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# Serendipitous discovery of an irregular and a semi-regular type variable in the field of BY Draconis

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**Abstract.** We present new evidence of the optical variability of two red giant stars: HD 172468 and HK Dra, based on photometric and spectroscopic observations. These stars had been included as check stars in our photometric monitoring program of BY Dra and turned out to be variable.

HD 172468, whereas almost constant for most of the time, suddenly started to drop in brightness to such a low level to become undetectable. We suspect that such an abrupt event may be an "obscurational" minimum, that is typical of eruptive RCB stars, or may be due to the variable extinction by circumstellar dust in a young Orion type object.

HK Dra, already known as an irregular variable, is characterised by periodic flux modulation with season-to-season changes of the photometric period, as inferred from a periodogram analysis. It also shows changes of the light curve peak-to-peak amplitude and shape. Such a behaviour in giant stars is commonly found among semi-regular giants (SR) at the Asymptotic Giant Branch (AGB). Our radial velocity measurements rule out that HK Dra may be a close binary system.

**Key words:** stars: AGB and post-AGB – stars: individual: HK Dra, HD172468 – stars: variables: general

## 1. Introduction

HD 172468 ($V_{\rm max}$ ≃7.49; B−V≃1.28, V−$I_c$ ≃1.21) is classified in the SIMBAD database as a K2 star and is listed in the Hipparcos Catalogue (HIP 91329) with a parallax of 3.11 mas (Perryman et al. 1997). HD 172468 along with HD 172268 have been generally used as comparison stars for differential photometric observations of the variable BY Dra, which is the prototype of the class of spotted and chromospherically active late-type dwarf stars (Bopp & Fekel 1977). However, Vogt (1981), Oláh & Soliman (1984) and Panov & Ivanova (1993) noted that their V-band differential magnitudes were variable within 0.03 mag. Such small variability could be attributed to one or both stars; however, Oláh & Soliman (1984) suggested that HD 172468 was most likely the star responsible for the observed variability because of its late spectral type (K2) and sound suspects on the presence of some kind of activity.

HK Dra (=HD 171911; $V_{\rm max}$ ≃6.40; B−V≃1.60, V−$I_c$ ≃1.49) is a giant star classified in the Perkins Catalogue of revised MK types as M4III-IIIb (Keenan & McNeil 1989). Its radial velocity of $v_{\rm r} = -86.5$ km s$^{-1}$ is reported as constant in the Wilson-Evans-Batten Catalogue (WEB) (Duflot et al. 1995). HK Dra is listed in the Hipparcos Catalogue (HIP 91061) as a variable star of irregular type with a parallax of 3.94 mas (Perryman et al. 1997). However, systematic photometric observations had never been carried out. In a recent study of M giants observed by Hipparcos (Dumm & Schild 1998) a radius of $40R_\odot$ and a mass of $1.3M_\odot$ were inferred. HK Dra was included in an extensive soft X-ray survey of 380 giants carried out with the *Einstein* satellite (Maggio et al. 1990), but it was not detected above the lower X-ray luminosity limit of $10^{29}$ erg sec$^{-1}$.

## 2. Observations

### 2.1. Photometry

Our photometric study on HD 172468 and HK Dra is based on the observations collected by the 80-cm Automated Photometric Telescope (APT-80) at the " M. G. Fracastoro" station of Catania Astrophysical Observatory on Mt. Etna (Italy), and by the Hipparcos satellite.

The APT-80 feeds a single channel charge-integration photometer equipped with an uncooled Hamamatzu R1414 SbCs photomultiplier and Johnson's standard UBV filters. From the fall of 1992 the APT-80 is being devoted to the systematic photometric monitoring of a selected sample of known or suspected chromospherically active stars (see e.g., Messina 1998).

HD 172468 (check star 1) and HK Dra (check star 2) were observed by the APT-80 from 1993 through 1999 differentially with respect to the primary comparison star (c) HD 172268 (K5; V=7.89; B−V=1.25) and the check star (ck3) HD 169028 (K1III; V=6.29; B−V=1.10). These stars were all included in the observational sequence of the primary variable star target BY Dra. The observations were corrected for atmospheric extinction and converted into the Johnson's standard UBV system. The typical errors of the APT-80 differential photometry are about

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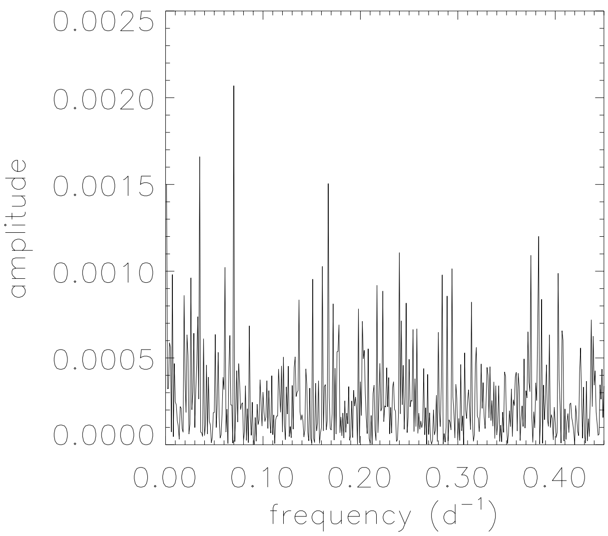


**Fig. 1.** The periodogram of the entire photometric data set of HD 172468.

0.008, 0.004 and 0.003 mag for the U, B and V filters, respectively. The differential values were finally averaged to obtain one single data point for each night in each filter. The standard deviation of the whole data set of *ck3−c* differential magnitudes clearly showed that these two stars were not variable.

The Hipparcos $H_p$ photometry was obtained from 1990 through the beginning of 1993. $H_p$ magnitudes were transformed into the Johnson V magnitudes by applying the correction: $V = H_p - 0.161$ mag for HD 172468 and $V = H_p - 0.128$ mag for HK Dra using the $H_p - V$ versus $V - I$ relation taken from Perryman et al. (1997).

### 2.2. Spectroscopy

Our spectroscopic observations were contemporarily performed at the 91-cm Cassegrain telescope of Catania Astrophysical Observatory feeding a REOSC echelle spectrograph. We used an echelle cross-dispersion configuration yielding a resolution of $\lambda/\Delta\lambda \sim 14000$. The spectra were recorded on a back-illuminated $1100 \times 1100$ pixel CCD camera with $24\,\mu m$ pixel size. In each frame five orders were recorded, covering the spectral range from about 5860 to 6700 Å and including the H$\alpha$ and Na I $D_1$, $D_2$ absorption lines.

A spectrum of HD 172468 was obtained on April 28, 1999. The HK Dra spectra were obtained on April 7 and 28, and June 3, 1999. The signal-to-noise ratio (S/N) was between 50 and 90 at H$\alpha$, depending on the exposure time (900-1800 s). A standard data reduction was performed by using the ECHELLE task of IRAF package.

## 3. HD 172468

### 3.1. Photometric analysis

The photometric observations of HD 172468 were analysed by using a Scargle-Press period search routine (Scargle 1982; Horne & Baliunas 1986). No evidence of periodic modulation was found (see Fig. 1). As shown in Figs. 2-3, for most of the time the mean V-band magnitude of HD 172468 was 7.52 mag, with a standard deviation of 0.014 mag, and mean colours U−B=1.11 and B−V=1.28. Triangles and filled dots in Fig. 2 represent the Hipparcos and the APT-80 photometry, respectively. However, during the 1993–1999 observations, the star's brightness did drop several times and randomly, from 1 up to 4 magnitudes (open diamonds of Fig. 2). As described in Sect. 2.1, the Catania APT-80 always observed HD 172468 along with the variable star BY Dra and other comparison stars. All stars in our observing sequence were regularly measured, except HD 1724678, which was not found and, therefore, not measured during several nights (short bars below the dotted line in the top panel of Fig. 2) and, in particular, during none of the 1992 and 1998 observing seasons. A star within an observing sequence is not found only if its magnitude results to be fainter than the APT-80 detection threshold. For example in the 1998 observing season such threshold resulted to be about V=12.6 mag (dotted line in the top panel of Fig. 2). Hence, we infer that during those nights the brightness of HD 172468 was fainter than V=12.6 mag. Moreover, it is interesting to point out that the photometric monitoring of HD 172468 by Hipparcos, whose limiting magnitude is V≃ 12.4 mag, presents a gap during 1992,

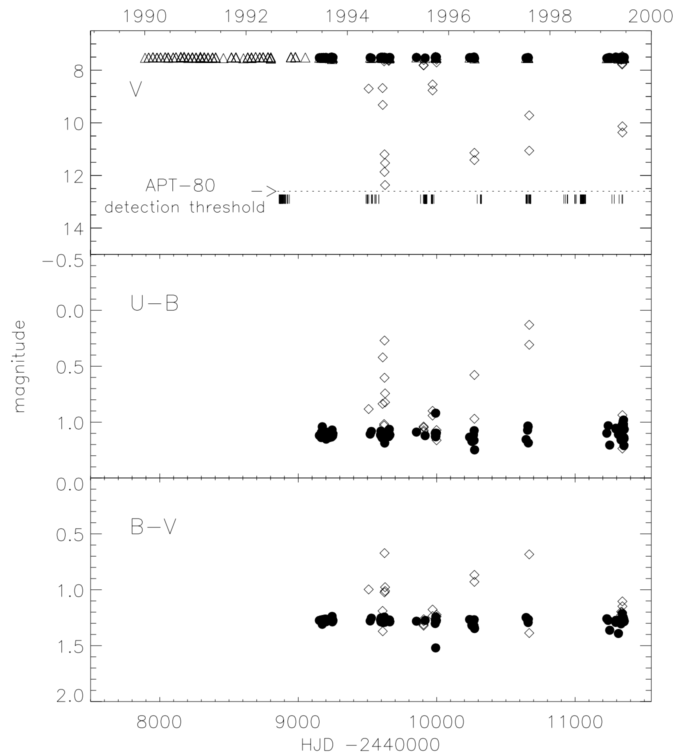


**Fig. 2.** Long-term UBV photometry of HD 172468. The observations from 1990 through the beginning of 1993 are from Hipparcos (open triangles); the observations from 1993 through 1999 are from APT-80 (filled dots). HD 172468 was undetectable, i.e., fainter than V=12.6 mag in the days marked by the short bars below the dotted line (top panel). Open diamonds and vertical bars represent the APT-80 observations of the light fading phases.

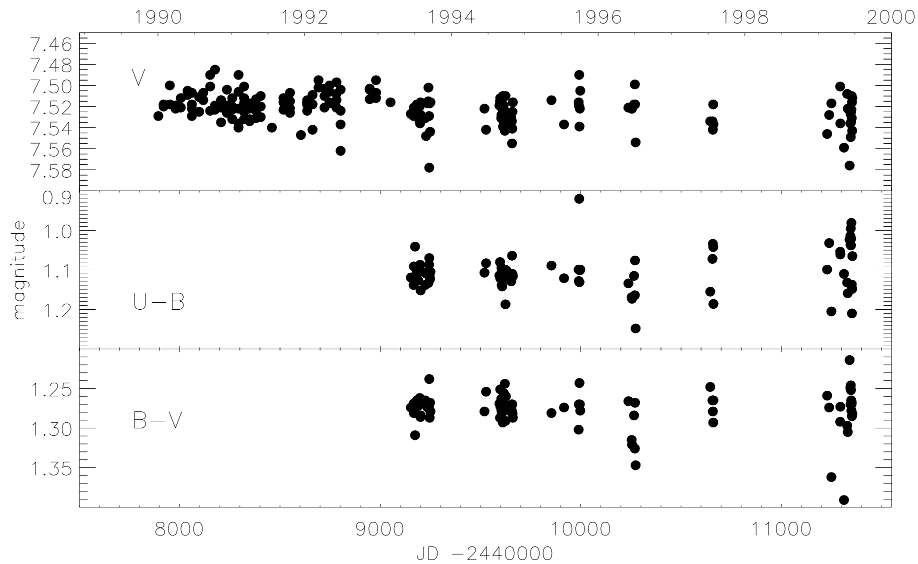


**Fig. 3.** Enlarged view of Fig. 2. The APT-80 observations of the light fading phases have been omitted to better show the detailed light curve.

**Table 1.** Equivalent width (EW) and full width at half maximum (FWHM) of H$\alpha$ absorption line for HD 172468 and HK Dra.

| date | UT | EW Å | FWHM Å |
|---|---|---|---|
| HD 172468 | | | |
| 28.4.1999 | 01:55 | 1.21±0.08 | 1.40±0.08 |
| HK Dra | | | |
| 7.4.1999 | 02:40 | 1.31±0.15 | 1.44±0.18 |
| 28.4.1999 | 01:34 | 1.41±0.15 | 1.59±0.18 |
| 3.6.1999 | 01:33 | 1.28±0.15 | 1.38±0.18 |

that corresponds to the interval over which the star was not found by our APT-80. We guess that the gap in the Hipparcos monitoring may be likely due to the faintness of the star below the cited limiting magnitude.

During the brightness decline, both U−B and B−V colours present a strong "blueing", as already observed for R CrB (Cottrel et al. 1990), up to ∼ 0.9 mag and ∼ 0.45 mag, respectively.

### *3.2. Spectroscopic analysis*

The H$\alpha$ and the Na I D spectral regions of HD 172468 are shown in Fig. 4. The H$\alpha$ equivalent width (EW) and full-width half-maximum (FWHM) are listed in Table 1. The radial velocities were obtained by cross-correlating the HD 172468 with the $\alpha$ Ari spectrum. The latter star is a bright slow-rotating primary standard ($v_{\rm r} = -14.3$ km s$^{-1}$, Wilson 1953) whose spectrum has been obtained almost contemporaneously with the HD 172468 spectrum. The wavelength ranges for the cross-correlation analysis were selected in order to exclude the H$\alpha$ line and the spectral regions heavily affected by telluric lines (e.g., the $6276 - 6315$ Å band of $O_2$). A RV of $v_{\rm r} = -21.2 \pm 0.5$ km s$^{-1}$ was derived.

Adopting the Hipparcos parallax of 3.11±0.61 mas and the V-band magnitude $V_0$=7.20, after correction for interstellar reddening (Johnson 1965), we determined an absolute magnitude $M_{\rm V} = -0.38 \pm 0.43$. The spectrum of HD 172468 was then compared with the spectra of two standard stars of spectral type K2 III ($\alpha$ Ari) and of K5 III ($\alpha$ Tau). Although HD 172468 is listed in the SIMBAD database as a K2 star, the best agreement is found with a K5 III spectral type classification. However, the mean dereddened $(U-B)_0 = 1.05$ and $(B-V)_0$=1.25 colours appear to be somewhat bluer than for a K5 III spectral type. The dotted lines in Fig. 4 represent the spectrum of $\alpha$ Tau (K5 III), which is wavelength shifted to account for the different radial

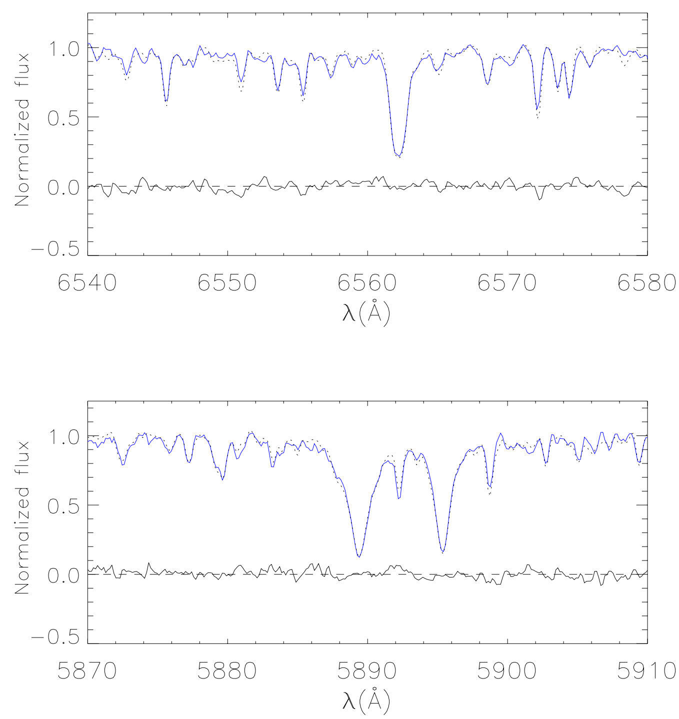


**Fig. 4.** H$\alpha$ and Na I spectra of HD 172468 (solid line) and the spectra of a K5 III ($\alpha$ Tau) star. The difference is shown in the the lower parts of each panel.

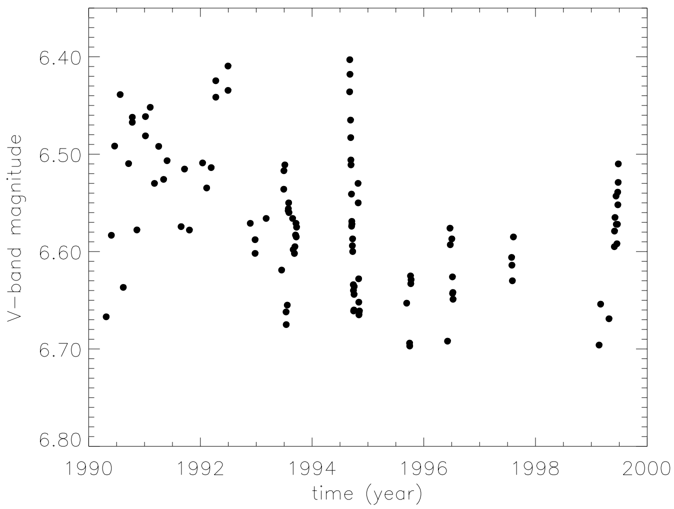


**Fig. 5.** Long-term variability of HK Dra. Observations from 1990 through 1992 are from Hipparcos; observations from 1993 through 1999 are from our APT-80.

velocities of the two stars in the plot. The residuals between the spectra of the two stars are also shown in the lower parts of the panels.

### 3.3. Discussion

The presently available photometric and spectroscopic data do not allow us to confidently infer to which class of variability HD 172468 may belong.

The brightness drops, up to several magnitudes, as well as the "blueing" showed by HD 172468 during the decline phases are typically observed in eruptive-type stars (RCB). The main characteristic of RCB stars is the abrupt drop in brightness, probably due to a sudden ejection of highly absorbent matter, followed by a longer lasting return to normal light (Sterne 1935; Proust & Verdenet 1983). Although HD 172468 has a photometric behaviour similar to an RCB star, however, its spectral type is quite late and the luminosity too low to confidently assign this star to the RCB class. Moreover, from the presently available photometry we did not find evidence of the pulsational modulation i.e., the semi-regular oscillations with amplitude of 0.2-0.4 mag and period between 30 and 100 days, which characterises RCB stars (Khopolov et al. 1998).

The irregular variations of colour and brightness showed by HD 172468 may be alternatively attributed to the variable light extinction due to a circumstellar dust cloud. In this case a classification as young Orion type object may be more appropriate.

We consider it important to present this preliminary work on HD 172468 in order to stimulate further photometric and spectroscopic observations. In fact, a systematic monitoring of the photometric and spectroscopic characteristics, especially close to the light fading, may provide important hints to understand the nature of the variability of HD 172468, as well as the composition and dynamics of the dust cloud, which we suspect to be the cause of the observed variability.

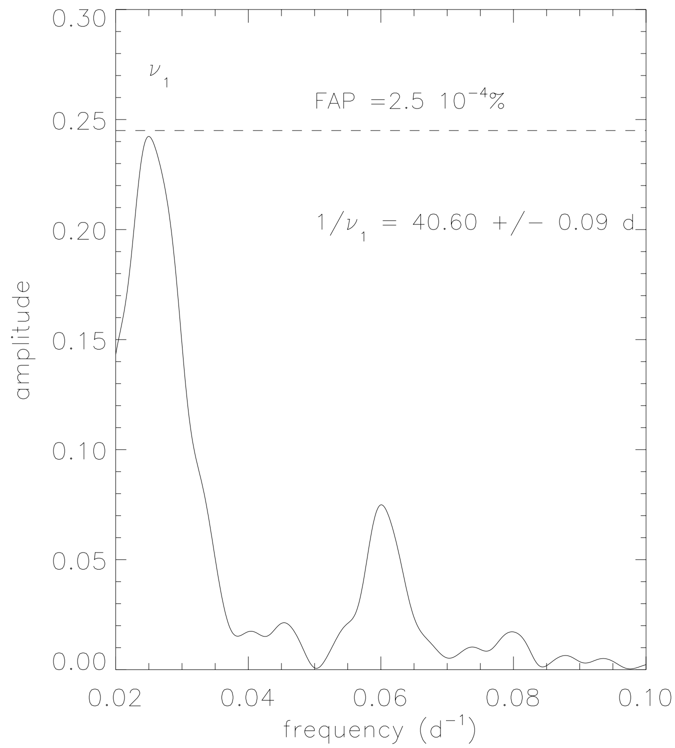


**Fig. 6.** The periodogram of the entire photometric data set with indication of the most significant frequency (see last row of Table 3).

## 4. HK Dra

### 4.1. Photometric analysis

In Fig. 5 the entire data set (Hipparcos and APT-80 photometry) is plotted versus time. The modulation amplitude as well as both the brightest and mean magnitudes show a very high variability from season to season.

Three time intervals of the entire data set, in which the observations are more numerous, have been analysed using the Scargle-Press period search routine to derive the period of the photometric modulation (Scargle 1982; Horne & Baliunas 1986). In Table 3 we report the mean epoch, the HJD date range, the number of observations ($N_{\rm m}$), the photometric period ($P$) revealed by the periodogram analysis and its uncertainty ($\Delta P$). The photometric period turns out to be variable from season to season. When the entire data interval is analysed a mean photometric period of $\langle P \rangle = 40.60 \pm 0.09$ d is found along with secondary periods (see Fig. 6). However, such secondary periods have *false-alarm-probability* (FAP) $> 30\%$ and they are never revealed when each of the three time intervals is analysed separately.

It proved possible to select ten time intervals during which the optical flux showed an almost stable modulation. The main characteristics of the analysed light curves are reported in Table 2. V-band, along with U−B and B−V, magnitudes (epochs: 1993.63, 1994.76, 1999.44) from APT-80 are plotted versus time in Fig. 7. These show remarkable variations in amplitude and shape, even on time scales of the order of the modulation period.

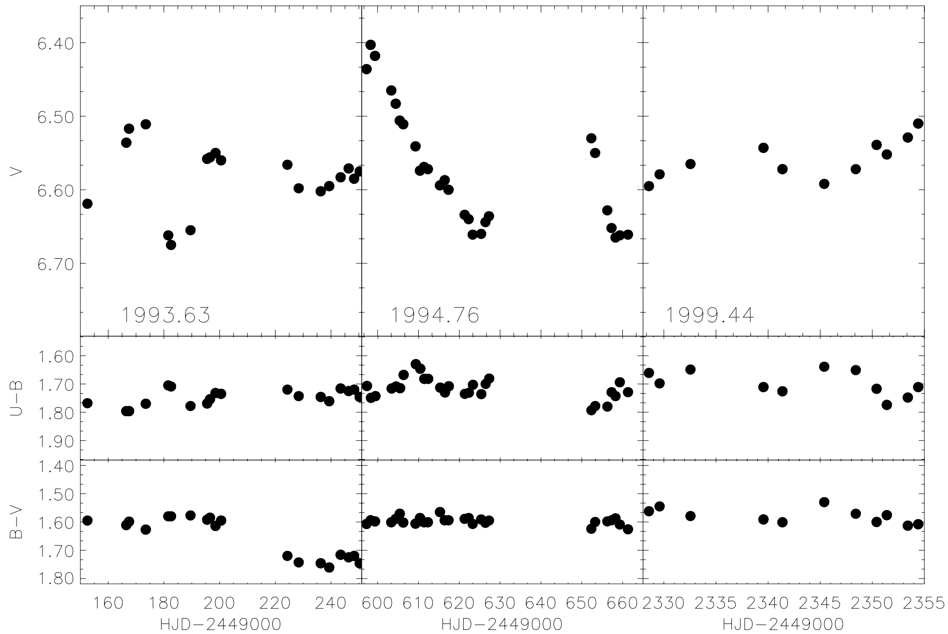


**Fig. 7.** Expanded view of Fig. 5 for three different epochs in which the APT-80 observations were more numerous. V-band light curves (upper panels) along with U−B and B−V colour indices of HK Dra are plotted versus Heliocentric Julian Day (−2449000).

**Table 2.** Mean epochs, number of observing nights, mean V-band magnitudes, colour indices and peak-to-peak amplitude of the light curves of HK Dra. The photometry data from 1990.66 to 1992.64 are from Hipparcos.

| Epoch<br># nights | 1990.66<br>11 | 1991.56<br>9 | 1992.64<br>9 | 1993.56<br>12 | 1993.69<br>8 | 1994.71<br>20 | 1994.83<br>7 | 1995.64<br>10 | 1996.49<br>7 | 1997. 58<br>4 | 1999.44<br>11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ⟨V⟩ | 6.55 | 6.51 | 6.51 | 6.58 | 6.58 | 6.56 | 6.62 | 6.65 | 6.63 | 6.62 | 6.56 |
| ⟨U−B⟩ | | | | 1.75 | 1.73 | 1.70 | 1.75 | 1.70 | 1.69 | 1.74 | 1.70 |
| ⟨B−V⟩ | | | | 1.60 | 1.60 | 1.59 | 1.61 | 1.60 | 1.60 | 1.58 | 1.58 |
| ΔU | | | | 0.12 | 0.06 | 0.24 | ≥0.09 | 0.10 | ≥0.20 | ≥0.20 | 0.20 |
| ΔB | | | | 0.14 | 0.04 | 0.27 | ≥0.14 | 0.12 | ≥0.11 | ≥0.07 | 0.11 |
| ΔV | 0.23 | 0.13 | 0.18 | 0.16 | 0.04 | 0.26 | ≥0.13 | 0.15 | ≥0.12 | ≥0.07 | 0.08 |

**Table 3.** Results of the periodogram analysis for HK Dra. The period in the last row is obtained when the entire data set is analysed.

| epoch (year) | date range HJD−2440000 | $N_m$ | P ±ΔP (days) |
|---|---|---|---|
| 1991.17 | 8005-8635 | 65 | 38.62 ± 0.09 |
| 1993.56 | 9152-9200 | 22 | 38.7 ± 2.4 |
| 1994.71 | 9597-9627 | 54 | 42.1 ± 0.4 |
| 1993.95 | 8005-9627 | 211 | 40.60±0.09 |

### 4.2. Spectroscopic analysis

HK Dra is classified by Hipparcos as a double system; however, the WEB catalogue reports a constant radial velocity. In order to check its binarity and to better define both spectral type and the nature of its variability, we carried out spectroscopic observations in the H$\alpha$ and Na I spectral regions. The H$\alpha$ line at the three different observation epochs, along with their residuals from the average spectrum, are plotted in Fig. 8. Taking into account the possibility of slight differences in the normalisation procedure, no clear variation is apparent. The slight asymmetry of the H$\alpha$ profile may be attributed to a blending effect due to the presence of numerous photospheric lines. The H$\alpha$ equivalent width (EW) and the full width half maximum (FWHM) are listed in Table 1.

The Na I lines are shown in Fig. 9. As for the H$\alpha$ line, these lines do not show appreciable variations.

The radial velocity, which was determined as described in Sect. 3.2, appears to be constant with an average value of $v_r = -87.8 \pm 0.36$ km s$^{-1}$, which is consistent with the $v_r = -86.5$ km s$^{-1}$ given in the WEB catalogue (Duflot et al. 1995), thus indicating that HK Dra is a single star or at least not a member of a close binary system.

### 4.3. Discussion

From the analysis presented in Sect. 3, the photometric variability of HK Dra is characterised by periodic modulation of the optical-band flux, quasi-sinusoidal light curves, as well as changes from season to season of the photometric period, light curve shape and amplitude. In giant stars these characteristics are commonly found among stars associated with the Asymptotic Giant Branch (AGB), in particular among semi-regular variables of type b (SRb) according to Khopolov et al. (1998) or, on a more astrophysical base, as "blue SRV" in the sense

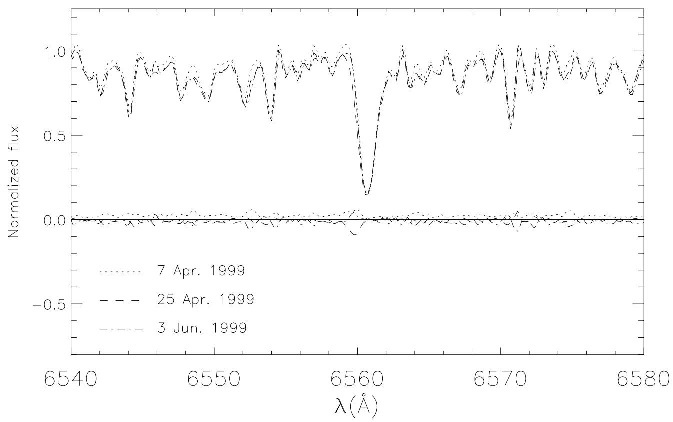


**Fig. 8.** H$\alpha$ spectra of HK Dra (*top*) and residuals from average spectrum (*bottom*). It is evident the stability of spectral behaviour through our observation date range.

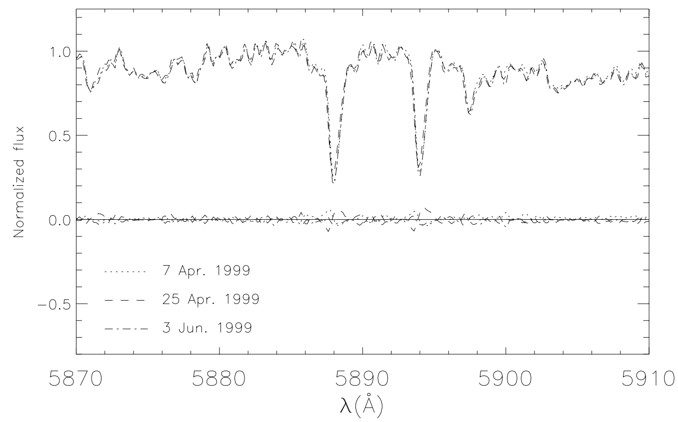


**Fig. 9.** As in Fig. 8, but for the Na I $D_1$, $D_2$ spectra of HK Dra.

of Kerschbaum & Hron (1992, 1994). Although reported in the Hipparcos Catalogue as a double component system, our spectroscopic analysis of HK Dra in the H$\alpha$ and Na I $D_1$, $D_2$ regions did not reveal any significant variation of the equivalent width or line profile, suggesting that it is unlikely a close binary system.

Further photometric and spectroscopic observations of HK Dra are very important because long time-series of light curves can provide important informations on the pulsational nature and variability of this star.

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