PERIODIC VARIATIONS IN THE SYMBIOTIC STAR SPECTRA

J. MIKOLAJEWSKA
Institute of Astronomy, N. Copernicus University, Toruń, Poland

ABSTRACT. Periodic variations of emission line intensities and radial velocities in three S-type symbiotic stars: BF Cyg, CI Cyg and AX Per are presented and discussed. The behavior of emission lines is different in these objects and suggests that significant differences in physical conditions and geometry may occur in these seemingly similar systems.

1. INTRODUCTION

The stars that are generally classified as symbiotic present a very heterogeneous collection of objects, and it is still uncertain if they have the same physical nature. Nevertheless, most of them can be naturally interpreted as interacting binaries consisting of a red giant and a hot companion responsible for the ionization and excitation in the nebula surrounding the binary system. Unfortunately, direct evidence for binarity (eclipses, radial velocity variations) exist for a small sample of systems. Indirect evidence (e.g. complex continous energy distribution) suggest that nearly all well-studied symbiotic stars are binaries. It should be also emphasized that single star models do not explain quantitatively the observational data of any well-examined symbiotic object.

The aim of this work is to discuss periodic variations of radial velocities and intensities of emission lines in three classical symbiotic systems: CI Cyg, AX Per and BF Cyg.

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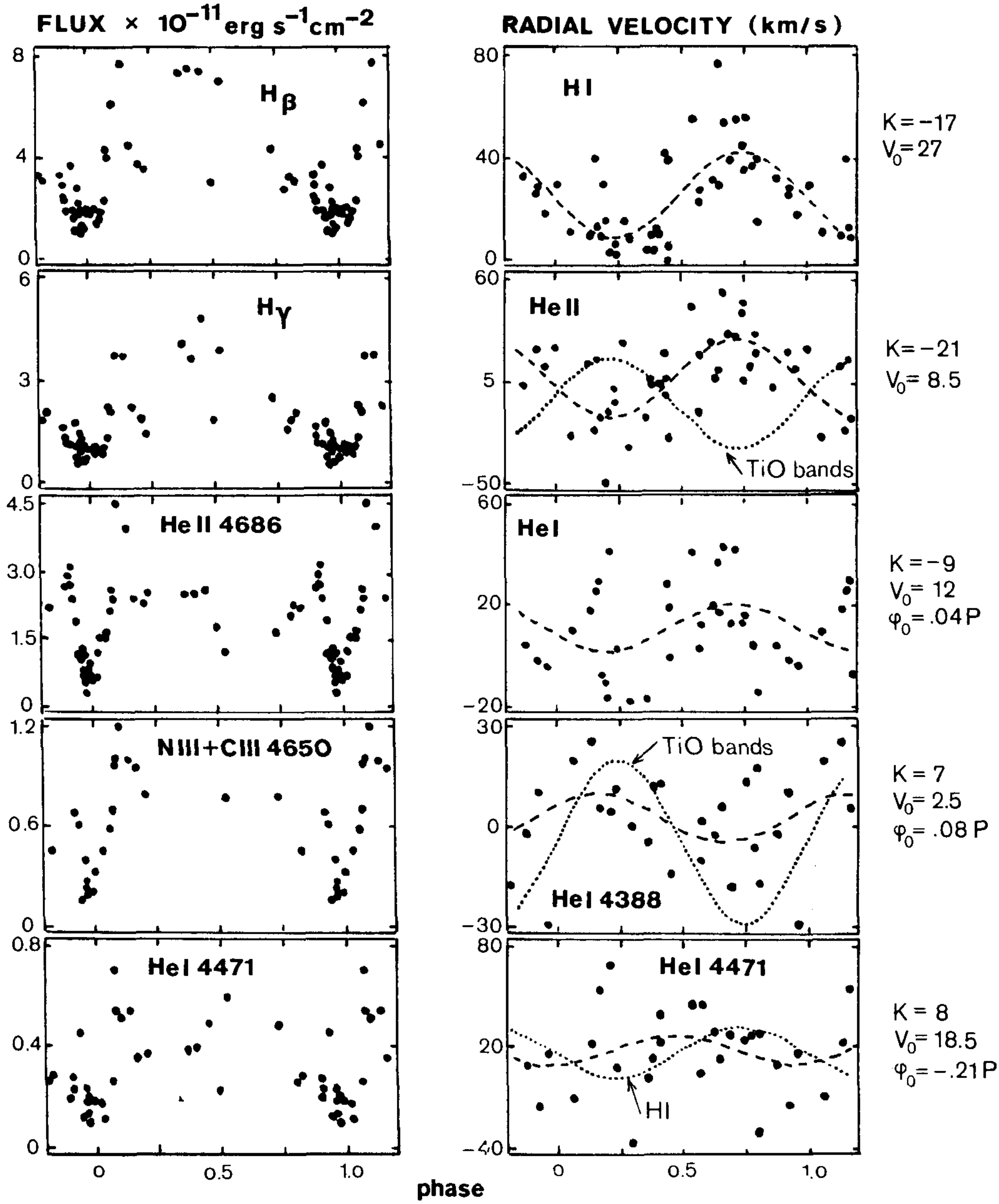

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Fig. 1. CI Cygni. Composite curves for emission line fluxes and radial velocity curves. Circular orbit solutions: $VR=V_o + K\ (\psi + \psi_0)$, are marked (dashed curves). For HeI radial velocity curves, the solution for Balmer lines and Iijima's (1982) solution for TiO bands (dotted curves) are plotted for comparison.

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2. COMMENTS ON INDIVIDUAL OBJECT

2.1. CI Cygni

CI Cyg holds a very important place among the symbiotic stars because of its eclipses occuring every 855.25 days and following the ephemeris:

$$\mathrm{Min} = \mathrm{JD}\ 2411902 + 855.25\ E$$

UBV photometry has allowed Belyakina (1979) and references therein) to establish that the hot component is totally eclipsed at primary minimum and this has been confirmed by subsequent optical and ultraviolet spectroscopic observation (e.g. Stencel et al, 1982; Mikolajewska & Mikolajewski, 1982, 1983; Oliversen & Anderson, 1983; Mikolajewska, 1985). These observers have found that many emission lines (e.g. HI, HeI, HeII, UV intercombination lines) were affected by eclipses, while others (e.g., UV resonance lines of CIV, SiIV, NV, optical nebular lines of [OIII], [NeIII], [NeV]) were not so. This implies that the nebula in CI Cyg is very complex, with HeII and UV intercombination lines produced close to the hot component and [OIII] and [NeIII] preferentially emitted in a much more extended region.

Iijima (1982) used the Balmer lines and the TiO bands to derive radial velocity curves for the hot component and the M giant, respectively. He obtained the mass ratio q+0.74 (cool:hot). Assuming a circular orbit, he derived M(cool)/sin(i) = 2.4 $M_\odot$, M(hot)/sin(i) = 3.3 $M_\odot$ and a separation A sin(i) = 650 $R_\odot$.

Figure 1 presents composite curves for emission line fluxes of HI, HeI, HeII and NIII+CIII together with their radial velocity curves (Merrill, 1933, 1950; Iijima, 1982; Chochol et al., 1984). The confrontation of the radial velocities with the line flux variations leads to the following conclusions:

- Spectroscopic conjunction for HI and HeII occurs at the minimum of their intensity. This confirms the eclipse interpretation of the presented HI and HeII line variation.
- HeI radial velocity curve (averaged over signlet and triplet lines) follows those of HI and HeII, although with lower amplitude. The separation of the radial velocity curves for the HeI 4388 and HeI 4471 lines shows a completely different behavior of HeI singlet and triplet lines. It might be interesting to examine variations of the singlet line intensities as well as of the singlet/triplet line ratio during the full orbital period.
- The very narrow minima in HeII λ4686 and NIII+CIII λ4650 (especially compared with those in HI and HeI) suggest that these lines originate close to the hot star and reflect its orbital motion better than Balmer lines. The HeII radial velocity amplitude (K=21 km/s) together with Iijima's amplitude of TiO bands lead to relatively high masses M(cool)= 3.3 $M_\odot$, M(hot)= 3,8 $M_\odot$ and a separation A=750 $R_\odot$.

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2.2. AX Persei

The light variation in AX Per was studied by many authors. Lindsay (1932) reported the 650 day oscillations observed in 1890-1904 and 1924-1929. Similair, low amplitude variation (Δm= 0.2-0.3 mag) were also detected by Seidel (1956) and Payne-Gaposhkin (1946). Kenyon (1982) analyzed the long series of observations in photovisual and photographic filters, published by Mjalkowskij (1977), and found very strong periodicity at 681.6 days, with the ephemeris:

$$\text{Min} + \text{JD } 2436679 + 681.6 \text{ E.}$$

The mean amplitudes are 0.7 and 0.36 mag in photographic and photovisual ranges, respectively. This variation has been interpreted as due to the reflection of light from the hot component by the cool giant.

Recently, Oliversen and Anderson (1983) reported changes of H-Balmer and HeII λ 4686 line intensities in phase with the optical ephemeris, and suggested that the hot component is eclipsed during minimum. UV observations of AX Per showed a spectrum very similair to that of CI Cyg, however nothing is known about its eventual eclipse behavior.

The analysis of optical spectra taken during 1979-1986 has shown periodic minima in all observed permitted lines and a lack of any periodic variation in forbidden lines (Mikolajewska and Iijima, 1986).

Fig. 2 presents normal points for the emission lines of HI, HeII 4686, HeI (triplets and singlets separately) and FeII together with nine published radial velocity measurements for HI, HeII, HeI and FeII (Merrill, 1933, 1944; Tcheng and Bloch, 1954; Gauzit, 1955). Unfortunately, no radial velocity data for the cool absorption spectrum exist. Of course many more data would be necessary to determine accurate radial velocity curves. Nevertheless, comparison of the radial velocities with the intensity variations may account for the eclipse interpretation of this emission line behavior. Some other conclusion can be drawn:

- The minimum in HeII 4686 is narrow in comparison with those in HI, HeI and FeII. The small depression around phase 0.5 suggests the possible presence of a secondary minimum. Such feature is absent in the other curves.
- The minima observed in HI and HeI are too broad to be consistent with an eclipse by the cool giant alone. Such broad minima may be due to an additional opacity arising in gas streaming between the stars.
- The shape of the radial velocity curve for HeII and HI may suggest an elliptical orbit (e=0.3-0.5, $\omega_h \sim 210$-$230°$). If HeII reflects the orbital motion of the hot component (as in the case of CI Cyg), the aplitude of radial velocity variations, K=30 km/s, leads to the mass function f(M)= 1.7 $M_\odot$ (e=0.3) or f(m)=1.2 $M_\odot$ (e=0.5).

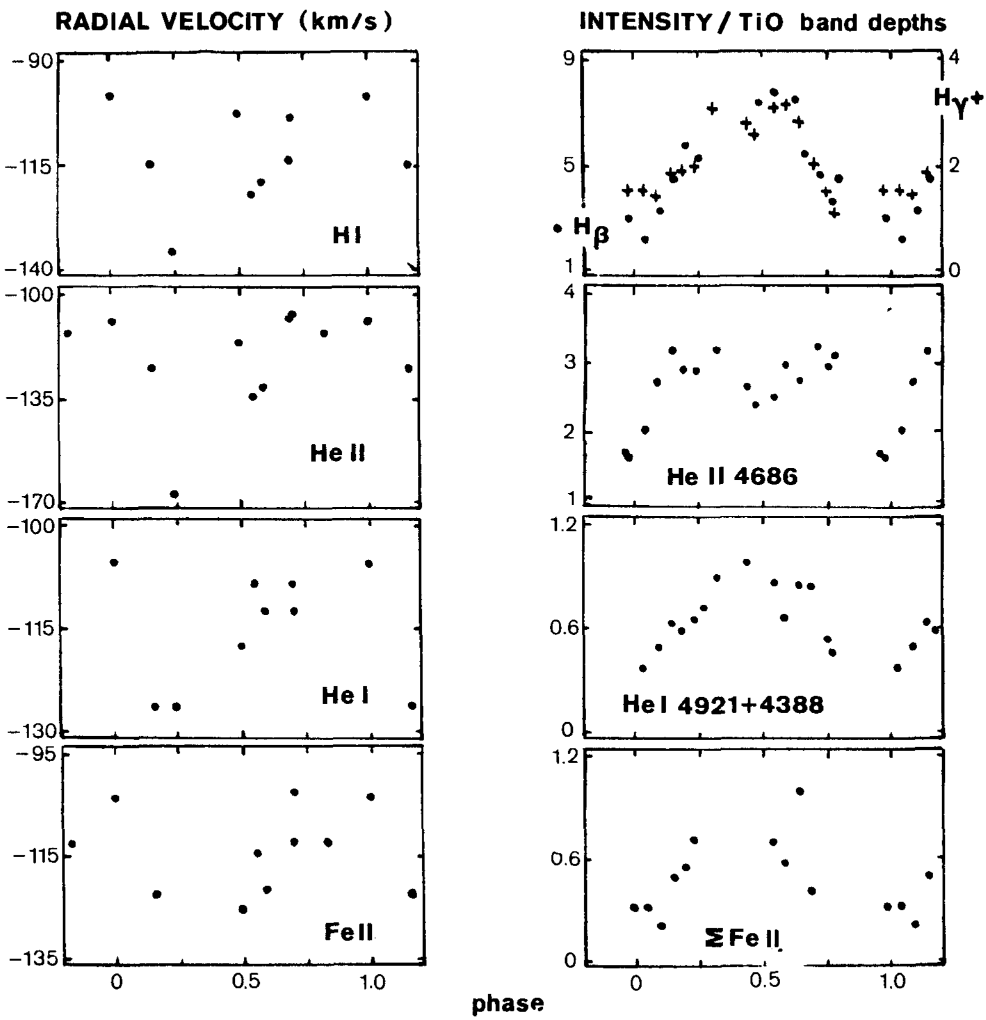

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Fig. 2. AX Persei. Normal points for emission line intensities of HI, HeII, HeI (singlet and triplet are plotted separately) and FeII (sum of intensities of the strongest lines) related to the mean TiO band depth (see Mikolajewska, 1985 and Mikolajewska and Iijima, 1986 for explanation) together with respective radial velocity measurements.

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- The confrontation of the HeII intensity curve with the radial velocity curve suggests that the spectroscopic conjunction occurs later than the minimum of intensity. It means the HeII formation region is far from the line connecting the two components, or the motion is not Keplerian (streams, wind etc.)
- Variations of FeII emission lines and their radial velocity curve are consisting with a formation region in the stream (or wind?) outflowing from the cool giant, but still close to its surface.

2.3. BF Cygni

Campbell (1940(described BF Cyg as a semi-regular variable with a period of 754 days. Jacchia (1941) analyzed the optical light curve from 1890-1940 and found the long period oscillations following the ephemeris: min=JD 2415090 + 754 E (days). The variations bear some resemblanche to eclipses, however there are long periods when they cease altogether - what may suggest grazing eclipses.

Optical spectra have been recently examined by Oliversen & Andersen (1983). They found significant variations in HI and HeI emission. Although their data were rather patchy, they suggested that these lines reached minimum near phase 0 predicted by Jacchia's ephemeris.

Optical spectra taken during 1979-1986 have shown periodic variations of all observed emission lines (Mikolajewska and Iijima, 1986). The renewed analysis of available photometric data has allowed to derive ephemeris:

$$\text{Min} = 2415058 + 756.8\ E$$

which better reproduced the photometric minima and those observed in emission lines. Figure 3 presents normal points for the emission lines of HI, HeI, HeII, FeII and [OIII] together with published radial HeI, HeII, FeII and [OIII] together with published radial velocities of HI, HeI, [OIII] 4363 and ionized metals (Merrill 1943, 1950). The confrontation of line intensity variations with the respective radial velocity curves leads to some interesting conclusions:

- The radial velocity curves for HI and HeI suggest a non-circular orbit (e)0.4-0.5, $\omega_h \sim 270°$).
- As noticed by Boyarchuk (1969), the radial velocity variation of HeII lines are in antiphase with those of the [OIII] 4363 line. If they indeed reflect the orbital motions of the cool and the hot component, respectively, the observed amplitudes lead to a mass ratio (cool:hot) q=K(OIII)/K(MeII)=2.5, M(cool)=2.7 $M_\odot$, M(hot)=1.1 $M_\odot$ and A=550 $R_\odot$ (assuming sin i = 1).
- Observed radial velocity and intensity variations of [COIII] lines (not observed in CI Cyg and AX per) may be connected with high eccentricity (the more so as t(rec) is much shorter than the orbital period). In this case the variations might reflect the changes of physical conditions in the nebula along the orbit.
- Minima in HI and HeI lines are too broad to be due to occultation only by the cool giant. An additional opacity source may be matter streaming between the components. An alternative

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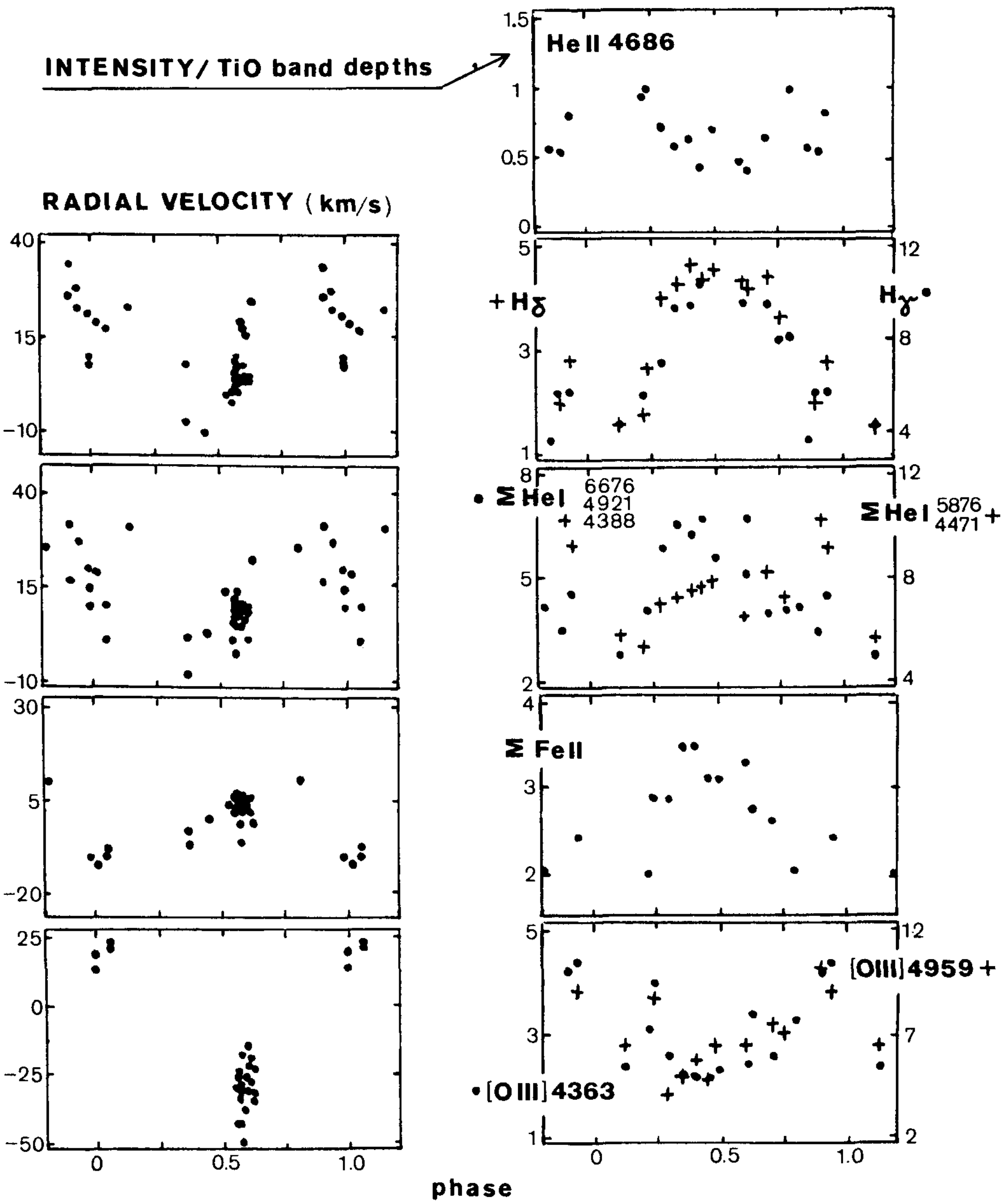

Fig. 3. BF Cygni. Same as in Figure 2.

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explanation might be changes of conditions in the HI and HeI formation region along the orbit (e.g., nebular density changes with the strongest emission as highest density).

- Although the intensity of $HeII_o$ 4686 was always measured with a relatively large error (the line was weak), it seemed to follow the variations of the [OIII] lines rather than those of HI or HeI as in CI Cyg and AX Per.

3. FINAL REMARKS

Although all presented objects belong to the same class of symbiotic stars (type S) and they all show both line intensity and radial velocity variations due to their binary nature, they are different in many respects:

- Only in the case of CI Cyg, the widths of minima can be explained as merely due to the eclipse by the cool giant. In the remaining systems, additional sources of opacity or other mechanisms of variations are necessary. Probably only in CI Cyg the cool component fills its Roche lobe, while in AX Per and BF Cyg the giant component loses mass via stellas wind.
- In AX Per and CI Cyg, the forbidden lines of [OIII] and [NeIII] do not shown periodic minima of intensity as well as radial velocity variations, while in BF Cyg such periodic changes in the [COIII] lines are observed. Simultaneously, the excitation level in the nebula of BF Cyg is much lower than in AX Per and CI Cyg (HeII weak, [FeVII) absent). The energy distribution in the UV spectrum of BF Cyg is also different (rather stellar continuum with $T_{eff}\sim 4-4.5x10^4$ K, while in CI Cyg and AX Per the UV continuum is flat).

This suggest that significant differences in physical conditions and geometry may occur in these seemingly similar systems.

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