POSSIBLE CANDIDATES FOR MULTIPLE OCCURRENCE OF VARIABLE STARS IN THE VSX CATALOGUE

Liška, J.[1,2]; Skarka, M.[1,2]; Auer, R. F.[2,3]; Prudil, Z.[1]; and Juráňová, A.[1]

1) Department of Theoretical Physics and Astrophysics, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic; jiriliska@post.cz

2) Variable Star and Exoplanet Section of the Czech Astronomical Society, Vsetínská 941/78, 757 01 Valašské Meziříčí, Czech Republic

3) South-Moravian-Observatory, 664 71 Chudčice 273, Czech Republic

Abstract: A paper about variable stars with possible multiple occurrence in the VSX catalogue is presented. Our main criteria for identification of such duplicities were the angular distance among stars (below 1 arcmin) and close periods of objects. In our approach, we also considered double or half values of periods to reveal possible misclassification among stars with similar light curve shapes. The probability of false identification is expressed by the parameter R giving the relative difference between periods. We found 1487 pairs of stars in angular distance lower than $1\,\mathrm{arcmin}$ with period difference R lower than $0.1\,\%$, which are high-probable candidates on duplicates. From this sample, 354 pairs have exactly the same periods ($R = 0.0\,\%$) and should be considered as definite duplicates. The main contribution of certain duplicates comes from the Catalina Sky Survey (73 pairs have two names with CSS acronym) and from the BEST projects (71 pairs). Distribution of identified duplicates on the sky is not homogeneous but contains surprising depression in Galactic plane.

We present a by-product of a new project SERMON (*SEarch for Rr lyraes with MOdulatioN*) which focuses on searching for modulation in RR Lyrae stars[1]. During preprocessing of the data for chosen RR Lyrae stars we noticed that there are several suspicious objects with very similar position and period among our targets. This finding initiated an analysis of the entire International Variable Star Index (VSX, version from February 9, 2015, Watson, 2006)[2] containing 325061 records (including suspected and non-variable objects).

Since our initial finding suggested that the misclassification comes mainly from the large sky surveys like ASAS[3] (e.g. Pojmanski, 2002), NSVS[4] (Woźniak et al., 2004) or Catalina Surveys[5] (CSS or CRTS, Drake et al., 2009) we assume that the problem could mainly be caused by their typically small angular resolution (several arcsec/pixel) and therefore such troubles are expected to appear preferably in crowded stellar fields (Milky Way, Galactic bulge, stellar clusters, etc.) where the cross-identification can be difficult. Additional biases could be caused by bright stars and atmospheric conditions. Bad seeing will definitely influence the angular resolution, and because large sky surveys are unable to avoid overexposure, the light of very bright stars can influence photometry of nearby

---

[1] Details of the project and the main results will be published in near future (Skarka et al., 2015, in prep.).
[2] http://www.aavso.org/vsx/index.php
[3] http://www.astrouw.edu.pl/asas/
[4] http://skydot.lanl.gov/nsvs/nsvs.php
[5] http://nesssi.cacr.caltech.edu/DataRelease/

objects as well. Instrumental artefacts such as diffraction patterns or bad pixels are additional effects which could bring problems.

Thus we decided to identify stars which are closer than 1 arcmin on the plane of the sky and check whether they have close periods and eventually similar variable types. We did not perform detail astrometry or visual inspection of particular cases, therefore the only criteria considered in our analysis were the formerly noted.

Angular distance r in arcsec between two objects was determined from their right ascensions α_1, α_2 and declinations δ_1, δ_2 given in VSX in degrees by equation

$$r = 3600 \sqrt{(\alpha_1 - \alpha_2)^2 \cos^2\left(\frac{\delta_1 + \delta_2}{2}\right) + (\delta_1 - \delta_2)^2}. \tag{1}$$

For a comparison whether two variables are in fact one single star, or a star misclassified as a nearby variable, we introduce parameter R that represents relative difference between their periods P_1 and P_2 as

$$R = \frac{|P_1 - P_2|}{\left(\dfrac{P_1 + P_2}{2}\right)} \times 100\,\%. \tag{2}$$

The period-similarity criterion is the only usable since different surveys use different devices and filters and also stars itself may undergo significant brightness changes – e.g. recurrent novae. Thus any information about brightness could be misleading. The VSX catalogue contains 264542 stars with known period $(81.4\,\%)$[6]. Unfortunately we cannot provide any closer information about non-periodic variables which can cause significant bias between our results and real fraction of duplicates.

If we apply R parameter, the number of stars which have one or more stars in angular distance lower than 1 arcmin (91315 objects) significantly reduces. For example, number of pairs from this set with $R < 5\,\%$, and thus potential candidates, is 5549. However, estimation of appropriate R is not straightforward. Many variable stars located in small area in dense stellar fields (Galactic bulge) can have similar periods, but are clearly different variables. In addition, due to similarity of light curves for some variable types (e.g. RRc and EW) when using poor quality data, these objects can be easily misclassified. Therefore we also checked the possibility that one object has double/half period of the other star[7].

We consider that stars with $R < 0.1\,\%$ are almost certainly duplicates since this ratio translates to a difference between periods of $0.0006\,\mathrm{d}$ ($\sim 1\,\mathrm{minute}$) in stars with periods about $0.6\,\mathrm{d}$ and in period-difference of $0.7\,\mathrm{d}$ in stars with period about 700-day. 1487 pairs comply this condition (Tab. 1, the whole table is only available on-line as a supporting material). Inside this group we found 354 pairs of stars with $R = 0.0\,\%$, thus these stars are definitely duplicates. The rest of stars should be considered as possible duplicates with high probability. We point out that there are also stars included several times (pairs with different objects), because they create multiple-occurrence objects.

This is the case of CI CrB which was discovered by ROTSE-1 (Akerlof et al., 2000) as a δ Sct variable with a period of $0.17503799\,\mathrm{d}$. The Simbad database known only its name

---

[6]97 stars have zero-period and were not analysed.

[7]Number of pairs from this set including possibility of double/half value of period with $R < 5\,\%$ is 9151.

Table 1: A list of stars with probable double occurrence in the VSX catalogue. Parameter R is relative difference of periods, r is mutual angular distance between both positions, α_1, δ_1, α_2, δ_2 are equatorial coordinates (J2000.0) for both objects, P_1 and P_2 are their periods and VAR_1 and VAR_2 are variability types of candidates.

Name 1	Name 2	R [%]	r [arcsec]	α_1 [deg]	δ_1 [deg]	α_2 [deg]	δ_2 [deg]	P_1 [d]	P_2 [d]	VAR_1	VAR_2
GM And	V0467 And	0.005872	38.1410	0.01521	35.36286	0.02721	35.36692	0.7067585	0.3534	RRAB	EW
CSS_J001145.6+181545	CSS_J001145.7+181545	0.001344	1.4644	2.94029	18.26264	2.94071	18.26256	0.297666	0.297662	EW	EW
CSS_J001228.5+274432	CSS_J001228.7+274431	0.000000	2.5535	3.11904	27.74231	3.11979	27.74206	0.23091	0.23091	EW	EW
ASAS J001231-1402.1	CSS_J001231.6-140208	0.005822	9.3048	3.12917	-14.03500	3.13171	-14.03578	0.326337	0.326318	RRC	RRC
CSS_J001610.2+273430	NSVS 6296844	0.007069	11.1860	4.04283	27.57525	4.04480	27.57268	0.325347	0.32537	EW	EW
CSS_J001701.6+165938	ASAS J001702+1659.6	0.001061	5.9996	4.25679	16.99411	4.25833	16.99333	0.376966	0.376962	EW	ESD—EC

$$\vdots$$

ROTSE1 J160820.64+281244.1. Later this star was reclassified as EW type by Jin et al. (2004). Nevertheless, CSS survey (Drake et al., 2014) found other 3 variables of EW types with almost identical periods in its close vicinity (Tab. 2). The position of CI CrB corresponds to one star in the field, three objects with CSS names are concentrated in position of another star in the field and object ROTSE1 J160820.64+281244.1[8] is located between CI CrB and CSS objects in a place without any star (Fig. 1).

Table 2: Nearby objects of CI CrB. The columns are identical as in Tab. 1 (R and r parameters are relative to CI CrB) complemented with brightness of stars in column Mag. range.

Name	R [%]	r [arcsec]	α [deg]	δ [deg]	P [d]	VAR	Mag. range
CI CrB	0.000	0.00	242.08654	+28.20825	0.350076	EW:	12.66 (0.178) R1
CSS_J160820.7+281300	0.011	30.6	242.08658	+28.21669	0.350038	EW	13.10 (0.22) CV
CSS_J160820.5+281301	0.013	31.8	242.08550	+28.21706	0.35003	EW	13.12 (0.19) CV
CSS_J160820.5+281303	0.013	33.6	242.08567	+28.21753	0.35003	EW	13.16 (0.25) CV

The sky position of positive identifications with $R < 0.1\,\%$ and $R = 0.0\,\%$ are shown in Fig. 2. As can be seen, the distribution is more or less random and proposed duplicates do not follow the Milky Way as was expected. However, the most of duplicates are located in the Galactic bulge. This should not be surprising since this region contains a huge number of very close stars and is intensively observed by MACHO and OGLE surveys (e.g. Bennett et al., 1991; Udalski et al., 1992).

A closer investigation of Fig. 2 and 3, which shows distribution in galactic coordinates, reveals a lack of potential duplicates along Milky Way. This is very surprising because it suggests that all-sky surveys identify variables in crowded fields with higher efficiency. We do not have any explanation for this finding because VSX contains variables in this area[9] which is seen in Fig. 3 and 4. Several sky-surveys such as ASAS, NSV and NSVS cover this area, another projects (e.g. CSS) avoid the Galactic plane (see Appendix A).

---

[8]Simbad coordinates for ROTSE1 J160820.64+281244.1 are $\alpha = 16^{\mathrm{h}}08^{\mathrm{m}}20.643^{\mathrm{s}}$, $\delta = +28°12'44.12''$ (J2000.0).
[9]222824 stars from VSX catalogue (68.55 %) are in area within galactic latitudes $-20°$ and $+20°$.

Figure 1: Position of CI CrB, ROTSE1 J160820.64+281244.1, and 3 almost identical objects with CSS names adopted from AladinLite view.

Except for the Milky Way there is lack of duplicates around Celestial and Galactic poles. We assume that this fact corresponds with decreasing number of stars towards the poles.

Our analysis also showed that more than half of the pairs with $R = 0.0\,\%$ were identified by the same project (the same acronym in designations). The worst results were found for Catalina Sky Survey with 73 pairs which have both names with CSS acronyms and BEST projects (e.g., Kabath et al., 2009a,b) with 71 pairs (numbers for other projects are in Tab. 3). Special case above all is EROS2 project (Derue et al., 2002), in which all 51 pairs with EROS2 acronym have the same period $P > 60\,\mathrm{d}$. This $60\,\mathrm{d}$ corresponds to the length of timebase and is defined as a lower limit for periods.

Table 3: Number of pairs with $R = 0.0\,\%$ (almost certain duplicities) with both names from the same project.

Project	ASAS	BEST	BOKS	CSS	EROS2	HAT	MACHO	NSVS	OGLE
Number	18	71	20	73	(51)	23	2	4	18

Although the majority of stars in our sample should reflect the real number of duplicates, we cannot exclude the possibility that some of given objects are real, independent variables. In addition, several objects are known to create a wide binary pairs with period in ratio of small integer numbers (e.g. BV and BW Dra with period ratio about 6:5, e.g. Batten & Hardie, 1965). Unresolved quadruple systems like CzeV343 (double eclipsing binary with period ratio of 3:2, Cagaš & Pejcha, 2012) could also bring some additional bias in our results when the ratio is 1:1 or 1:2.
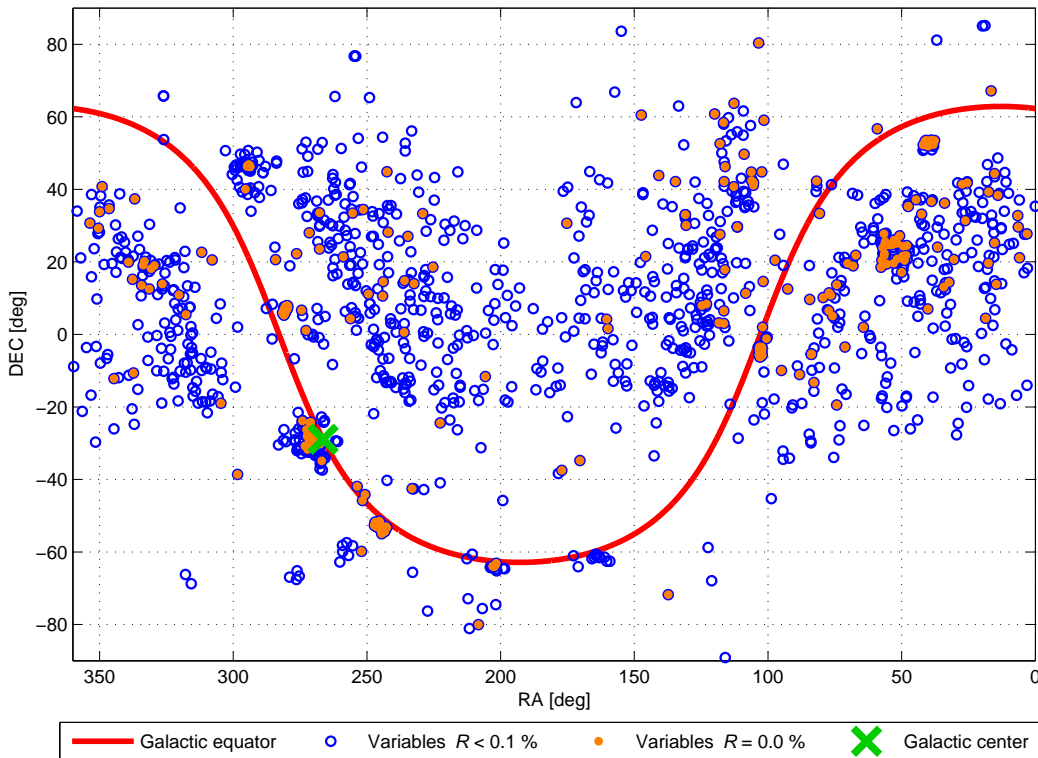
Figure 2: A distribution of possible misclassified variables with mutual distance $r < 1\,\text{arcmin}$ and period differences $R < 0.1\,\%$ and $R = 0.0\,\%$ in equatorial coordinates. Galactic equator is shown by the red line, the green cross shows the position of the Galactic center. Note the condensation around the Galactic center with stars located in the Galactic bulge.

An interesting situation brings the first pair of stars in Tab. 1. GM And is an RRab star with a pulsation period of 0.7067585 d and V0467 And is a binary system of EW type with an eclipsing period of 0.3534 d. Their angular distance is only about 38 arcsec. When we used double value of period for V0467 And, their relative difference between periods is $R \sim 0.0059\,\%$ and thus well bellow our criterion $R < 0.1\,\%$. The both variables have well-known types and periods – GM And (Schmidt & Reiswig, 1993), V0467 And (Maintz, 2008).

V2660 Oph (EA, $P_{\text{eclipse}} = 1.2061988\,\text{d}$) Haussler et al. (2005) and EP Ser (RRab, $P_{\text{puls}} = 0.6032100\,\text{d}$) Haussler et al. (2006), with $r = 58.46\,\text{arcsec}$ and $R = 0.018\,\%$, are another example of close stars which are definitely different objects with close periods. The probability of two close stars having the same period is low but non-zero (even in sparse fields).

In addition, we found three Kepler objects which should be excluded from the main VSX catalogue (Tab. 4). Coughlin et al. (2014) already realized that KID 10342065, KID 10342041 and KIC 10407221 are false positives identified as EA binaries, which is caused by very bright EA star V2083 Cyg (about 7 mag). Unfortunately, physical parameters of false binary systems KID 10342065 and KID 10342041 have been already determined based on light curve analysis by Slawson et al. (2011). A huge influence of
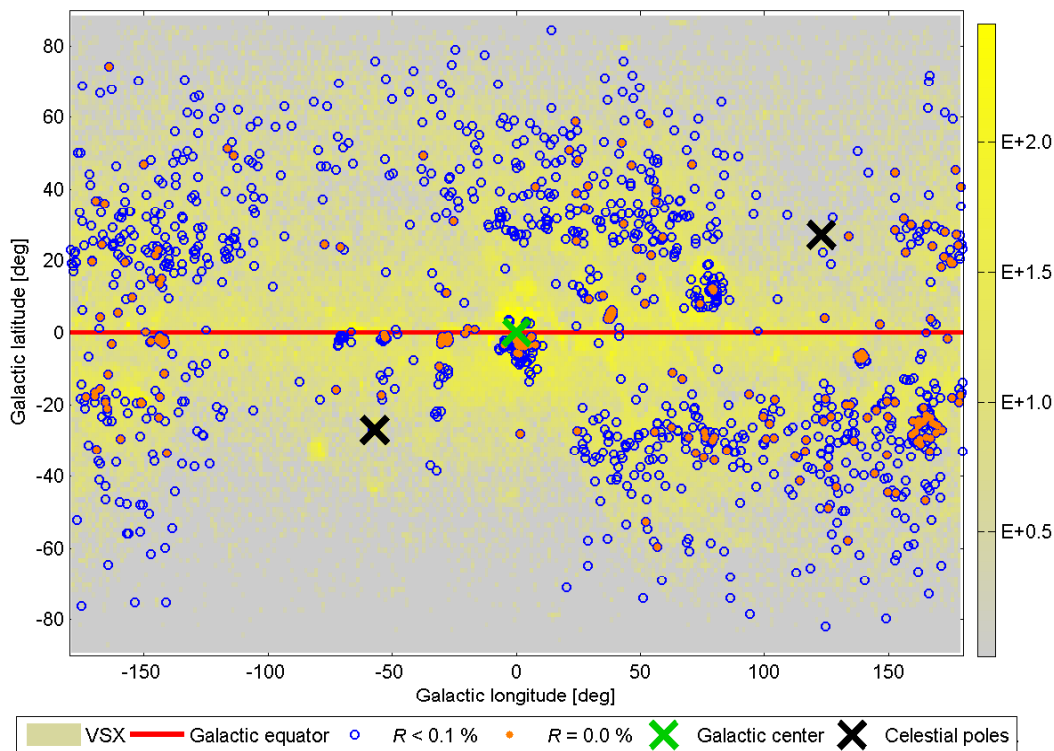
Figure 3: The same distribution as in Fig. 2 in galactic coordinates, together with all variables in VSX (density of stars in logarithmic scale, gray-yellow) and Celestial poles (black crosses). The lack of duplicates along Milky Way and around Celestial and Galactic poles is apparent.

this bright star can be illustrated on KIC 10407221 which is 15.6 mag star in a distance of 4.29 arcmin. The information about brightness of stars could therefore not be used as additional criterion for duplicity.

Table 4: Nearby objects of V2083 Cyg. The columns are identical as in Tab. 2 (R and r parameters are relative to V2083 Cyg).

Name	R	r	α	δ	P	VAR	Mag. range
	[%]	[arcsec]	[deg]	[deg]	[d]		
V2083 Cyg	0.000	0.00	292.81817	+47.48117	1.86742	EA	6.94 – 7.18 Hp
KID 10342065	0.014	59.1	292.84213	+47.48383	0.933837	EA	13.964 (0.002) Kp
KID 10342041	0.007	63.0	292.83300	+47.49553	0.933771	EA	14.658 – ? Kp
KIC 10407221	0.002	257.4	292.84448	+47.55042	0.933728	EA	15.647 – ? Kp

Finally we noticed another bias present in the VSX catalogue. Some long-period variables have unrealistically accurate periods (five and more decimal places)[10]. Furthermore we identified several hundreds stars with periods longer than 300 days (especially from

---

[10]For example, period accuracy of stars with period longer than 100 days would be maximally 2 or 3 decimal places.
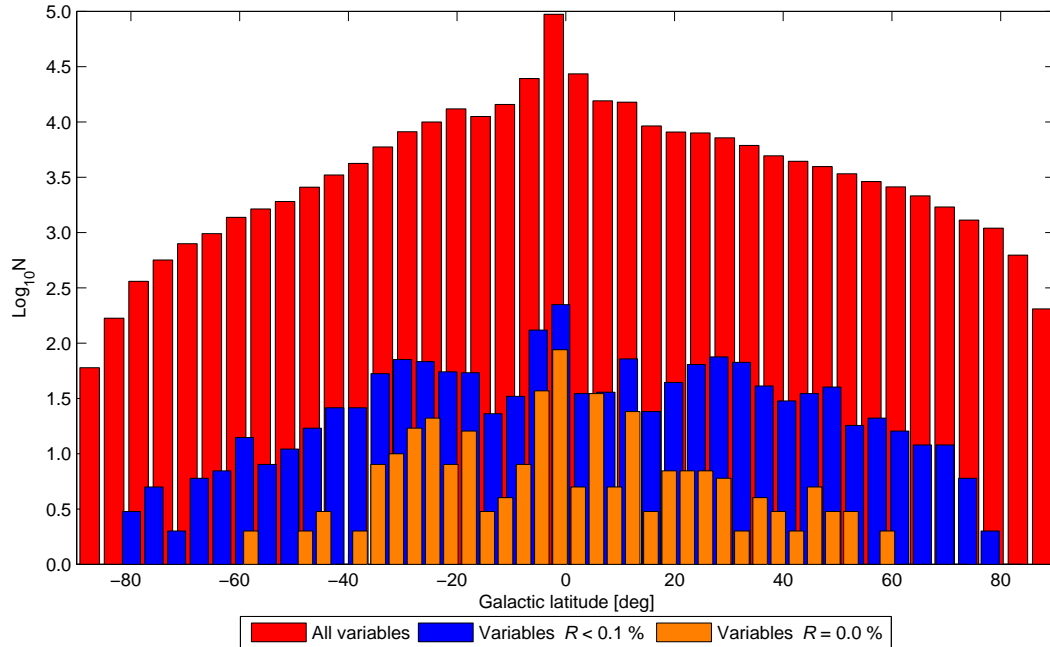
Figure 4: A distribution of variable stars in VSX and our candidates in logarithmic scale as a function of galactic latitude.

ASAS survey) spread out over the whole sky, which have exactly the same period. The extreme examples are 18 ASAS objects with period of 450.819672 d. These stars are probably not duplicates, but are very likely badly processed. The list with such objects is given on-line as a supporting information (file is sorted in VSX format).

Our study should serve as a warning for observers interested in objects we identified because they could have false identifications or be non-variable objects at all.

References

Akerlof, C., Amrose, S., Balsano, R., et al. 2000, *AJ*, **119**, 1901, 2000AJ....119.1901A

Batten, A. H., & Hardie, R. H. 1965, *AJ*, **70**, 666, 1965AJ.....70..666B

Bennett, D. P., Alcock, C., Axelrod, T., et al. 1991, *Bulletin of the American Astronomical Society*, **23**, 1331, 1991BAAS...23Q1331B

Cagaš, P., & Pejcha, O. 2012, *A&A*, **544**, LL3, 2012A&A...544L...3C

Coughlin, J. L., Thompson, S. E., Bryson, S. T., et al. 2014, *AJ*, **147**, 119, 2014AJ....147..119C

Derue, F., Marquette, J.-B., Lupone, S., et al. 2002, *A&A*, **389**, 149, 2002A&A...389..149D

Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009, *ApJ*, **696**, 870, 2009ApJ...696..870D

Drake, A. J., Graham, M. J., Djorgovski, S. G., et al. 2014, *ApJS*, **213**, 9, 2014ApJS..213....9D

Haussler, K., Berthold, T., & Kroll, P. 2005, *Information Bulletin on Variable Stars*, **5637**, 1, 2005IBVS.5637....1H

Haussler, K., Berthold, T., & Kroll, P. 2006, *Information Bulletin on Variable Stars*, **5732**, 1, 2006IBVS.5732....1H

Jin, H., Kim, S.-L., Lee, C.-U., Lee, D.-J., & Kim, K.-S. 2004, *AJ*, **128**, 1847, 2004AJ....128.1847J

Kabath, P., Fruth, T., Rauer, H., et al. 2009a, *AJ*, **137**, 3911, 2009AJ....137.3911K

Kabath, P., Erikson, A., Rauer, H., et al. 2009b, *A&A*, **506**, 569, 2009A&A...506..569K

Maintz, G. 2008, *BAV Rundbrief - Mitteilungsblatt der Berliner Arbeits-gemeinschaft fuer Veraenderliche Sterne*, **57**, 150, 2008BAVSR..57..150M

Pojmanski, G. 2002, *Acta Astronomica*, **52**, 397, 2002AcA....52..397P

Skarka, M. et al. 2015, in prep.

Slawson, R. W., Prša, A., Welsh, W. F., et al. 2011, *AJ*, **142**, 160, 2011AJ....142..160S

Schmidt, E. G., & Reiswig, D. E. 1993, *AJ*, **106**, 2429, 1993AJ....106.2429S

Udalski, A., Szymanski, M., Kaluzny, J., Kubiak, M., & Mateo, M. 1992, *Acta Astronomica*, **42**, 253, 1992AcA....42..253U

Watson, C. L. 2006, *Society for Astronomical Sciences Annual Symposium*, **25**, 47, 2006SASS...25...47W

Woźniak, P. R., Vestrand, W. T., Akerlof, C. W., et al. 2004, *AJ*, **127**, 2436, 2004AJ....127.2436W
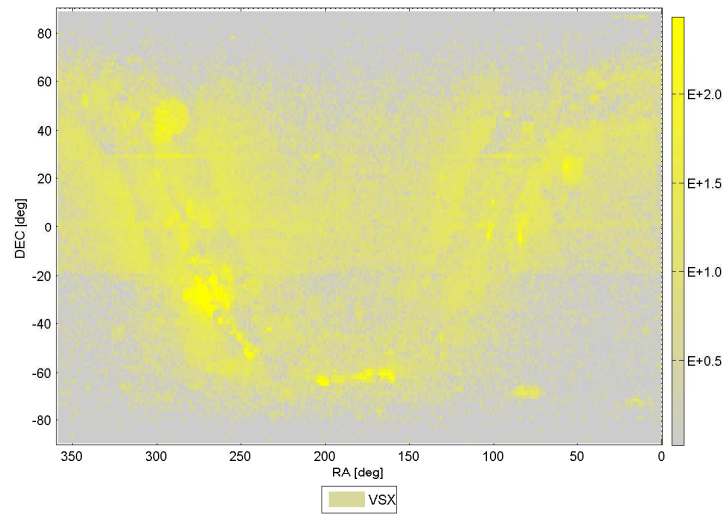
Appendix A

Figure 5: The distribution of 325061 variable stars from VSX in equatorial coordinates.
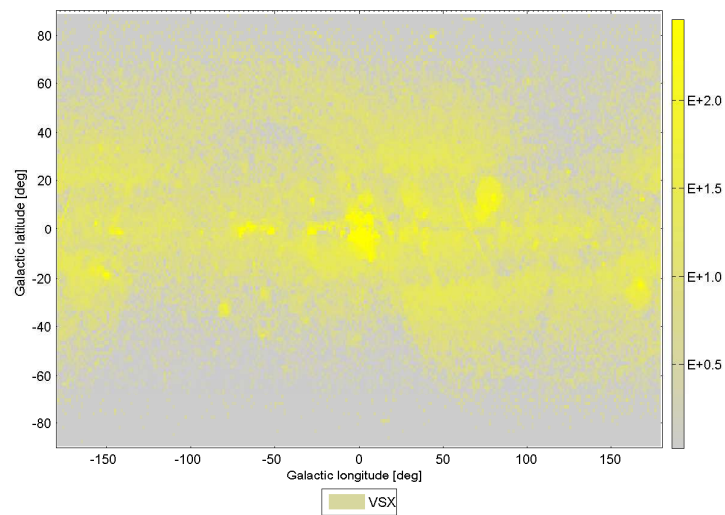

Figure 6: The distribution of 325061 variable stars from VSX in galactic coordinates.
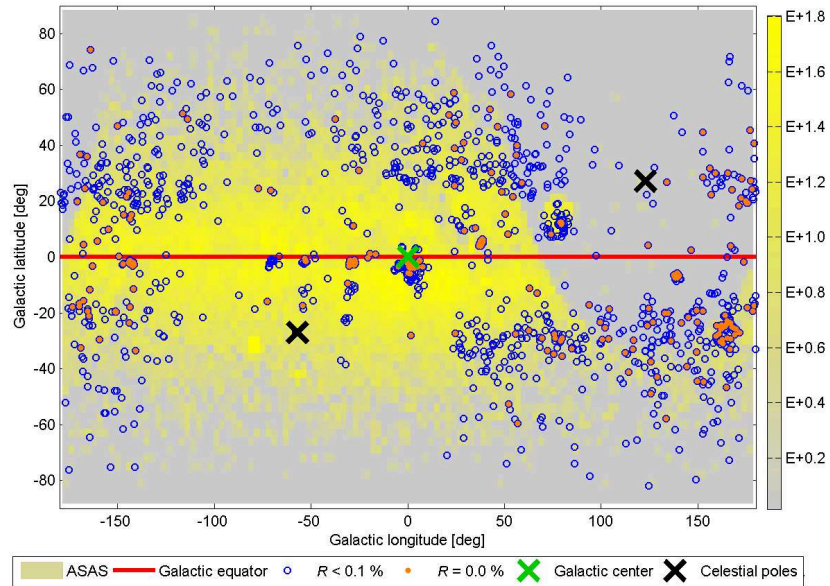
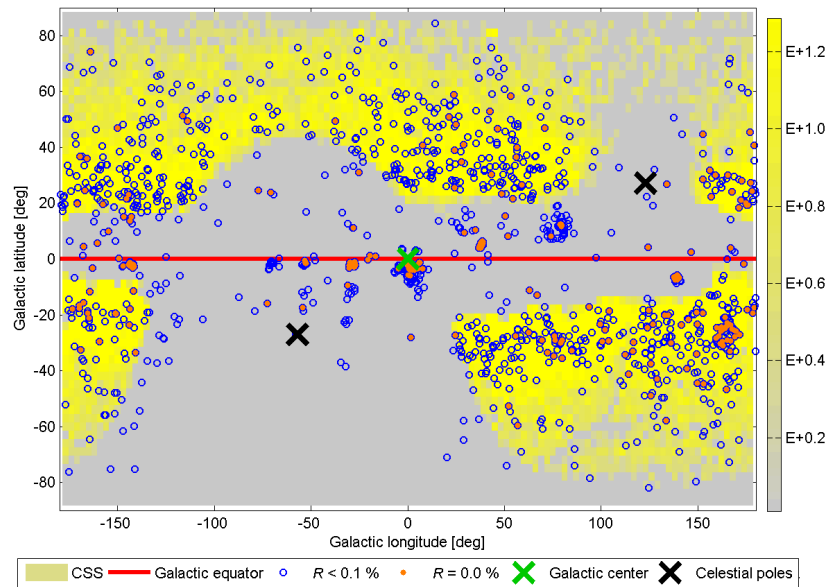Figure 7: The distribution of 44846 variable stars with ASAS names (gray-yellow) in galactic coordinates.

Figure 8: The distribution of 49834 variable stars with CSS names (gray-yellow) in galactic coordinates.
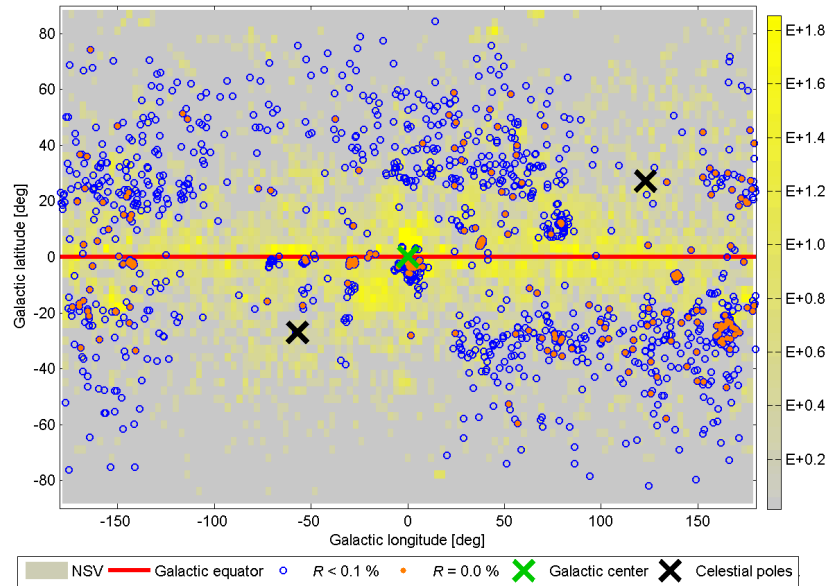
Figure 9: The distribution of 22177 variable stars with NSV names (gray-yellow) in galactic coordinates.
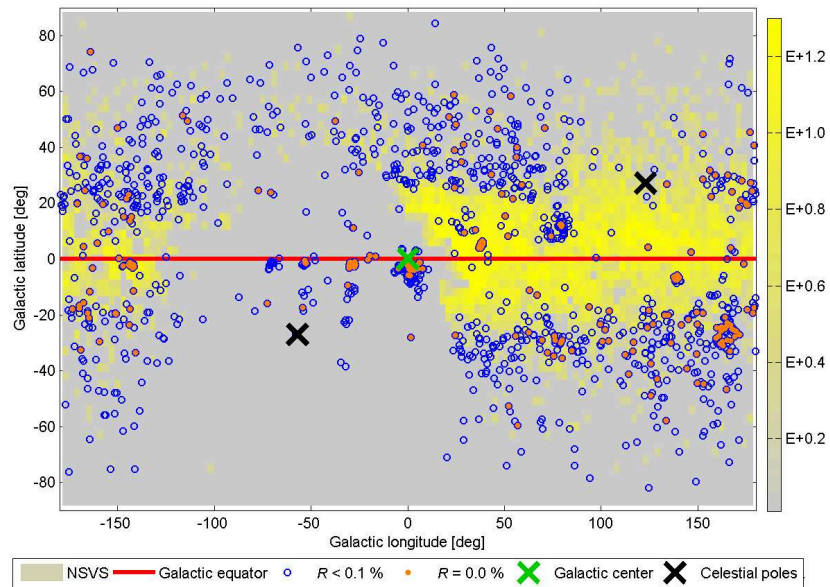

Figure 10: The distribution of 13058 variable stars with NSVS names (gray-yellow) in galactic coordinates.