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Study of long-term spectroscopic variability of symbiotic stars based on observations of the ARAS Group

J. Merc[1,2], R. Gális[1] and F. Teyssier[3]

[1] *Institute of Physics, Faculty of Science, P. J. Šafárik University, Park Angelinum 9, 040 01 Košice, Slovak Republic*

[2] *Astronomical Institute, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Prague, Czech Republic*

[3] *Astronomical Ring for Amateur Spectroscopy Group*

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Abstract. The importance of small-telescope observations is demonstrated by investigation of long-term outburst activity of the symbiotic systems AG Dra, Z And and AG Peg based on spectroscopic measurements obtained by amateur astronomers organized in the Astronomical Ring for Amateur Spectroscopy. Preliminary results of our ongoing spectroscopic campaign focused on AG Dra are presented. The temperature of the white dwarf is studied based on behaviour of the prominent emission lines, which are well detectable even in low-resolution spectra. The activity of AG Dra is compared to that of two other symbiotic systems - Z And and AG Peg, which have shown outbursts recently. Z And is a prototype of classical symbiotic stars which manifested the outburst at the turn of the years 2017 and 2018. AG Peg is the slowest symbiotic nova with the Z And-type outburst in 2015, 165 years after its nova-like flare-up.

Key words: symbiotic stars – outbursts – spectroscopy

1. Introduction

Symbiotic stars are strongly interacting systems, in which physical mechanisms related to the mass transfer and accretion cause observable activity by manifesting increases of brightness (about 2 – 5 mag) and significant changes in their spectra. These binaries consist of a cool giant of spectral type K - M and a hot compact star, mostly a white dwarf. The mass transfer most likely takes place via the stellar wind of the cool giant, which is also the source of the dense circumbinary envelope of these systems.

Symbiotic systems are wide binaries with orbital periods of hundreds to thousands of days and their stages of activity may last from a few days to decades. Therefore, the long-term photometric as well as spectroscopic observations of these interacting systems are needed to study the physical mechanism responsible for their observed activity. Both amateur and professional astronomers utilizing small telescopes play an important role in such monitoring.

2. Selected symbiotic systems

AG Draconis is one of the best studied symbiotic systems. The cool component is a red giant of early spectral type (K0 - K4), with low metallicity and higher luminosity than that of standard class III (Smith et al., 1996). The hot component is considered to be a white dwarf sustaining a high luminosity and temperature (Mikołajewska et al., 1995). The orbital period of this binary is 551 days (Hric et al., 2014). The system undergoes characteristic symbiotic activity with alternating quiescent and active stages. The latter ones consist of several outbursts repeating at about one-year interval.

Z Andromedae is a prototype of the classical symbiotic systems, which consists of a late-type M4.5 III giant (Mürset & Schmid, 1999) accompanied by a white dwarf. The orbital period of the binary system is 758 days (Mikołajewska & Kenyon, 1996). During more than hundred years of monitoring, the system showed several active stages with changes of brightness ranging from a few tenths of magnitude to about three magnitudes (e.g. Skopal et al., 2000). The system has been in the active stage since 2000.

AG Pegasi is the slowest symbiotic nova, which showed a Z And-type outburst 165 years after its nova-like flare-up (Skopal et al., 2017). The symbiotic system consists of a M3 III giant (Schulte-Ladbeck, 1988) and a white dwarf. The orbital period was determined to be 816.5 days (Fernie, 1985). The brightness of the system began to be recorded before 1820 (although with very low cadence). Its nova-like outburst began in 1850 and maximum brightness was reached around 1885 (Boyarchuk, 1967).

3. Observational data

Astronomical Ring for Amateur Spectroscopy (ARAS) is an initiative dedicated to promotion of amateur astronomical spectroscopy and pro/am collaborations. Observations of the group[1] focus on novae (34, to date) and symbiotic binaries (54, to date). Moreover, 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 different resolution (500 to 15000), covering the range from 3500 to nearly 8000 Å. The advantages of the ARAS Group are rapid response to alerts, long-term monitoring and high cadence of observations.

In this work, we used medium resolution spectra of the selected symbiotic stars obtained by 22 individual ARAS observers. These observations were used to study the activity and overall behavior of AG Dra during the ongoing active stage (274 spectra obtained by 17 observers) and to compare the recent evolution of prominent emission lines in its spectra to that of Z And (61 spectra, 6 observers) and AG Peg (111 spectra, 15 observers).

[1] http://www.astrosurf.com/aras/Aras_DataBase/DataBase.htm

4. Analysis and results

All three studied symbiotic binaries manifested Z And-type outbursts recently. In this section, the spectroscopic behaviour of AG Dra, Z And and AG Peg during their last active stages is discussed and compared to their previous activity. Moreover, the temperature of white dwarfs in the symbiotic system is derived based on characteristics of the prominent emission lines in their spectra.

4.1. Recent outburst activity of AG Dra, Z And and AG Peg

AG Dra entered the new active stage in 2015 and since then four outbursts have been observed (upper panel of Fig. 1). After the last outburst, the brightness of AG Dra returned to values typical for its quiescent stage at the end of July 2018 (Merc et al., 2018b).

Leedjärv et al. (2016) showed that it is possible to distinguish between the *cool* and *hot* outbursts of AG Dra (see González-Riestra et al., 1999) according to the behaviour of the prominent emission lines in its optical spectra. The outbursts at the beginning of active stages of AG Dra are usually major, *cool* ones. During the *hot* outbursts, the brightness is more or less linearly correlated with equivalent widths (EWs) and other spectral characteristics of the emission lines. With respect to this behaviour, the activity of AG Dra during the ongoing active stage is very unusual. The increase of the EWs of prominent emission lines observed during all four outbursts suggests their *hot-type* character.

Z And has been active since 2000 and its recent outburst was detected at the turn of the years 2017 and 2018 (middle panel of Fig. 1). The EWs of studied emission lines in spectra of Z And showed significant decline during the recent outburst and their values are anti-correlated with its brightness changes. In the case of AG Dra, such behaviour is typical for the *cool* outbursts. The Raman-scattered O VI and [Fe VII] lines completely disappeared during this outburst. The latter reappeared at the time when O VI lines remained undetectable.

Similar behaviour of emission lines in the spectra of Z And was observed in 2006, when the star underwent the major outburst accompanied by the ejection of bipolar jets (Skopal & Pribulla, 2006). During that outburst, the He II line also practically disappeared. Despite the similarity of the outbursts in 2006 and 2018, no sign of the jet components around the Hα and Hβ lines was observed in the spectra of Z And during the recent one.

AG Peg manifested the outburst in 2015 with very slow decline in brightness lasting for more than a year (bottom panel of Fig. 1). Similar double-peaked structure as in the light curve was also observed in the spectral behaviour of this object. During the outburst, the EWs of studied emission lines increased significantly compared to their quiescence values although the observed increase of EWs was not so steep as for the brightness. The Raman-scattered O VI lines disappeared from the spectra during both outburst maxima.

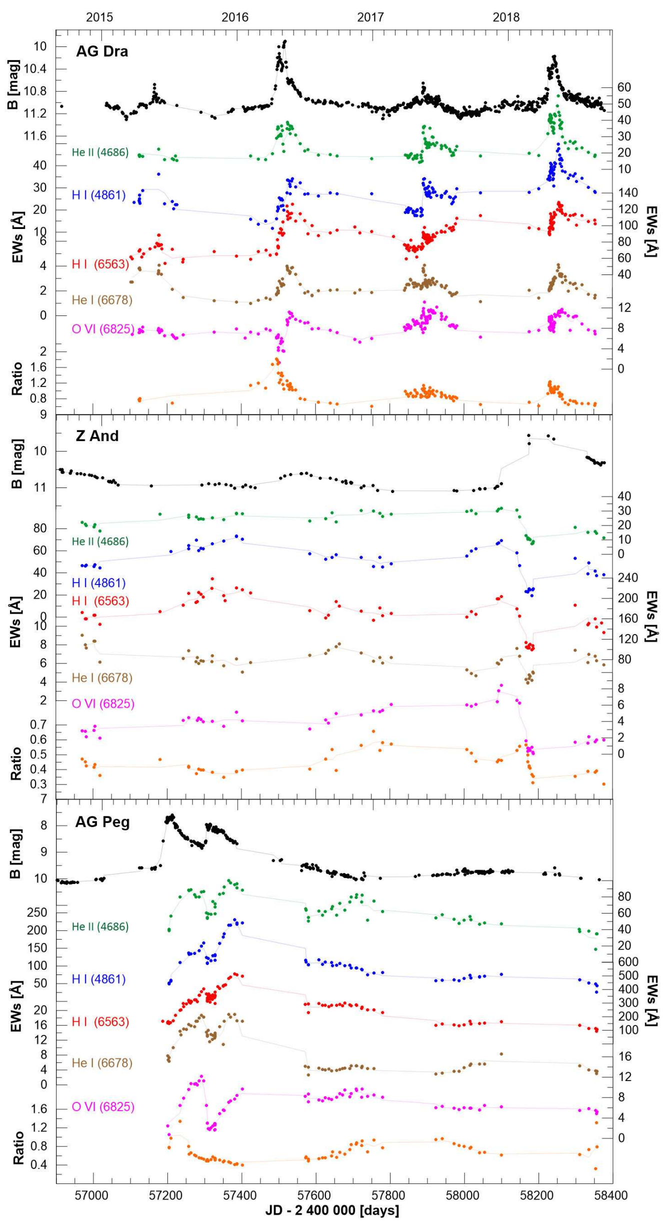

Figure 1. The light curves of studied symbiotic stars in the *B* filter plotted together with EWs for selected emission lines and the He II/Hβ ratio.

4.2. Temperature evolution of the white dwarfs

The fluxes of He I 4471 Å, He II 4686 Å and Hβ emission lines can be used to derive the temperature of the hot component in symbiotic systems (Iijima, 1981).

Sokoloski et al. (2006) neglected the flux of the He I 4471 Å line in the case of Z And, because $F_{4471} \leq 0.1 F_{H\beta}$. The same relation is valid for AG Dra (Leedjärv et al., 2016; Merc et al., 2018a) and AG Peg (this work). Making this assumption allows us to use the ratio of EWs instead of the fluxes:

$$T_{\rm hot}\,(\mathrm{in}\,10^4\,\mathrm{K}) \approx 14.16\sqrt{\frac{\mathrm{EW}_{4686}}{\mathrm{EW}_{\mathrm{H}\beta}}} + 5.13. \qquad (1)$$

In general, this approximation increases the estimate of the hot component's temperature. Moreover, there are also other phenomena (e.g. the presence of additional ionization mechanisms; the phase dependence of the EWs of low excitation lines on the orbital motion; presence of the absorption component in Hβ line profile) which have to be taken into account in studying the temperature changes of white dwarfs using the He II/Hβ ratio (Merc et al., 2018a).

Counting all these effects, the main findings can be summarized as follows: a) All four recent outburst of AG Dra were of the *hot* type. Moreover, during the outburst in 2016, the historical maximum of the white dwarf's temperature was detected. b) During and after the last outburst of Z And, a decrease in the temperature was observed. c) The outburst of AG Peg in 2015 was accompanied by an increase of the hot component's temperature as in the case of AG Dra.

4.3. The Raman-scattered O VI lines

The Raman-scattered O VI lines are broad emission lines at 6825 and 7082 Å which are a product of Raman-scattering of the photons of the O VI resonance lines at 1032 and 1038 Å off the atoms of neutral hydrogen (Schmid, 1989). They occur almost exclusively in the spectra of symbiotic variable stars.

The Raman-scattered O VI 6825 Å line almost disappeared during the *cool* outburst of AG Dra in 2006, confirming a drop in the hot component's temperature (Leedjärv et al., 2016). The outburst of this symbiotic system in May 2016 manifested the same vanishing of this line although it was not of the *cool* type (Merc et al., 2017). Similar vanishing was observed during the recent outbursts of Z And and AG Peg (the curves of the Raman-scattered O VI EWs are depicted in Fig. 1 by purple color).

In the case of Z And, the minima of the Raman-scattered O VI EWs can be explained by a cooling of the hot component. On the other hand, observations of AG Dra and AG Peg during studied outbursts showed that temperatures of their white dwarfs were high enough to produce original O VI lines. Their values reject the usual interpretation for disappearance of the Raman-scattered O VI lines due to the cooling of the ionizing source. During the outburst of AG Dra in May 2016, the temperature reached the historical maximum. In the case of AG Peg, the minimum of the Raman-scattered O VI EWs was also observed when the temperature of the hot component was very high. Skopal et al. (2017) suggested that the transient weakening of the Raman-scattered O VI lines during the outburst of AG Peg in 2015 is a result of an increase of mass-loss rate from the hot component which makes the O VI zone optically thick. Probably, a similar effect played a role in the case of AG Dra.

5. Conclusions

The medium-resolution spectra of AG Dra, Z And and AG Peg were used to study the variability and behaviour of the prominent emission lines formed in the circumbinary envelope of these symbiotic systems. In addition, changes in profiles of the spectral lines were studied. The high cadence of the obtained spectra allowed us to study the evolution of the white dwarf's temperature during the outbursts of these systems. Moreover, we have used the same mid-res spectra of AG Dra for radial velocity measurements, which will be presented in our forthcoming paper. Low-resolution spectra play an important role not only in monitoring, but can be used also for spectral energy distribution modelling.

Our results showed the importance of long-term monitoring of symbiotic stars as well as how the pro/am collaborations is essential for investigation of these strongly interacting binaries. The ARAS Group is a perfect example that such collaborations can be very successful and can bring significant results.

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