Research Note

Time-resolved spectroscopy
of the peculiar Hα variable Be star HD 76534

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Abstract. We present time-resolved spectroscopy of the Be star HD 76534, which was observed to have an Hα outburst in 1995, when the line went from photospheric absorption to emission at a level of more than two times the continuum within 2.5 hours. To investigate the short-term behaviour of the spectrum of HD 76534 we have obtained 30 spectra within two hours real-time and searched for variations in the spectrum. Within the levels of statistical significance, no variability was found. Rather than periodic on short time scales, the Hα behaviour seems to be commonly episodic on longer ($>$ 1 year) time scales, as an assessment of the existing data on the Hα line and the Hipparcos photometry suggests. HD 76534 underwent only 1 photometric outburst in the 3 year span that the star was monitored by the Hipparcos satellite.

Key words: stars: activity – stars: circumstellar matter – stars: emission-line, Be – stars: individual: HD 76534 – stars: mass-loss – stars: variables: general

1. Introduction

In a previous paper we reported on the discovery of an Hα burst in the B emission line star HD 76534 (Oudmaijer & Drew, 1997). During an observing run in 1995, two days after a strong Hα emission line was observed, the star was re-observed, and found to have only a photospheric absorption line. Spectacularly, two hours later, the line was again in emission, still increasing its strength with respect to the continuum.

Especially marked spectral variations have been detected in a few other Be stars, notably μ Cen (Peters, 1986; Hanuschik et al. 1993, Rivinius et al. 1998) and λ Eri (Smith et al. 1991, Smith et al. 1997a+b). These two stars have long periods with relatively stable Hα emission, and sometimes undergo an Hα outburst where the emission grows to a maximum within days, displaying rapid variations of the violet and red peaks of the Hα line. The emission then fades on longer timescales.

In contrast to both μ Cen and λ Eri, the observed timescale of the Hα outburst of HD 76534 was an order of magnitude shorter,

while the line profile did not show any V/R variability. Instead, the line that was present only two hours after the absorption was observed, was similar in profile and V/R ratio to existing high resolution Hα spectra of the object, and did not betray any signs of on-going formation of recently ejected disk material.

Two hypotheses were put forward by us to explain the rapid variations. In analogy with the hypothesis for μ Cen, a sudden burst of mass loss was first considered (see Hanuschik et al. 1993, Rivinius et al. 1998), but based on the above arguments it was discarded in favour of the idea that a stable rotating Keplerian disk was already present around the star, but that a lack of ionizing photons from, for example, the stellar photosphere failed to produce sufficient ionizations and subsequent recombinations to push the Hα line into emission. From simple considerations, it was found that a slight change in ionizing flux can indeed ionize an existing stable neutral disk, and result in detectable Hα emission.

It is not clear however where the change in ionizing radiation should come from. By analogy with the EUV variations of the β Cep star β CMa (Cassinelli et al. 1996), it is possible that stellar pulsations are responsible for this behaviour. β CMa shows relatively large (30%) variations in its Lyman continuum, which are not as readily visible in the optical (Cassinelli et al. 1996). A similar effect could be happening in the case of HD 76534; at the times when the Lyman continuum is at minimum, no Hα emission is visible, while at maximum the line will develop. A critical test of the stellar pulsation hypothesis would be to monitor the star for several hours up to several days to investigate whether any periodicity would be present in the Hα emission of the object.

On the other hand, Smith et al. (1997b) reaches a similar conclusion to explain, amongst other phenomena, the Hα variations in λ Eri. A source of extra Lyman continuum photons could be responsible for extra ionizations and recombinations in the circumstellar material. Smith et al. (1997b) find that this can be explained by the occurrence of heated slabs, possibly related to magnetic activity, close to the stellar photosphere. This activity does not appear regularly, so no apparent periodicity in the Hα line, certainly not on timescales of hours, would be expected.

Table 1. Log of the observations

UT start	t_{exp} (s)	SNR	Zenith Distance (°)
09:03:19	60	60	39
09:05:35	60	58	39
09:07:51	60	77	39
09:10:07	60	73	40
09:12:24	60	68	40
09:14:50	150	84	40
09:18:36	150	79	41
09:22:23	150	96	42
09:26:09	150	117	43
09:29:55	150	114	43
09:34:05	240	144	44
09:39:21	240	138	45
09:44:37	240	140	46
09:49:54	240	119	47
09:55:10	240	109	48
10:02:40	60	56	49
10:04:56	60	56	50
10:07:12	60	65	50
10:09:28	60	61	51
10:11:45	60	71	51
10:14:09	150	86	52
10:17:55	150	100	53
10:21:41	150	124	53
10:25:27	150	89	54
10:29:13	150	102	55
10:33:04	240	87	56
10:38:21	240	117	56
10:43:37	240	93	57
10:48:53	240	77	58
10:54:09	240	84	59

SNR measured in the range 6537–6542 Å

Previous to Oudmaijer & Drew (1997), observations of the Hα line of HD 76534 were reported only twice, by Thé et al. (1985) and Praderie et al. (1991). Their spectra were taken one year apart, and showed 'indistinguishable' (cf. Praderie et al. 1991) line profiles. We measure an equivalent width (EW) from Thé et al. of –7 Å. The exposure times used by these authors were 2 and 2.5 hours respectively, so that any shorter term variations in either the line profile or EW would have been washed out.

Since our previous paper, several new datasets on HD 76534 have been published. Recently, Corcoran & Ray (1998), report a measurement of the EW of the Hα of –14.3 Å, on a spectrum that was obtained in the last week of 1991 (their only Southern observing run) and Reipurth et al. (1996) show a spectrum, obtained in February 1993, with an EW of –10 Å. These two papers do not mention the exposure times. Oudmaijer & Drew (1999) report on observations taken in December 1995 and December 1996 and found an EW of –6 Å and –4 Å respectively (we note a typographical error in their Table 2, the data for 30 December 1996 and December 1995 should be interchanged). It is clear that the Hα line of HD 76534 is variable on long timescales.

The main aim of this paper is to present time-resolved observations of the object at high resolution as a first step in determining whether Hα is prone to any variations on timescales of minutes. The observations thus serve as a check whether the long integration times by Praderie et al. (1991) and Thé et al. (1985) would indeed have washed out any short-term variations.

This *Research Note* is organized as follows: In Sect. 2 we present the time-resolved observations of the object obtained with the UCLES spectrograph on the AAT. In Sect. 3 we will search for variations in the data and revisit the multi-epoch *V* band photometry obtained by Hipparcos. We will conclude in Sect. 4.

2. The observations

During the night of 7 June 1996 (UT), HD 76534 was observed in service time, employing the UCLES spectrograph mounted on the 3.9 m Anglo-Australian Telescope. The observational set-up included the 31 grooves/mm echelle and a 1024×1024 Tektronix CCD detector. The resulting spectrum contains 44 orders covering the spectral coverage of 4650 to 7240 Å, including both Hα and Hβ. The observing strategy was fairly straightforward, we aimed to obtain spectra every few minutes, and employed different exposure times in order to compromise between time-resolution and signal-to-noise. Within a time span of two hours, we obtained 30 spectra with signal-to-noise ratios (SNR) in the Hα setting ranging from ∼ 60 in the shortest (60 s) exposures to ∼ 140 in the longest (240 s) exposures. The observing conditions were not ideal, so the total count-rates and SNR are slightly variable.

Data reduction was performed in IRAF (Tody, 1993), and included the procedures of bias-subtraction, flatfielding and wavelength calibration. An observation of a Th-Ar arc lamp was used to provide the wavelength calibration of each spectrum. The resulting spectral resolution was determined to be ∼ 10 km s^{-1} from Gaussian fits through telluric absorption lines.

In total 30 spectra with different exposure times were taken. The summed total spectrum, with a total exposure time of 4500 s has a SNR of ∼200 in the Hβ order and ∼300 in the Hα order. The log of the observations and the SNR in the Hα order are provided in Table 1.

3. Results

3.1. Short description of the spectrum

Apart from the strong Hα emission (EW = –8 Å) and the filled-in Hβ absorption, no apparent emission lines are found. Strong HeI lines at 4921, 5047, 5876 and 6678 Å show absorption and allow for a determination of the stellar velocity, which is found to be 14 ± 3 km s^{-1} (heliocentric). This is consistent with other determinations (see Oudmaijer & Drew 1997). Within the observational error-bars, we do not find evidence for radial velocity variations.

The continuum corrected spectra around the Hα and Hβ lines are shown in Fig. 1. Hα is a strong doubly-peaked emission line, while the doubly-peaked Hβ emission hardly reaches
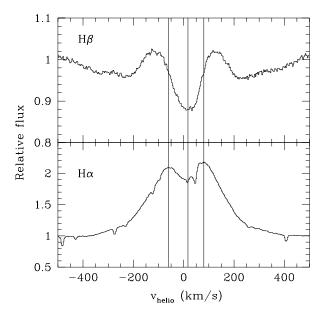
Fig. 1. The spectrum around Hα and Hβ. The vertical lines are drawn through the Hα peaks and the systemic velocity. The larger peak separation in Hβ suggests that the hydrogen recombination lines are formed in a rotating Keplerian type disk.

above the local continuum. The peak separation in the Hβ line is $242 \pm 5 \text{ km s}^{-1}$ which is almost twice as large as observed in the Hα line ($143 \pm 5 \text{ km s}^{-1}$). The larger peak separation in Hβ is consistent with the fact that both lines are formed in a rotating Keplerian type disk. If both lines, or Hα alone, are optically thick, the Hα forming region is larger than the Hβ forming region, and will thus trace lower rotational velocities.

3.2. Variability on short time scales

3.2.1. Method

Visual inspection of the 30 individual spectra did not reveal any obvious variability in the Hα line, so instead, we adopt the simple statistical formalism presented by Henrichs et al. (1994), and already exploited by Oudmaijer & Bakker (1994) for a similar experiment for the post-AGB star HD 56126. This method was devised by Henrichs et al. to spot the regions of interest in their multi-epoch data on hot stars. The variability can be expressed in a temporal variance spectrum (TVS):

$$(TVS)_\lambda \approx \frac{1}{N-1} \sum_{i=1}^{N} \left(\frac{F_i(\lambda) - F_{av}(\lambda)}{\sigma_i(\lambda)} \right)^2 \qquad (1)$$

where N is the number of spectra, $F_{av}(\lambda)$ represents the constructed average spectrum, $F_i(\lambda)$ the individual spectra, and $\sigma_i(\lambda) = F_i(\lambda)/(\text{SNR})$ of each individual pixel of the spectra.

Then, the so-called temporal sigma spectrum, TSS = $\sqrt{TVS}$), is calculated. This quantity represents approximately (σ_{obs}/σ_{av}). σ_{obs} traces the standard deviation of the variations of the individual spectra with respect to the average spectrum, while σ_{av} represents the standard deviation of the average spectrum. If no significant variations are present in the spectra, the
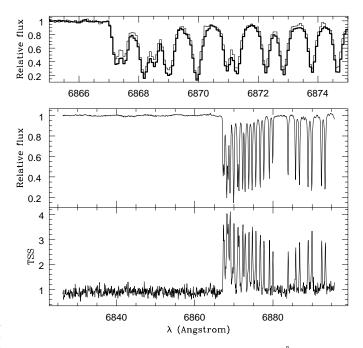

Fig. 2. The spectrum around the telluric lines at 6860 Å. The upper panel shows part of the spectrum, where the thick line represents the last spectrum taken and the thin line the first spectrum, obtained almost two hours earlier. It is clear that the telluric absorption has become stronger. The middle panel shows the total, continuum rectified, spectrum, and the lower panel presents the TSS. While the continuum does not show any significant variations, the changes in the telluric lines show up as strong peaks in the TSS.

ratio of these two numbers, σ_{obs}/σ_{av}, will be close to one, deviations are directly represented in units of the noise level, that is to say a peak 'Temporal Sigma Spectrum' of three corresponds to a variability at a 3σ level.

During the extraction process, IRAF provides a SNR spectrum based on the photon-statistics of the data. This is very convenient, as the SNR changes strongly over a given order because the blaze of the spectrograph results in lower count-rates and thus lower SNR at its edges, while, of course, the countrates and SNR also change across absorption and emission lines compared to the local continuum. As a check, we measured the SNR in several wavelength intervals. The IRAF-extracted SNR were scaled up by 40% to bring the measured and the IRAF SNR in agreement. In the remainder of this exercise, we will use these SNR spectra as input for Eq. 1.

The average spectrum was constructed by summing all individual spectra. After this, the spectra were continuum rectified as input for Eq. 1. In the case of the Hα line, the wavelength region used for the fit were the blue and red continua beyond 13 Å from the center of the line. The $\sigma(\lambda)$ spectrum was computed by dividing the individual continuum rectified spectra by their respective SNR spectra.

Fig. 2 shows an example of the usefulness of the method. In the middle panel the total spectrum in the order around the telluric absorption bands at ∼ 6870 Å are shown, the lower panel shows the derived TSS. The continuum shows a trend from TSS

~ 0.9 to ~ 1.1, indicating a slight variation in the continuum of the extracted spectrum. The telluric lines vary however at the 2–4σ level. This is due to the changing airmass during the observations: as the airmass increases from 1.30 (zenith distance $39°$) to 2.0 ($59°$) the telluric absorption becomes stronger. This is visible in the upper panel which shows an overplot of the first and last spectrum taken. The changes, which are only a few percent of the continuum level, are real.

The fact that a slight variability is traced in the continuum illustrates a very important caveat of the method. The TSS only depends on photon-statistics, and is insensitive to any systematic errors that may be present. In particular, a variable response curve ('blaze') of the echelle, can show up as variability, while in reality such variations are purely systematic rather than intrinsic. In the case of Fig. 2 this is not so important, as the entire order can be used for the continuum rectification, effectively removing this effect. In the case of Hα however, a large part of the spectrum can not be used for the continuum rectification as, of course, it is covered by the Hα line itself.

3.2.2. The Hα line

Fig. 3 shows the resulting TSS for the Hα order. The telluric lines show variability at the 2.5σ level. This is smaller than the variability observed for telluric lines in Fig. 2, but can be explained by the fact that these lines and their changes are weaker. It is nevertheless an important check to note that the method also works in the Hα order.

Hα itself hardly shows any variability. In fact, the most significant variability is due to the telluric absorption in the central minimum of the line. The low $<1.5\sigma$ variability observed across the line is statistically not significant. Nevertheless, we investigated the possible cause of these marginal variations. This was done bearing in mind the fact that a heavily rebinned spectrum has a much larger SNR, and thus any variations should show up with greater significance.

Unfortunately, the echelle orders' wavelength ranges are rather limited (about 67 Å or 3000 km s^{-1} in the Hα order) compared to the extent of the line itself (full-width at zero intensity ~ 1000 km s^{-1}). It is thus possible that systematic variations in the continuum interpolated underneath Hα may be mis-interpreted as revealing intrinsic variations in the line. Indeed, by dividing all individual spectra around Hα by the same (rescaled) continuum fit, it became clear that the curvature of the spectra varies in time on a level less than a few%, having biggest impact on the red end of the spectrum. This is probably related to a well-known varying blaze due to the de-rotator optics in UCLES.

In order to check whether the line may be intrinsically variable, we performed some tests. The main reasoning behind these tests is that if the response curve of the echelle is variable in time, the adjacent (line-free) orders should show a similar variability. We therefore investigated the two orders next to the Hα order in the echellogram, and continuum rectified these using the same pixel range as the Hα order, i.e. not using the ~ 25 Å around the center of Hα, and looked for evidence of variability.
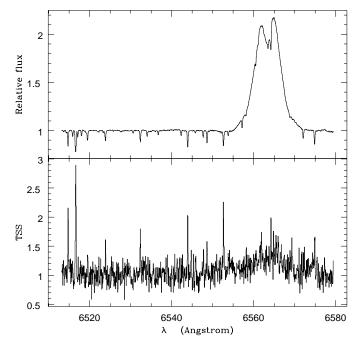

Fig. 3. Top panel: The continuum corrected total spectrum of the echelle order covering Hα. Lower panel: TSS spectrum in the Hα order. The telluric absorption lines again show up as healthy variable lines, across the Hα line the variations are marginal.

We measured the EW of a fiducial line over the same pixel-range in these orders (corresponding to 26 Å) as Hα. The measured EW in both orders is close to 0 Å, but has a scatter of 0.12 Å. This is to be compared with the scatter in the EW of the Hα line of 0.21 Å. Based on the variations of the EW of the fiducial lines in the continuum of the adjacent echelle orders and the mean height of Hα line over the measured interval, we would expect a scatter of 0.16 Å in the EW of Hα. The scatter of the EW of Hα is slightly larger than this, corresponding to variability at a 1.3 σ level.

Having established that the total Hα EW is hardly variable, the question is whether this is because the total line is not variable at all, or whether the line-profile changes in such a way that the total line-flux is nearly constant. Checks on the individual spectra show that the small changes in the line-profile are in phase with each other, and more importantly, in phase with changes in the red continuum flux. This indicates that the line-profile as such does not vary, while it traces the changes in the continuum level. Hence the insignificant variability in the EW is not due to changes in the line-profile.

Based on the facts that the EW of the Hα line changes at a similar amplitude as the EW in the same pixel-range of the adjacent orders, and that the 'changes' traced by the TSS spectrum are in phase with the red continuum, we conclude that during the two hours of these observations, no significant variability was present in the Hα line of HD 76534.
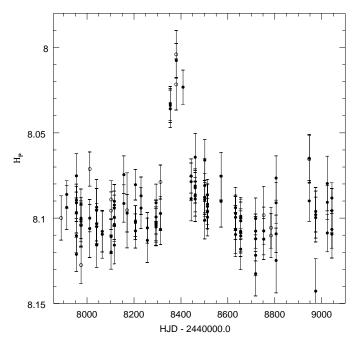
Fig. 4. Hipparcos photometry of HD 76534. The open circles are the data with HT4 > 0, indicating, mostly in this case, that only one of the two consortia obtained this value.

3.3. Hipparcos photometry re-visited

The Hipparcos satellite observed HD 76534 125 times between 1989 and 1993 photometrically in a passband similar to the *V* band (ESA 1997). These observations were reported on in the paper on Herbig Ae/Be stars by van den Ancker, de Winter & Tjin A Djie (1998). These authors mentioned that the star is probably photometrically variable, which they based on the fact that the variance of the individual photometric points is larger than the observational errors. No lightcurves were provided however.

Here we look at the data provided by the Hipparcos catalogue into more detail. The photometry is plotted as function of Julian Date in Fig. 4. In the first year of the mission, HD 76534 was constant within the errorbars until the object brightened by about 0.1 magnitude, reaching a maximum around May 1991. The period of brightening and fading lasted about 100 days. Afterwards the object 'flickers' around a mean value close to what was measured before the maximum.

Could this rise in brightness be associated with the spectral behaviour of the object? Mennickent et al. (1998) published 11 year long photometric monitoring of λ Eri, and found several similar changes in the Strömgren photometry of the object. A period search revealed that rises in brightness of $\sim$0.1 mag. occurred with a period of 486 days, while the rising and fading of the object lasted about 100 days. From the colour changes, they found that the brightness maxima correspond to slight increases in effective temperature of the star. Although the overlap between spectroscopic and photometric data is not very complete, Mennickent et al. find a rough correlation between the jumps in brightness and periods of Hα emission in the star.

4. Concluding remarks

In this paper we have investigated whether the Hα flaring star HD 76534 is variable on short timescales of order minutes and hours. We find no evidence for statistically significant variations. One of our original suggestions to explain the Hα outburst in 1995 was to invoke a pulsation-type behaviour of the star. If this would have been the case, we might have seen at least some variability on short time scales, but these are not seen.

Including the current data, Hα measurements for this object have now been reported 9 times in the astronomical literature (see the Introduction), and all but one show the line in emission. Considering this, one would conclude that the observed collapse and the subsequent rapid recovery of the Hα emission is only a sporadic event. If we were to associate the brightening of the object in the Hipparcos photometric data to a strong emission variability, it may be that the relevant timescale is the hundreds of days between events. A monitoring programme sampling a range of timescales is needed to clear this up.

In terms of variability, HD 76534 can be regarded as belonging to the same class as μ Cen and λ Eri. But there are some striking differences. In the first place, the Hα variations in 1995 were the strongest and fastest ones observed to date in a Be star. Secondly, whereas μ Cen and λ Eri are most often observed in a quiescent state, interrupted by bursts of emission that gradually declines, HD 76534 is most often observed with Hα emission, interrupted by absorption, suggesting a different process governing the Hα behaviour. Indeed, the Hα line that was observed only two hours after it had been in absorption showed a smooth doubly-peaked emission profile, similar to what has been observed now, suggesting that a neutral disk was present before the source of ionizing photons increased in strength contrary to the common idea that a disk has been built up in the case of μ Cen and λ Eri.

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