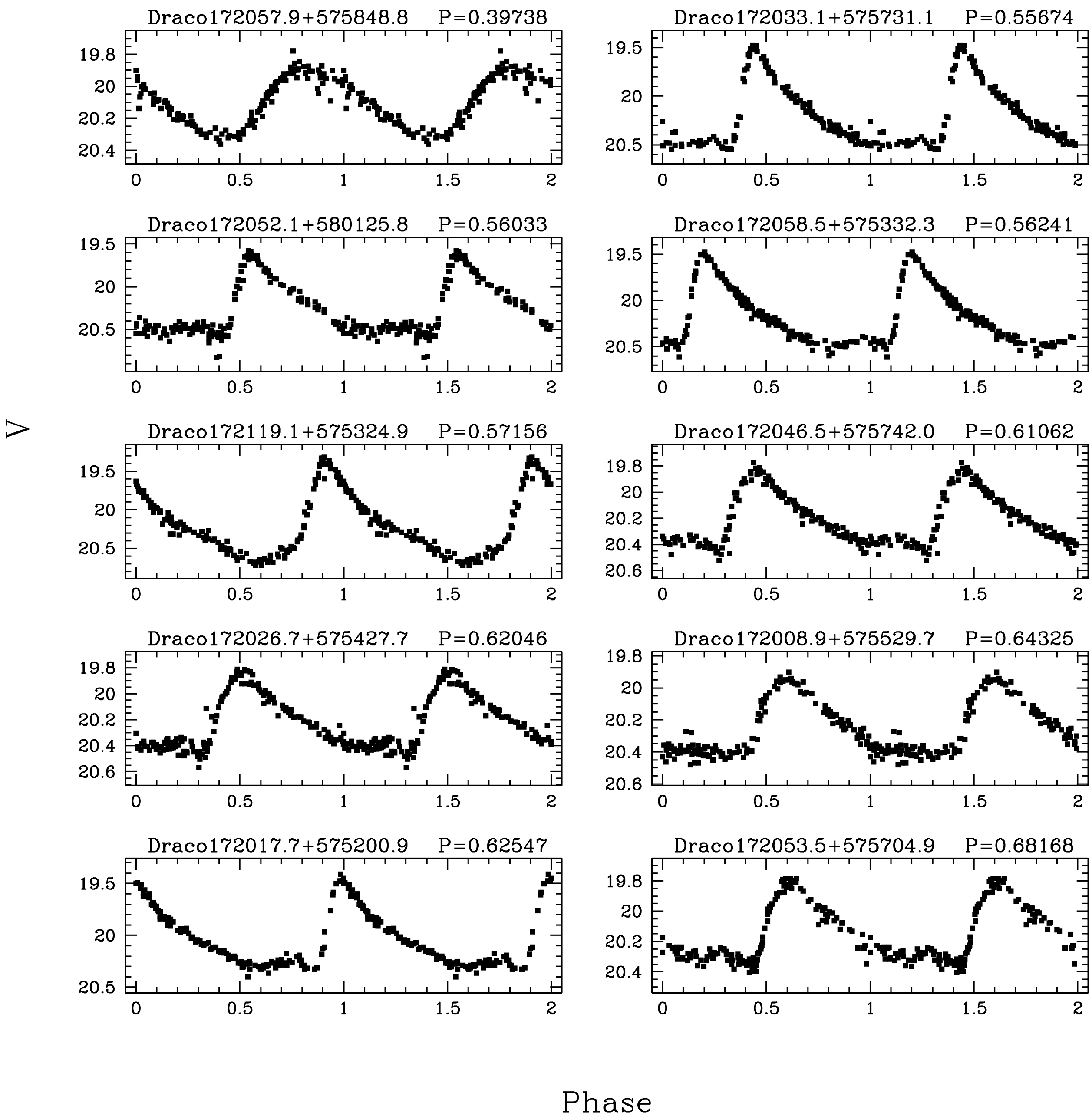

Fig. 1.— Sample light curves of RR Lyrae variables found in Draco dSph, representing typical quality data over a range of periods.

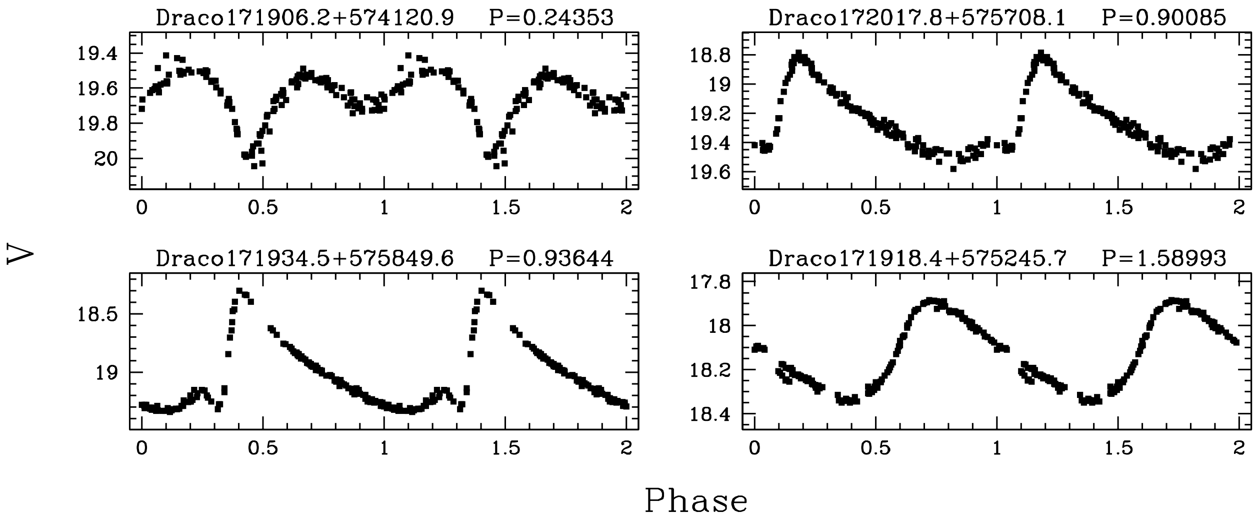

Fig. 2.— Light curves of selected other periodic variables found in Draco dSph. An eclipsing binary and 3 anomalous Cepheids are shown.

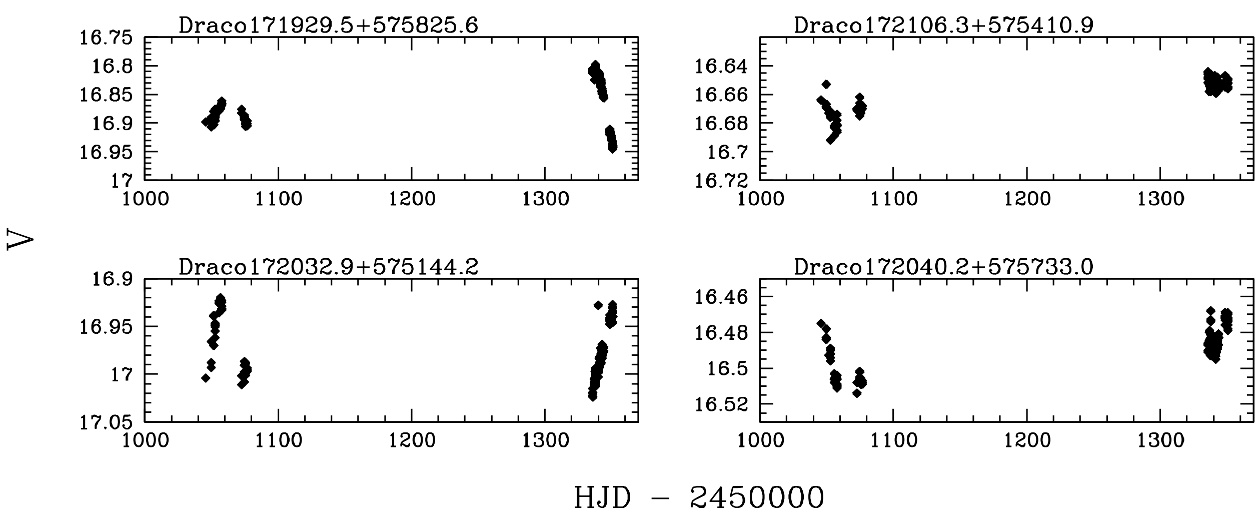

Fig. 3.— Sample light curves of other variables found in Draco dSph.

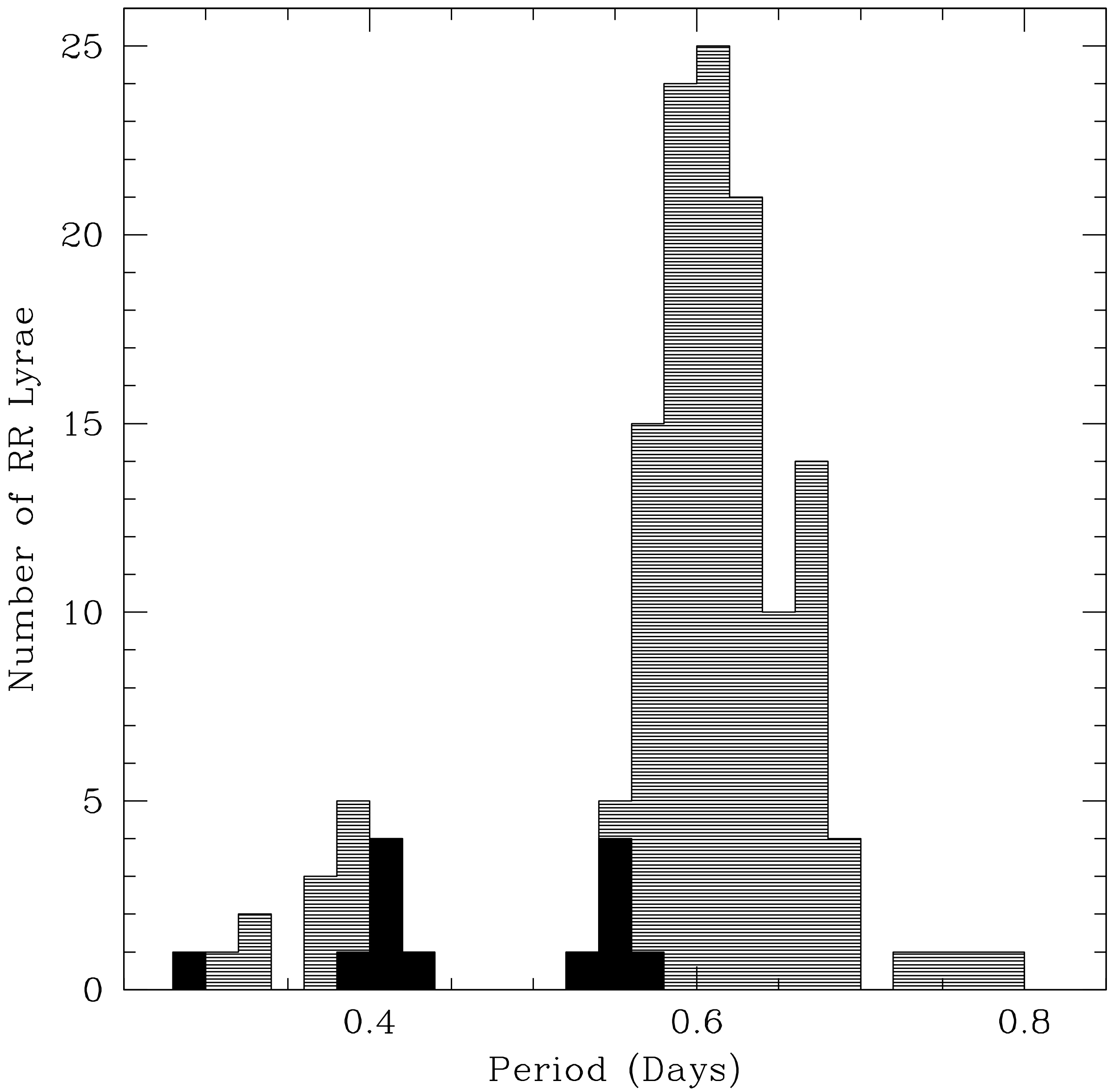

Fig. 4.— Period distribution of 146 RR Lyrae in Draco. The median period for RRab stars is 0.617 and for RRc stars 0.392. Both components of the double-mode stars are also plotted in black.

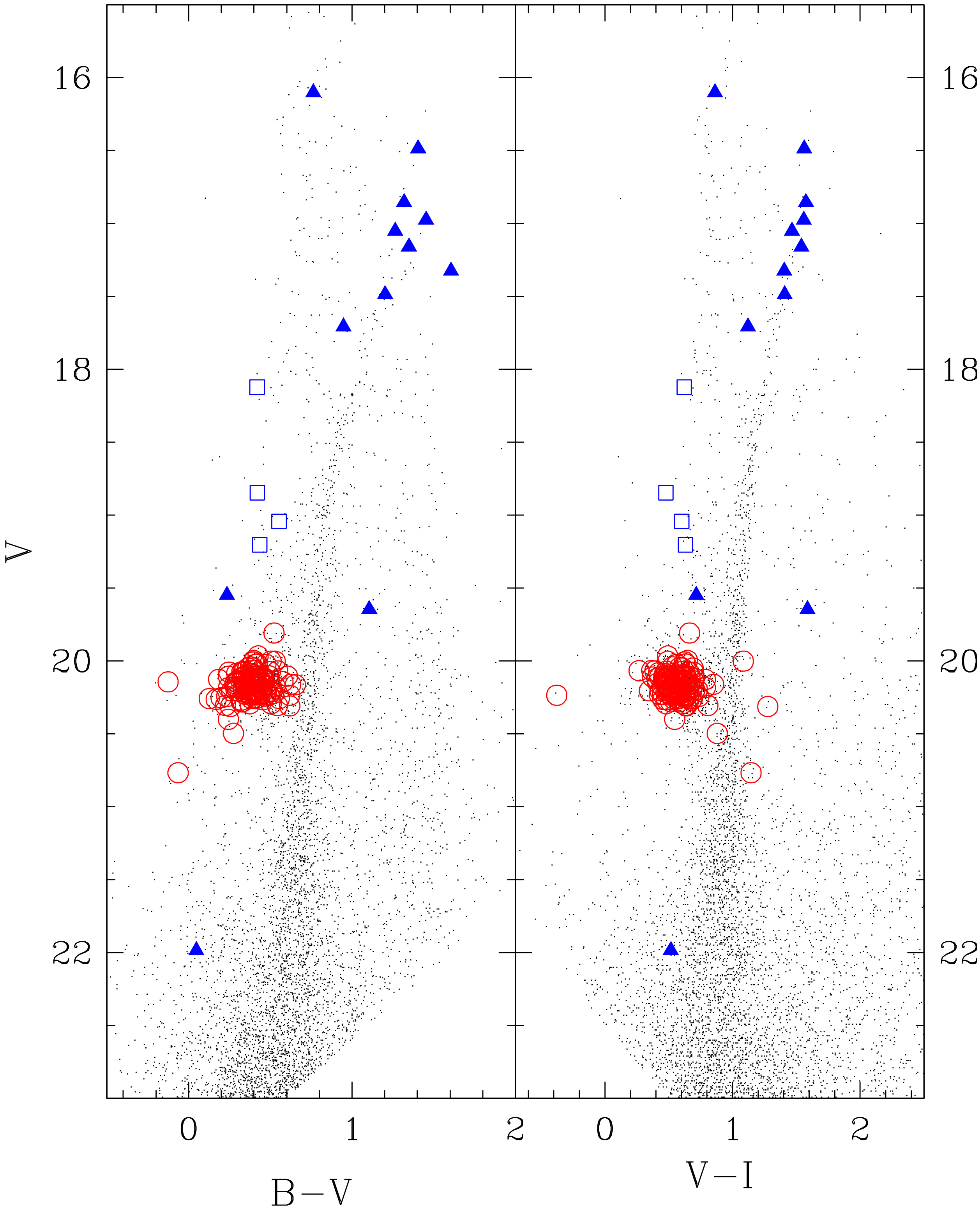

Fig. 5.— CMD for variables and nonvariable stars. Circles represent RR Lyrae, squares are anomalous Cepheids and triangles are other variables.

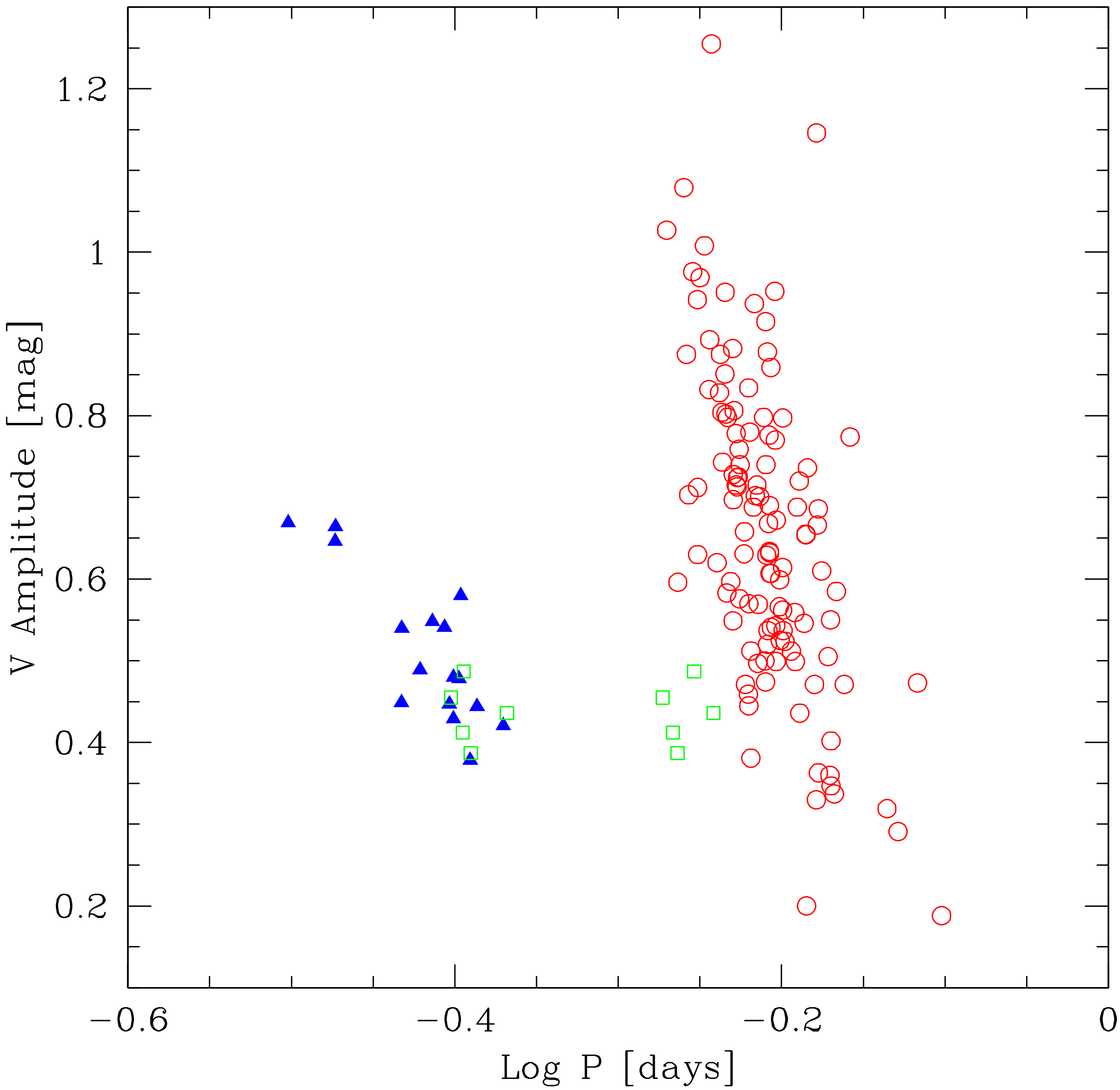

Fig. 6.— Period-amplitude relation for 146 RR Lyrae in Draco dSph. Circles represent RRab stars, triangles RRc stars and squares RRd stars, for which both periods are plotted.

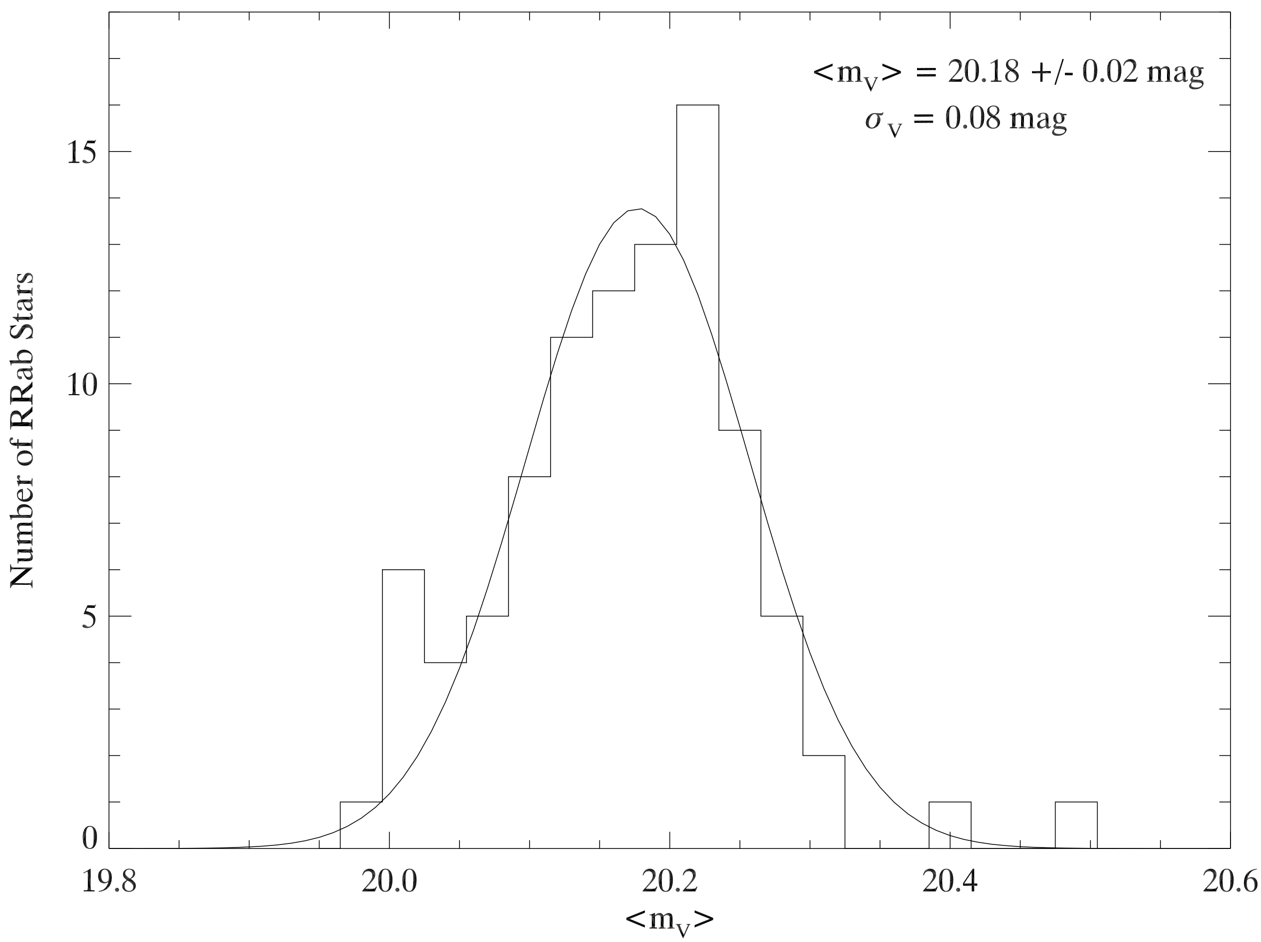

Fig. 7.— Histogram of 94 RRab magnitudes and the Gaussian fit, centered at $\langle m_V \rangle = 20.18 \pm 0.02$ mag.

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Table 1. RR Lyrae in Draco Dwarf Galaxy

Name	P (*days*)	$\langle V \rangle$ (mag)	$\langle I \rangle$ (mag)	$\langle B \rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Type	Comments[a]
Draco172052.0+575532.4	0.28767†	20.205	19.855	20.496	0.356	RR12	BS-170
···	0.40431	···	···	···	···	···	···
Draco172059.1+580006.0	0.31478*	20.263	19.808	20.432	0.669	c	BS-97
Draco171936.4+574930.0	0.33633	20.230	19.802	20.627	0.646	c	BS-46
Draco171936.1+575415.8	0.33646*	20.081	19.659	20.417	0.664	c	BS-121
Draco171908.1+575835.0	0.36924†	20.204	19.769	20.576	0.449	c	BS-110
Draco172059.5+575542.7	0.36947*	20.151	19.735	20.517	0.540	c	BS-173
Draco171938.4+574724.7	0.37903†	20.152	19.683	20.570	0.489	c	BS-50
Draco172112.7+580131.2	0.38572†	20.176	19.726	20.462	0.548	c	BS-181
Draco172110.8+574736.2	0.39233†	20.068	19.675	20.613	0.541	c	BS-179
Draco171917.5+580107.5	0.39502	20.145	19.671	20.433	0.447	c	···
Draco172042.5+575153.5	0.39597*	20.120	19.617	20.509	0.455	d	BS-190
···	0.53351	···	···	···	···	···	···
Draco171917.5+574843.0	0.39728†	20.120	19.640	20.580	0.480	c	BS-191
Draco172057.9+575848.8	0.39738*	20.071	19.589	20.408	0.429	c	BS-145
Draco171942.4+575837.9	0.40049†	20.108	19.607	20.448	0.478	c	BS-120
Draco172017.5+574601.7	0.40155†	20.151	19.624	20.604	0.580	c	BS-153
Draco172042.3+575852.7	0.40258*	20.126	19.591	20.310	0.412	d	BS-169
···	0.54144	···	···	···	···	···	···
Draco171942.5+575449.8	0.40319*	20.129	19.594	20.519	0.487	d	BS-143
···	0.55789	···	···	···	···	···	···
Draco172119.5+575236.0	0.40685†	20.116	19.632	20.448	0.378	c	BS-131
Draco172012.4+575412.0	0.40720*	20.105	19.614	20.710	0.387	d	BS-72
···	0.54489	···	···	···	···	···	···
Draco171930.5+575633.7	0.41080†	20.110	19.681	20.512	0.444	c	BS-182
Draco172041.9+575827.6	0.41215*	···	19.616	20.310	···	d	BS-11
···	0.55075	···	···	···	···	···	···
Draco171907.8+574432.7	0.42626	20.122	19.635	20.510	0.421	c	···
Draco172106.4+575153.4	0.42842*	20.115	19.482	20.442	0.436	d	BS-112
···	0.57322	···	···	···	···	···	···
Draco172047.2+575759.7	0.53656	20.110	19.736	20.449	1.027	ab	BS-13
Draco172017.0+575240.2	0.54513	20.497	19.617	20.772	0.596	ab,Bl?	BS-34
Draco171919.5+575738.9	0.54967	20.280	19.700	20.604	1.079	ab	BS-18
Draco171923.3+575555.9	0.55185	20.002	18.917	20.506	0.875	ab	···
Draco172008.4+575203.7	0.55345	20.181	19.653	20.474	0.703	ab,Bl	BS-37
Draco172033.1+575731.1	0.55674	20.156	19.664	20.441	0.976	ab	BS-124
Draco172052.1+580125.8	0.56033	20.212	19.698	20.573	0.942	ab	BS-94

Table 1—Continued

Name	P ($days$)	$\langle V \rangle$ (mag)	$\langle I \rangle$ (mag)	$\langle B \rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Type	Comments[a]
Draco172058.9+575344.6	0.56055	20.266	19.783	20.720	0.630	ab	BS-163
Draco172032.5+575509.8	0.56062	20.244	19.508	20.477	0.712	ab	BS-21
Draco172049.8+575405.5	0.56174	···	19.530	20.615	···	ab	BS-25
Draco172058.5+575332.3	0.56241	20.119	19.660	20.546	0.969	ab	BS-175
Draco172042.5+573955.7	0.56600	20.142	19.597	20.719	1.008	ab	···
Draco172016.7+575312.0	0.56917	···	···	···	···	ab	BS-29
Draco172015.2+575917.5	0.56957	20.195	19.663	20.532	0.832	ab	BS-8
Draco172020.5+580056.3	0.57011	20.252	19.625	20.451	0.893	ab	BS-5
Draco172119.1+575324.9	0.57156†	20.067	19.799	20.459	1.255	ab	BS-130
Draco172038.4+575236.1	0.57603	20.270	19.593	20.592	0.620	ab,Bl	BS-35
Draco171927.1+574653.5	0.57631†	···	19.693	···	···	ab	BS-116
Draco172041.9+575750.5	0.57642	···	19.732	20.572	···	ab	BS-12
Draco171926.6+575334.2	0.57804	20.279	19.764	20.610	0.828	ab	BS-15
Draco172042.9+575129.2	0.57877	20.219	19.683	20.573	0.875	ab,Bl	BS-41
Draco171934.1+575535.8	0.58002	20.107	19.562	20.508	0.804	ab	BS-107
Draco171941.4+575327.6	0.58048†	20.249	19.691	···	0.743	ab	BS-22
Draco171939.1+575803.9	0.58258†	20.160	19.568	20.606	0.851	ab	BS-102
Draco171949.9+574904.5	0.58273	20.101	19.633	20.592	0.951	ab	BS-48
Draco171935.7+575832.2	0.58332†	20.206	19.571	20.623	0.802	ab	BS-76
Draco172103.5+575950.9	0.58410	20.124	19.653	20.508	0.583	ab,Bl	BS-96
Draco171948.2+575451.6	0.58468†	20.253	19.622	20.674	0.798	ab	BS-73
Draco171942.9+575527.1	0.58722	20.201	19.495	20.612	0.597	ab,Bl	BS-147
Draco171931.8+575705.0	0.58886	20.259	19.680	20.646	0.882	ab	BS-144
Draco172011.5+575802.9	0.58921	20.106	19.490	20.350	0.549	ab,Bl	BS-123
Draco172059.3+580126.6	0.58938†	20.065	19.697	20.473	0.697	ab	BS-118
Draco171939.9+575753.5	0.58939	20.209	19.636	20.609	0.728	ab,Bl	BS-196
Draco171924.8+575847.2	0.59003	20.219	19.628	20.652	0.806	ab,Bl	BS-129
Draco171858.2+575256.6	0.59182	20.041	19.510	20.419	0.778	ab	BS-104
Draco171953.4+574844.9	0.59191	20.007	19.273	20.459	0.715	ab	BS-84
Draco172047.3+575523.5	0.59256	20.235	19.714	20.615	0.713	ab	BS-185
Draco172008.9+575623.3	0.59285	20.166	19.671	20.510	0.724	ab	BS-126
Draco171902.2+574754.6	0.59369†	20.241	19.605	20.708	0.725	ab	BS-115
Draco172113.0+575351.1	0.59441	20.136	19.630	20.512	0.759	ab	BS-189
Draco171912.0+575437.2	0.59466†	20.151	19.588	20.785	0.576	ab	BS-109
Draco172107.3+575800.8	0.59507	20.174	19.615	20.525	0.740	ab	BS-183
Draco172040.3+575604.5	0.59854	20.220	19.723	20.622	0.631	ab	BS-17
Draco171849.6+575356.1	0.59875	20.147	19.566	20.536	0.658	ab	BS-64

Table 1—Continued

Name	P (*days*)	$\langle V \rangle$ (mag)	$\langle I \rangle$ (mag)	$\langle B \rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Type	Comments[a]
Draco172015.4+575328.0	0.59960	20.085	19.615	20.380	0.471	ab	BS-171
Draco172010.7+574559.1	0.60202†	20.258	19.721	20.813	0.459	ab	BS-88
Draco172102.7+575251.0	0.60231	20.146	19.587	20.444	0.834	ab	BS-80
Draco171922.9+574957.9	0.60241†	20.160	19.308	20.785	0.445	ab	BS-137
Draco172116.6+575332.4	0.60257	20.120	19.712	20.434	0.570	ab,Bl	BS-26
Draco172057.2+575821.5	0.60336	20.215	19.651	20.633	0.780	ab	BS-62
Draco172006.1+580206.8	0.60417	20.143	· · ·	20.018	0.512	ab	BS-58
Draco172056.6+575352.9	0.60435	20.232	19.656	20.652	0.381	ab,Bl	BS-75
Draco172028.3+575701.2	0.60638	20.171	19.679	20.637	0.688	ab	BS-103
Draco172009.2+574538.3	0.60730†	20.229	19.599	20.575	0.937	ab	BS-89
Draco171922.9+575411.8	0.60813	20.305	19.497	20.531	0.702	ab	· · ·
Draco171847.5+575305.3	0.60939	20.156	19.497	20.597	0.715	ab	BS-60
Draco172051.2+575148.3	0.60998	20.075	19.420	20.575	0.497	ab	BS-133
Draco172046.5+575742.0	0.61062	20.192	19.606	20.586	0.569	ab	BS-63
Draco171951.3+574843.6	0.61159	20.211	19.703	20.721	0.701	ab	BS-85
Draco172108.7+574746.7	0.61525†	20.308	19.670	20.927	0.798	ab	BS-87
Draco172036.9+575213.1	0.61638	20.136	19.442	20.469	0.500	ab	BS-40
Draco172009.3+575438.8	0.61688	20.024	19.458	20.433	0.474	ab,Bl	BS-68
Draco172055.1+574335.2	0.61701	20.306	19.675	20.850	0.915	ab	· · ·
Draco172107.0+575942.5	0.61720	20.077	19.383	20.324	0.740	ab	BS-95
Draco171835.1+575654.9	0.61790	20.134	19.580	20.524	0.629	ab	BS-23
Draco171858.7+575257.0	0.61837	20.044	19.456	· · ·	0.878	ab	BS-14
Draco171945.6+575241.0	0.61864	20.127	19.339	20.584	0.520	ab	· · ·
Draco172009.5+575957.7	0.61892	20.293	19.814	20.668	0.537	ab	BS-7
Draco171917.6+575332.7	0.61954	20.146	19.591	20.546	0.668	ab	BS-101
Draco171838.4+575238.4	0.61995	20.196	19.472	20.579	0.776	ab	BS-20
Draco172008.5+574728.6	0.62023†	20.003	19.510	20.533	0.690	ab	BS-49
Draco171851.9+574728.1	0.62029	20.236	19.602	20.728	0.634	ab	· · ·
Draco172026.7+575427.7	0.62046	20.215	19.737	20.624	0.632	ab	BS-106
Draco172053.1+575304.1	0.62066	20.136	19.531	20.548	0.607	ab	BS-151
Draco172015.7+575417.4	0.62150	20.767	19.622	20.703	0.859	ab	BS-71
Draco172040.6+575452.7	0.62158	20.206	19.703	20.707	0.607	ab	BS-161
Draco172038.0+575531.2	0.62171	20.176	19.493	20.590	0.541	ab	BS-162
Draco172107.1+575409.2	0.62505	20.183	19.396	20.428	0.952	ab	BS-70
Draco172017.7+575200.9	0.62547	19.997	19.349	20.396	0.770	ab	BS-36
Draco171845.3+575222.5	0.62589	20.111	19.473	20.566	0.543	ab	BS-28
Draco172045.1+575128.0	0.62606	20.201	19.522	20.591	0.499	ab	BS-164

Table 1—Continued

Name	P ($days$)	$\langle V\rangle$ (mag)	$\langle I\rangle$ (mag)	$\langle B\rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Type	Comments[a]
Draco172029.9+580057.8	0.62629	20.258	19.571	20.385	0.672	ab	BS-4
Draco171946.3+574744.4	0.62898†	20.229	19.774	20.704	0.566	ab	BS-86
Draco172007.1+575949.7	0.62923	20.205	19.503	20.468	0.599	ab	BS-98
Draco172053.3+575314.6	0.62974	20.235	20.611	20.854	0.525	ab	BS-30
Draco171924.5+575336.3	0.63182	20.200	19.639	20.617	0.562	ab	BS-19
Draco172024.2+575141.4	0.63182	20.400	19.853	20.643	0.614	ab	BS-132
Draco172050.9+574517.2	0.63203†	20.174	19.640	20.655	0.797	ab	BS-154
Draco171928.9+574916.6	0.63237†	20.223	19.676	20.742	0.537	ab	BS-47
Draco172114.1+575435.9	0.63392	20.193	19.660	20.586	0.524	ab	BS-128
Draco171942.6+575329.9	0.63957	20.225	19.652	20.597	0.512	ab	BS-77
Draco172014.4+574402.3	0.64279	20.111	19.539	20.721	0.559	ab	···
Draco172008.9+575529.7	0.64325	20.259	19.605	20.671	0.499	ab,Bl	BS-160
Draco171955.4+574900.5	0.64495	19.809	19.145	20.332	0.688	ab	BS-114
Draco172014.9+580146.6	0.64701	20.313	19.036	20.569	0.720	ab	BS-3
Draco171858.8+575805.6	0.64741†	20.208	19.553	···	0.436	ab	BS-66
Draco171905.6+575538.9	0.65139	20.048	19.440	20.444	0.546	ab	···
Draco171945.0+575418.1	0.65290†	20.142	19.514	20.638	0.655	ab	BS-159
Draco172031.2+575737.5	0.65294	20.178	19.612	20.532	0.654	ab	BS-158
Draco172029.3+575808.3	0.65345	20.232	19.646	20.643	0.200	ab	···
Draco172017.1+574641.0	0.65431†	20.293	19.685	20.798	0.736	ab	BS-140
Draco171929.3+574159.4	0.66096	20.164	19.586	20.541	0.471	ab	···
Draco172013.2+575526.4	0.66261	20.183	19.580	20.516	0.330	ab	BS-192
Draco172036.8+574820.6	0.66284	20.107	19.442	20.551	1.146	ab	BS-172
Draco171931.8+575927.0	0.66353	20.117	19.420	20.568	0.666	ab	···
Draco171951.3+575321.1	0.66449	20.193	19.536	20.636	0.686	ab	BS-127
Draco172025.9+580002.3	0.66465	20.157	19.530	20.582	0.363	ab	BS-119
Draco172007.7+580140.5	0.66755	20.205	19.607	20.591	0.610	ab	BS-167
Draco171948.8+575657.0	0.67368	20.096	19.499	20.449	0.505	ab	BS-188
Draco171928.2+580043.3	0.67538	20.230	19.672	20.667	0.360	ab	BS-149
Draco171905.7+575520.1	0.67602	20.073	19.475	20.400	0.550	ab	BS-174
Draco172031.4+575303.0	0.67633†	20.095	19.471	20.497	0.402	ab,Bl	BS-150
Draco172021.6+575431.2	0.67650	···	19.625	20.624	···	ab	BS-193
Draco172046.5+574818.9	0.67655	20.163	19.500	20.817	0.347	ab	···
Draco172051.8+575636.0	0.67955	20.049	19.358	20.412	0.337	ab	BS-198
Draco172053.5+575704.9	0.68168	20.157	19.596	20.547	0.585	ab	BS-125
Draco171944.0+575509.7	0.68413	···	19.442	···	···	ab	BS-9
Draco171926.1+574851.4	0.68930†	20.174	···	20.703	0.471	ab	BS-187

Table 1—Continued

Name	P (*days*)	$\langle V \rangle$ (mag)	$\langle I \rangle$ (mag)	$\langle B \rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Type	Comments[a]
Draco172018.9+580038.0	0.69487	20.086	19.549	20.469	0.774	ab	BS-6
Draco172021.1+575219.1	0.73201	20.024	19.459	20.497	0.319	ab	BS-81
Draco171944.8+575737.2	0.74359	20.021	19.388	20.442	0.291	ab	BS-100
Draco172006.0+575349.4	0.76408	19.966	19.473	20.392	0.473	ab	BS-27
Draco172039.0+575732.6	0.79062	20.006	19.381	20.403	0.188	ab	···

[a]Names given in Baade & Swope (1961).

*Notes different period from that found by Baade & Swope (1961).

†Notes a star with no period in Baade & Swope (1961).

Table 2. Other Variables in Draco Dwarf Galaxy

Name	P (*days*)	$\langle V \rangle$ (mag)	$\langle I \rangle$ (mag)	$\langle B \rangle$ (mag)	$\mathrm{Amp_V}$ (mag)	Comments[a]
Draco172017.3+574817.3	0.068,0.073,0.079	21.985	21.468	22.033	0.873	SX Phe
Draco171906.2+574120.9	0.2435	19.645	18.058	20.751	0.266	Ecl. Binary
Draco171906.4+574948.2	0.59229*	18.846	18.368	19.267	0.877	Ceph, BS-134
Draco172017.8+575708.1	0.90085	19.204	18.573	19.640	0.679	Ceph, BS-141
Draco171934.5+575849.6	0.93644	19.043	18.439	19.597	0.888	Ceph, BS-157
Draco171918.4+575245.7	1.58993	18.123	17.501	18.542	0.460	Ceph, BS-194
Draco171855.0+574733.1	5.1150	17.707	16.586	18.655	0.101	
Draco172037.4+575913.0	···	17.051	15.584	18.315	···	
Draco172032.9+575144.2	···	16.977	15.418	18.430	···	
Draco172040.2+575733.0	···	16.488	14.927	17.893	···	
Draco172106.3+575410.9	···	16.658	19.396	20.428	···	
Draco171929.5+575825.6	···	16.855	15.279	18.173	···	
Draco171922.5+575404.2	···	17.326	15.921	18.932	···	
Draco171935.5+575846.4	···	17.161	15.622	18.509	···	
Draco171945.8+575626.1	···	19.548	18.832	19.783	···	BS-203
Draco171952.2+575909.3	···	17.487	16.078	18.690	···	
Draco172120.1+580118.7	···	16.102	15.239	16.866	···	

[a]Type of variable and name given in Baade & Swope (1961).

*Notes different period from that found by Baade & Swope (1961).