

Bipolar jet growth and decline in Hen 3-1341: a direct link to fast wind and outburst evolution[★]

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ABSTRACT

We report on and investigate the evolution and disappearance in the symbiotic star Hen 3-1341 of collimated bipolar jets, which take the form of symmetrically displaced components of emission lines. From modelling of the emission-line spectrum it turns out that the accreting white dwarf (WD) in quiescence has $T_{\text{WD}} \sim 1.2 \times 10^5$ K and $R_{\text{WD}} \sim 0.14 R_{\odot}$, for a luminosity of $3.8 \times 10^3 L_{\odot}$, and it is stably burning hydrogen on the surface at a rate of $\dot{M}_{\text{H}} \sim 5 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$, feeding ionizing photons to a radiation bounded circumstellar nebula extending for ~ 17 au. The WD underwent a multimaxima outburst lasting from 1998 to 2004 during which its H-burning envelope reacted to a probable small increase in the mass accretion by expanding and cooling to $T_{\text{eff}} \sim 1 \times 10^4$ K and $R \sim 20 R_{\odot}$, mimicking an A-type giant that radiated a total of $\sim 6 \times 10^{44}$ erg, at an average rate of $\sim 1 \times 10^3 L_{\odot}$. Bipolar jets developed at the time of outburst maximum and their strength declined in parallel with the demise of the fast wind from the inflated WD, finally disappearing when the wind stopped halfway to quiescence, marking a 1:1 correspondence between jets presence and feeding action of the fast wind. The total mass in the jets was $M_{\text{jet}} \sim 2.5 \times 10^{-7} M_{\odot}$ for a kinetic energy of $E_{\text{jet}}^{\text{kin}} \sim 1.7 \times 10^{42} (\sin i)^{-1}$ erg, corresponding to $\sim 0.3(\sin i)^{-1}$ per cent of the energy radiated during the whole outburst. We suggest that the spectroscopic search for jets in symbiotic stars could pay higher dividends if focused on the outburst phases characterized by maximum wind intensity.

Key words: binaries: symbiotic – stars: mass-loss – stars: winds, outflows – ISM: jets and outflows.

1 INTRODUCTION

Tomov, Munari & Marrese (2000, hereafter TMM) discovered spectroscopically in Hen 3-1341 (=V2523 Oph) one of the finest examples of highly collimated bipolar jets seen in a symbiotic binary. The jets, with a projected velocity of $|\Delta R V_{\odot}| \sim 820 \text{ km s}^{-1}$, were observed when the system was in outburst at $V \sim 10.5$ mag. No follow-up study monitored the jet or outburst evolution.

Some symbiotic binaries are already known to present or have presented jets, in the optical, radio and/or X-rays: R Aqr (Burgarella & Paresce 1992; Dougherty et al. 1995; Kellogg, Pedelty & Lyon 2001), CH Cyg (Taylor, Seaquist & Mattei 1986; Solf 1987; Crocker et al. 2002; Galloway & Sokoloski 2004), MWC 560 (Tomov et al. 1990; Shore, Aufdenberg & Michalitsianos 1994; Schmid et al. 2001), RS Oph (Taylor et al. 1989), Hen 2-104

(Corradi et al. 2001) and Hen 3-1341 (TMM). Other possible examples of jets or collimated mass outflows from symbiotic binaries and related systems are StH α 190 (Munari et al. 2001), Z And (Brocksopp et al. 2004), AG Dra (Mikolajewska 2002), V1329 Cyg and HD 149427 (Brocksopp, Bode & Eyres 2003).

It is not an easy task to correlate in symbiotic stars the appearance of jets with the system properties. In fact, the ionized circumstellar gas is so bright in the optical and ultraviolet as to prevent direct observation of the central engine, which is believed to be an accreting white dwarf (WD) that in many cases experiences quasi-stable surface H-burning (Munari & Buson 1994; Sokoloski 2003). The standard scenario for the production of jets (e.g. Livio 1997) involves an accretion disc which is threaded by a vertical magnetic field and an energy/wind source associated with the central accreting object. A widespread presence of accretion discs and magnetic fields in symbiotic binaries is still a matter of debate. Convincing detection of a magnetic field in a symbiotic binary has so far been obtained only for Z And (Sokoloski & Bildsten 1999), in the form of a persistent ≤ 0.005 mag amplitude oscillation at 28-min period interpreted as the spin period of a magnetic WD. The detection was made possible by the outburst state of Z And at the time of

[★]Based in part on observations secured at the Observatoire de Haute-Provence within the OPTICON 2004 access programme.

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Table 1. The table collects existing and new multiband information on the photometric history of Hen 3-1341. Sources are as follows: *a* = DSS-1, DSS-2, GSC, Vehrenberg's photographic surveys remeasured by us; *b* = Asiago 67/92-cm Schmidt telescope archival plates; *c* = Allen (1982); *d* = Munari & Buson (1994); *e* = derived from covolution with band transmission profiles of the fluxed spectra in Gutiérrez-Moreno et al. (1997); *f* = similarly for Munari & Zwitter (2002) spectra; *g* = 2MASS; *h* = TMM; *i* = photometry with the USNO 1-m telescope; *l* = DENIS.

	<i>U</i>	<i>B</i>	<i>V</i>	<i>R_C</i>	<i>I_C</i>	<i>K</i>	<i>J-H</i>	<i>H-K</i>	Source
1954-04-26				10.8					<i>a</i>
1954-07-01		14.0							<i>a</i>
1969-07-14		13.3							<i>b</i>
1969-07-16		13.2							<i>b</i>
1970-04-06		14.0							<i>a</i>
1970-06-02		14.4			11.0				<i>b</i>
1970-07-01		13.8			10.9				<i>b</i>
~1981						7.58	0.98	0.34	<i>c</i>
1982-03-22		13.0							<i>a</i>
1987-06-29			12.5						<i>a</i>
1990-06-24	12.72	13.73	12.94	11.82	10.82				<i>d</i>
1990-03-16						7.66	1.06	0.31	<i>d</i>
1991-07-01	12.6	13.7	12.9	11.6	10.8				<i>e</i>
1992-03-09				11.7					<i>a</i>
1993-07-27		14.1	13.1	12.0					<i>f</i>
1996-06-16			12.7						<i>a</i>
1998-04-23						7.48	0.87	0.41	<i>g</i>
1999-06-08			10.5						<i>h</i>
2000-04-30	10.97	11.82	11.32	10.65	10.03				<i>i</i>
2000-05-02	11.00	11.91	11.36	10.74	10.07				<i>i</i>
2000-05-28	11.08	11.90	11.38	10.70	10.09				<i>i</i>
2000-10-10					10.11	7.50			<i>l</i>
2004-07-16	13.15	13.84	13.09	11.72	10.72				<i>i</i>
2004-08-04	13.22	13.91	13.14	11.74	10.74	7.56	0.94	0.36	<i>i</i>

the observations, which largely increased the optical brightness of the WD. Direct evidence for accretion discs is missing, given their low luminosity compared with the glare of the circumstellar nebular material and the brightness of the central star (especially if burning hydrogen at the surface). Indirect suggestions for the presence of discs are generally based on the interpretation of the flickering so far detected in ~ 20 per cent of surveyed symbiotic stars, e.g. CH Cyg (Sokoloski & Kenyon 2003), T CrB (Zamanov et al. 2004), MWC 560 (Tomov et al. 1995; Dobrzycka, Kenyon & Milone 1996), RS Oph and Mira A+B (Sokoloski, Bildsten & Ho 2001), and the appearance sometimes during outbursts of secondary periodicity (at $\sim 0.9 \times P_{\text{orb}}$) and light-curve shapes resembling the 'superhumps' found in cataclysmic variables (Mikolajewska et al. 2002).

In this paper we present direct evidence that, at least in the symbiotic binary Hen 3-1341, the spectroscopic appearance of bipolar jets is limited to the early and brightest outburst phases, and that the jets are fed by the wind from the outbursting component. When the wind quenches during the decline from outburst maximum, the jets also vanish, in a 1:1 correspondence.

2 CONDITIONS IN QUIESCENCE AND OUTBURST

When TMM discovered the jets in the summer of 1999 they found Hen 3-1341 at $V = 10.5$, much brighter than on the Palomar charts ($B = 14.0$), and concluded the system was undergoing an outburst. Not much else is known about the photometric and spectroscopic history of Hen 3-1341 or the reality and characteristics of the outburst itself. A proper investigation is mandatory for the obvious implications on the nature and evolution of the jets.

With the aim of recovering the photometric history of Hen 3-1341, (i) we have obtained $UBV(RI)_C$ JHK photometry of Hen

3-1341 with the United States Naval Observatory (USNO) 1.0-m and 1.5-m telescopes, (ii) we have measured the brightness on photographic plates found in the Asiago 67/92 Schmidt archive and on plates of the DSS-1, DSS-2, GSC and Vehrenberg's photographic surveys, and (iii) we have derived $UBV(RI)_C$ magnitudes from published optical spectra calibrated into absolute fluxes. These data are given in Table 1 together with values from the Two-Micron All-Sky Survey (2MASS) and the Deep Near-Infrared Southern Sky Survey (DENIS), and $UBV(RI)_C$ JHK from the symbiotic star photometric catalogues of Allen (1982) and Munari et al. (1992). These are plotted in Fig. 1, together with amateur estimates kindly provided by Albert Jones (New Zealand) and the Variable Star Network

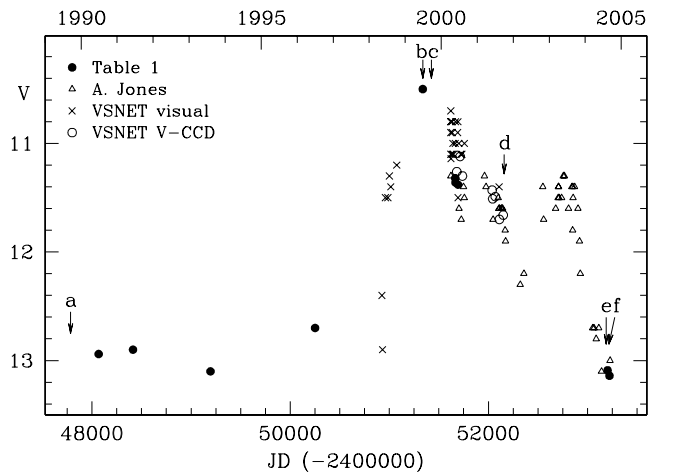


Figure 1. The V-band light curve of Hen 3-1341 over the last 15 yr showing the 1998–2004 outburst. The arrows point to the epochs of the spectra in Fig. 3.

The 6×10^{44} erg radiated during the outburst instead corresponds to the nuclear burning of $\sim 5 \times 10^{-8} M_{\odot}$ of hydrogen, at an average rate of $\sim 1 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$ or $\sim 1 \times 10^3 L_{\odot}$. This corresponds to about $\sim 1/4$ of the luminosity in quiescence. This suggests that the 1998–2004 event, which we previously called an ‘outburst’, was actually a partial reprocessing into the optical of the radiation flowing into the far-ultraviolet during ‘quiescence’. In fact, strong hydrogen and He I emission lines remained always visible, in spite of a recombination time of the order of $t_{\text{rec}} \sim 1/(n_s \alpha_B) \sim 2$ months, even at the outer boundary of the ionized gas region, indicating that not all ultraviolet radiation was suppressed. The reprocessing took place in the envelope of the WD that expanded and cooled to $T_{\text{eff}} \sim 1 \times 10^4$ K and $R \sim 20 R_{\odot}$. The width of the stable H-burning strip in the $M_{\text{WD}}, \dot{M}_{\text{acc,WD}}$ plane is a narrow one, and minimal increases in $\dot{M}_{\text{acc,WD}}$ triggers an expansion and consequent cooling of the WD envelope (see Iben 2003). We are therefore led to interpret the 1998–2004 ‘outburst’ as having been caused by a temporary (and marginal) increase in the mass loss from the M2 III that gave no appreciable signal in the infrared photometry of Table 1 but caused $\dot{M}_{\text{acc,WD}}$ to rise above the narrow equilibrium strip. The surplus accreted material was partially burned and partially carried away by the fast wind traced by the P Cyg profiles of He I lines in Fig. 3. When the WD envelope mass returned to the equilibrium value, the envelope retraced to small radius and high temperature and Hen 3-1341 resumed the photometric and spectroscopic ‘quiescent’ appearance.

3 EVOLUTION OF THE JETS AND THEIR FEEDING MECHANISM

Following the discovery of bipolar jets by TMM in 1999 June, we reobserved Hen 3-1341 at high spectral resolution at later dates. The results for H α and He I 5876-Å profiles are shown in Fig. 3 together

with the original TMM discovery spectrum and a pre-outburst spectrum obtained at the European Southern Observatory (ESO) by van Winckel, Duerbeck & Schwarz (1993). From Fig. 3 it is evident how the blueshifted and redshifted emission components due to the bipolar jets were absent in the quiescence before as well as after the outburst, and were strongest at peak outburst optical brightness, declining in strength with the outburst retracing from maximum. It is worth noticing the similarity between the terminal wind velocity ($\sim 770 \text{ km s}^{-1}$) and jet projected velocity ($|\Delta R V_{\odot}| \sim 820 \text{ km s}^{-1}$) at the time of onset of the jets (1999 June), which is best appreciated in the left insert of the bottom panel of fig. 1 of TMM. A most interesting comparison is between the strength of optical jet lines and the amount of mass loss by wind from the WD as traced by the P Cyg profiles of He I lines in Fig. 3. The correlation is a very tight one. The jets were most prominent when the wind was strongest, and declined in parallel with the decrease of wind intensity. To our knowledge, this evidence is among the most direct and convincing proof of the ‘energy/wind source associated with the central accreting object’ postulated by the Livio (1997) mechanism of jet production. Given the association between jet appearance and outburst states also for other objects (e.g. CH Cyg, Z And, StH α -190 and MWC 560), the symbiotic stars as a class support the energy/wind source hypothesis. We suggest that the spectroscopic search for jets in symbiotic stars could pay higher dividends if focused on the outburst phases characterized by maximum wind intensity.

From the integrated flux of the jet features in the H α spectrum at outburst maximum in Fig. 3 (1999 June 8), and assuming that all the hydrogen within the jets is ionized and that the jets are optically thin in H α , a total mass in the jets of $M_{\text{jet}} \sim 2.5 \times 10^{-7} M_{\odot}$ is derived. This amount would rise in the presence of neutral gas or optically thick conditions. The kinetic energy deposited in the jets corresponding to the observed 820 km s^{-1} projected velocity is therefore $E_{\text{jet}}^{\text{kin}} \sim 1.7 \times 10^{42} (\sin i)^{-1} \text{ erg}$, where i is the unknown

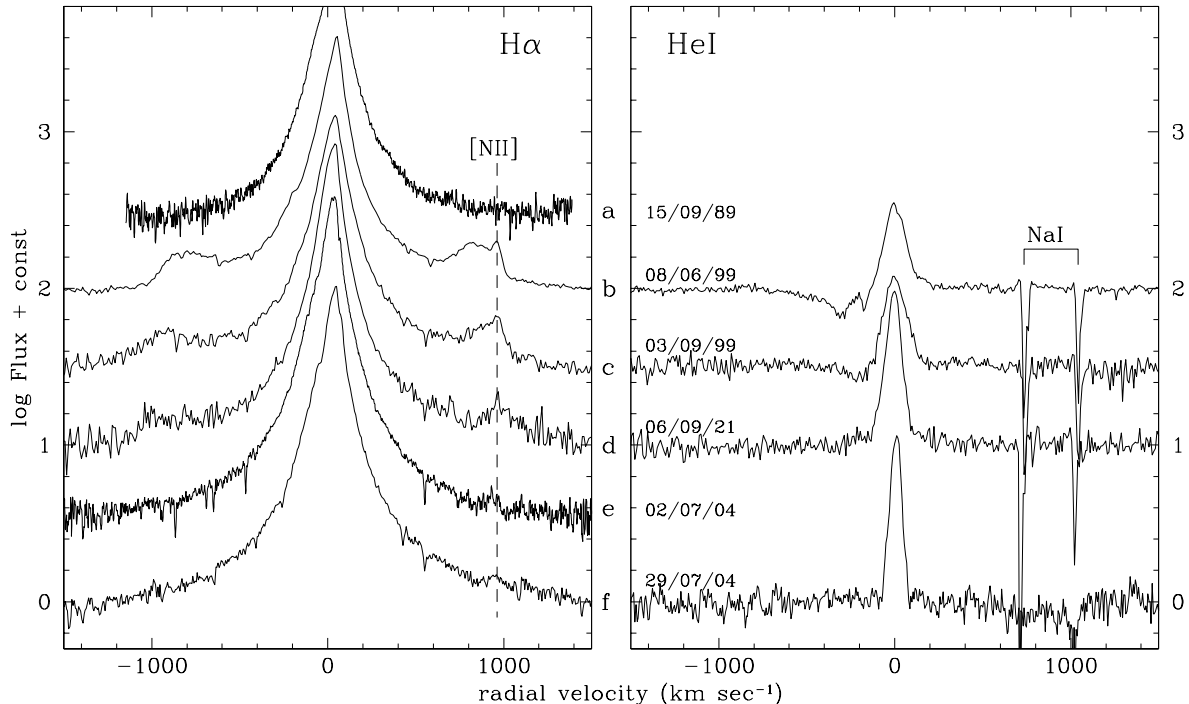


Figure 3. Evolution of H α and He I 5876-Å profiles between 1989 and 2004. The profiles are plotted on a logarithmic flux scale to emphasize visibility of the jets in H α and the wind absorption signatures in He I. (a) From van Winckel et al. (1993); (b), (c), (d), (f) Echelle spectrograph at the Asiago 1.82-m telescope; (e) ELODIE spectrograph at the OHP 1.93-m telescope.

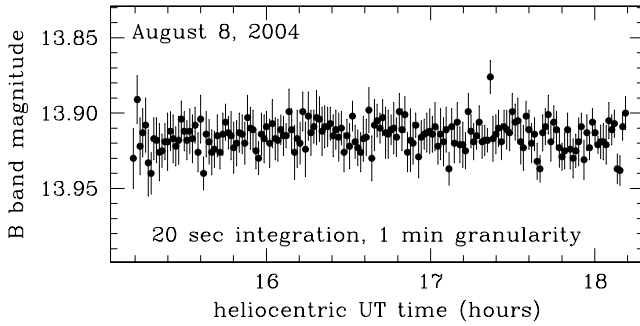


Figure 4. Time-resolved monitoring of Hen 3-1341 in the *B* band on 2004 August 8 with the USNO 1-m telescope, looking for flickering and signature of rotation of a magnetic WD.

orbital inclination. This corresponds to $\sim 0.3(\sin i)^{-1}$ per cent of the total energy radiated during the outburst.

Fig. 3 suggests a small increase with time in the observed velocity separation of the jets, amounting to $|\Delta R V_{\odot}| \sim 820 \text{ km s}^{-1}$ in 1999 June, 910 km s^{-1} in 1999 September and 1000 km s^{-1} in 2001 September. Different explanations could be invoked – including a variable projection angle of the jet axis on the line of sight as caused by a precession motion – but there are not enough data to decide in favour of any of them.

Finally, we have also searched for a signature of rotation of a magnetic WD in Hen 3-1341 by looking for coherent modulation in time-resolved *B*-band photometry that we secured in 2004 with the USNO 1.0-m telescope (see Fig. 4). None was found with an amplitude in excess of 0.004 mag, but this was an expected result, because with the system in quiescence the circumstellar nebular emission is enormously brighter than the WD in the *B* band. A more profitable search will have to wait for the next outburst state of Hen 3-1341.

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