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ORBITAL SPECTRAL VARIABILITIES IN SYMBIOTIC STAR AG PEGASI

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ABSTRACT. The results of the study of orbital spectral variability due to binary nature of the symbiotic star AG Peqasi are presented. We used high-resolution spectra (R = 28,000) taken by 2-m telescope of the Shamakhi Astrophysical Observatory during 2016–2019, and medium-resolution amateurs' spectra (R = 9,000–11,000) taken from the Astronomical Ring for Access to Spectroscopy (ARAS) database obtained during 2020–2024. The system's orbital period is approximately 815 days, and its spectral changes are correlated with this period. In this paper we present the radial velocity curve of the cold component (M3III), as well as the emission lines Hα, Hβ, and the HeII lines λ4686 Å and λ5412 Å formed around the hot component of the AG Peg system, constructed according to our measurements. We determined the mass function of the cool component, $f_1 \approx 0.023$ $M_\odot$.

Keywords: symbiotic star, binary star, spectroscopy, radial velocity.

АНОТАЦІЯ. Представлено результати дослідження орбітальної спектральної змінності, зумовленої подвійною природою симбіотичної зорі AG Pegasi. Внаслідок взаємодії гарячого білого карлика та холодного гіганта спостерігаються періодичні зміни променевих швидкостей як абсорбційних ліній холодного гіганта, так і емісійних ліній, що формуються поблизу гарячого компонента.

У даному дослідженні використано два набори спектральних спостережень. Перший набір – 16 спектрів, отриманих у фокусі Кассегрена 2-метрового телескопа Шамахинської астрофізичної обсерваторії імені Н. Тусі на волоконному ешель-спектрографі (ShAFES) з роздільною здатністю R = 28 000 у 2016–2019 роках. Другий набір – 25 спектрів, запозичених із бази даних ARAS Spectral Database, отриманих у 2020–2024 роках із роздільною здатністю 9 000–11 000.

Орбітальний період системи становить приблизно 814 діб, і спектральні зміни системи AG Peg корелюють із цим періодом. У роботі представлено криву променевих швидкостей холодного компонента (зорі спектрального класу M3III), а також лінії випромінювання Hα, Hβ і HeII λ4686 Å та λ5412 Å, що формуються навколо гарячого компонента системи AG Peg, побудовані за результатами наших вимірювань. Масова функція холодного компонента симбіотичної системи AG Pegasi була оцінена за кривою швидкостей червоного гіганта: $f_1 \approx$0,023 M$\odot$.

Побудовано криву променевих швидкостей і визначено орбітальні елементи для зорі класу M у системі AG Peg: максимальні та мінімальні значення орбітальних швидкостей зорі M3III — υ(max) = -10,72 км/с, υ(min) = -23,65 км/с; швидкість центра мас системи (γ-швидкість): $V_\gamma \approx$ -17 км/с; швидкості в перицентрі та апоцентрі: υp = 6,65 км/с, υa = 6,28 км/с. Ексцентриситет орбіти: $e \approx 0{,}027$. $a_1 \sin i = 7{,}2 \cdot 10^7$ km $\approx$ 0,48 a.u. $\approx$ 103$R_\odot$.

Ключові слова: симбіотична зоря, подвійна система, спектроскопія, променева швидкість.

1. Introduction

Symbiotic stars are the most interesting, because they host the white dwarf (WD), which may be progenitors to Type Ia supernova explosions (Munari U. 1994; Boffi F.R et al. 1994). The symbiotic system consists of two completely different types of stars that interact: A cold red giant (RG in some cases yellow) and hot compact star, most frequently a WD. By studying symbiotic stars, we simultaneously study 3 different types of space objects:

1. Red giant
2. White dwarf and accretion disk
3. Star environment gas and dust nebula.

In systems of this type, a powerful flow of matter occurs through the stellar wind from a cold star, and an accretion disk is formed around a hot compact star. Symbiotic stars can reflect a transitional stage in the evolution of several types of double systems with a powerful flow of matter from a large-mass star to a small-mass star (Munari, 1994; Boffi et al., 1994).

The system AG Peg (HD 207757) is the oldest known symbiotic nova (Boyarchuk, 1967). The symbiotic star AG Peg is a binary system that consists of a more massive M3 III RG and a less massive hot WD surrounded by nebulous gas.

a) massive RG star: spectral type MIII, mass – 2.6 $M_\odot$, radius – 85$R_\odot$, luminosity – 1100 $L_\odot$, eff. temperature – 3650 K.

b) dwarf (WD) star: mass – 0.65 $M_\odot$, radius – 0.06 $R_\odot$, luminosity – (1180-2400) $L_\odot$, eff. temperature – (95000-168000) K. (Kenyon et al., 1993; Fekel et al., 1985; Skopal, 2005; Sion et al., 2019; Skopal et al., 2017; Murset & Schmid, 1999).

The orbital period of AG Peg, according to published data, is (812-818) days (Kenyon et al., 1993; Fekel et al., 2000; Fernie, 1985).

Based on the AAVSO data for the period 1954-2022, a periodicity in the star's bright changes was identified, with a period of about 815 days. (Mikailov et al., 2023).

The recent major outburst occurred in 2015, which is the second major one since the first major nova outburst in 1850 (see: Kenyon et al., 2001; Ramsay et al., 2016; Tomov et al., 2016; Skopal et al., 2017). The analysis of the observations carried out in different spectral regions during the past years, model of this system – a stage of colliding winds. For the first time this model was proposed by Penston & Allen (1985) on the basis of three IUE high resolution spectra. Since the cool giant also loses mass through a stellar wind, it was concluded that the two winds probably interact. A model of winds in collision was proposed also by Tomov N.A. (1993b) on the basis of profiles, fluxes and radial velocities, derived from homogeneous high dispersion spectral observations in the visual during two consecutive orbital cycles (Tomov & Tomov, 1992; Tomov, 1993a).

The star AG Peg belongs to the subclass of symbiotic novae. Only eight nova-like symbiotic stars are currently known. During an outburst, the visible brightness of these stars reaches a very high value, and they maintain their brightness at such an elevated state for tens, sometimes hundreds of years. Powerful shock waves generated during flares heat the surrounding plasma to temperatures of (10^7-10^8) K and these regions become sources of emission lines with different degrees of ionization. In the spectrum of the star AG Peg, along with coronal lines FeX, FeXI, [NiXV], forbidden lines [NII], [OII] and Balmer lines of hydrogen are observed.

2. Observations and data reduction

Two sets of spectroscopic observations were used in the present study. The first set 16 spectrum were carried out at the Cassegrain focus of the 2-m telescope of the Shamakhi Astrophysical Observatory named after N.Tusi, on fiber echelle spectrograph (ShAFES) with the spectral resolution of R = 28000, in 2016-2019 years (Mikailov et. al., 2020), the second set 25 spectrum borrowed from the ARAS Spectral Database, obtained in 2020–2024 with spectral resolutions of 9000–11000 (https://aras-database.github.io/database/). The reduction of echelle spectra was carried out according to the standard technique using the new version of the DECH 30 program developed by Galazutdinov (Galazutdinov, 1992).

3. Results of observations

Due to the orbital motion of the hot WD and the RG, periodic variations in the radial velocities of the absorption lines of the RG and the emission lines formed around the WD are observed. The system's orbital period is approximately 815 days (Mikailov et al., 2023), and its spectral changes are correlated with this period. In this paper we present the radial velocity curve of the cold component (M3III), as well as the emission lines Hα, Hβ, and the HeII lines λ4686 Å and λ5412 Å formed around the hot component of the AG Peg system, constructed according to our measurements. The mass function of the cold component of the symbiotic AG Pegasi system was estimated from the velocity curve of the red giant.

Fig. 2 shows the radial velocity curve of the cool component of the star AG Peg constructed on the basis of the average values of the measured absorption lines of the star M3III.

The measured heliocentric radial velocities of more than thirty pure (unblended) absorption lines of metals (FeI, CaI, CrI, TiI) in the length range of $\lambda\lambda$5000-8000 Å were used.

The results of determining the spectral parameters of RG are presented in Table 1. This table also contains similar data from other authors. Since the spectral lines of only one component of the star AG Peg are observed, we cannot determine the masses of both components but can only estimate the mass function and $a_1$sini.

Figures 3-5 shows the radial-velocity curves for emission lines: HeII λ4686 Å, λ5412 Å; HI Hα and Hβ as well as forbidden lines 4363[OIII], 5721 [FeVII] in spectrum of the star AG Pegasi compared to the M star.

In Fig. 5, when constructing the radial velocity curves of forbidden lines, the radial velocity values were used: at half maximum intensity - FWHM (Full Width at Half Maximum) and at the level of maximum intensity and were designated as, for example, [OIII]1/2 and [OIII]peak.

The change in the radial velocities of the HeII emission lines occurs in antiphase with the changes in the radial velocities of the absorption lines of the cold giant (Fig. 3). Apparently, the He II emission lines are formed in the close vicinity of the hot component.

Table 1: Spectral orbital parameters for RG star

maximum of orbital velocity	-10.72 km/s
minimum of orbital velocity	-23.65 km/s
velocity at periastron	6.65 km/s
velocity at apastron	6.28 km/s
orbital eccentricity	≈ 0.027
semi amplituda of the velocity change (K)	6.46 km/s
$a_1 sini = 1.376{\cdot}10^4 K_1 P{\cdot}(1 - e^2)^{1/2}$	$\approx 7.2{\cdot}10^7$ km
mass function: $f_1 = 1.038{\cdot}10^{-7}\ K_1{}^3{\cdot}P(1 - e^2)^{3/2}$	0.023 $M_\odot$

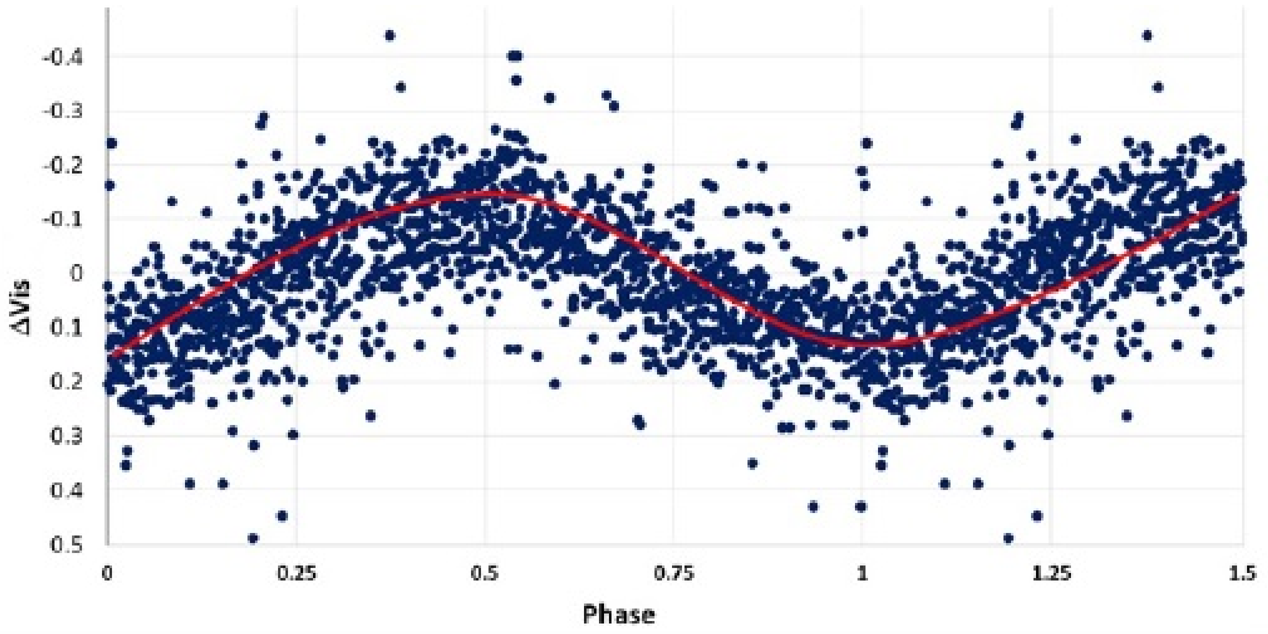

Figure 1: Based on the AAVSO data for the period 1954-2022, periodicity in the star's brightness changes was identified, with a period of about 815 days (Mikailov et al., 2023).

The behavior of the HI Hα, Hβ and 5721 [FeVII] lines is similar to the HeII lines (Fig. 4-5). The change in radial velocities of the forbidden lines 4363[OIII] differs from these lines (Fig. 5). Apparently, this line is formed by a gas flow from a hot component near a cold component.

Based on the radial velocities and intensities of the He II emission lines and the hydrogen Balmer lines in the spectrum of AG Pegasi, one can determine the regions where these lines are formed. The line half-widths allow us to estimate the distances of these regions from the hot component (the white dwarf). The width of a spectral line reflects the maximum velocity of the gas emitting it. Assuming that the gas is gravitationally bound to the white dwarf and moves in a Keplerian orbit, its velocity is given by

$$v = (GM/r)^{1/2}$$

where G is the gravitational constant, M is the mass of the white dwarf, and r is the distance of the line-formation region from the white dwarf.

Hence,

$$r = GM/v^2$$

The velocity v is inferred from the measured line width. Two width parameters are commonly used:

a) FWHM (Full Width at Half Maximum): gives the characteristic velocity of the gas.

b) HWZI (Half Width at Zero Intensity): the line wings trace the fastest (innermost) gas, so

$$v_{max} \approx \mathrm{HWZI}$$
$$r \approx GM/v^2{}_{max}$$

Thus, comparing the widths of Hα, He II 4686, and [O III] lines makes it possible to reconstruct the structure of the circumstellar environment and estimate the distances to different emitting regions.

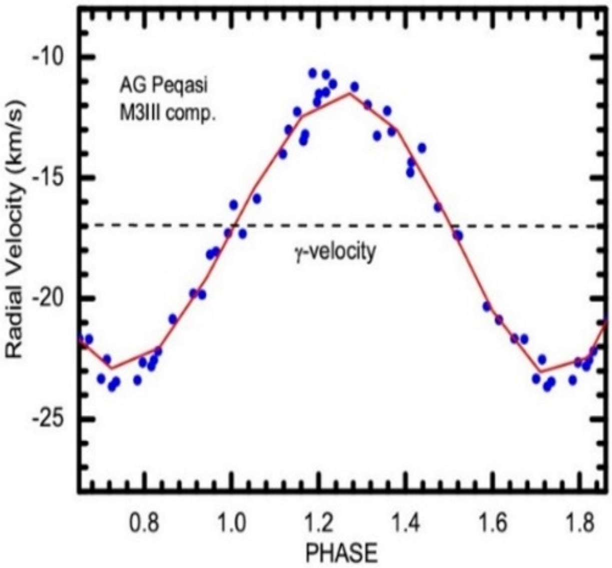

Figure 2: Radial velocity curve for the M3 III star in AG Peg (Mikailov et al., 2023). Orbital phases were calculated based on the ephemeris Min (Vis)=JD2439050 + 814.99E (Mikailov Kh.M. et al., 2023).

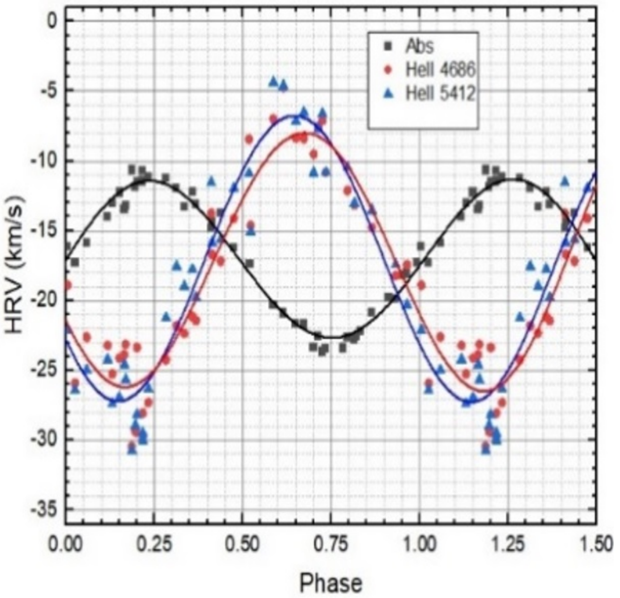

Figure 3: Radial-velocity curves for emission lines HeII $\lambda4686$ Å and $\lambda5412$ Å compared to the M star.

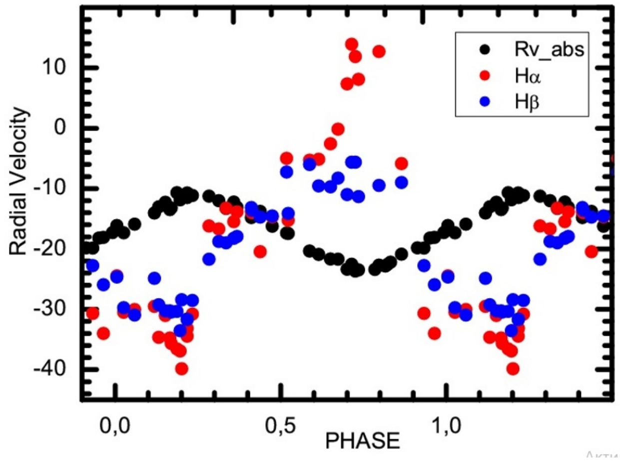

Figure 4: Radial-velocity curves for emission lines HI Hα and Hβ compared to the M star.

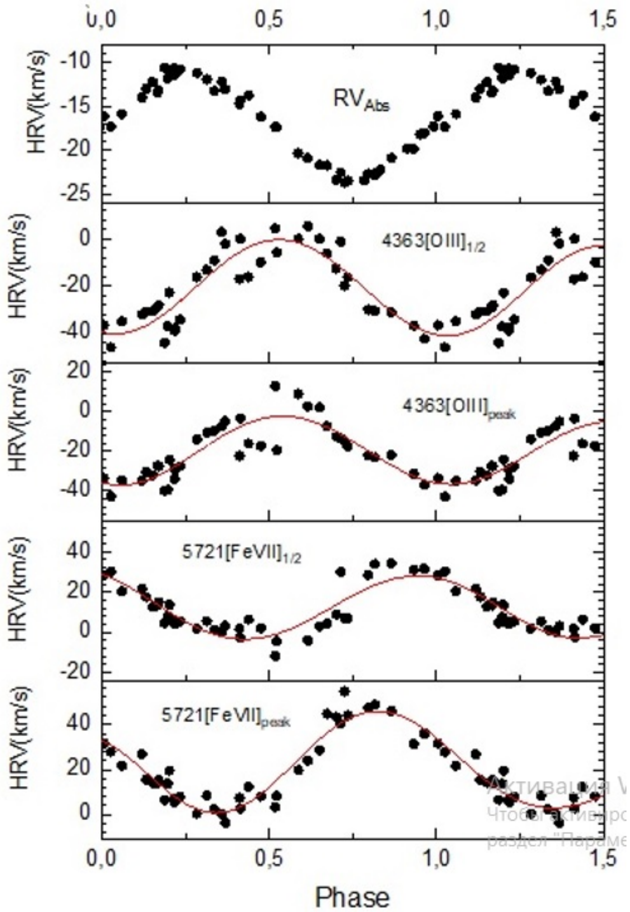

Figure 5: Radial-velocity curves for the M3 III star and the forbidden lines 4363[OIII] and 5721 [FeVII]

4. Conclusions

Radial velocity curve was constructed, and orbital elements were determined for the M Star in AG Pegasi:

• Maximum and minimum values of orbital velocities of the star M3III υ(max) = -10.72 km/s, υ(min) = -23.65 km/s

• Velocity of the center of mass of the system (γ-velocity) V$\gamma \approx$ -17 km/s

• Velocity at periastron and at apastron υa = 6.28 km/s, υp = 6.65 km/s

• Orbital eccentricity, e $\approx$ 0.027.; Period of the system: P $\approx$ 815 d.

• $a_1$sini = 7.2·10^7 km $\approx$ 0.48 a.u. $\approx$ 103$R_\odot$. Mass function: f_1=0.023 M$\odot$

• The results of comparative behavior of absorption and emission lines in the spectrum of the symbiotic system AG Pegasi are presented.

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