PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **122**:12–16, 2010 January


# The Spectrum and Light Curve of CH Cygni during its Recent Broad Minimum

GEORGE WALLERSTEIN

Department of Astronomy, University of Washington, Seattle

U. MUNARI AND A. SIVIERO

INAF, Astronomical Observatory of Padova,
Asiago (VI), Italy

AND

S. DALLAPORTA AND I. DALMERI

ANS Collaboration, c/o Astronomical Observatory,
Asiago (VI), Italy

*Received 2009 July 2; accepted 2009 September 27; published 2009 December 11*

**ABSTRACT.** During 2006 CH Cyg declined steadily from $V = 7.3$ to 9.4, which is close to the faintest recorded minimum of 11.0 achieved after its outburst in the 1980s. We present light and color curves as well as low-resolution spectra that demonstrate that the decline was largely due to an increase in circumstellar absorption. In addition to the main 95 day pulsation period, a long secondary period of 1410 days, which is twice the spectroscopic period noted by Hinkle et al., modulates the pulsation light curve of the M7 III cool giant. The presence of two pulsation periodicities with such a large ratio is typical of AGB semiregular stars. Spectra of resolution 35,000 show the usual absorption lines of the M6 giant and various emission lines, especially Fe II and [Fe II], with radial velocities showing gas on the near side of CH Cyg to be expanding at $10\ \mathrm{km\,s^{-1}}$. Sharp resonance lines of Na I and K I in absorption show expansions of 20 and $40\ \mathrm{km\,s^{-1}}$.

*Online material:* extended table

## 1. INTRODUCTION

CH Cygni is a very complicated and enigmatic variable. The first useful spectra of CH Cyg were obtained by Joy (1942) during the interval of 1924 and 1927. From 5 spectra well distributed over its semiperiod of 100 days, the spectral type was M6 and the radial velocity was $-52.5 \pm 2.2\ \mathrm{km\,s^{-1}}$. No emission lines were reported. As part of his study of mass loss from cool stars, Deutsch (1967) found emission lines of H, Fe II, and [Fe II] in CH Cyg. The star has been monitored ever since as it has gradually revealed itself to be a symbiotic system (Wallerstein et al. 1986). The bibliography for CH Cyg is extensive with 605 references noted in the SIMBAD database as of this writing. Both permitted and forbidden lines have been seen in CH for the last 20 yr. Radial velocities of the absorption lines of the cool star have revealed the presence of two periods, which may be due to a triple stellar system (Hinkle et al. 1993) or a combination of stellar pulsation and a binary pair with a dusty shell (Munari et al. 1996). Hinkle et al. (2009) now favor the binary model in which the short period is ascribed to a pulsation mode of the cool star. The light curve is now irregular and has increased its amplitude from about one magnitude in the visual region in the 1930s to a full range from about $V = 5.5$ during its outburst in the 1980s, down to 11 a few years later. When it was brightest, its spectrum was dominated by a hot continuum, though its color (as noted at the telescope) remained distinctly yellow. At times the star showed very rapid variations (Cester 1967; Wallerstein 1968; Panov & Ivanova 1992; Hoard 1993; Karovska et al. 1993). Flickering has been reported for several symbiotic systems such as MWC 560, RS Oph, V407 Cyg, and T CrB (Dobrzycka et al. 1996; Gromadzki et al. 2006) but not in a number of other systems observed by those authors. In addition, CH Cyg has been known to emit X-rays ever since it was first detected by the Einstein Observatory (Galloway & Sokoloski 2004; Karovska et al. 2007; Mukai et al. 2007). During its outburst in 1985 it was detected with the EXOSAT satellite (Leahy & Taylor 1987).

In 2006 April CH Cyg began to decline from $B = 9.0$ to 11.5 which it reached by 2007 January. During that interval the color increased from $B - V = 1.7$ to 2.1, indicating that the M giant dominated the visual and blue light with no evidence of a continuum from a hot source. This has been the second deepest minimum since the period of enhanced activity began with the 1985 maximum. However, Taranova & Shenavrin (2007) noted the presence of a new dust shell during the interval of

2006 August–November, which may have been responsible for the dimming of the system.

High-resolution spectroscopic observations were started on 2006 August 24 and continued until 2007 January 24 when the star was near minimum. We show a light and color curve in Figure 1.

## 2. OBSERVATIONS

### 2.1. Photometry

$BV$ photometry of CH Cyg was independently obtained with three separate telescopes, identified by their codes: (R029) a 0.30 m Meade RCX-400 f/8 Schmidt-Cassegrain telescope located in S. Cristoforo al Lago (TN, Italy), and equipped with a SSP-5 photoelectric photometer and native Johnson filters; (R031) a 0.28 m Celestron C11 f/8 Schmidt-Cassegrain telescope located in Cembra (TN, Italy) and equipped with a SSP-5 photoelectric photometer and native Johnson filters; and (R030) a 0.30 m Meade RCX-400 f/8 Schmidt-Cassegrain telescope owned by Associazione Astrofili Valle di Cembra (Trento, Italy). The CCD was a SBIG ST-9, $512 \times 512$ array, 20 $\mu$m pixels $\equiv 1.72'' \mathrm{pixel}^{-1}$, with a field of view of $13' \times 13'$. The $B$ filter was from Omega and the $V$ filter from Custom Scientific.

All photometric measurements were accurately fluxed and color corrected using the local photometric sequence calibrated by Henden & Munari (2006) around CH Cyg. They are presented in Table 1. The Poissonian component of the total error budget is less than 0.004 mag for all the data. The rms of the local standard stars around the color equations was, on the average, 0.018 mag. The light curve from 2007 to 2009 is shown in Figure 2.

TABLE 1

$B$, $B-V$ PHOTOMETRY OF CH CYG.

| HJD | $B$ | $B-V$ | ID |
|---|---|---|---|
| 3548.4498 ........... | 9.467 | 1.738 | R031 |
| 3554.4972 ........... | 9.424 | 1.719 | R031 |
| 3557.4674 ........... | 9.446 | 1.742 | R031 |
| 3563.4650 ........... | 9.398 | 1.734 | R031 |
| 3566.4444 ........... | 9.401 | 1.753 | R031 |
| 3571.4248 ........... | 9.341 | 1.733 | R031 |
| 3580.3822 ........... | 9.302 | 1.751 | R031 |
| 3585.4684 ........... | 9.279 | 1.729 | R031 |
| 3590.3794 ........... | 9.287 | 1.740 | R031 |
| 3597.4441 ........... | 9.295 | 1.750 | R031 |

Table 1 is published in its entirety in the electronic edition of the *PASP*. A portion is shown here for guidance regarding its form and content.

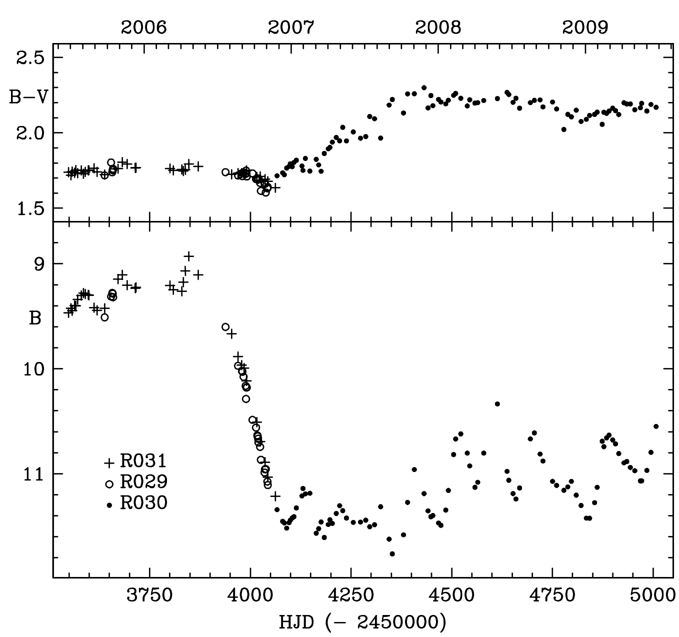


FIG. 1.—$B$, $B-V$ light curve of CH Cyg over the last 4 yr from our observations in Table 1. Symbols refer to the instruments described in § 2.1.

### 2.2. Spectroscopy

A high-resolution spectrum of CH Cyg was obtained on 2006 October 3 with the echelle spectrograph of the 3.5 m telescope of the Apache Point Observatory. The middle UT was 04:54 and the total exposure time was 320 s. The spectral coverage extended from 3900 to 10000 Å. The resolving power of the echelle is about 35,000 and the signal-to-noise ratio (S/N) in the continuum varies from about 200 at 7700 Å down to about 50 near the blue cutoff at 3900 Å.

A low-resolution, absolutely fluxed spectrum of CH Cyg was obtained on 2007 December 29 (middle UT 19:27) with the B&C spectrograph of INAF Astronomical Observatory of Padova attached to the 1.22 m telescope operated in Asiago by the Department of Astronomy of the University of Padova. The slit, aligned with the parallactic angle, projected onto 2″ on the sky, and the total exposure time was 2160 s. The detector was an ANDOR iDus 440A CCD camera, equipped with a EEV 42-10BU back-illuminated chip, $2048 \times 512$ pixels of 13.5 $\mu$m size. A 300 ln/mm grating blazed at 5000 Å provided a dispersion of 2.26 Å $\mathrm{pixel}^{-1}$ and a covered range extending from 3265 to 7965 Å. The spectrum is presented in Figure 3. According to Table 1, at the time of this spectrum CH Cyg was shining at $B = 11.45$ and $B-V = +2.21$.

## 3. THE EMISSION SPECTRUM IN 2006 OCTOBER

Prior to the decline of 2006, high-resolution spectra of CH Cyg were obtained by Yoo (2005, 2007) in 2004 April and October, and have been monitored by Burmeister & Leedjarv (2009) from 1996 to 2007. We describe here the general morphology of

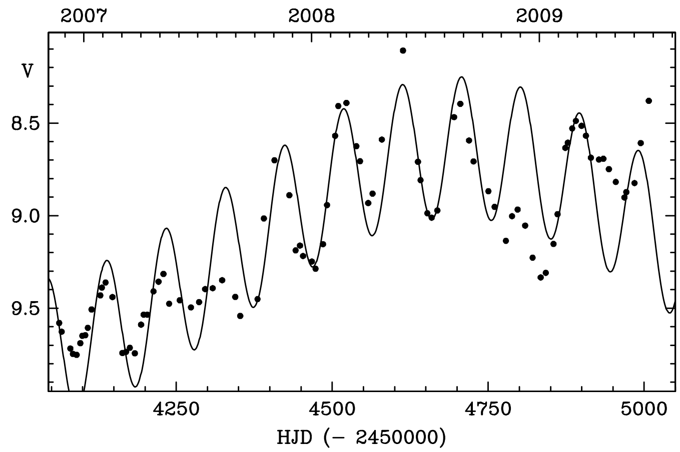


FIG. 2.—Faint portion of the CH Cyg light curve with the two component (95 and 1410 day periods) sinusoidal fitting described in § 4.

TABLE 2

RADIAL VELOCITIES OF EMISSION LINES IN CH CYG ON 2006 OCT 3

| Species | $V_r$ (km s$^{-1}$) | $\delta V_r$ (km s$^{-1}$) | Number of Lines |
|---|---|---|---|
| H[a] .......... | … | … | 5 |
| He I ....... | −70.1 | 6.5 | 3 |
| [N II] ...... | −57.7 | … | 1 |
| [O I] ....... | −63.3 | 0.6 | 2 |
| [O III] ..... | −68.5 | 6.5 | 3 |
| Mg I ....... | −67.6 | … | 1 |
| Fe II ....... | −70.8 | 1.0 | 17 |
| [Fe II] ..... | −70.0 | 0.7 | 21 |
| [Fe III] ..... | −70.3 | … | 1 |
| [S II] ....... | −57.0 | 7.2 | 2 |

[a] Complex profiles.

the spectrum (Zwicky 1957) rather than attempt a quantitative analysis of the lines and a model to explain their flux ratios. The emission lines are very sharp and their wavelengths can usually be measured with an uncertainty of about 0.02 Å. Hence line identifications are usually very easy, though some weak lines defy identification for unknown reasons. The spectrum of CH Cyg showed a rather low level of excitation, as exemplified by the presence of He I but not of He II. The highest states of ionization are shown by the well-known [O III] lines and one line of [Fe III]. As is often the case with symbiotic stars of moderate excitation, lines of Fe II and [Fe II] are very common. Rather than publish a long list of lines most of which are often seen in symbiotics, we summarize the emission lines present by listing the elements and ions present in Table 2 including their radial velocities. In this way we characterize the spectrum rather than attempt to derive the parameters of the emitting region. To some extent this is all that can be done when we could only make measurements relative to the local continuum but cannot establish the

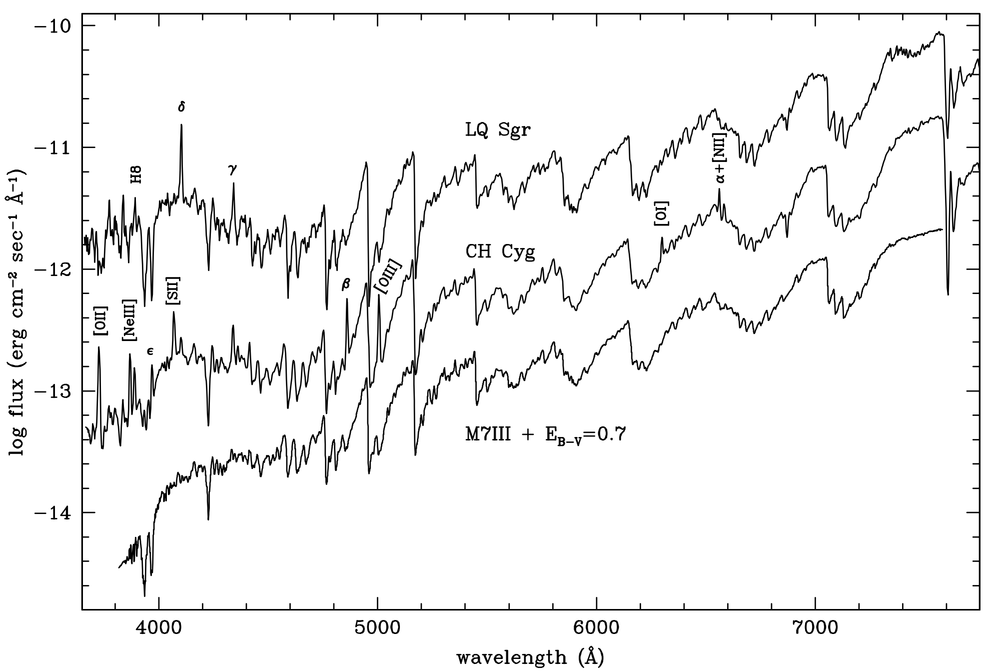


FIG. 3.—Low-resolution, absolutely fluxed spectrum of CH Cyg for 2007 Dec 29 compared to that of a classical Mira variable (LQ Sgr), and to an M7 III spectrum from the atlas of Fluks et al. (1994), reddened by $E_{B-V} = 0.7$ (for a standard $R_V = 3.1$ reddening law). The LQ Sgr and M7 III spectra are offset for clarity.

absolute flux as a function of wavelength in the continuum. In Table 3 we show the radial velocities of the absorption lines.

The emission lines must come from gas on the near side of the system, and show gas moving outward at about $10\ \mathrm{km\,s^{-1}}$ which is common in variable, late M, giants. If the emission were due to a large envelope of expanding gas, their radial velocity would be closer to that of the M giant.

Emission lines of H and He I are usually attributed to recombination. Lines of Fe II and [Fe II] are likely to be collisionally excited from their ground or metastable levels. For [O III] to be present requires a hot source that can ionize oxygen twice. It appears that all of these processes are in progress in CH Cyg during its recent minimum, even if no direct evidence of the hot star is seen down to 3900 Å. This is a rather severe condition since there does not appear to be any continuum at the bottoms of the Ca II and Al I resonance lines between 3930 and 3970 Å.

The absorption lines from excited levels of neutral atoms, which are likely to be formed in the atmosphere of the cool component, show a velocity that is not very different from that of Joy from the 1920s. Most of the emission lines are about $10\ \mathrm{km\,s^{-1}}$ more negative. The strong resonance lines of Na I and K I show components roughly 20 and $40\ \mathrm{km\,s^{-1}}$ more negative than the stellar lines. They are indicative of outward moving gas from the system.

TABLE 3

RADIAL VELOCITIES OF ABSORPTION LINES IN CH CYG

| Line Sources | $V_r$ ($\mathrm{km\,s^{-1}}$) |
|---|---|
| Neutral atoms, excited levels ..... | $-58.5 \pm 1.5$ |
| NaD + K I ........................ | $-102.4 \pm 2.5$, $-80.0 \pm 1.5$ |
| Ca II triplet ...................... | $-68.9 \pm 1.8$ |
| Mn I, Cr I, zero volt lines ....... | $-60.5 \pm 3.0$ |

## 4. PULSATION OF THE M GIANT

After the drop in brightness at the end of 2006 (cf. Figure 1), CH Cyg started to display a semiregular pulsation activity, characterized by two main periodicities of 95 and 1410 days.The latter is not far from twice the spectroscopic period of 766 days (Hinkle et al. 2009), but needs to be confirmed over a longer interval. Figure 2 presents an expanded view of this part of the light curve, where the line fitting the data is given by the following expression (where $t$ is in HJD $-$ 2450000):

$$V(t) = 9.18 + 0.38 \sin \frac{t - 4565}{95} + 0.55 \sin \frac{t - 3995}{1410}. \quad (1)$$

While the general fitting is good, nevertheless there are significant deviations indicative of a complex pulsation activity. The simultaneous presence of two periodicities with a large ratio of period lengths (known as the LPV phenomenon) is seen in AGB semiregular variables (see Soszynski et al. 2007, and Munari et al. 2008 for recent examples, calibration, and literature review). The short 95 day period has been present in CH Cyg since its early recorded history, well before the eruptive phase that began during the sixties (cf. Kenyon 1986 and references therein).

## 5. REDDENING

Fitting the low-resolution spectrum in Figure 3 with the Fluks et al. (1994) atlas of unreddened M giant spectra, provides a classification as M7 III for the cool star and fix the reddening affecting CH Cyg of $E_{B-V} = 0.7$ (for a standard $R_V = 3.1$ extinction law).

The intrinsic $B - V$ color of M giants does not depend on the spectral type and hence the effective temperature, as illustrated by Johnson (1966), Lee (1970), and Fitzgerald (1970). Their tabular compilations provide $\langle (B - V)_\circ \rangle = +1.54$ as the mean intrinsic color of M5 to M8 class III giants. The mean $B - V$ color of CH Cyg at the time of the low-resolution observation in Figure 3 was $B - V = +2.21$, which corresponds to a reddening $E_{B-V} = 0.67$, in excellent agreement with the above results on spectrum fitting.

The color change was noted by Taranova & Shenavrin (2007) who suggested that the change was due to enhanced circumstellar absorption. At the Galactic coordinates of CH Cyg, the map of Burstein & Heiles (1982) shows that the interstellar reddening is not likely to be move than 0.05 mag in $B - V$.

## 6. SUMMARY

As one of the closest symbiotic stars, CH Cyg continues to be one of the most difficult to understand. With a parallax of $4.12 \pm 0.67$ mas (from the rereduction of the *Hipparcos* database, van Leeuwen 2007) the distance is $243^{+47}_{-34}$ pc. Its radial velocity is about $-50\ \mathrm{km\,s^{-1}}$, indicating its membership in the thick disk, implying small initial masses. We do not know why its emission spectrum first appeared in the 1960s. Either its hot companion spontaneously became active, or more likely, mass loss from the M giant increased and was captured by the white dwarf inducing activity, thereby exciting the emission lines, culminating in the rise to $V = 5.8$ and subsequent collapse to $V = 11$ and the ejection of the radio and x-ray emitting jets. The recent decline shows that the ejection of gas and dust from the cool giant is intermittently active. There is no way to predict if and when another rise to $V$ near magnitude 6 will occur. Only multiwavelength monitoring of CH Cyg (and other symbiotics) will allow them to reveal themselves to us. In this brief article we have presented new photometric and spectroscopic observations during the 2006–2007 deep minimum. We leave to others the difficult task of modeling a system as complicated as CH Cyg.

We thank Wenjin Huang for assistance in preparing the manuscript.

## REFERENCES


Bermeister, M., & Leedjärv, L. 2009, A&A, in press (arXiv:0907.2017)
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Cester, B. 1967, Inf. Bull. Variable Stars, 219, 1
Deutsch, A. J. 1967, IAU Circ., No. 2020
Dobrzycka, D., Kenyon, S. J., & Milone, A. A. E. 1996, AJ, 111, 414
Fitzgerald, M. P. 1970, A&A, 4, 234
Fluks, M. A., Plez, B., The, P. S., de Winter, D., Westerlund, B. E., & Steenman, H. C. 1994, A&AS 105, 311
Galloway, D. K., & Sokoloski, J. L. 2004, ApJ, 613, 61
Gromadzki, et al. 2006, ACA, 56, 97
Hoard, D. W. 1993, PASP, 105, 1232
Henden, A., & Munari, U. 2006, A&A, 458, 33
Hinkle, K. H., Fekel, F. C., Johnson, D. S., & Scharlach, W. W. G. 1993, AJ, 105, 1074
Hinkle, K. H., Fekel, F. C., & Joyce, R. 2009, ApJ, 692, 1360
Johnson, H. L. 1966, ARA&A, 4, 193
Joy, A. H. 1942, ApJ, 96, 344
Karovska, M., Bernes, T., & Fruch, M. 1993, J. AAVSO, 22, 101
Karovska, M., Carilli, C. L., Raymond, J. C., & Mattei, J. M. 2007, ApJ, 661, 1048
Kenyon, S. J. 1986, The Symbiotic Stars, (Cambridge: Cambridge Univ. Press)
Leahy, D. A., & Taylor, A. R. 1987, A&A, 176, 262
Lee, T. A. 1970, ApJ, 162, 217
Mukai, K., et al. 2007, PASJ, 59, 177
Munari, Yudin, B. F., Kolotilov, E. A., & Tomov, T. V. 1996, A&A, 311, 484
Munari, U., Siviero, A., Ochner, P., Dallaporta, S., & Simoncelli, C. 2008, Baltic Astron., 17, 223
Panov, K. P., & Ivanova, M. S. 1992, Inf. Bull. Variable Stars, 3245
Soszynski, I., Dziembowski, W. A., & Udalski, A., et al. 2007, AcA, 57, 201
Taranova, O. G., & Shenavrin, V. L. 2007, Astron. Lett., 33, 531
van Leeuwen, F. 2007, Hipparcos, the New Reduction of the Raw Data, (Dordrecht: Springer)
Wallerstein, G. 1968, Observatory, 88, 111
Wallerstein, G., Bolte, M., Whitehill-Bates, P., & Mateo, M. 1986, PASP, 98, 330
Yoo, K. H. 2005, NewA, 11, 359
———. 2007, NewA, 12, 569
Zwicky, F. 1957, Morphological Astronomy (Dordrecht: Springer)