Variable stars classification based on photometric data from the"Pi of the Sky" project

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ABSTRACT

We present the first few steps of creation the second edition of the variable stars catalogue, based on the "Pi of the Sky" data, collected during two years 2006-2007. We have chosen ~ 3000 variable star candidates from about 1.5 million objects.

Keywords: Stars: variables: catalog

1. INTRODUCTION

There is no doubt that all stars shows changes of brightness and colour during its stellar evolution. In spite of that, variable star is only such object, for which we can detect brightness or colour variations on time scales of the mean life of man. Time scale of these variations range from a few minutes to over century, and the variations may be periodic, semi-periodic or irregular. Features like typical time scales, amplitude of the brightness variations, and the shape of the light curve can be obtained from photometric observations, and these parameters let us classify a given star to the proper class.

There are two main families of variable stars: intrinsic variable stars and extrinsic variables. Extrinsic variables vary due to processes external to the star, for example eclipsing binaries or rotational variables. In the case of intrinsic variable stars, parameters like brightness or colour vary because of pulsation, flares or even explosions. Each family mentioned above is divided on several groups, and sometimes subgroups. It is not rare situation that a given group consists a prototype star and only a few members.

Nearly every classification is based on the most characteristic features of the light curves. Unfortunately this gives a non-homogeneous results. As it follows, every classification should take into account also physical properties of the star and other parameters like position of the star on H-R diagram, its metalicity, presence or not characteristic spectral lines etc. of the classified star. Sometimes, diversity of physical phenomena related to a given star could be a problem. For instance, Kurtz & Marang (1995[5]) discovered that the well-studied pre-main sequence Herbig Ae star, HR 5999 (V0856 Sco), showed δ Scuti type pulsations with a period 4.99 hr. So in fact this star is a member of two classes - δ Scuti type stars (DSCT according to GCVS nomenclature) and Orion variables (INA).

Despite problems mentioned above, the light curve, temperature, luminosity and population type are sufficient to form the basis for the classification system for variable stars, as it is used in General Catalogue of Variable Stars (GCVS) (Kholopov, Samus', Frolov et al. 1990[4]).

In GCVS variable stars are divided to 6 main families and each of them to smallest groups.

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1. **Eruptive variables**

   These are stars show brightness variation because of violent processes and flares occurring in their chromospheres and coronae, usually accompanied by shell events or mass outflow in the form of stellar winds of variable intensity and/or by interaction with the surrounding interstellar medium.

2. **Pulsating stars**

   Pulsating stars undergo periodic expansion and contraction of their surface layers called pulsations. These pulsations may be radial, when shape of pulsating star remains spherical, or non-radial, when the star's shape periodically deviates from a sphere, and even neighboring regions of its surface may have opposite pulsation phases.

   - BCEP - β Cephei
   - CW - W Virginis
   - DCEP - δ Cephei
   - DSCT - δ Scuti
   - M - o Ceti (Mira Ceti)
   - RR - RR Lyrae
   - L - slow irregular variables
   - SR - semi-regular variables

3. **Rotating variables**

   These variables have nonuniform surface brightness, caused by the presence of spots or by some thermal chemical inhomogeneities of the atmosphere caused by a magnetic field with axis not parallel to the rotation axis.

   - BY - BY Draconis
   - ELL - rotating ellipsoidal variables (b Per, α Vir)
   - FKCOM - FK Comae Berenices
   - PSR - optically variable pulsars

4. **Cataclysmic variables (explosive and novalike)**

   Cataclysnic variables show outbursts caused by thermonuclear bursts on their surface (novae) or deep in their interiors (supernovae). To this class belong also stars with outbursts caused by rapid energy release in the surrounding space (i.e. UG type) or stars with no explosions because of their spectra or other features. Most of cataclysmic variables are close binary systems which components have strong mutual influence on the evolution of each star. Generally hot, dwarf component is surrounded by an accretion disk made from the matter lost by its cooler and more extended companion.

   - N - Novae sometimes called Classical Novae
   - NL - Novalike variables
   - NR - Recurrent novae
   - SN - Supernovae
   - UG - U Geminorum
   - ZAND - Z Andromedae

5. **Eclipsing binary systems**

   There are three ways of classifying eclipsing binary systems taking into account shape of the light curve, physical characteristics of components (their luminosity classes) and degree of their Roche lobe filling. Below we present classification based on the shape of the light curve, because in the following we present such a classification applied to the "Pi of the Sky" data.

– classification based on the shape of the light curve

  - EA - Algol or β Persei
  - EB - β Lyrae
  - EW - W Ursae Maioris

6. **Intense variable X-ray sources**

   This group is formed by close binary systems which are sources of strong, variable X-ray emission, and that emission dominate over emission in other wavelenghts. The primary component is a hot compact object (white dwarf, neutron star, or a black hole). X-ray photons are produced by matter and photons interacting with the accretion disc or falling onto compact object. These sources show many different behaviours (bursts, spectral variations or even eclipses).

For more details about above classification see Kholopov, Samus', Frolov et al. 1990,[4] Sterken and Jaschek (2005[9]) Table 1 shows few examples of light curves with short descriptions. To illustrate GCVS classification of variable stars presented above we chose few different type variables. All the light curves originate from "Pi of the Sky",[7] except for the light curve of CW type star, which was taken from ASAS (Pojmański 1997[8]).

2. OBSERVATIONS AND DATA REDUCTION

The "Pi of the Sky" telescope consists of two cameras installed on one mount. Each camera is equipped with 2048×2048 CCD sensor and uses Canon telephoto lenses with f = 85cm and d = f/1.2. Both detectors observe the same $20° \times 20°$ 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 data reduction was made automatically using software and scripts adapted from the ASAS project (Pojmański 1997[8]) or created specially for the "Pi of the Sky". Data were divided into two streams: the first containing raw 10 seconds exposures and the second with 200 s exposures obtained by co-adding of 20 images. Due to the readout time the temporal resolution is 12 s and 240 s respectively. During each night a large amount of data is collected (about 3GB/hr), so only the data reduction results can be saved in our database – raw images are deleted after one week. The photometry is made with two 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 exposures and $\sim$ 11 − 12 mag for 200 s.

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 defined as rms is equal to $\sim$ 0.07 mag, but dispersion of the observational points in the light curve iincreases to 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 distortions at the edge of the image. 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 is needed 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,[2] Høg 1997[3]). Identification relies mainly on star coordinates. Only a crude check of magnitude is performed because of the instrumental magnitudes uncertainty 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. TYPE VARIABILITY DETERMINATION AND PREPARATION OF THE CATALOGUE

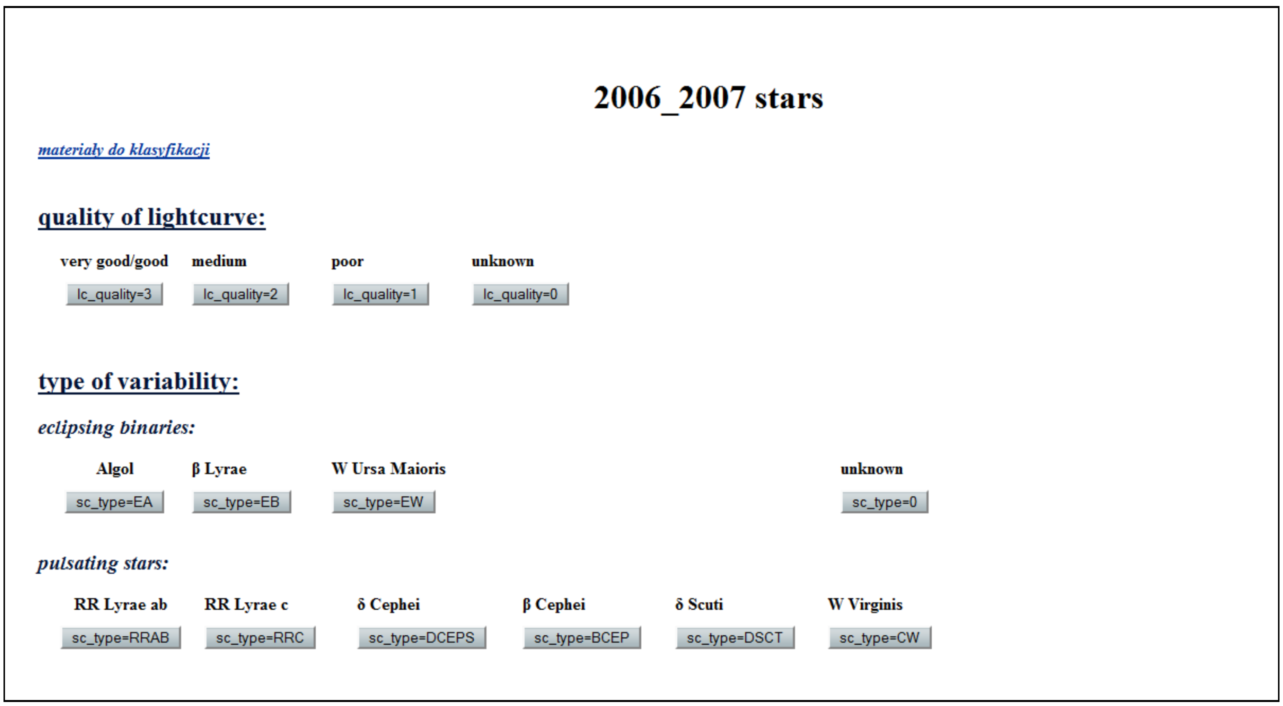
In this paper we report on the preparation to create the second edition of the variable stars catalogue from the "Pi of the Sky" data. We use the same procedure as for the first edition (Majczyna et al. 2008[6]). Below we describe briefly subsequent steps of our procedure.

Data collected during two years (2006 and 2007) were processed to find all variable stars and determine their variability periods. About 1.5 million stars with at least 200 observational points were considered.In addition we applied filter cuts to reject low quality data. We do not analyze stars with close neighbours (within the radius of 15 pixels) because of blending. We also reject stars which lie near the border of the frame, closer than 100 px from the edge. We used the AoV algorithm proposed by Szwarzenberg-Czerny (1989[10]) to determine period, and we rejected stars with the statistic $\Theta > 120$. Only periods in the range from 0.01 to 50 days were considered. Eventually, we selected a group of about 3000 stars which we should classify based on their light curves.

We determined types of variability without any automatic procedures, by visual inspection of each star light curve only. It is very difficult to prepare such an automatic procedure for many reasons. First of all, the quality of the data is not always sufficient, and large point dispersions on the light curve are often observed. Moreover, the measured star brightness is correlated with its position on the CCD chip, and we are unable to fully correct for this effect. Therefore, we often have to limit our analysis to good quality data and it is only possible with visual inspection.

This is a very hard and arduous work to classify few tousends stars so we prepared a web interface to made this work easier and faster. Figure 1 shows main page of this interface.

Figure 1. Main page of the web interface preparing for variable stars classificaton.



Using this interface we can list, for example, stars with light curves of required quality or stars with given type of variability. User can then display the light curve, made his own classification or change the existing one. He can also enter a comment in proper window as shown Figure 2. All informations are saved in the database.

4. CONCLUSIONS AND FUTURE PERSPECTIVE

During a period of two years (2006-2007) we collected a large amount of data, sufficient to prepare a second edition of the “Pi of the Sky” catalogue of variable stars. We finished the first part of work, choosing about 3000 variable star candidates from about 1.5 million objects. We are currently working on visual inspection of the light curves and type of variability determination. We expect the catalogue to be finish in the next months.

Figure 2. A page of the web interface for a given star

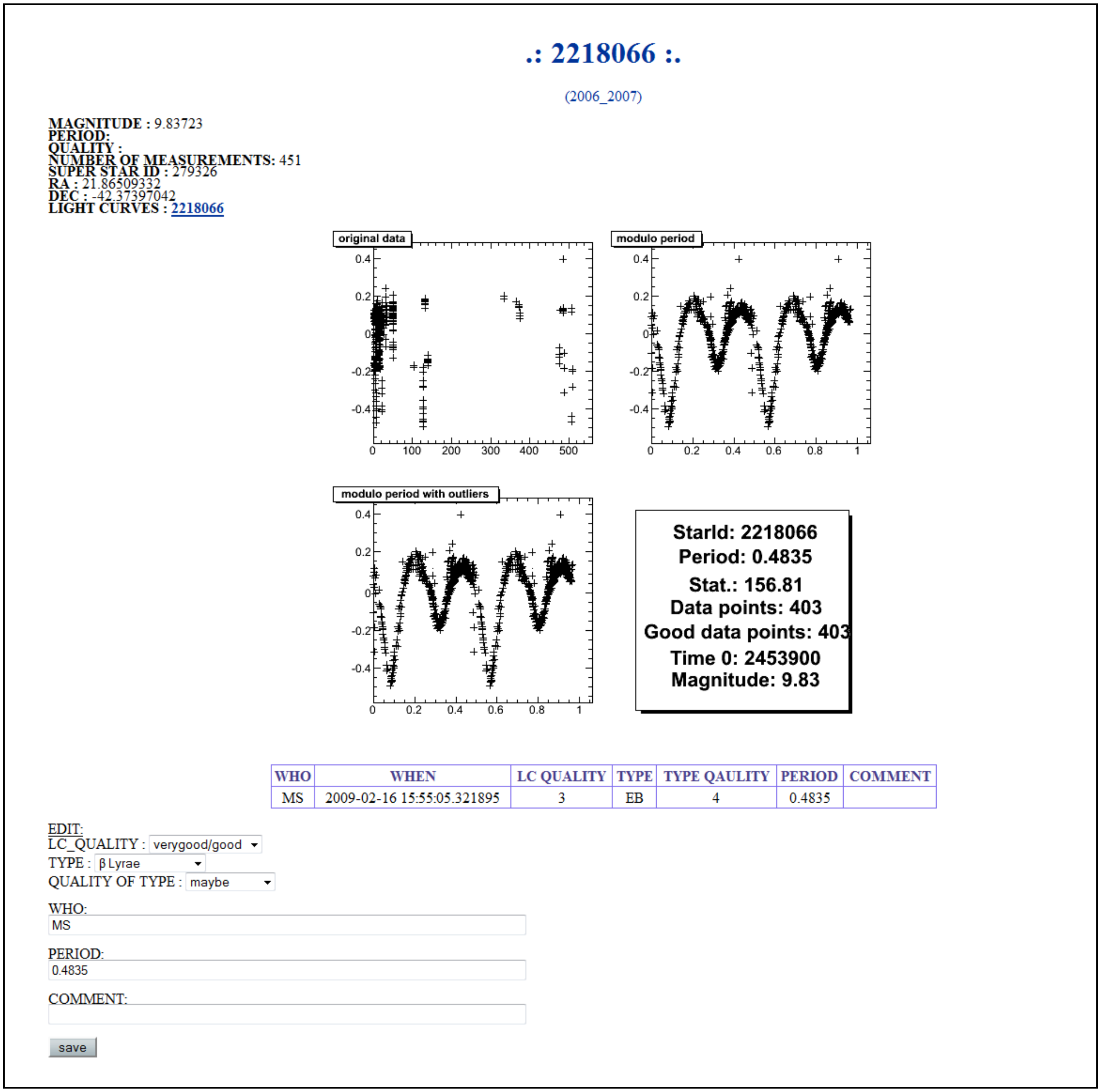


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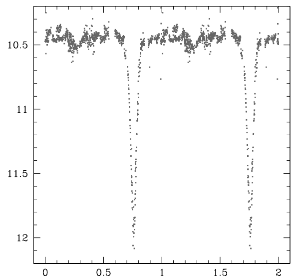
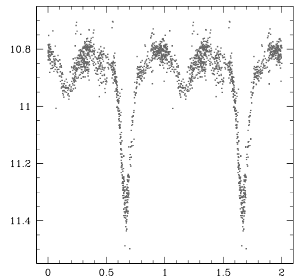
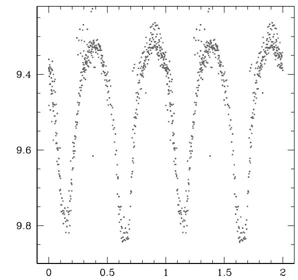
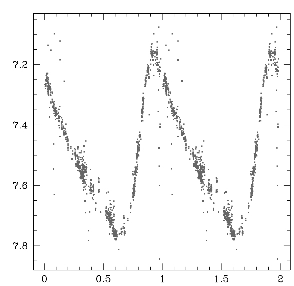
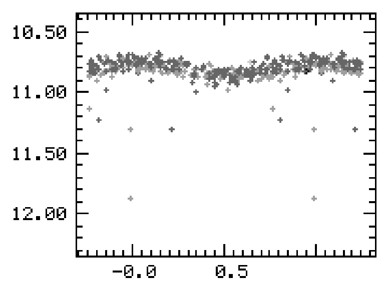
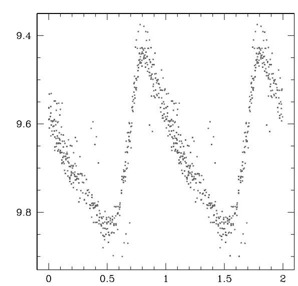
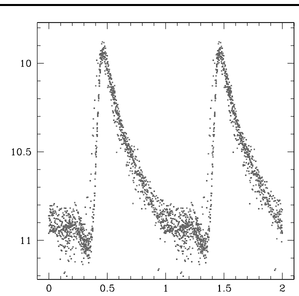
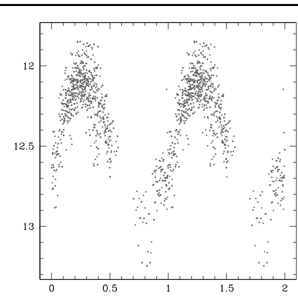
Table 1.

Eclipsing binaries		
β Persei (Algol)	β Lyrae	W Ursae Maioris
EA	EB	EW
		
$0.2 < P \leq 10000$ d A < several mag	P > 1 d $A_V < 2$ mag	P < 1 d $A_V < 0.8$ mag
Pulsating stars		
δ Cephei	W Virginis	δ Scuti
DCEP	CW	DSCT
		
P < 7 d $A_V < 0.5$ mag	$0.8 < P > 35$ d $0.3 < A_V < 1.2$ mag	$0.01 < P < 0.2$ d $0.003 < A_V < 0.8$ mag
Pulsating stars		
RR Lyrae	RR Lyrae	
RRab	RRc	
		
$0.3 < P < 1.2$ $0.5 < A_V < 2$ mag	$0.2 < P > 0.5$ d $A_V < 0.8$ mag	

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