10.1515/astro-2017-0137

Baltic Astronomy, vol. 25, 317–323, 2016

DETAILS OF THE CLASSIFICATION OF SYMBIOTIC STARS: THE CASE OF THE SYMBIOTIC NOVA AG PEG

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Received: 2016 September 27; accepted: 2016 October 17

Abstract. We analyze archival and modern spectroscopic and photometric observations of the oldest known symbiotic nova AG Peg. Its new outburst (which began in 2015 June) differs greatly from the first one (which occurred in the mid-1850s). Fast photometric evolution of the new outburst is similar to that of Z And-type outbursts. However, the SED of AG Peg during the 2015 outburst, as well as during the quiescence, can be fitted by a standard three-component model (cool component + hot component + nebula), which is not common for an Z And-type outburst.

Key words: stars: binaries: symbiotic – stars: individual (AG Peg)

1. INTRODUCTION

AG Peg is the oldest known symbiotic nova. The binary underwent a slow nova eruption in the mid-1850s (Lundmark 1921). Its visual light curve (see Fig. 1) demonstrated a very slow rise to maximum light (from 9th to 6th magnitude in about one decade or less), a long-standing plateau near maximum and a slow decline which lasted until the summer of 2015. Periodic light variations ($P = 816$ days) due to orbital motion have been clearly observed since the 1960s (Belyakina 1968).

The first spectrum of AG Peg was taken in 1897 by Williamina Fleming (1907). It looked like a Be-type spectrum with P Cygni-type Balmer hydrogen lines. Despite the lack of spectroscopic observations we can suggest that the symbiotic binary AG Peg evolved as a typical symbiotic nova with A–F supergiant phase near maximum light ($L_{\rm bol} \approx 3000 L_{\odot}$, according to Kenyon et al. 1993). After that the hot component of AG Peg mimicked a Wolf-Rayet star (WN6 spectrum) and later its spectrum became similar to that of a hot subdwarf with an effective temperature of about 10^5 K (Gallagher et al. 1979). In the late 1920s, TiO molecular bands appeared in the spectrum of AG Peg and the star revealed its symbiotic nature.

Kenyon et al. (1993) showed that the bolometric luminosity of the hot com-

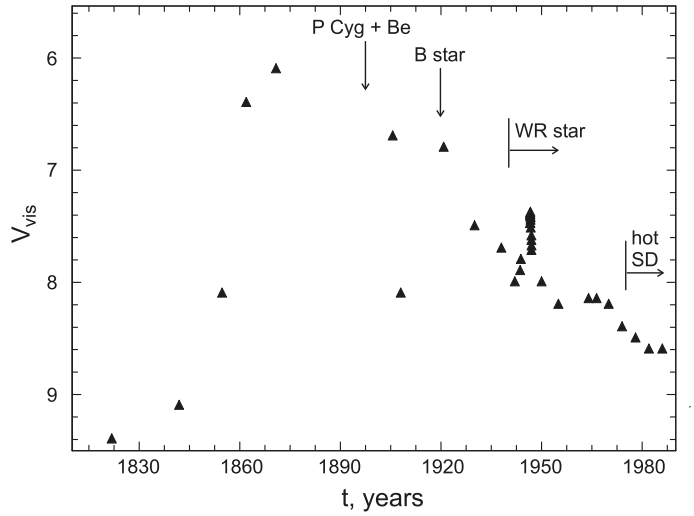

Fig. 1. Visual light curve of the symbiotic nova AG Peg in 1820–1985.

ponent remained nearly constant during the century, although its temperature increased by a factor of 10. A slow decline of bolometric luminosity began in the 1980s and in 1997 the luminosity of the hot component was about $500L_{\odot}$ (Kenyon et al. 2001). Kenyon et al. (1993) suggested that AG Peg was evolving towards lower luminosities along a white dwarf cooling curve according to the theoretical model of a symbiotic nova outburst.

The second outburst of AG Peg was detected quite simultaneously in optical and X-ray ranges (AAVSO alert notice 521 and Luna et al. 2015). In the present work we analyze spectral and photometric evolution of two outbursts of AG Peg and try to evaluate the role of AG Peg in the classification of symbiotic stars.

2. OBSERVATIONS

We used the following two standard stars for our spectroscopic observations: HR 8344 and 38 Peg. The observations were acquired with the 2.6-m G. A. Shain reflector of the Crimean Astrophysical Observatory, using the SPEM slit spectrograph at the Nasmyth focus (with a dispersion of about 2 Å/pixel). We observed AG Peg also with the 125-cm reflector at the Crimean Station of Moscow State University, equipped with a grating spectrograph and an SBIG ST-402 CCD (765×510 array, 9 micron pixels) on August 7, 2015. The spectral resolution (FWHM) was 7.4 Å. The spectrum was flux calibrated using the star α Del observed on the same night. The spectral energy distribution (SED) for α Del was adopted from Glushneva et al. (1998).

3. DISCUSSION

Figure 2 shows the AAVSO V-band light curve of AG Peg (Kafka 2016). It describes the behavior of the binary in the quiescent state and during the outburst of 2015. The photometric evolution of the second outburst differs greatly from that

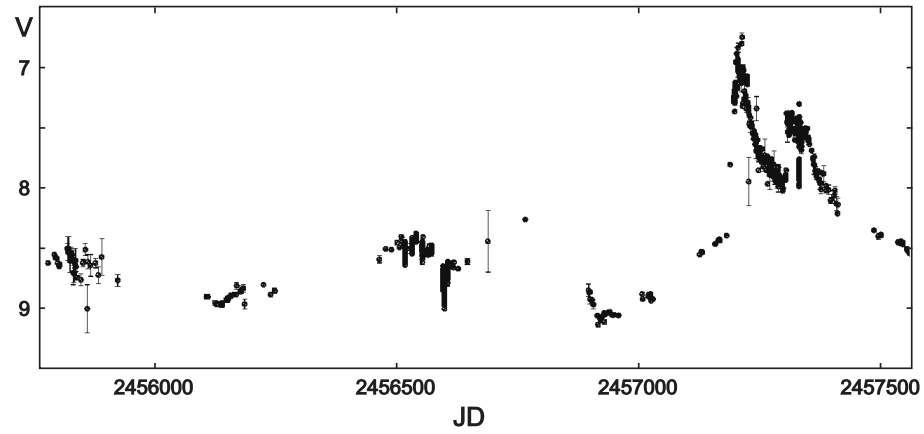

Fig. 2. AAVSO V-band light curve of the symbiotic nova AG Peg before and during the outburst of 2015.

of the first one. A very fast rise (2 mag in less than a month) was observed in June 2015. The new outburst had two-maxima light curve (the second maximum was observed 100 days after the first one). By the summer of 2016 the visual brightness decreased to quiescent level but we cannot determine the state of the hot component without new spectroscopic observations.

The short timescale of the new outburst and the shape of its light curve are typical of an Z And-type outburst, but not of a symbiotic nova outburst. It is also quite common for some Z And-type stars to show a weak optical brightening preceding bright outbursts, such as was detected for AG Peg in 2013 (Munari et al. 2013) (see, for example, BF Cyg in Tatarnikova et al. 2008).

Figure 3 shows a typical quiescent state spectrum of AG Peg. In the 2000s, AG Peg exhibited poor emission-line spectrum dominated by H I, He I, and He II lines. Forbidden lines of [Ne V] and O III Bowen fluorescence lines are clearly seen in the near UV. The [O III] nebular lines appeared in 1943 (Merrill 1951) and nearly disappeared in the mid-1990s (Kenyon et al. 2001). There is only one important difference between the spectra obtained in the 1990s (they were described in detail by Kenyon et al. 2001) and our spectra taken in 2007–2015: Raman-scattered O VI lines 6825,7082 have been clearly visible in our spectra at least since 2008.

All our estimates of the temperature and luminosity of the hot component are based on the modified Zanstra method (Munari et al. 1997 and references therein) for the He II 4686 line. Due to sufficient contribution of the cool component's radiation near 4686 Å we did not operate with the equivalent width of He II 4686 Å ($F(\mathrm{He\,II}\ 4686\,\text{Å})/F_{\mathrm{cont}}(4686\,\text{Å})$) and calculated the modified equivalent width of He II 4686 Å ($F(\mathrm{He\,II}\ 4686\,\text{Å})/F_{\mathrm{cont}}(3600\,\text{Å})$) instead. We suggested that (1) electron temperature of the nebula is about 15 000 K and (2) all Lc photons are absorbed in the nebula (otherwise we overestimate the temperature of the hot component). Murset et al. (1991) analyzed IUE spectra of AG Peg and proved the last suggestion for the spectrum obtained in 1990.

The combined SED of AG Peg in the quiescent state consists of the contributions from the cool component (M3 giant), hot component, and gaseous nebula (see Fig. 3). This complex structure of the spectrum is typical of symbiotic stars.

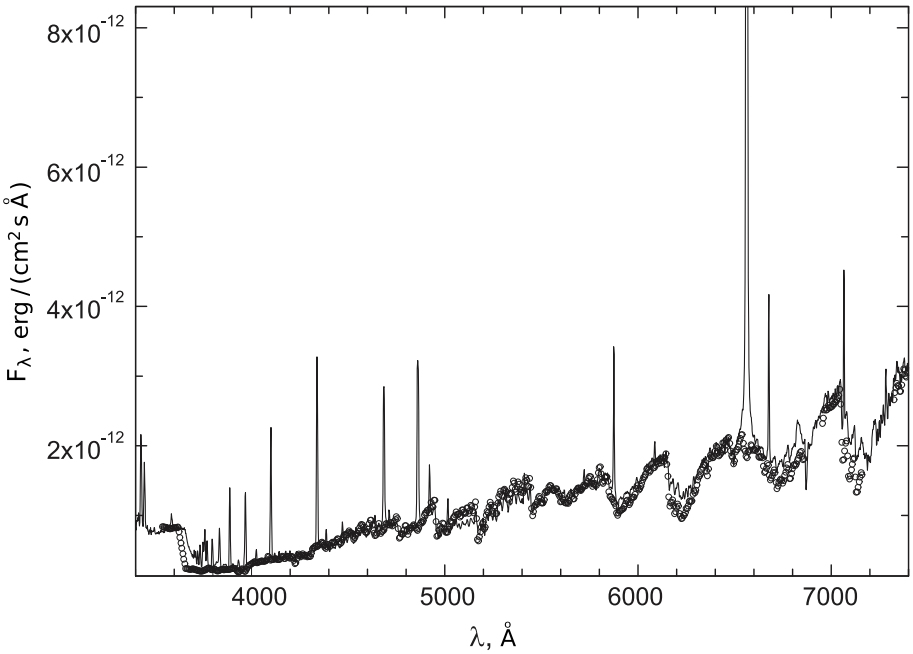

Fig. 3. Quiescent spectrum of AG Peg taken on 2011 August 6 and the model curve (open circles).

It is worth mentioning that physical parameters of the hot component are nearly the same as they were in 1997 (according to Kenyon et al. 2001).

During the outburst of 2015 the contribution of the gaseous continuum increased greatly (the continuum flux near the Balmer jump increased by a factor of 10) and it veiled absorption bands of the cool component (see Fig. 4). However, the real spectral class of the cool component did not change. The temperature of the hot component was also the same as it was before the outburst, although the luminosity of the hot component increased by a factor of 10. Although the photometric properties of the 2015 outburst are typical of classical symbiotic stars (CSS), there was one peculiarity in the SED during the outburst. Fig. 5 demonstrates the fact that during the outburst the SED of AG Peg can be fitted by a standard three-component model. Usually a typical near-UV spectrum of a CSS in active state points out the presence of an additional source of optically thick radiation (may be accretion disk?). Sometimes the Balmer jump is not observed in emission spectra of active CSS, sometimes it is, but the presence of additional source of radiation decreases the Balmer jump significantly. Both cases are shown in Fig. 6. And, as regards AG Peg, we can see no additional source in the SED.

4. CONCLUSIONS

Figure 7 shows the track of the hot component in the Hertzsprung-Russell diagram. A white dwarf cooling curve was adopted from Kenyon et al. (1993). During more than a century the observed evolution of AG Peg was in line with the theoretical model of a symbiotic nova outburst. However, now the situation

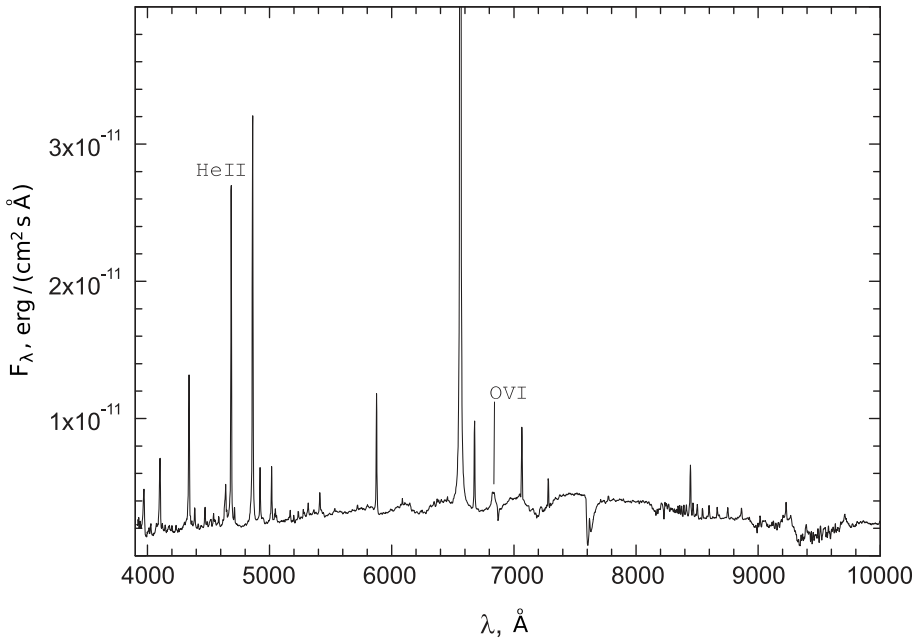

Fig. 4. Spectrum of AG Peg taken on 2015 August 8, during an outburst.

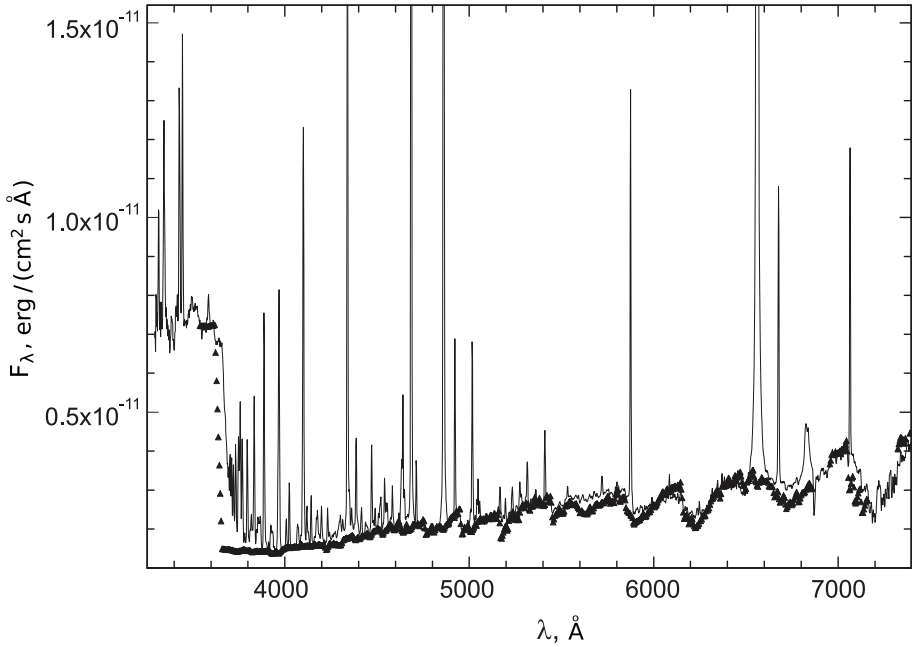

Fig. 5. Spectrum of AG Peg taken on 2015 August 18 and the model curve (triangles).

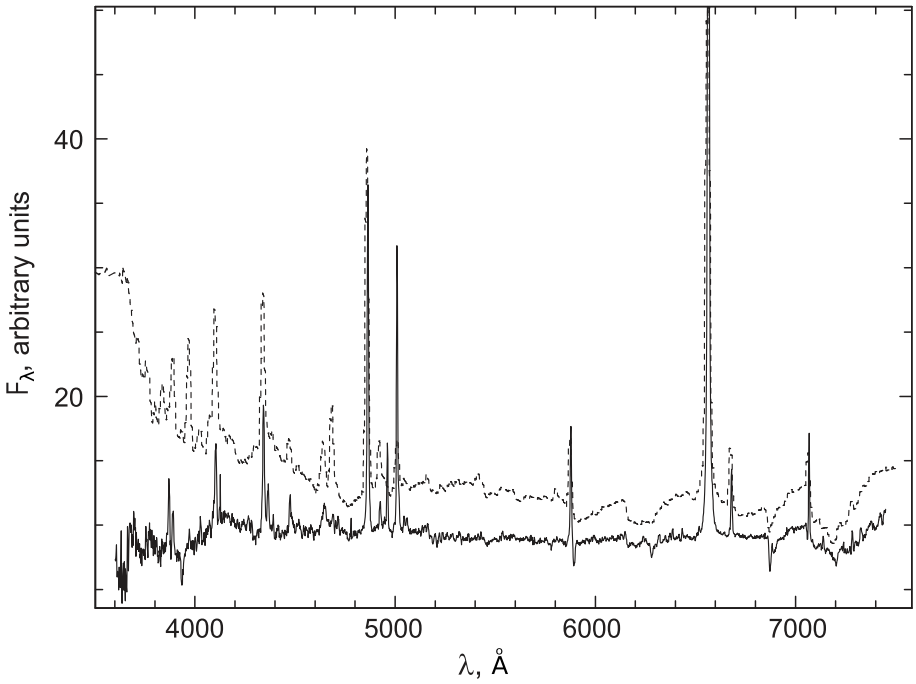

Fig. 6. Spectra of two CSS in active state: YY Her (the dashed line – Munari et al. 1997) and V1413 Aql (the solid line – Esipov et al. 2013).

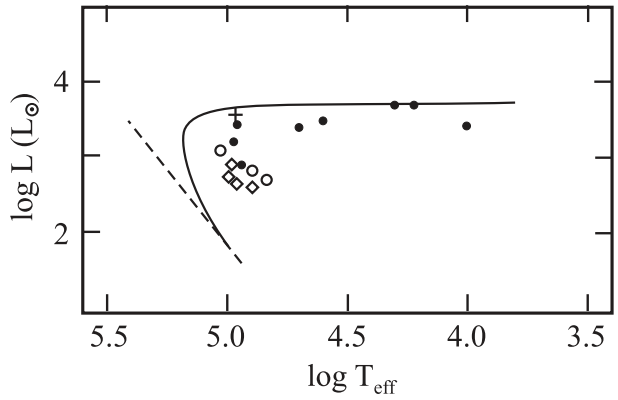

Fig. 7. Evolution of the hot component of the symbiotic nova AG Peg in the HR diagram based on the data from Kenyon et al. (1993) (dots), Kenyon et al. (2001) (circles), and this work (diamonds and a cross). The cross represents observations obtained during the outburst of 2015.

is different. There was no evidence of any significant decrease in temperature in 1990–2015 (when the luminosity decreased by a factor of four).

Given its photometric evolution, the second outburst of AG Peg may be classified as a Z And-type outburst, although the absence of additional source of optically thick radiation in the near-UV is not common for this type of events.

The classification of symbiotic stars according to their outburst types was theoretically based on the different accretion rates of hot components (Iben 1982). We now know some cases of complicated classification. For example, V407 Cyg has demonstrated different outbursts: two Z And-type outbursts and one recurrent symbiotic nova event (Esipov et al. 2012). The historical light curve of the CSS BF Cyg revealed an old outburst which was similar to symbiotic nova outburst (Leibowitz & Formiggini 2006).

And now the new outburst of AG Peg raises two questions to be discussed: (1) Can a classical symbiotic star be just a stage of the evolution of a symbiotic star? In other terms, have all CSS ever manifested themselves as symbiotic novae? (2) Does the classification scheme of symbiotic stars (its observational and theoretical aspects) need any modernization?

ACKNOWLEDGMENTS. The reported study was partially supported by the Russian Foundation for Basic Research (projects Nos. 15-07-04512 and 14-02-00027).

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