Research Article

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Future of the General Catalogue of Variable Stars from the Experience of Recent Name-lists

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Abstract: We briefly outline the history of the General Catalogue of Variable Stars (GCVS) and the New Catalogue of Suspected Variable Stars (NSV catalogue). Recently, we have completed a revision of the NSV catalogue. Positional information was checked for all its stars and, in many cases, new photometric data were added. As a result, one third of all NSV stars have been transferred to the GCVS. Having determined equatorial coordinates for variable stars in globular star clusters, we began to add them to the GCVS. Two Name-lists published so far contain more than 1700 variable stars in 36 globular clusters; an additional Name-list (about 900 variable stars in 27 globular clusters) will be published before the end of 2021. We discuss problem cases in the literature and in the Catalogue of Variable Stars in Galactic Globular Clusters revealed during our preparation of the Name-lists. The future of traditional catalogues of variable stars (GCVS; AAVSO Variable-star Data Index VSX) is discussed.

Keywords: stars: variable, star clusters: globular

1 Introduction

Works on compilation of the General Catalogue of Variable Stars (GCVS) were initiated in the USSR in 1948 on behalf of the IAU. Before the World War II, variable-star catalogues were regularly published by German astronomers. After the war, the IAU decided to make the Soviet Union responsible for two formerly German projects, catalogues of variable stars and ephemerides of minor planets (asteroids). The decision concerning variable-star catalogues was taken after inspection of Moscow astronomical facilities by IAU emissaries. They found a very thoroughly kept card catalog, initiated by P. P. Parenago, at the Sternberg Astronomical Insti-

tute (SAI), a structure in the system of Lomonosov Moscow University. The GCVS author team formed in Moscow consisted of scientists from SAI and from the variable-star commission of the USSR Academy of Sciences and was headed by Prof. B. V. Kukarkin (1909–1977) and Prof. P. P. Parenago (1906–1960).

The collaboration of scientists from the Russian Academy of Sciences and from the SAI in the GCVS project continues till now. The structure in the system of the Academy currently responsible for the GCVS is the Institute of Astronomy of Russian Academy of Sciences (INASAN).

The last variable-star catalogue published in Germany (Schneller 1942) contained 9476 stars. The first edition of the GCVS published in the USSR (Kukarkin and Parenago 1948) included 10930 objects.

Since 1948, there appeared four editions of the GCVS, from the one-volume first edition to the five-volume fourth edition (1985–1995; Kholopov 1985a,b, 1987; Samus 1990, 1995). While GCVS I, as mentioned above, contained 10930 stars, GCVS IV had already 28435 variable stars of our Galaxy plus about 12000 stars in external galaxies. The decision to add variable stars in external galaxies to the GCVS, taken by P. N. Kholopov (1922–1988), appeared not practical in the future activity of the GCVS team because of the dramatic increase of extragalactic variable-star discoveries, and we do not continue this line of work nowadays.

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GCVS is now a purely electronic catalogue (GCVS 5.1; Samus' *et al.* 2017). New objects are added to the GCVS via the so-called Name-lists of variable stars. Till recently, they were published in the IAU Information Bulletin on Variable Stars (IBVS) issued by Konkoly Observatory (Budapest). In 2019, publication of the IBVS was quite unexpectedly discontinued, so we had to begin publishing new Name-lists in the *Peremennye Zvezdy/Variable Stars* electronic journal, starting with Part II of the Name-list No. 82. As of August, 2021, there exist 57247 stars with GCVS names. A GCVS name consists of a variable-star designation in a constellation plus the constellation name in Latin Genitive, like RR Lyrae.

By tradition, the GCVS contains only stars with comparatively well-studied brightness variations. In principle, only stars that can be attributed to one of the types of the existing classification system, or shown to be probable prototypes of new types, should enter the GCVS. All other stars, even those with definitely confirmed brightness variations, are considered “suspected variables”. Catalogues of such stars were repeatedly published at least since the 19th century. After World War II, several catalogues of this kind were published in the USSR. “New Catalogue of Suspected Variable Stars” was the last of them published in the book format (Kholopov 1982), it contained 14810 objects. Kazarovets *et al.* (1998) published a supplement to the NSV catalogue, with 11206 objects in it.

Currently, the GCVS is not the richest source of information on variable stars. The American Association of Variable Star Observers (AAVSO) established, around 2005, an International Index of Variable Stars (VSX; Watson *et al.* 2007). As of August 9, 2021, this list contained 2 114 281 objects. From the GCVS point of view, the VSX is a combination of variable-star and suspected-variable-star catalogues. There are cases of duplicate entries for the same star (in the occasions of wrong coordinates in the literature). Also, to a certain extent, the VSX includes extragalactic variable stars. It should be emphasized that the GCVS team highly estimates activities of the VSX team and keeps good working contacts with it.

For reasons of tradition, neither the German variable-star catalogues published before the World War II nor the GCVS included the majority of variable stars in galactic globular clusters. Probably, at certain times, it was not clear if globular clusters and stars populating them should be considered a component of our Galaxy. There exist special Catalogues of Variable Stars in Globular Clusters, compiled and published in Canada. Several editions were prepared by H. Sawyer Hogg (1905–1993). Later on, the catalogue was continued in the electronic form in Canada (Clement *et al.* 2001). By now, it contains about 8000 variable and

suspected variable stars. A small number of variable stars in globular clusters, nevertheless, had regular GCVS names, like T Sco, Nova 1860 in the central region of the globular cluster M80 (NGC 6093).

2 Results

2.1 Revision of the NSV catalogue

For several years, our team member E.V. Kazarovets, with assistance from co-authors, was working on a total revision of the NSV catalogue. Recently, this revision has been completed. As already mentioned, the NSV catalogue contains 14810 entries. 3105 of these stars had no finding charts published by the discoverers, or the published charts were found erroneous (the coordinates of old catalogues had accuracy standards insufficient for identifying stars without finding charts). To find them, it is, in most cases, necessary to detect brightness variations using available sky images or use the help of astronomers having access to working materials of the discoverers that can contain finding sketches. In this way, we were able to find 2809 objects and to provide their accurate coordinates.

As one of the most important results of the revision, about 4850 stars (one third of all the NSV catalogue) are now being transferred into the GCVS. Interestingly, 52 of these stars could be simply identified with stars already contained in the GCVS, which had not occurred earlier because of inaccurate coordinates. 17 NSV “stars” turned out to be asteroids with available ephemerides, 22 objects were identified with galaxies. We could not identify 16 doubtful Novae. Among them, there can be plate defects, double exposures on the same plates, or “phantoms” of bright stars. A detailed paper on the results of the NSV complete revision is in preparation.

2.2 Variable stars in globular clusters

The fact that variable stars in globular clusters are, as a rule, not included into the GCVS, contradicts the announced purpose of the GCVS to serve as a *general* catalogue of galactic variables. However, there existed an important obstacle making it difficult, and almost impossible, to add globular-cluster variables to the GCVS. Namely, catalogues of variable stars in globular clusters did not contain equatorial coordinates of stars but used rectangular coordinates, referred to very approximate centers of globular clusters. The GCVS team took the effort to deter-

mine good-quality equatorial coordinates, by identification with modern catalogues or by astrometric measurements using existing images. The result was published for 3398 stars in 103 globular clusters (Samus *et al.* 2009). Later on, equatorial coordinates were introduced in the Canadian catalogues of variable stars in globular clusters (<http://www.astro.utoronto.ca/~cclement/read.html>).

In 2019–2020, we started issuing Name-lists that contained GCVS names for variable stars in globular clusters, selected from Canadian catalogues as stars satisfying GCVS criteria. It should be noted that the number of catalogued globular-cluster variables increased twofold since 2009. Our task was to select those variables that can be considered GCVS stars and not just suspected variables and to provide for them all variability information according to the GCVS standards.

It should be reminded that the GCVS uses the naming system based on constellations. The two lists of GCVS names for globular-cluster variables issued so far (Kazarovets *et al.* 2019; Samus *et al.* 2020) contain more than 1700 variable stars in 36 globular clusters (constellations Apus – Lynx). The next list we have now prepared, expected to be published before the end of 2021, will contain about 900 stars in 27 clusters (Musca–Ophiuchus). Wherever possible, we give equatorial coordinates from Gaia Data Release 2 and Early Data Release 3.

A GCVS tradition is to improve and update information, to derive new light elements from data mining. This is not easy in the case of faint and crowded globular-cluster variable stars. Nevertheless, we always check existing possibilities. Thus, the second of the lists we have published (Samus *et al.* 2020) presents light elements derived by our author team in 16% of all cases. The sources of observations that were used most often were Catalina Sky Surveys and ASAS-SN.

As mentioned above, we started considering name-lists for variable stars in globular clusters after we had determined equatorial coordinates of variables in 103 clusters (Samus *et al.* 2009). These results turn out to be as accurate as it could be achieved during the pre-Gaia era. A small number of mistakes were noticed by attentive users (we should like to mention, with thanks, a thorough work by Arellano Ferro *et al.* (2013), who found two wrong identifications made by Samus *et al.* (2009), in the globular cluster M9 = NGC 6366 and correctly understood the reasons for these mistakes). However, replacing coordinates from Samus *et al.* (2009) with coordinates from newer papers, coordinates differing considerably not only from those suggested by us but also from those suggested by other authors, seems a wrong decision.

Nevertheless, we noticed several decisions of this kind in the online version of the Canadian catalogue of variable stars in globular clusters. In NGC 5286 (Centaurus), our coordinates were replaced with those from Zorotovic *et al.* (2010). In the latter paper, all declinations are wrong by different amounts, on average by $\sim 6''$, while right ascensions are nearly correct. Our coordinates agree with those from Gaia DR2, Gaia EDR3 well. In the Canadian catalogue, our disagreement in declinations with Zorotovic *et al.*, as well as the agreement of our declinations with those from Figuera Jaimes *et al.* (2016), is mentioned but not considered as a reason for using our coordinates.

A similar situation is in M62 (NGC 6266, Ophiuchus). All declinations from Contreras *et al.* (2010), used in the Canadian catalogue instead of those, essentially correct, from Samus *et al.* (2009), are erroneous, again by several arcseconds, with more or less correct right ascensions. The Canadian catalogue mentions the discrepancy and even claims that Contreras *et al.* are going to publish an Erratum – but such an Erratum cannot be seriously expected with 11 years already elapsed since the original publication. And it remains difficult to understand why not to return to the correct coordinates earlier used in the catalogue.

We also encountered problem cases with photometric information, periods, variability types.

For the globular cluster NGC 4833 (Musca), we used photometric data from a 2018 publication by A.N. Darragh and B.W. Murphy, paper not reflected in the ADS data base, cited through a preprint in the Canadian catalogue, with

Figure 1. Top: the light curve of V3 (M14) with the RRAB elements. Bottom: same data with the RRC elements.

the preprint also not accessible any longer. The light curves published in this paper sometimes have obviously incorrect magnitudes along the ordinate axis. Upon our request, Prof. B. W. Murphy kindly provided us with corrected light curves and new information for several other stars in the cluster.

An example of a correction in the light elements is a variable star in the cluster M14 (NGC 6402, Ophiuchus). Contreras Peña *et al.* (2018) provided access to their CCD observations. Their light elements for the RR Lyrae variable V3 with the period they determined, 0.52244d (type RRAB), give a low-quality light curve with a comparatively small amplitude, unusual asymmetry, and something like a secondary maximum. We used their own observations to derive light elements we find more probable, with the period 0.33797d (type RRC) (Figure 1).

3 Future GCVS prospects

Until recently, there remained ample possibilities for individual researchers and research teams to discover new variable stars. For example, the SAI keeps a rich collection of astronomical plates, a digitalization program is under way. Digitized plates are used for semi-automated search for variable stars; new discoveries get preliminary names with the prefix MDV (Moscow Digital Variable) and are later included into GCVS Name-lists. So far, 870 MDV stars (MDV 1 – MDV 870) were announced, see Antipin *et al.* (2018) for details.

The results of the MDV program were of interest for general statistics of variable stars. Thus, there were rather many discoveries of high-amplitude δ Scuti stars in the MDV program, implicating that too many of them remained undiscovered in the past, despite their large amplitudes. Possibly, periods for a considerable fraction of such stars could not be found manually in the pre-computer era because the shorter is the period, the larger is the volume of computational work.

The distribution of MDV eclipsing stars over periods also differs from that in the whole GCVS in the sense that we discover a considerably higher fraction of short-period EW and EB stars (Kolesnikova *et al.* 2010).

Antipin *et al.* (2018) performed automated classification of the stars MDV 596 – MDV 870 using the Random Forest algorithm, with earlier MDV discoveries as a training set. For each star, three most probable classifications were suggested. The results were compared to non-automated classification performed by very experienced variable-star astronomers. There was coincidence with the most proba-

ble automated classification in 57% of all cases. The non-automated classification disagreed with any option from the automated classification in 12% of all cases; of them, nine stars (~3%) belong to types not represented in the training sample. In our opinion, these results are promising but show that future effort is needed in order to make the automated classification more reliable.

Further work on the MDV project makes it more and more clear, however, that chances to make a new discovery from scans of photographic plates quickly decrease. A very large fraction of detected candidates are now stars already found by large ground-based automated projects (like the ASAS-SN project of the Ohio State University; Jayasinghe *et al.* 2019) or space projects (like Gaia DR2; Brown *et al.* 2018).

As for prospects of CCD discoveries, they look as follows. Estimates based on the number of catalogued stars (currently of the order of one billion) and on the fraction of all stars that turn out variable at typical ground-based accuracies of 0.03–0.05 mag (one variable out of 80–100 stars) lead to about 10 million easily detectable variable stars. We have seen above that some 2 million variable stars are already known.

However, we encounter much larger numbers when dealing with discoveries from space. Basri *et al.* (2011) summarized early results of the Kepler program. Of ~150000 program stars, about 60000 were found to be periodic variable stars; 34000 more stars varied with poorly expressed periodicity or irregularly. Thus, about two thirds of all stars can be detected as variables with Kepler photometric accuracy.

In our opinion, an extremely important problem of all variable-star catalogs is that, at no point in the history of variable-star research, there existed general agreement concerning the minimal brightness-variation amplitude the star should have in order to be considered variable. Because of this, stars with smaller and smaller amplitudes are claimed to be variable with the progress of observing techniques.

Currently, the smallest-amplitude variable star in the GCVS is α Aquilae (Altair). Its peak-to-peak variations amount to 0.005 mag. Quite certainly, even smaller amplitudes can already be detected by space missions. It becomes possible to detect variations due to star spots, chromospheric activity, and other effects.

There is no doubt that the history of traditional variable-star catalogues is approaching its end. However, it is of outmost importance that future astronomers do not begin to discover the same variable star again and again. A possible way out of this problem is to include variable-star information in major star catalogues of general purpose, like it

has already been done in the Gaia catalogue (Brown *et al.* 2018).

4 Conclusion

The GCVS team is planning to publish new Name-lists covering globular-cluster variable stars in all remaining constellations. We are working on regular Name-lists for variable stars in the general field, including Novae. Our experience shows that, among discoverers of Novae and other transient objects, there exists a strong demand for GCVS names for their new objects.

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