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Identification of RR Lyrae stars in the Tycho-2 catalogue

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Abstract. The Tycho-2 catalogue provides astrometric and photometric data for the 2.5 million brightest stars in the sky. Therefore it can provide much larger samples than the Hipparcos samples used to date in statistical studies. The object of this paper is the cross-identification of Tycho-2 sources and known variable stars of RR Lyrae type. The Tycho-2 data of cross-identified sources are added into the ASTRID specialized database. The present selection almost doubles the size of the sample of RR Lyrae stars with available proper motions.

Key words. stars: variables: RR Lyr – catalogs

1. Introduction

The Tycho-2 catalogue (Hog et al. 2000) – hereafter TYC2 – contains positions, proper motions and two-colour photometric data for the 2.5 million brightest stars in the sky. The completeness is 90% to $V = 11.5$ mag and 95% to $V = 11.0$. The main observational basis of the catalogue is the Tycho star-mapper observations by the Hipparcos satellite. About 130 observations per object provide homogeneous photometry from which mean magnitudes in two passbands close to Johnson B and V, B_T and V_T, were derived.

Many statistical results based on kinematic and photometric Hipparcos data, particularly luminosity calibrations, have been published (see for instance: Fernley et al. 1998; Popowski & Gould 1998). The luminosity calibration of RR Lyrae stars is one of the steps in the determination of the Universe distance scale (Luri et al. 1998). Some of these statistical results could be greatly improved by using the TYC2. Indeed TYC2 astrometry and photometry are homogeneous and a larger sample size can compensate for less accurate astrometric data. We present the identification of known RR Lyrae variable stars in the TYC2. Section 2 describes the sample of known RR Lyrae stars. The criteria adopted for the cross-identification are given in Sect. 3. Finally, Sect. 4 describes the sample of RR Lyrae stars identified in the TYC2.

2. RR Lyrae stars

There are 6543 galactic RR Lyrae stars known. Most of them (6526) are listed in the GCVS (Durlevich et al. 1996) and NSV (Kazarovets et al. 1998) catalogues, and in the more recent Name-list of Variable Stars (Nos. 67–74) published by Kholopov et al. (1999, 2000) in the IAU Information Bulletin of Variable Stars. Among the new variable stars discovered by Hipparcos 17 were identified as RR Lyrae stars (Perryman et al. 1997). All of them are included in the ASTRID database[1].

The Hipparcos catalogue gives measurements for 202 RR Lyrae stars. All of them are in the TYC2 that indicates the Hipparcos identifiers. Among them, 22 belong to the TYC2-suplement1 and 1 to the TYC2-suplement2; these supplements contain respectively stars without TYC2 data and false or heavily disturbed data. Thus only 179 RR Lyrae stars with an Hipparcos identifier will finally be considered. The properties of these 179 stars will be a guide in checking the criteria adopted for the cross-identification (Sect. 3). Let us remark that two stars (MS Ara = HIP 88402 and TZ Aur = HIP 34743) have no proper motion in TYC2 and so may not be useful for any kinematical applications.

Many RR Lyrae stars in the GCVS and NSV are fainter than the magnitude limit of the TYC2. Thus among the 6341 known RR Lyrae stars that were not observed by Hipparcos, only a few more than 400 can be present in TYC2. They are brighter than 12.5 mag in V and 12.8 mag in P at their maximum luminosity.

3. Criteria of cross-identification

3.1. Positions

The main criterion is the comparison between the positions of known RR Lyrae stars possibly observed by Tycho and

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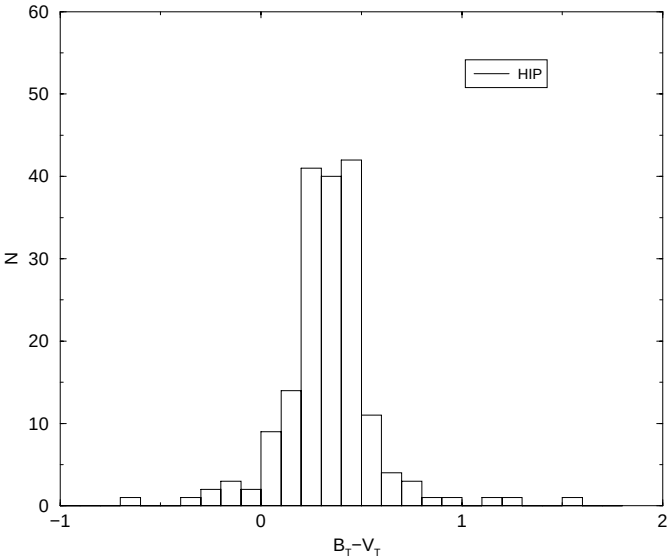

Fig. 1. Histogram of the colour index $(B_T - V_T)$ for TYC2 RR Lyrae stars with an Hipparcos identifier. N is the number of stars in each 0.1 mag interval.

the positions of TYC2 sources. The epoch of TYC2 positions is J2000.0. Only 345 non-Hipparcos RR Lyrae stars have a J2000.0 position in the SIMBAD database[2], so we cannot use this database for our purpose, but it allows us to verify the agreement with our J2000.0 GCVS position computation. The comparison of our computed J2000.0 positions and those of SIMBAD for these 345 stars shows that 60% and 40% of the differences between the two positions are smaller than 2″ and 1″ respectively, which agrees with the accuracy of the GCVS positions.

As a first step, we retain the TYC2 sources closer than 3 times the mean quadratic error on the TYC2 and GCVS J2000.0 positions of one RR Lyrae star. Thus, 482 TYC2 sources are selected as possibly related to 270 known GCVS non-Hipparcos RR Lyrae stars. In some cases one RR Lyrae star has been matched with more than one TYC2 source by this first selection. The criteria described in the next sections refine this selection.

3.2. Colour indices

It is very important to check that TYC2 sources positionaly matched with a RR Lyrae star have physical characteristics consistent with this type of stars. The $(B_T - V_T)$ colour should be compatible with the range for RR Lyrae stars, which can be estimated at [0, 0.7]. The histogram of the observed $(B_T - V_T)$ for Hipparcos RR Lyrae stars fulfills this assumption, as can be seen in Fig. 1.

Since we are dealing with variable stars the standard error of the mean magnitudes in TYC2 is large. We denote by σ_{B_T} and σ_{V_T} the respective accuracy on B_T and V_T. The colour criterion adopted for acceptance of a matched TYC2 star is:

- all sources, if $0 \leq B_T - V_T \leq 0.7$
- sources with $|\ (B_T - V_T)/(\sigma_{B_T} + \sigma_{V_T})\ | \leq 1$, if $B_T - V_T \leq 0$
- sources with $((B_T - V_T) - 0.7)/(\sigma_{B_T} + \sigma_{V_T}) \leq 1$, if $B_T - V_T \geq 0.7$.

The error measure $\sigma_{B_T} + \sigma_{V_T}$ is used instead of $\sqrt{\sigma^2_{B_T} + \sigma^2_{V_T}}$ to have a greater margin of acceptance. This enlarged margin is wide enough to retain faint RR Lyrae stars placed on the galactic plane, in which $(B_T - V_T)$ is substantially reddened (see Sect. 4). The last two criteria are satisfied by all Hipparcos RR Lyrae stars showing that they are flexible enough to allow good candidates with anomalous colours.

3.3. Magnitudes

A second criterion to refine the selection can be defined by taking into account that the TYC2 magnitude of the star must agree with the magnitude range for the matching object in the GCVS. To establish this we define the ratios:

$$R_{\max} = (P(B_T) - P_{\max})/\sigma_{B_T}$$

$$\text{and } R_{\min} = (P_{\min} - P(B_T))/\sigma_{B_T}$$

or

$$R_{\max} = (V(V_T) - V_{\max})/\sigma_{V_T}$$

$$\text{and } R_{\min} = (V_{\min} - V(V_T))/\sigma_{V_T}$$

where $P_{\max}$ and $P_{\min}$ (or $V_{\max}$ and $V_{\min}$) are respectively, following the GVCS rule, the P (or V) brightest and faintest magnitudes ever observed for the variable stars[3]. $P(B_T)$ and $V(V_T)$ are the TYC2 magnitudes reduced to photographic and visual magnitudes respectively. There is one pair of values $(R_{\max}, R_{\min})$ for each star because there is only one photometric measurement (P or V) in the GCVS. We use the approximate relations derived between Johnson and Tycho systems over the $(B_T - V_T)$ range of RR Lyrae stars:

$$V = V_T - 0.09(B_T - V_T)$$

$$B = B_T - 0.24(B_T - V_T)$$

(Perryman et al. 1997, Vol. 1, Sect. 3), and the unaccurate relation between B and P:

$$B = P + 0.11$$

which is given by Allen (1973) with no indication of the spectral range validity. Applying these approximate corrections could be questionable. However, for the colour range of the RR Lyrae stars, the difference $V - V_T$ is clearly negligible (−0.02 on average) and the difference $P - B_T$ (−0.22 on average) is smaller or of the same order as the uncertainty on the GCVS magnitudes due to the long-term changes of several tenths of magnitude in the light curves of the RR Lyrae stars (see, for instance, Tsesevich 1969). We have checked that the effect of the correction on the selected stars is marginal.

The distribution of the Hipparcos RR Lyrae stars in the plane $(R_{\max}, R_{\min})$ (see Fig. 2, where these ratios are plotted

[2] http://simbad.u-strasbg.fr/

[3] Defining $R_{\max}$ and $R_{\min}$, we have neglected the GCVS errors in extrema magnitudes because they cannot be properly estimated.

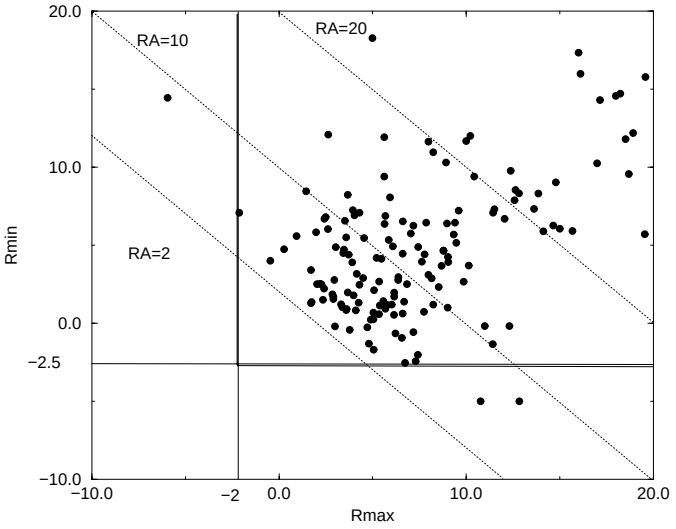

Fig. 2. Distribution of the Hipparcos RR Lyrae stars in the plane $(R_{\max}, R_{\min})$.

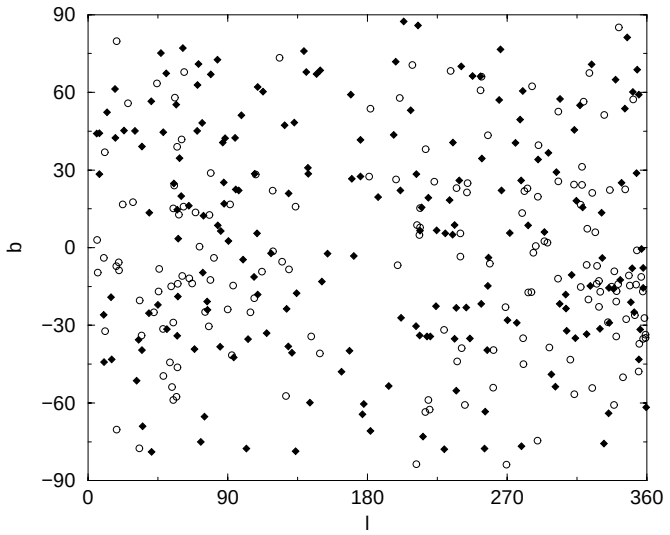

Fig. 3. Distribution of Hipparcos (filled diamonds) and new-identified TYC2 (open circles) RR Lyrae stars in galactic longitude and latitude.

for all stars simultaneously, i.e. those having photographic and visual magnitudes in the GCVS) helps to determine the acceptance limit for a cross-identification. The mean of $R_{\max}$ is greater than the mean of $R_{\min}$, in agreement with the shapes of the light curves of RR Lyrae stars: a RR Lyrae star spends a larger part of its variability cycle closer to the minimum of luminosity than to the maximum and is thus observed by the satellite more times at fainter luminosities.

Thus, looking at the Hipparcos RR Lyrae star behaviour, we adopt as a criterion for acceptance:

$R_{\max} \geq -2$ and $R_{\min} \geq -2.5$

which can be expressed as:

$$P_{\max} - 2\sigma_{B_T} \leq P(B_T) \leq P_{\min} + 2.5\sigma_{B_T}$$

or

$$V_{\max} - 2\sigma_{V_T} \leq V(V_T) \leq V_{\min} + 2.5\sigma_{V_T}$$

if the GCVS data are, respectively P or V magnitudes.

These zones are indicated by bold lines in Fig. 2. Five Hipparcos stars are far out of this area (hip 54694, 67227, 78891, 101545, 112532), thus, their cross-identification with a Tycho source as given in the TYC2 catalogue can be doubtful.

4. Results

The positions, proper motions, and B_T, V_T magnitudes of TYC2 sources identified as known RR Lyrae stars (Hipparcos and non-Hipparcos) are available in the ASTRID database.

Table 1 shows the number of selected sources after the application of each criteria. At the end of the selection process, 172 TYC2 sources are cross-identified with a non-Hipparcos RR Lyrae star. The physical criteria drastically decrease the number of matches deduced only from the position criterion, showing the importance of taking into account physical properties in a cross-identification procedure.

Table 1. Number of known GCVS non-Hipparcos RR Lyrae stars identified with a TYC2 source after each selection step.

Criterion	Selected sources
Position	270
Colour	216/270
Magnitude	172/216
Total	172

The list of GCVS and TYC2 identifiers of the 172 non-Hipparcos matched RR Lyrae stars is given in Table 4.

Several aspects of the above selection procedure have been checked:

- The selection process does not present zonal effects as a function of the galactic latitude or longitude (see Fig. 3).
- The distribution of non-Hipparcos RR Lyrae stars in the plane $(R_{\max}, R_{\min})$ reflects the fact that this kind of variable stars spend a larger part of its variability cycle closer to the minimum of luminosity than to the maximum (see Sect. 3.3), as shown in Fig. 4.
- The variability of TYC2 sources cross-identified with non-Hipparcos RR Lyrae stars is checked by using their σ_{V_T} values. We compare the σ_{V_T} of non-Hipparcos and TYC2 sources to the mean precision of all TYC2 sources within given intervals of V_T magnitude (Hog et al. 2000). Figure 5 shows that the individual σ_{V_T} values of nearly all the TYC2 sources cross-identified with a known and non-Hipparcos RR Lyrae star is larger than the TYC2 mean precision. Let us remark that, on average, the σ_{V_T} decreases for the faintest stars because of the "survival analysis technique" used to obtain faint Tycho magnitudes (Perryman et al. 1997, Vol. 1, Sect. 3) that is more important for variable

Table 2. The mean σ_{V_T} values within given intervals of V_T magnitude, of the TYC2 sources cross-identified with a known RR Lyrae star and of all TYC2 sources.

Interval of V_T	8 – 9	9 – 10	10 – 11	11 – 12	>12
mean σ_{V_T} of RR Lyrae					
Hip stars	0.015	0.025	0.053	0.118	0.199
non-Hip stars				0.156	0.220
mean σ_{V_T} of all stars (Hog et al. 2000)					
	0.014	0.023	0.050	0.114	0.198

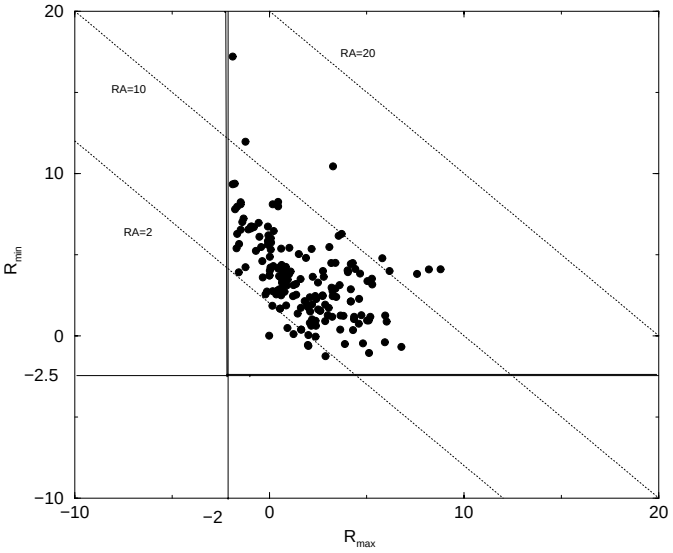

Fig. 4. Distribution of the kept non-Hipparcos RR Lyrae stars in the plane (R_{max}, R_{min}).

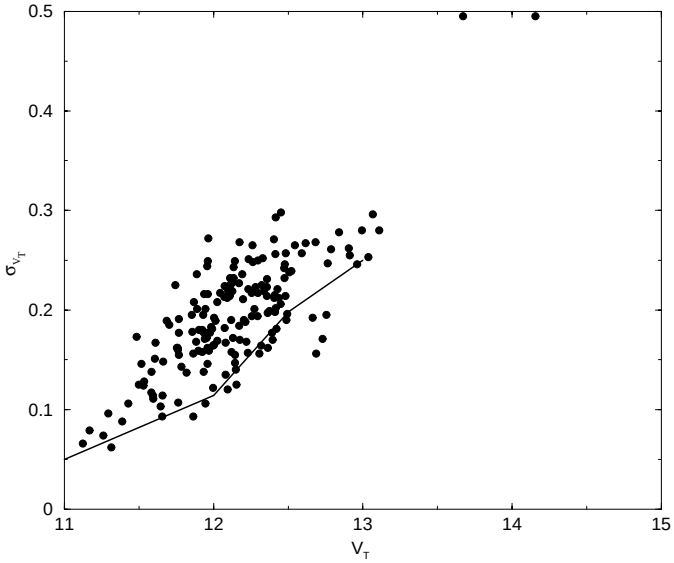

Fig. 5. Comparison of the σ_{V_T} of RR Lyrae stars new-identified in TYC2 (open circles) with the mean precision of TYC2 sources within given intervals of V_T magnitude (solid line).

stars than for constant stars. There are 4 well-identified stars (SW Boo, IU Cas, BH Pav, ES Peg) with σ_{V_T} under the line of mean σ_{V_T} values (Fig. 5). However, Table 2 shows that, in all the given intervals of V_T magnitude, the mean σ_{V_T} value of the TYC2 sources cross-identified with a known RR Lyrae star is larger than the mean precision of all TYC2 sources, as is to be expected for variable stars. The effect of the censoring is even more important when considering B_T estimates. Thus it is better to use σ_{V_T} than σ_{B_T} for checking the variability. This check strengthens the classification of these sources as variable stars. Consequently the possibility of a contamination by non-variable stars, if some remains, is only marginal.

– The ratio between the amplitude of the light curve given by the GCVS catalogue and the standard error of the mean TYC2 magnitude:

$$RA = (P_{\min} - P_{\max})/\sigma_{B_T}$$

or

$$RA = (V_{\min} - V_{\max})/\sigma_{V_T}$$

could in principle provide a check for our selection. It is remarkable that the values of *RA* for the non-Hipparcos RR Lyrae stars are, on average, smaller than those for the Hipparcos ones because of their fainter magnitudes. Thanks to the large *RA* values for a great number of sources, one expects that RR Lyrae light curves and periods could be extracted from Tycho multi-epoch photometry. Comparison of periods from Tycho and GCVS should entirely clean the cross-identifications compiled here.

– In a forthcoming paper, Mennessier et al. (2002), we apply the LM method (Luri et al. 1996) to the sample of RR Lyrae stars considered here and make an estimation of the individual distance and, simultaneously, of the interstellar absorption for each star. These results allow us to compute the $(B_T - V_T)_0$ colour indices for Hipparcos and non-Hipparcos RR Lyrae stars, whose histograms are shown in Fig. 6. Both distributions have their maximum at the same colour index range, but there are non-Hipparcos RR Lyrae stars with large intrinsic colour index values. There are two possible reasons for the greater dispersion of the non-Hipparcos RR Lyrae star distribution: these stars are, on average, more distant than the Hipparcos ones and the applied interstellar correction is not accurate enough for them; in addition, they have bigger measurement errors as a result of their fainter magnitudes, as can be seen in Table 3 that shows the median value of V_T and the mean measurement accuracy

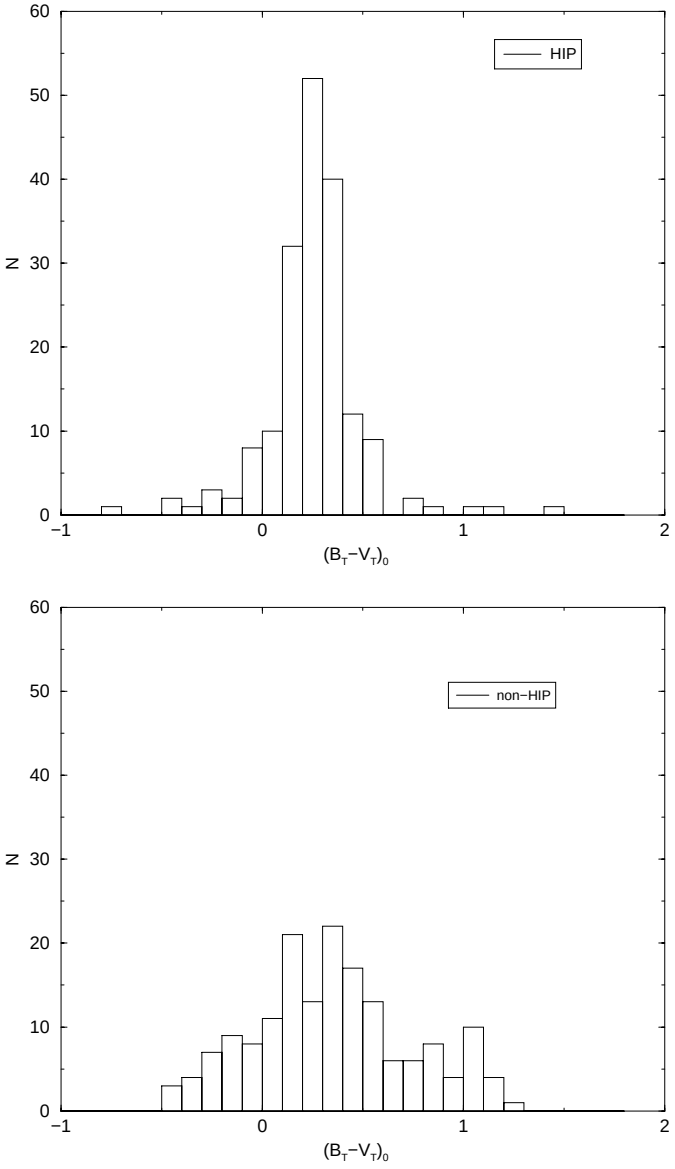

Fig. 6. Histograms of the colour index $(B_T - V_T)_0$ for TYC2 RR Lyrae stars with and without an Hipparcos identifier. *N* is the number of stars in each 0.1 mag interval.

Table 3. Median values of V_T and mean measurement accuracies of Hipparcos and non-Hipparcos RR Lyrae stars cross-identified with a TYC2 source.

	median V_T	σ_o
non-HIP	12.13	0.32
HIP	10.98	0.08

($\sigma_o = \sqrt{\sigma^2_{B_T} + \sigma^2_{V_T}}$) for Hipparcos and non-Hipparcos RR Lyrae stars. Both effects will populate the tails and flatten the peak of $(B_T - V_T)_0$ distribution.

5. Conclusions

351 TYC2 sources are identified with known RR Lyrae stars: 179 and 172 with and without Hipparcos measurements, respectively.

Among the 179 Hipparcos RR Lyrae stars, 120 have a Tycho identifier in the SIMBAD database.

Only 8 non-Hipparcos GCVS RR Lyrae stars have a Tycho identifier in the SIMBAD database:

- Four of them are not in our list:
  - Two of them were considered too faint to have been observed by Tycho: EQ Hya (P_{max} = 12.8) and V411 Sgr (P_{max} = 14.0). The TYC sources associated in SIMBAD have B_T = 11.786 and 10.706, respectively, that seems to be a doubtful identification even if we do not consider the difference of photometric systems which is of order of 0.1 mag.
  - V680 Mon ($(B_T - V_T) = -0.07$) does not pass our colour index criterion, and DR And (11.768 ± 0.096 for a *P* magnitude range 12.0–12.8, respectively) does not pass our magnitude criteria for the cross-identification with TYC2 sources.
- The last three are present in our list of cross-identified sources:
  - V674 Cen and AO Tuc agree with our cross-identification,
  - V816 Oph, cross-identified with TYC "423 00179 1" differs from our cross-identification. We cross-identify V816 Oph with the Tycho source TYC "423 01493 1". The *V* magnitude range given by GCVS for V816 Oph is 11.71–13.04. Our TYC2 source has a V_T magnitude value of 12.362 that is in perfect agreement with the GCVS values while TYC "423 00179 1" has a V_T magnitude value of 10.967, out of the *V* magnitude range of V816 Oph.

The present selection almost doubles the size of the sample of RR Lyrae stars available for statistical studies based on proper motions. Moreover these stars have available B_T and V_T photometry. Their TYC2 identifiers and data have been added into the ASTRID database, where additional astrometric, photometric (visible, infrared, radio) and spectroscopic data can be found. Table 4 gives crossed identifiers for these 172 RR Lyrae stars not included in the Hipparcos catalogue. The TYC2 data are available at the CDS[4].

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[4] Catalogue I/259 is available in electronic form at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr (130.79.128.5)` or via `http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/390/173`

Table 4. GCVS and TYC2 identifiers of the 172 RR Lyrae non-Hipparcos stars identified with a TYC2 source.

TYC2	GCVS	TYC2	GCVS	TYC2	GCVS	TYC2	GCVS
3235 00649 1	BK And	7816 01300 1	V501 Cen	6027 01044 1	XX Hya	6261 02361 1	V756 Sgr
2773 01607 1	DM And	7308 01432 1	V535 Cen	5448 00107 1	DH Hya	7937 01579 1	V796 Sgr
9281 01742 1	BS Aps	7213 01978 1	V590 Cen	6728 01236 1	FY Hya	6882 00389 1	V866 Sgr
9293 01637 1	LU Aps	7214 01559 1	V595 Cen	0215 01036 1	GL Hya	6281 01857 1	V1025 Sgr
5230 00535 1	TZ Aqr	7278 00390 1	V671 Cen	5471 00817 1	IV Hya	6282 00744 1	V1055 Sgr
5806 00188 1	YZ Aqr	7292 01029 1	V674 Cen	9353 00088 1	SX Hyi	6278 01906 1	V1176 Sgr
5814 01330 1	AA Aqr	4650 00982 1	DX Cep	8444 01013 1	AO Ind	7953 01362 1	V1645 Sgr
5816 00616 1	BO Aqr	6482 00328 1	RT Col	3204 00101 1	CQ Lac	7442 01549 1	V1646 Sgr
5782 00484 1	BU Aqr	1993 02658 1	RY Com	1983 00539 1	RX Leo	7957 00491 1	V2277 Sgr
5816 00282 1	CE Aqr	1997 00754 1	BS Com	0860 00368 1	AA Leo	7957 01101 1	V2281 Sgr
5193 00708 1	CP Aqr	7911 01078 1	WW CrA	1437 00734 1	AE Leo	6866 01681 1	V3859 Sgr
5228 00828 1	FY Aqr	7916 01708 1	CV CrA	0270 00519 1	AN Leo	7384 00434 1	V487 Sco
5181 00028 1	AA Aql	7913 01356 1	V592 CrA	1976 00905 1	V LMi	6782 00893 1	V765 Sco
5739 01986 1	KM Aql	7405 01427 1	V593 CrA	3000 00744 1	X LMi	6427 01515 1	RV Scl
1057 00788 1	V672 Aql	7906 00492 1	V629 CrA	8292 01452 1	VW Lup	6985 00559 1	TX Scl
0500 02240 1	V793 Aql	6101 00033 1	SW Crv	8303 00119 1	AW Lup	7507 00715 1	UZ Scl
9052 01546 1	CV Ara	8973 01776 1	SW Cru	7313 01084 1	GZ Lup	6999 01283 1	AE Scl
9056 00731 1	CZ Ara	2707 00757 1	DM Cyg	2960 00958 1	RW Lyn	5705 00778 1	AF Sct
8746 01083 1	HX Ara	3171 00285 1	V830 Cyg	2641 01678 1	RZ Lyr	0366 00711 1	AV Ser
8369 01766 1	QU Ara	3556 02064 1	V894 Cyg	2115 02066 1	AQ Lyr	1503 00507 1	AW Ser
8354 00751 1	V532 Ara	3609 02052 1	V1815 Cyg	2121 02123 1	CX Lyr	1489 00510 1	DF Ser
1217 01508 1	RW Ari	2679 01388 1	V1823 Cyg	3120 01293 1	NR Lyr	5499 00814 1	RV Sex
1761 01979 1	TY Ari	1632 00667 1	ZZ Del	7962 01089 1	TT Mic	8744 01879 1	BI Tel
2559 00874 1	SW Boo	1078 00034 1	CK Del	0163 01482 1	V535 Mon	8762 01412 1	FU Tel
2569 00519 1	UU Boo	1647 02135 1	EG Del	9253 00898 1	ET Mus	8401 00104 1	GZ Tel
2022 00180 1	XX Boo	1640 01518 1	FF Del	8724 00541 1	VW Nor	8389 01466 1	HH Tel
7586 00270 1	U Cae	8510 01671 1	VY Dor	5080 01878 1	ST Oph	9027 03628 1	TT TrA
4339 00474 1	UU Cam	9165 00722 1	XX Dor	0423 01493 1	V816 Oph	8837 00411 1	YY Tuc
1927 00426 1	SS Cnc	3523 01442 1	AV Dra	0717 02302 1	CM Ori	8470 00493 1	AO Tuc
0825 00680 1	AQ Cnc	4574 01625 1	BD Dra	9058 02328 1	TY Pav	9345 00132 1	BK Tuc
3023 00942 1	Z CVn	3946 00531 1	CY Dra	9077 02070 1	BH Pav	7671 02298 1	AN Vel
0168 01084 1	X CMi	0535 01242 1	RT Equ	8785 00001 1	HV Pav	7735 00975 1	FS Vel
0172 00642 1	RV CMi	7044 01598 1	DT Eri	9084 00277 1	QR Pav	0282 00632 1	UV Vir
0192 00043 1	AL CMi	6440 00701 1	Z For	1685 01784 1	VV Peg	0300 00375 1	VZ Vir
8627 02481 1	TX Car	6440 00028 1	RS For	1678 00330 1	CY Peg	4965 00838 1	WW Vir
8957 02820 1	FT Car	6442 00690 1	RX For	1713 01366 1	DZ Peg	4981 01329 1	AD Vir
8548 01214 1	IU Car	7560 00526 1	SW For	2735 00326 1	ES Peg	0321 00306 1	AE Vir
3677 01213 1	HU Cas	7992 00369 1	RR Gru	3671 01241 1	ET Per	5538 00115 1	AS Vir
3650 02043 1	IU Cas	8451 00553 1	AO Gru	7537 00083 1	TZ Phe	0306 00647 1	BC Vir
4015 00150 1	NO Cas	2597 00581 1	CW Her	0025 00423 1	SY Psc	9198 01105 1	RV Vol
8642 01380 1	BI Cen	3063 01333 1	GY Her	6007 02820 1	AK Pup	9203 01588 1	SV Vol
7749 01536 1	KS Cen	2608 01343 1	IP Her	6542 01690 1	BQ Pup	1646 00197 1	FH Vul
7260 00309 1	V480 Cen	8062 00084 1	UU Hor	8866 01496 1	X Ret	1659 00679 1	FK Vul

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