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Multiwavelength evidence for a 15-year periodic activity in the symbiotic nova V1016 Cygni⋆

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Abstract. The ∼15.1 years period found in the long-term UBV photoelectric and photographic photometry of the symbiotic nova V1016 Cyg is detected also in the $(J - K)$ colour index and in the UV continuum and emission line fluxes from IUE and HUT spectra. It could be interpreted either as the effect of recurrent enhanced mass loss episodes from the Mira type variable companion to a hot component along its ultra-wide orbit (proposed from recent HST observations) or the true orbital period of the inner, unresolved binary of a triple system. The 410-day delay of the maximum of UV emission lines fluxes with respect to the maximum of continuum was found. The pulsation period of the Mira type variable was improved to 474 ± 6 days.

Key words. stars: binaries: symbiotic – stars: individual: V1016 Cyg – stars: activity

1. Introduction

V1016 Cyg (MHα 328-116) is a member of a small subgroup of symbiotic stars, called symbiotic novae, also including V1329 Cyg and HM Sge, whose outbursts lead to a nebular spectrum (Mürset & Nussbaumer 1994). Symbiotic novae are wide interacting binaries, where matter from a late-type giant is transferred onto the surface of the more compact companion. The nova-like optical outburst ($\Delta m \sim$ 5–7 mag), lasting decades, is caused by a thermonuclear runaway on the surface of a wind-accreting white dwarf after the critical amount of material has been accumulated (cf. Mikolajewska & Kenyon 1992). V1016 Cyg underwent such nova-like outburst in 1964 (McCuskey 1965). The object is classified as a D-type symbiotic, the cool component being a Mira type variable embedded in a dust envelope whose pulsation period turned out to be ∼478 (Munari 1988). The onset of a dust formation episode in 1983 is reported by Taranova & Yudin (1986).

The orbital period of V1016 Cyg is not yet established. Taranova & Yudin (1983) made use of the increase of Balmer emission lines in combination with the appearance and disappearance of FeII lines to derive an orbital period of ≈20 years. Afterwards, Nussbaumer & Schmid (1988), though unable of recording two consecutive maxima, proposed an orbital period of 9.5 years on the basis of the apparent periodicity seen in the flux of OI and MgII UV emission lines by means of the IUE satellite. At the same time Munari (1988), by resorting to IR observations taken over two decades, proposed instead a 6-year orbital period by modeling the sequence of dust obscuration episodes, likely related to the passage of the Mira type variable at the inferior conjunction in the system.

Much longer periods have been proposed by Wallerstein (1988) and Schild & Schmid (1996). In the former paper the author, assuming that the sharp FeII emission lines are formed in the chromosphere of the cool star so as to reflect its orbital motion, concludes that their observed radial velocities between 1978 and 1985 limit any high inclination orbit to a period greater than 25 years or to a large eccentricity. The latter analysis, based on spectropolarimetric data taken from 1991 to 1994, indicates that the orbital period is about 80 ± 25 years, though later observations obtained in 1997 put this result into question (Schmid 1998). Finally, Brocksopp et al. (2002), adopting a projected separation of the two stellar components as large as 84 AU on the basis of their HST/WFPC2 images, are forced to propose an astonishingly long orbital period of ∼544 years.

In the context of this still-to-be-settled issue, one has also to interpret the evidence for the 15-year periodic activity (not necessarily representing the sought *orbital* period) recently presented by Parimucha et al. (2000) (hereafter PAC) who

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⋆ Partly based on observations obtained with the International Ultraviolet Explorer (IUE) satellite retrieved from the IUE Newly Extracted Spectra (INES) Archive and the Hopkins Ultraviolet Telescope (HUT) retrieved from the Multimission Archive at STScI (MAST).

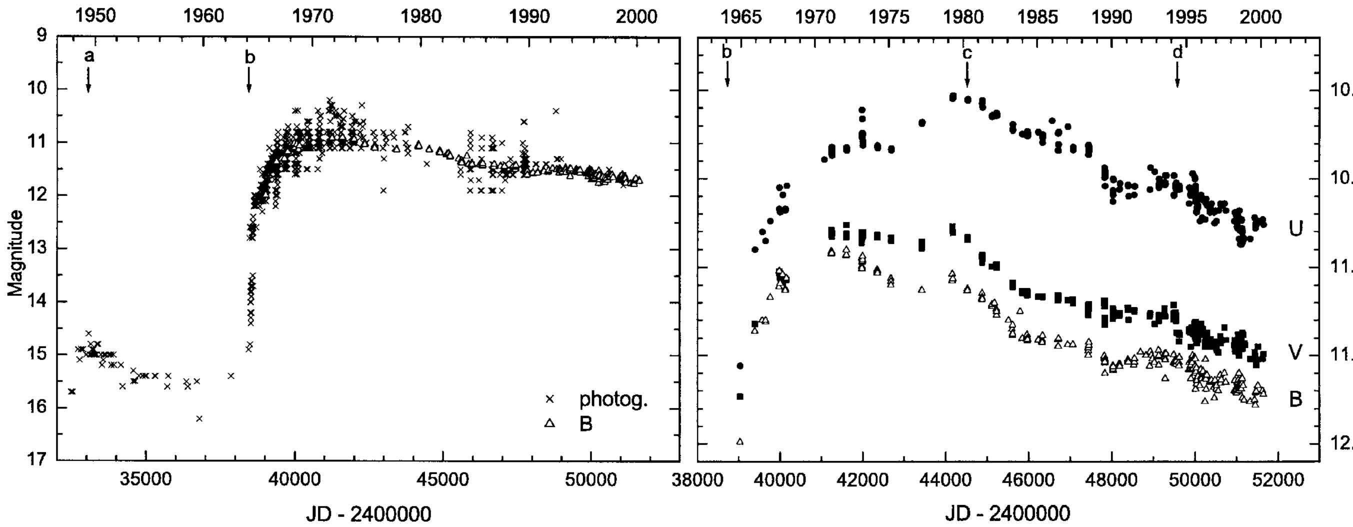

Fig. 1. Photographic (left) and *UBV* (right) light curves of V1016 Cyg. Arrows *a*, *b*, *c* and *d* mark the epochs of subsequent activity episodes of the system (see text).

gathered and analysed long-term photographic, photoelectric and visual photometry of the object. The aim of the present paper is indeed to give further (i.e., multiwavelength) support to the existence of such a periodicity making use of both IR photometry and UV spectroscopy, as well as to investigate its own origin.

2. Long-term photometry

2.1. UBV photoelectric and photographic data

The historical light curve of V1016 Cyg based on the photographic and *UBV* data given in PAC is presented in Fig. 1. The light curve suggests four stages of activity marked by arrows in the figure: the pre-outburst flare *a* in 1949, the main nova-like outburst *b* in 1964 and two post-outburst, decreasing-amplitude flares *c* and *d* in 1980 and 1994, respectively. Evidently the activity episodes affecting the system repeat themselves (though at quite a different intensity level) with an interval of ≈15 years. The ephemeris for the activity maxima calculated in PAC is as follows:

$$\mathrm{JD}^{\mathrm{phot}}_{\mathrm{max}} = \underset{\pm 250}{2\,427\,590} + \underset{\pm 90}{5510} \times E. \qquad (1)$$

It is worth noticing that both maxima recorded in 1980 and 1994 followed appreciable brightness decreases which, in turn, could be interpreted as signatures of an enhanced mass transfer from the cool to the hot component. A similar effect has been detected in the light curve of the very slow classical nova V723 Cas (Chochol & Pribulla 1998).

2.2. JHK data

Infrared photometry of V1016 Cyg was published by Harvey (1974), Kenyon & Gallagher (1983), Lorenzetti et al. (1985), Taranova & Yudin (1986), Munari (1988), Ananth & Leahy (1993), Kamath & Ashok (1999) and Taranova & Schenavrin (2000). We make use here of this whole dataset plus a few unpublished *JHK* observations obtained in 1993 (kindly provided by F. Strafella) to newly estimate the period of pulsation of the Mira type variable. The Fourier period analysis (Fig. 2) applied to the *JHK* data leads to the values 476 ± 10, 472 ± 11 and 474 ± 10 days for *J*, *H* and *K* photometry, respectively. The adopted period of the Mira type variable pulsations (whose corresponding phase diagrams are also presented in Fig. 2) is thus $P = 474 \pm 6$ days.

The long-term behaviour of the $(J - K)$ color index of V1016 Cyg using all available infrared data is presented in Fig. 3. As pointed out by Whitelock (1987), the $(J - K)$ color index in symbiotic Miras is little affected by the Mira type variable pulsation, being conversely very sensitive to the amount of circumstellar dust around the cool component. As a consequence, the abrupt change (∼1 mag) of the IR color recorded in 1983 by Taranova & Yudin (1986) comes likely from a short (though strong) dust formation episode. Although orbitally-related dust obscuration episodes are indeed expected in these systems, we interpret this unique, major episode which occurred three years after the observed maxima both in the *U* passband and space-borne UV (see below) as dust formation in the ejecta of the symbiotic nova (cf. Bode 1995).

According to this view, one has to be cautious when interpreting possible periodicities emerging from the analysis of the long-term behaviour of the $(J - K)$ color index (Fig. 3) which shows an additional maximum in 1988 and a clear minimum in 1992, together with a more uncertain maximum (in 1973) and a further possible minimum (in 1977). Indeed, the phenomena lying beneath the two possible periods (namely, 2070 and 5630 days; see Fig. 4) one can identify by means of the Fourier analysis of its residuals (after removing a parabolic trend) is likely quite different. While the longer period, besides being close to the *UBV* photometric estimate, could well reflect the real orbital motion of the system, as suggested by the wave-like variation exhibited by the $(J-K)$ residuals phased with the ephemeris (1) (see Fig. 4), the shorter period of 5.6 years, close to the 6-year period interpreted by Munari (1988) as the orbital

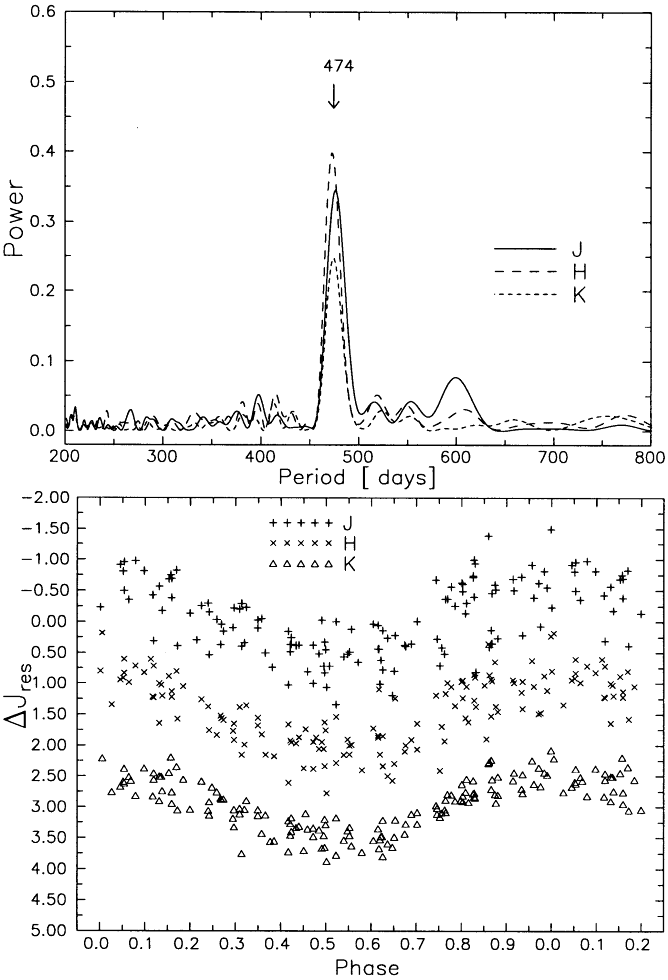

Fig. 2. Upper panel: the Fourier power spectra of the pulsation period of the Mira type variable in the JHK data. Lower panel: the resulting light curves phased with the ephemeris $JD_{max} = 2\,447\,442 + 474 \times E$. The ΔH_{res} and ΔK_{res} are shifted by 1.5 and 3.0 mag, respectively.

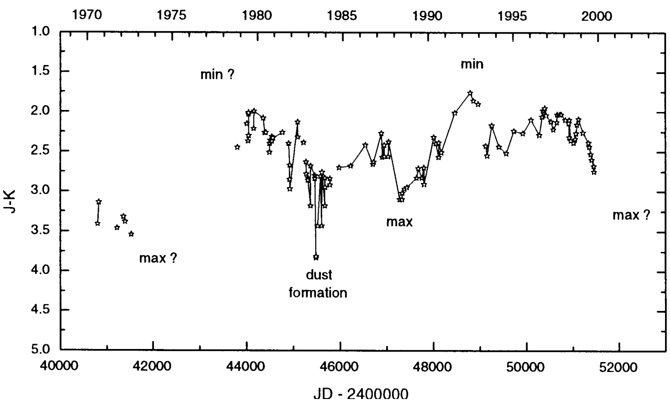

Fig. 3. $(J - K)$ color index of V1016 Cyg.

period of the binary system, is likely due to the superposition of several effects such as dust formation induced by the activity of the hot component and possible mass tranfer events from the cool to the hot component.

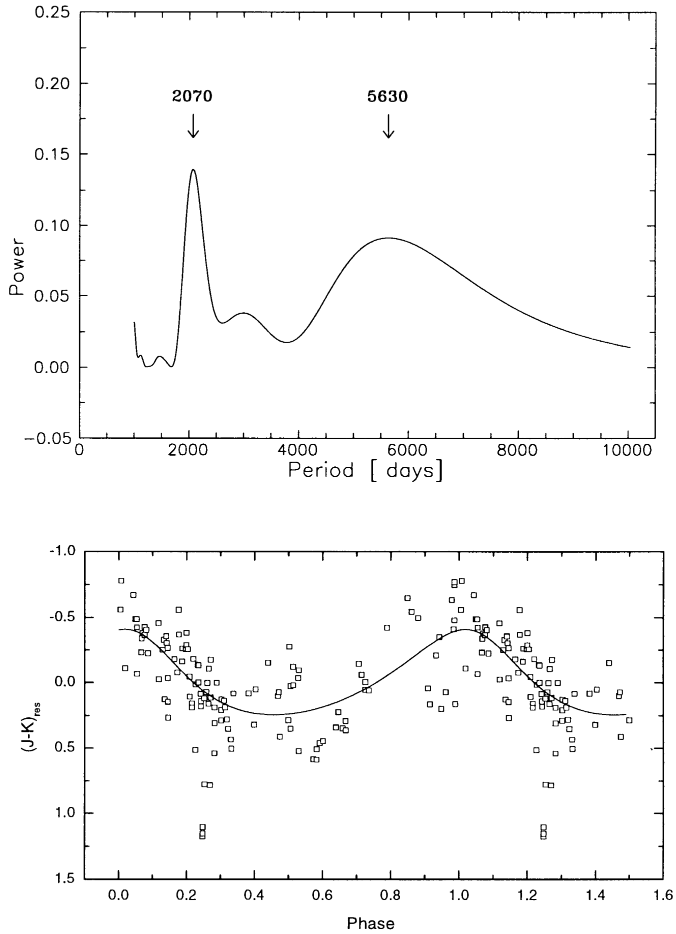

Fig. 4. Upper panel: the Fourier power spectrum for the $(J-K)$ residuals in the interval 1000 to 10 000 days. Lower panel: the phase diagram of the above data corresponding to the ephemeris (1). A trigonometric polynomial has been adopted for the fit.

3. UV spectroscopy

The UV dataset discussed here includes both low and high dispersion IUE (International Ultraviolet Explorer) spectra spanning the interval from Aug. 1978 to Aug. 1995 (for a complete list see Parimucha 2002), and a single HUT (Hopkins Ultraviolet Telescope) spectrum taken on March 6, 1995. Properly calibrated IUE NEWSIPS data have been retrieved from the IUE Newly Extracted Spectra (INES) Archive, while the calibrated HUT spectrum was extracted from the Multimission Archive at STScI (MAST).

Average continuum fluxes in emission-free, 20 Å bins centered at λ 1840 Å and λ 2530 Å have been derived from low dispersion, large aperture IUE spectra (SWP and LWR/LWP cameras, respectively), plus the HUT spectrum (for the λ 1840 Å region alone). Both measured and dereddened fluxes are given in Table 1 (having adopted $E(B - V) = 0.28$, according to Nussbaumer & Schild 1981). Dereddened continuum fluxes are also shown in Fig. 5.

High dispersion, large aperture IUE/SWP spectra were used to derive fluxes of OIII] ($\lambda\lambda$ 1661, 1666 Å), NIII] (λ 1750 Å), SiIII] (λ 1892 Å) and CIII] (λ 1909 Å) emission lines. A single measurement of the OIII] lines flux was obtained

Table 1. Measured (I) and corrected (II) (with $E(B-V) = 0.28$) UV continuum flux in 10^{-14} erg cm s^{-1} Å^{-1}.

JD	1840 Å			2530 Å		
2 400 000+	SWP	I	II	LWR/P	I	II
43752	2427	15.8	122.1	2229	16.5	102.6
43920	4271	15.4	119.1	3778	18.4	114.0
44049	5611	16.9	130.6			
44072	5832	17.6	136.1	5080	20.7	128.3
44076				5136	22.6	140.1
44139				5675	19.9	123.3
44140	6617	16.3	125.9			
44202				6227	20.9	129.5
44268	7803	13.9	107.4			
44474				8593	20.8	128.9
44475	9878	16.0	123.7			
44672	13431	15.0	115.9	10095	19.1	118.4
44706				10344	17.8	110.3
44707	13704	13.8	106.7			
44761	14193	12.4	95.8	10786	19.6	121.5
45065				12966	20.2	125.2
45192				13920	17.9	110.9
45193	17658	11.9	91.9			
45301	18669	14.2	109.7	14733	15.9	98.6
45422	19566	12.4	95.8	15597	14.6	90.5
45799				3133	12.6	78.1
45800	22701	10.0	77.3			
45822				3261	12.8	79.3
46045	24656	11.7	90.4	4959	12.0	74.4
46616				8552	12.8	79.3
46771				9656	11.9	73.8
46935	31006	11.1	85.8	10793	12.6	78.1
47111	32296	12.6	97.4	12065	13.2	81.8
47332	33783	11.4	88.1	13464	12.8	79.4
47512	35047	11.8	91.2	14651	12.6	78.1
47750				16106	12.9	79.9
47751	36825	12.0	92.7			
47777	36953	9.7	74.9	16298	14.9	92.3
47855				16822	10.6	65.7
48004				17793	13.1	81.2
48005	38658	10.2	78.8			
48122	39486	12.0	92.8	18609	12.7	78.7
48420				20582	17.3	107.2
48472	42161	10.9	84.3	20934	12.4	76.8
48613				22055	14.9	92.4
48614	43445	13.2	102.1			
48814				23483	16.0	99.2
48917	46028	13.9	107.4	24127	16.0	99.2
49514				28380	15.3	94.9
49782	11301[a]	15.7	121.3			
49955				31358	14.2	88.1
49956	55707	12.0	92.8			

Note: [a] HUT spectrum.

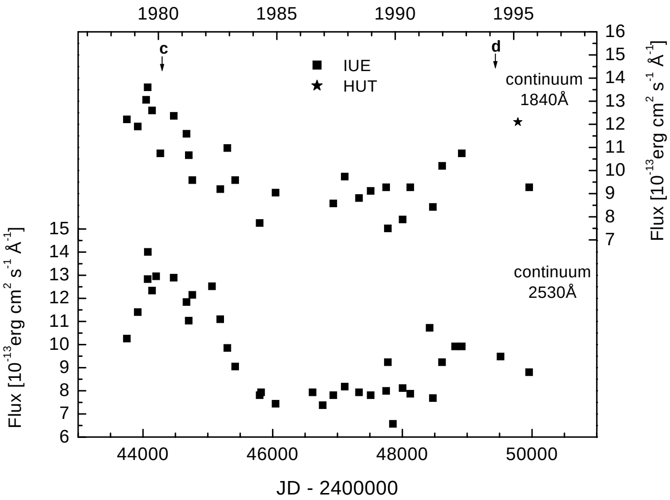

Fig. 5. Dereddened continuum fluxes at 1840 Å and 2530 Å.

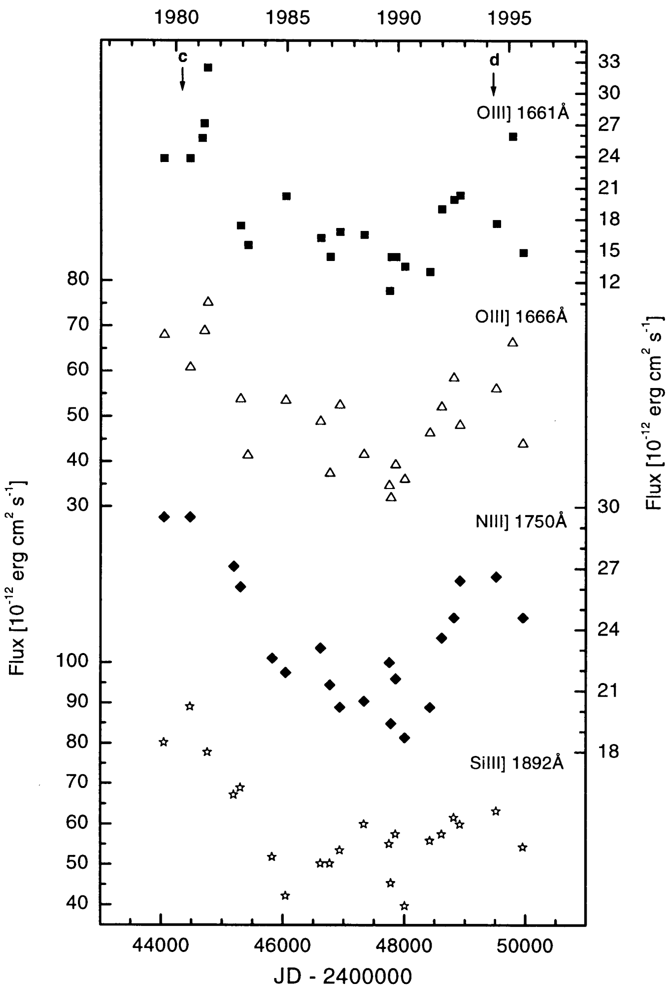

Fig. 6. Dereddened UV emission line fluxes.

also from the HUT spectrum of 1995. The emission line profiles show a broad component superposed to the dominant, narrow component (cf. Kindl et al. 1982). Fluxes given here are the result of fitting Gaussian profiles to the latter narrow component. Dereddened fluxes for OIII], NIII] and SiIII] lines are shown in Fig. 6 and listed (together with the original fluxes) in Table 2.

For the strong CIII] λ 1909 Å which falls by chance in the overlapping region between the IUE short-wavelength (SWP) and long-wavelength (LWR/LWP) camera spectral ranges,

Table 2. Measured (I) and corrected (II) (with $E(B-V) = 0.28$) UV emission line fluxes in 10^{-12} erg cm^{-2} s^{-1}.

JD	SWP	OIII]1661 Å		OIII]1666 Å		NIII]1750 Å		SiIII]1892 Å	
2 400 000+		I	II	I	II	I	II	I	II
44049	5612	3.2	23.8	9.1	68.0	3.7	29.5	9.9	80.2
44475	9879	3.2	23.8	8.1	60.8	3.7	29.5	11.0	89.1
44672	13432	3.4	25.7						
44707	13705	3.6	27.1	9.2	68.9				
44761	14192	4.3	32.4	10.0	75.1			9.6	77.8
45193	17657					3.4	27.1	8.3	67.2
45301	18670	2.3	17.4	7.2	53.8	3.3	26.1	8.5	68.9
45422	19568	2.1	15.5	5.5	41.4				
45823	22890					2.8	22.6	6.4	51.8
46045	24658	2.7	20.2	7.2	53.5	2.7	21.9	5.2	42.2
46617	28618	2.2	16.2	6.5	48.9	2.9	23.1	6.2	50.2
46771	29823	1.9	14.4	5.0	37.4	2.7	21.3	6.2	50.2
46935	31005	2.2	16.8	7.0	52.5	2.5	20.2	6.6	53.5
47332	33785	2.2	16.5	5.6	41.6	2.6	20.5	7.4	60.0
47751	36826	1.5	11.2	4.6	34.7	2.8	22.4	6.8	55.1
47777	36954	1.9	14.4	4.3	32.0	2.4	19.4	5.6	45.4
47855	37673	1.9	14.4	5.3	39.3	2.7	21.6	7.1	57.5
48005	38659	1.8	13.5	4.8	36.1	2.3	18.7	4.9	39.7
48420	41828	1.7	13.0	6.2	46.4	2.5	20.2	6.9	55.9
48614	43446	2.5	19.0	7.0	52.1	2.9	23.6	7.1	57.5
48815	45115	2.7	19.9	7.8	58.5	3.1	24.6	7.6	61.6
48917	46029	2.7	20.3	6.4	48.1	3.3	26.4	7.4	59.9
49514	51059	2.4	17.6	7.5	56.1	3.3	26.6	7.8	63.2
49782	11301[a]	3.4	25.9	8.8	66.3				
49956	55705	2.0	14.8	5.9	44.0	3.1	24.6	6.7	54.3

Note: [a] HUT spectrum.

simultaneous flux estimates obtained from both cameras are shown in Fig. 7 and listed in Table 3. In order to make the best use of the whole dataset, Fig. 7 includes also – as a lower limit – the estimated flux of CIII] in case the line saturation was marginal (i.e. affecting no more than 2 high-resolution pixels).

It should be stressed that the availability of a *large aperture* spectrum taken on August 31, 1978 (namely, LWR 2228), allowing the measurement of the CIII] λ 1909 Å emission line flux, *does assure that the flux rise exhibited by the UV continua from mid-1978 to mid-1979* (see Fig. 5) *also affects the UV emission lines* so as *both* UV continua and emission lines reflect the 1980 peak of activity of the system recorded in other wavebands (see above). Strictly speaking, this verification turns out to be not possible for the remaining set of UV emission lines, as high resolution SWP spectra assured earlier than June 24, 1979 were obtained through the *non-photometric* IUE small aperture.

One can easily recognize that the evolution of both UV continua and emission lines from 1978 to 1996 is characterized by two maxima matching the activity epochs c, d shown by optical photometry. Moreover, interesting clues to the physical properties of the system could come from the observed delay of the onset of emission line activity, whose first maximum (at epoch JD 2 444 635 ±15) appears shifted by 410 days from the corresponding epoch for both UV continua (JD 2 444 225 ± 12).

Finally, it should hold reader's interest the fact that the major dust formation episode discussed in the Sect. 2.2 reflects in a recognizable flux drop of the majority of UV emission lines in 1983–84 (see Fig. 6).

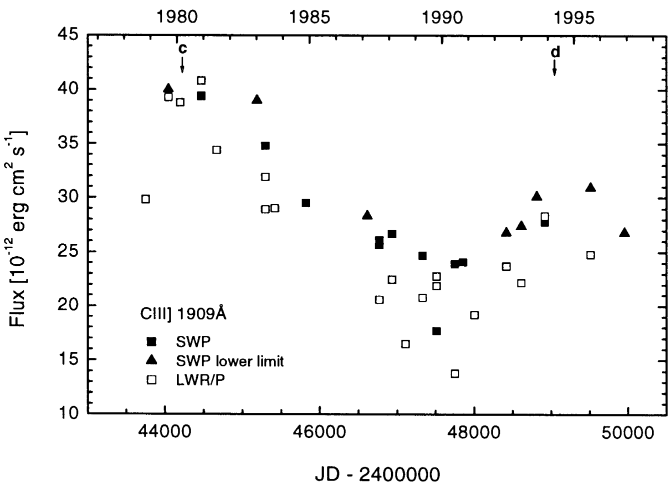

Fig. 7. Dereddened fluxes of CIII] λ 1909 Å emission line.

4. Discussion

No doubt the symbiotic nova V1016 Cyg includes a pulsating Mira type variable and an accreting white dwarf that underwent a thermonuclear outburst in 1964, leading straight to a nebular spectrum (FitzGerald et al. 1966). According to the ionization

Table 3. Measured (I) and corrected (II) (with $E(B-V) = 0.28$) CIII]1909 Å emission line fluxes in 10^{-11} erg cm^{-2} s^{-1} from SWP and LWP/R spectra.

JD 2 400 000+	SWP	I	II	LWR/P	I	II
43752				2228	3.6	29.8
44049	5612[1]	4.8	40.0	4869	4.7	39.3
44203				6228	4.7	38.8
44475	9879	4.7	39.4	8594	4.9	40.8
44672				10096	4.1	34.4
45193	17657[1]	4.7	39.0			
45301	18670	4.2	34.8	14734	3.8	31.9
45301				14735	3.5	28.9
45422				15599	3.5	29.0
45823	22890	3.6	29.5			
46617	28618[1]	3.4	28.3			
46771	29823	3.2	26.1	9646	2.4	19.5
46771				9647	2.5	20.6
46771	29828	3.1	25.7			
46935	31005	3.2	26.7	10794	2.7	22.5
47111				12066	2.0	16.5
47332	33784	3.0	24.7	13463	2.5	20.8
47512	35046	2.1	17.7	14652	2.7	22.8
47512				14653	2.6	21.9
47751	36826	2.9	23.9	16108	1.7	13.8
47855	37673	2.9	24.1			
48005				17795	2.3	19.2
48420	41828[1]	3.2	26.8	20583	2.9	23.7
48614	43446[1]	3.3	27.4	22056	2.7	22.2
48815	45115[1]	3.6	30.1			
48917	46029	3.4	27.8	24128	3.4	28.3
49514	51059[1]	3.7	30.9	28379	3.0	24.8
49956	55705[1]	3.2	26.8			

Note: [1] Lower limit.

model of symbiotic binaries, the hot luminous component ionizes the neutral wind of the giant giving rise to the nebula in the system. Such a mechanism is confirmed by the strict coincidence of the epochs of maxima in the U passband (observed in 1980 and 1994) and those recorded in the space-UV continuum combined with the 410-day delay of the OIII], CIII], NIII] and SiIII] emission line maxima which, in turn, assures that the lines are collisionally excited in the surrounding nebula when the fast wind from the hot object interacts with the slow wind from the Mira type variable.

At present, the above well-understood phenomenology leaves still open two alternative scenarios for V1016 Cygni.

If this symbiotic nova is a wide-orbit binary with a 544-year period as proposed by Brocksopp et al. (2002), one is forced to interpret the periodic (15-yr) variations of the optical and UV continuum as induced by flares of the hot component triggered by the recurrent enhanced mass loss episodes from the Mira type variable companion. According to Fleischer et al. (1995), this mass loss is most pronounced every few periods of the Mira type variable pulsations. It can trigger individual flares in the accretion disk of the hot white dwarf. The existence of the disk is supported by the 3D simulation of the wind accretion by the compact star (Theuns & Jorissen 1993).

Alternatively, V1016 Cygni could be interpreted as a *triple* system, whose *inner*, unresolved binary has an *orbital* period of 15 years. If this is the case, flares would be triggered by an enhanced mass transfer from a cool giant *during its periastron passage on the 15-year orbit*. In this respect, a hint of enhanced mass transfer, coming just before the weak flare in 1994, can be found in the long-term infrared photometry performed by Taranova & Schenavrin (2000) showing a brightness increase in the J and H passbands in 1992. Moreover, the coincidence of the observed maximum of the $J-K$ index in 1988 (Fig. 3) and the wide minima of the UV continua (Fig. 5) would constrain to that epoch the inferior conjuction of a cool giant along its 15-year orbit.

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