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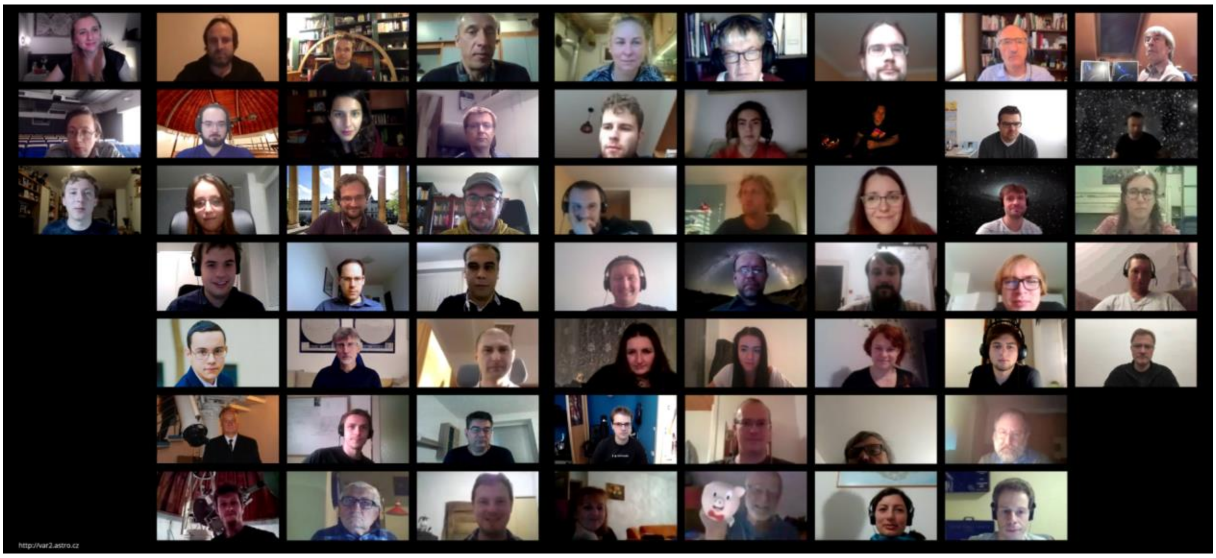

Participants of the conference

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INTRODUCTION

The Variable Star and Exoplanet Section of the Czech Astronomical Society organized traditional autumn conference on research and news in the field of variable stars. In 2020, all human activities were affected by a global pandemic. The restrictions associated with the pandemic also affected the holding of our conference. For the first time in the history of the conference, we were forced to move it to a virtual space.

Despite all the obstacles and limitations of the internet meeting, many quality contributions were made, and many questions were answered in subsequent discussions. Some of these contributions are presented in this paper. Of course, all presented contributions can be also viewed on our YouTube channel.

We can only believe that in 2021 we will meet again face to face.

Kateřina Hoňková

president of Variable Star and Exoplanet

Section of Czech Astronomical Society

Valašské Meziříčí, May 2021

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HI LACERTAE - HER PERIOD, LIGHT CURVE AND MODEL

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Abstract: Paper presents the results of the photoelectric observations of the HI Lacertae system in which there have been successfully determined the period and the complete light curve of this variable. There has been confirmed that the binary is of the Algol type variable. The model of the system based on the BM3 package is presented too. The period of the algolid's IH Lac is P = 1.04244486 day according to our observations.

1 Introduction

In the frame of our scientific program focused to the light curves study of the binaries with very short periods we have selected for our program the HI Lacertae system. The period of this system was declared to be P = 0.166666 d in the database http://var2.astro.cz/. Yet our first observations had shown that this is not true. We have tried to find other results on the WEB. We have found the results of C.Hoffmeister (1967) with four times of minima only. More these minima have been rather far one from the other and so there have not been suite for the period determination. So, we have decided to solve this problem with our own observations, with our own data. Moreover, considering that, according to the WEB, no one has observed HI Lacertae approximately eighty years since the times of C.Hoffmeister, we feel us that we are (immodestly) the successors of his work and of the efforts of his collaborators. So, there is finally suite to observe this system as we have done.

2 Observational technics and method

The system HI Lacertae we have observed photometrically mainly at our observatory "Júlia" (East 19.25598 degrees; North 48.564446 degrees, 350 m (asl)) in the integral light with our Schmidt-Cassegrain telescope Celestron 9.25", f = 2350 mm, equipped with the MI G2-1600 camera (FOV = 20 * 13.4 arcmin). As the comparison star we have selected the star 3UC288 227712 and as the check star we have selected the star 3UC288 227711. The exposition time = the length of exposure had been 30 seconds. We have observed in 16 nights from July 5th, 2019 till October 27th, 2019. Next, we have observed from August 22nd, 2020 to September 15th, 2020 in the nine nights and we have been able to register three new minima too. All the relevant data are given in the Tab.1.

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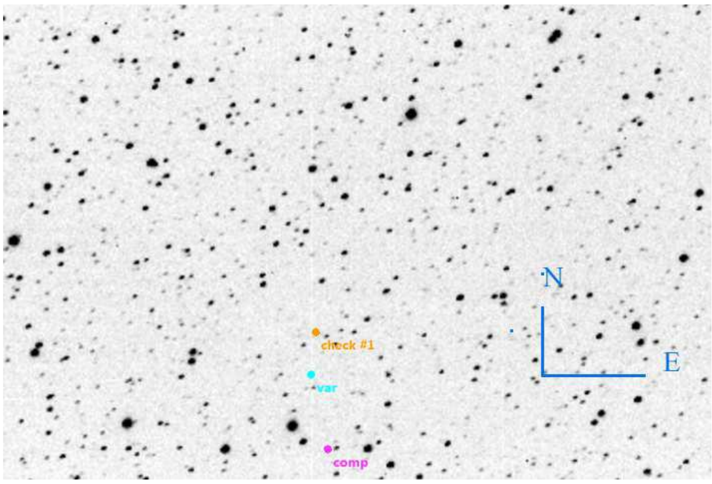

Figure 1: The field of HI Lacertae

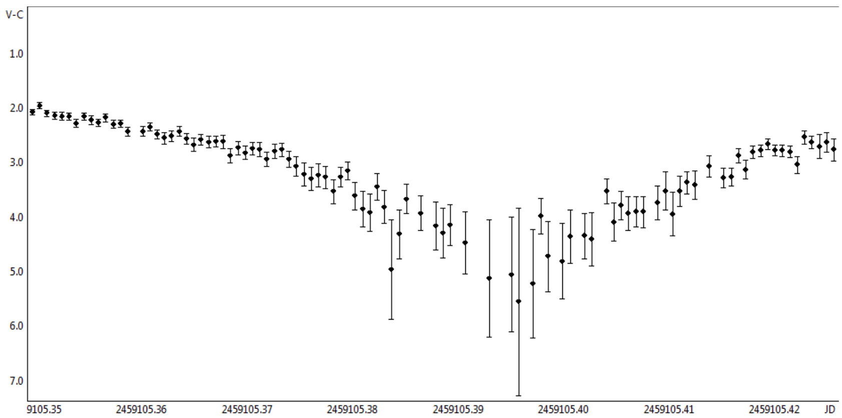

Figure 2: The minimum from JD = 2459105.39532. Data and their error bars

The astronomical map of the variable in common with the selected comparison and check star is on the Fig.1. The precision of our data is demonstrated with the Fig.2 which is partial result from the MUNIWIN 2.1 software package for the JD = 2459105.39532 minimum.

3 Data analysis

As we have mentioned in the introduction, we have selected the HI Lacertae system in our observational program owing to the pre-declared very short period of variability. Having at our disposal our own observations longer in time more than 0.26 d with no variation in magnitude there had been clear that the system is worth to observe. And really, after yet mentioned 25 nights in which we have observed eight primary and two secondary minima we have been able to construct the full light curve and determine the period of the system of course. We allow us to mention that we have not find any next observations of this system except for the data of C.Hoffmeister (1967) which had published four times

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of minima of the HI Lacertae system. Our results in common with the results of C.Hoffmeister are in the Tab.1. The full light curve constructed on the base of our data only is on the Fig.3.

The O-C diagram for our data and for the data of C. Hoffmeister are on the Fig.5. The O-C value +0.169 for the just first observation of the HI Lacertae from the night 1942-01-17 (JD = 2430377.26) is rather out from order. All the data we are presenting on the Fig.5 - left. We present the data where there is this minimum excluded on the right part of the Fig.5. The character of the fitting line is not changed too much.

On the Fig.6 there is the O-C diagram for our data only with the relevant fit linear line.

Table 1: HI Lacertae primary and secondary minima

Number	JD-min	Minimum type	O-C	Date
1	2430377.26	primary	+0.169	1942-01-17
2	2431267.46	primary	+0.070	1944-06-25
3	2341316.46	primary	+0.072	1944-08-13
4	2431413.42	primary	+0.079	1944-11-18
5	2456477.43975	primary	+0.180	2013-07-03
6	2458714.4884	primary	+0.010	2019-08-18
7	2458727.518	secondary	-0.008	2019-09-01
8	2458739.5076	primary	+0.009	2019-09-13
9	2458748.364	secondary	-0.004	2019-09-21
10	2458783.2981	primary	-0.014	2019-10-26
11	2458784.3266	primary	0	2019-10-27
12	2459105.39532	primary	-0.023	2020-09-12
13	2459106.437095	primary	-0.024	2020-09-13
14	2459109.518307	primary	-0.028	2020-09-17

Table 2: Characteristics of comparison stars. Magnitudes are taken from GUIDE9 software

Star	ID	*RA*[h m s]	*DEC* [° ´ ´´]	Mag [mag]
Comp	3UC288 - 227712	22:56:50.2757	+53:45:42.763	13.48
Check	3UC288 - 227711	22:56:50.2697	+53:48:50.007	12.38

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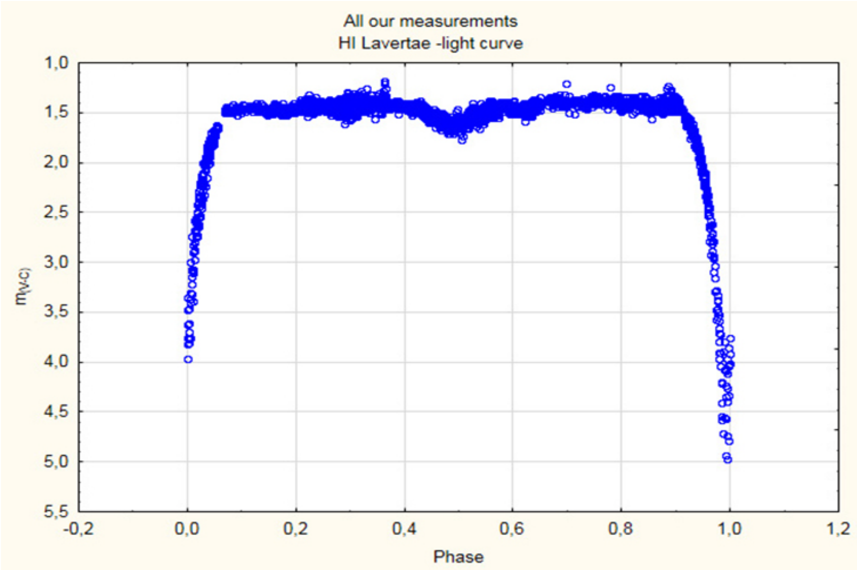

Figure 3: The light curve of HI Lacertae constructed from our measurements

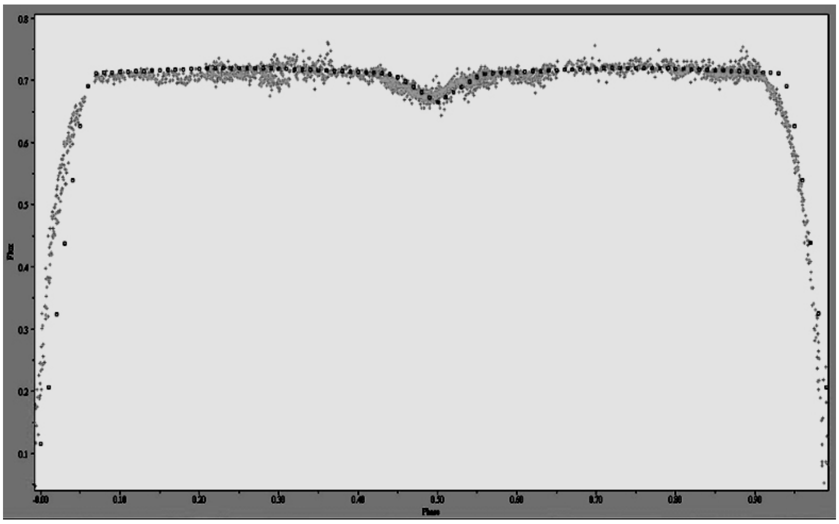

Figure 4: The light curve of HI Lacertae with the BM3 model data

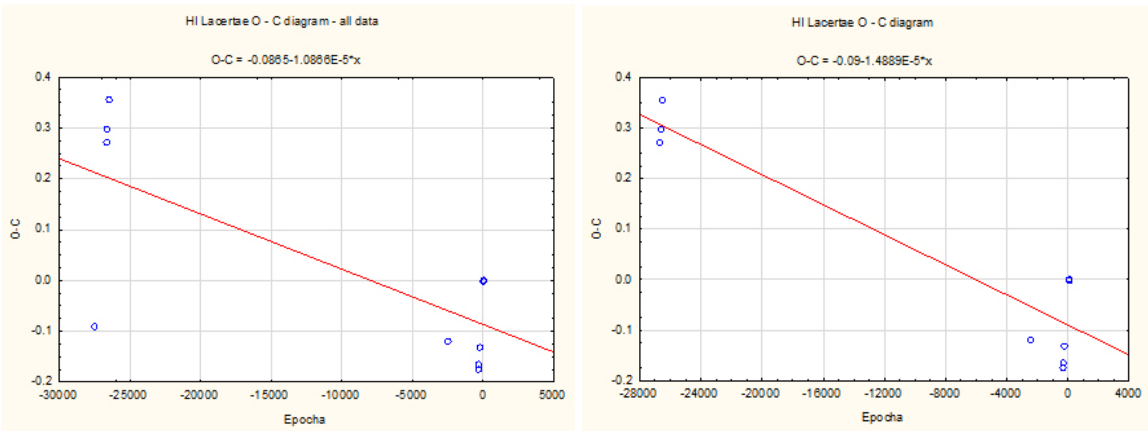

Figure 5: Left: The O-C data all. Right: The O-C data. Minimum of 2430377.26 excluded

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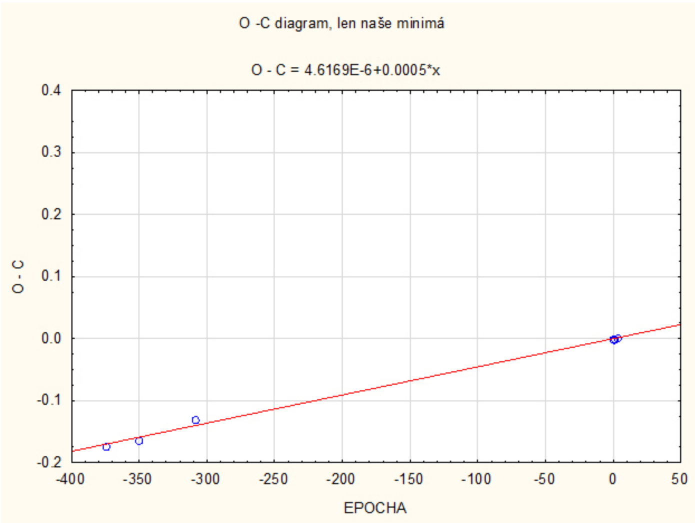

Figure 6: The O-C diagram for our measurements only

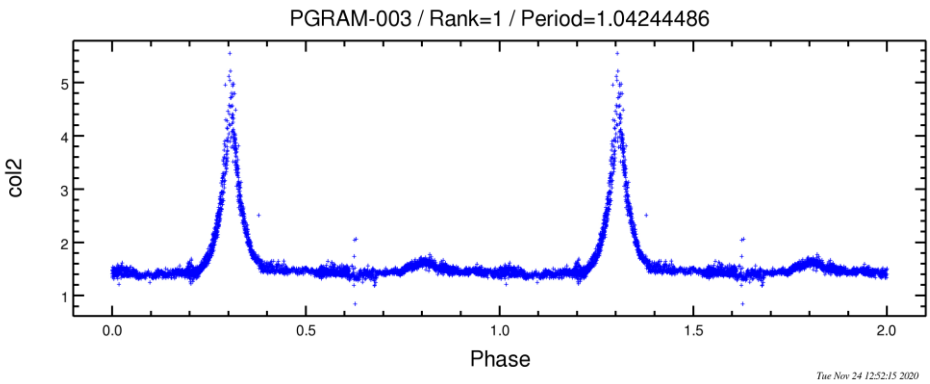

Figure 7: The result of the period search by the usage of the NASA nph-pgram

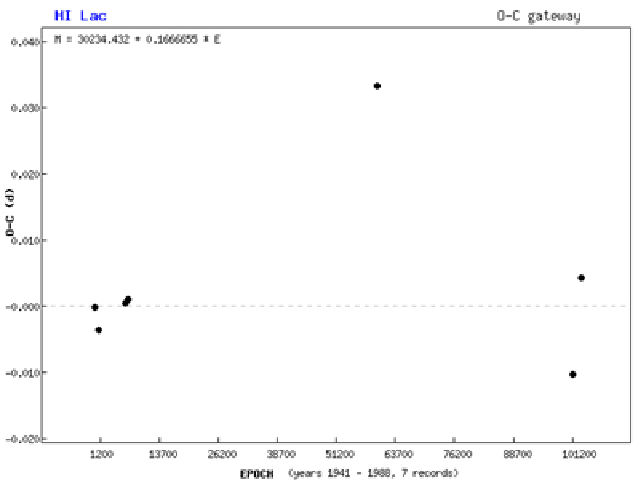

Figure 8: The O-C diagram HI Lacertae from www.var2.astro.cz

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- EPOCH O-C HJDmin P/S METHOD OBSERVER SOC,BULLETIN,S2,
- BUL2,REMARK,INSTRUMENT
- 0 0.0000 30234.4320 p pg none V,0010,V,0010,,
- 857 -0.0033 30377.2610 p pg none V,0010,0,GCVS,,
- 6492 0.0006 31316.4250 p pg none V,0010,V,0010,,
- 7074 0.0013 31413.4250 p pg none V,0010,V,0010,,
- 59825 0.0335 40205.2290 p pg none V,0010,V,0010,,
- 101118 -0.0100 47087.3040 p pg none V,0010,V,0010,,
- 103063 0.0046 47411.4830 p pg none V,0010,V,0010,,

Figure 9: The relevant data for Figure 8

Table 3: HI Lacertae BM3 model data

Parameter	Value
geometry	spherical
mass ratio	0.91
input mode	Omega potentials
omega-1	5.9
omega-2	6.1
wavelength	4400
temperature-1	17000.0
temperature-2	7000.0
gravity-1	0.5
gravity-2	0.8
limb-1	0.8
limb-2	0.7
reflection-1	0.1
reflection-2	0.5
user norm factor	0.72
inclination	88

4 Results

The first goal of our effort and of our observations there had been to check the period of the HI Lacartae. Yet our first observations have excluded the period 0.16666 d. So, we decided to observe as many nights as we had been able to determine the period of this system correctly. We have used the NASA *nph-pgram* for this goal. Our results are presented or documented with the Fig.7. The character or the shape of this diagram needs no comments according to our opinion.

The period of the algolid‘s system HI Lacertea is 1.04244486 d. More as there is possible to fit the O - C data with the equation O - C = 4.6169E-6 + 0.0005*E we allow us to conclude that the period of the system is not stable. The period is slightly growing up according to our observations.

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5 Conclusions

We have determined the period of the HI Lacertae binary from our data and we feel this as the basic result of our paper.

Of course, on the WEB page var2.astro.cz in the section concerning the eclipsing binaries and the system HI Lacertae especially there is possible to see the data given on the Fig.8 and Fig.9. This information disagrees with our results. We will not allow us to comment this but surely, we allow us to stress that our observations are correct and in any case the period of the HI Lacertae is not 0.16666 d as there is given on the up mentioned WEB page.

Next the amount and quality of our photometric data allow is to construct the model of the HI Lacertae system. Our results are on the Fig.4 and in the Tab.3. As we have at our disposal the BM3 close binaries modelling software we have applied it on these our data. The basic results of our model are in the Tab.3. The obtained light curve model is on the Fig.4. These results fully confirm our supposition the HI Lacertae is Algol type variable system with the main component as very hot or bright star and with the secondary component as very cold or dark star. Next as the period of the system is rather short the stars should not to be of giant but of dwarf character. Of course, to solve the model in its complex character there should be realized the spectroscopic observations too. Unfortunately, these observations are out of our technical possibilities in this moment.

Of course, there is possible to work with residuals between model and observations but this we feel to be of mathematical value only. To have real physical information requires the radial velocities data. Of course, we are accepting the BM3 model as true and full one but indicative - orientational only from the physical point of view.

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SYMBIOTIC BINARIES AS IDEAL TARGETS FOR AMATEUR OBSERVERS

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Abstract: Symbiotic systems are interacting binaries, usually composed of a cool giant and a hot white dwarf. They are characterized by significant brightness changes on various time scales from minutes to decades, associated with interesting effects in their spectra. Although many new symbiotic binaries have been discovered in recent years, several questions about their components, evolution, and activity mechanisms remain unresolved. At least some of the answers can be provided by long-term monitoring of the symbiotic population. The present article discusses the importance of photometric and spectroscopic observations of symbiotic binaries obtained by amateur observers in the time of space satellites, all-sky photometric surveys, and a large amount of spectroscopic data obtained by professional observatories. It also illustrates the importance and possibilities for observers with the example of several successful collaborations of professional and amateur astronomers in this field.

1 Introduction

Symbiotic binaries are unique astrophysical laboratories in the study of stellar evolution, mass transfer, accretion processes, stellar winds, jets, dust formation, or thermonuclear (TN) outbursts. Systems classified as symbiotics usually consist of a cool giant of a spectral type M (less commonly K or even G)[1] and a hot, luminous white dwarf (see, e.g., the reviews by Mikołajewska, 2012; Munari, 2019). In the recent literature, such systems are referred to as burning symbiotic binaries, as the relatively high luminosity (~ 10^{2-4} $L_\odot$) and temperature (~ 10^5 K) of the hot component is maintained by TN burning of hydrogen-rich matter on its surface (e.g. Mikołajewska, 2003; Munari, 2019).

Based on the adopted definition of a symbiotic binary, systems of a giant transferring matter to a low luminosity white dwarf, or a neutron star are also considered to be symbiotics (Luna et al., 2013; Mukai et al., 2016). These belong to the group of so-called accreting-only symbiotics. Moreover, some authors also include the systems with mainsequence accretors to the symbiotic group (e.g. Kenyon, 1986). Others classify them

[1] In addition to O-rich giants (spectral type M, K), several symbiotic stars, especially in the Magellanic Clouds with a lower metallicity, are C-rich (carbon stars).

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as pre-symbiotic stars (e.g. Munari, 2019), which could eventually evolve into 'normal' symbiotics when the giant becomes a white dwarf, and the current main-sequence star evolves to a giant provided that they survive the common-envelope stage. In the following text, the description is mostly limited to burning symbiotic stars, as these are of particular interest at optical wavelengths. However, it is clear, that the symbiotic stars are a rather heterogeneous group of objects.

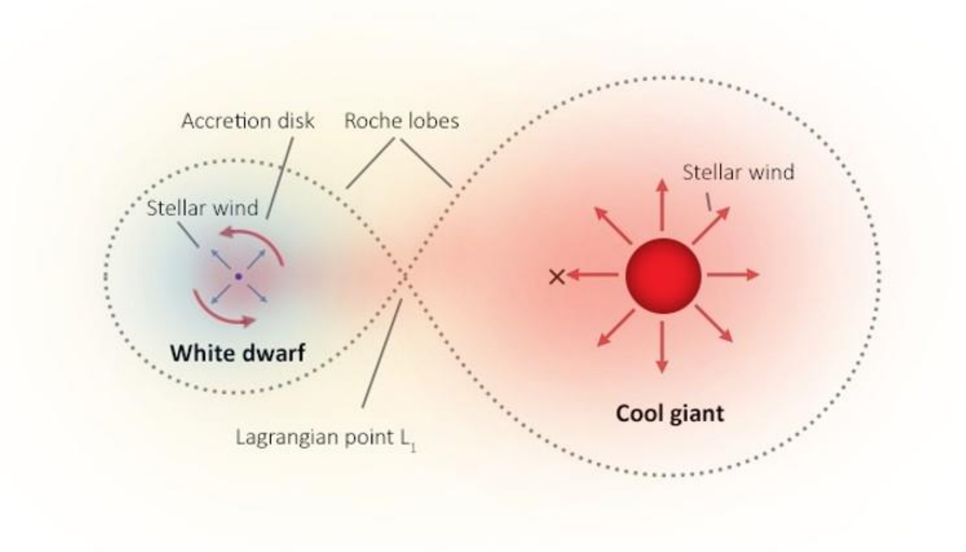

Figure 1: Simplified model of a burning symbiotic binary consisting of the cool giant as the donor and the white dwarf as the accretor of matter. The size-to-distance ratios in the figure are calculated for the symbiotic binary AG Dra.

In every symbiotic star (regardless of the aforementioned types), the mass donor is a giant star, which implies that these systems have to be large enough to accommodate such an evolved star. Typical orbital periods of symbiotic systems range from hundreds to thousands of days (e.g. Belczyński et al., 2000; Gromadzki et al., 2009, 2013). If the cool component is a Mira, the orbital period could be even longer (few to tens of years). The mass transfer between the components takes place via the Roche-lobe overflow or via the stellar wind of the cool giant (e.g. Kenyon & Webbink, 1984; Mikołajewska, 2007; Mohamed & Podsiadlowski, 2012), which is also the source of the dense circumbinary envelope of these systems. The simplified model of a burning symbiotic binary is shown in Fig.1.

All the aforementioned radiation sources contribute to the overall spectral energy distribution of a symbiotic star (e.g. Skopal, 2005). In addition to two stellar (the giant and the hot component) and one nebular source, the emission of the heated dust (e.g. Whitelock, 2003; Mikołajewska, 2012; Akras et al., 2019) or signatures of bipolar outflows of matter (e.g. Leedjärv, 2004; Skopal et al., 2018; Lucy et al., 2018a; Merc et al., 2019a) also contribute to the spectrum of some systems. Due to the relatively different temperatures, these sources dominate in different wavelength regions. Hot components dominate the X-ray and UV region, while giants are especially prominent in the IR, with characteristic signatures observable also in the red part of the optical

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region. The nebular emission is usually dominant in the optical part of the spectrum. In addition to continuum emission, prominent emission lines (e.g., Balmer lines of H, lines of neutral and ionized He, Fe, forbidden lines of [O III], [Ne III], [Ne V]) could also be present. An example of an optical symbiotic spectrum is shown in Fig.2.

Most recent surveys searching for symbiotic stars focus on detecting prominent emission lines in their spectra (e.g., Miszalski et al., 2013; Miszalski & Mikołajewska, 2014; Mikołajewska et al., 2014, 2017, and references therein). For this reason, they detect especially the burning symbiotic stars. The accreting-only symbiotics are quiescent in the optical region, without prominent activity and emission lines, and can be detected only by their hard X-ray spectrum and/or fast UV variability (Mukai et al., 2016).

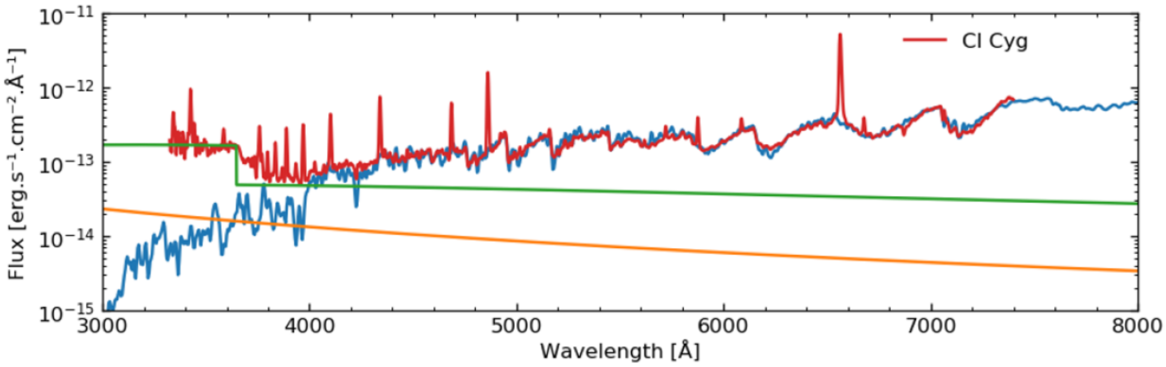

Figure 2: Comparison of the observed optical spectrum of CI Cyg (shown in red) with the one of M4 giant (in blue; from Pickles, 1998). The Balmer jump presented at 3646 Å is caused by the nebular radiation (green color). The contribution of the hot component is shown by the orange line. The spectrum of CI Cyg was obtained from the ARAS database (Teyssier, 2019).

Symbiotic systems have been detected not only in the Milky Way. The New Online Database of Symbiotic Variables[2] (Merc et al., 2019b) lists objects located in another 14 galaxies (e.g., M31, M33, LMC, SMC). In total, it consists of almost 600 confirmed and suspected symbiotic stars. However, many of these systems are only poorly studied. Longterm monitoring is needed to reveal the orbital parameters of the systems, characterize the components, and understand the physical mechanisms responsible for the observed behavior of these interacting binaries. As will be discussed later in this article, the amateur observers' contribution and pro/am collaborations are significant in this particular field.

2 Photometric variability

Symbiotic stars display a wide variety of interesting photometric activity. Their light curves are often very complicated and irregular. The most prominent changes in the light

[2] http://astronomy.science.upjs.sk/symbiotics/

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curves of symbiotics are outbursts (Fig.3). Depending on their nature, symbiotic stars can be divided into three main categories (see, e.g., Mikołajewska, 2007; Munari, 2019):

- **classical (Z And-type) symbiotics** - alternation of the active stages with quiescence; activity usually lasts from a few weeks to years and series of several outbursts (1 - 3 mag) are observed (e.g. Munari, 2019; Merc et al., 2019c),
- **'slow' symbiotic novae** - prominent thermonuclear outbursts of 3 - 7 mag; slow decline for several decades (e.g. Mikołajewska, 2010),
- **recurrent symbiotic novae** - short outbursts (days) with a recurrence time of few years (e.g. Mikołajewska, 2010; Mróz et al., 2014).

We should note that there are confirmed symbiotic binaries without an observed outburst. In addition to the outburst activity, the light curves of symbiotic binaries are rich in various other changes on time scales from minutes, through months and years to decades (Mikołajewska, 2007). Except for flickering, these are not related to mass transfer between components.

Orbitally-related variations are usually well observed during quiescent phases of symbiotics (Friedjung et al., 1998). The light curves show minima during the giant's inferior conjunctions (see, e.g., the quiescent part of the light curve of AG Peg or Z And in Fig.3), and the amplitude of these variations increases towards the shorter wavelengths. This effect is partly caused by the reflection effect on the giant and partly by the asymmetry of the symbiotic nebula due to its various optical thickness in different directions (e.g. Skopal, 2008; Munari, 2012).

If the giant is significantly tidally distorted, the observed area of its surface changes during the orbital motion (Munari, 2012). Consequently, two minima of brightness are observed during the giant's superior and inferior conjunctions (ellipsoidal effect). As this effect is associated with the giant's radiation, it is more pronounced on longer wavelengths. Both reflection and ellipsoidal effects are more prominent for binaries with higher inclinations and vanish for symbiotics seen pole-on. If the inclination of the symbiotic system is close to 90°, the eclipses of the hot component (and/or the surrounding ionized nebula) by the giant can be detected (see, e.g., the light curve of AX Per or AR Pav in Fig.3).

Apart from the variations that occur on orbital period time scales and the activity of symbiotic binaries, both their components often exhibit intrinsic variability on various time scales from minutes to years. The cool components of symbiotic systems are regularly (Mira variables in D-types; periods ~ 300 - 600 days) or semi-regularly (in S-types; periods 50 - 200 days) pulsating (Whitelock, 2003; Gromadzki et al., 2009, 2013). The pulsations are more pronounced at longer wavelengths, at which the giants dominate the spectra of symbiotics (see, e.g., the light curve of R Aqr in Fig.3). In some cases, the rotation of both components can be detected in the light curves (Munari, 2012).

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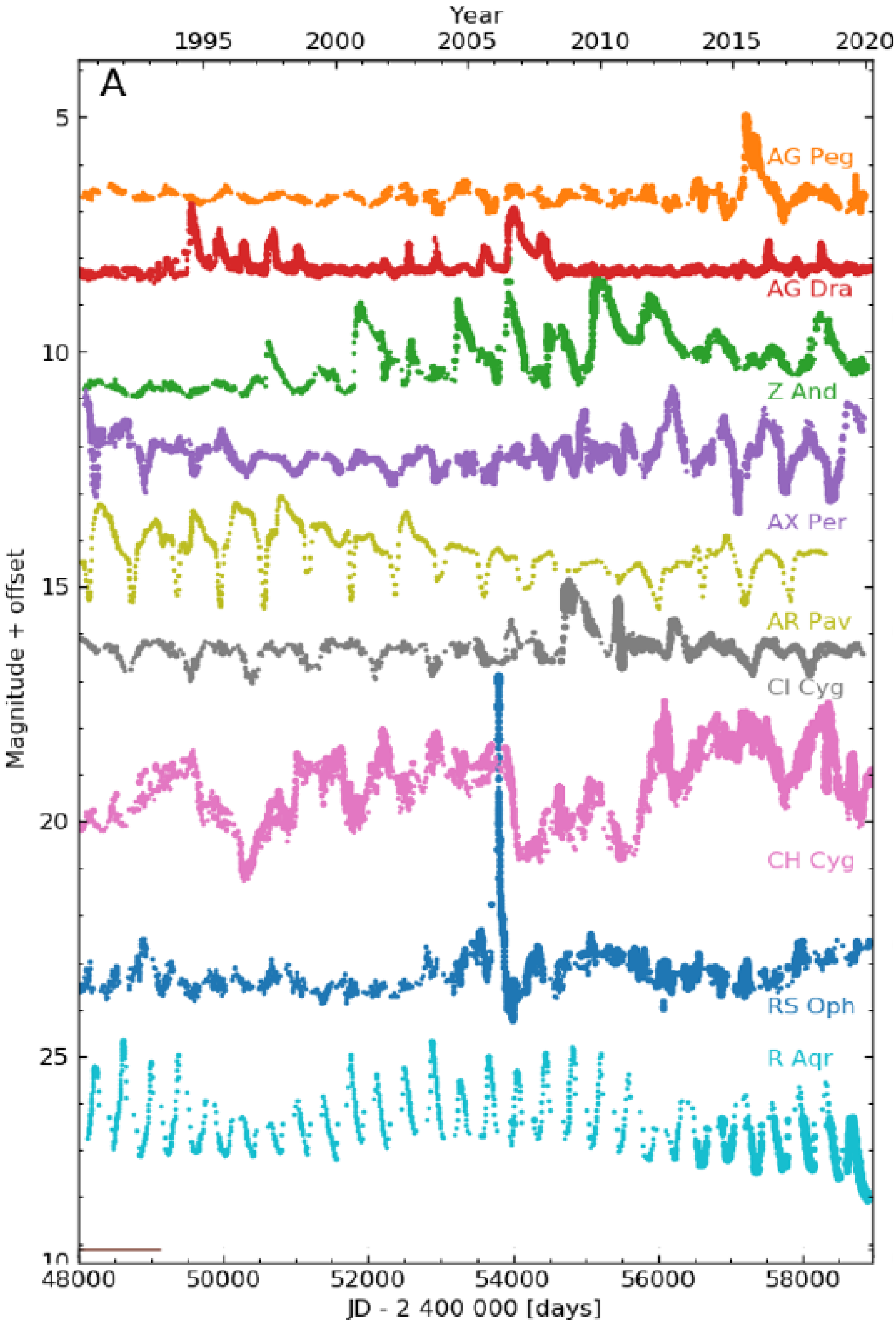

Figure 3: Long-term light curves of selected classical symbiotic stars (AG Peg, AG Dra, Z And, AX Per, AR Pav, CI Cyg, and CH Cyg), the recurrent symbiotic nova (RS Oph), and the Mira pulsator R Aqr over the last 30 years. Smaller dots represent visual data, larger ones CCD data in V filter. Most of the data were obtained from the database of the American Association of Variable Stars Observers (AAVSO, https://www.aavso.org/). These data are supplemented by photometric observations from the literature (see Merc et al., 2020a, and references therein).

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Last but not least, light curves of few symbiotic systems show stochastic photometric variations (flickering) with amplitudes of several hundredths to tenths of magnitude (more prominent on shorter wavelengths) and time scales of minutes to hours (Dobrzycka et al., 1996; Sokoloski et al., 2001). This effect is probably related to the presence of accretion disks around the hot components, similarly to cataclysmic variables.

3 Spectroscopic changes

The typical spectra of symbiotic binaries are shown in Fig.4. The most prominent changes in their spectra are due to the outbursts of these interacting binaries. These events significantly influence the overall shape of the continuum and the presence, intensity, and shape of the emission lines. Naturally, different effects could be observed during the outbursts of slow symbiotic novae, recurrent symbiotic novae, and classical symbiotic stars as they differ in the triggering physical mechanism.

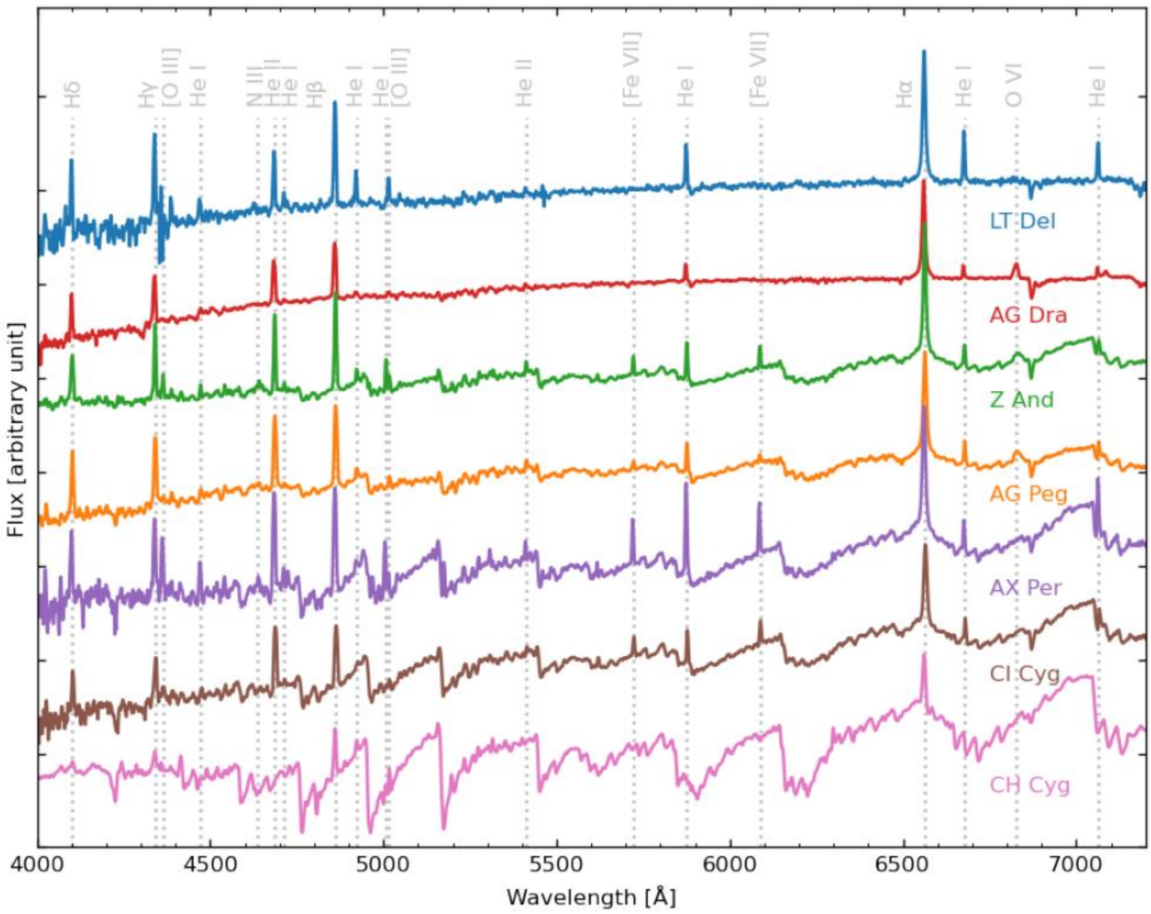

Figure 4: Spectra of classical symbiotic stars sorted according to the temperature of the giant. LT Del (the spectral type of the giant is G6) and AG Dra (K3) are yellow symbiotic stars. Z And, AG Peg, AX Per, CI Cyg, and CH Cyg contain M giants. Identification of prominent emission lines is given by the vertical dotted lines. Spectra were obtained from the ARAS database (Teyssier, 2019).

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Thermonuclear outbursts of slow symbiotic novae are characterized by a significant increase in brightness and a prolonged decline to the quiescent magnitudes. During the maximum, their spectra are characterized by an A/F-type supergiant continuum with only a handful of emission lines of H I and Fe II (e.g., Mikołajewska, 2010; Munari, 2019). After weakening of the A/F-type continuum during the brightness decline (which can take years), a nebular continuum starts to dominate, and strong emission lines with a higher ionization degree appear (see, e.g., figure 6.5 in Munari, 2019). On the other hand, the evolution of recurrent symbiotic novae is usually much faster - their outbursts last only for several days or weeks. The emission lines in their spectra not only strengthen due to the outburst, but also the matter, which is ejected at a very high velocity, causes these lines to become very broad (e.g., Munari, 2019).

The outburst mechanisms of classical symbiotic stars remains an open question. Today, it is clear, that there are various types of outbursts in Z And-type symbiotics. It seems that they might be caused by the release of energy from extra-accreted matter, instabilities in the accretion disks, or by expansion and consequent cooling of the hot component's pseudo-photosphere (e.g., Munari, 2019). In addition, more than one type of outburst is observed in some classical symbiotic stars. Munari (2019) showed the presence of two different types of outbursts in the symbiotic star StHα169 (figure 6.4 therein). Based on the UV data, González-Riestra et al. (1999) detected two types of outbursts (*cool* and *hot* ones) in AG Dra. Leedjärv et al. (2016) showed that it is possible to distinguish them also using the optical spectra.

Typically, the outbursts caused by the expansion of the hot component’s pseudoatmosphere are associated with the significant strengthening of the hot continuum, which greatly suppresses the red giant continuum (especially the molecular bands). Highly ionized lines (e.g., [Fe VII], He II, Raman-scattered O VI lines) usually disappear from the spectrum or become less prominent. On the other hand, the emission lines with lower ionization strengthen significantly (see Fig.5). In contrast, the accretion events lead to the strengthening of the emission lines and the nebular continuum. Some outbursts are accompanied by bipolar outflows/jets. Depending on the system’s geometry and the orientation towards the observer, these can be observed in the spectrum as satellite components of some emission lines or as P Cygni profiles (e.g., Leedjärv, 2004; Skopal et al., 2018; Lucy et al., 2018a; Merc et al., 2019a).

Other variations, such as giant pulsations, can also significantly affect the continuum and spectral lines of a symbiotic star. From what was mentioned in this section, it is clear, that long-term monitoring is needed to disentangle the effects and characterize the components of a particular system.

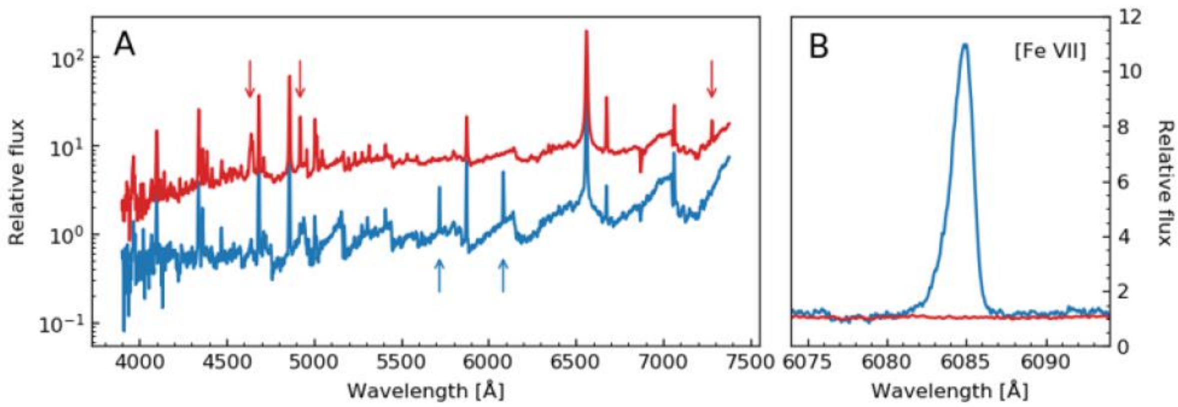

Figure 5: Significant changes in the degree of ionization of the nebula during the AX Per outburst. **A:** The spectra shown in red and blue were obtained during the outburst and the quiescence, respectively. The disappearance of the [Fe VII] lines (blue arrows) and strengthening of neutral lines (e.g., He I, red arrows) is visible. At the same time, it can be seen, that the growing continuum covers the molecular bands of the M giant during the outburst. **B:** Detailed view on the [Fe VII] 6087 line. The spectra were obtained at JD 2 458 379 (blue) and JD 2 458 584 (red).

4 The role of the observations by amateur observers

The goal of two previous sections was to demonstrate how interesting symbiotic stars can be, which type of effects can be observed in their light curves and spectra, and that long-term monitoring is especially needed to understand these effects, characterize their orbital properties, and the parameters of their components. This makes them ideal targets for amateur observers equipped with small telescopes. It is important to emphasize that even today, in the era of all-sky surveys, the data (both spectroscopic and photometric) of avid observers are invaluable. As proved by several pro/am collaborations discussed in Section 5, at present, many amateur astronomers can provide competitive spectroscopic and photometric data.

Amateur observers can carry out long-term monitoring, which is often longer than the lifetime of a particular photometric survey or for how long an object can be observed spectroscopically at a professional observatory, creating long uninterrupted sets of data. Another great advantage is that observers can respond very quickly to alerts or plan time-critical observations compared to a typical observation cycle (proposal-evaluation-observation), which can take a rather long time at professional observatories. Thanks to the involvement of several observers in a program, they can provide the required cadence of observations and eliminate weather limitations compared to photometric surveys with a fixed cadence or monitoring at a single professional observatory. Their observations can also focus on lower-priority targets, which do not obtain observing time at professional observatories. However, such data are often invaluable in case of unforeseen events.

Unlike surveys, amateur observers usually obtain multi-color photometric observations, which is of extreme importance in order to understand the spectral behavior of symbiotic binaries - let's remind that the components of symbiotic binaries dominate

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the spectra at various wavelengths (see Section 1). Another important aspect of observations aimed directly at a specific object, compared to surveys, is that the observer can adjust the exposure time to the brightness of the observed object at the time of observation. Sometimes, the object with the brightness within the magnitude range of a particular survey in the quiescence is too bright during its activity, or the object that is observable during the outburst is too faint when it returns to its quiet stage (see, e.g., Merc et al., 2020b). The small angular resolution of some ground or space-based surveys also sometimes requires confirmation of variability by higher-resolution observations (see, e.g., Merc et al., 2020c).

Of course, there are certain disadvantages of amateur observations in comparison with observations obtained with large telescopes. Especially in spectroscopy, fainter targets are out of the reach of amateur instruments. The issue that can be solved much more easily is that many observers are excited about symbiotic binaries only when they are in an outburst. However, the data obtained during the quiescence are as important as the data from the activity of these interacting binaries.

5 Selected results of pro/am collaborations

The quality and importance of observations of symbiotic binaries obtained by amateur observers have been confirmed by their use in research. Photometric observations are usually collected in specialized databases, e.g., that of the American Association of Variable Stars Observers (AAVSO)[3] and the British Astronomical Association (BAA)[4] or are provided by individuals directly to the research teams.

In recent years, organizations associating amateur spectroscopic observers have also emerged. One of the most active groups is Astronomical Ring for Amateur Spectroscopy (ARAS)[5], an initiative dedicated to the promotion of amateur astronomical spectroscopy and pro/am collaborations (Teyssier, 2019). Observations of the group focus on novae and symbiotic binaries. Moreover, selected Be stars, cataclysmic variables, supernovae, and other objects are observed. The network consists of observers equipped with small telescopes (20 to 60 cm) with spectrographs of various resolution (500 to 15 000), covering the range from 3 500 to nearly 8 000 Å. Recently, AAVSO also established its own spectroscopic database, and another is maintained by BAA[6]. In the following sections, we briefly discuss interesting results in the field of symbiotic stars, which are fully (or partly) based on the data obtained by amateur observers.

[3] https://www.aavso.org/

[4] https://britastro.org/photdb/

[5] 5http://www.astrosurf.com/aras/Aras DataBase/DataBase.htm

[6] https://britastro.org/specdb/

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5.1 Long-term monitoring of symbiotic stars

As has been emphasized several times here, long-term monitoring is crucial in the case of symbiotic variables, as they are variable on time scales of years and decades. It is particularly interesting to observe changes in classical symbiotic stars, in which stages of quiescence and activity alternate. The mechanisms of the latter ones still remain an open question (see Sections 2 and 3).

Observations by amateur observers are very often used in such research. It is not possible to list here all the studies in which amateur photometric and spectroscopic observations of symbiotic stars have been used, so we will mention only a few selected from recent years and discuss some of our own results briefly.

Stoyanov et al. (2020) used the data from the AAVSO database, together with their own observations and data from all-sky surveys to analyze the variability of the D-type symbiotic star EF Aql. Luna et al. (2020) analyzed the historical light curve of symbiotic recurrent nova T CrB, partly based on the amateur observations, to predict the next outburst of the system, which will occur in 2026 with an error of ± 3 years. Lucy et al. (2020) employed amateur observations to supplement the multi-wavelength observations of V694 Mon during its 2016 high state in their research of outflows in symbiotic stars. Kondratyeva et al. (2020) studied the recent outbursts of BX Mon, and the observations from AAVSO have been important to supplement their own photometric and spectroscopic observations. Iłkiewicz et al. (2019) utilized measurements of amateur observers in addition to other photometric data in the study of the first Magellanic symbiotic recurrent nova, LMC S154.

Amateur astronomers have made tremendous progress over the last few years, and also spectroscopic data obtained by amateurs (especially from the ARAS Group and by enthusiastic individuals) are widely used nowadays. It is interesting to note that it was only ten years ago when one of the first studies of a symbiotic outburst based on amateur data was published (2010 outburst of CI Cyg; Teyssier, 2011). Since then, several groups made advantage of amateur observations of symbiotic variables.

Skopal et al. (2019, 2020) used an extensive spectroscopic data set obtained at professional and amateur observatories to study the recent Z And-type outburst of V426 Sge, which manifested symbiotic nova outburst 60 years ago. Interestingly, AG Peg experienced a similar evolution. Its Z And-type outburst happened 165 years after the nova outburst. The recent brightening of AG Peg was also studied with significant contribution of amateur observers (Ramsay et al., 2016; Skopal et al., 2017; Merc et al., 2019c). Lucy et al. (2020) supplemented their multi-wavelength photometry and spectra with amateur spectroscopic observations in the study of the outflows in V694 Mon. The analysis of active stages of the symbiotic recurrent nova T CrB by Iłkiewicz et al. (2016) also benefited greatly from amateur spectroscopic data. These were complemented by photometric observations (both amateur and professional) and X-ray data.

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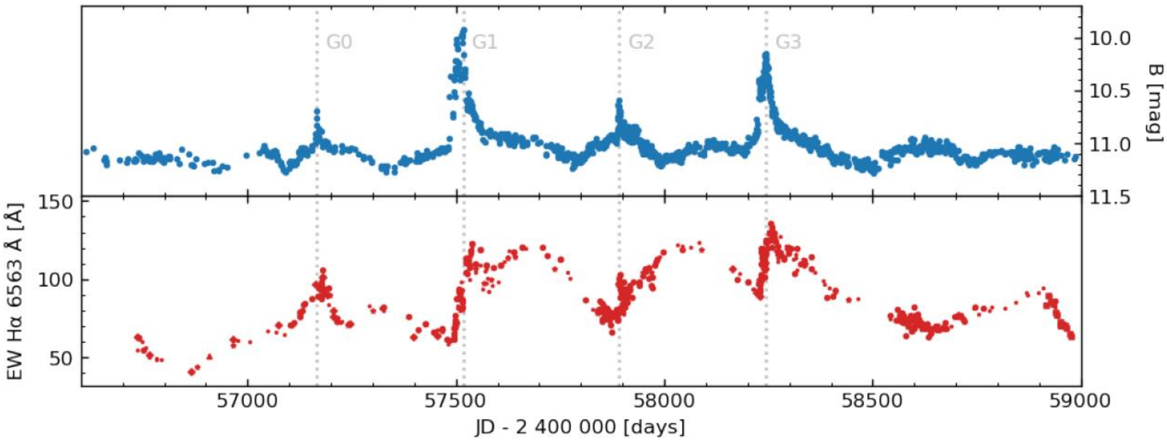

Figure 6: Light curve of AG Dra in *B* filter covering the recent active stage (in blue), together with the curve of the equivalent width of Hα emission line (in red). Most of the spectra used in this analysis were obtained from the ARAS database (Teyssier, 2019).

In the articles Merc et al. (2017a,b, 2018, 2019a,c); Gális et al. (2016, 2017, 2019a,b), we have used the amateur photometric and spectroscopic observations of the classical symbiotic stars Z And, AG Peg and AG Dra to study their recent active stages. AG Dra entered a new active stage after seven years of quiescence in 2015 and manifested four minor outbursts until 2018. Comparing the recent activity with more than 130 years of photometric monitoring, its behavior seems unusual. More often, there is a prominent, major outburst observed at the beginning of the active stage. The evolution of the equivalent width of Hα together with the brightness during the recent active stage of AG Dra is shown in Fig.6. Z And is still in a very long active stage which started in 2000. It is also one of the symbiotic systems forming jets which can be detected in the optical spectra as satellite components of Hα emission line. Although jets were detected several times during the recent active stage, extensive observational data set obtained by the ARAS observers has not shown any sign of jets during the last outburst of Z And in 2017 - 2018. AG Peg was already mentioned before to be the slowest symbiotic nova ever recorded. We have used the data obtained by amateur observers to analyze its Z And-type outburst recorded in 2015. Studies of similar systems are crucial because they can provide a better insight into the link between symbiotic novae and classical symbiotic stars.

5.2 Spectroscopic analysis of symbiotic candidates

In addition to studying the well-known symbiotic stars discussed in the previous section, we also selected several objects from the New Online Database of Symbiotic Variables with no or limited spectroscopic information in the literature. Many of them were proposed to have symbiotic nature based on their peculiar photometric variability or photometric colors.

We have initiated an international observing campaign in cooperation with the ARAS Group. The campaign is still ongoing and discussing all the detailed results is beyond the scope of this article. However, a preliminary analysis of the obtained observations has already provided interesting results. We have confirmed the symbiotic nature of two new symbiotic stars - V2204 Oph and Hen 3-860. V2204 Oph has been suspected to be a symbiotic star based on the outbursts observed in its light curve by Ross (1926) and Samus' (1983). However, no spectrum has been obtained since then. The observations obtained during our campaign confirmed that this object is indeed a symbiotic star, whose cool component is a K giant. Hen 3-860 was selected based on the peculiar light curve showing recent activity (2018 - 2019) and eclipse-like features. The spectroscopic observations obtained in the scope of our campaign confirmed the symbiotic nature of the object, making it representative of a rare group of eclipsing symbiotic stars. Some other symbiotic candidates were reclassified to nearby main-sequence stars, single giants, or binaries of other types.

Interesting objects from our campaign are planned to be observed with larger telescopes to obtain their spectra with a higher signal-to-noise ratio (especially in the case of faint objects) and better resolution allowing detailed characterization of the components and physical conditions in these binaries. It is worth noting that ARAS observers also helped confirm one of the candidates selected from the SkyMapper photometric survey (Lucy et al., 2018b).

6 Conclusions

Symbiotic stars belong to an interesting class of interacting binaries whose typical orbital periods are longer than one year. Their light curves and spectra are characterized by the various changes caused by orbital motion, mass transfer from the giant and consequent stages of activity, and the intrinsic variability of the components. Only long-term monitoring can reveal the parameters of individual objects and thus help to understand the whole symbiotic population.

This contribution had two main goals: (i) to demonstrate what can be detected using the observations with a relatively small telescope, how symbiotics vary in brightness on various timescales and how their spectra change accordingly; (ii) to show the place of amateur observations of symbiotic binaries in the era of all-sky photometric surveys discovering many new variables, in the era of ultra-precise space measurements, in the era of large spectroscopic data sets. Ever-improving amateurs still have many advantages over those mentioned above, making their data indispensable for the analysis of objects such as symbiotic stars. We believe that the successful cooperation of amateur and professional astronomers in this field will grow in the coming years.

Acknowledgements: We are grateful to all AAVSO and ARAS members for their contribution to our observing campaigns focused on symbiotic binaries. Particularly we acknowledge and thank C. Buil and F. Sims whose spectra are presented in this article. This research was supported by the Slovak Research and Development Agency under contract No. APVV-15-0458, by the Charles University, project GA UK

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LONG-TERM PHOTOMETRIC ACTIVITY OF AX PERSEI

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Abstract: Symbiotic variable stars are interacting binaries in which matter is transferred from a cool giant by its stellar wind to a hot white dwarf, causing various manifestations of activity. The aim of our research was a detailed analysis of photometric observations of the symbiotic system AX Persei. We collected from the literature all available brightness measurements of this binary and constructed historical light curves in the *U, B, V,* R_c, and I_c filters. By analyzing the light curves, we identified 6 quiescent and 7 active phases, during which 25 outbursts of this symbiotic system occurred. Our correlation analysis revealed a high degree of correlation of the AX Persei light curves in individual filters. Lower values of the correlation coefficients for the combinations of the I_c light curve with ones in other filters may indicate the presence of a source of variability manifested mainly at longer wavelengths. By period analysis of the AX Persei light curves, we confirmed the presence of variations with the orbital period and determined its value of 680.4 ± 4.3 days. We also detected other periods, the origin of which will need to be determined by further research.

1 Introduction

Symbiotic stars are binary systems consisting of cool and hot components. The cool component is a G, K, or M giant (S-type) or Mira-type variable (D-type). The hot component is usually a white dwarf or neutron star. The mass is transferred from the cool to the hot component by a stellar wind or Roche-lobe overflow.

AX Persei is a symbiotic system consisting of an M4.5 III giant (Mürset & Schmid, 1999) with the effective temperature $T_{\rm eff}$ = (3400 ± 150) K (Skopal et al., 2001) and a hot white dwarf. The orbital period of the binary is $P_{\rm orb}$ = 680.83 days (Skopal et al., 2011). The analysis of photometric minima showed that the hot white dwarf and the surrounding nebula are eclipsed by its cool companion (Skopal, 1994).

The studied system belongs to the group of classical symbiotic stars that are characterized by an alternation of active and quiescent stages. During the active stages, outbursts of few magnitudes are observed. The active stages of AX Persei last typically 700 – 1100 days (Skopal, 1994). From the end of the 19th century, several major outbursts were observed in 1893, 1924, 1949, 1978, 1988 - 1992 (Skopal, 1994; Merc et al., 2019). After the outbursts in the nineties, the system was in a quiescent stage till 2007, when the new activity started. Several outbursts were detected in 2009 (Munari et al., 2009), 2010 (Munari et al., 2010), 2012 (Munari et al., 2012), 2014 (Munari et al., 2014), 2019 (Merc et al., 2019), and further activity of AX Persei cannot be ruled out in near future.

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In this article, we present the results of the investigation of the AX Persei long-term photometric activity. We collected all available brightness measurements from the literature to construct the historical light curves of this symbiotic system in the photometric filters *U*, *B*, *V*, R_c, and I_c. The observational data are described in Section 2. By the detailed analysis of the light curves, we recognized quiescent and active stages and identified all detectable outbursts of AX Persei (Section 3.1). Such analysis of the long-term photometric behavior of this symbiotic system has not been presented in the literature to the best of our knowledge. The light curves were also subjected to the correlation and period analysis, the results of which are presented in the Sections 3.2 and 3.3.

2 Observational data

To study the long-term behavior of symbiotic stars, it is necessary that the observational data cover very long time periods. For AX Persei, we have collected 22 550 brightness measurements in various filters covering 133 years of the photometric history of the symbiotic system. In this section, we describe the sources of photometric measurements and the processing steps employed in order to construct the historical light curves of the object.

2.1 Sources of the measurements

For the purpose of this study, we collected all available photometric data of AX Persei from the published articles or databases of amateur associations of variable star observers. Among the main data sources were scientific articles, astronomical telegrams (ATel[1], CBET[2]), and circulars (IAUC - visual observations) accessed using the SAO/NASA Astrophysics Data System[3]. However, a key source of data for the construction of long-term light curves were the measurements obtained by amateur observers. We employed the database of the American Association of Variable Star Observers (AAVSO)[4].

Most of the articles published in the last decade or two were supplemented by tables of photometric measurements in a machine-readable format. For older sources, data had to be obtained by an OCR method directly from the articles (some of which were a scanned versions of their printed copies). The complete list of the observational data sources is available in Mártonfi (2020).

[1] The Astronomer's telegram: http://astronomerstelegram.org/

[2] Central Bureau for Astronomical Telegrams: http://www.cbat.eps.harvard.edu/

[3] The database is available at https://ui.adsabs.harvard.edu/

[4] https://www.aavso.org/

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2.2 Processing of the data

To study the long-term variability of objects using measurements from various sources, the data must be analyzed in a uniform photometric system. Since most of the recent observations are obtained with CCD in the Johnson-Cousin's $UBVR_cI_c$ system, we employed this photometric system to construct the long-term light curves of AX Persei. Observations obtained using other filters or detectors (e.g. photographic magnitudes) were transformed to the selected photometric system using a simple algorithm. Due to the larger observational errors of most older measurements, we assumed that the transformation does not depend on the color index of the studied object and is given only by the difference of magnitudes obtained in the used and Johnson-Cousin's system. We determined the magnitude difference using pairs of observations that were obtained at about the same time. With respect to the long-term nature of the AX Persei variability, a time difference of up to one day was allowed. In the analyzed measurements and dataset obtained in a close filter (in terms of spectral transmittance) of the Johnson-Cousin's system, we searched for all such pairs and the transformation shift was determined as the average of the magnitude differences of these pairs.

According to the spectral transmittance of the filters $UBVR_cI_c$, the photographic measurements acquired from the article of Leibowitz & Formiggini (2013) were transformed to *B* magnitudes. On the other hand, due to the spectral sensitivity of used photographic material, the data presented in Hric et al. (1993) and Hric et al. (1994) are closer to the measurements obtained in the V filter and therefore were transformed into *V* magnitudes. The observations acquired in Johnson's *R* filter were transformed into R_c magnitudes. If the used comparison stars were not known, we applied the same algorithm for the ΔR and ΔR_c observations and transformed them into the R_c magnitudes.

We also used visual magnitudes to construct the historical light curve of AX Persei. These observations are not as accurate as photoelectric or CCD ones but can be very useful if they cover time periods during which other measurements are not available. The visual as well as *CV* and *TG*[5] measurements from the AAVSO database were smoothly transformed to the *V* magnitudes.

Our thorough revision showed that some measurements were not obtained using the same observational setup throughout the covered period, although this was declared in the source articles. In these cases, we divided the datasets and determined the transformation shifts separately for each period. All suspicious data (typically marked with the symbols : or ::) and observations outside the 3σ interval of the mean light curves were excluded from the next analysis.

[5] The CV and TG tag clear (unfiltered) reduced to V sequence and DSLR green channel measurements, respectively.

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3 Results and their discussion

The long-term photometric and spectroscopic observations are very important because they are necessary to deduce physical mechanisms leading to the activity of AX Persei. In the next paragraphs, we describe the results of our investigation of the long-term photometric variability of this interacting system. Our research consisted of three parts: morphological, correlation, and period analysis of the historical light curves of AX Persei.

3.1 Historical light curves of AX Persei

The alternation of active and quiescent phases is a very significant characteristic of Z Andromedae stars such as AX Persei. In the first part of our research, we constructed the light curves in the Johnson-Cousin's $UBVR_cI_c$ system and conducted a thorough inspection of them in order to identify the active and quiescent phases of this symbiotic system.

Phase	Start (JD 24..)	End (JD 24..)	Years	Duration [days]	N_{U}	N_{B}	N_{V}	$N_{\mathrm{R_c}}$
A	11 660	14 350	1890 - 1898	2 690	-	4	-	-
Q1	14 350	15 440	1898 - 1901	1 090	-	0	-	-
B	15 440	17 200	1901 - 1905	1 760	-	1	-	-
Q2	17 200	21 190	1905 - 1916	3 990	-	0	-	-
C	21 190	26 720	1916 - 1932	5 530	-	4	-	-
Q3	26 720	32 410	1932 - 1947	5 690	-	1	-	-
D	32 410	34 960	1947 - 1954	2 550	-	1	-	-
Q4	34 960	43 050	1954 - 1976	8 090	-	0	-	-
E	43 050	44 840	1976 - 1981	1 790	-	2	-	-
Q5	44 840	46 920	1981 - 1987	2 080	0	0	0	0
F	46 920	50 420	1987 - 1996	3 500	3	4	3	1
Q6	50 420	54 140	1996 - 2007	3 720	0	0	0	0
G	54 140	-	2007 -	5 075*	7	8	8	7

Table 1: Active and quiescent phases of the symbiotic system AX Persei. N_U, N_B, N_V and N_{Rc} give the numbers of outbursts in particular filters. The dash means that observations are not available in the given phase and filter. The active phase G can last until the present and its listed duration indicates the number of days before January 1, 2021.

The oldest observations of AX Persei are photographic magnitudes published by Leibowitz & Formiggini (2013). We have transformed these measurements to *B* magnitudes, so that the light curve in the *B* filter covers the longest time period, almost 130 years. For this reason, we decided to use this light curve as a reference one for our morphological analysis. The historical light curve of AX Persei in the *B* filter is shown in Fig.1.

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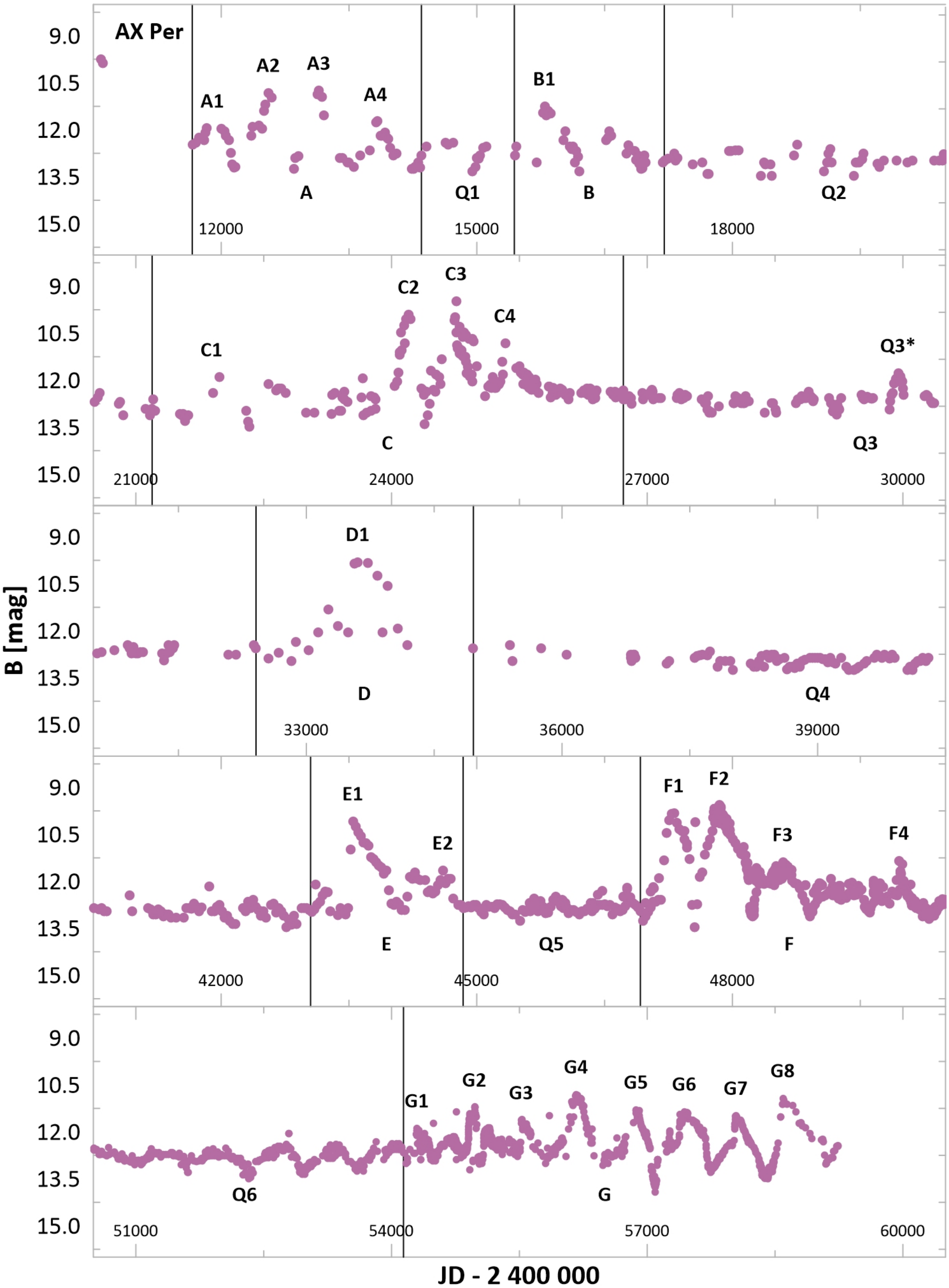

Figure 1: Historical light curve of the symbiotic system AX Persei in the filter *B* over the period 1887 - 2020 (JD 2 410 592.6 - 2 459 240.4). The light curve is divided into active (A - G) and quiescence (Q1 - Q6) phases by the vertical lines. Particular outbursts are assigned as A1 - A4, B1, C1 - C4, Q3*, D1, E1, E2, F1 - F4, and G1 - G8.

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During the 130-year photometric history of AX Persei, 7 active (marked as **A - G**) and 6 quiescent (marked as **Q1 - Q6**) phases were detected. Their basic characteristics (start, end, duration) are chronologically listed in Tab. 1. The numbers of outbursts recognized in the *U*, *B*, *V*, and R_c filters for each phase are also noted in the table. Note that the number of outbursts may vary from filter to filter if, for example, a given phase was not fully covered by the available observations.

The median of magnitudes during all quiescent phases of AX Persei was 12.28, 12.78, 11.50, and 10.10 mag in the *U*, *B*, *V*, and R_c filter, respectively. Note that there were no available I_c observations in quiescent phases of the symbiotic system. The amplitude of the AX Persei brightness variations in the quiescence was 1.83, 1.46, 1.09, and 1.34 mag in the *U*, *B*, *V*, and R_c filters, respectively. The quiescent phases lasted a total of 24 660 days, which represents 52.2% of the time covered by the observations (47 210 days).

The outbursts - sudden increases in brightness are typical for the active phases of Z Andromedae symbiotic variable stars. Maximum brightness is usually followed by a slow or fast decrease to the pre-outburst level. The outbursts are observable over a wide spectral range, but their amplitudes decrease for longer wavelengths. We detected the outbursts of AX Persei in the *U*, *B*, *V*, and R_c filters. It was not possible to recognize them in the I_c filter. In total, we identified 25 outbursts in the 130-year photometric history of this symbiotic system.

Some of the detected outbursts are also studied in another articles. However, we have introduced a uniform outburst labeling system. The major outbursts of AX Persei in 1893, 1924, 1949, and 1978 mentioned in Skopal (1994), we recognised and labeled as follows: **A2** (JD 2 412 555.6; 1893), **C2** (JD 2 424 203.7; 1925), **D1** (JD 2 433 604.7; 1950), and **E1** (JD 2 443 549.3; 1978). The outbursts during the ongoing active phase **G** were announced in the papers: Munari et al. (2009) (**G2**), Munari et al. (2010) (**G3**), Munari et al. (2012) (**G4**), Munari et al. (2014) (**G5**), and Merc et al. (2019) (**G8**). After the outburst **G8**, AX Persei reached the photometric minimum around JD 2 459 100 and its brightness is increasing at present. Next outburst is not excluded, so we do not yet consider the active phase **G** to be definitively over.

Concerning the definition of the individual quiescent and active phases of AX Persei, several questions remain open. The **Q3*** outburst may represent a sole, unusually short active phase of this symbiotic system, and then the quiescent phase **Q3** should be divided into two separate periods. On the other hand, the **F3** and **F4** outbursts were considered to belong to separate active phases in the articles of Skopal (1994) and Merc et al. (2019). Since the activity of AX Persei is also manifested spectroscopically, an analysis of the spectra of this interacting binary can provide a definitive answer to these questions.

3.2 Correlation analysis of the AX Persei light curves

The evolution of the AX Persei brightness may vary with the spectral region in which the symbiotic star is observed. The correlation analysis is a suitable tool for examining the similarities and differences between light curves in individual photometric filters.

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There are several methods of correlation analysis and they are implemented in various software. We used the Correlation and Period Analysis Software CorrLAB (Merc & Gális, 2018) to perform the analysis of the AX Persei light curves using the method of classical and discrete correlation analysis and compared the obtained results. As the classical correlation analysis required the equidistant data, the photometric measurements of AX Persei were interpolated using 3 methods implemented in the CorrLAB: PCHIP[6], spline, and linear interpolation. In the case of the discrete correlation analysis, the observations were binned. Subsequently, we compared the results obtained using different interpolation methods and different bin sizes.

In order to compare the photometric behavior of AX Persei during the active and quiescent periods of this symbiotic system and with respect to the available observations, we performed the correlation analysis of the light curves covering the active periods **F** and **G** and the quiescent period **Q6**. The light curves in the U, B, V, R_c and I_c filters were analyzed except the active phase **F**, for which the I_c magnitudes were available in insufficient quantities.

For the active phases **F** and **G**, we obtained high correlation coefficients for the U, B, V, and R_c light curves using both methods: 0.83 - 0.94 and 0.76 - 1.23[7] for classical and discrete correlation, respectively. Such behavior may be related to the dominant effect of outbursts on the shape of AX Persei light curves. The correlation analysis for combinations of the I_c light curve with the ones in other filters provided significantly lower correlation coefficients: 0.50 - 0.75 and 0.47 - 1.08 for classical and discrete method, respectively. The result may indicate the presence of a source of photometric variability manifested mainly at longer wavelengths. Because the cool giant of the symbiotic system dominates this spectral region, these variations may be related to its intrinsic variability.

Relatively high correlation coefficient was obtained for the AX Persei light curves during the quiescent phase **Q6**: 0.71 - 0.86 and 0.70 - 1.09 for classical and discrete correlation analysis, respectively. The values are lower as for the active phases which may be related to the greater relative impact of observational errors during quiescence phases when the amplitude of brightness variations is significantly lower. The lowest values of correlation coefficients were determined for the combinations with the R_c light curve, which again may indicate a source of variability manifested mainly at longer wavelengths.

3.3 Period analysis of the AX Persei light curves

The period analysis allows studying in detail periodic photometric or spectroscopic variations of symbiotic systems related to the orbital motion, an intrinsic variability of their individual components, or other periodic physical mechanisms presented in these interacting binaries. There are many methods of the period analysis implemented

[6] Piecewise Cubic Hermite Interpolating Polynomial.

[7] The coefficients are not normalized to unity for the discrete correlation analysis.

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in various software packages. To study periodic variations presented in the AX Persei light curves, we used the *Lomb-Scargle* (LS) method (Lomb, 1976; Scargle, 1982) and the *Phase Dispersion Minimization* (PDM) method (Stellingwerf, 1978) implemented in the Peranso[8] software. The LS method is based on the discrete Fourier transform of the analyzed data, and its output is a *power spectrum* in which the maxima correspond to the detected periods. PDM belongs to the group of qualitative methods in which the minima of a specific quantity (the phase dispersion in the case of PDM) in a *periodogram* indicate the presence of variations with given periods in the data.

In addition to real periods, the analysis can detect also many others, which can be harmonic, subharmonic periods of the real periods, or aliases that arise due to the presence of certain regularities in the observation time spacing (e.g. the 1-year alias if observations are obtained at a specific part of the year). The whole observation interval can also be detected by the period analysis. These false periods can be identified using the *spectral window* or the *prewhitening* method, which is also very useful in the case of the multiperiodic nature of the analyzed data.

Using the LS and PDM methods, we realized the period analysis of the AX Persei light curves in the U, B, V, R_c and I_c filters. The analysis was performed individually for each active and quiescent phase, as well as for the whole light curves of the symbiotic system. The periodograms for the latter case are shown in Fig. 2. For most analyzes, the dominant period was related to photometric variations caused by the orbital motion of this eclipsing binary. However, in some cases (e.g. the light curve in the I_c filter), the orbital period was not dominating and additional study of the AX Persei light curves is needed to find out the reasons for this fact. We also detected the harmonic, subharmonic periods, and the 1-year alias of the orbital period, as well as the period corresponding to whole analyzed observational interval. Our detailed analysis showed that most of the other detected periods are more likely related to the complex morphology of the AX Persei light curves, especially during the active phases than to the real variability present in this symbiotic system. We also detected other periods, the origin of which will need to be determined by further research.

Based on the analysis of the light curve in the B filter, which covers the time interval of 130 years, we determined the value of the orbital period of the symbiotic system as 680.4 ± 4.3 days. The obtained value is very close to the ones mentioned in recent articles, e.g. 680.83 days in Skopal et al. (2011) and 681.48 days in Leibowitz & Formiggini (2013). Verification and further refinement of the orbital period value are possible by analyzing the radial velocity curve of the cool giant presented in AX Persei, which is the subject of our ongoing research.

[8] CBA Belgium Observatory, https://cbabelgium.com/peranso/

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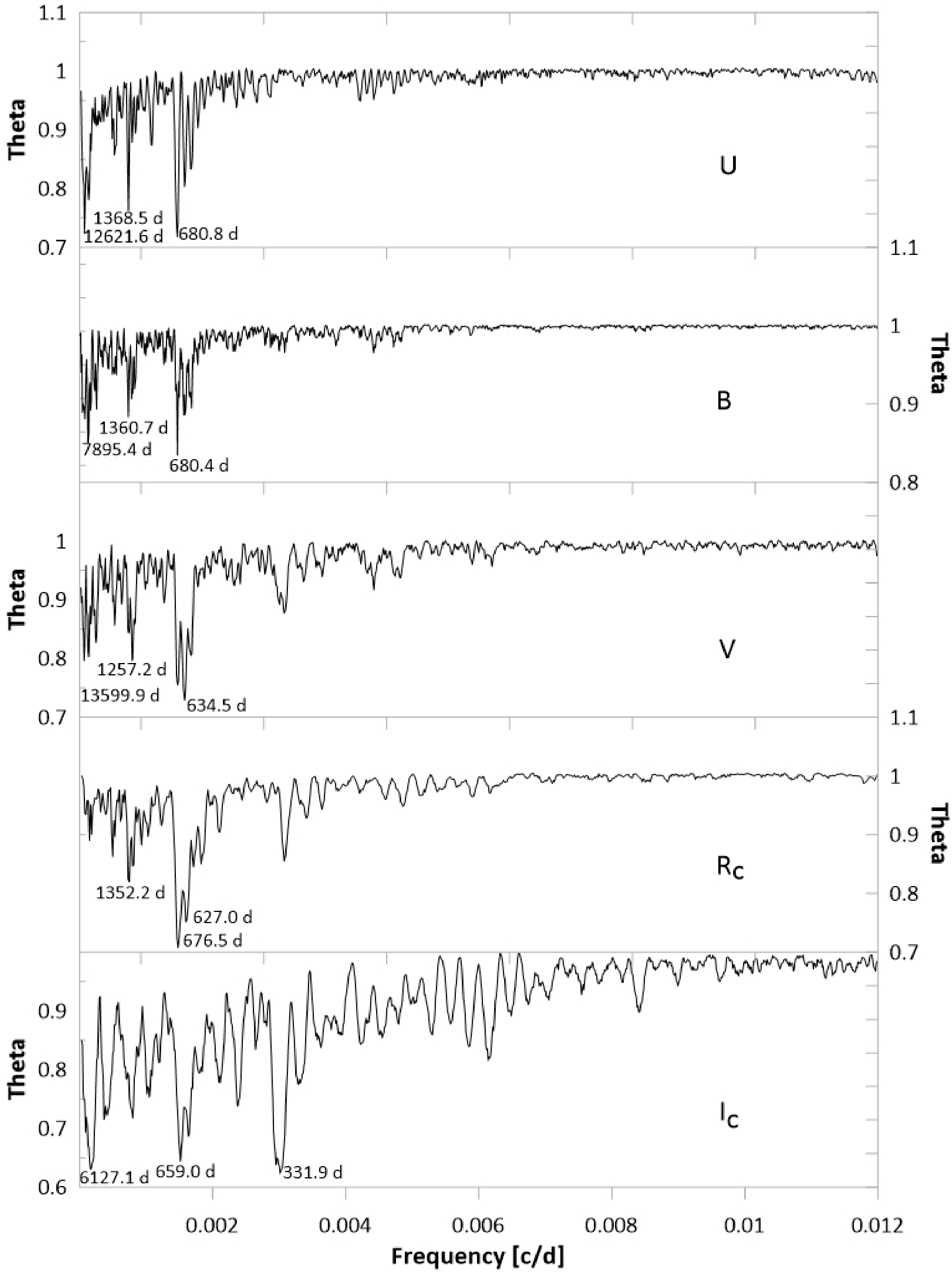

Figure 2: Periodograms of the light curves of the symbiotic system AX Persei in the *U*, *B*, *V*, *Rc* and *Ic* filters. The most significant periods are indicated by their values. The frequency is given in the cycles per day and theta represents the phase dispersion. Note that the scale of each periodogram varies from filter to filter.

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4 Conclusion

To construct the historical light curves of AX Persei in the *U, B, V, Rc* and *Ic* filters, we compiled all available published articles, astronomical telegrams, and circulars in relation to the studied object as well as databases of amateur associations of variable star observers. In total, we collected 22 550 photometric measurements covering the 130-year photometric history of the symbiotic system.

AX Persei belongs to the group of classical symbiotic stars characterized by an alternation of active and quiescent phases. Based on a thorough analysis of the morphology of the AX Persei light curves, we have identified 7 active and 6 quiescent phases. During the covered period, we detected a total of 25 outbursts of the symbiotic system. Such analysis of the long-term photometric behavior of AX Persei has not been presented in the literature to the best of our knowledge. On the other hand, the definition of the individual quiescent and active phases of AX Persei has still remained open. Since its activity is also manifested spectroscopically, an analysis of long-term spectroscopic observations of this interacting binary can provide a definitive answer to this task.

To investigate the evolution of the AX Persei brightness in various spectral regions, we performed the correlation analysis of its light curves in individual photometric filters. The analysis revealed that the photometric variations at shorter and longer wavelengths are caused by different sources. The outbursts have a dominant effect on the shape of the AX Persei light curves in the *U, B, V, Rc* and *Ic* filters. The correlation analysis for combinations of the *Ic* light curve with the ones in other filters may indicate the presence of a source of photometric variability manifested mainly at longer wavelengths. Due to the fact, that the cool giant of the symbiotic system dominates the spectral region, these variations may be related to its intrinsic variability.

We performed the period analysis of the AX Persei light curves in the used filters to study in detail periodic photometric variations of the binary caused by its orbital motion, an intrinsic variability of its individual components, or other periodic physical mechanisms. Based on the analysis of the light curve in the *B* filter, we determined the value of the orbital period of AX Persei as 680.4 ± 4.3 days, which is very close to the values mentioned in recent articles. Our analysis revealed many other periods, a part of them are more likely related to the complex morphology of the AX Persei light curves, especially during the activity than to the real variability present in this symbiotic system.

The investigation of the long-term photometric activity of AX Persei presented in this article yielded very interesting results. However, some open questions remain and the following study can provide answers related to the physical mechanisms responsible for the observed activity of this symbiotic system. For this reason, the analysis of the longterm spectroscopic observations of AX Persei is the subject of our ongoing research.

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V1391 CAS - SLOW NOVA WITH MULTIPLE MAXIMA

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Abstract: Nova Cas 2020 was discovered by Stanislav Korotkiy and Kirill Sokolovsky at unfiltered magnitude 12.9 (V zero-point) on 2020 July 27 and classified spectroscopically as an FeII type classical nova. It was later given a definitive designation V1391 Cas. As soon as the technical, personal and meteorological conditions allowed us, we started simultaneous photometric and spectroscopic observations. The photometry is provided by a 14" Schmidt-Cassegrain telescope equipped with MII G2-1600 CCD camera and B, V, R_c, I_c filters. We obtain low resolution spectra (R~1000) using 11" Schmidt-Cassegrain telescope and LISA spectrograph. In this paper we present the preliminary results of our observations. The nova eruption evolved to the dust forming phase in 2020 December. It is too faint for small size telescopes in this phase. But the complex behavior during the oscillations deserves detailed analysis using all available observations.

1 Discovery

V1391 Cas (Nova Cas 2020, TCP J00114297+6611190) was discovered on 2020-07-27.9302 UT by S. Korotkiy and classified as a Fe II type classical nova (Sokolovsky et al., 2020a). Sokolovsky et al. (2020b) found out that the pre-discovery images by FRAM-ORM wide-field camera constrain the explosion date between 2020-07-26.10104 (last non-detection) and 2020-07-27.23087 (first detection). In this paper we use JD 2459057.5 as the time T0. In the following months the nova showed a series of flares (each lasting days to a week) with the brightest flare peaking at V=10.8 on 2020-08-10.08738 (according to FRAM and AAVSO photometry). Munari et al. (2020) estimated strong interstellar reddening E(B-V)=1.39 mag. We used this value for dereddenig of our spectra.

2 Observations

In August 2020 we started simultaneous photometric and spectroscopic observations of the nova at the Astronomical Observatory on Kolonica Saddle. For photometry we used telescope C14, Celestron Edge HD, aperture 356 mm, the focal length with focal reducer 0.7x is 3000 mm. CCD camera MII G2-1600 and Johnson – Cousins filters B, V, R_c, I_c. With binning 2x2 we have the scale 1.24 arcsec/px, field of view is 13.4 x 8.9 arcmin. Autoguiding is performed on a separate telescope attached to the main tube. Data acquisition is managed using the software MaXimDL. Differential photometry with multiple comparison stars was performed using the recently developed package

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CoLiTecVS (Kudzej et al., 2019). As a main comparison star we have used UCAC4 81-000332, 00:10:56.01 +66:07:21.3, *B*=15.741, *V*=14.658, *Rc*=13.894, *Ic*=13.185. These values were converted from Pan-STARRS DR1 catalogue (Chambers et al., 2016). The instrumentation for the spectra acquisition was the following: Telescope C11, Celestron CGEM 1100, aperture 280 mm, the focal length with focal reducer 0.66x is 1750 mm, Spectrograph LISA (produced by Shelyak Instruments) and CCD camera ATIK-460ex with binning 1x1 gives the resolution power around 1000. Images for off axis autoguiding are taken with ATIK-317 camera. Data acquisition is managed using the software MaXimDL. Post-processing was done using software packages ISIS, VisualSpec and PlotSpectra. In total we have collected 43 spectra, in 41 cases we have also simultaneous photometry in B V R_c I_c bands.

The complete record of our observations is presented on Fig.1. including photometric data from AAVSO International Database[1] and spectra collected in ARAS Spectral Database[2]. Observations acquired in Kolonica are marked as DPV (it is the shortcut of the first author as an observer contributing to AAVSO). First of all, one can see relatively good coverage mainly in August and September. Later the activity of observers was decreasing. In our case the reason is simply bad weather. After the brightness peak a long lasting plateau with notable variability started. The rapid decline occurred in the middle of December 2020 accompanied by the dust forming event as reported by Banerjee et al. (2020). 17 additional peaks of brightness can be found during the oscillations phase. In the following we will focus on the period 120 days after eruption where we have good coverage and the object was sufficiently bright. Most drastic brightness changes are marked with vertical dashed lines on Fig.2. Note the complex behavior of color indexes. There are several situations when different indexes evolve in opposite ways. In other words: only the V-R index mimics the optical light curve quite well. The rest behave differently.

Of course, more information can be found in spectra. Thanks to the simultaneous photometry we were able to convert relative flux units into absolute fluxes using the equation Eq.1 based on Henden & Kaitchuck (1982) conversion.

$$F_{5556\,\text{Å}}(erg/cm2/s/\text{Å}) = 10^{-0.4V-8.449} \quad (1)$$

where V is the V band magnitude value.

We have corrected the spectra the spectra for interstellar extinction by using the extinction curve of Cardelli, Clayton & Mathis (1989). Note that only after the dereddening the spectra looks like those of classical nova in fireball stage i.e. resembling the star of spectral type A to F.

[1] https://www.aavso.org/data-download

[2] http://www.astrosurf.com/aras/Aras_DataBase/Novae/2020_NovaCas2020.htm

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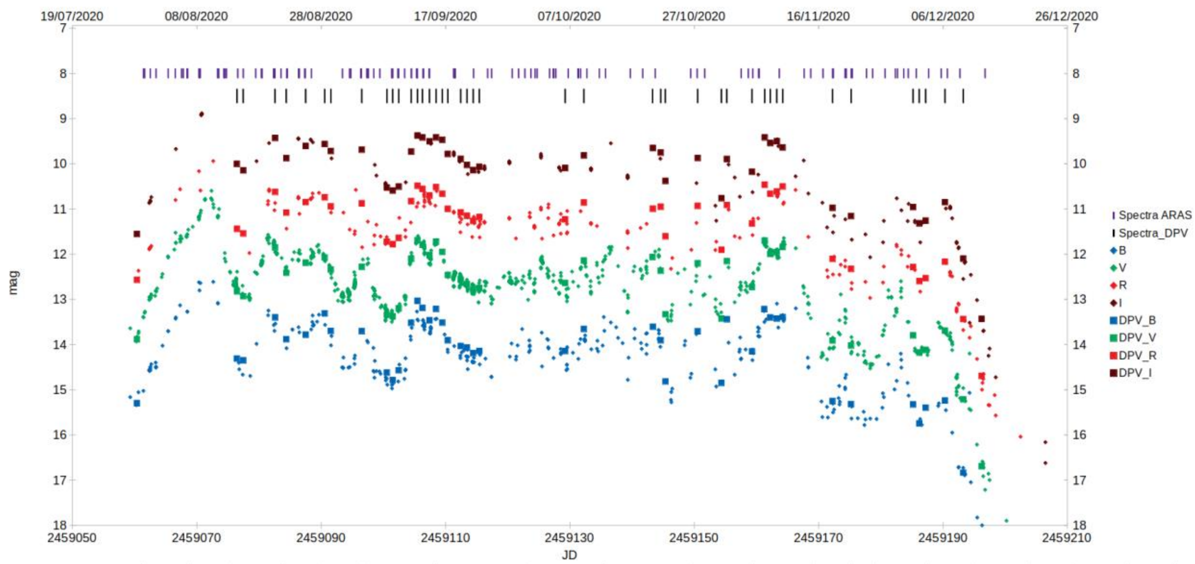

Figure 1: Overall light curve of V1391 Cas during the present eruption.

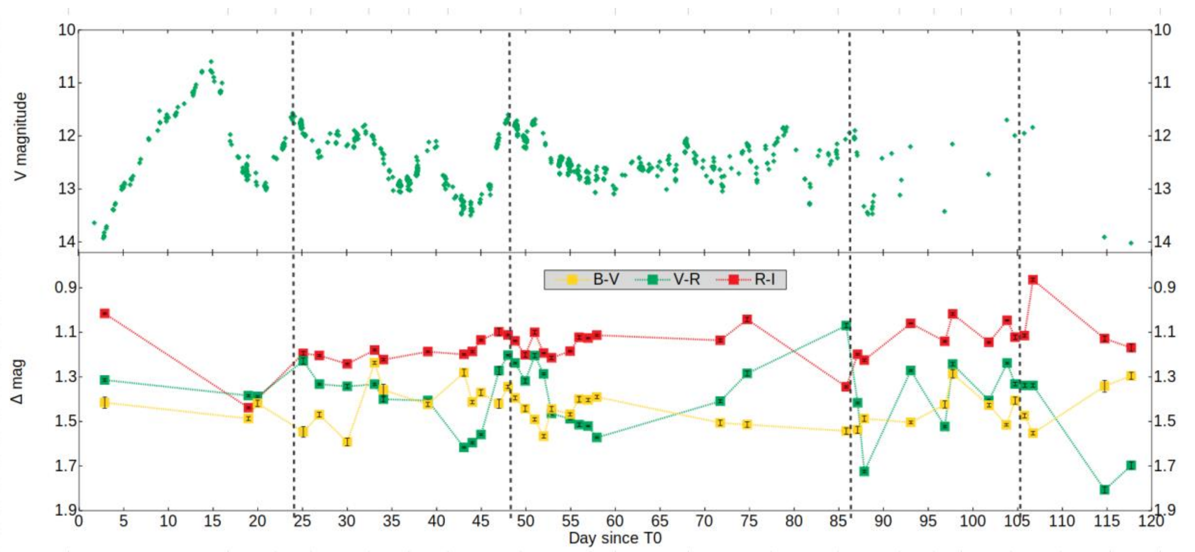

Figure 2: Evolution of color indexes. Result of our simultaneous 4 band photometry. On the upper panel the V band light curve from our photometry.

Few of them are shown on Fig.3. Most prominent spectral lines are identified. The evolution of emission lines intensity is visible. The absorption component is mainly weak, sometimes disappearing completely and sometimes is hidden due to the low resolution of our spectra. We are aware about the last case thanks to medium resolution spectra found in ARAS database. Also changes in continuum are evident. We have included more spectra in Fig.4. Only spectra taken in consecutive days were excluded for clarity. The moments identified on the optical light curve are presented here with the red lines. So we can see that major changes in photometry are connected with major changes in spectra as expected. For more quantitative evaluation we have calculated basic

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parameters for several emission lines. On Fig.5 the evolution of Full Width at Half Maximum (FWHM), Equivalent Width (EW) and integral flux of emission components for Halpha, Hbeta and OI 6300 lines are presented. First observation is that balmer lines became narrower during the peak of brightness. Looking at EW evolution seems that they are also weaker at the same time. But one has to be careful when making analysis of emission lines on a variable continuum. Higher continuum leads to lower value of EW for the same emission line. Indeed the plots of integrated flux reflect the optical light curve much better especially for Hbeta and the oxygen line. So we can conclude that changes in the continuum are more or less simultaneous with the changes in the emission lines strength. But the alignment is not perfect. Mainly in the case of Halpha. We can speculate about the reason. It could be the influence of the hidden absorption component (for our resolution), or different timing of the events in continuum and in the line. To explain the strange behavior of color indexes we will need to examine the relevant moments in more detail using all available data.

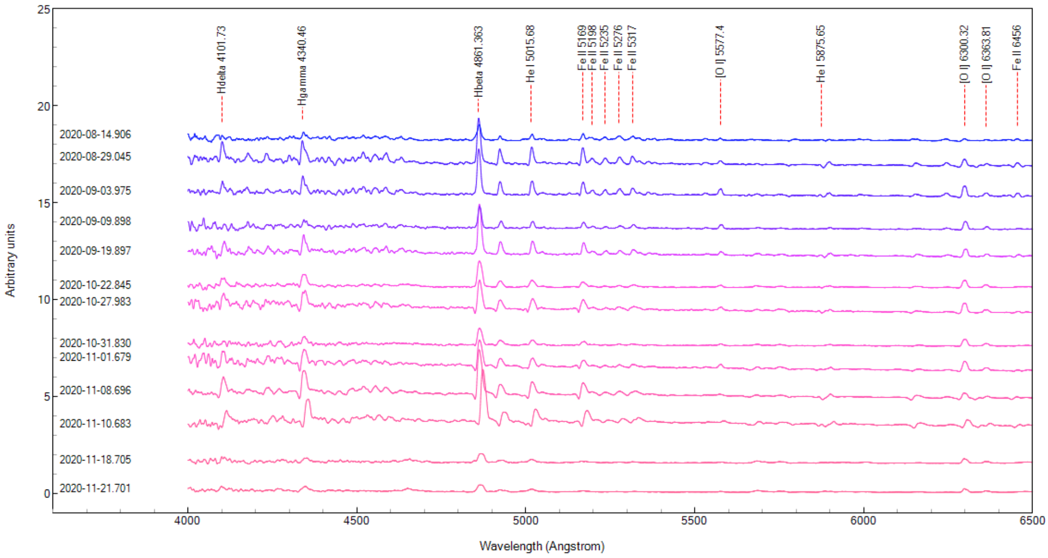

Figure 3: Selected low resolution spectra without the Halpha region. The spectra are dereddened using the value E(B-V) = 1.39 for interstellar reddening. Arbitrary shift between all individual spectra is the same. So the changes in continuum are visible as different gaps between plotted curves.

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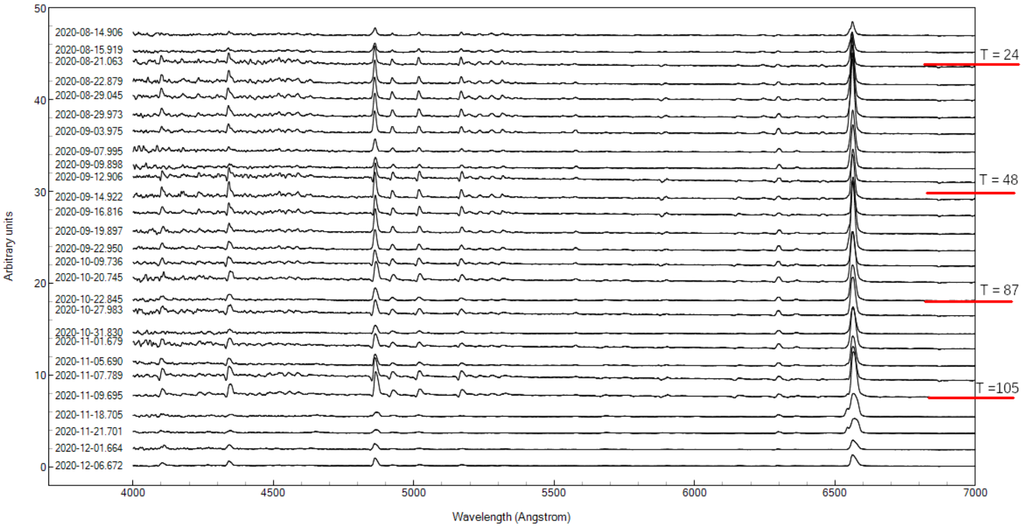

Figure 4: The same as in Fig.3 but more spectra plotted. The range contains also the Halpha region now. The red lines correspond to the timing of the most important photometric changes marked with vertical dashed lines on Fig.2.

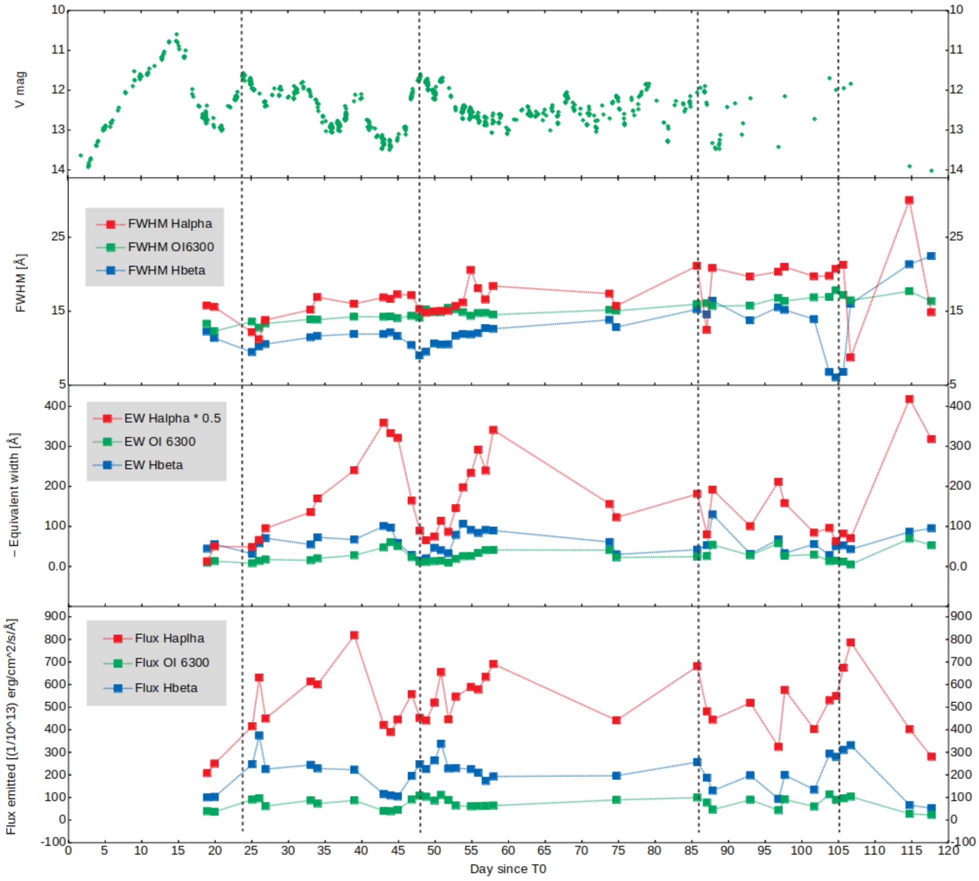

Figure 5: Evolution of measured parameters of emission lines. The EW values for Halpha are multiplied by 0.5 for clarity. The absolute flux was measured on spectra corrected for interstellar extinction.

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3 Discussion and Conclusion

We have observed a long lasting period of oscillation in maxima of the nova V1391 Cas. This phenomenon is still poorly explored in classical novae and its origin remains a matter of debate. Proposed explanations include instabilities in the envelope of the white dwarf leading to multiple ejection episodes, instabilities in an accretion disk that survived the eruption, and variations in mass transfer from the secondary to the white dwarf. Recently Aidy et al. (2020) proposed that shocks generated by interaction of the wind from the white dwarf with the envelope can produce substantial part of the luminosity in classical novae. If the envelope has complex structure with different densities, we can see flares like these observed.

Our measurements are not sufficient to solve the problem. We just want to point out that nova V1391 Cas is a very interesting object which deserves attention, more observations and further analysis. We have plans to continue the analysis including more spectra from the ARAS database and all available photometry. This way we will have better time resolution to study the rapid variability during the oscillation phase. Mainly we want to separate emission lines from continuum and investigate their behavior in all individual spectra.

For other researchers we provide the results of our photometry in Tab.1. Our spectra are available in the ARAS database.

Table 1: Differential photometry of V1391 Cas. The individual points were calculated as the mean value of usually 5 measurements on 5 images for each filter. In the final columns the mid time of the corresponding spectrum is listed [JD – 2459000] and corresponding Halpha flux measured [10^{-13} erg cm^{-2} s^{-1} Å^{-1}].

Band	*B*			*V*			R_c			I_c			Spectrum	Hα
Evening Date	JD	mag	σ	JD	mag	σ	JD	mag	σ	JD	mag	σ	JD mid	flux
2020-07-29	60.369	15.298	0.022	60.375	13.883	0.004	60.376	12.569	0.002	60.371	11.554	0.002		
2020-08-14	76.446	14.311	0.006	76.459	12.824	0.002	76.461	11.440	0.002	76.444	10.002	0.001	76.406	207.8
2020-08-15	77.467	14.350	0.011	77.462	12.932	0.004	77.464	11.544	0.001	77.465	10.145	0.001	77.419	249.7
2020-08-20	82.586	13.398	0.017	82.580	11.852	0.007	82.582	10.624	0.006	82.584	9.429	0.002	82.563	415.4
2020-08-21													83.510	631.0
2020-08-22	84.376	13.882	0.010	84.378	12.413	0.001	84.379	11.080	0.003	84.388	9.876	0.002	84.379	449.6
2020-08-25	87.505	13.782	0.010	87.504	12.191	0.007	87.502	10.848	0.002	87.503	9.606	0.002		
2020-08-28	90.563	13.311	0.003	90.565	12.075	0.003	90.572	10.742	0.002	90.569	9.562	0.002	90.545	613.7
2020-08-29	91.553	13.699	0.016	91.552	12.341	0.009	91.553	10.941	0.002	91.554	9.718	0.003	91.473	600.9
2020-09-03	96.523	13.705	0.006	96.525	12.282	0.004	96.526	10.876	0.002	96.527	9.689	0.001	96.475	818.2
2020-09-07	100.563	14.622	0.014	100.565	13.341	0.002	100.566	11.725	0.001	100.567	10.526	0.002	100.495	421.0
2020-09-08	101.499	14.787	0.006	101.498	13.374	0.002	101.504	11.779	0.003	101.502	10.593	0.002	101.446	389.6

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2020-09-09	102.465	14.569	0.011	102.468	13.199	0.003	102.469	11.640	0.002	102.476	10.506	0.002	102.398	444.8
2020-09-11	104.471	13.520	0.010	104.474	12.100	0.010	104.475	10.828	0.008	104.479	9.730	0.008	104.310	557.1
2020-09-12	105.488	13.034	0.006	105.490	11.690	0.002	105.491	10.487	0.002	105.489	9.376	0.002	105.406	451.8
2020-09-13	106.281	13.188	0.006	106.284	11.794	0.002	106.282	10.556	0.001	106.286	9.418	0.002	106.273	440.7
2020-09-14	107.413	13.464	0.009	107.415	12.021	0.004	107.416	10.703	0.005	107.417	9.502	0.005	107.422	520.2
2020-09-15	108.473	13.213	0.003	108.475	11.722	0.005	108.476	10.517	0.004	108.477	9.417	0.004	108.302	654.9
2020-09-16	109.483	13.516	0.005	109.476	11.950	0.003	109.484	10.664	0.002	109.476	9.470	0.002	109.316	445.8
2020-09-17	110.365	13.906	0.009	110.367	12.462	0.003	110.358	10.998	0.003	110.356	9.783	0.004	110.329	546.4
2020-09-18													111.323	
2020-09-19	112.434	14.033	0.005	112.436	12.565	0.002	112.437	11.077	0.002	112.438	9.892	0.002	112.397	589.2
2020-09-20	113.446	14.065	0.009	113.448	12.664	0.004	113.449	11.150	0.004	113.450	10.028	0.004	113.384	577.7
2020-09-21	114.446	14.191	0.005	114.448	12.788	0.002	114.449	11.267	0.001	114.450	10.141	0.002	114.402	633.9
2020-09-22	115.431	14.141	0.006	115.433	12.751	0.002	115.434	11.179	0.002	115.435	10.066	0.002	115.450	691.2
2020-09-20	129.235	14.144	0.009	129.237	12.638	0.004	129.238	11.229	0.003	129.239	10.094	0.003		
2020-09-22													131.308	
2020-10-06	132.240	13.656	0.007	132.247	12.142	0.005	132.243	10.858	0.006	132.249	9.816	0.003	132.236	441.8
2020-10-09	143.334	13.608	0.007	143.286	12.065	0.007	143.327	10.995	0.003	143.333	9.651	0.001	143.245	680.9
2020-10-20	144.605	13.905	0.014	144.607	12.368	0.002	144.605	10.951	0.002	144.603	9.752	0.002	144.577	481.1
2020-10-21	145.347	14.817	0.009	145.349	13.330	0.003	145.350	11.606	0.002	145.351	10.381	0.003	145.345	444.3
2020-10-22	150.546	13.708	0.003	150.545	12.204	0.003	150.547	10.932	0.002	150.550	9.873	0.001	150.483	519.4
2020-10-27	154.353	14.850	0.013	154.360	13.427	0.003	154.356	11.904	0.002	154.362	10.763	0.002	154.330	323.8
2020-10-31	155.242	13.442	0.014	155.234	12.156	0.004	155.235	10.913	0.004	155.231	9.896	0.002	155.179	576.1
2020-11-01	159.298	14.152	0.005	159.282	12.725	0.003	159.287	11.320	0.002	159.281	10.176	0.001	159.190	402.9
2020-11-05	161.245	13.216	0.004	161.324	11.701	0.002	161.323	10.464	0.002	161.325	9.418	0.002	161.289	530.1
2020-11-07	162.215	13.401	0.012	162.217	11.995	0.004	162.219	10.663	0.004	162.220	9.541	0.006	162.196	549.5
2020-11-08	163.264	13.426	0.005	163.266	11.952	0.004	163.264	10.615	0.004	163.295	9.500	0.002	163.195	674.5
2020-11-09	164.219	13.393	0.005	164.215	11.841	0.003	164.220	10.503	0.004	164.214	9.639	0.003	164.183	786.7
2020-11-10	172.230	15.252	0.019	172.232	13.911	0.007	172.237	12.104	0.007	172.235	10.976	0.006	172.205	401.9
2020-11-18	175.212	15.319	0.009	175.220	14.024	0.007	175.215	12.326	0.010	175.216	11.157	0.007	175.201	280.4
2020-11-21	185.177	15.326	0.033	185.185	13.797	0.004	185.180	12.285	0.002	185.181	10.958	0.004	185.164	150.8
2020-12-01	186.175	15.745	0.022	186.177	14.178	0.004	186.179	12.598	0.002	186.180	11.318	0.002	186.170	129.1

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2020-12-02	187.215	15.396	0.012	187.203	14.120	0.012	187.213	12.532	0.003	187.205	11.259	0.004	187.169	125.1
2020-12-06	190.311	15.239	0.014	190.314	13.693	0.004	190.315	12.166	0.004	190.316	10.849	0.003	190.172	165.8
2020-12-09	193.251	16.835	0.096	193.254	15.213	0.015	193.255	13.436	0.006	193.257	12.099	0.003	193.205	76.5
2020-12-12	196.201	18.014	0.095	196.200	16.692	0.014	196.198	14.695	0.008	196.200	13.432	0.005		

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