

# Revised Version of the New Catalogue of Suspected Variable Stars, NSV Release 2

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**Abstract**—We present NSV Release 2, an electronic version of the “New Catalogue of Suspected Variable Stars”. A detailed file-by-file description of the new catalogue version is given. By its structure, we preserve the catalogue as a historical document, but the information it contains has been considerably renewed compared to its first electronic version. Accuracy of coordinates has been drastically improved for the objects in the catalogue; for most of them, we revised photometric and spectroscopic data. Remarks have been renewed. In the cases when there were no finding charts, we recovered variability of 2800 stars of the catalogue, despite large errors of the coordinates earlier published for them. Using photometric data from several sky surveys, we studied and transferred to the General Catalogue of Variable Stars about 5000 NSV stars.

**Keywords:** variable stars, variable-star catalogs

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## 1. INTRODUCTION

This paper presents the revision results and the newly compiled electronic version of the printed book “New Catalogue of Suspected Variable Stars” [1]. It was the third catalogue of its kind published in the USSR since 1946, when the Executive Committee of the International Astronomical Union had transferred the function of keeping the astronomical database, compiling and printing catalogues of variable stars and suspected variables to Soviet researchers. Before the World War II, these functions were performed by the German Astronomical Society (*Astronomische Gesellschaft*). However, during the years immediately before the war, scientists in the USSR also worked actively on the bibliography of variable stars: a complete bibliographic card catalogue of variable-star research, with numerous auxiliary tables and special catalogues, was compiled at the Sternberg Astronomical Institute (SAI) of Moscow State University. Thus, a united team of staff members of the SAI and of the Variable-star Commission of the USSR Academy of Sciences (later, the Astronomical Council of the USSR Academy of Sciences, now the Institute of Astronomy of Russian Academy of Sciences, INASAN) became responsible for this work.

Historical aspects of the development of compilation of variable-star catalogues, from the first lists containing dozens of variables to the most recent edition that already contained several dozens of thousands of variable objects in our Galaxy as well in other

galaxies, were described by Samus et al. [2], Kazarovets [3]. According to the variable-star naming rules adopted in 1947, to get its final designation and to be included into the General Catalogue of Variable Stars (GCVS) [4], the star should exhibit reliably detected brightness variations and it should be possible to decide upon its possible variability type. Variable stars that do not satisfy these requirements enter catalogues of stars suspected of variability.

In 50 years, the united team from the Astronomical Council (later, INASAN) and SAI compiled and published 4 GCVS editions (3 of them, in several volumes) and three books of suspected-variable catalogues: “Catalogue of Suspected Variable Stars” (CSV 1951) [5], “Second Catalogue of Suspected Variable Stars” (CSV 1965) [6], and “New Catalogue of Suspected Variable Stars” [1]. Stars of the latter catalogue get abbreviated designations consisting of the Latin prefix NSV (New Suspected Variable) and a number after it.

The NSV catalogue [1] joined 8856 stars remaining insufficiently studied since the publication of CSV 1951 [5] and CSV 1965 [6] plus additional 5954 stars suspected of variability between 1965 and 1973. The authors had to include into the catalogue even some well-studied variable stars because of their coordinates being close to those of variable stars already having GCVS names. Because of lacking finding charts either for the GCVS star or for the newly discovered and well-studied variable, or because of high-accuracy coordinates not available for them, it was not possible

to identify them and confidently judge that we dealt with the same star. Without such information, we cannot avoid repeated naming of an already known variable star.

The NSV catalogue [1] differed in its format from the first two paper editions (CSV 1951 [5] and CSV 1965 [6]) in the aspect that, for the first time, this catalogue, also in the form of a book, was not set by the printers from a manuscript (like catalogues of 1950s) or not printed from the original set with a special typographic typewriter (like catalogues of 1960s). Its main tables were recorded on a magnetic tape, then used to type them out using the BESM-4M computer of the SAI computing laboratory. However, specific features of computer printing in those years required using only capital letters, with a particular result that abbreviated variability types contained only capital letters (causing no problems even now).

The structure of information presented in the paper version of the NSV catalogue had no differences from earlier catalogues of the same type, with the exception that, for the first time in the practice of the GCVS team, coordinates and precession were computed for the equinox 1950.0 rather than 1900.0. However, the format used to present the equatorial coordinates remained unchanged: to one second of time in right ascension and to one tenths of an arcminute in declination. A novelty appeared in the information on brightness variation range: in the column with information on the magnitude at brightness minimum, we can now encounter the brightness variation amplitude in round brackets.

All 14812 stars in the printed edition of the NSV catalogue are presented in one table, not in two tables as in the earlier editions. After the main table, there follow remarks in Russian and English and the list of bibliographic sources (for a detailed description of the catalogue, confer the GCVS site, <http://www.sai.msu.su/gcvs/gcvs/nsv/readme.txt>).

At the end of the catalogue, we find a table giving, for NSV stars, identifications with their numbers from major sky surveys: Bayer, Flemsteed, BS, HD, BD, CoD, CPD, SAO, ADS, IRC, NGC, CSV, Zinner, Prager, Parenago's stars in the Orion Nebula, as well as with numbers in preliminary designations of variable stars: the system by discovery years—AN (Astronomische Nachrichten); by the discovery country—SVS (USSR); by the observatory—HV (Harvard), S (Sonneberg), BV (Bamberg), VV (Vatican), HBV (Hamburg—Bergedorf); by discoverer—GR (Romano), Wr (Weber), Inn (Innes), Ross, etc. The corresponding references can be found at the GCVS web page, in the section devoted to abbreviations of catalogues and lists we used: <http://www.sai.msu.su/gcvs/gcvs/iv/html/>.

## 2. WORK ON VERSION 2 OF THE NSV CATALOGUE

### 2.1. Astrometric Programs

Astrometric aspects in compiling variable-star catalogues became most important when first results of reductions of photometric data from the Hipparcos mission's observing program of 1989–1993 had arrived, and at the stage of the further rapid increase of the number of variables with the advent of automatic observations with space-borne and ground-based observations and large-scale discoveries of variable stars. Thus, by 1990, the task of improving variable-star coordinates became acute. Earlier accuracies (to one tenth of an arcminute or worse) already became insufficient for reliable identifications of faint stars not contained in old positional catalogues, especially in crowded sky fields.

In 1992, the SAI department of astrometry mainly completed its work on the “four-million” astrographic catalogue [7]. The AC catalogue is based on Carte du Ciel astrographic catalogues compiled during the late 19th–early 20th century at many observatories throughout the world (first epoch), with reductions from modern astronomical photographs (second epoch); it presented the users, besides accurate coordinates, also proper motions for stars to 12th magnitude. From the point of view of its compilers, the catalogue was not improved to perfection, and thus it was not made available to users. However, a part of the obtained measurements was used to compile a supplement to the PPM catalogue [8] for stars to the 10th magnitude.

Another application of the “four-million catalogue” in the department of astrometry became the program aimed at the compilation of the ACVS, Astrometric Catalogue of Variable Stars, by Gulyaev and Ashimbaeva [9]. It contains high-accuracy astrometric parameters for 21 478 stars from the GCVS and NSV catalogues that could be identified with the FK5, PPM, AC, or GSC catalogues. It does not include stars without finding charts or references to Durchmusterung sky surveys. Unfortunately, the ACVS catalogue [9] is still not publicly available from the web site of the department or from the Strasbourg Center of Astronomical Data (CDS), but the authors kindly provided it to the GCVS team in 2000.

Among the first attempts of the GCVS team to considerably improve the standard coordinate accuracy of catalogued variable stars, there was a compilation of the Supplement (11 206 stars) to the NSV catalogue [10]; the effort-consuming work aimed at improving coordinate accuracy for more than 40 000 stars of the General Catalogue of Variable Stars and switching their coordinates to the equinox J2000.0 was completed in 2005 [11–13]. Three years later, the GCVS team also completed its astrometric program of replacing rectangular coordinates with high-accuracy equatorial coordinates for 3398 variable stars in 103 globular clusters [14].

An analysis of the ACVS catalogue [9] revealed several features. Most important is that, in the presence of deeper catalogues discussed below, the authors restricted their searches of faint stars only to the Guide Star Catalogue of the Hubble Space Telescope (GSC), its limiting magnitude being 14–15 in different fields [15]. Thus, the ACVS compilers were able to identify only a half of all GCVS and NSV stars possessing published finding charts. Our checks show that a small part of stars were identified erroneously or missed. For these reason, the GCVS team undertook all the work on GCVS astrometry anew, adding identifications with catalogues of faint stars and measuring coordinates of variable stars that were also missing from such catalogues.

In 2010, we initiated the project NSV (Release 2) aimed at a revision of the old electronic version of the main NSV catalogue [16] not only from the astrometric point of view but with a re-consideration of astrophysical parameters in the base of the catalogue, using new techniques developed when compiling the electronic version of the NSV Supplement and performing astrometry for the GCVS, and also removing format restrictions originating from the printed edition, changing remarks, and expanding the list of catalogues for identification.

### 2.2. *Historical Part of the Catalogue*

In order to preserve the catalogue as a historical document, we decided not to revise the particular information of the NSV main table that justified the objects' being included into the catalogue. We kept the numbering and the order of stars in the table, despite cases of inversion of the B1950.0 coordinates after their improvement. As a rule, no changes were introduced into suggested variability types given by discoverers or investigators, into ranges of brightness variations, or into bibliographic references to publications on possible variations. We found data on precession not necessary and removed them, it is easy to compute them from known coordinates. For a small number of stars, we corrected the photometric system for their magnitudes given in the catalogue; the presented variability types were put in agreement with the description of the types in the GCVS. In particular, type L for poorly studied slow variables was changed to LB for certainly red stars. We corrected detected misprints, added omitted data.

Initially, we intended only to improve the coordinate accuracy, but our plans were corrected with time. In the course of our work, we also solved some additional problems. One of them was that publications cited (and hence the catalogue) lacked magnitudes for some of the variables. As a rule, this happened for fainter stars not contained in the Durchmusterung sky surveys mentioned in Section 1 (BD, CoD, CPD) or in HR, HD, etc. For example, researchers could provide in their publications, in the best case, only the amplitude of brightness variations or brightness

difference between the variable and the comparison star; in the worst case, none of these data but only an announcement of possible variations based on certain criteria. Thus, for 830 NSV stars, discovery papers provided photographic finding charts but did not specify the star's brightness. For these objects, we adopted brightness estimates from GSC2.3 (Guide Star Catalog version 2.3) [17], or from the USNO-A2.0 [18] or USNO-B1.0 [19] catalogues of astrometric standards of the US Naval Observatory, with limiting magnitudes 21–23 in different fields. Using these standards as comparison stars, in the cases of stars of interest for us not contained in the cited catalogues, we estimated brightness of our stars with respect to those with known magnitudes on images from the digital archive of the Hubble Space Telescope Science Institute or from the Aladin Sky Atlas of the Strasbourg Center of Astronomical Data (CDS). Also, if possible, we replaced photographic magnitudes for many bright and relatively bright stars with photoelectric magnitudes (as a rule, in the V band). These magnitudes were taken either from the SIMBAD Astronomical Database (Strasbourg) or from photometry provided by modern sky surveys.

### 2.3. *Improvement of Positional Accuracy*

Future quick checks, in the automatic mode, for identifications in large volumes of data on new variable stars would be impossible without preliminary search for the variables, their identification, and determination of coordinates for every star contained in the GCVS and NSV catalogues. Thus, the main part of our work on data revision in the NSV catalogue was devoted to star positions. Already in the previous century, a fourth part of NSV objects, more than 3700 bright stars contained in old sky surveys, had high-accuracy coordinates for the equinox B1950.0 (for example, in the GC [20] or SAO [21] astrometric catalogues), but their coordinates were specially made rougher, to 0.1', according to the format of variable-star catalogues of that time. For these stars, we took positions accurate to 0.01" and proper motions for the equinox J2000.0 from the Hipparcos [22] and Tycho2 [23] astrometric catalogues.

Our approach to the search for fainter stars and their subsequent identification with modern positional catalogues had two modes, for stars with available published finding charts and for stars without them. It is relatively easy to find a star of the first group using a photographic finding chart or a good hand-plotted finding chart and coordinates with an error not exceeding the field size of the chart. Otherwise, the search could be delayed indefinitely. From the accumulated statistics, errors of coordinates published by discoverers could be from tenths of an arcminute to one degree. Having compared the charts to the sky, we took coordinates of faint stars, as a rule, from 2MASS (Two Micron All-Sky Survey) [24], UCAC2 (The

Second U.S. Naval Observatory CCD Astrograph Catalog) [25], Gaia DR2 [26], and several other astrometric catalogues. For a small number of stars (about 110), we measured the coordinates ourselves. The search for stars of the second group is described in Subsection 2.4 of this paper.

We gratefully acknowledge the assistance provided by the US astronomers M. Hazen and D. Williams in the search for variable stars discovered at the Harvard Observatory and lacking published finding charts. Between 2000 and 2006, they used ink marks on photographic plates taken at the observatory or hand-drawn sketches in observatory logbooks to identify them with the sky and sent us more than 3000 images of  $15' \times 15'$  fields from digital sky surveys (DSS) for the GCVS and about 600 images for the NSV catalogue, with variable stars marked.

#### 2.4. Search for Catalogue Objects

As expected, the most effort-consuming process was to find a variable in the absence of a finding chart. In variance with the GCVS, where, by now, the task of doubtless identification remains unsolved, because of lacking finding charts and hence of accurate coordinates, for a relatively small number of stars (214 of about 58000 stars), the number of stars in the NSV catalogue that, at the beginning of our work, had no finding charts or erroneous charts was 3105, or 21% of all stars of the catalogue. We had to find and identify them. This search did not have 100% success expectations because our experience of photometric analysis for stars identified using charts shows that a considerable fraction of them were erroneously suspected of variability.

We used several approaches when solving this search problem. First, discoverers of some stars published their good astrometric coordinates or coordinates with errors not exceeding  $1''$ . In such cases, we uniquely choose the necessary star in not too crowded fields. Second, we used possibilities to plot finding charts ourselves. We mean a large number of stars from Kapteyn's Selected Areas (SA) ([27] and other papers) with variability suspected from comparison of brightness estimates published for them in different catalogues of the first half of the previous century. Fortunately, some of these catalogues provide, beside other information, also rectangular coordinates of stars with respect to certain centers. We used these  $X, Y$  coordinates (in arcminutes) to plot a chart of the necessary size when we needed it for identification. Third, even in the case of rough coordinates, there exists a high probability that variable stars with considerable amplitudes can be found by eye when comparing several images in one band (B, R, I) for sky regions of a pre-defined size from digital survey archives (POSS, DSS). Fourth, access to electronic archives of CCD observations from different sky surveys was opened during the recent decade. It is possible to select stars with magnitudes in accordance with the discoverer's photometry in a field with a given radius around

the published position and then to find the variable star reducing archive data for them. If we get no positive result, we can expand the search field. Our studies used photometric archives from the following sky surveys: ASAS-3 (All Sky Automated Survey) [28], NSVS (Northern Sky Variability Survey) [29], CRTS (Catalina Real-time Transient Survey) [30], SuperWASP (Wide Angle Search for Planets) [31], ASAS-SN (Sky Patrol All-Sky Automated Survey for Supernovae) [32, 33]. Unfortunately, each of these surveys has its own limitations: a too bright limit for faint stars or too faint limit for bright stars; only partial coverage of the northern or southern sky hemisphere; excluded Milky Way band; very poor angular resolution of objects; low photometric accuracy, etc. Because of these reasons, a part of stars were not found. Additionally, open access to each survey was first opened at large time intervals, and we did not return to objects already analyzed and not found by that time.

#### 2.5. Results of the Search for Variability

A good illustration of the results of our search for variable stars in the absence of finding charts is the statistics from stars studied by one of researchers. In the first half of the previous century, W. Luyten, the most prominent American discoverer of variable stars of the time, published a paper on the discovery of 2350 new variables [34]. Since the paper provided neither charts nor good coordinates for them, finally about a half of his stars (1186) entered the NSV catalogue as non-found objects. By now, we recovered about 920 variable stars, or 78% of the non-found half of Luyten's stars from the paper cited above. We reduced archive observing data available for most of them, established their variability types, determined light elements, and already included 731 stars into the GCVS. Despite efforts to find Luyten's variables undertaken by us and by other researchers, 195 stars remain not found so far.

In general, the results of our search for 3105 suspected variable stars lacking finding charts or having erroneous finding charts are the following. By now, we found more than 2800 of them. In total, during the revision of the NSV catalogue, with simultaneous studies of brightness behavior of some stars using open-access sky survey archives, we transferred 4858 stars, or one third of the NSV catalogue, to the GCVS [4]. Of them, 52 NSV stars could be identified with GCVS stars named before 1980. Also, after improvement of their coordinates, we were able to cross-identify 27 pairs of NSV stars, plus 4 stars were identified with objects in the Supplement to the NSV catalogue. Among "stars" suspected of variability, we found 22 galaxies. About 300 objects remain not found. Among them, besides Luyten's stars, there are 43 "missed" stars from the BD, CoD, and DO catalogues; 16 asteroids with known ephemerides and the dwarf planet Ceres; and 16 doubtful Novae. In the latter case, they could be plate defects or "phantoms" of

bright stars due to erroneous second exposure of the same plate. In the other cases, searches should be repeated using archives of observations from renewed sky surveys.

### 2.6. Other Changes in the NSV Catalogue

Thanks to high accuracy of modern positional catalogues, they can be used as finding charts by means of their visualization. For this purpose, we used the SIMFOV code [35] designed for catalogue visualization by A.A. Volchkov (SAI). As a result, having found a star that previously had no reference to the chart in the corresponding column, we added a reference to the catalogue corresponding to the star's brightness, for example, "DM" for bright stars, "GSC" for relatively bright stars, "USNO" (A2.0/B1.0) for faint stars, "2MPS" (Two Micron Point Source) for faint stars with large infrared excesses; several other abbreviations were also used.

Besides changes listed above in this section, we also revised spectral classification, remarks, and the list of references. Thus, data on spectral types in the main table of the revised version of the NSV catalogue were changed or newly introduced for many stars. In variance with the old book format, where only two symbols were left for spectral types, so that all luminosity classes were omitted, now the records appear complete. Remarks are now given only in English (as determined by the requirements to the electronic version). The number of remarks has slightly decreased; for example, there is no need to introduce a remark with a complete designation of the spectral type or a remark with the star's identification by its number in an open cluster because a corresponding cross-identification table is now available. Other redundant information was also eliminated. Obsolete information was removed, new information added. Parameters of double and multiple systems are presented in accordance with modern knowledge. If parameters of a multiple system noticeably varied during the time covered with observations, they are followed with the year of the most recent measurement. Note that if the remarks do not identify the particular component of the system suspected of variability, the main table contains the coordinates of the primary component. The remarks also contain other useful information. The list of references was appended with numbers from 2894 to 2913. The majority of these papers contain finding charts that were earlier overlooked when compiling the book version of the catalogue or that had appeared after it was published. Numerous misprints were corrected. The list of cross-identification tables with different catalogues was expanded (see Section 3 for more details). In the old tables, we corrected detected mistakes and added overlooked identifications. As earlier, identification tables of the NSV catalogue are merged with similar tables for the GCVS.

### 3. REVISED NSV CATALOGUE

The resized NSV catalogue (NSV release 2) is available at the GCVS web site <http://www.sai.msu.su/gcvs/gcvs/nsv2/>, and also as files `nsv2.txt` (main table), `rem.txt` (remarks), `ref.txt` (bibliographic references), and `readme.rtf` (description of the catalogue).

There also exists a possibility to search the GCVS database, including cross-identifications with different catalogues: <http://www.sai.msu.su/gcvs/cgi-bin/search.htm>.

The file `nsv2.txt` contains the main table of the catalogue. It includes the following information: star number; a flag for the presence of a remark; astrometric data; possible variability type (cf. the description of types at the GCVS web site); brightness at Max and Min; photometric band; two bibliographic references (to the study and to the finding chart); the star's name in the reference to its study; spectral type; identification (if any) with the GCVS or NSV catalogue. The astrometric data are the equatorial coordinates R.A., Decl., accurate to 0.01", for the equinox and epoch J2000.0 and proper motions (if there is no proper-motion information, the epoch of measurement is presented); references to the source of astrometry are given (for explanation of corresponding abbreviations, see `readme.rtf`). The low-accuracy coordinates of non-identified objects are marked with an asterisk "\*"; coordinates accurate to 1" are marked with a colon ":".

The file `rem.txt` contains remarks for 4379 stars whose numbers in the main table are followed with an asterisk "\*". Topics of the remarks are numerous: from the star's name in the published study that is longer than the format provided in the main table to additional astrophysical descriptions and data. On the remarks, see also the text in the Subsection 2.6 of the present paper.

The file `ref.txt` contains bibliographic references to the discovery or study of brightness variations and to the finding chart. It differs from the original version, containing 2913 entries (20 more than in the printed version). Also, detected misprints were corrected in this file.

The text file `readme.rtf` contains a brief introduction, a byte-by-byte description of the catalogue's main table and remarks, a list of abbreviated catalogue names with complete bibliographic references, and the list of references to the text of the file.

### 4. CONCLUSIONS

The coordinate part of the revised NSV catalogue was mainly ready when the third version of the Gaia catalogue, Gaia EDR3 [36], appeared. We undertook an attempt to identify about 2000 NSV stars with this catalogue. For this purpose, we mainly selected faint stars with unknown proper motions from the GSC, USNO, 2MASS, and other catalogues as well as with coordinates measured by us or taken from publica-

tions. Also added were stars with known proper motions determined in relatively old catalogues: SAO, PPM, AC, etc. As a result, coordinates of objects down to 20th magnitude were corrected.

As mentioned in Subsection 2.5, we are going to continue our search for some 250 still not found suspected variable stars lacking published finding charts. We are also planning to use photometric archives of modern sky surveys in order to study that part of NSV stars for which such works was not yet performed.

As the next development stage of the catalogue of suspected variables, we see compilation of a new catalogue that would combine stars from the main part of the NSV catalogue and its Supplement that were not transferred to the GCVS with approximately five thousand poorly studied stars for which the GCVS team has collected information in its archive during the recent two decades.

#### CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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