CH CYG : TEN YEARS OF ACTIVITY

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ABSTRACT. The results of multi-frequency observations of CH CYG during the last outburst are reviewed, and the time-sequence of the variations related to the jets formation is discussed.

1-INTRODUCTION

CH Cyg was classified as a normal M6III semiregular variable until 1963, when spectroscopic observations made by Deutsch (1964) revealed the presence of an "extra" hot continuum and of emission lines of H, HeI, OI, [FeII], [OIII] etc., which were superimposed onto the M6III spectrum, thus producing a combination spectrum. These features constitute the distinguishing signature of a symbiotic star, and CH Cyg was included in this class of variables, although the absence of HeII emissions in its spectrum has cast some doubt on its classification as a "classical" symbiotic star.
The first activity episode lasted until Aug. 65 and was followed by another one with similar characteristics which started in June '67and lasted until the end of 1970.
A description of the main characteristics of these first two outbursts can be found in Hack and Selvelli (1982) and in Kenyon (1987).
The third , last episode started around Aug. 1977 and is now probably close to its end. Unlike in the two previous outbursts, the behavior of CH Cyg during this last outburst has been monitored in a wide frequency range, from the radio to the x-ray. These observations, although generally not simultaneous or coordinated, have provided valuable data and set strict physical constraints on the nature of the system.

Certainly, a very important step for understanding the physical model of CH Cyg was the discovery by Yamashita and Maehara (1979) of its duplicity with P ~ 5700 days.
The M6III absorption lines vary in antiphase with respect to the absorption lines of once ionized metals, which are asso-

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ciated with the hot component. The Balmer lines absorption components vary also with the same trend (Mikolajewsky and Biernikovicz, 1985). The smallness of the amplitude in the r.v. curves and the presence of a large scatter around the mean points has led some researchers to suggest different mass ratios in the system. Thus, Tomov and Luud (1984) give M(hot)/M(giant)$\sim$0.3-0.5, while Hack et al. (1986) using the [Fe II] emissions give a ratio of about 1.
In any case, the length of the period implies that the giant does not fill its Roche lobe, and, therefore the transfer of material from the giant to the companion does not occur via Roche lobe overflow.

2-THE FIRST PHASES OF THE OUTBURST (from mid'77 to mid'81)

The first phases of the outburst were quite similar to the previous episodes, with the appearance of emission lines of H, HeI, FeII, OI, and a blue continuum veiling the giant's absorption lines. The once ionized metals show weak, broad emission bands in Sept. 1977, stronger emissions in 1978, and inverse P Cyg profiles since 1980. H_β and H_γ are double peaked and show generally V/R$>$1, with a true absorption core which goes below the continuum level. Very few absorption lines are observed in the visible by June 1980 (Wallerstein, 1981). H_α has a peak intensity of $\sim$10 - 30 times the local continuum (Anderson et al., 1980) and wings which reach 400 km s^{-1} in 1980. Inverse P Cyg profiles in the Balmer lines started appearing already in 1977 (Faraggiana, 1980). It is noteworthy that in the 1967 outburst the Balmer lines showed only direct P Cyg profiles.

A flickering activity was detected in 1978 by Slovak and Africano (1978) with changes of $\sim$0.1 mag. on a time-scale of $\sim$20 min. , and of 0.02-0.04 mag. on a time scale of $\sim$ 5 min.. A similar behavior was observed also in 1967-1969 and in 1974 (Luud, 1980). The flickering increases generally toward the blue; 2% at λ7000, 30% at λ3200 .
Piirola (1982) also detected a variable linear polarization which increases toward the UV and reaches values of $\sim$1% .

Taranova and Yudin (1984), Ipatov et al. (1984) performed extensive IR observations from 1978 to 1982.
They found that the IR radiation had semiregular fluctuations coinciding in period and phase with the quiescent variability. Brightness variations occur with an amplitude of 0.25 mag. and a period of approximately 1000 days.
The near IR was interpreted as consistent with a 2600 °K black body. An "excess" attributable to silicate dust is present longward of 3μ and is greater by about a factor of ten at $\lambda > 20\mu$. The "excess"is correlated with the changes in the hot source , and is probably due to the heating of a silicate dust shell by the hot source. IRAS observations

at 10 μ have confirmed the excess.

The first UV observations were made soon after the l launch of IUE by Hack (1979). Emission lines of low ionization character , mainly FeII and MgII , are present , mostly in the λ 2000-3200 range , while at shorter λ absorptions lines of once-ionized metals , mainly FeII and NiII, dominate the spectrum (Hack and Selvelli, 1982a). On sept. 1980 the continuum flux reached the value of $3\cdot10^{-12}$ erg cm^{-2} A^{-1} s^{-1} at λ ~ 1400 Å . A comparison of the observed flux distribution with the Kurucz's models indicate that no one of them agrees with the observations, but the slope of the continuum toward short λ suggests a temperature less than 10^4 °K .

3-THE "SHELL" PHASE (from mid '81 to mid '84)

During this phase , the absorption spectrum of once-ionized metals developed a more specific "shell" character.Between June and Nov. 1981 sharp deep absorptions of FeII, TiII, and CrII became clearly evident and these variations were accompanied by a weakening of the [FeII] lines and by a brightening by 0.5 mag..The inverse P Cyg profiles were still clearly evident in the hydrogen and FeII lines.

Wallerstein (1983) reported the presence of two absorption shells in Oct. 1981.

The optical shell was studied by Luud and Tomov (1984) and by Rodriguez (1984) who found T_{exc} of the order of 9000-10000 °K, and log Ne ~ 12.5 - 12.9. These conditions are close to those of the atmosphere of a A1Ia star. The dilution factor W was estimated as 10^{-1} - 10^{-3} by Luud and Tomov. The 1981-1982 spectrum was studied also by Yoo (1984), who derived from the FeII lines a dilution factor W ~ 10^{-3} .

IUE observations made in Dec. 1981 (Hack et al., 1982b) showed a wealth of FeII, NiII, and CrII absorption lines. Persic et al.(1982) estimated a colour temperature of 9000 °K and log g ~ 1-2, in agreement with the optical data.

The UV continuum reached its maximum intensity (of the order of 10^{-11} erg cm^{-2} s^{-1} A^{-1} at 1400 Å) in Dec. 1981 , but the distribution was still similar to that of 1979 and 1980.

The optical spectrum between 1982 and 1984 has been studied also by Mikolajewsky and BierniKowicz (1985) , who have described the complex changes which occurred in the Hβ profile. Since autumn 1983 the old shell of 1981 had become weaker and sharp lines of neutral and ionized metals have appeared, e.g. CaI 4227. This new shell is cooler than the previous one and resembles that of an F-type supergiant.

Absolute spectrophotometry made in 1981 and 1982 by Kaler et al. (1983) shows a clear correlation between the Hβ flux and the ground U flux.

Ipatov et al.(1984) found a maximum in U during the spring of 1982, while a maximum in the optical occurred in 1983. It is noteworthy that the flickering became redder in 1982 (Spiesman et al.,1984). The amplitude was ~20% of the total UBV in 1983, and showed a weaker dependance on λ (Reshetnikov and Khudyakova, 1984). No flickering was detected in the near IR, but again, flickering was detected in the H and K bands.

In Jan. 1984 (Selvelli and Hack,1985), high resolution IUE observations still showed the presence of a shell of once-ionized metals, together with the few emissions of low excitation (FeII, OI, MgII) which were present since the beginning of the outburst. The continuum was still almost as strong as in Nov. 1981 (with a flux at λ~1400 Å of $7\cdot10^{-12}$ erg cm^{-2} s^{-1} $\mathrm{Å}^{-1}$) and the distribution was quite similar.

4-THE JET FORMATION AND THE LAST OUTBURST PHASES

The last outburst phase started around July 1984, when dramatic changes were observes at all wavelengths. The veiling of the MIII absorption bands decreased substantially, at the same time as there was a drop by 1.2 mag. in the optical brightness. Emission lines of [OIII] and of [NeIII] were observed in August 1984, simultaneously with a strong increase in the [FeII] emissions (Tomov,1984).

VLA observations at λ=2 cm made after mid 1984 detected a strong radio outburst , and high resolution images showed a rapidly expanding jet . The map taken in Nov. 8, 1984 showed the presence of two jets expanding at $1''.1$ yr^{-1} , and originating in the star position. Other VLA observations in Jan. 22 1985, and May 3, 1985 confirmed this trend.

The total ejected mass was estimated by Taylor et al.(1986) as larger than $2\cdot10^{-6}$ $M_\odot$, and the expansion velocity was on the order of 1000/sin i km s^{-1} , if the system is at ~400 pc.

The first UV observations after the formation of the jet were made in Jan.25,1985 and revealed dramatic changes in the UV spectrum (Selvelli and Hack,1985a). The UV continuum was much weaker than in Jan. 1984 (the flux at λ~1400 Å was less than 10^{-12} erg cm^{-2} s^{-1} $\mathrm{Å}^{-1}$) and very flat , and only emission lines were present, in a wide ionization range, from OI to HeII, CIV, and NV.

The most striking feature was the appearance of a wide Lyman alpha emission (Fig. 1),with an asymmetrical profile and an enhanced red wing , typical of formation in an accelerating outflow. It is remarkable that Johanssos and Jordan (1984) have reported the presence of a similar profile in high resolution spectra of cool giants and supergiants.

The peculiar shape of the CIV λ1550 emission, which shows a composite structure suggesting formation in an inhomogeneous expanding medium, is also remarkable (Fig. 2).

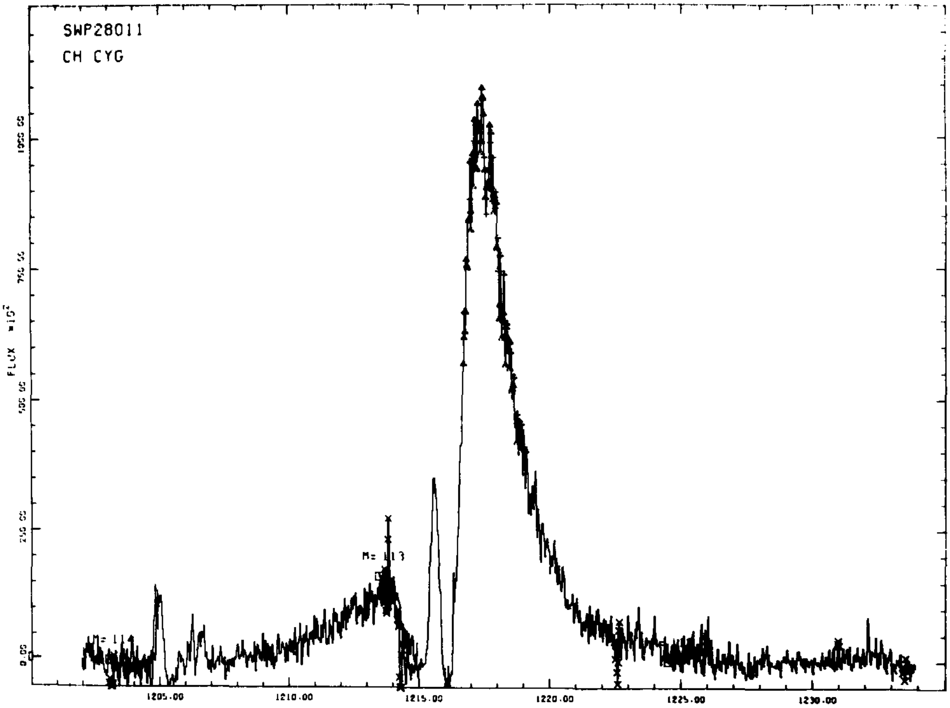

Figure 1. The Lyman-alpha emission (March 1986).

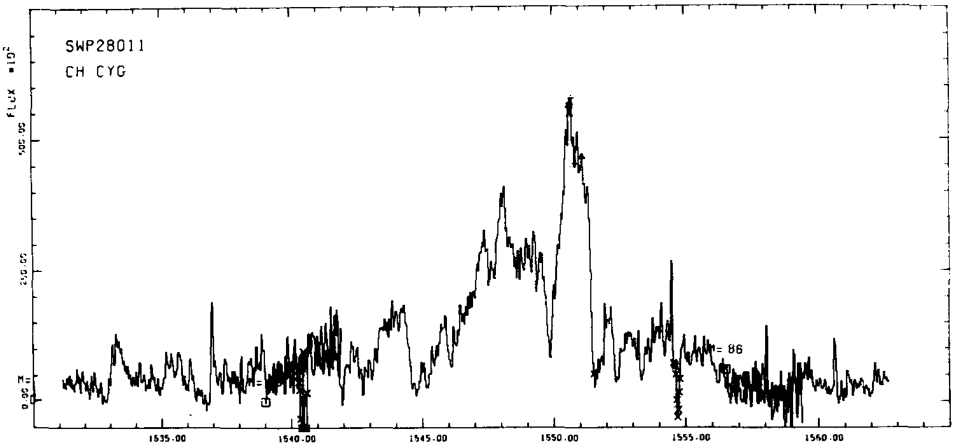

Figure 2. The CIV λ 1550 doublet (March 1986).

The FeII emission lines showed a great increase in number and intensity since 1985. The total FeII UV luminosity was of about 10^{34} erg s^{-1} in Jan. 1985. Marsi et al. (1987) applied the self absorption curve (SAC) method (Friedjung and Muratorio, 1987) to determine the physical parameters of the FeII emitting region. The slope of the SAC is in agreement with a model of formation of FeII in a wind region.

Mikolajewska et al.(1987) have recently made a systematic study of the variations in the UV continuum and in the UV emission lines using all the available low resolution IUE spectra, taken from 1978 to Dec. 1986. They found that, in general, the UV continuum can be matched with a combination of a Kurucz model atmosphere with $T \sim 9000$ °K and log g 1-2, and hydrogen b.-f. plus f.-f. emission with $Te \sim 10^4$ K. The bulk of the high excitation UV emission lines (which appeared in 1985) are formed in a region with $10^7 \lesssim Ne \lesssim 10^9$ cm^{-3} and electron temperature $10^4 \lesssim Te \lesssim 2{\cdot}10^4$ °K. The typical emission measure is 10^{55} cm^{-3}. The emission measure of a weak hydrogen continuum observed during the 1985 minimum ($\sim 3{\cdot}10^{57}$ cm^{-3}) is the same as the radio emission measure and suggests that it is formed in the jets. It is remarkable that at all epochs the observed UV luminosity was far below the Eddington luminosity and ranged from $\sim 200\ L_\odot$ (Nov. 1981) to $\sim 2\ L_\odot$ (Oct. 1986).

A drop in the U light was observed at the beginning of May 1985 , and the plateau in the minimum was reached around mid May (JD 2446200) and lasted until September. The IUE observations confirmed this trend, with a flux at $\lambda \sim 1400$ Å of the order of $2.5{\cdot}10^{-13}$ erg cm^{-2} s^{-1} $Å^{-1}$. Mikolajewsky et al. (1986) pointed out that a similar drop in the U light occurred about 5750 days before , and suggested that the drop was due to an eclipse. It is notable that the maximum in the radio flux (Taylor et al.,1986) occurred near May 1985 and that on May 24 1985 CH Cyg was detected by EXOSAT as an x-ray source with a 0.02-2.5 keV luminosity of $5{\cdot}10^{32}$ erg s^{-1}. The UV luminosity at nearly the same epoch was $4.6{\cdot}10^{33}$ erg s^{-1}. The x-ray data indicated a variability on a time scale of a few minutes , at a 94% confidence level. The emission measure was $2{\cdot}10^{55}$ cm^{-3}, ,smaller than the radio one by a factor of 10^2. It is also remarkable that previous x-ray observations with HEAO-2 gave only a marginal detection at 2-20 keV, while observations with EINSTEIN gave no detection after 8644 sec. of integration time (Wallerstein, 1981).

Several arguments in favour of the eclipse suggestion (e.g.: the single peak shape of the Balmer emission lines in July 1985, the minimum of the UV flux, the absence of optical flickering, etc.) have been listed by Szczerba et al. (1987). On the other hand , the x-ray flickering cannot be easily explained if the x-ray emission originates , as suggested in the boundary layer of the hot component. Moreover, in Sept. 1986 the UV flux fell to values lower than those observed during the "eclipse" ; this decrease , however, could be just the consequence of a general "decay" in the accretion disk (if any!) , in the last phases of the outburst. If the eclipse was indeed real, a careful study of the changes in the continuum and emission lines at that epoch would be of paramount importance for the determination of the regions of formation of the continuum and of the emission lines, and of their sizes.

Recent radio observations (Taylor et al.,1987) show that the star is still active in the radio and suggest the presence of a secondary maximum at the end of June 1986.

Spectroscopic observations made by Solf (1987) at high spatial and spectral resolution in Sept. 1986, have revealed a very compact emission nebulosity in the [OIII] lines This feature is located at an angular distance of 1".1, north-west of the star , and has been identified with a component of the jets detected in the radio in Nov. 1984. The velocity of the flow has been estimated of the order of 800 km s^{-1} , and the direction of the jet axis is almost perpendicular to the line of sight. It is noteworthy that the nebulosity has not been detected in H-alpha.

Very recent IUE observations made in June 1987 by Selvelli et al. (1987), indicate a decrease in the continuum and emission lines intensity. Also ground-based observations (Hack et al., 1987) indicate that the activity phase is almost over ; only a few, rather weak emissions are still present and the [OIII] and [NeIII] lines are below the detection level.

5.-COMMENTS AND SPECULATIONS

Observationally,the last outburst phases were characterized by a substantial drop in the optical and UV continua and by the formation of a jet, which, in turn, was mainly responsible for the radio emission and the optical and UV high excitation emission lines, which started to appear in the second half of 1984. The x-ray detection of May 1985 is also certainly related to this set of phenomena.

The time correlation among the various events which took place in the last outburst phases (from June 1984 to June 1987) suggests a causal, physical relation among them and also between them and the end of the activity

It is remarkable that "mutatis mutandis" the above reported variations (drop in luminosity, appearance of high excitation emission lines, radio emission) closely resemble the "obscuration events" (O.E.) described for R Aqr by Willson et al. (1981) , and more generally found in symbiotic Miras (Whitelock,1987) , although no detection of jets has been reported

for this last class of objects. The obscuration events" have been tentatively attributed to an "eclipse" of the mira's IR emission by an extended accretion disk, or by clouds, or alternatively, to spontaneous mass-loss from the mira.
The possible occurrence of an eclipse in CH Cyg around the mid of 1985 has been claimed by Mikolajewsky et al.(1986). It is possible that the eclipse was due to the orbital motion and occurred, by chance, close in time to the above - mentioned sequence of severe multispectral variations. From a more speculative viewpoint, a physical connection between the eclipse occurrence and the other variations can be considered. Unless nature is indeed capricious, it seems unlikely that the whole set of events, eclipse included, had occurred, just by chance, at nearly the same epoch, close to the last phases of the outburst.

A comprehensive model of CH Cyg has to take into account all these observational constraints and determine the physical processes which have led to the formation of the jet contemporaneously with the decline in luminosity, the appearance of high excitation emission lines, radio emission, x-ray emission, and the "eclipse",shortly before the end of the outburst.
Systematic multi-frequency observations of other symbiotic stars during their last outburst phases will cast light on the extension of these phenomena to objects other than CH Cyg and might also give significant constraints on the elusive physical mechanismms which are responsible for the formation of astrophysical jets .

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