Classification of Variable Stars Based on their Photometric Colours

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Abstract. We present photometric classification of variable stars (transients) based on their colours using General Catalogue of Variable Stars (GCVS) that has the coordinates of about 47,000 variable stars in addition to the information on their type, period of variability etc. The magnitude of a subset of these objects were obtained from Sloan Digital Sky Survey (SDSS) Data Release 10 (DR10). The colour distribution of different variable stars in various colour space were studied using TOPCAT. We conclude that colour can be used with reasonable confidence to guess the nature of the transient.

Keywords. Variable stars, Photometric colours.

1. INTRODUCTION

Stars emit radiation in almost all wavelengths in the electromagnetic spectrum. Their mass varies from a fraction of the solar mass to 10 - 100 solar masses. The colour of the star depends on their temperature. The hottest star emits blue light and has a temperature of $50,0000^0\ C$. A star of lesser temperature would be bluish-white in colour, followed by white, yellowish-white, yellow, yellow-orange, orange-red. The coolest of the visible stars would be deep red. Since stars emit outside the visible spectrum of the electromagnetic radiations, a more precise definition of colour is used in astronomy context.

Astronomers usually subdivide the entire electromagnetic spectrum into different bands of frequency (wavelengths) and represent the flux in each band on a logarithmic scale known as magnitude. Since this flux may vary in different bands for the same object, depending on how its spectra looks like, the magnitude is defined for each band. Thus the flux emitted by a star in the wavelengths close to green colour may be called g-band magnitude or simply g-magnitude. But since the visible region is a very narrow band, we also have infrared bands like i-magnitude, K-magnitude etc. Now colour need not mean the same blue, green colours and in the astronomical context it is defined as the difference in the magnitude between two different bands of the electromagnetic spectra.

Almost all stars vary their brightness as a function of time. Variable stars are those that vary brightness beyond a certain threshold from their mean magnitudes. Some of these variable stars exhibit periodic behaviour, while some others exhibit a once-off dramatic change in brightness by

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several orders of magnitude before fading away. These changes may take place within a day, a week, a month, a year, or over many years. There are a number of reasons for variability. These include changes in star luminosity, star mass, obstructions in the amount of light that reaches earth etc. Since the cause of light variation is different, variable stars are classified into different groups.

Variable stars are mainly classified into intrinsic and extrinsic variables. In the case of an intrinsic variable star, the variation is due to the physical changes in the star or stellar system. This type of stars provides a large amount of information about the internal structure of the star that helps astronomers to model the stellar evolution. Pulsating stars and eruptive or cataclysmic variable stars belong to this category. Extrinsic variable stars are those in which the light output changes due to some process external to the star itself. That is, variation is caused by the eclipse of one star by another or by the effect of stellar rotation. The two main classes of extrinsic stars are the eclipsing binaries and rotating variables. Variable stars are usually studied utilising the light curve data. In this study, we make use of photometric colour information to classify variable stars.

2. MATERIALS AND METHODS

The main objective of this paper is to identify features other than light curve data for the classification of the variable stars. The methodology is to use variable stars with known type and see how well they are separated in the colour space. Since colour is one of the easiest features that can be obtained, it will greatly aid automated classifications if they can produce moderate segregation between the different classes. The Virtual Observatory platform developed by astronomers offers several good tools to do these things and some of them that we used for this study are briefly described below.

Vizier

Vizier catalogue service [1] is an astronomical catalogue service provided by Centre de donnes astronomiques de Strasbourg. It provides access to the most complete library of published astronomical catalogues and data tables available online. These catalogues are arranged in a self-documented database.

General Catalogue of Variable Stars

The General Catalogue Of Variable Stars [GCVS; 2] is a reliable reference source on all known variable stars. The catalogue contains 47,969 variable stars and information regarding their positions, variable type and period.

Sloan Digital Sky Survey

The magnitudes of the objects were obtained from the Sloan Digital Sky Survey [SDSS, 3]. SDSS is one of the most influential surveys in astronomy through which multicolour images covering more than a quarter of the sky were obtained to create a 3-dimensional map containing more than 9,30,000 galaxies and more than 1,20,000 quasars. SDSS has five filters u, g, r, i and z so it is possible to obtain 10 different colours.

TOPCAT

Tool for operations on catalogues and tables [4] is an interactive graphical viewer and editor for tabular data. It provides many facilities for the analysis and manipulation of source catalogues and other tables. TOPCAT provides fast access to large data, performs flexible or fast matching of rows in the same or different tables, concatenate the rows of existing tables to create new ones, allow different plots, broadcast tables with other VO tools etc.

DATA

As mentioned earlier, the data for this study is obtained from GCVS. Out of the 47,969 variable stars in GCVS, only 7453 comes in the sky covered by (footprint of) SDSS. Out of this, 3679 are pulsating, 1168 are eclipsing, 930 are eruptive, 377 are rotating and 163 are cataclysmic. Each of this class is subdivided into many subclasses according to their mass, period etc. To make sure that the plots have enough points, we took 12 of these classes that had at least fifty points in each. The number and type of stars selected from each class are described below.

Pulsating

Twenty two different classes of objects were present in this main group and from this we obtained six. We have used the same notations as given in the GCVS catalogue for representing the variable stars. They are:

LB: Slow irregular variables of late spectral types, usually giants. 561 LB type stars were available.

M: Mira type variables. These are long-period variable giants with characteristics emission spectra. They have longer periods which lie in the range between 80 and 1000 days. 446 M variables were available.

RRAB: RR Lyrae variables with asymmetric light curves. The period ranges from 0.3 to 1.2 days, and amplitudes from 0.5 to 2 magnitude. 1302 RRAB were available in our data sample. RRC: RR Lyrae variables with nearly symmetric, sometimes sinusoidal, light curves. Period ranges from 0.2 to 0.5 days and amplitude is less than 0.8 magnitude. 233 RRC variable stars were available.

SR: Semiregular variables, which are giants or supergiants of intermediate and late spectral types showing noticeable periodicity in their light changes, accompanied by various irregularities. 248 SR variable stars were present in the sample.

SRB: Semiregular giants with poorly defined periodicity (means cycles in the range of 20 to 2300 days). Sometimes the simultaneous presence of two or more periods of light variation is observed. Our data sample contains 261 SRB variable stars.

Eruptive/cataclysmic

By the same criteria described before, we shortlisted three type of variable stars out of 15 classes in this group. They are:

UVN: Red dwarf stars showing outbursts up to 6 magnitudes lasting for only a few minutes caused by flares. There are 312 UVN stars available in our sample.
INB: Orion variables, young stars and protostar in or near nebulae. These stars produce irregular variations up to several magnitudes. 235 such variables are present in the sample.
UG: Close binary systems consisting of a dwarf or subgiant star. Orbital periods are in the range 0.05 to 0.5 days. These system acts as source of x-ray emission. 66 UGs were available.
Eclipsing Out of five eclipsing star types, only two had enough representation in our sample.
EA: Algol type eclipsing system. An extremely wide range of period is observed from 0.2 to ¿= 10000 days. 346 EAs were present in our sample.
EW: Eclipsing systems with period shorter than 1 day. The depth of primary and secondary minima are almost equal or differ insignificantly in EW variables. 486 EWs were available in the data.

Rotating
Among the three type of rotating stars only BY type had sufficient sample size.
BY: Emission line dwarfs showing quasi-periodic light changes with periods from a fraction of a day to 120 days. There exist 290 BYs in the sample.

Thus, a total of 4786 variable stars were used in the present study.

3. RESULTS AND CONCLUSION

From the five magnitudes of SDSS, we obtained ten colours. The colours used are $u-g$, $g-r$, $r-i$, $i-z$, $u-r$, $g-i$, $r-z$, $u-i$, $g-z$ and $u-z$. Out of this, $u-g$, $g-r$, $r-i$, $i-z$ are called primary colours. Plot window of topcat allows us to draw two dimensional scatter plots of one or more pairs of table columns and three sample cases are shown below.

As seen, the BY type stars were concentrated around grids 1 to 3 of $u-g$ and -2 to 2 of $r-z$ while UG type concentrated mainly around grid 0 of both $u-g$ and $r-z$.

Similarly, EA is located from 0 to 2 of $u-g$ and around 0 of $g-z$. SRB stars were concentrated between 2 to 4 of $u-g$ and 0 to 5 of $g-z$.

Analysis of the graph shows that the UG stars are centered on grid 0 of $u-r$ and are positioned in between -1 and 1 on $r-z$. RRAB stars are placed from grids, -2 to 2 on $u-r$ and mainly from -1 to 3 on $r-z$.

Verification of classification accuracy using CRTS variable star data
Now that we have observed significant separation between the different classes of stars, we extended our study to classify the variable stars detected by the Catalina Real-Time Transient Survey [CRTS; 5,6]. CRTS is a synoptic sky survey started with the goal to explore and characterize the faint variable sky. It is the first sky survey which publishes all optical transients immediately after detection through various electronic mechanisms such as Skyalert [7] and CRTS home page.

Figure 4 displays the distribution of cataclysmic variables, considered for the study, in SDSS

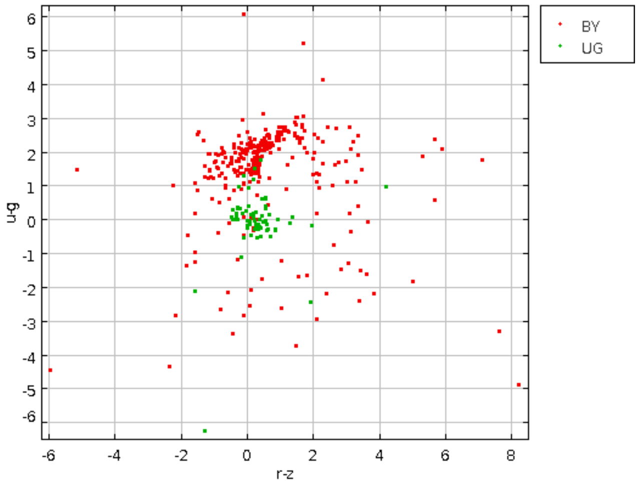

Figure 1. Colour space diagram of rotating type (BY) and eruptive type (UG) in $u-g$, $r-z$ colour space.

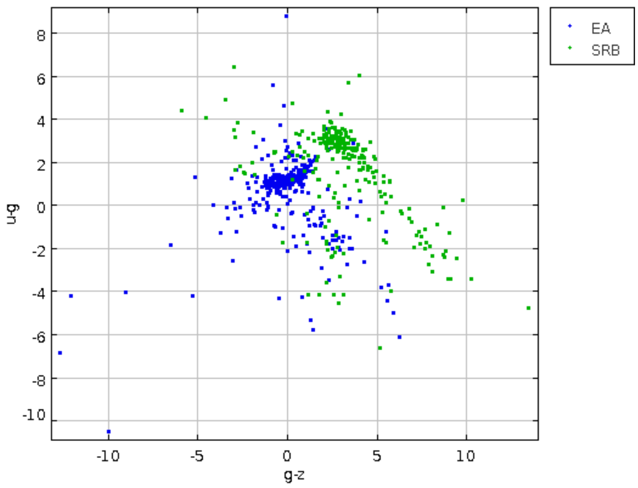

Figure 2. Colour space diagram of Algol type eclipsing (EA)and Semi Regular type(SRB) in $u-g$, $g-z$, colour space.

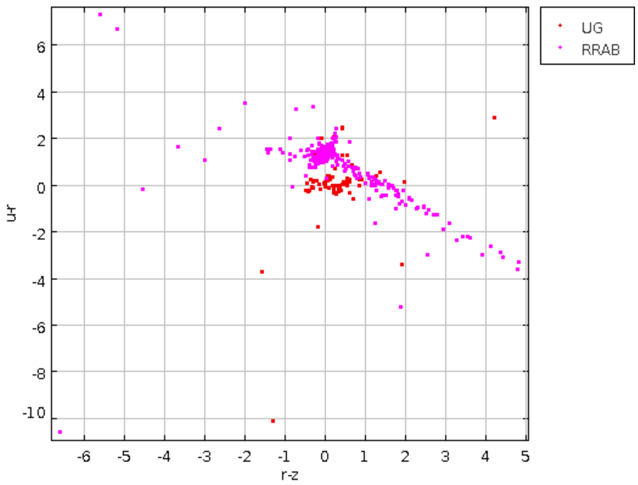

Figure 3. Colour space diagram of eruptive type (UG) and RR Lyrae type (RRAB) in $u-r$, $r-z$ colour space.

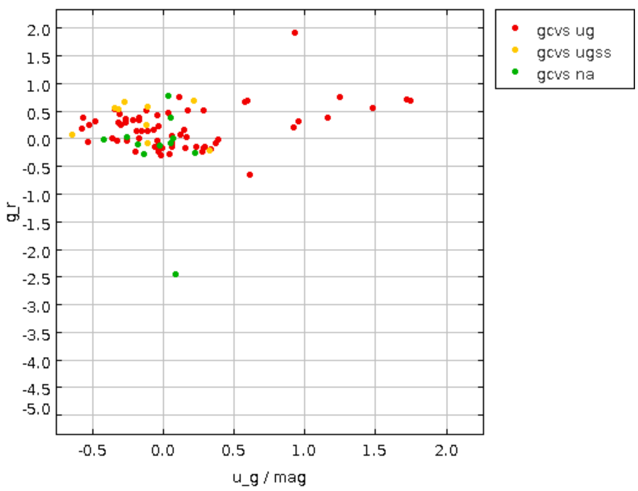

Figure 4. Colour distribution of cataclysmic variable star in GCVS catalogue.

$g - r$, $u - g$ colour space. The main subclasses considered in cataclysmic variable star are UG, UGSS and NA.

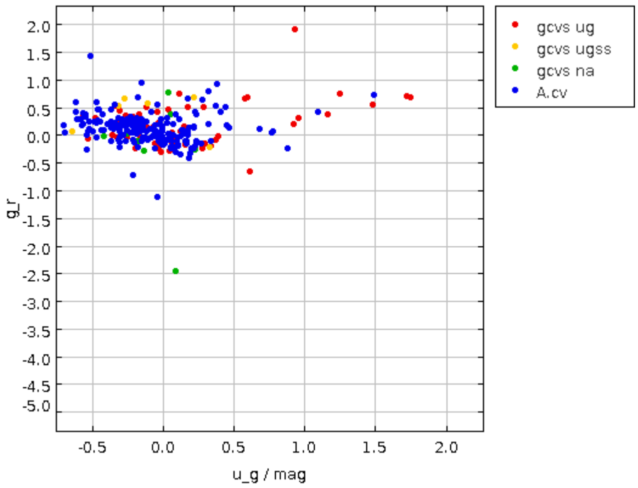

Figure 5. Colour distribution of cataclysmic variables in GCVS and CRTS. The blue points represents the cv in CRTS while others are from GCVS. The figure is obtained by overplotting cataclysmic variables of CRTS with GCVS data shown in figure 4. The cataclysmic variables in CRTS lie in the same region of colour feature space where the GCVS variables are.

4. CONCLUSION

In this work, colour distribution of different variable stars in the same colour space was plotted using TOPCAT. The results show that various types of stars can be easily identified in colour space.

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