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First Results of the Semi-Automatic Variability Search*

by

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ABSTRACT

A short description of the Semi-Automatic Variability Search is given. Six new red variable stars discovered recently by SAVS are presented: GSC 02907-00779, GSC 02904-00834, GSC 02908-00024, GSC 02976-00401, BD+42° 1814 and HD 76190.

Key words: *Stars: Wolf-Rayet – Stars: atmospheres – stellar winds*

1. The Survey

The Semi-Automatic Variability Search (SAVS) is a photometric CCD sky survey aiming at discovering new variable stars in the northern hemisphere. It is conducted at the Astronomical Observatory of the Nicolaus Copernicus University in Piwnice near Torun, Poland. The survey started in spring of 2002 with a two-month test run during which 16 selected fields were monitored (Maciejewski, 2002). Since July 2002 observations are performed regularly.

So far over 12 000 stars brighter than 13 mag in the *V* band were observed in 25 selected fields covering 150 square degrees. 17 new variable stars were discovered, for some of them (short-period eclipsing binaries) the results have already been published (Maciejewski and Niedzielski 2002, Maciejewski, Karska and Niedzielski 2002, Maciejewski, Karska and Niedzielski 2003, Karska and Maciejewski 2003, Maciejewski, Ligeza and Karska 2003, Maciejewski, Czart, Niedzielski and Karska 2003). In this paper we briefly describe SAVS and present six new red semi-regular and irregular variables recently discovered.

*Based on observations collected at the Piwnice Observatory.

1.1. The Instrument

The SAVS project uses the already existing infrastructure of the Piwnice Observatory. Its hardware consists of a CCD camera, simple optics, camera mount and a control computer.

The SBIG ST-7 commercial CCD camera with Kodak KAF-0400E chip (768×512, 9 μm pixel size) is used as the detector. The camera is cooled thermoelectrically down to 30 degrees below the ambient temperature. In practice it allows to achieve the working temperature of -10°C in summer and -30°C in winter. The camera is connected to the control PC *via* a parallel port and operated with the CCDOPS software of Santa Barbara Instrument Group. The camera is equipped with the SBIG CFW-8 filter wheel containing 5 filters. Currently observations are performed mostly in the near-Johnson *V*-band and sporadically in the *B*-band.

An achromatic telephoto MC APO Telezenitar-M 135/2.8 lens is used as the optical system. It gives a field of view of 3×2 deg with a scale of $13\farcs8$/pixel. The optics is good enough to obtain the sharp stellar images with typical FWHM of 2 pixels.

For positioning the camera on required coordinates and tracking a Meade LX200 telescope is used. The CCD camera is attached at the top of the telescope's tube. A dedicated software was written to control the camera mount and the dome's slit position. The mount communicates with the control PC *via* a serial port. The dome is controlled by a dedicated ISA-bus controller card.

The control computer is located in the control room in the dome building. It is a PC with Pentium 200 MHz CPU, 32 MB RAM, 3 GB hard disk space and an ethernet card. The observations are stored on the local hard disk during a night and then copied *via* LAN to a workstation for further reduction.

1.2. The Software Pipeline

The Semi-Automatic Variability Search Pipeline was developed for the SAVS sky survey purposes. It is an easy-to-use and intuitive software which was created for semi-automatic reduction and analysis of a large amount of CCD frames and detecting new variable stars. The package consists of two main programs: DAPHOT and JAMP.

The DAPHOT code performs the standard reduction process of raw CCD frames by removing instrumental effects such as bias, dark current and flat-field (optional). It also detects stars in each frame in an automatic way, and conducts astrometry for all of them by transforming instrumental coordinates into the equatorial ones. DAPHOT also performs aperture photometry for all detected sources.

The detection of stellar objects is done with the technique described by Pojmański (1997). The astrometric calibration of CCD frames is based on stars brighter than 10 mag, for which positions, precession and proper motions are calculated from TYCHO-2 Catalogue (Høg *et al.* 2000). The typical *rms* error of the transformation is 0.1 pixel, typical astrometric uncertainty is $1''$. Practically this precision makes identification of objects unambiguous. DAPHOT measures magnitudes of stars using differential aperture photometry against selected comparisons. The aperture size is set automatically by the software based on current PSF width of a given stellar profile. The aperture width is equal to 3.5 $\sigma_{\rm PSF}$. The background level is defined as the median of the sky signal within a ring around the stellar center. The inner radius of the ring is set to 6 pixels while the outer to 10 pix. Typical uncertainty of the measurement of brightness represented by the standard deviation depends on the stellar magnitude and ranges between 0.03 mag and 0.2 mag for bright ($V = 8$ mag) and faint ($V = 13$ mag) stars, respectively. The same uncertainty calculated for comparison stars does not exceed 0.03 mag. The estimated V magnitudes for the comparison stars are calculated from TYCHO-2 Catalogue (Høg *et al.* 2000) data as $V = V_T - 0.090(B-V)_T$.

The JAMP is designed for managing and analyzing the collected data. In a fully automatic way it adds data from single frame to databases which are separately created for every observed field. The candidates for variable stars are selected by the analysis of variance (ANOVA) method (Schwarzenberg-Czerny 1996) of all observed objects. All objects with the normalized power exceeding a preselected threshold are assumed to be variable and studied in detail. The threshold level is set as 60%. This application is also used as a previewer of the content of databases.

2. CCD Observations

GSC 02907-00779 is identified in the SIMBAD database as a carbon star (Guglielmo *et al.* 1997) and the infra-red source IRAS 05063+4416 also known as IRC +40116. According to TYCHO-2 Catalogue GSC 02907-00779 is a $V = 10.49$ mag star with $(B-V) = 1.378$ mag. IRAS data indicate 39% likelihood of variability of the source in the far infra-red.

Our photometric measurements show variability of the star in the optical range. GSC 02907-00779 was observed during 29 night between November 6, 2002 and April 24, 2003. In total 210 data points were collected. HD 32948, HD 33878 and HD 33532 were used as comparison stars. The light curve is presented in Fig. 1. The light variations of GSC 02907-00779 reached the amplitude of the $\Delta m_V = 0.5$ mag. During the first 120 days the star slowly increased its brightness. Near HJD 2452701 the sudden brightness increase reaching in the next 9 days a maximum of $m_V = 10.0$ mag was observed. Then the fading phase began. The variability of GSC 02907-00779 is apparently irregular.

The coordinates of GSC 02904-00834 coincide with those of the infra-red source IRAS 05100+4233. According to TYCHO-2 this is a $V = 10.48$ mag and $(B-V) = 1.121$ mag star. IRAS variability likelihood is only 3%, but our photometric data (Fig. 1) clearly show variability of the star. The observations were obtained during 25 nights between December 10, 2002 and April 20, 2003. 158 single measurements were collected with HD 33785, HD 33896, HD 33168, HD 33411

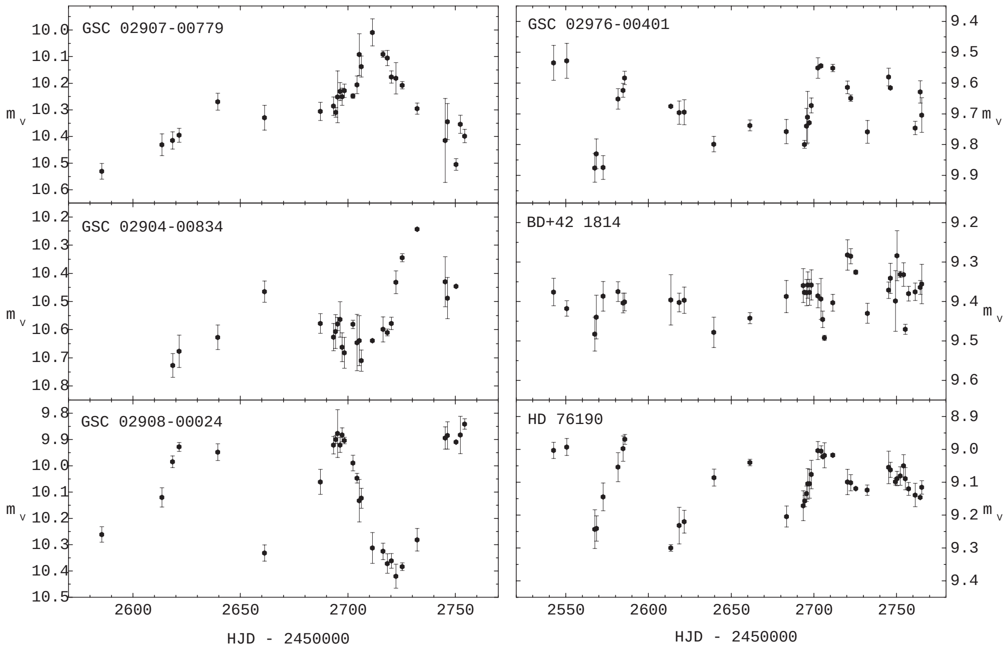

Fig. 1. Light variation of all six new red variables.

and HD 33911 as comparison stars. GSC 02904-00834 varied irregularly with a total amplitude of $\Delta m_V = 0.45$ mag. Near HJD 2452708 a brightness drop followed by a sudden light increase with maximum at $m_V = 10.25$ mag near HJD 2452736 was observed.

According to TYCHO-2 GSC 02908-00024 is a $V = 9.99$ mag star with $(B-V) = 1.442$ mag. It coincides with the infra-red source IRAS 05123+4354. The IRAS variability likelihood of the source is high: 92%. GSC 02908-00024 was observed during 29 night between November 6, 2002 and April 24, 2003. In total 213 data points were collected (comparison stars: HD 32948, HD 33878 and HD 33532). Our data presented in Fig. 1 show that GSC 02908-00024 is most probably a variable star of semi-regular type with an amplitude of about $\Delta m_V = 0.52$ mag.

GSC 02976-00401 is a $V = 9.56$ mag star with $(B-V) = 1.687$ mag. Its coordinates coincide with those of the infra-red source IRAS 07580+4235. Our 132 brightness measurements obtained during 30 night between September 24, 2002 and May 5, 2003 (comparison stars: HD 67586 and HD 66469) clearly show its variability (Fig. 1). The light curve variability is apparently irregular and the total observed amplitude is 0.33 mag.

BD+42°1814 (= SAO 42186 = GSC 02976-01660) is also an infra-red source. In the IRAS catalog it is identified as IRAS 08046+4154. According to SIMBAD

BD+42° 1814 is a $V = 9.39$ mag star with $(B-V) = 1.91$ mag, what makes it very red as for the spectral type of K5. The $(B-V)$ color index calculated from TYCHO-2 data is much lower, 1.65 mag. The star was observed during 40 nights between September 24, 2002 and May 5, 2003. In total 175 observations were collected. The light curve (Fig. 1) shows irregular light changes with total amplitude of 0.2 mag. BD+42° 1814 was used by Nelson (2003) as a comparison star while determining the time of minimum of the nearby eclipsing binary star SW Lyn. Our comparison stars for this field were: HD 67586 and HD 66469.

As it is recorded in SIMBAD, HD 76190 (= BD+44° 1803 = SAO 42604 = GSC 02989-00901) is a $V = 9.07$ mag star with $(B-V) = 1.54$ mag and spectral type of M2III. It is also the infra-red source IRAS 08527+4432. The star was observed during 40 nights between September 24, 2002 and May 5, 2003. 171 data points were collected. HD 76191 and HD 76617 were used as comparison stars for this field. As it is seen in Fig. 1, the total light curve variation amplitude is 0.27 mag. During the observed period the amplitude gradually decreased.

The astrometric positions of program stars, obtained from our observations, are in all six cases identical, within observational uncertainties, with those given in FK5.

3. Period Search

The photometric data presented in the previous section were used to search for periodicity of the new variable stars. Both Lomb-Scargle and Schwarzenberg-Czerny periodograms were calculated. The Lomb-Scargle periodograms were obtained using the numerical code by Press *et al.* 1989. The period search algorithm CZERNY (Schwarzenberg-Czerny 1996) was adopted from the ISIS package (Alard and Lupton 1998). Periodograms of artificial datasets with the white noise generated at observational moments instead of actual photometric data, characterized by the same mean value and amplitude as in original data, were also calculated in all cases to check reality of the obtained results.

Of the six variables under considerations four are apparently irregular (or our data are of insufficient quality to find periodicity) and the period search did not reveal any significant periodicity. HD 76190 might be a semi-regular variable. Its possible period of about 59 days is, however, very uncertain. The only semi-regular star in our sample is GSC 02908-00024. In the case of this star the light curve suggests a more or less periodic character of variation (Fig. 1) in the period covered by our CCD observations. The period search revealed a period of 63.50 ± 0.24 days ($f = 0.015748$/day) (Fig. 2). Folded light curve is presented in Fig. 3 where the original observations are averaged in 4-hour intervals. In Fig. 3 the mean values are presented for every bin as well as the uncertainties determined as standard deviations. The time of the maximum light is $T_{\rm max} = {\rm HJD}2452754.41 \pm 0.45$.

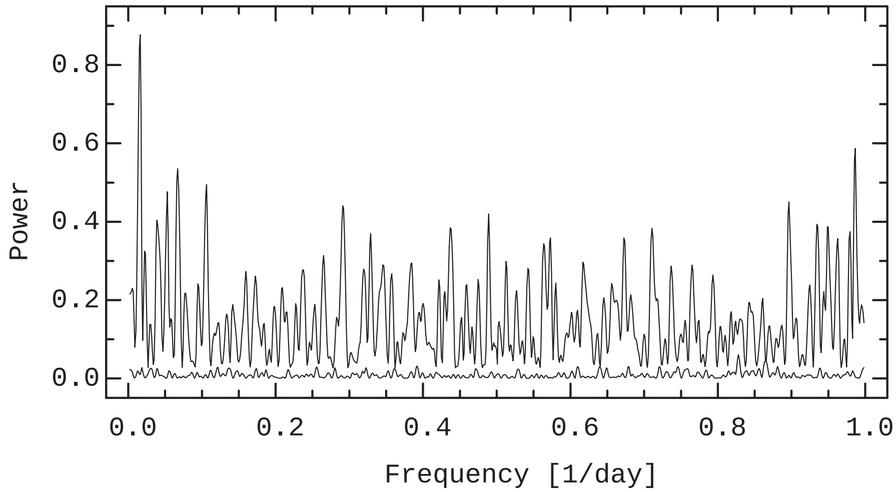

Fig. 2. Periodogram for GSC 02908-00024 obtained with the algorithm of Schwarzenberg-Czerny (1996). The power spectrum of white noise data replacing original observations at the same JD is presented as well.

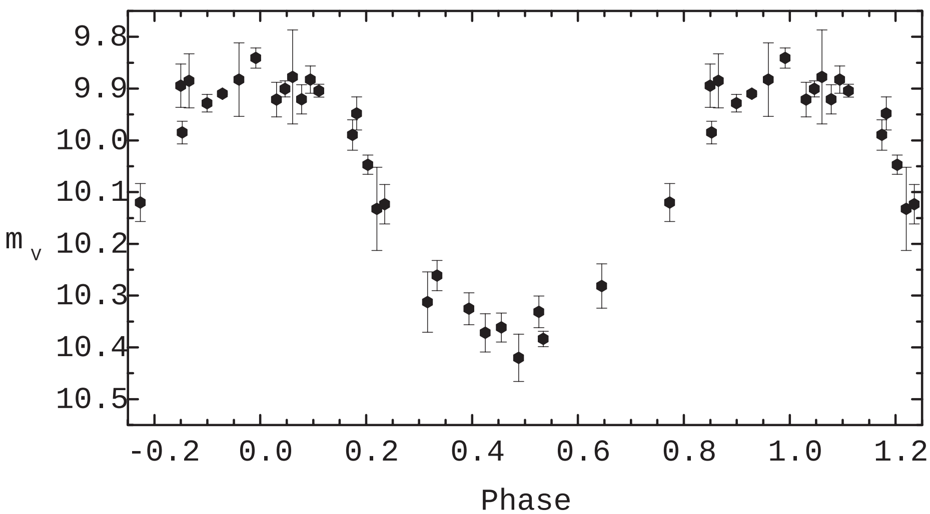

Fig. 3. Folded light curve of GSC 02908-00024. The original observations are averaged over 4-hour intervals.

4. Spectral Classification

Three of our new variables (HD 76190, GSC 2976-401 and BD+42° 1814) were observed with the 0.9 m Schmidt-Cassegrain telescope of the Piwnice Observatory (see Woszczyk (1984) for more detail on the telescope). The telescope in the Cassegrain optical configuration was equipped with the Richardson spectrograph (Richardson and Brealey 1973) and the Wright CCD camera (1024×256, 24 μm pixel size) as detector. With three gratings in use: 300, 600 and 1200 gr/mm we obtained spectra at resolutions of 8, 4 and 2 Åpix respectively. See Table 1 for details. All images were extracted using standard IRAF procedures. No flux calibration was applied. Resulting spectra are presented in Fig. 4.

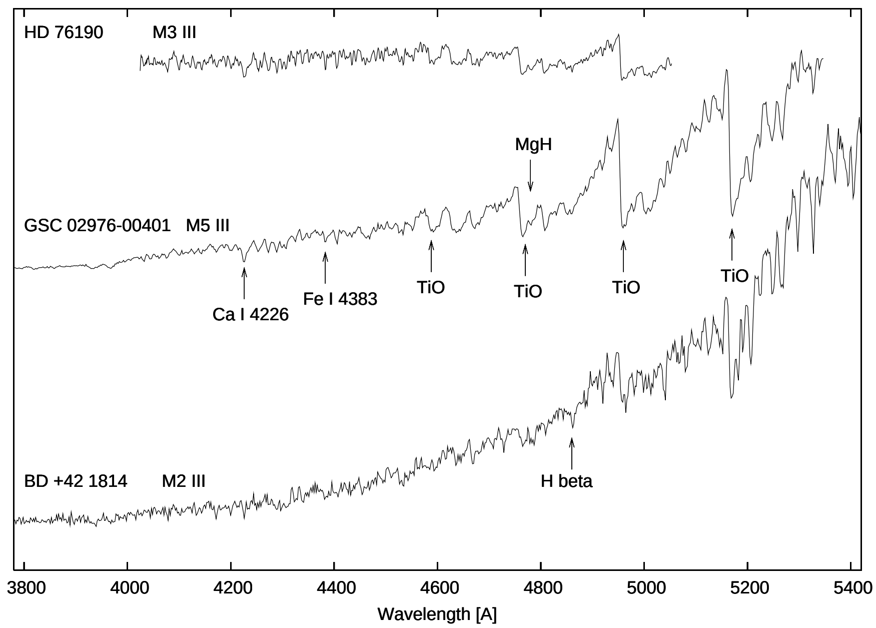

Fig. 4. Optical spectra of three new red variables. The most characteristic spectral features are indicated. The spectra are presented in relative intensity units.

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Star	date of observation	JD	exposure time [s]	spectral range [Å]	grating [gr/mm]
HD 76190	Dec 12 2002	2452621.5808	1800	4025–5050	1200
	Dec 12 2002	2452621.6024	1800	4025–5050	1200
GSC 02976-00401	Dec 7 2002	2452616.3668	1200	3290–5340	600
	Dec 7 2002	2452616.6240	1200	4870–6920	600
SAO 42186	Jul 3 2003	2452794.3853	1200	5020–9100	300
	Jul 8 2003	2452799.3772	1200	3660–5700	600

Spectral classification was performed by applying the criteria from Jaschek and Jaschek (1987) and by comparing the obtained spectra with the *Digital Spectral Classification Atlas* by R.O. Gray. The resulting spectral types are presented in Table 2.

Table 2

Summary of results

Star	Amplitude [mag]	Period [day]	Sp. type	Var. type	$T_{\rm eff}$ [K]
GSC 2907-779	0.5	–		SRb/Lb	2650
GSC 2904-834	0.45	–		SRb/Lb	3035
GSC 2908-24	0.52	63.5		SRa	2950
GSC 2976-401	0.33	–	M 5 III	SRb/Lb	3410
BD+42°1814	0.2	–	M 2 III	SRb/Lb	3670
HD 76190	0.27	59?	M 3 III	SRa/SRb	3205

The spectral type of GSC 2976-401 is derived for the first time. The spectral type of HD 76190 was determined by Upgren and Staron (1970) as M2III. Our results suggest slightly later type of M3III. The spectral type of K5 was assigned to BD+42°1814 in SIMBAD according to AGK3 Catalog and it comes from the HD Catalog. Our observations show much later type of M2III.

Presented here spectral types are generally in agreement with photometric $B-V$ values (within 0.07 mag) except for BD+42°1814. This star appears very red. Interstellar reddening, $E(B-V) = 0.31$ mag, or its photometry cited in SIMBAD are seriously in error. More consistent with the spectral type determined here is its TYCHO-2 photometry, *i.e.*, $(B-V) = 1.65$ mag and $E(B-V) = 0.05$ mag.

Our spectra show no trace of typical Swan C_2 bands at 4737 Å and 5165 Å in neither of the three stars observed.

5. Effective Temperature

The existing archive photometric data allow to estimate effective temperature with the method of Kerschbaum and Hron (1996) and Kerschbaum (1999) used for SRa, SRb and Lb variables.

For all six stars both TYCHO and IRAS photometry is available. However, only the upper limit of the 100 μm IRAS flux is present in all cases.

Additional infrared photometry from 2MASS is available for GSC 2976-401 (K), BD+42°1814 (J and K) and GSC 2907-779 (I and K). Some B and/or V photometric data are available in SIMBAD for all six stars. Both GSC 2904-834 and GSC 2976-401 have additional photometric data in GSC and USNO catalogs. GSC 2908-24 and BD+42°1814 have photometric records in GSC only. All compiled data were calibrated to absolute units in νF_ν using Bessel (1979) and CIT calibrations from NICMOS Instrument Handbook for Cycle 12 v.5 (Nicmos Instrument Team, 2002). The effective wavelengths of the photometric filters were adopted from Moro and Munari (2000).

First, T* was calculated by minimizing χ^2 fit to the combination of Planck distributions (Eq. 1 in Kerschbaum and Hron 1996). Since the quality and the number of the available IR observations was limited and only the IRAS 100 μm upper limit was available we switched the dust envelope term off to avoid unrealistic results. Finally, the $T_{\rm eff}$ was estimated by including the corrections determined by Kerschbaum and Hron (1996).

Using the [25]-[60] *vs.* [12]-[25] diagram of van den Veen and Habing (1988) we can safely assume that GSC 2907-779 and BD+42° 1814 are C-rich stars, while GSC 2908-24, GSC 2904-834, HD 76190 and GSC 2976-401 may possibly be C-rich. According to results of Kirschbaum and Hron (1992) we can confirm that statement in the case of GSC 2907-779 but with these criteria BD+42° 1814 is rather O-rich. The status of other stars cannot be confirmed. Therefore we assume that they are likely C-rich type for the purpose of applying correction term of Kerschbaum and Hron (1996).

The final results are presented in Table 2, where the value of temperature is rounded to 5 K. The uncertainty in temperature is certainly larger, of the order of 50–100 K.

It is interesting to note that in the case of HD 76190 and BD+42° 1814 the *K* magnitudes from 2MASS indicate flux excess compared to optical and IRAS photometry.

The spectral types obtained by us and the effective temperatures estimates are generally in reasonable agreement. However, GSC 2976-401 (M5III) appears to be hotter than HD 76190 (M3III) by 200 K which is most probably a result of low quality of its existing IR photometry.

6. Summary and Conclusions

Short description of the Semi-Automatic Variability Search project and some first results are presented. Using SAVS photometry, new spectroscopic observations and archive data we assigned variability types and estimated effective temperatures of the new variables (Table 2).

The SAVS software pipeline – SAVS.PL – is a freeware and is available from
http://www.astri.uni.torun.pl/∼gm/SAVS/

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