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The Fifth Edition of the General Catalogue of Variable Stars: experiences in the constellation Centaurus

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Abstract We have recently announced that the General Catalogue of Variable Stars enters the stage of its fifth, purely electronic edition (GCVS 5.1). We have included 1408 variable stars in the constellation Centaurus in this new version, GCVS 5.1. Working on this revision, we applied current possibilities from data mining, suggested new variability types for many variable stars and found new light elements for a large number of periodic variables. This paper describes the work completed during the preparation of GCVS 5.1 for Centaurus and discusses in detail a number of the most astrophysically significant cases.

Key words: catalogs — techniques: photometric — stars: variables: general — binaries: eclipsing

1 INTRODUCTION

We briefly discussed the history of variable-star catalogs published in the USSR and Russia in Samus' et al. (2017). After World War II, the catalogs were being compiled in our country on behalf of the International Astronomical Union. The purpose of the General Catalogue of Variable Stars (GCVS) is to include reliable variable stars: as a rule, the associated variability types, at least tentatively, should be known. Stars with doubtful variability or with unknown variability types should be included into Catalogues of Suspected Variable Stars. Since 1948, four major editions of the GCVS, in book form, have been published. The Fourth Edition (Kholopov et al. 1985–1995) consisted of five volumes and contained 28 435 variable stars in its main part (Volumes I–IV) plus almost 12 000 variable stars in external galaxies and extragalactic supernovae in its Vol. V. Catalogues of Suspected Variable Stars (Kukarkin & Kholopov 1982; Kazarovets et al. 1998), contain more than 26 000 stars; about 4500 of them have already received their GCVS names.

After completion of the Fourth Edition, the GCVS team identified almost all GCVS stars with astrometric catalogs or, in a number of cases when such identification was not possible, measured accurate coordinates using available images. Identification was found to be completely impossible (only rough coordinates published; lacking charts) for about 240 stars, a very small fraction. For a vast majority of GCVS objects, it is now possible to find them using solely the coordinates presented in the GCVS.

Samus' et al. (2017) announced the current electronic version of the GCVS (*http://www.sai.msu.su/gcvs/gcvs/*) to be version GCVS 5.1; Samus' et al. (2017) is now considered the standard reference for this GCVS version. As of June 2017 (after publication of the most recent Name-list, see below), the version contains 51 853 variable stars (not counting entries corresponding to nonexistent stars or to objects that, by mistake, obtained two or even three different GCVS names, mainly because of published coordinates being erroneous).

Stars enter the GCVS through the so-called Name-lists of variable stars. One of the main current problems for the GCVS is that the Name-lists Nos. 67–77 that had appeared after the Fourth Edition of GCVS contained only coordinates, variation magnitude ranges and variability types but did not present such important information as light elements (for periodic variable stars) or spectral types. The subsequent Name-lists Nos. 78–81 (more than 13 300 variable stars) are mini-catalogs of variable stars, containing all the above-mentioned kinds of data.

Our further work will eventually result in the next version, GCVS 5.2. This work consists of:

– Preparing new Name-lists providing, for stars added to the GCVS, all information that should be contained in the GCVS;

– Filling in the information gap (due to incompleteness of the Name-lists Nos. 67–77) with all relevant data;

– Updating the information provided for stars in the Fourth Edition of GCVS and for stars from relatively recent Name-lists taking into account new publications and processing photometric data available through data mining.

The last two tasks are being gradually performed in alphabetical order of Latin names of the associated constellations[1]. By 2017, this work was completed for 18 constellations (Andromeda–Cassiopeia). This paper presents the results for the 19th constellation, Centaurus.

2 GCVS REVISION FOR CENTAURUS

As of February 2018, GCVS 5.1 contains 1408 variable stars in the constellation Centaurus (actually, the main GCVS table for Centaurus consists of 1412 lines, but four entries are for star names no longer recommended for use: at some time, these stars erroneously obtained their second GCVS names). Note that there were only 833 in Centaurus in the Fourth Edition of GCVS. Name-lists Nos. 67-77 presented limited information on 216 variable stars. More detailed information on 359 variable stars can be found in Name-lists Nos. 78–81, but new sources of data have provided possibilities for improving GCVS information for some of them.

To improve the GCVS, we used variable-star studies published in many papers from recent astronomical literature. Whenever possible, we checked the published data ourselves by means of photometric data mining. The main sources of data mining we used in this study in order to improve the GCVS data in Centaurus were the All Sky Automated Survey-3 (ASAS-3) photometric survey (Pojmanski 1997) and the Catalina Sky Survey (Drake et al. 2009). ASAS-3 provides V-band photometry for stars between approximately magnitudes 7 and 14.5; it covers the whole sky to the south of declination +30°. The survey is based on observations with very small telescopes, and thus the angular resolution in crowded fields is poor. The Catalina Sky Survey is based on observations with CCDs that are sensitive to red light, but the magnitudes are calibrated using V-band standard stars. The Catalina magnitudes are sometimes designated CV. The telescopes used in this survey are moderate-sized, providing much better angular resolution. The survey covers the northern and southern sky, but with the celestial poles and the Milky Way strip excluded. In Centaurus, it can be used only in the parts of the constellation most distant from the Milky Way. Bright stars are overexposed, and the best results can be achieved for stars in the magnitude range $13 - 17$ mag. The observation times provided by the ASAS-3 survey are heliocentric, but the Catalina Sky Survey presents geocentric times, which we convert to heliocentric times for short-period variable stars.

[1] Note that, due to tradition, GCVS names consist of the variable star's name proper and the genitive form of the constellation name, like RR Lyrae. For a description of this system, see *http://www.sai.msu.su/gcvs/gcvs/gcvs5/htm/*.

3 RESULTS

Accurate coordinates of variable stars in Centaurus were presented by Samus' et al. (2002). When working on GCVS 5.1 for Centaurus, we revised identifications or improved coordinates for 35 variable stars.

In the Fourth Edition of GCVS, among the 833 variable stars in Centaurus, only 20 had first references to research of the GCVS authors. For the same 833 stars, we now have 549 references (66%) to our research, performed mainly by data mining. In total for the 1408 stars in Centaurus, the number of references to research done by the GCVS team is currently 793 (56%).

Among the variables AF Cen–IT Cen (180 stars in total), 135 stars had references to Hoffleit (1930) in our Fourth Edition. GCVS 5.1 for Centaurus currently has only 38 references to this paper (for stars with no possibilities to improve the data using data mining). This was the first paper ever published by Dorrit Hoffleit (1907–2007). In her autobiography published by the AAVSO (Hoffleit 2002), she remembers that, when preparing her first scientific publications, she did not even know about the possibility of spurious periods. Our analysis shows, as the most frequent mistake, that red semiregular or irregular variable stars were erroneously believed to be stars with rapid brightness variations (the author did not use color information to check her results). The GCVS 5.1 classification for some of these stars is confirmed by spectral types; in other cases, infrared color indices are known from the 2MASS catalog.

Table 1 summarizes the most important changes in GCVS 5.1 for Hoffleit's stars. Columns (2) and (3) reproduce GCVS 4 type and period, taken from Hoffleit (1930), and the following columns are GCVS 5.1 data, mainly determined by us. "VSX" means information from the International Variable Star Index (Watson et al. 2007).

The light curve of HQ Cen, an eclipsing (EB) star with a rather long period, is presented in Figure 1. This star was sufficiently correctly described in the ASAS-3 catalog (Pojmanski 1997).

Among the variables V444 Cen–V490 Cen (46 stars in total: the name V467 Cen is no longer recommended for use, the current name of the star is V746 Cen), 41 variable stars had references to Huruhata (1940), again a study based on plates in the Harvard stacks. Only three stars remain with references to Huruhata (1940) in GCVS 5.1. We were able to find types and light elements.

In most cases, the changes were just an improvement in the period, but there were also more serious corrections (spurious periods in Huruhata 1940). The most important changes in GCVS 5.1 for Huruhata's stars are collected in Table 2. Columns (2) and (3) reproduce GCVS 4 type and period, taken from Huruhata (1940), and the following columns are GCVS 5.1 data, mainly determined by us.

Among the variables V500 Cen–V569 Cen (70 stars), all but one have GCVS 4 references to McLeod & Swope (1941). This study in the Harvard plate stacks resulted in much better periods than those determined in Huruhata (1940). Nevertheless, the revision of these results in GCVS 5.1 was also significant (Table 3). Columns (2) and (3) reproduce GCVS 4 type and period, taken from McLeod & Swope (1941), and the following columns are GCVS 5.1 data, mainly determined by us.

Data for eight variable stars (V647 Cen–V654 Cen) in the Fourth Edition of GCVS were based on Ninger-Kosybowa (1949). All these stars have now been revised by the compilers of GCVS 5.1 (Table 4). Especially impressive are the cases of V653 and V654 Cen that are definitely W UMa eclipsing variables rather than rapid irregular stars (the expression used in the original paper by Ninger-Kosybowa 1949: "Probably an irregular variable star with short variations of brightness"). The light curves for these two stars are presented in Figures 2 and 3. Note the O'Connell effect (different heights of maxima) for both variables, especially for V654 Cen.

The famous German variable-star researcher Cuno Hoffmeister (1892–1968), who also made a large contribution to studies of southern variable stars (based on several observing trips to Africa), did not work much in Centaurus. Twenty-nine variable stars in the Fourth Edition of GCVS (V714, V715, V718–V736 Cen, V738–V741 Cen, V792–V794 Cen, V797 Cen) had references to Hoffmeister (1963). In this paper, the author suggested variability types on the basis of very limited numbers of photographic brightness estimates, usually not deriving any light elements. Among the stars listed above, he gave the type "RR" (without subtype) for 22 variables (one of them uncertain); five stars were reported as eclipsing variables and two stars as slow irregulars (only one of them is definitely red). No light elements were presented for any of the 29 stars. We have studied all these stars using Catalina data (ASAS-3 data for V794 and V797 Cen). Classification was confirmed for all the 22 RR Lyraes and for all announced eclipsing stars, with the exception of V797 Cen. We determined light elements and subtypes for RR Lyraes (20 of them are RRAB variables), and light elements for eclipsing stars. V792 Cen (type L from Hoffmeister) is actually an EW eclipsing star; V794 Cen is an SRA variable (instead of LB), and V797 Cen is not an eclipsing star but rather an SRB variable.

Here we briefly present only several big blocks corresponding to the transition between the Fourth Edition of GCVS and GCVS 5.1 in Centaurus. Cases of contribution from the GCVS authors to information on individual stars are also numerous.

V667 Cen is an RR Lyrae variable discovered by Shapley et al. (1954). They did not publish a finding chart and their published coordinates were not accurate enough, so a search in a rather wide field was required, which consisted of checking stars in the appropriate magnitude range for variations in photometric surveys. Our attempts to locate the variable in 2000–2004, supported by A. Paschke (private communication, 2004), led to a wrong identification. Luckily, when revising the GCVS in 2017 and feeling unsure about the identification of V667 Cen, we repeated the search using data from Catalina surveys and were able to identify the variable correctly, which corresponded to GSC 7303–00247. The period of this RRAB star, determined by us from

Table 1 Variable stars from Hoffleit (1930) in GCVS 5.1

GCVS name (1)	Type (GCVS 4) (2)	Period (GCVS 4) (d) (3)	Type (GCVS 5.1) (4)	Period (GCVS 5.1) (d) (5)	Spectral type (GCVS 5.1) (6)
BQ Cen	S:	–	EW	0.5468423	–
BU Cen	RV:	85.5	RVA	170.4	–
CP Cen	S:	–	SRB	147.7	M4
CR Cen	M	180.5	M	347	M8
CV Cen	SR	150	M	320:	M9
CW Cen	S:	–	SRB	122	–
CZ Cen	SR	–	SRB	132.5	–
DD Cen	S:	–	SRB	44.7	–
DE Cen	E	$1.0/N$	EA	0.59004 (VSX)	–
DF Cen	L	–	SRD	56.2	K4–K5
DH Cen	E	$2/N$	EA	0.870765	–
DQ Cen	S:	–	SRB	190.5	M6
DS Cen	RR	–	EW:	0.47512:	–
DT Cen	–	–	SRB:	36:	–
DV Cen	E	–	EA	1.205901	–
DX Cen	–	–	M:	296	M
EL Cen	E	–	EA:	21.8674:	–
EN Cen	E	$3/N$	EA	1.775753	–
EQ Cen	RR:	–	SRB	99.2	M6
ES Cen	M	173.6	M	355.2	–
EU Cen	S:	–	M:	452	–
EV Cen	S:	–	LB	–	–
FF Cen	–	–	SRB	71.1	–
FI Cen	S:	–	SRB	195	–
FL Cen	RR:	–	LB:	–	–
FN Cen	S:	–	SRB	1059	–
FO Cen	S:	–	LB:	–	–
FS Cen	RR	–	RRAB:	0.50860:	–
FT Cen	RR	–	LB:	–	–
FU Cen	S:	–	LB:	–	–
FV Cen	L	–	M	249	–
FY Cen	–	–	LB:	–	–
FZ Cen	S:	–	LB:	–	–
GI Cen	S:	–	RRAB	0.635 (Zorotovic et al. 2010)	–
GK Cen	RRAB	0.6599	CWB:	1.949773	–
GM Cen	S:	–	SRB	306	–
GN Cen	S:	–	SRB:	98:	–
GO Cen	RR:	–	LB:	–	–
GQ Cen	S:	–	SRB:	56:	–
GT Cen	–	–	LB:	–	–
GU Cen	RR:	–	LB:	–	–
GV Cen	L	–	SR:	–	M6–M7
GZ Cen	S:	–	M:	345:	–
HH Cen	S:	–	SRB	61.1:	–
HK Cen	E	$7/N$	EA	2.421757	–
HN Cen	RR	–	SRB	79	–
HQ Cen	S:	–	EB	19.91363	–
HS Cen	L:	–	SRB:	327:	–
HU Cen	S:	–	SRB:	72.6	–
HX Cen	E:	–	SRB:	81.9	–
IL Cen	S:	–	SRB	422	–
IN Cen	E	–	RVA	75.8196	–
IP Cen	M	188.5	M	377	–
IT Cen	RR	–	SRB	110	–

Table 2 Variable Stars from Huruhata (1940) in GCVS 5.1

GCVS name (1)	Type (GCVS 4) (2)	Period (GCVS 4) (d) (3)	Type (GCVS 5.1) (4)	Period (GCVS 5.1) (d) (5)	Spectral type (GCVS 5.1) (6)	Rem. (7)
V445 Cen	E	14.1	EB:	28.3935	–	
V446 Cen	RR	0.52	RRAB	0.5613849	–	
V447 Cen	RR	0.46	EB	0.638603	–	
V449 Cen	SRD	123	SR	57.9	G8	1
V452 Cen	RR	0.406	RRAB	0.7500541	–	
V453 Cen	SR	118	SRB:	90.6:	–	
V454 Cen	RR	0.52	EA:	0.4248050	–	
V466 Cen	RR	0.573	RRAB	0.3973631	–	2
V469 Cen	RR	0.538	RRAB	0.5812984	–	
V470 Cen	RR	0.420	RRAB	0.7239056	–	
V483 Cen	RR	0.610	RRAB	0.5713941	–	

Remarks:

1. *V449 Cen.* The classification "SRD" was based on the G8 spectral type in the literature, but the 2MASS infrared colors suggest a much later spectral type.
2. *V466 Cen*. This RRAB star has a somewhat unusual period and a very large amplitude, $13.62 - 14.90$ mag CV.

Table 3 Variable Stars from McLeod & Swope (1941) in GCVS 5.1

GCVS name (1)	Type (GCVS 4) (2)	Period (GCVS 4) (d) (3)	Type (GCVS 5.1) (4)	Period (GCVS 5.1) (d) (5)	Spectral type (GCVS 5.1) (6)	Rem. (7)
V504 Cen	RCB	–	NL	–	pec(e)	1
V517 Cen	L	–	SRB	178.0	–	
V523 Cen	RR	0.38091	RRAB	0.616281	–	
V525 Cen	LB	–	SRB	108.9	–	
V528 Cen	L	–	SR	147	–	
V531 Cen	LB	–	SRB	205.5	M6–7e	
V535 Cen	RR	0.37150	RRAB	0.5920464	–	
V537 Cen	LB	–	SRB	302.1	–	
V538 Cen	RR	0.60022	RRC	0.3747118	–	
V541 Cen	M:	196	SRB	200.8	–	
V563 Cen	RRAB	1.07638	CWB	1.0769065	–	

Remark:

1. *V504 Cen.* Definitely classified as a VY Scl cataclysmic variable by Kato & Stubbings (2003).

Table 4 Variable Stars from Ninger-Kosybowa (1949) in GCVS 5.1

GCVS name (1)	Type (GCVS 4) (2)	Period (GCVS 4) (d) (3)	Type (GCVS 5.1) (4)	Period (GCVS 5.1) (d) (5)	Spectral type (GCVS 5.1) (6)
V647 Cen	SR	210	SRB	198.7	–
V648 Cen	L:	–	SRB:	59:	–
V649 Cen	L:	–	EW:	0.454410:	–
V650 Cen	M	300:	M	410	Me
V651 Cen	SR	400:	SRB:	57:	–
V652 Cen	SR	86.38	SRD	86.9	–
V653 Cen	IS:	–	EW	0.3648759	–
V654 Cen	IS	–	EW	0.3726044	–

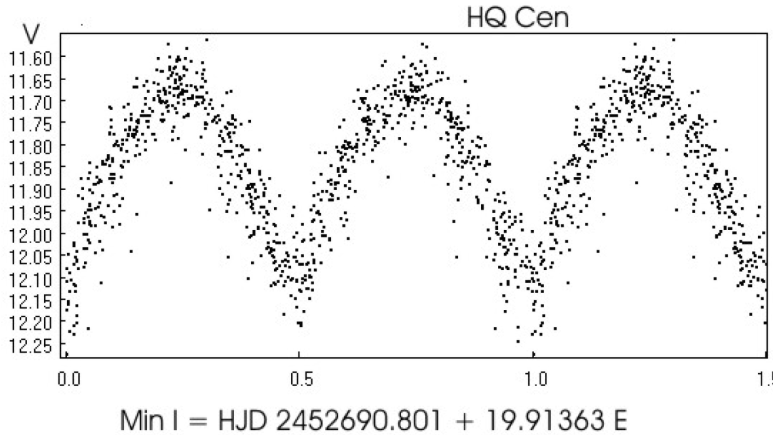

Fig. 1 The light curve of HQ Cen, from ASAS-3 observations.

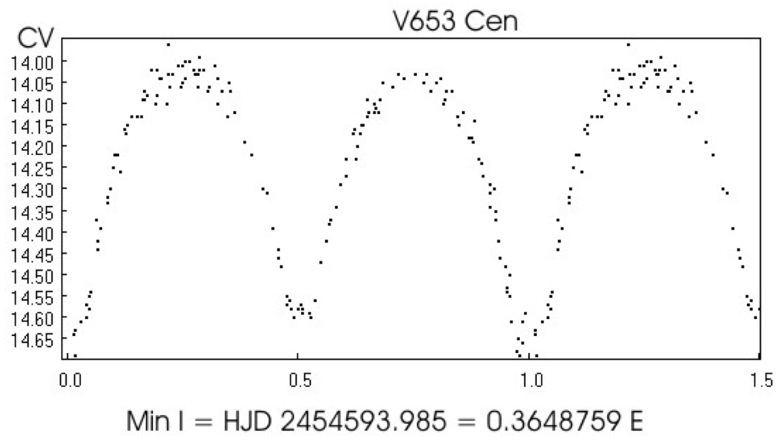

Fig. 2 The light curve of V653 Cen, from Catalina observations.

Catalina data, is 0.6637930 d, while Shapley et al. (1954) suggested a different one, 0.60135 d.

V786 Cen entered the GCVS as a possible eclipsing variable discovered by Ebisch (1973), with no light elements. As of February 2018, the well-known internet resource "O–C Gateway" suggested two possible periods for the star, 0.855098 and 1.19741 d. From Catalina data, we find both these periods to be wrong, with the correct one for this Algol (EA) star being 5.9864070 d.

V805 Cen was discovered by Strohmeier (1967) who had not determined its variability type. Wälder (1975) correctly attributed this star to be an eclipsing variable, but her period, 2.211155 d, is wrong. The "O–C Gateway" site suggests two solutions, that by Wälder (1975) and that with a new period, 3.3166 d. This period is nearly correct but not accurate enough. Our new light elements from ASAS-3 data are

$$\mathrm{Min} = 2453560.652 + 3.3167193^{\mathrm{d}} \times E.$$

The most interesting feature of the light curve with this period is that the secondary minimum is observed at phase 0.547. Such eccentric eclipsing stars are important from the point of view of possible apsidal motion.

Several astrophysically important corrections for stars in Centaurus contained in the Fourth Edition of GCVS were suggested by other authors. Thus, the compilers of the Fourth Edition decided, on the basis of the discovery paper (Elvius 1975), that V803 Cen belonged to the rare RCB type. It is now clear that here we deal with a cataclysmic, nova-like variable (cf., for example, Patterson et al. 2000). V819 Cen was believed to be a pulsating variable, probably an RR Lyrae star, with $P = 0.6755$ d (Moffat 1977). The variable is now known to be a silicon Ap star (e.g., Maitzen & Vogt 1983), so we consider it an ACV variable star. Paschke & Poretti (2006) determined its period to be 2.078588 d from ASAS-3 data.

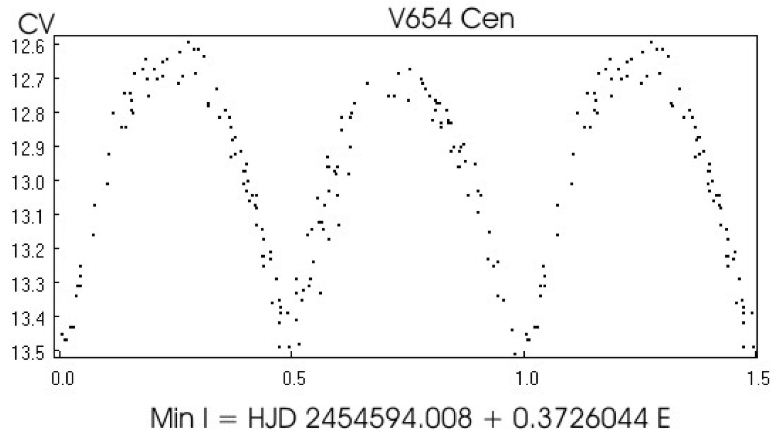

Fig. 3 The light curve of V654 Cen, from Catalina observations.

As noted above, Name-lists Nos. 67–77 presented only limited information compared to what is standard for the GCVS. In Centaurus, these Name-lists contained 219 objects. GCVS 5.1 now gives complete information for all of them, with references to the original work of GCVS compilers in 82 cases (37%).

Name-lists Nos. 78–81 were prepared in the complete GCVS format. Nevertheless, when preparing the new version, GCVS 5.1, for Centaurus, we revised all these stars, introducing, whenever necessary, new light elements and other corrections. For these 357 stars, there are now 151 references to our work (42%). Additionally, 27 stars have references to the papers we published when preparing these Name-lists (Kazarovets et al. 2005; Kazarovets & Pastukhova 2007, 2008a,b, 2009).

4 CONCLUDING REMARKS

The work on the new version, GCVS 5.1, is being continued. The GCVS team is currently working on the next, 82nd Name-list of variable stars, expected to contain several thousand variable stars covering the whole sky. We are finishing a complete revision of information in GCVS for the next constellation, Cepheus. Our nearest plans include incorporating sufficiently well-studied variable stars in globular clusters into the GCVS system (note that, for reasons of tradition, the GCVS, intended to be a catalog of all *Galactic* variable stars, so far contains variables in open clusters but, as a rule, not in globular clusters).

The number of photometrically variable stars, with variations detectable using modern ground-based techniques, is very large. Discoveries from space-borne observatories are able to detect even smaller brightness variations. Note that astronomical tradition never introduced any lower limit for the amplitude a star should have to be called variable, making almost any star a potential variable. In the not so distant future, it will become impractical to continue the traditional system of naming variable stars. We expect (Samus & Antipin 2015) that future large general-purpose star catalogs will contain sections with characteristics of brightness variations for sufficiently well-studied stars. Meanwhile, the astronomical scientific community still expresses interest in having traditional GCVS names for their new discoveries. As long as it remains technically possible, we will continue compiling new Name-lists and updating GCVS information.

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