CI CYGNI - THE WELL UNDERSTOOD SYMBIOTIC BINARY ?

J. Mikolajewska & M. Mikolajewski
Institute of Astronomy, Nicolaus Copernicus University
Chopina 12/18, PL-87100 Torun, Poland

ABSTRACT. The observed properties of CI Cyg are reviewed. Spectroscopic and photometric changes due to orbital effects as well as intrinsic variability of the components are discussed.

1. GENERAL CHARACTERISTICS

CI Cyg is among the best studied "prototype" symbiotic stars. It is also important as one of the few eclipsing symbiotics. Its physical nature seems to be well established and beyond all question (Roche lobe overflow, disk accreting main sequence star).

Since its discovery on a Harvard objective prism plate by A. Cannon (Shapley 1922), CI Cyg has been studied many times, both photometrically and spectroscopically. Its main optical characteristics are: a composite spectrum with Balmer series and high excitation emission lines (e.g. HeII, HeI, [OIII], [FeVII], [NeV]) superimposed on a late type continuum with low excitation absorptions (TiO bands, FeI), and quasi-periodic activity with outbursts observed in 1911, 1937, 1971-73 and 1975.

The optical spectrum of CI Cyg in outburst is radically different from that observed in quiescence. The rise in brightness is accompanied by an increase in the intensity of the blue continuum and a weakening of the high ionization emission line intensity as well as of the relative intensity of the TiO absorption bands. At maximum light, the spectrum resembles that of an F0-5 supergiant with superimposed HI and HeI emission lines. As the star declines from maximum and the blue continuum diminishes in intensity, the excitation of the emission line spectrum increases and the TiO absorption bands return.

The *IUE* spectra of CI Cyg show a bright flat continuum, up to about 2500 Å dominated by the Balmer continuum (T_e~20000 K), with numerous strong emission lines. Kenyon & Webbink (1984) found that it is understood best as an accretion disk surrounding a main seaquence star. Their derived accretion rate, ~10^{-5} $M_{\odot}yr^{-1}$, requires a Roche lobe filling giant companion. The available IR and optical data suggest the cool star may have supergiant dimensions (luminosity class II) and fill its tidal lobe (Kenyon & Gallagher 1983; Kenyon & Fernandez-Castro 1987). Additional evidence for a very evolved red giant is provided by the 10 μm excess.

J. Mikolajewska et al. (eds.), The Symbiotic Phenomenon, 187–192.

https://doi.org/10.1017/S0252921100103380 Published online by Cambridge University Press

The summary of CI Cyg and bibliography has been recently presented by Kenyon (1986) and Mikolajewska (1985).

2. ORBITAL EFFECTS

Whitney (Aller 1954) first noticed periodic minima in the light curve of CI Cyg, following the ephemeris: ***JD MIN=2411902+855.25 E***. Extensive and systematic *UBV* photometric studies carried out since 1970 in Crimea have allowed Belyakina (1979) to confirm the eclipse character of the minima: the hot component is occulted by a cool giant (Fig.1). The mid-eclipse brightness (V=11.1; B=12.6–12.8) is practically independent on the phase of activity. The eclipse observed during the 1975 outburst also permitted to ascertain that the hot component is responsible for the outbursts. The duration of the eclipse allows for estimation of relative sizes of the components: $R_{cool}/A \gtrsim 0.37$, $R_{ecl}/A \lesssim 0.11$ (Mikolajewska & Mikolajewski 1983). Reasonable mass ratios require the occulting star to be near to filling its Roche lobe.

IR photometry (e.g. Taranova & Yudin 1981, 1986) revealed low amplitude, irregular fluctuations of brightness (ΔJ<0.3). These variations do not depend on the phase of activity and are probably due to intrinsic variability of the cool giant. On the other hand Kenyon & Fernandez-Castro (1987) detected periodic changes of relative depths of TiO absorption bands, consistent with the larger absorption when the cool giant lies in front of the hot component. Their result suggests that (1) radiation from the hot component raises the observed continuum level (thus changing the relative depth) and/or (2) the hot companion illuminates the facing hemisphere of the giant. To produce the observed effect in TiO bands the continuum level ($\lambda\lambda$~6000–7000 Å) should vary by about 10% which is consistent with the eclipse effects observed in the R band (Mikolajewska & Mikolajewski 1983). Simultaneously, if the hot component is embedded in an accretion disk it cannot directly illuminate the cool companion.

IUE and optical spectroscopic observations (Stencel *et al.* 1982; Barratta *et al.* 1982; Oliversen, Kenyon & Stencel 1987, in preparation; Mikolajewska & Mikolajewski 1983; Oliversen & Anderson 1983; Mikolajewska 1985) show that the shortwavelength UV continuum disappears during the eclipses while the Balmer continuum as well as many emission lines (e.g. HI, HeI, HeII, UV intercombination lines) are partially eclipsed.

Fig.2 presents secular and periodic variations of integrated line fluxes (optical and *IUE*) and the Balmer continuum brightness (λ3000 Å) in 1979–84, and suggests that the nebula in CI Cyg is very complex with a few distinct line emission

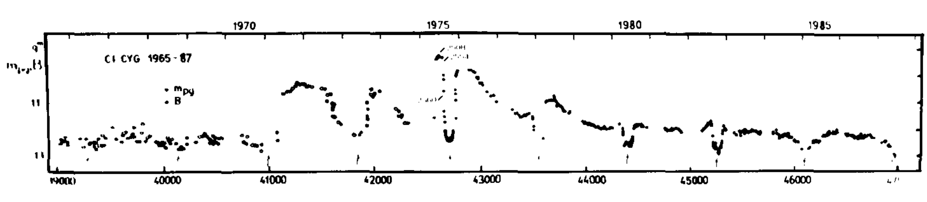

Figure 1. The B light curve of CI Cyg in 1965–87 (Belyakina 1987, presented at IAU Coll. No. 103). Arrows indicate times of minima from the Whitney's ephemeris.

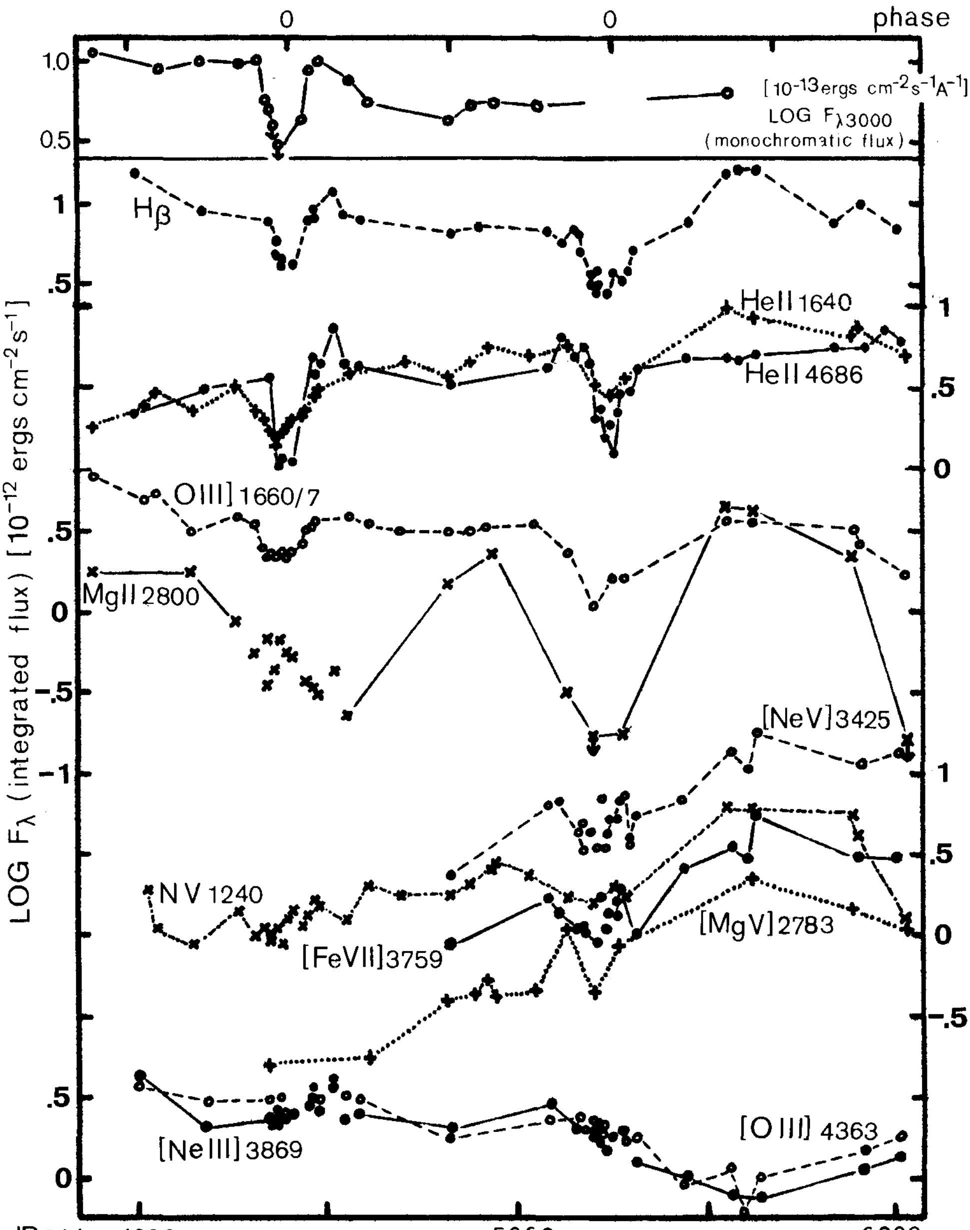

Figure 2. Secular and periodic variations of continuum brightness (o) and integrated emission line fluxes of Hβ (•), HeII 4686 (•), HeII 1640 (+), OIII] 1660/7 (o), MgII 2800 (x), [NeV] 3425 (o), NV 1240 (x), [FeVII] 3759 (•), [MgV] 2793 (+), [NeIII] 3869 (•) and [OIII] 4363 (o). The unpublished *IUE* line fluxes were provided by Oliversen, Kenyon and Stencel.

https://doi.org/10.1017/S0252921100103380 Published online by Cambridge University Press

regions. The eclipses in optical emission lines and the Balmer continuum are deeper and narrower than in the UV intercombination lines and HeII 1640. This probably reflects difference in sizes of the optical and UV line emission regions and/or different physical properties of the cool giant atmosphere in the optical and UV range (see Mikolajewska *et al.* 1983). The bulk of the HI, HeII and UV intercombination line emission is produced close to the hot component, in a region with $T_e \simeq 20000$ K, $n_e \simeq 10^{10}$ cm^3 and r $\simeq$ 100–300 $R_\odot$, while the nebular [OIII] and [NeIII] lines are preferentially emitted in a much more extended region (lack of any orbital effects) with $n_e \simeq 10^7$ cm^{-3} and r > 1000 $R_\odot$ (Mikolajewska 1985). The fluxes of the high ionization UV resonance lines (NV, CIV, SiIV) as well as those of the high ionization forbidden lines ([MgV], [NeV] and [FeVII]) are strongly correlated (very weak, **shifted** eclipse effects?) and show increasing secular trend, contrary to the optical nebular lines ([OIII] and [NeIII]). These high ionization lines may be formed either in an extended thin shock region between the components, or in a corona above the accretion disk (see Mikolajewska 1985). The strong variation of the MgII lines with the orbital period (not due to the eclipses!) is very interesting and suggests that they are produced in vicinity of the L_1 point in the extended atmosphere of the M giant.

Garcia & Kenyon (1987, this volume) have recently presented very reliable orbital radial velocity curve of the M giant component of CI Cyg, and confirm its eclipsing nature. Although the orbital radial velocity curve based on the emission lines can be uncertain, the eclipse behaviour of the HeII and HI lines suggests that these lines may reflect the orbital motion of the hot component. The radial velocities of HI and HeII 4686 show phasing correct for eclipse (Mikolajewska 1987) and systemic velocity ($\gamma \simeq$10–20 km/s) consistent with that found by Garcia & Kenyon. The amplitude of the M giant radial velocity curve (K_{cool}=6.5 km/s) combined with that of the HeII and HI radial velocities ($K_{hot} \simeq$20 km/s) leads to relatively low masses: $M_{cool} sin^3 i \simeq 1.2 M_\odot$, $M_{hot} sin^3 i \simeq 0.4 M_\odot$, and a separation $A sin\ i \simeq 440 R_\odot$. Simultaneously, any increase of the component masses leads to very high mass ratios ($q=M_{cool}/M_{hot} \gtrsim 5.5$; $M_{hot} \gtrsim 1\ M_\odot$).

3. THE 1975 EPISODE

The eclipse observed in 1975 was particularly spectacular since it occured in the middle of the largest outburst in CI Cyg. A bright F-type continuum as well as most of the absorption lines observed at the maximum activity practically disappeared during the eclipse and the spectrum was dominated by the absorption features of the M giant. The star brightness was the same as during eclipses observed in quiescence (Belyakina 1979).

Variations of the H_β and H_γ emission profiles during the eclipse ingress were analysed by Mikolajewska & Mikolajewski (1985). The profiles were double-peaked with a central absorption. During the eclipse ingress the violet peak rapidly declined while the red peak remained unaffected (Fig.3). Such behaviour is consistent with the occultation of a rotating disk-like envelope.

Audouze *et al.* (1981) noted the peculiar systematic trend in radial velocities as a function of excitation potential in the spectra taken in July-August 1975. Kenyon *et al.* (1982) interpreted this phenomenon as due to the eclipse of an optically thick, differentially rotating accretion disk. Fig.3 presents fragments of the same spectra as those analysed by Audouze *et al.* The spectra were taken before the first contact, close to the first contact and in the mid-ingress, respectively (see Fig.1). The continuum and Balmer lines in the first spectrum (GA 2508) are

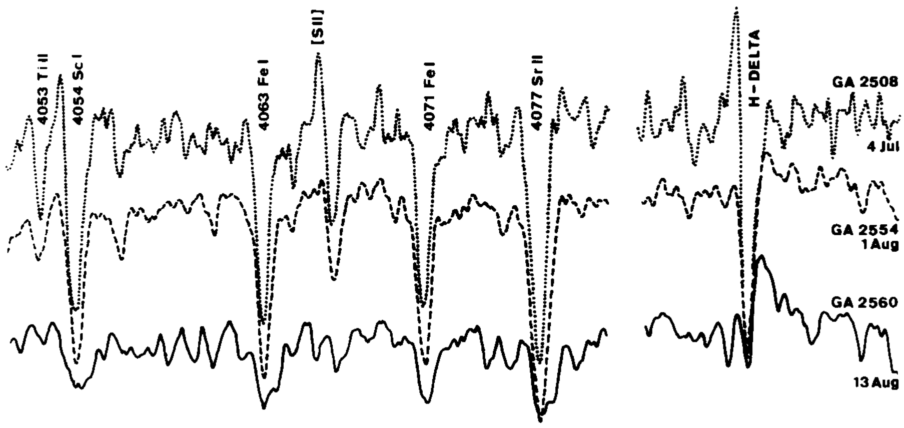

Figure 3. Changes in the blue spectral region (4100-4050 A) in 1975. The spectra are presented in the same intensity scale, so decrease of the continuum level reflects the real changes of brightness during eclipse ingress.

practically unaffected by the eclipse but the peculiar trend in radial velocities is present. The next spectrum (GA 2554) shows the radial velocities redshifted by about 5 km/s with respect to GA 2508 and similar dependence on the excitation potentials. So, the peculiar radial velocity structure cannot be explained as the partial occultation of the accretion disk (Kenyon *et al.* 1982). The last spectrum (GA 2560) exhibits the steepest dependence of the radial velocities on the excitation potentials. According to the interpretation of Kenyon *et al.* the profiles should be asymmetric during eclipse ingress, as the blue-shifted portion of the disk is the first to be occulted. Such asymmetry is not observed, instead of that additional redshifted components appear in most absorption lines (Fig.3). In addition, the radial velocities in all spectra are redshifted by about 25-40 km/s with respect to the systemic velocity ($\gamma \simeq$ 18 km/s; Garcia & Kenyon 1987, this volume). The discussed behaviour of the profiles suggests that the peculiar velocity structure of the aborption lines is due to velocity stratification effects in a matter streaming seen against a background of the accretion disk. The analysis of the spectra is complicated by a possible atmospheric eclipse (GA 2508 & GA 2554) and considerable contribution of the M giant absorption lines (GA 2560).

4. CONCLUDING REMARKS

The new radial velocity curve of the M giant presented by Garcia & Kenyon (this volume) allows to revise the masses of the components and suggests that the M giant is near to filling its Roche lobe ($R_{lobe} \simeq 200\ R_\odot$). The assumption that the accretor is a low mass ($\sim$0.5 $M_\odot$) main seaquence star leads to almost the same accretion rates as derived by Kenyon & Webbink (1984), $10^{-5}\ M_\odot yr^{-1}$ in quiescence and $10^{-4}\ M_\odot yr^{-1}$ (close to $\dot{M}_{cr} \simeq 6\times10^{-4}\ M_\odot yr^{-1}$) in outburst.

A resumption of old observational data might be very interesting, especially:
(1) a thorough reanalysis of changes of the UV and optical continuum and emission lines due to the secular and orbital effects (including eclipses);

(2) a detailed study of the spectra taken in the 1971-75 active phase particularly emphasizing eclipses.
Preliminary analysis of these observations suggest much more complicated picture than that proposed by Kenyon *et al.* (1982).

We thank N.A. Oliversen, S.J. Kenyon and R.E. Stencel for providing their unpublished *IUE* measurements of line fluxes and T.S. Belyakina for poviding the light curve. We also acknowledge A. Woszczyk who made the 1975 spectra accessible.

REFERENCES:

Aller, L.H., 1954, *Publ. DAO Victoria*, **9**, 321.
Audouze, J., Bouchet, P., Fehrenbach, C., Woszczyk, A., 1981, *Astron. Astrophys.*, **93**, 1.
Barratta, G.P., Altamore, A., Cassatella, A., Friedjung, M., Ponz,D., Ricciardi, O., 1982, in *The Nature of Symbiotic Stars*, eds. M. Friedjung and R. Viotti, D. Reidel, 145.
Belyakina, T.S., 1979, *Izv. Krym. Astrofiz. Obs.*, **59**, 133.
Kenyon, S.J., 1986, *The symbiotic stars*, Cambridge Univ. Press.
Kenyon, S.J., Fernandez-Castro, T., 1987, *Astron. J.*, **93**, 938.
Kenyon, S.J., Gallagher, J.S., 1983, *Astron. J.*, **88**, 666.
Kenyon, S.J., Webbink, R.F., 1984, *Astrophys. J.*, **279**, 252.
Kenyon,S.J., Webbink,R.F., Gallagher, J.S., Truran, J.W., 1982, *Astron. Astrophys.*, **106**, 109.
Mikolajewska, J., 1985, *Acta Astr.*, **35**, 65.
Mikolajewska, J., 1987, *Astrophys. Space Sci.*, **131**, 713 (IAU Coll. No.93).
Mikolajewska, J., Mikolajewski, M., 1983, *Acta Astr.*, **33**, 403.
Mikolajewska, J., Mikolajewski, M., 1985, in *Recent Results on Cataclysmic Variables* ESA SP-236, 201.
Mikolajewska, J., Mikolajewski, M., Krelowski, J., 1983, *I.B.V.S.*, No. 2356.
Oliversen, N.A., Anderson, C.M., 1983, *Astrophys. J.*, **268**, 250.
Shapley, H., 1922, *Bull. Harv. Coll. Obs.*, Nos. 762 and 778.
Stencel, R. E., Michalitsianos, A. G., Kafatos, M., Boyarchuk, A. A., 1982, *Astrophys. J. Letters*, **253**, L77.
Taranova, O.G., Yudin, B.F., 1981, *Astr. Zh. Akad. Nauk SSSR*, **58**, 1051.
Taranova, O.G., Yudin, B.F., 1986, *Astron. Tsirk.*, **1454**.