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Long term spectral variability of Hen 3-640 (A1118-61)

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Abstract. We present spectroscopic observations of the peculiar emission line star Hen 3-640, the optical counterpart of the hard X-ray source A 1118-61, from 1985 to 1997. Our data confirm strong spectral variability (both on long and short time scales) of the star and the correlation between the hard X-ray flux and the Hα equivalent width. We also found a significant Hα/Hβ flux ratio variability during the last 12 years and a clear evidence of a general decrease of the ionization level after the 1992 outburst. The derived scenario is that of a large extended envelope surrounding Hen 3-640, expanding because of processes intrinsic to the optical star; when the density around the compact object reaches a value large enough to generate a steady accretion disk around the A1118-61 pulsar, the mass transfer efficiency and thus the X-ray flux sharply increases. Our scenario does not foreseen any exact periodicity in the X-ray outbursts of the systems.

Key words: X-rays: stars – stars: individual: Hen 3-640 (A1118-61) – stars: emission-line, Be

1. Introduction

The A1118-61 hard X-ray transient underwent a major outburst only twice: in 1974, when it was discovered by Ariel-5 satellite, and from December 1991 to February 1992 (Bildsten et al., 1997; for a detailed discussion of the system, see also Coe et al., 1994). The peculiar star Hen 3-640 (V=12.1, spectral type O9.5 IVe), optical counterpart of A1118-61 (Chevalier & Ilovaisky, 1975; Motch et al., 1988) has been found to show long term minor photometric (0.1 mag; Wray, 1966) and spectral variability (Motch et al., 1988). Previous spectroscopic studies (Villada et al., 1992; Polcaro et al., 1993; Coe et al., 1994) have demonstrated also the presence of strong spectral variability in Balmer line equivalent width on a short time scale (of order of a few hours): this behaviour has been suggested as due to the presence of the compact companion of Hen 3-640, the 405 s pulsar A1118-61.

The physical mechanism producing the X-ray outbursts in binary systems is the sudden increase of the mass accretion on the neutron star, that can be due to an activity enhancement of the primary emission line star. Other possibilities are that, close to the periastron passage, gravitational effects can trigger the release of blobs of material from the optical star or the neutron star can cross the equatorial disk of the B star as demonstrated in the case of A0535+26/HDE245790 (e.g. Giovannelli & Sabau-Graziati, 1992). A combination of these effects is also possible. Indeed Hen 3-640 very probably usually does not fill up its Roche lobe and the Hen 3-640/A1118-61 system has probably a long orbital period (Motch et al., 1988; Lund et al., 1992) and the reason of the X-ray outbursts generation is still unclear. Actually, the intriguing spectra recorded after the January 1992 outburst show that the system underwent a very complex event (Coe et al., 1994 and references therein).

Hen 3-640 has been repetitively observed within the framework of the collaborative program between the Observatorio de la Universidad de Cordoba and the Istituto di Astrofisica Spaziale (CNR) devoted to the monitoring of the optical counterparts of hard X-ray transients.

The 1990, 1992 and 1993 observations have been previously discussed in details (Villada et al., 1992; Polcaro et al., 1993; Coe et al., 1994; Giovannelli et al., 1994a); we present here the scenario that we derive from our 12-year observation campaign.

2. Observations and data analysis

Our group first observed Hen 3-640 in March and July 1985, at ESO La Silla with the 1.52m telescope equipped with the B&C spectrometer and IDS detector, using a 4 arcsec slit; the seeing was always better than 2 arcsec. The data were reduced at ESO (Garching), using *IHAP*. Then, a long term monitoring started in February 1990 (and it is still in progress) at the CASLEO (Argentina) 2.15 m telescope. This telescope was equipped up to 1993 with a B&C spectrograph; an Intensified Photon-Counting Reticon ("Z-machine"; Tonry & Davis, 1979; Da Costa et al., 1984) was used as detector. The instrumental configuration and the related data reduction process were described in Villada et al., (1992). Since 1994 the telescope was equipped with a REOSC echelle spectrogaph on loan from the Institute d' Astrophysique de Liege and a TEX 1024 CCD detector. During our observations, the seeing was always better than the slit size (3 arcsec or 5 arcsec, depending from the seeing conditions).The

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Table 1. Hen 3-640: log of the observations discussed in this paper.

date (dd.mm.yy)	Range (Å)	Exp. time (min)	Resolution (Å FWHM)
15-03-85	4765-7100	10	5.3
16-03-85	4000-5100	20	2.0
17-03-85	4250-8900	6	10.5
09-07-85	4600-7000	20	5.3
10-07-85	4250-8900	15	10.5
11-07-85	4250-8900	15	10.5
04-03-94	3500-6000	20	5.1
05-03-94	6000-9000	10	7.3
20-03-95	3500-6000	30	5.1
21-03-95	6000-9000	15	7.3
10-03-96	3500-6000	30	5.1
11-03-96	6000-9000	30	5.1
22-02-97	6000-9000	30	7.3
24-02-97	3500-6000	45	5.1

data were reduced at the Observatorio de la Universidad de Cordoba and at the Istituto di Astronomia of the Rome University *"La Sapienza"*, using standard *IRAF* procedures. Table 1 gives the log of the observations discussed in this paper.

3. Results

Tables 2 and 3 report the Balmer lines parameters measured on our spectra from 1985 to 1997. The statistical uncertainties on the lines equivalent widths are evaluated following Chalabaev & Maillard (1983). We are confident about the measured flux values since the flux integral over the V filter band gives a value V=12.1 in the 1985 spectra that is in agreement with the V magnitude reported in literature. To our knowledge, no V photometry is available in other epochs. In any case all our spectra taken from 1994 to 1997 give V values between 12.2 and 12.3. These variation in magnitude with respect to the 1985 value are compatible with the classical behaviour of Be stars (e.g. Piccioni et al., 1985). Fig. 1 shows the Hα equivalent width (EW) from 1979 to 1997; in addition to our data, the whole set of observations reported by Coe et al. (1994) is also shown.

We can see that the Hα EW is of order of 50–60 Å when the system is in a quiescent state, while it rose to EW$\geq$100 Å during the outburst. However, the figure shows also that the enhancement of Hα EW is consistent with a gradual rise, while a sharp decrease followed the 1991–1992 outburst. At the same time, minor, but statistically significant short term variability is evident in all epochs. A similar behaviour is seen in Hβ.

In 1985, Hα/Hβ flux ratio was $\simeq$6.0 (after dereddenning with E$_{(B-V)}$=1.2), while EW$_{H\alpha}$/EW$_{H\beta}$ $\simeq$7. After the outburst, we can evaluate an approximate Hα/Hβ flux ratio $\simeq$3 in 1994 and 1995 and $\simeq$5 in 1996 and 1997, while the EW$_{H\alpha}$/EW$_{H\beta}$ is always $\simeq$10, which is roughly in agreement with the 1985 value and also in agreement with the ratios found in in other Be/X systems (e.g. Giovannelli & Sabau-Graziati, 1992).

Higher lines of the Balmer series are more difficult to measure because of the uncertainties on the continuum, that is strongly affected by a crowd of metal lines. However, Tables 2 and 3 clearly demonstrate a significant variability in all the measured Balmer lines.

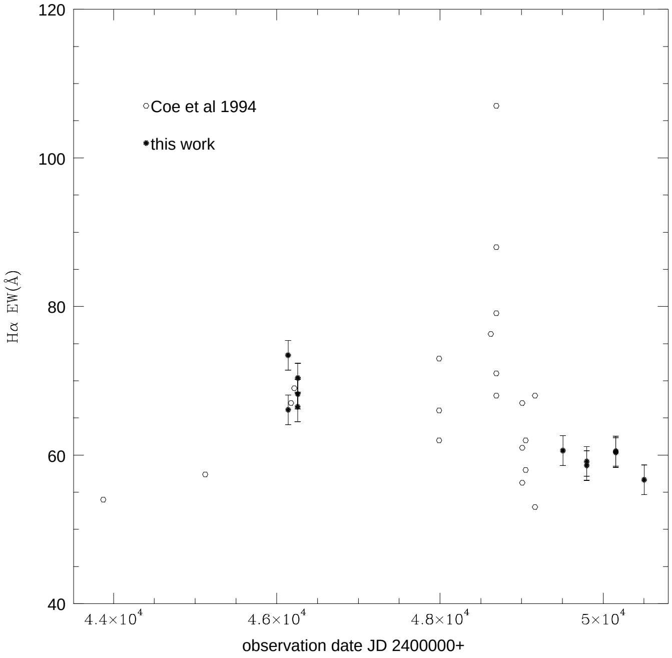

Fig. 1. Hen 3-640 Hα equivalent width from 1979 to 1997; in addition to our data, the whole set of observations reported by Coe et al. (1994) is also shown.

Table 2. Hen 3-640 - Hα and Hβ parameters. Fluxes and their errors are in erg s^{-1} cm^{-2}

Date (dd-mm-yy)	EW (Å)	σ_{EW} (Å)	flux 10^{-11}	σ_{flux} 10^{-11}
Hα				
15-Mar-85	66	2.0	8.1	0.1
17-Mar-85	74	2.0	7.3	0.1
09-Jul-85	68	2.0	6.8	0.1
10-Jul-85	70	2.0	7.0	0.1
11-Jul-85	72	2.0	6.8	0.1
05-Mar-94	61	1.5	5.0	0.1
21-Mar-95	59	1.5	5.2	0.1
11-Mar-96	60	1.5	5.8	0.1
22-Feb-97	57	1.5	5.4	0.1
Hβ				
15-Mar-85	5.1	1.5	1.4	0.2
16-Mar-85	6.3	1.5	1.3	0.2
09-Jul-85	5.1	1.5	1.0	0.2
10-Jul-85	4.7	1.5	0.9	0.1
11-Jul-85	5.3	1.5	1.0	0.2
04-Mar-94	7.1	1.0	1.6	0.1
20-Mar-95	6.6	1.0	1.8	0.1
10-Mar-96	6.0	1.0	1.2	0.1
24-Feb-97	5.5	1.0	1.1	0.1

Table 3. Hen 3-640 - H γ and H δ parameters. Fluxes and their errors are in erg s^{-1} cm^{-2}

Date (dd-mm-yy)	EW (Å)	σ_{EW} (Å)	flux 10^{-11}	σ_{flux} 10^{-11}
Hγ				
a) emission				
15-Mar-85	1.3	0.3	1.4	0.42
16-Mar-85	1.5	0.3	1.3	0.42
10-Jul-85	1.2	0.5	0.9	0.30
11-Jul-85	0.0	0.5	1.0	0.42
04-Mar-94	0.8	0.2	0.3	0.01
20-Mar-95	0.9	1.0	0.5	0.01
20-Mar-95	1.3	0.2	0.7	0.01
10-Mar-96	0.8	0.2	0.3	0.01
24-Feb-97	0.5	0.2	0.2	0.01
b) absorption				
04-Mar-94	0.3	0.2	-0.13	0.01
20-Mar-95	0.1	0.2	-0.08	0.01
20-Mar-95	0.3	0.2	-0.19	0.01
10-Mar-96	0.3	0.2	-0.10	0.01
24-Feb-97	0.2	0.2	-0.09	0.01
Hδ				
a) emission				
04-Mar-94	0.4	0.2	0.11	0.01
20-Mar-95	0.5	0.2	0.40	0.01
10-Mar-96	0.0	0.2	0.0	0.01
24-Feb-97	0.1	0.2	0.05	0.01
b) absorption				
04-Mar-94	1.6	0.2	-0.91	0.01
20-Mar-95	1.3	0.2	-1.2	0.01
10-Mar-96	0.9	0.2	-0.44	0.01
24-Feb-97	0.7	0.2	-0.30	0.01

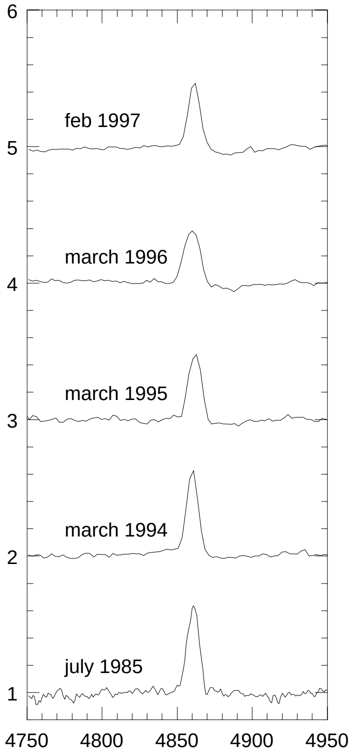

Fig. 2. Detail of the Hβ region of the averaged spectrum of Hen 3-640 at different epoch. The spectra are rectified and vertically shifted for clarity.

We discussed elsewhere (Villada et al., 1992; Polcaro et al., 1993; Coe et al., 1994 and refereneces therein) the Hα and Hβ profiles during and immediately after the 1991-1992 X-ray outburst. The following year's spectra never showed the line splitting that was present during the outburst. However, Hβ is always asymmetric, suggesting that a double component is still present, albeit at a velocity separation which is now lower than our spectral resolving power. A similar asymmetry was also present in 1985 spectra (see Fig. 2).

The post-outburst spectra of Hen 3-640 (Figs. 3 and 4) show the general decrease of the ionization level: the He II 4686 line, that was clearly visible from 1990 to 1992 (see Fig. 1 in Villada et al., 1992, is undetectable. The He I 4471 line, that presented in 1992 a narrow but evident re-emission peak (see Fig. 3 in Polcaro et al., 1993), is now always in absorption.

The Fe II emissions disappeared, while the Fe I lines are usually quite strong. In 1996, two strong emission lines, that were never previously detected, appeared at 5569 and 5580 Å: we tentatively identified these lines as blends Fe I 5569.6,5572.1 and Ti I 5579.0,5583.0. The two lines are clearly visible in the 1997 spectrum shown in Fig. 4 and are clearly separated from the 5577 Å night-sky feature, that is completely removed by the sky subtraction procedure (as well as all the other sky lines).

4. Discussion

Despite the large observational efforts made during last years and mainly after the 1991–1992 outburst, the Hen 3-640/A1118-61 system is still poorly understood.

Actually, the orbital period of the system is unknown. Corbet's pulse period/orbital period diagram (Corbet, 1986) gives an orbital period estimate of ∼350 days.

Recently, Reig et al. (1997) have found another correlation between the orbital period of Be/X-ray binaries and the Hα EW of the optical companion. However in their diagram, the representative point of A1118-61 (assuming the period deduced from the P_{spin}-P_{orb} diagram and the maximum Hα EW) lies definitely out of the best fit of the other points. On the contrary, if we consider the average Hα EW (∼70 Å), A1118-61 could have an orbital period of ∼350 days, in agreement with the Corbet's diagram. If the maximum measured value of the Hα EW (∼107 Å) is used, the A1118-61 orbital period deduced by the Reig et al. (1997) relationship is ∼585 days.

However, none of these periodicities is clearly present both in the X-ray and the Hα EW time history, that are now relatively well known due to the CGRO-BATSE X-ray monitoring (Bildsten et al., 1997) and our long term optical survey. On the other hand, our data seem to confirm the correlation between the

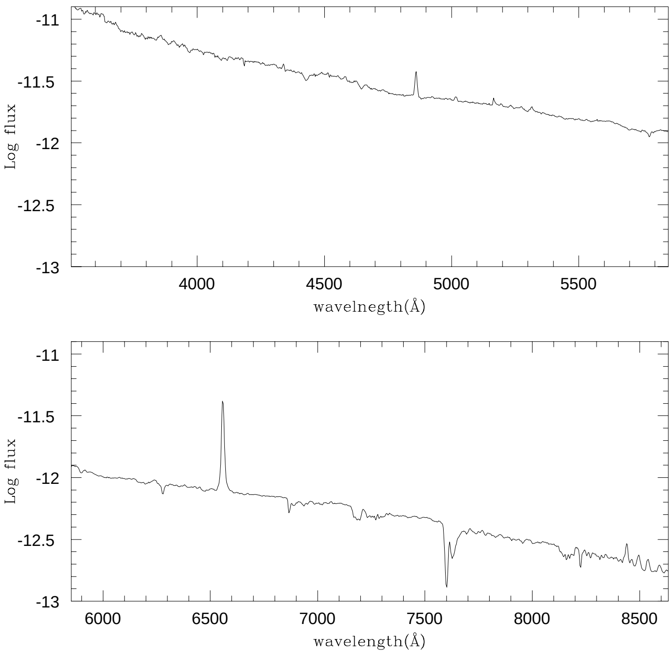

Fig. 3. Combined flux calibrated spectrum of Hen 3-640 on 5/6 March 1994; the spectra are dereddened with $E_{(B-V)}$=1.2. Flux is in erg s^{-1} cm^{-2} $Å^{-1}$.

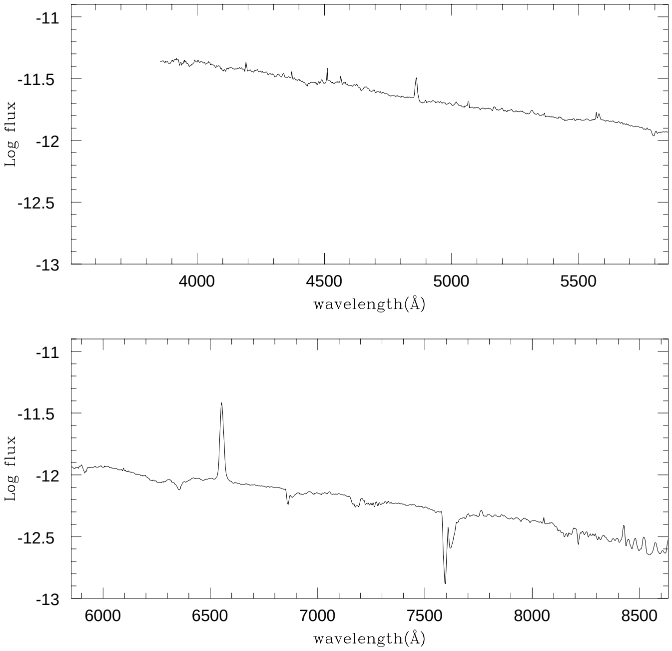

Fig. 4. Combined flux calibrated spectrum of Hen 3-640 on 23/25 February 1997; the spectra are dereddened with $E_{(B-V)}$=1.2. Flux is in erg s^{-1} cm^{-2} $Å^{-1}$.

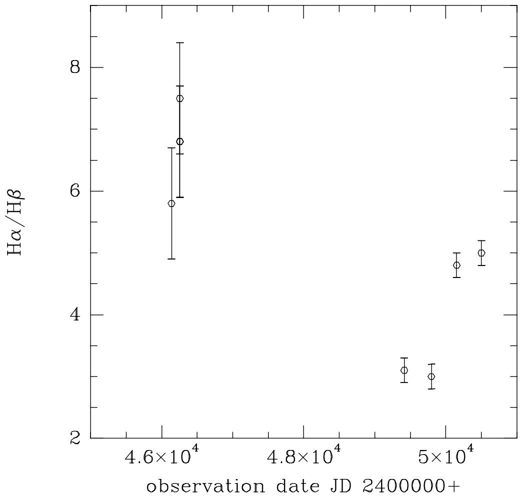

Fig. 5. The Hα/Hβ flux ratio of Hen 3-640 from 1985 to 1997.

hard X-ray flux and the Hα EW, suggested by Coe et al. (1994). However, the long time interval ($\sim$ 16 years) between the two recorded outbursts of A1118-61 suggests that the neutron star is usually weakly interacting with Hen 3-640. Thus, apart from the outburst phase, the long term spectral variability of the optical star is most probably intrinsic and not connected with the presence of the compact companion. Motch et al. (1988) and Coe et al. (1994) already suggested that the neutron star is orbiting just at the boundary of a large extended envelope surrounding Hen 3-640 and is continuously accreting matter at low rate from this environment.

The long term Hα EW variability is compatible with a smooth rise of the star activity from a quiescent state to the outburst, while the post-outburst data demonstrate a short timescale passage to the quiescent state. The Hα increase can be due either to increasing UV radiation flux of Hen 3-640 or to higher UV absorption efficiency in a larger envelope surrounding the optical star. In the framework of the experimental evidence discussed in this paper, the second mechanism seems the most probable. Actually, the variability of the amount of circumstellar matter is suggested by the dectected variability of the Hα/Hβ flux ratio (see Fig. 5): the 1985 value ($\simeq$6) indicates a strong residual circumstellar extinction, while the post-outburst value ($\simeq$3) is compatible, inside the uncertainties, with a standard “case A” nebular emission, indicating that we are looking the star only through the interstellar matter. The 1997 value ($\simeq$5) shows that the circumstellar extinction is again increasing.

Many mechanisms of matter accumulation around Be stars have been proposed in the past in order to explain the secular variability of the emission line fluxes (see, e.g., Underhill & Doazan, 1982; Slettebak et al., 1992, and references therein). Recently, Marlborough (1997) has suggested that a non-linear amplification of non-radial pulsation should occur in Be stars, resulting in the ejection of a significant amount of matter in the line of sight. On the other hand, Kakouris & Moussas (1998) have studied a physical mechanism which is able to generate in a short time a steady-state shell around hot stars.

Whatever the process of matter accumulation around Hen 3-640 may be, the compact object is orbiting in an increasing density environment and the X-ray flux gradually increases due to the higher mass transfer rate. But, when density around the compact object reaches a value high enough to generate a steady accretion disk, the X-ray flux sharply increases. This higher energy input should be able to transfer to the circumstellar envelope an energy equal to the gravitational binding energy, and all the matter is swept out in a very short time. Actually, our data taken immediately after the outburst shown the presence of a significant matter flux leaving the system at high velocity (Villada et al., 1992; Polcaro et al., 1993).

If this scenario is proven true, we cannot expect a real periodicity in the X-ray outburst, that will be not linked in any way to the system orbital parameters. We can thus foresee that the next outburst will happen after an interval connected to the matter accumulation time-scale: a 16 year interval between the two recorded outbursts is fully compatible with this hypothesis. If this scenario is valid, it is not surprising that the periodicity deduced from the pulse-period/orbital-period relationship has not been detected. Actually, we cannot obtain information about the orbital period from Corbet's diagram, when the outburst mechanism is not connected with the periastron passage of the compact object.

Therefore we could have recognized a new sub-class of *"atypical"* X-ray/Be systems in which X-ray outbursts are not triggered by periastron passage mechanism like for instance in the so-called *"typical"* X-ray/Be system (A0535+26/HDE245770-like). One possibility of the formation of "atypical" or "typical" X-ray/Be systems could be related to the explosion of a supernova in a progenitor medium-mass (10-20 $M_\odot$) early type binary system: the "atypical" X-ray/Be system would be the remnant of a symmetric SN explosion (low eccentricity: $e \leq 0.3$); the "typical" X-ray/Be system would be the remnant of an asymmetric SN explosion ($0.3 \leq e \leq 0.8$). The possibility of such events has been discussed and demonstrated by Giovannelli et al. (1994b; 1996) and in references therein.

Of course, the lack of continous monitoring before of the 1991-1992 outburst does not allow us to completely rule out the possibility that the Hen 3-640/A1118-61 system has a very long orbital period. However, such a period will not satisfy Corbet's relationship.

The final answer will come only after a long monitoring of this interesting system: we suggest that the next X-ray outburst of A1118-61 will start when the Hen 3-640 Hα EW will reach again values $\simeq$100 Å.

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