A REVIEW OF THE PROPERTIES OF THE SYMBIOTIC STAR CH CYGNI

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Introduction

The spectrum of CH Cygni usually has the appearance of a normal M6 III star, but at intervals of several years, it has phases of activity during which it shows the characteristics of a symbiotic star, that is, a blue continuum extending shortward of the Balmer discontinuity, and strong emission lines of He I, Fe II, [Fe II], [S II], [O I], [O III]; the Balmer lines and the H and K lines of Ca II present emission wings. Outbursts were observed: 1) in September 1963; the star returned to its normal phase by August 1965 (Deutsch, 1964); 2) in June 1967 (Deutsch, 1967); the spectrum was observed by Faraggiana and Hack (1971) until December 1970, when the activity phase was over; 3) another outburst was observed in August 1977 (Morris, 1977; Fehrenbach, 1977), and at the time of our last spectroscopic observations (June 1981) it was still going on. During this last period of activity several observations were made with IUE in both the low and high resolution modes, from 1175 A to 3100 A.

The first observed outburst lasted less than two years, the second one a slightly more than three years; the present one is at the end of its fourth year.

The most obvious hypothesis for explaining symbiotic stars is that they are binary systems formed of a late-type giant and a hot subdwarf which occasionally has outbursts. The other possibility is that the cool star may be surrounded by an extended corona, heated by shock waves during episodic phases of eruptive mass loss. This corona is supposed to be responsible for the blue continuum and for the emission lines. A third hypothesis, that a hot star is surrounded by a cool envelope, is ruled out at least in the case of CH Cyg, by our spectroscopic observations of 1967-70 and of 1977-81, because there is clear evidence that the blue continuum is filling up the M6 photospheric lines, deleting them almost

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completely, especially in the blue-violet region of the spectrum. Several symbiotic stars present orbital motions; however, CH Cygni does not show any evidence of periodic radial velocity variations. Instead, our observations of the 1967-70 episode supported the hypothesis that shock waves heat the envelope surrouding the M6 giant. However, photometric observations by Slovak and Africano (1978) indicate that CH Cygni presents a rapid flickering, characteristic of cataclysmic variables, most of which are close binary systems. We will summarize the results of the observations of the 1967-70 activity phase in the photographic spectral range (3300-4900), and of the activity phase which started in 1977 in the spectral range 6700-3400 A and 3100-1175 A, and we shall compare the phenomena observed during the two outbursts.

The 1967-70 outburst

The M6 spectrum is veiled by a continuum which partially fills the absorption lines and increases in intensity toward the violet. This continuum was absent in August 1965 and in September 1970; it appeared at the moment of the explosion, in June 1967, and reached a maximum in August 1968. The color temperature was about 10000 K. No measurable Balmer discontinuity was observable. Emission lines of He I, Fe II, [Fe II], [S II] were present. In July 1968 λ 5007 [O III] appeared. The Balmer lines had red and violet emission wings, R/V $>$ 1, while the H and K lines presented a P Cygni contour. At some epochs H and K presented two absorption cores. Absorption chromospheric lines, which were completely missing in July 1967, appeared in the ultraviolet continuum in July 1968. Only lines of metallic ions were present. In May 1970 the absorption lines of low excitation at $\lambda < 3800$ give radial velocities systematically more negative by about 20 km/s than the other lines having the same low level. The resonance lines behave like the ultraviolet lines. The H and K absorption cores have presented two well-separated components since July 1968; the sharpest of the two in July and August 1968 has a radial velocity of -170 km/s, which in 1969-70 reaches a value of -120 km/s, while the broad component decreases from -80 km/s in July-August 1968 to -10 in 1969-70. The photospheric lines (i.e. lines from excited levels of neutral metals) have an almost constant velocity, included between -60 and -65 km/s, which we assume to be the velocity of the center of mass of the star. The forbidden and permitted emission lines of Fe II have generally velocity, included between -50 and -60, but systematically less negative by 5 to 10 km/s than the photospheric velocity. Radial velocities for a large number of Balmer lines could be measured only on the spectrograms taken in July and August 1968, i.e. at the epoch of maximum intensity of the blue continuum. There is a

Balmer progression, the radial velocity of Hβ,Hγ,Hδ and H7 being about -60 km/s in July 8-11 and -70 on August 14, while the other members of the series give -45÷ -50 in July and -55÷ -60 in August, i.e., values equal to or less negative than the photospheric ones. The picture emerging from these data is that just after the outburst (spectrogram of July 15, 1967) the layers where Hβ and H and K are formed are expanding relatively to the photosphere. One year later one layer has the same velocity as the photosphere; another, identified with the sharp component of the Ca II resonance lines, is expanding outward at -170 km/s; then the latter continues to expand at -120 km/s and the former falls toward the photosphere.

The outburst starting in 1977

The most striking difference between the outburst of 1967 and that of 1977 is the greater intensity of the blue continuum during the latter. The spectra taken in July and August 1968, at the epoch of maximum intensity of the blue continuum, and those taken in September 1977, when the continuum observed during the present outburst was at minimum intensity, appear comparable, but on February 1978 the photospheric absorption lines are almost completely filled up by the continuum extending longward of Hβ. Another striking difference between the two outbursts is found in the Balmer line emission wings. The upper members of the series had two emission wings in 1967-70, while from 1977 onward they present P Cygni inverse contours. The H and K lines of Ca II, on the contrary, have similar contours at the two epochs. Hα, Hβ, Hγ, Hδ, have two emission wings with $V/R > 1$. Hence during this last outburst we have the peculiar occurrence of the simultaneous presence of upper layers, where the H and K lines are formed, which are expanding relatively to the photosphere, and of lower layers, where the higher members of the Balmer series are formed, which are moving toward the photosphere. Also the absorption lines of Sc II, Ti II, V II, Mn II, Sr II have an inverse P Cygni contour and about the same velocity as the Balmer lines with $n \gtrsim 9$. The emissions of Fe II, on the contrary, have a radial velocity of about -75 km/s, systematically more negative than that of the forbidden lines, -65 km/s (Faraggiana, 1980).

Since February 1978 no strong variations in the spectrum have been observed. One of the most evident variations is that of the H and K cores. Two components are clearly present in September 1977 and February and June 1978; the shortward component, at about -140 km/s, is sharp, the longward one at about -110 km/s is broader. In September 1978 the two components are blended; in July 1979, February 1980, and September 1980 the two components are blended, the longward one being the faintest;

in January and March 1981 the emission wing is much fainter than at previous epochs. In June 1981 the two components are clearly separated again, the longward component being the sharper, just the contrary of what was observed in September 1977–June 1978. Several spectra of the red part of the spectrum have been taken since September 1977. Hα has strong emission wings with V/R $>$1. The forbidden lines of O I were absent in September 1977 and have been present as two strong sharp emissions since July 1979 . Instead, no O III forbidden lines have been observed during this outburst. The radial velocity of the H α absorption core ranges between about -60 and -65 km/s.

The ultraviolet spectrum observed with IUE

Low resolution spectra were obtained in 1978, 79 and 80; high resolution spectra in the near UV were obtained in March 1979, and in the far UV in September 1980. Comparison of the observed flux with the Kurucz models indicates that no one of them agrees with the observations. Faint discontinuities are observable at λ1500 and λ1700, as if the strong discontinuities present in theoretical spectra for effective temperatures ranging between 8000 and 7500 K were partly filled by continuous emission extending up to 1300 A.

On September 1, 1980 the flux reached its maximum value after the beginning of the present phase of activity (3x10^{-12} erg s^{-1} cm^{-2} $\AA^{-1}$ at 1400 Å).

The line spectrum shows rather different behaviors for the far UV and the near UV ranges. At short λ, absorptions of once-ionized metals (mainly FeII and NiII) dominate the spectrum, while only a few emissions (i.e. OI 1300, 1355 and 1641.2, NI 1745, FeII m=191, SiIII λ1892 and CIII λ 1908) are present. At longer λ, on the contrary, the spectrum shows numerous emissions that, except for MgII 2800, MgI 2852, CII 2324 and AlII λ 2669.2 are all attributable to FeII.

It is evident that the resonance fluorescence mechanism, i.e. absorption in the far UV region followed by re-emission toward longer λ, is responsible for the FeII emissions. In this respect CH Cyg is very similar to the peculiar Be star HD45677, where the FeII lines show the same behaviours (Selvelli, Stalio 1980; Stalio, Selvelli 1980).

The OI λ1300 resonance triplet shows relative intensities that disobey the theoretical 5/3/1 ratio.This fact together with the presence of the semiforbidden 1641.3 emission, which shares the same upper level with the 1300 lines and has comparable intensity, can be explained in terms of "trapped" 1300 resonance radiation and multiple resonance scattering processes. The excitation mechanism for the strong OI triplet emission seems to be Lyβ fluorescence (Swings, 1955). Two other possible

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mechanism are recombination from O^{++} and continuum fluorescence. Both seem unlikely, the first one because no quintet lines (e.g. λ 6158 and λ 3947) are observed, and the second because the far UV continuum is rather weak and the λ 4368 line is not present.

Apart from FeII and OI, the other emissions in the UV range are the resonance lines of MgI λ 2852 and MgII λ 2800 and the intersystem lines of AlII λ 2669.2 and SiIII λ 1892.0. The MgII resonance doublet presents two absorption cores, the sharp one, probably of interstellar origin, at rest velocity, and a broader one shortward shifted at about -110 km s^{-1}. The emission wings give V/R<1.

MgI, AlII and SiIII, together with MgII, AlII and SiIV, form two iso-electronic sequences. Inside each sequences the same terms scheme applies, but the energies of the corresponding terms are different. It is commonly agreed that the population of the lowest terms of the above species is attributable to collision by electrons with $T_e \approx$ some e V. This explains why all the intersystem lines of the MgI, AlII, SiIII sequence (i.e. λ 4571, λ 2669 and λ 1892 respectively) are observed; the low lying metastable term is easily populated by collisions. On the contrary, only the resonance line of MgI λ 2852 is present because the upper term of the resonance lines of AlII (λ 1670) and SiIII λ 1206 needs higher electron energies to be populated. In the MgII, AlIII, SiIV sequence only the resonance doublet of MgII λ 2800 is observed. Either the electron energy is not sufficient to populate the first excited level of AlIII and SiIV, or these ions are formed in a higher density region where collisional de-excitation takes place. But the presence of the SiIII λ 1892 and CIII λ 1908 emissions seems to favour the first hypothesis.

Conclusion

These observations indicate that: a) the velocity of the star, as given by the photospheric lines, ranges irregularly between -65 and -55 km/s; b) a rarefied outer layer, where the forbidden lines are formed, has about the same velocity as the star, plus or minus 5-10 km/s; the intensity of the forbidden lines of FeII relative to the permitted ones varies, from one outburst to another; in 1964 [Fe II] /Fe II>1, in 1967-70 [Fe II] /Fe II~1 and during the present episode [Fe II] /Fe II<1, thus indicating that the density of the envelope during this outburst is larger than during the previous ones; c) between the photosphere and the outer envelope where the forbidden lines are formed, there are several regions characterized by different motions. The general behavior seems to be the following: the upper layers (where the strong resonance lines of Ca II and Mg II are formed) are expanding outward, and sometimes dividing into two layers, one continuing to expand at a velocity greater than escape velocity, and the other falling back toward the star, while the lower layers (where the higher members of the Balmer series are formed) are falling toward the stellar surface. Intermediate layers, where the first members of the Balmer series and the strong permitted lines of Fe II and other abundant ions are formed, are sometimes observed to move outward, sometimes inward with a velocity differing no more than 20 km/s from that of the photosphere; d) the blue-ultraviolet continuum has a distribution which is not attributable to a hot star. Hence, if the presence of a hot companion can be discarded, the blue-ultraviolet continuum must be formed in the dense, optically thick parts of a layer above the photosphere, where also the sharp "chromospheric" absorptions of ionized metals are formed.

It is generally believed that the red giant stage is followed by the planetary nebula stage. It is possible that the outburst episodes observed in CH Cygni, with mass-loss estimated of the order of a few times 10^{-8} the solar mass per episode, indicate that CH Cygni is in the transition phase.

Note added in proof

Andrillat (1982) reports that in spectra taken in 1977 and in 1981, the OI λ 8446 emission (that feeds the 1300 triplet in the cascade following the excitation by Ly β) is missing. This seems to rule out the proposed Ly β fluorescent mechanism as responsible for the OI emissions. Comments on this matter together with more details on the UV observations will be reported in a paper that is to appear soon in Astronomy and Astrophysics.

References

Andrillat, Y.: 1982, This colloquium, p. 47.
Deutsch, A.J.: 1964, Ann. Rep. Mt. Wilson and Palomar Obs., 11
Deutsch, A.J.: 1967, IAU Circ. No. 2020
Faraggiana, R.: 1980, Astr. Astrophys. 84, 366
Faraggiana, R., Hack, M.: 1971, Astron. Astrophys. 15, 55
Fehrenbach, Ch.: 1977, IAU Circ. No. 3102
Morris, S.C.: 1977, IAU Circ. No. 3101
Selvelli, P.L., Stalio, R.: 1980, Second European IUE Conference Tübingen ESA SP-157, p.155
Slovak, M.H., Africano, J.: 1978, Mon. Not.R. astr. Soc. 185, 591
Stalio, R., Selvelli, P.L.: 1980, Proceedings of the Conference "The Universe At UV wavelengths" GSFC
Swings, P.: 1955, Aurorae and the Airglow, Eds.Eb.Armstrong & A. Dalgarno. Pergamon Press Ltd., Oxford, p.249