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UV CETI TYPE VARIABLE STARS PRESENTED IN THE GENERAL CATALOGUE OF VARIABLE STARS

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Abstract. We present the place and the status of UV Ceti type variable stars in the General Catalogue of Variable Stars (GCVS4, edition April 2013) having in view the improved typological classification, which is accepted in the already prepared GCVS4.2 edition. The improved classification is based on the understanding of the major astrophysical reasons for variability. The distribution statistics is done on the basis of the data from the GCVS4 and addition of data from the 80thName List of Variable Stars - altogether 47 966 variable stars with determined type of variability.

The class of the eruptive variable stars includes variables showing irregular or semi-regular brightness variations as a consequence of violent processes and flares occurring in their chromospheres and coronae and accompanied by shell events or mass outflow as stellar winds and/or by interaction with the surrounding interstellar matter. In this class the type of the UV Ceti stars is referred together with the types of Irregular variables (Herbig Ae/Be stars; T Tau type stars - classical and weak-line ones, connected with diffuse nebulae, or RW Aurigae type stars without such connection); FU Orionis type; YY Orionis type; Yellow massive evolved hypergiants with Rho Cas as aprototype); S Doradus type variables - giants and supergiants with high mass loss and occasional larger eruptions (with subtypes η Car and P Cyg, connected with diffuse nebulae and surrounding by expanding envelopes); R Coronae Borealis variables (prototype R CrB), which are simultaneously eruptive and pulsating variables, showing brightness fading suddenly for months to years; Wolf–Rayet variables with binary interactions and rotating gas clumps around the star; Gamma Cassiopeiae fast-rotating Be spectral type variables with formation of equatorial rings or disks; proto-planetary objects; as well as L dwarfs with causes of variability not quite clear yet.

The statistics shows that the eruptive stars are the most common class of variable stars after pulsating and eclipsing classes on the base of their total number. About 60% of all eruptive stars are considered as irregular variables with not completely clear origin of light variations and spectral types and that is why being rather inhomogeneous group of objects. The type of UV Ceti flare stars designated as UV (for flare stars from the solar vicinity) and UVN types variables (flare stars in stellar clusters and associations) are the next ones (30%), and only 10% are the other eruptive variable stars – with designations GCAS+Be, SDor, WR, and RCB.

1. INTRODUCTION

Borne (2013) describes Astroinformatics as a fourth paradigm of astronomical research, after the observation, theory, and computation/modeling. Astroinformatics as data oriented astronomy includes a lot of disciplines as data-intensive computing, astrostatistics, data mining, knowledge extraction, information visualization, information retrieval methods, semantic science presented by semantic data integration, sky-based and catalog-based indexing techniques, consensus semantic annotation tags, astronomical classification taxonomies, astronomical concept ontologies (see Borne, 2010). The significant role of the semantic science is defined by the benefit of the semantic search and indexing in the shared astronomical data and in the academic literature, as well as by the possibility to increase the level of connectivity between them.

In order to support the classification and semantic enrichment of the scholarly literature, where a certain search is conducted, the International Virtual Observatory Alliance (IVOA) Semantics Working Group pleads for usage of standard keywords in the field of astronomy and astrophysics. The idea is to transform the list of keywords into an IVOA standard vocabulary. As a result appeared the Unified Astronomy Thesaurus (http://astrothesaurus.org.), which is intended to provide a formal language that can be used to describe the entire concept field and thus to stimulate the development of astronomical resources. One of the suggested keyword by the IVOA Semantics Working Group is "star: flare". Under the term "*Flare*" a lot of variable stars showing flares with different origin can be found – the red dwarf flare UV Ceti stars from the Solar neighborhood, the flare stars in the open stellar clusters and associations, BY Draconis stars, FU Orionis stars, R Coronae Borealis variables, RS Canum Venaticorum variables, i.e. the concept of flare star is not clear and needs a defining.

In order to define the term *Flare Star* here we consider the flare stars designated in the General Catalogue of Variable Stars (GCVS, Samus et al. 2013) as of types UV and UVN, respectively located in the Solar neighborhood, and in the open stellar clusters and associations. The reason for putting together both types of flare stars is their common physical nature of the observed flares. The prototype is the UV Ceti star, which is the only star (up to the moment) having a dedicated monument in Toronto (Canada) since 1982 presenting a bronze V-shaped center piece with a big orb in the middle situated in a fountain with a sitting area around as was the idea of the sculptor Andrew Posa. The sculptor inspiration obviously comes from the fact that the classical flare stars of the UV Ceti type around the Sun form a physical system - several nearby red dwarf stars including the nearest stellar neighbor of the Sun – Proxima (at distance of 1.3 pc), are flare stars (together with CN Leo at 2.4 pc, UV Cet at 2.7 pc, V1216 Sgr at 2.9 pc), etc.

2. CLASS OF THE ERUPTIVE VARIABLE STARS IN GCVS

According to the typological classification of the variable stars in GCVS (**http://cdsarc.u-strasbg.fr/afoev/var/etypo.htx**) the class of the eruptive variable stars includes variables showing irregular or semi-regular brightness variations as a consequence of violent processes and flares occurring in their chromospheres and coronae, and accompanied by shell events or mass outflow as stellar winds and/or by interaction with the surrounding interstellar matter. The class includes the following separated types of variable stars: UV Ceti stars; Irregular variables (Herbig Ae/Be stars; T Tau type stars - classical and weak-line ones, connected with diffuse nebulae, or RW Aurigae type stars without such connection; FU Orionis type; YY Orionis type; Yellow massive evolved hypergiants with Rho Cas as aprototype); S Doradus type variables - giants and supergiants with high mass loss and occasional larger eruptions (with subtypes η Car and P Cyg, connected with diffuse nebulae and surrounding by expanding envelopes); R Coronae Borealis variables (prototype R CrB), which are simultaneously eruptive and pulsating variables, showing brightness fading suddenly for months to years; Wolf–Rayet variables with binary interactions and rotating gas clumps around the star; Gamma Cassiopeiae fast-rotating Be spectral type variables with formation of equatorial rings or disks; proto-planetary objects; as well as L dwarfs with causes of variability not quite clear yet.

In 1958 at the X General Assembly of the International Astronomical Union (IAU) especially accepted a terminology for eruptive variables of UV Ceti type, which is adopted in GCVS. UV Ceti type stars were ranked as a special type of eruptive variables with UV Cet as a prototype of the flare stars from the solar neighbourhood and the best-known flare star.

The UV Ceti type stars are designated as “UV” in the GCVS in order to distinguish them from the flaring Orion variables designated as “UVN”. In addition to being related to nebulae and their location in stellar clusters and associations, UVN variables are normally characterized by being of earlier spectral types (Ke-Me), and having greater luminosity, with slower development of flares and greater amplitudes reaching up to 9.0 magnitudes in U photometric band - e.g. at V341 Tau, V515 Per, SV Ori, etc. according to the Flare Star Database (Tsvetkova et al. 1995, 1996).

According to the typological classification of GCVS the variable dwarf stars of M spectral class have unpredictable flare activity expressing itself with sudden increases in brightness across the spectrum with quit various amplitudes, reaching the maximum brightness for seconds or a few minutes and returning to their quiescent brightness in several more minutes to hours. They are located in the solar neighbourhood and the common belief is that their flares are analogous to the solar flares but far more energetic and intensive. The cause of the flares is the sudden release of magnetic energy in the photosphere of the star, expressing itself as a spike in brightness, i.e. a flare.

The observed differences between UV and UVN variable stars are due to the difference in ages. Except the increased luminosity during the flare, high energy particles are released such as x-rays and gamma rays. Still in the beginning of the discovery and the investigation of flare stars the idea that these flares may be similar to the solar flares is evinced.

The common physical nature of UV and UVN variables obviously is the cause that in the improved typological classification based on understanding the major astrophysical reasons for variability and accepted in the already prepared GCVS4.2 edition (Samus 2006, http://www.sai.msu.su/gcvs/future/classif.htm), these two types of eruptive variables are merged in one with designation UV.

Some basic characteristics derived from investigations of flare stars applying different methods for observations (optical, spectral, polarimetric, ultraviolet, infrared and radio) of the flares and their random characters, are:

- The relative number of flare stars among all red dwarfs increases at lower luminosities.
- The flare stars are formed in a system from certain luminosity, and this limiting luminosity decreases with increasing age of the system.
- Their evolutionary status gives a plausible scenario how the most numerous stars in the Galaxy – the red dwarf stars - are evolved passing through the stage of flare activity.

3. FLARE STARS STATISTICS

The distribution statistics is on the base of standardization of the object types used in the GCVS, which refers to a categorization of the nature of astronomical sources. At http://www.sai.msu.su/gcvs/gcvs/iii/vartype.txt one can find a distribution statistics of designated variable stars according to their types of variability on the base of the GCVS volumes I-III and the 67th – 79th Name Lists of Variable Stars (NLVS). What has to be done is to add the information for the variable stars from the 80th NLVS. Table 1 presents our sources of information for the total number of designated variable stars - the GCVS edition (Feb. 12, 2009) and the 80th NLVS with its three parts, published in Information Bulletin of Variable Stars (IBVS).

In the following updated versions of the GCVS4 (edition from March 2014 which is uploaded on April 9, 2014, as well as the last one from September 25, 2014, Samus et al. 2014) the total number of designated variable stars is 47968 (or with two stars more than is calculated in Table 1). There is some discrepancy in the total number of variable stars – 47811, quoted in the Introductory of GCVS at http://www.sai.msu.su/gcvs/gcvs/intro.htm and the downloaded GCVS4. The downloaded catalogue contains exactly 47968 variable stars. The difference of 155 variable stars obviously is due of not updated number of stars in the introductory notes of GCVS, but even if there is another reason this difference presents 0.3% from the total number of variable stars and can be neglected for the statistics needs.

Table 1. Statistics sources

Source	Date of source publishing	Number of variable stars
GCVS4	2009, February 12	41638
80th NLVS:		
IBVS 5969	2011, January 31	2036
IBVS 6008	2011, December 21	2159
IBVS 6052	2013, April 5	2133
	Total Number of Variable Stars:	47966

Searching for the latest GCVS edition one can find at http://www.sai.msu.su/groups/cluster/gcvs/gcvs/GCVS5/, the designation "GCVS5", which may cause some misunderstanding. Practically this is a part of the GCVS, which takes into account the new data accumulated since the GCVS4 edition for only three southern constellations: Aquila, Caelum and Camelopardalis.

Following the criteria of the GCVS4 for attachment to certain class of variability given in http://www.sai.msu.su/gcvs/gcvs/iii/vartype.txt, as well as the improved typological classification at http://www.sai.msu.su/gcvs/future/classif.htm), we performed a distribution statistics on the basis of the presented in Table 1 sources. All variable stars are referred to the classes of Pulsating, Eruptive, Rotating, Cataclysmic, Eclipsing, X-ray sources and Other Symbols variable stars.

To Other Symbols are referred also a group of the variable stars designated in GCVS with symbol * which stands for unique variable stars outside the range of the given classifications and representing either short stages of transition from one variability type to another or the earliest and latest evolutionary stages of these types, or they are insufficiently studied members of future new types of variables. Their number is 95. Another group of variable stars which we included in Other Symbols is the group of variable stars without any assigned type of variability – their number is 564. Fig. 1 presents the distribution of all 47966 variable stars according to their class of variability. This distribution among the classes of variable stars shows that the class of the eruptive variable stars according to their number follows the classes of the pulsating and eclipsing variables. In Fig. 2 the distribution of the number of stars from a certain type of variables constituting the class of eruptive variables with total number of 5383 stars is shown. Inside the class of eruptive variables about 60% of all eruptive stars (with total number 5383) are considered as irregular variables with not completely clear origin of light variations and spectral types and that is why being rather inhomogeneous group of objects. The type of UV Ceti flare stars designated as UV (for flare stars from the solar vicinity) and UVN types variables (flare stars in stellar clusters and associations) with total number 1608, are the next ones (30%). About 10% are the other eruptive variable stars – with designations GCAS+Be, SDor, WR, and RCB.

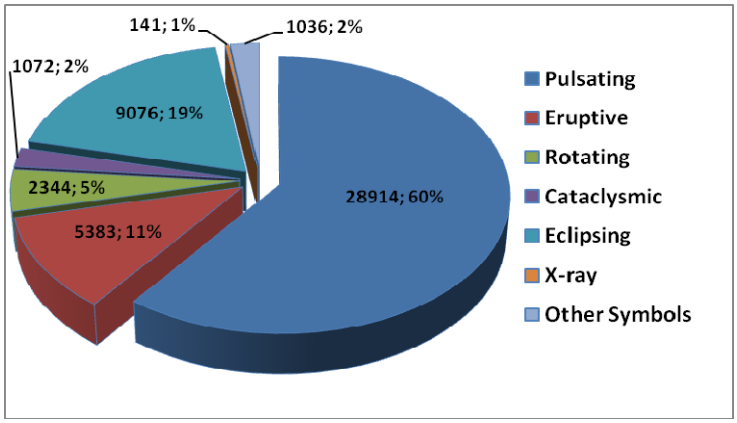

Figure 1: Distribution of 47966 variable stars according to their class of variability.

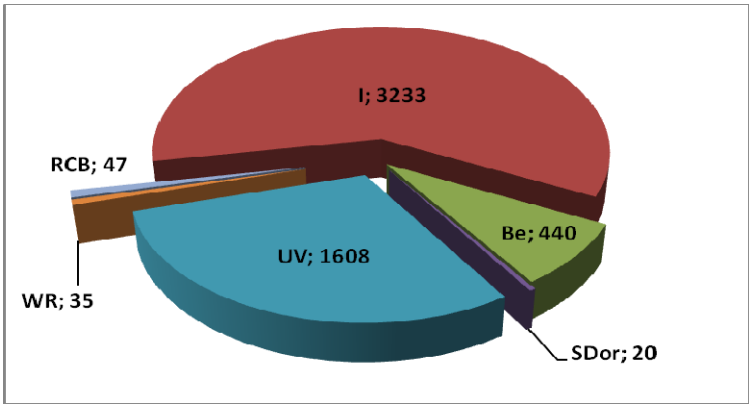

Figure 2: Distribution of the number of variable stars from a certain type inside the class of eruptive variables.

4. CONCLUSIONS

The need of defining the term *Flare Star* initiated the present work on the distribution statistics of the UV Ceti type variable stars presented in GCVS4 edition.

More than 11% of all known variable stars belong to the class of eruptive variable stars, whose number is 5383, and which have different nature of the physical processes, leading to irregular/semi-regular brightness variations or sudden eruptions. The considered types of eruptive variable stars UV and UVN, which are united in the proposed improved typological classification of variable

stars in one type – UV, are well defined type – 30%, having in view that the group of the irregular variables, which are 60%, are not homogeneous group - with not completely clear origin of light variations and spectral types. These 30% of all known eruptive stars are evidence that the flare activity is a common characteristic of all red dwarf stars, whose evolution scenario follows the scheme: T Tau type stars - Flare stars - Main Sequence stars. The number of flare stars among all red dwarfs increases at lower luminosities, which is proved also by the present light-curve data from the *Kepler* Space Observatory by applying a Bayesian method for detecting stellar flares (Pitkin et al. 2014).

An attempt to build a digital data library providing interlinking of original data about the UVN flare stars and their recorded flares on photographic plates (from the Wide-Field Plate Database, http://wfpdb.org) with scholarly literature (especially with Information Bulletin on Variable Stars, http://www.konkoly.hu/IBVS/IBVS.html) was made in Holl et al. (2006).

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