The discovery of the variability of HD 46089, which visible to the naked eye, the most important one made by the Galati Astronomical Observatory

Abstract We present the a new variable star discovery made by the mentor Jan Ovidiu Tercu and the student Gabriel Cristian Neagu in the last two months of 2020. The observations needed for this discovery have been made using a 16 inches Ritchey-Chretien telescope with an SBIG STL-6303 CCD camera. The data was taken in the course of 2 nights in B and V photometric filters. The data was calibrated with dark and flat frames in MAXIMDL, the darks being calibrated with bias frames. After the calibration process, the photometric analysis was made using ASTROIMAGEJ and analysed in PERANSO.

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1. Introduction

Variable stars are stars that don’t show constant brightness. Their brightness changes over time in a periodic manner of not. The two main variability groups are:

1. Extrinsic
   Eclipsing, rotating or microlensing events
2. Intrinsic
   Pulsating, Eruptive, Cataclysmic or X-ray

DSCT stars are variables of the δ Scuti type. These are pulsating variables of spectral types A0-F5 III-V displaying light amplitudes from 0.003 to 0.9 mag in V. DSCT stars are representatives of the galactic disk (Samus et al. 2017). Astronomers searching for variable stars sometimes find interesting ones, like HD 46089, which is a bright star considered constant in the past. The data was reported to the American Association of Variable Star Observers (AAVSO), where it was included into the Variable Star Index (VSX).

1.2 Introducing new stars in VSX

Each new variable star submission to the VSX is checked by a moderator. He verifies if the star is already known as a variable. Also, the parameters resulting from the analysis are verified. The extrema have to be well identified, the given epoch has to be the right one for the analysed variable star type and the period needs to fit all the data.

After the the moderator approves the submission it becomes available in the variable star index and the discovery credit is given like in our case.
The VSX database can be queried in search of certain variable star types for educational purposes. The query menu is presented in the next figure:

Fig. 1 The VSX query menu
1.3 Photometry

Photometry is the science of measuring light. Photometry is one of the most important part of variable star research. Before analysing a lightcurve, first time, you have to analyse the images from the CCD camera. The telescope and camera have to be first calibrated using certain stars with known magnitude and color. The extracted data can be plotted using the magnitude and the time to get a lightcurve giving important informations about what causes the brighness change.

Another technique is the surface photometry. It can be used with planets, galaxies, comets and nebulae. That measures the apparent magnitude in terms of magnitudes per square arcsecond.

Magnitude differences between filters indicate color differences, that being related to the temperature. The most used color index is the B-V index in the UBV system. For example, we have the case of 51 Pegasi star. The magnitude in B filter is 6.16 and in V filter 5.46. From this, we get the B-V= 0.70 suggesting a yellow star, around G2 spectral type.

1.4 A short history of variable stars

Variable stars have been observed since ancient times. The Crab nebula is one of the brighest cataclysmic variable stars observed. It exploded in the year 1054 and its the first astronomical object to be connected to a supernova explosion. Another similar object is Tycho's Supernova, discovered by Tycho Brahe in 1572. One more interesting variable star is Mira. Mira is a long period variable star, the prototype for the Mira type. Those stars are red, cool stars at the end of their lives. They show long periods, over 70 days and high amplitudes, some of them having amplitudes bigger than 5 magnitudes. Mira stars are pulsating variable stars. Pulsating variables have different amplitudes in different filters. The redder the filter, the smaller the amplitude.

2. Methodology

Bright stars like this one usually saturate the CCD’s sensor because of the big mirrors used and the high quantum efficiency of the CCD camera. To observe this star we used a unique method involving a sub-aperture mask built at the Galati Astronomical Observatory. The mask blocked most of the mirror's surface allowing only 100 mm's of it to be exposed to the star’s light. This way, we could take images of the star to accurately measure it’s brightness. The data was acquired using both B and V filters and 20 s exposures to get a high ADU value without saturating the sensor.
The photometry was executed in ASTROIMAGEJ (Collins et al. 2017). Both B and V datasets were combined with Hipparcos data (Perryman et al. 1997) and analysed for periodicity in Peranso using the DCDFT algorithm (Ferraz-Mello 1981). It is possible to transform the data in Hp filter into V using a formula available at the AAVSO webpage. For variable stars, where it is possible it is recommended to give the range of variability in V filter. After the Hp data was transformed, the Galati Observatory’s B and V data was shifted to match the first one.

Before the analysis, each frame had to be calibrated with dark and flat frames. The calibration screen is presented in Fig 2.

![Fig. 2 MAXIMDL with the calibrated set of images](image)

The dark frames have to match the exposure and temperature of the lights. This is very important for accurate noise extraction. Also, flats are important to remove the vignetation.

After all the frames are calibrated and aligned it is possible to perform the photometric analysis. As presented in the abstract, we used ASTROIMAGEJ for this in the following manner. First, the target star was selected in the image and then the stars used for comparison. In this case, 6 comp stars with their known magnitudes in the needed filters were used, like shown in Fig. 3. The magnitude of the target star was calculated and extracted into a spreadsheet.
The extracted data was then sorted in the format "HJD, mag, magerr". After the data sorting, we had to download the Hipparcos epoch photometry in the Hp filter and transform it to V. All three datasets were then uploaded in PERANSO and the Galati Observatory B and V data was shifted to the Hipparcos transformed zero point for an accurate extrema determination. After doing the DCDFT analysis with the following parameters: maximum possible period= 0.1, minimum possible period= 0.01 and resolution= 5600, a periodogram was created.

After creating the Phase Plot, a fitting algorithm was applied to determine the maxima and minima of the curve. Also, the error of the measurement is important so we know how accurate was our analysis. For this, we created a spreadsheet. The mean magnitude of the extrema was taken as a baseline, from where we subtracted the average of 3 datapoints around it.

3. Results

From the analysis we got the parameters in the following table:

Table 1. Table showing the analysis results.

<table>
<thead>
<tr>
<th>Internal name</th>
<th>HD identifier</th>
<th>Max mag (V)</th>
<th>Min mag (V)</th>
<th>Epoch of maxima(HJD)</th>
<th>Period (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galati V22</td>
<td>46089</td>
<td>5.21±0.02</td>
<td>5.25±0.02</td>
<td>2459175.642</td>
<td>0.050492±0.000001</td>
</tr>
</tbody>
</table>

The Phase Plot is presented in Fig. 4 with the legend.
4. Discussion

The purpose of this paper is to present the newly discovered variability of HD 46089 by us which has not been recognized in the past. The basis of this statement is that position searches (i.e., R.A. and Dec.) in SIMBAD, and position searches in the General Catalogue of Variable Stars (Samus et al. 2017) and through the SAO/ NASA ADS Astronomy Query Form (http://adsabs.harvard.edu/abstract_service.html) failed to find any reference to the target star. The variability in the demonstrated period and the star’s spectral type from the literature suggest a variable star of DSCT type. In this case, the time of maxima is needed. Using the epoch and period it is possible to make an ephemeris, so in case we want to observe certain phases of the star we can precisely calculate them.

The spectral type is A5Vp, suggesting a hot star around 7880 K. The “p” at the end means that the target star shows a peculiarity, in this case MgII 4481A line weakness (ABT H.A. and MORRELL N.I. 1995). This characteristic arises the possibility of this star being a Lambda Boötes star. A Lambda Boötes star is a type of peculiar star which has an unusually low abundance of iron peak elements in its surface layers. One possible explanation for this is that it is the result of
accretion of metal-poor gas from a circumstellar disc, and a second possibility is the accretion of material from a hot Jupiter suffering from mass loss. The prototype is Lambda Boötes (Jura, M. 2015).

Other variable stars discovered by the mentor and the student

Table 2. Table presenting some of the variable star discoveries made by the mentor and the student

<table>
<thead>
<tr>
<th>VSX name</th>
<th>Period (d)</th>
<th>Max mag</th>
<th>Min mag</th>
<th>Epoch of maxima (HJD)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galati V21</td>
<td>0.039660 ± 0.000001</td>
<td>14.332 ± 0.002 V</td>
<td>14.418 ± 0.002 V</td>
<td>2457277.883</td>
<td>DSCT</td>
</tr>
<tr>
<td>Galati V20</td>
<td>0.071515 ± 0.000001</td>
<td>8.846 ± 0.001 V</td>
<td>8.859 ± 0.001 V</td>
<td>2459114.226</td>
<td>DSCT</td>
</tr>
<tr>
<td>NGCA-V1</td>
<td>220 ± 5</td>
<td>14.8 ± 0.1 r</td>
<td>19.7 ± 0.1 r</td>
<td>2458646</td>
<td>M</td>
</tr>
</tbody>
</table>

In the next figures, we present the plots of those discoveries

Fig. 5 Phase plot of Galati V21
Fig. 6 Phase plot of Galati V20

Fig. 7 Phase plot of NGCA-V1
5. Conclusion

The star HD 46089 is confirmed as a new variable star of DSCT type with the characteristics in the Table 1. The data was reported to the AAVSO/VSX and accepted. A finderchart was created for this star using Stellarium Web. As shown in Fig.4 the star is very easy to observe from a dark sky using the naked eyes, a binocular or a telescope. The star's VSX entry looks like this:

![Fig. 8 Star's VSX entry](image)

6. Acknowledgements

This research used the SIMBAD database and the AAVSO International Variable Star Index (VSX) variable star type designations. We want to thank Sebastian Otero (AAVSO) for guidance regarding the reports.
Mentor’s pedagogical evaluation

After this research, the student got the following perks:
- Investigative skills in the field of scientific research;
- Competences in using the telescope and the CCD camera;
- Competences in the field of photometry
- Competences in the use of astronomical software necessary for data reduction;
- Competences in the analysis and interpretation of data and information acquired as a result of data reduction;
- Competences in the study of variable stars, showing perseverance and precision.

After doing this research, the student is able to do the following:
- to use the equipment from an astronomical observatory;
- to perform photometry on a variable star and to choose the comparison stars necessary for photometric measurements;
- to obtain a light curve of a variable star;
- To determine the period and range of a variable star
- To calculate errors
- To determine variable star types
- To report the data to VSX

The student showed the following attitudes and values during the project:
- coherence and correctness in the use of specific scientific language;
- interest and curiosity for scientific research in the field of variable stars;
- perseverance and precision in obtaining scientific data;
- attention in making astronomical observations;
- creativity in developing a scientific method for observing variable stars;
- capitalizing on critical thinking for developing an astronomical observation plan and reducing data to variable stars;
A finderchart for the Galati V22 star was created in Stellarium Web, presented in the next figure:
References

E. Paunzen, T. Vanmunster; 2016, Peranso - Light Curve and Period Analysis Software
Jura, M. 2015 Lambda Boo Abundance Patterns: Accretion from Orbiting Sources, Astron. J., 150, 166.