VARIABLE STARS, THE GALACTIC HALO
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Variable Star Catalogs: Their Past, Present and Future

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Abstract. After the second World War, the International Astronomical Union made astronomers of the Soviet Union responsible for variable-star catalogues. This work has been continued ever since the first edition of the General Catalogue of Variable Stars compiled by the team headed by P. P. Parenago and B. V. Kukarkin and published in 1948. Currently, the catalogue work is a joint project of the Institute of Astronomy (Russian Academy of Sciences) and Sternberg Astronomical Institute (Moscow University). This paper is a brief review of recent trends in the field of variable-star catalogues. We discuss problems as well as new prospects related to modern large-scale automatic photometric sky surveys, and outline the state of discussions on the future of the variable-star catalogues in the profile commissions of the IAU.

1. Introduction

Variable-star catalogues have a long history. Probably the first list that can be called a variable-star catalogue was published by E. Pigott in 1786, though it contained only 12 stars. The number of known variable stars was increasing very slowly till the advent of astronomical photography at the end of the 19th century (for example, only 143 variables were catalogued by 1875), but then the score of known variables quickly reached several thousands. Between 1926 and 1942, the work on variable-star catalogues and ephemerides was organized by the German society Astronomische Gesellschaft, and a new catalogue was published each year. The first of these (Prager 1926) contained 2 906 variable stars and the last of them (Schneller 1942), 9 476. The quality of the catalogues compiled by R. Prager, who had to emigrate from the Nazi Germany in the early 1930s and terminate his catalogue work, is especially good. After 1942, the situation in Germany made German astronomers unable to continue publishing their catalogues.

After the second World War, the Executive Committee of the International Astronomical Union (IAU) decided to make astronomers of other countries responsible for several projects previously fulfilled in Germany and important for the world astronomical community. The Soviet Union was assigned two of such projects, Ephemerides of Minor Planets (which went to the Institute of Theoretical Astronomy) and the General Catalogue of Variable Stars (GCVS). The Executive Committee's decision concerning the GCVS was preceded with an inspection visit of one of the high-level IAU officers to Moscow, who found a well-kept card catalogue of variable stars founded by P. P. Parenago (1906–1960) and maintained by Parenago, B. V. Kukarkin, and their collaborators.

The new arrangement discontinued the yearly-published series of catalogues: it was decided to issue a catalogue once in several years, with supplements containing only new variables and stars with important changes in the catalogue data, printed between the major editions.

The new Soviet compilers of variable-star catalogues were able to publish the first, one-volume edition of the GCVS already in 1948 (Kukarkin & Parenago 1948). In the style of Soviet scientific publications of that period, the title page of the book mentions only two authors, though an author team (listed only in the Russian version of the bilingual Introduction) already existed. This catalogue contained 10 930 stars.

2. The GCVS

The GCVS surely may be called the main project of B. V. Kukarkin's life. After his death in 1977, the GCVS work was continued by a joint team of researchers in the Astronomical Council of the USSR Academy of Sciences (now the Institute of Astronomy of the Russian Academy of Sciences) and the Sternberg Astronomical Institute of the Moscow University. Till 1988, the team was headed by Prof. P. N. Kholopov (1922–1988), who already played a very important role during Kukarkin's life.

Despite the name, the GCVS actually never was a genuine "general" catalogue. First of all, originally it was not intended to contain Galactic novae or supernovae; there were several exceptions due to tradition. In astronomy of the first half of the 20th century, researchers tried to distinguish between variable stars and novae. By 1950, it was clear that novae and supernovae were just one of numerous classes of variable stars. Soon after the start of the Soviet GCVS project, historical Galactic novae and supernovae were added to the catalogue, and after that all further novae of our Galaxy acquired GCVS names. Also, as a rule, extragalactic variable stars were not included (and are not included, with the exception of several traditional cases, like S Dor, S And, or Z Cen, and a special list in Volume V of the 4th GCVS edition). Currently, there are no comprehensive catalogues of all known extragalactic variable stars; only the situation with catalogues of extragalactic supernovae is good (see `http://www.sai.msu.su/sn/sncat/`).

Probably the most strange tradition limiting the scope of the GCVS is not to include variable stars in the globular star clusters of our Galaxy (variables in open clusters are included). These stars are listed in special catalogues of variable stars in globular clusters, to be discussed in the next invited talk at this conference (Clement 2010). Nevertheless, we have recently opened a possibility to add those stars that meet the GCVS criteria also to our catalogue, having determined accurate equatorial coordinates for many variable stars in globular clusters earlier listed only with rectangular coordinates with respect of their cluster centers (Samus et al. 2009).

Other circumstances now adding to the GCVS being not a genuine "general" catalogue will be mentioned in Section 3.

In 1958, the second, two-volume (14 708 stars) edition of the GCVS was published (Kukarkin et al. 1958). The third edition (Kukarkin et al. 1969–1971) (20 437 stars) already consisted of three volumes.

The GCVS is intended to contain only proven and more or less well-studied variable stars. Currently, the criterion for the star to be considered studied well enough for the GCVS is the possibility to ascribe it at least a tentative variability type or to decide that the star is "unique" (possibly belongs to a type not yet introduced). Earlier, the rules used to be even stricter, like the requirement of the period being known for a periodic variable. Variable stars not meeting the GCVS criteria are called "suspected variables", even if their photometric variations are beyond doubt, and listed in special catalogues. Till the third GCVS edition, the system of the GCVS included two catalogs of suspected variable stars, supplementing each other (Kukarkin et al. 1951, 1965). They contained a total of 12 041 stars.

The fourth edition of the GCVS, surely the last one to consist of printed books, started with the "New Catalogue of Suspected Variable Stars" (the NSV catalogue) with 14 810 entries (Kholopov 1982). It replaced the two earlier catalogues of suspected variables. A supplement to the NSV catalogue, with 11 206 additional entries, was published by Kazarovets et al. (1998). After the NSV catalogue, five GCVS volumes appeared in 1985–1995. The first three of them (Kholopov 1985–1987) are the catalogue of Galactic variables proper, containing 28 435 stars. After them, two more books (Samus 1990, 1995) appeared. The most important part of the first of them, devoted to different auxiliary tables, are cross-identification tables that permit a user to find the GCVS name for an object of interest if its name in one of the major astronomical catalogues is known. The second of them is the GCVS team's first and only attempt, initiated by P. N. Kholopov, to add extragalactic variables to the GCVS and thus make the catalogue more "general". This book contains some 12 000 entries for extragalactic variables, including supernovae. Immediately after its publication, the flow of new discoveries of extragalactic variables became too strong to permit the GCVS team, with its limited human power and funds, to continue this direction of work.

Till 1994, the IAU provided some financial support to the GCVS project. Due to the realities of the Soviet Union, these funds almost never reached the GCVS team directly but permitted it to rely on better attitude of local administrative bodies. Unfortunately, the support was discontinued just at the time of a serious financial crisis in Russian science and just when it became possible to make the IAU money available to the scientific group compiling the catalogue. The IAU Commissions 27 and 42 (now Division V) never discontinued their moral support of our effort.

Currently, it is too expensive for us to continue the GCVS in the form of printed books, and the role of printed catalogues also has become secondary compared to electronic catalogs. The fourth GCVS edition, with corrections, is available at the Strasbourg data center. The most recent version of the GCVS can be found at our web site (`http://www.sai.msu.su/groups/cluster/gcvs/gcvs/`). The site also has a search engine permitting to retrieve GCVS information by the star's name (in the GCVS or in other catalogues), coordinates, variability type, and other parameters.

Stars are added to the GCVS via Name-Lists. The last one published so far was No. 79 (Kazarovets et al. 2008), it makes the number of GCVS stars as high as about 41500. The GCVS+NSV system now contains more than 60 000 Galactic variable stars. The GCVS data base contains stars from the fourth GCVS

edition as well as stars from the subsequent Name-Lists, but, until recently, information provided in the data base for Name-List stars used to be incomplete. We have now started preparing catalogues of Name-List variables in the complete GCVS format. Recently, the first catalogue of this kind (Kazarovets et al. 2009) has been published for the 79th Name-List.

Since the 1990s, the GCVS team has an agreement with the IAU Bureau of Astronomical Telegrams that, upon their request, we give GCVS names for novae and other unusual variables announced in the IAU Circulars within several days, after performing checks necessary for GCVS naming.

For a number of constellations, the web version of the GCVS now contains completely revised information on variability types, magnitude ranges, light elements, with new remarks. This revision will be continued.

3. Current GCVS problems

These days, very many new variable stars are being discovered in automatic photometric sky surveys. Some of the surveys provide their own catalogues of variable stars. In the near future, automatic surveys, especially those from space, will discover millions of new variable stars.

For several reasons, it is not easy to incorporate the stars of variable-star catalogues of automatic surveys into the GCVS. First of all, most ground-based automatic sky surveys use wide-field, small-focal-length instruments, and thus the variable-star coordinates in their catalogues are not precise enough.

Note that the GCVS is ready for automatic identifications with newly-discovered stars having accurate coordinates. In 2002–2006, we checked identifications of all "old" GCVS variable stars using published as well as unpublished finding charts and other sources of information and provided accurate coordinates (to about $1''$) for virtually all of them (Samus et al. 2002, 2003, 2006). We highly appreciate assistance provided by Dr. M. L. Hazen (1931–2006) who sent us finding charts for thousands of Harvard variable stars she had found using the observatory's logbooks and original plates. In the process of identification, we revealed many cases of very wrong coordinates, with mistakes as large as about 10° in several exceptional instances. Only about 200 catalogued variable stars seem to be lost forever because of poor-quality coordinates in their discovery announcements and lacking finding charts.

In several important automatic surveys (like ASAS-3 or ROTSE-I/NSVS, see below), the angular resolution is $15''-30''$, and if a variable star is in a pair, its catalogued coordinates can be wrong by a dozen of arcseconds. Thus, in many cases, automatic-survey catalogues contain quite reliable variable stars at formal positions between two stars separated by $10''-15''$. We strongly prefer not to worsen the standard of coordinate accuracy now established in the GCVS and not to add such stars to the GCVS till the true variable in the pair is reliably identified. It is often possible to determine which of the two stars varies using photographic plate collections. However, the large number of automatic discoveries makes such checks very time-consuming. To improve the situation, it is highly desirable to digitize the existing astronomical plate stacks. Such work is in progress in many plate archives, including the Moscow plate stacks at the Sternberg Institute. Digitizing Moscow plates, we simultaneously develop

effective techniques of variable-star discoveries. Recently, Kolesnikova et al. (2008) used the scans to discover and study 274 new variable stars in the northern half of a $10^\circ \times 10^\circ$ field centered at the star 66 Oph. The continuation of this work, now in preparation, gave about 200 new discoveries in the southern half of the field.

Then, as a rule, variability types quoted in the variable-star catalogues of automatic surveys were determined also automatically. They do give some idea of what is observed, but the GCVS classification is much more detailed and informative. The progress in developing algorithms for automatic variable-star classification is not fast enough, they still provide a large percentage of erroneous classifications. On the other hand, we admit that the GCVS classification system requires serious modification that would take into account the developments of astrophysics but not make the system too clumsy. We presented our suggestions to the IAU Division V (Variable Stars) at the XXVIth General Assembly of the IAU (2006) in Prague. At that IAU meeting, the IAU Commission 27 established a working group to study the future of variable-star catalogues. In 2009 in Rio de Janeiro, the working group has been prolonged for the next three years. We invite everyone interested in the problem to join the discussion. Some materials of the working group can be found at our web site (`http://www.sai.msu.su/gcvs/future/future.html`). The recent revisions of the GCVS use two systems of variable-star classification, the traditional one and the experimental one, suggested by us to the IAU.

It should be noted regarding the problem of the GCVS variable-star classification that the GCVS team receives opposite suggestions from two categories of users. The general astronomical community wants to have an understandable system, and in their opinion, the existing system is too complex, with too many different variability types. However, specialists engaged in studies of particular variable-star classes suggest new and new types. A way out would be to simplify the GCVS classification system and to present more detailed classifications in specialized catalogues. One of the best examples of such a catalogue, kept online in a very careful way and also containing excellent finding charts, was the catalogue of cataclysmic variables. However, this project is no longer continued after the publication of the catalogue's final version (Downes et al. 2005).

Some of the modern automatic photometric surveys are especially important for catalogues of variable stars. First of all, we would like to mention the excellent ASAS-3 survey of the sky to the south of $+28^\circ$ declination (Pojmanski 2002), made with small telescopes. It is a continuing project, photometry is regularly obtained and made public, since mid-2000, for several millions of stars between V-magnitudes 8.5 and 15.0 (this photometry is quite usable in variability studies of stars brighter than $V = 14$). The photometric data are in the standard V band and they can be retrieved at the ASAS web site not only for the stars included in the ASAS-3 variable-star catalogue (some 50 000 variables, among them about 30 000 new) but for each observed star. Thus, it is possible to use these observations for data mining, including discoveries of new variables and improving GCVS data for old ones. The ASAS-3 data have already been extensively used by the GCVS team for checking the catalogued information; for example, see Antipin et al. (2005), Kazarovets et al. (2009), and GCVS information in several constellations revised as mentioned at the end of Section 2.

In the very important ROTSE-I/NSVS project (Woźniak et al. 2004), the northern sky is covered, to declination -38° in the south, also with small telescopes. The photometric data available online for some 14,000,000 stars are limited to a rather short time interval between April, 1999 and March, 2000, making this survey less adequate for studies of long-period variables or slow phenomena. The number of variables announced by the project team is not as large as in the case of the ASAS project, but the prospects of data mining are also very good. However, the NSVS survey is in an instrumental red photometric system, which is also a disadvantage compared to the ASAS-3 survey.

Other surveys, like the excellent OGLE survey (Optical Gravitational Lensing Experiment; see `http://ogle.astrouw.edu.pl/`) in the fields of the Magellanic Clouds and the Galactic bulge with 1-m telescopes, also resulted in many discoveries of new variable stars. The OGLE project should be specially mentioned because of its discoveries of transiting exosolar planets. Most of such projects also provide access to all their observations but do not have interfaces as user-friendly as those of the ASAS or NSVS projects.

Variable-star catalogues of large automatic surveys may be considered self-sufficient for the time being. Adding their stars to the GCVS will be very effort-consuming. So far, the GCVS team finds it more important not to miss variable stars announced individually or as a result of minor surveys. We use to add stars from large automatic surveys to the GCVS if they are studied in detail in subsequent publications.

The possibilities of data mining opened by survey data accessible in the Internet unexpectedly led to a crisis in variable-star publication facilities because of the very large flow of information. The Information Bulletin on Variable Stars (IBVS) published by the IAU Commissions 27 and 42 has been the main place for discovery announcements for several decades but is no longer able to accept all such announcements, especially those based on data mining. However, it does not seem to us a correct decision to publish only "astrophysically significant" discoveries, as it now becomes an IBVS rule. For example, no one could predict astrophysical significance of HZ Her (believed to be a usual irregular variable) for decades after its variability had been announced; but after the discovery of the X-ray source Her X-1, the star became one of the most "significant" variables for many years. Thus, in 2005, having discussed the problem with the editors of the IBVS, we decided to restart the "Peremennye Zvezdy" (Variable Stars) journal, founded by B. V. Kukarkin in 1928, now as a purely electronic, English-language journal, open, among other topics, for all discovery announcements (for details, cf. `http://www.astronet.ru/db/varstars/`).

Several years ago, the AAVSO (American Association of Variable Star Observers) started a new large-scale project, the Variable Star Index (`www.aavso.org/vsx`). It is a kind of a general list of variable stars, with extensive search possibilities, access to finding charts, possibilities to introduce users' additions and corrections. In the opinion of the AAVSO leadership, it can become a future main entry point to the GCVS system. In April 2009, prospects of interaction between the VSX project and the GCVS were discussed in detail between one of the authors (N.N.S.) and the AAVSO Director, Dr. Arne Henden. After this discussion, the coordinates of GCVS variable stars in the two data bases were attentively compared, with a number of mistakes revealed and corrected in both of them. We invited the team of the SIMBAD data base (Strasbourg) to join our

effort, and they also started the mutually benefiting process of checking their coordinates of variable stars against those in the GCVS.

4. Conclusions

The GCVS project, initiated by B. V. Kukarkin and P. P. Parenago on behalf of the IAU in the 1940s, has a long and eventful history. The recent developments in astronomy have led to the necessity to solve a number of problems in order to enable future successful continuation of the project. The current GCVS problems can be summarized as follows.

- The GCVS is no longer (and actually never was) a true "general" catalogue, even for variable stars in our Galaxy;
- no reliable software for automatic classification of variable stars exists;
- the GCVS classification scheme should be simplified but also improved according to the current state of variable-star astrophysics;
- individual approach of a human expert to each star, characteristic of the best catalogues in the past, will be impossible in future, but the experience of automatically updated catalogues shows that they contain too many mistakes;
- virtual data sources have unpleasant imperfections, access to such sources is insufficiently standardized;
- light-curve-analysis software is not standardized, and the experience of automatic surveys evidences for low precision of periods and other derived parameters.

The discussion of these and other problems during the Prague and Rio de Janeiro General Assemblies of the IAU shows that the astronomical community still wants quality variable-star catalogues. Thus, we need to seek solutions of the problems listed above most actively, with participation of variable-star experts worldwide.

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