The catalog of short periods stars from the ”Pi of the Sky” data

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Abstract

Based on the data from the ”Pi of the Sky” project we made a catalog of the variable stars with periods from 0.1 to 10 days. We used data collected during a period of two years (2004 and 2005) and classified 725 variable stars. Most of the stars in our catalog are eclipsing binaries - 464 (about 64%), while the number of pulsating stars is 125 (about 17%). Our classification is based on the shape of the light curve, as in the GCVS catalog. However, some stars in our catalog were classified as of different type than in the GCVS catalog. We have found periods for 15 stars present in the GCVS catalog with previously unknown period.

Key words: Stars: variables: catalog

1 Introduction

The ”Pi of the Sky” (Burd et al. 2005 [2], and the project’s web page [5]) was designed and built by a team from the Andrzej Sołtan Institute for Nuclear Study, Faculty of Physics University of Warsaw, Warsaw University of Technology and Center for Theoretical Physics of the Polish Academy of Science. This project applies small telescopes to observe bright objects according to the idea proposed by prof. Bohdan Paczyński (Paczyński 1997 [8]). In 2004 thanks to Grzegorz Pojmański from Warsaw University Observatory, the ”Pi of the Sky” project was installed in ASAS (Pojmański G., 1997 [9]) dome in Las Campanas Observatory (operated by the Carnegie Institution of Washington).

In this work we report on observations from the first phase of the project dating from July 2004 to December 2005. At this time the telescope was equipped with 2048×2062 CCD cameras with $15 \times 15 \mu m$ pixels and 12 e^- readout noise using Carl-Zeiss telephoto lenses with $d = f/1.4$. The robotic telescope consists of two cameras installed on one mount. Both cameras observe the same $33^\circ \times 33^\circ$ field. The telescope located at Las Campanas Observatory could observe stars with RA = $< 0 ; 24 >$ hr and Dec = $<$ -89.8°; +36° $>$. We do not use any filter except for IR-cut one in order to maximize the limiting magnitude.

The main goal of the "Pi of the Sky" is searching for the gamma ray burst optical afterglows so whenever it is possible, cameras track the Swift or INTEGRAL field of view. In the remaining time the telescope observes interesting objects from a specially prepared list, so strong observational selection effects can be present in the data.

2 Data Reduction

The data reduction was made automatically using software and scripts adapted from the ASAS project or created specially for the "Pi of the Sky". Data were divided in two streams, the first obtained directly from 10 seconds exposures and the second from 200 s exposures obtained by co-adding of 20 images. Due to the readout time the time resolution is 12 s and 240 s respectively. During each night a large amount of data is produced (about 3GB/hr), so only the results are saved in our database – raw images are deleted after one week. The photometry is made with different apertures – a small one for faint stars and a large one for bright objects. System design and observational strategy determine limiting magnitude to about $10-11$ mag for 10 sec exposure and $\sim 11-12$ mag for 200 s (Burd et al. 2005 [2]).

As the "Pi of the Sky" does not use any filter, except for the IR-cut one, transition from the instrumental magnitude to the V filter magnitude is a source of a systematic error. Unfortunately, value of this error is different for different stars. The formal photometry error described as rms is equal to ~ 0.07 mag, but dispersion of the observational points in the light curve is about 0.1 mag for stars fainter than 9 mag. A large correction is needed for different positions of stars on the CCD due to strong vinieting and optical distorsions of lenses. To avoid this problem one could use data taken from one field only, but then the number of data points drops dramatically. A visual inspection was helpful to find compromise between the number of points and measurement quality.

The star identification in the "Pi of the Sky" database is based on comparison with stars from the Tycho-2 catalog (ESA 1997 [3], Høg 1997 [4]). Matching is based mainly on coordinates. Only a crude check of magnitude is performed because

of the filter correction problem mentioned above. The identification procedure assumes that identification is positive if an investigated star is closer than 2 acrmin to a star in the Tycho-2 catalog. An estimated error of astrometry is about 0.5 acrmin (Biskup 2007 [1]).

3 Searching for variability

We checked our data to find all variable stars and determine their variability periods. All measurements for 925 201 stars were analyzed. We used the AoV algorithm (Schwarzenberg-Czerny 1989 [11]) to determine periods, and rejected stars with the statistic Θ larger than 50.0. We checked periods in the range from 0.1 to 10 days for stars with a number of observational points larger than 200. Next, some stars were rejected during the visual inspection, so only 725 stars were classified as variable stars. The details of this procedure are described in Biskup (2007) [1]. In the next step we determined variability type of each star.

Stars were divided in two groups (Biskup 2007 [1]) - stars existing in the ASAS catalog (Pojmański 1997 [9]) and these existing only in the GCVS catalog (Kholopov et al. 1985 [6], Kholopov et al. 1992 [7]). The automatic procedure of a period determination returned half period instead of the full one for a significant number of stars (about 26%). For this reason each period was checked visually and corrected if necessary.

Table 1
Stars and periods which were determined for the first time from our data.

ID	RA	Dec	P [d]	Pi class	P_{GC}	GCVS class	other name
000360+1208.8	00:03:60	12:08:46	0.1701	DSCT	no	DSCTC	NN Peg
001231+1433.8	00:12:31	14:33:51	1.8178:	var	no	RS	LN Peg
023602+0625.8	02:36:02	06:25:49	0.2079	DSCT	no	DSCT	DX Cet
052760+1254.8	05:27:60	12:54:45	0.3793:	var	no	EB	V1371 Ori
104508+1620.1	10:45:08	16:20:07	0. 2043	EW	no	EW	EX Leo
114157-2423.2	11:41:57	-24:23:10	0.1363	DSCT	no	DSCTC	VY Crt
120920-2759.3	12:09:20	-27:59:18	0.2923	EB	no	EB	QY Hya
124420-0840.3	12:44:20	-08:40:16	0.1167	EA	no	EA/D	HW Vir
132654-0555.7	13:26:54	-05:55:40	0.4923	EB:	no	EB	LU Vir
141420-1521.2	14:14:20	-15:21:11	0.2984	DSCT/BY	no	BY	MV Vir
141742-2149.6	14:17:42	-21:49:37	0.1539	DSCT:	no	DSCTC	MX Vir
143205-2742.7	14:32:05	-27:42:40	0.9123	EB	no	EB	V0356 Hya
150401-2803.7	15:04:01	-28:03:43	0.1466	DSCT	no	DSCT	HY Lib
173737-4048.8	17:37:37	-40:48:48	3.3864	DCEP	no	DCEPS	V0950 Sco
234535+2528.5	23:45:35	25:28:31	0.5790	EW	no	EW	V0357 Peg

In Table 1 we present a list of 15 stars with previously unknown periods, which were determined from our data. These stars are present in the GCVS catalog, but

without period determinations.

The classification is based on the shape of the light curve analogically to the procedure in the GCVS catalog and in some cases based on the additional information about a spectral type. Our strategy is different from that in the ASAS catalog, where the classification is based on a decomposition of the light curve (Pojmański 2002 [10]). Variability types were determined simply by a visual inspection of light curves.

Symbols denoting variability types used in our classification are summarized in Table 2. In addition, we have introduced symbols describing a situation when the classification is ambiguous: E - eclipsing binary, var - variable star, and ":" uncertain.

Table 2
Different types of variability described in our catalog of variable stars.

Symbol	Name of prototype	Period (days)	Amplitude (in V filter)
Eclipsing binaries			
EA	Algol	0.2 – 1000	$<$ several
EB	β Lyrae	$>$ 1.0	$<$ 2
EW	W Ursa Maioris	$<$ 1.0	$<$ 0.8
Pulsating stars			
RRAB	RR Lyrae	0.3 – 1.2	0.5 – 2.0
RRC	RR Lyrae	0.2 – 0.5	$<$ 0.8
DCEPS	δ Cephei	$<$ 7.0	$<$ 0.5
BCEP	β Cephei	0.1 – 0.6	0.01 – 0.3
DSCT	δ Scuti	0.01 – 0.2	0.003 – 0.9
CW	W Virginis	0.8 – 35.0	0.3 – 1.2
Other			
ACV	Alpha2 CVn	0.5 – 160.0	0.01 – 0.1
INT/IT	—	1.0 – 10.0	$<$ 1.0

In case of the classification of eclipsing binaries β Lyrae type (EB) and W Ursae Majoris (EW) we used two criteria. First, we assumed that for EW stars the period should be shorter than 1.2 d. Second, the secondary minimum of the light curve should be deeper than 1/3 depth of the primary minimum. If at least one of these conditions had not been fulfilled, such star was denoted as EB/EW.

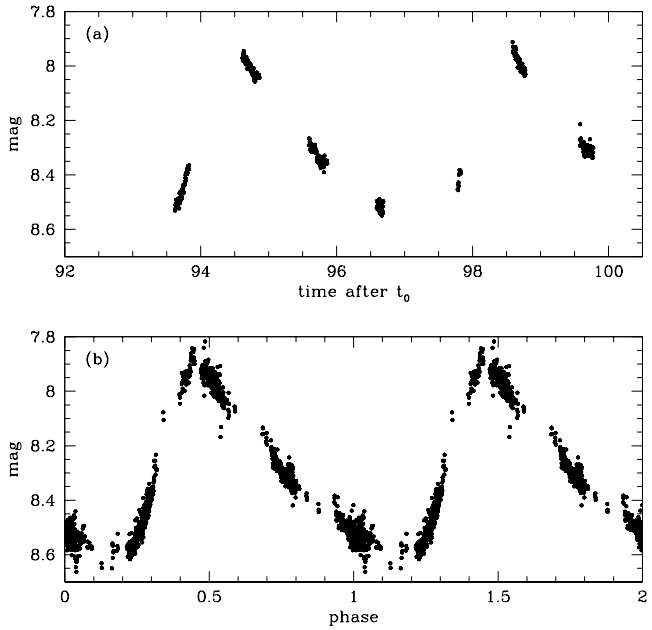

Fig. 1. (a) the light curve of the ST Tau star of DCEP type, with the period P = 4.0259 d; (b) phased light curve

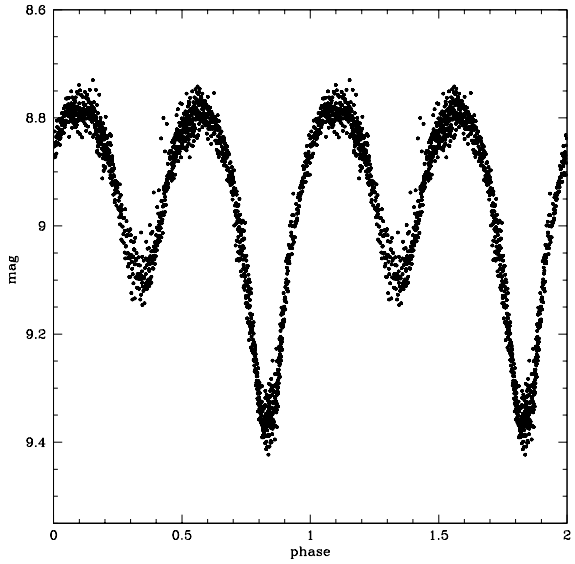

Fig. 2. Phased light curve of the RV Crv star of EW type with the period P = 0.7473 d

4 Conclusions

4.1 Eclipsing binaries

In Table 3 we summarized the number of stars with a different type of variability. The most numerous group of stars is of the EW type. This is in disagreement with

the GCVS catalog, where the number of EW stars is about 4 times smaller than the number of EA stars. On the other hand, the number of EB type stars is almost as large as the number of EW type stars much like in the GCVS catalog. Such effects are artificial, resulting from assumptions made during searching for the variability. We investigated only variable stars with periods in the range from 0.1 d to 10 days, so for that reason there is an excess of stars with short periods in comparison with the GCVS catalog.

Table 3
Number of stars of each type from the project "Pi of the Sky"

Type	Number of stars	Type	Number of stars
EA	43	RR	2
EA:	4	RRAB	36
EB	83	RRC	11
EB:	10	RRC/DSCT	3
EW	163	RR/DCEP	1
EW:	50	DCEP	18
EA/EB	40	DCEPS	4
EB/EW	35	BCEP	1
E	10	DSCT	48
E:	26	BCEP/DSCT	1
EW/RR	1	DSCT/BY	1
EW/RRC	5	CW	5
EW/DSCT	12	ACV	3
INT/IT	1	CW/DCEP	1
EW/DSCT/RRC	1	var	73
var:	33		

Such discrepancy disappears when we comapare our results with the ASAS catalog. Note that Pojmański (1997 [9]) used different classification criteria than in our work, so there is no simple relation between e.g. EW and EC stars, and a comparison of results from these two catalogs is difficult. However, it is possible to make some general conclusions. Table 2 of Pojmański (2002) [10] shows that most of binary stars are contact ones - EC type, where both stars fill their Roche lobe. In our catalog the situation is similar, the most numerous are EW type (W UMa type) binary stars. Less numerous in our catalog are EB and EA types stars and a similar trend appears in the ASAS catalog for ESD and ED stars as well. One should keep in mind differences in classification criteria in the ASAS and Pi catalogs, and strong selection effects in the "Pi of the Sky" data.

4.2 Pulsating stars

Discrepancy between the number of different types of pulsating stars in the "Pi of the Sky" and GCVS catalogs can not be explained by the simple fact that we

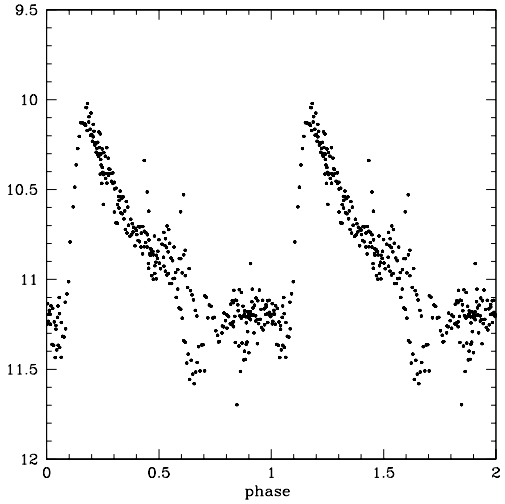

Fig. 3. Phased light curve of the RR Leo, RRAB type star with the period P=0.4520d

investigated only stars with periods shorter than 10 days. All pulsating stars present in our catalog have periods much shorter than 10 days. For example, the ratio of the number of RRAB stars to the number of all stars in our catalog is 0.05, while in the GCVS catalog it is equal to 0.11. Comparing the ratio of numbers of RRAB and DSCT type stars, we obtained the following values: ASAS 1.7 (based on Pojmański 2002 [10]), "Pi of the Sky" about 0.75, and GCVS 39.6. Similar situation occurs for other types of pulsating stars as well. The main difference between the "Pi of the Sky" or ASAS and GCVS catalogs is the magnitude range. In the GCVS catalog there are informations about stars with -1.4 – 20 mag, while the magnitude range for "Pi of the Sky" is 5 – 12 mag and for ASAS 8.5 – 15 mag. We interpreted differences in the number of each type of stars in these 3 catalogs as an effect of a different magnitude range in theses projects and effect of a specific observational strategy in the "Pi of the Sky" project.

5 Summary and future perspective

We presented the catalog of 725 variable stars from the first phase of the "Pi of the Sky" project. The catalog contains stars with periods ranging beetwen 0.1 and 10 days. The types of variability were determined through a visual inspection.
Most of the variable stars in our catalog are eclipsing binaries, W UMa type. Among the pulsating stars most of them are δ Scuti type stars (48), but RRAB stars are only slightly less numerous (36). Both type of stars have rather large variability amplitude, so are easy to detect. We determine accurate periods for 15 stars from the GCVS catalog with periods unknown so far.

The catalog and whole data base of measurements are available at the "Pi of the Sky" website `http://grb.fuw.edu.pl/pi/index.html#star_catalog`

Since the primary goal of the ”Pi of the Sky” is searching for the GRB prompt optical emission, the algorithm has been optimized for the flash recognition. We work on improving the photometry and we plan to develop an automatic procedure for a classification of variable stars. This will be necessary for the final version of the ”Pi of the Sky” project where the amount of data will increase by almost two orders of magnitude.

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