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A catalogue of RR Lyrae stars from the Northern Sky Variability Survey

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ABSTRACT

A search for RR Lyrae stars has been conducted in the publicly available data of the Northern Sky Variability Survey. Candidates have been selected by the statistical properties of their variation; the standard deviation, skewness and kurtosis with appropriate limits determined from a sample 314 known RRab and RRc stars listed in the General Catalogue of Variable Stars. From the period analysis and light-curve shape of over 3000 candidates 785 RR Lyrae have been identified of which 188 are previously unknown. The light curves were examined for the Blazhko effect and several new stars showing this were found. Six double-mode RR Lyrae stars were also found of which two are new discoveries. Some previously known variables have been reclassified as RR Lyrae stars and similarly some RR Lyrae stars have been found to be other types of variable, or not variable at all.

Key words: stars: Population II – stars: variables: other.

1 INTRODUCTION

Statistical studies of the relative numbers of the different classes of RR Lyrae variable stars and especially the incidence rate of multi-periodicity may give indications of the metallicity of different stellar systems and of their evolution (see e.g. Moskalik & Poretti 2003). Exhaustive studies have been done in the Magellanic Clouds by the Massive Compact Halo Object (MACHO) collaboration (Alcock et al. 2000, 2003) and the OGLE survey (Soszynski et al. 2003). Other studies have searched for RR Lyrae stars in the Galaxy, such as QUEST (Vivas et al. 2004) and also OGLE (Collinge, Sumi & Fabrycky 2006). Most of the stars found in these studies are faint, and limited to a small region of sky (the galactic bulge and the equator for OGLE and QUEST, respectively). The Robotic Optical Transient Search Experiment (ROTSE-1, Akerlof et al. 2000) found a fairly large number of previously unknown bright (magnitude <15) RR stars in a part of the sky.

This paper sets out to extend this search for field galactic RR Lyrae stars to the whole northern sky in the ROTSE-1 data, made publicly available via the Internet (Northern Sky Variability Survey–NSVS, Wozniak et al. 2004).

2 METHODOLOGY

With only photometric data, and no spectral information, the type of a short period variable can only be determined once the (phased) light curve is known, and hence only once the period is known. However, determining the period from sparse data is a computationally demanding process. Therefore, it was decided to limit the number of objects by statistical parameters involving much less computation: s.d., skewness, kurtosis and the mean square of successive differences of the magnitude data.

By looking at the values for these statistics for the RR Lyrae stars listed in the General Catalogue of Variable Stars (GCVS, Kholopov et al. 1985, and its online edition), limiting conditions were then derived. The aim was to set these limits as strict as possible, so that not too many objects needed to be checked, but still to include the majority of RR Lyrae stars. Those GCVS stars that did not follow the criteria, can then provide an estimate for the completeness of the survey.

2.1 Data

The ROTSE-1 was an unfiltered CCD survey of the sky from the north pole to declination (Dec.) ~ -38, reaching magnitude ~ 15 with varying levels of completeness. The survey lasted nominally for 1 yr but depending on the circumstances coverage of individual objects may be significantly less than this. Objects typically have 100 to 500 measurements with a median photometric accuracy of 0.02 mag for 10th magnitude stars and a positional accuracy of 2 arcsec. The spatial resolution of 14 arcsec compromises the photometry in crowded fields, typically with $|b| < 20$, but also at higher galactic latitudes for stars with companions within $\sim$45 arcsec.

The data are publicly available from the Sky Data base for Objects in Time-Domain web site (Wozniak et al. 2004) and it is possible

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to select data with respect to eight extraction flags and seven photometric correction flags. The default selection for good data sets all but one, PATCH, of the photometric correction flags and only one, SATURATED, of the extraction flags. However, experience of working with the data has shown that observations with the extraction flag APINCOMPL set are often completely out of range and should be rejected. On the other hand, data with the photometric correction flag RADECFLIP set are often indistinguishable from the other data. So the data have been selected with the SATURATED and APINCOMPL flags set and the PATCH and RADECFLIP flags unset.

It was also decided that only stars with 100 good NSVS observations or more were to be considered, in order to get good statistics and reliable period determinations, and to possibly detect multiperiodicity (double-mode pulsation or a Blazhko effect). With fewer data points, statistics may be influenced substantially by erroneous observations, such as those introduced by, for example, a close companion. Also, it is then not always possible to derive the correct period: in view of the sampling frequency, and the rather short total time span of the available data (less than a year) alias frequencies will be more important.

RR Lyrae stars are fairly blue stars (spectral types A and F). The NSVS survey however observed only in one colour (unfiltered CCD), so colour information has to be retrieved from another source, such as two-Micron All-Sky Survey (2MASS) (Cutri et al. 2003). The NSVS positions are not very accurate however, and matching them to 2MASS coordinates may be troublesome in crowded fields. In view of this and of reddening aspects, it was decided not to use colour information as a filter.

2.2 Control group: GCVS stars

The GCVS stars that were to be considered for the control group, had to be well known and have an accurate position. Therefore, only the GCVS types RRab or RRc were taken (no RR, RR:, RRab: or RRc: stars, i.e. the GCVS classification should be precise enough to give the exact subtype). Because of the limited number of RRd stars in the GCVS [the RR(B) class], these were not taken into account either. For practical purposes, as far as their statistical parameters are concerned, these double-mode stars can be considered to be RRc stars. The known RR Lyrae stars in the GCVS were further limited to the constellations And to Ori for which precise positions had been determined by the GCVS team at the time this study started. Many stars in other constellations did not have accurate enough coordinates, which could lead to misidentifications with the NSVS stars. It is however still possible that a faint RR Lyrae star unobservable by the ROTSE camera, lies close to a brighter (constant) companion, leading to a false identification. Because of this, the success rates for finding an RR star, may be underestimated. On the other hand, especially at fainter magnitudes, some stars which should have been detectable, will not have been registered, thus overestimating the success rate.

With the above restrictions imposed, 582 NSVS objects were identified as GCVS RR Lyrae stars by their HTM identification (see Wozniak et al. 2004). NSVS synonyms, the same object observed in overlapping NSVS fields, have been counted separately here. This will be done also for the remainder of this section, as it will not change the statistics very much.

The further restriction that there needed to be at least 100 good data points limited the sample to 314 objects (273 RRab and 41 RRc), or 54 per cent of the total number of stars identified. Compare this to the overall 42 per cent of objects with at least 100 good points (8 393 519 out of a total of 19 995 106 NSVS objects).

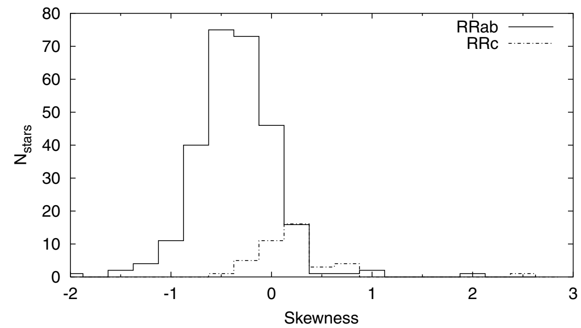

Figure 1. Distribution of the skewness values of the NSVS data for RRab and RRc stars from the GCVS.

60 per cent of the GCVS stars that are on average brighter than magnitude 14, have more than 100 observations, and 68 per cent if only objects north of the equator are counted.

2.3 Skewness

RRab stars have a typical light curve, spending more time near minimum than near maximum, while RRc stars have more symmetric light curves. It distinguishes them from eclipsing binaries, by far the most common type of variable star found in the NSVS data base. As a result, the distribution of magnitudes of an RRab star shows a negative skewness, while those of an RRc star shows a skewness near zero (note that a perfect sine curve has a skewness equal to 0). The distribution of the skewness values for the selected GCVS stars is given in Fig. 1.

The maximum value for the skewness statistic was set to 0.5, which selects 303 out of 314 stars (96 per cent). Most of the GCVS objects with higher skewness values did not satisfy the s.d. criterion either. Therefore, the chosen restriction seems to be an appropriate one. The objects not selected include HM Aql (probably a constant star, see below) and UU Cam (often referred to as an EW type variable) and a few objects near the magnitude limit resulting in a disproportionally high number of bright observations, and hence a larger skewness. One star had two very faint data points, outside its normal range, most probably data errors, also influencing skewness to rise abnormally.

Some of the objects selected with positive skewness are eclipsing variables of the W UMa type (EW). Especially for skewness values >0.5, most of the variables are EW stars or other eclipsing binaries. Some of these have been reported by Otero Wils & Dubovsky (2004). In a number of cases, it is impossible to distinguish between EW and RRc on the basis of the light curve alone. These stars have not been withheld.

2.4 Mean square of successive differences

The mean square of successive differences (MSSD) gives an indication for the time-scale of the variation of a star as compared to the sampling time-scale. The statistic considered further in this paper is in fact the rescaled value

$$\theta = \frac{1 - \mathrm{MSSD}}{2\sigma^2}, \qquad (1)$$

with σ the s.d. For a purely random distribution of the data $\theta = 0$ (Cuypers 1985), and for a star that only brightens or fades during the total time interval, θ will approach 1. RR Lyrae stars are rapidly changing stars (their periods range between about 0.2 and 1 d), compared to the frequency of observation by ROTSE (up to five points per night). Therefore, a raw light curve will show almost random variation. The criterion $\theta < 0.65$ was chosen. 307 (98 per cent) of the selected GCVS stars satisfy this criterion.

Because of the ROTSE observing regime, in some cases it is possible that a star with a period close to an integer fraction of a day, will show a raw light curve that resembles one of a much longer period star. This extreme aliasing is the case for RU Boo (period 0.4927 d), V1949 Cyg (0.4989 d), AW Lyr (0.4975 d), BT Leo (0.4997 d) and FY Aqr. For the latter, a period has not been given in the GCVS, but from All Sky Automated Survey (ASAS3) (Pojmanski 2002) and NSVS data a period of 1.0229 d may be derived; see also Domingo et al. (2004) for another period determination of this star.

2.5 Kurtosis

Kurtosis is a measure of the 'peakedness' of a distribution and it was found to be useful here as a discriminator against stars with extreme values. A maximum value of 4.5 was set for the kurtosis value of the magnitudes (a perfect sine has kurtosis = 1.5). It excludes stars that have some unusually faint or bright data points. This criterion effectively removes stars with bad data points making the s.d. erroneously large. It may however hide true variation in some particular cases, as some stars with highly deviating points which are really variable are excluded as well. This did not affect the majority of the RR Lyrae stars as the criterion selects 301 (96 per cent) of the GCVS stars, All of the objects that failed this test also violated other criteria as well. Overall with all criteria so far applied (without limits on the s.d.) 287 (255 RRab and 32 RRc) out of 314 (91 per cent) are left.

2.6 Standard deviation

Being the most important parameter for the recognition of a variable star, a cut is difficult to define for the s.d., as it strongly depends on the average magnitude of the stars, especially for fainter objects. From a Fourier fit to the observations, 'theoretical' s.d. values (i.e. without observational errors) for the selected RR Lyrae stars were found to be always larger than 0.1 mag, unless the star was in a close pair which could not be resolved by the instrument. Most RRab stars have 'theoretical' s.d. values between 0.15 and 0.30 mag, RRc variables between 0.10 and 0.20 mag (note that in the case of a perfect sine curve, the s.d. $\sigma = \Delta m/2\sqrt{2}$, with Δm the total amplitude from minimum to maximum).

A survey for Cepheids in Milky Way fields of the NSVS (Wils & Greaves 2004) has shown that the s.d. needed to be at least about twice that of the average s.d. at the magnitude of the star, to be certain the star is a genuine variable star, and not one with unusually high observational scatter. Therefore this restriction was chosen. Without imposing it, the number of stars to be checked grows exponentially with decreasing s.d. True variables exist which have a lower s.d., as shown by some of the GCVS stars, but these cases are rather rare and/or hard to confirm, as true variation gets masked by observational scatter. In addition, inaccuracies on the other statistics calculated, increase as well.

The cut-off for the s.d. σ is graphically illustrated in Fig. 2. It plots σ for the 314 GCVS RR Lyrae stars against their average magnitude. The thin full lines represent the average σ (lower line) and the chosen lower limit 2σ (upper line) at the given magnitude for all stars with more than 100 data points in the NSVS data base. 0.1 per cent of the stars have a value of σ above the upper dashed line, and 1 per cent above the lower dashed line. Almost all the RR Lyrae stars belong to the latter group.

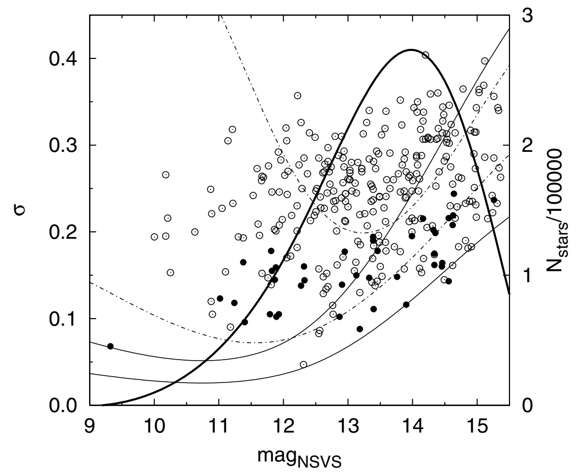

Figure 2. NSVS s.d. compared to magnitude for the RRab (open circles) and RRc stars (filled circles) selected from the GCVS. The lower and upper dashed lines represent, respectively, the 99 and 99.9 percentiles of the NSVS s.d. values (σ) as a function of magnitude. The bottom thin full line gives the average s.d. for a given magnitude (1σ level). The upper thin full line is the 2σ level and it represents the chosen cut-off limit. The total number of stars with at least 100 data points, is given per 0.1-mag bin by the thick line (right-hand axis).

It is probably worth looking at the brightest stars with low s.d. HM Aql (Harwood 1962) looks constant in NSVS data as well as in ASAS3 data (Pojmanski, Pilecki & Szczygiel 2005). Also V1510 Cyg and HU Cam appear to be constant in NSVS data. There might be an identification problem for these stars or a bright close companion.

2.7 Detection probability

Only 205 RRab and 16 RRc stars out of the total of 314 GCVS objects are left after applying the criterion on the s.d. So the overall detection possibility for RRab stars is 75 per cent, for RRc stars it is only 40 per cent. However, for stars on average brighter than magnitude 13, the success rate is 91 and 83 per cent, respectively. For stars brighter than magnitude 14, these rates are reduced to 83 and 57 per cent. If these numbers are then applied to the requirement that the stars needed to be observed at least 100 times, it follows that 56 per cent of the RRab stars on average brighter than magnitude 14 in the northern hemisphere are detectable with the assumed criteria and nearly 40 per cent of the RRc stars. These detection probabilities will be compared with the results from the ASAS3 survey. Because of the different detection possibilities, it is hard to accurately determine the ratio between the number of RRab and RRc stars.

3 RESULTS

More than 3000 objects satisfy all the criteria. These are not all RR Lyrae stars however, some are not even genuine variables. The final selection was based on the period and the shape of the phased light curve. Periods were determined using the phase dispersion minimization (PDM) technique (Stellingwerf 1978). For RRab stars the default setting $N_b = 5$ gives only approximate values, because the rise to maximum is so steep both minimum and maximum observations may appear in the same bin, with an excessively large value for the PDM statistic as a consequence. Therefore $N_b = 10$ was used.

Table 1. RR Lyrae objects identified in the NSVS data base (sample only).

NSVS ID	Right ascension (RA) (2000) (°)	Dec.	NSVS magnitude	Type	Period (d)	Epoch HJD 245 0000	Cross-ID
6 313 547	0.0164	+35.3631	12.71–13.88	RRab	0.706 69	1465.50	GM And
14 654 207	0.9480	−11.4764	12.58–13.62	RRab	0.740 84	1438.52	ASAS 000348−1128.6
17 443 023	1.5857	−35.2884	13.43–14.12	RRab	0.365 95	1487.71	NSV 29
3 703 390	6.2954	+51.5924	13.30–14.04	RRab	0.483 25	1540.62	
3 707 286	6.9956	+49.1627	12.22–12.62	RRc	0.392 02	1541.62	
6 381 354	8.2156	+26.3040	14.30–15.37	RRab	0.512 03	1532.63	
3 735 016	8.2257	+47.1466	12.73–13.39	RRab	0.567 41	1443.72	
2 284 759	92.6941	+52.7789	13.52–14.38	RRab	0.564 47	1593.61	MisV 1268
15 119 319	93.2337	−14.6690	11.90–12.34	RRc	0.320 07	1542.66	ASAS 061256−1440.1
12 919 472	131.9456	−3.6501	10.78–11.26	RRd	0.420 78	1554.73	GSC 4868−0831[a]
4 879 610	147.7964	+47.1534	13.92–14.82	RRab	0.516 15	1279.68	GSC 3433−1003[b]
4 966 885	168.2751	+40.3605	11.69–12.02	RRc	0.318 01	1573.81	GSC 3010−01290[c]
975 559	214.4808	+71.6857	12.95–13.75	RRab	0.652 52	1330.67	GALEX J141755.4+714107.6
7 732 274	214.9131	+25.7898	14.26–15.42	RRab	0.591 65	1615.70	ROTSE-1_J141939.17+254723.2
13 383 049	223.3877	−2.1144	13.86–14.71	RRab	0.441 51	1608.89	QUEST-374
5 152 353	223.4165	+40.5286	12.65–13.18	RRd	0.352 99	1312.71	GSC 3047−0176[d]
13 399 707	229.5561	−1.3191	13.68–14.46	RRab	0.604 88	1617.97	FASTT 701
5 222 076	236.6077	+44.3125	12.71–13.22	RRd	0.494 02	1336.88	GSC 3059−0636[e]
2 930 719	270.4686	+60.1119	12.22–12.69	RRab	0.579 27	1318.73	IBVS 5700−28[f]
17 147 355	310.8157	−9.1581	13.17–14.41	RRab	0.512 31	1390.72	GSC 5756−373[g]
...	...		...				

References to cross-IDs: [a]Wils & Otero (2005); [b]Nicholson, Sutherland & Sutherland (2005); [c]Kazarovets, Pastukhova & Samus (2005); [d]Koppelman et al. (2004); [e]Oaster et al. (2005); [f]Nicholson (2005); [g]Bernasconi et al. (2004); ASAS: Pojmanski et al. (2005); FASTT: Henden & Stone (1998); GALEX: Welsh et al. (2005); MisV: http://www.aerith.net/misao; ROTSE: Akerlof et al. (2000); QUEST: Vivas et al. (2004).

The RR Lyrae subtype was determined by inspection of the phased light curve: stars for which the ascending branch takes less than 30 per cent of the period were considered to be of type RRab (in most cases it is much less), others of type RRc. Stars with a symmetric light curve, which could also be contact binaries, were rejected from the final catalogue. All in all 785 RR Lyrae stars were detected, for which the following details are given in the main catalogue (Table 1; the complete table is available electronically only): NSVS number, coordinates in degrees, magnitude range (brightest and faintest observed magnitude), type, period in days, epoch of maximum light (HJD 245 0000) and a cross-identification if one exists. References for some of the abbreviations used in the cross-identifications are given below the table. NSVS synonyms have not been included in this table.

714 of these stars are of type RRab (of which 469 are brighter than magnitude 14 on average), 65 of type RRc (all brighter than magnitude 14; not surprisingly since the lower limit for the s.d. at magnitude 14 is larger than the average s.d. for RRc stars) and six of them are of type RRd. Of the 785 stars, 188 are previously unknown. Many others have only been suspected of variability before or had been wrongly classified. For others, it is the first time a period has been given. The catalogue contains 342 RR Lyrae stars already known in the GCVS and 23 stars with an incorrect type in the GCVS. However, it does not contain 178 GCVS RR Lyrae stars with 50 or more good data points that could be confirmed to be RR Lyrae stars from the NSVS data, but that did not satisfy all of the selection criteria given above. For completeness, these variables are given in Table 2 (available in full electronically only), with the same layout as Table 1.

3.1 Blazhko stars

Some RR Lyrae stars show a cyclic modulation of the amplitude and shape of their light curves known as the Blazhko effect (Blazhko

Table 2. Confirmed RR Lyrae stars from the GCVS excluded by the selection criteria (sample only).

NSVS ID	RA (2000) (°)	Dec.	NSVS magnitude	Type	Period (d)	Epoch HJD 245 0000	Cross-ID
14 641 662	1.0211	−16.9979	12.03–12.54	RRab	0.605 89	1456.70	UU Cet
14 682 480	8.4095	−15.4874	11.27–11.94	RRab	0.573 47	1514.73	RX Cet
17 478 336	13.9943	−26.3831	13.27–14.28	RRab	0.520 74	1402.95	UV Scl
3 763 277	15.7183	+45.1897	14.28–15.66	RRab	0.485 25	1492.84	IY And
3 860 939	19.6106	+50.6715	13.03–13.61	RRc	0.373 55	1456.63	V830 Cas
17 510 932	20.7232	−26.2927	13.25–14.51	RRab	0.451 51	1536.65	RW Scl
6 452 465	23.2962	+32.5946	14.22–15.64	RRab	0.705 59	1336.90	TV Tri
17 530 684	23.8484	−35.1285	11.94–12.75	RRab	0.637 06	1486.71	VX Scl
17 532 959	26.2484	−30.0577	11.48–11.91	RRc	0.377 38	1463.88	SV Scl
17 528 524	31.9667	−26.8660	9.86–10.90	RRab	0.495 50	1455.92	SS For
...	...		...				

Table 3. RR Lyrae stars showing the Blazhko effect.

Name	NSVS ID	RA (2000) Dec. (°)		Period (d)	Blazhko period (d)
OV And	3 656 843	5.1850	+40.8276	0.470 60	27:
GSC 0607−0591	9 149 730	11.9844	+11.7048	0.455 70	55:
DR And	6 429 832	16.2945	+34.2184	0.563 07	57:
UX Tri	6 471 887	26.3959	+31.3801	0.466 90	45
RV Cet	14 762 124	33.8121	−10.8001	0.623 40	117
FM Per	4 241 456	60.8624	+47.9978	0.489 27	20
AH Cam*	2 094 283	61.6628	+55.4999	0.368 73	11
NSV 2724	12 370 363	88.6547	+ 4.9031	0.479 08	28
NSV 4034	2 480 497	126.1037	+65.7181	0.599 09	65:
TT Cnc*	10 141 483	128.2299	+13.1912	0.563 44	88
GSC 1948−1733	7 404 884	130.0100	+27.7248	0.502 02	42:
GSC 4378−1934	777 167	133.0631	+70.4399	0.518 71	46:
GSC 0275−0090	13 144 199	175.8841	+ 2.6987	0.595 00	59:
Z CVn*	5 034 191	192.4388	+43.7736	0.653 87	21:
GSC 1454−0093	10 452 666	199.9771	+19.8991	0.601 00	74
RV UMa*	2 723 669	203.3252	+53.9872	0.468 08	93:
SS CVn	5 089 959	207.0666	+39.9010	0.478 54	97
TV Boo*	5 099 771	214.1517	+42.3597	0.312 56	10
GSC 0318−0905	13 340 626	215.7734	+ 1.9001	0.446 93	48
AR Ser*	13 439 617	233.3782	+ 2.7768	0.575 40	63:
AR Her*	5 207 933	240.1339	+46.9240	0.470 00	32
LS Her	10 678 349	240.5157	+17.4807	0.230 81	13
RW Dra*	2 830 506	248.8814	+57.8394	0.442 95	41
NSV 8170	10 767 118	256.1358	+14.4427	0.551 02	39
V365 Her*	10 806 471	256.4160	+21.5167	0.613 03	40:
DL Her*	10 783 891	260.0929	+14.5113	0.591 64	34
V421 Her	5 344 210	263.0232	+39.7586	0.556 75	56:
AV Dra	5 401 723	269.9339	+51.8839	0.555 56	96
BD Dra	1 132 043	274.4687	+77.2975	0.589 01	24
GSC 1581−1784	11 037 662	277.3025	+21.0728	0.591 12	23
RZ Lyr*	8 234 128	280.9082	+32.7979	0.511 26	26:
NR Lyr	5 525 581	287.1147	+38.8118	0.682 01	27:
GSC 1667−1182	11 622 872	320.1423	+18.6219	0.562 32	84
AE Peg	11 780 560	336.8397	+16.8046	0.496 75	23:

1907). The effect manifests itself as one or two additional frequencies in the periodogram, very close to the main frequency. The total time-span of available NSVS data is only about 9 months, which is short to accurately determine Blazhko periods. However, it can provide reasonable indications, as a number of the known Blazhko stars were easily picked up, and gave Blazhko periods in good agreement with the values from the literature. All stars from Tables 1 and 2 were checked for a Blazhko effect. Objects for which no effect was found include SW And, RS Boo (known Blazhko period >500 d, so it is not surprising its effect was not noticed), SW Boo, XZ and DM Cyg, XZ Dra, RU Psc and RR Lyr itself (in the latter case too few data points are available). It has been impossible to detect a Blazhko effect in stars fainter than about magnitude 13.5.

The results are summarized in Table 3. Stars for which at least one linear combination of the main frequency and the additional frequency have been found, can be positively identified as Blazhko stars. Stars for which no such combination has been detected are indicated with a ':' after the Blazhko period, and need further confirmation. The stars which are known to be Blazhko stars in the GCVS are marked with an asterisk after their name. Except for RZ Lyr and AR Ser, the Blazhko periods given are not much different from those derived here. For RZ Lyr the Blazhko period given in the GCVS is 59 d. For AR Ser, a variable Blazhko period between 80 and 120 d has been given. Lee & Schmidt (2001a) give a Blazhko period of 122 d for FM Per and 57.5 d for DR And (Lee & Schmidt 2001b). Lee, Gay & Smith (1996) already noted the Blazhko effect in V421 Her. Finally, the Blazhko effect of OV And has been studied in more detail by Kolenberg et al. (2005), but the data were inconclusive.

3.2 Double-mode stars

Galactic field double-mode RR Lyrae stars (RRd) are very rare with less than twenty currently known. These are low-amplitude variables very similar to RRc stars but showing two periods, the fundamental P_0 and first overtone, P_1, with a ratio $P_1/P_0 \approx 0.744$. In most cases, the first overtone mode has the highest amplitude. Six RRd stars have been detected. The double-mode nature of V372 Ser (García-Melendo, Henden & Gomez-Forrellad 2001) was already known before. The true nature of GSC 3047−0176 (Koppelman et al. 2004), GSC 3059−0636 (Oaster, Smith & Kinemuchi 2005) and GSC 4868−0831 (Wils & Otero 2005) was recently found in other studies of the NSVS or ASAS3 data. The two remaining RRd stars are identified here for the first time. Table 4 gives the fundamental period P_0 and the first overtone period P_1, as well as the period ratio for the six double-mode stars.

Table 4. Double-mode RR Lyrae stars.

Name	NSVS ID	RA (2000) Dec. (°)		P_0 (d)	P_1 (d)	Period ratio
GSC 4868−0831	12 919 472	131.9456	−3.6501	0.563 92	0.420 81	0.7462
GSC 3047−0176	5 152 353	223.4165	+40.5286	0.474 62	0.352 98	0.7437
V372 Ser	13 399 252	229.3958	−1.0889	0.471 35	0.350 72	0.7441
GSC 3059−0636	5 222 076	236.6077	+44.3125	0.494 04	0.366 91	0.7427
V458 Her	10 809 333	257.1295	+18.5213	0.483 74	0.359 98	0.7442
GSC 4421−1234	1 088 957	258.3326	+69.1317	0.540 80	0.403 20	0.7456

3.3 Misclassified GCVS stars

Ten stars classified as RR Lyrae variables in the GCVS, turned out to be of another type. V1180 Aql is a close double (Hoffmeister 1967), one star of the pair is a Mira variable, not an RR. AU and V556 Cas, V811 Oph, V421 Per and BQ Pup are Cepheids and V1823 Cyg and IT Her are probably EW-type stars. V1069 Sgr may be constant or its position may be in error. Also BU UMa is most likely a constant star (P. Van Cauteren private communication).

23 genuine RR Lyrae stars (included in Table 1) are also misclassified in the GCVS. These include DP Aqr, AL and TZ Cap, V939 Cyg, SX and FM Del, AQ and KO Dra, V534 Her and V1429 Oph. Others like V344 Ser and KQ UMa have been identified earlier also by Khruslov (2005).

3.4 Period corrections

Some stars in the GCVS are correctly classified but have a wrong period, mostly an alias of the correct period. These stars include GT Aqr (Diethelm 1996), X CMi, RW Equ, DG Hya, V418 Her and V784 Oph.

3.5 Estimates of the number of RR Lyrae stars

From the analysis and the detection possibilities discussed above, it is found that there should be about 650 RRab stars in the northern hemisphere brighter than magnitude 14 (of which 365 have been detected in this study) and about 140 RRc stars (56 have been detected). One could state that about four out of five galactic field RR Lyrae stars are of type RRab. However, because of selection effects which favour RRab stars, the exact fraction of the different subtypes are uncertain. Only about 2 per cent of the RR Lyrae stars are double-mode stars. But because of the low number of RRd stars, this frequency is even more uncertain.

These estimates can be compared to those obtained from a comparison of the current catalogue with the results of the ASAS3 (Pojmanski et al. 2005). That survey is based in the southern sky and detected variables south of Dec. ∼+28. In the overlapping region from Dec. −15 to +15, ASAS3 detected 323 objects unambiguously identified as RRab stars on average brighter than magnitude 14 (assuming that the average magnitude of an RRab star equals the maximum magnitude plus 0.65 times the full amplitude), and 73 RRab stars fainter than magnitude 14. Of these, respectively, 150 and 28 were detected in the NSVS data, giving detection probabilities of 46 and 38 per cent. These probabilities do not change when only the region from Dec. −10 to +10 is considered. However, if the declination zone between 0 and +15 is considered only, the detection probability for RRab stars brighter than magnitude 14 rises to 53 per cent (89 out of 168 stars were identified), very close to the 56 per cent found from the GCVS sample. It is clear that the efficiency of the search deteriorates fast for negative declinations, probably for a large part due to the requirement of at least 100 data points.

The estimate for the RRc stars differs more. ASAS3 identified 83 stars unambiguously as RRc stars in the considered overlapping region (all brighter than magnitude 14), of which only 10 were found in the NSVS data. This results in a detection probability of only 12 per cent (14 per cent if the region from Dec. −10 to +10 is considered, and 19 per cent for stars in the declination zone between 0 and +15). The large difference with the estimate from the GCVS sample can probably be explained by the small number of RRc stars found overall, so that the chosen samples are not really representative for the total population. Again, it can be concluded that the estimate for the number of RRc stars is not very reliable, and may in reality be considerably higher.

Figures for the southern sky can be obtained from the reverse comparison. Of the 124 RRab stars brighter than magnitude 14 between Dec. −15 and +15 found in this study, 114 were identified as well by ASAS3 (including four that have an ambiguous variability type, but not including five stars with a different type in ASAS3). This results in a detection probability of 92 per cent for ASAS3. As the survey unambiguously identified 817 objects south of the equator and brighter than magnitude 14 as RRab stars (1015 if ambiguous types are considered as well), there will be about 890 in total (or 1100 when all the ambiguously typed stars are taken into account). It may be concluded that there is an overabundance of RRab stars in the southern sky compared to the northern sky.

For the RRc stars the figures are as follows: of the 16 RRc stars found in this study in the overlapping region between Dec. −15 and +15, 12 or 75 per cent were identified by ASAS3 as RR Lyrae stars as well. With 259 stars brighter than magnitude 14 unambiguously identified as RRc stars, there may be about 345 in total south of the equator. This may be considered as a lower limit as there are 1047 possible RRc stars given by ASAS3. However, a large part of those are probably not genuine RRc stars.

4 CONCLUSION

This paper has enlarged the known number of galactic field RR Lyrae stars in the northern sky. The number of known stars showing multiperiodicity (Blazhko effect and double-mode pulsation) has been enlarged as well. The number of RR Lyrae stars brighter than magnitude 14 has been estimated, showing that there is an overabundance of RRab stars in the southern hemisphere.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online.
Table 1. RR Lyrae objects identified in the NSVS data base.
Table 2. Confirmed RR Lyrae stars from the GCVS excluded by the selection criteria.

This material is available as part of the online article from http://www.blackwell-synergy.com.

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