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Photometry of yellow semiregular variables: HR 8752 (=V509 Cassiopeiae)

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Abstract. New photoelectric photometry of the yellow semiregular variable HR 8752 (=V509 Cas) made between 1986 and 1991 is presented. Its light curve is very complex, showing a steady decrease in brightness and colours. Period analysis revealed two (possibly three) periods with changing amplitudes. The origin of the amplitude changes may be a change from fundamental to overtone pulsation though other explanations are equally possible. The evolutionary state of the variable is uncertain. A possible connection between HR 8752 and the H II zone S151 is pointed out.

Key words: stars: variable – stars: oscillations — supergiants — stars: HR 8752

1. Introduction

HR 8752 (=HD 217476=V509 Cas) is a yellow hypergiant (luminosity class 0) variable. It is a member of the rather heterogeneous group of pulsating stars designated as SRD. This group contains such different objects as the high-mass population I variable ρ Cas (Zsoldos & Percy 1991) or the low-mass, metal-poor star WY And (Zsoldos 1990).

The variability of HR 8752 (the star is better known by this name than by its proper variable star name, V509 Cas) was discovered by Ljunggren & Oja (1964) though radial velocity variations were suspected earlier (Harper 1923; Campbell & Moore 1928). The first long-term (three-year long) photometry of the star was made by Walker (1983). Systematic monitoring of HR 8752 was started in 1984 by Halbedel (1985, 1986, 1988, 1991) and by Zsoldos (Zsoldos & Oláh 1985; Zsoldos 1986b) and in 1986 by the American Association of Variable Star Observers (AAVSO). The lack of observations before 1960 is unfortunate since the star became brighter by about 1^{m} in the last 150 years (Zsoldos 1986a).

The published spectral types of HR 8752 are more consistent than in the case of ρ Cas, the latest is G4v 0 (Keenan & McNeil 1989) or F6–7 (Mantegazza 1988, see, however, Sect. 3.2.). Early spectroscopy showed a cepheid-like spectrum of the star (Adams & Joy 1919), though Stebbins (1920) could not detect light variation at that time (this does not necessarily mean that HR 8752 was constant — Stebbins did not find any variation in ρ Cas either, though it was a known variable). The star proved to be very rewarding for spectroscopy. From the observed [N II] lines Sargent (1965) inferred the presence of a circumstellar shell. Lambert et al. (1981) divided the outer atmosphere of the variable further, the outer one being an H II zone (observed in radio waves by Smolinski et al. (1977)), the inner one being the circumstellar shell. Based on the UV spectrum of the star Stickland & Harmer (1978) suggested that HR 8752 is a binary, the companion is supposed to be a B1 main-sequence star.

This paper (which is one in a series dealing with yellow semiregular variables) presents new photoelectric photometry of HR 8752. The pulsational properties of the star are discussed based on the period analysis of all available photoelectric observations. The interstellar neighbourhood of the star is also discussed.

2. Photometry of HR 8752

HR 8752 has been observed with the 50-cm and 1-m telescopes in Piszkéstető in 1986–90 and with the 60-cm telescope in Budapest in 1990–91 in the *UBV* system. The comparison star was HR 8761 ($V=6\overset{\mathrm{m}}{.}20$, $B-V=1\overset{\mathrm{m}}{.}50$, $U-B=1\overset{\mathrm{m}}{.}53$). No check star was used since the constancy of HR 8761 is well established (Halbedel 1986). The reductions were made in the usual way, the errors of the individual measurements made in Piszkéstető are less than $0\overset{\mathrm{m}}{.}008$ in V, $0\overset{\mathrm{m}}{.}012$ in $B-V$ and $0\overset{\mathrm{m}}{.}018$ in $U-B$. The Budapest observations may have slightly larger errors. Because of the condition of the sky near Budapest the star was not observed in U there.

Since 1983, HR 8752 has been observed as part of the AAVSO photoelectric photometry program (Percy et al. 1989). Measurements are made in V only, relative to the comparison star HR 8832 ($V=5\overset{\mathrm{m}}{.}56$, $B-V=1\overset{\mathrm{m}}{.}01$) and the check star HR 8688 ($V=5\overset{\mathrm{m}}{.}43$, $B-V=1\overset{\mathrm{m}}{.}17$). Reductions are made in the standard way, correcting the measurements for differential extinction and transforming them to the *UBV* system. A small error is made by using the mean $B-V$ of the variable in the transformation process. The AAVSO measurements agree well with the others, however, and are accurate to $0\overset{\mathrm{m}}{.}01$ on the average. In total, 90 measurements were made by the AAVSO observers, as follows: Donald Pray (37), Frank Dempsey (4), Howard Landis (24), Hans Sorensen (14), Jim Wood (10) and Robert Johnsson (1)[1].

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[1]A table of AAVSO observations can be obtained from author JRP or from the AAVSO archives: 25 Birch Street, Cambridge,

Table 1. Photometry of HR 8752

J.D. 2440000+	V	$B-V$	$U-B$	J.D. 2440000+	V	$B-V$	$U-B$	J.D. 2440000+	V	$B-V$
6466.230	4.930	1.239	1.073	7335.517	5.022	1.203	0.798	8093.542	5.087	1.127
6678.491	4.929	1.235	0.904	7349.477	4.997	1.179	0.884	8101.538	5.103	1.096
6679.464	4.925	1.223	1.028	7371.475	4.962	1.148	0.869	8109.517	5.060	1.101
6680.444	4.917	1.223	1.007	7372.463	4.976	1.150	0.836	8128.492	5.040	1.109
6690.381	4.905	1.220	0.972	7374.429	4.961	1.162	0.942	8134.432	5.058	1.103
6693.371	4.903	1.199	0.984	7375.421	4.986	1.161	0.841	8151.442	5.057	1.083
6694.357	4.915	1.174	0.905	7408.450	5.002	1.141	0.843	8163.342	5.040	1.101
6722.351	4.891	1.229	0.971	7409.400	5.013	1.144	0.846	8174.358	5.053	1.073
6738.503	4.909	1.224	0.962	7411.507	4.963	1.106	0.791	8176.292	5.037	1.092
6746.258	4.919	1.183		7433.328	5.022	1.154	0.807	8190.293	5.065	1.102
6748.275	4.925	1.233	0.960	7446.346	5.056	1.163	0.807	8202.276	5.085	1.108
6775.269	4.947	1.228	0.921	7454.349	5.050	1.165	0.765	8232.196	5.138	1.097
6966.502	4.976	1.218	0.881	7461.301	5.055	1.170	0.830	8271.225	5.092	1.131
6983.528	4.977	1.211	0.883	7489.240	5.035	1.133	0.783	8475.561	5.120	1.062
6984.490	4.994	1.208	0.913	7509.224	4.992	1.119	0.743	8477.562	5.159	1.051
6985.487	4.985	1.222	0.938	7529.242	4.985	1.108	0.783	8480.462	5.171	1.046
6997.515	5.000	1.203	0.917	7530.217	4.991	1.104	0.755	8485.488	5.178	1.041
7016.490	5.022	1.237	0.935	7538.199	4.982	1.096	0.706	8502.431	5.173	1.035
7018.466	5.018	1.245	0.941	7552.222	4.989	1.079	0.701	8506.415	5.172	1.043
7019.443	5.020	1.240	0.940	7712.496	5.070	1.137	0.772	8508.428	5.168	1.031
7027.372	5.029	1.232	0.956	7805.386	4.988	1.077	0.768	8533.460	5.159	1.020
7029.386	5.023	1.239	0.954	7806.350	4.989	1.093	0.757	8534.356	5.165	1.021
7031.405	5.040	1.232	0.935	7820.304	5.003	1.082	0.771	8536.360	5.158	1.027
7032.401	5.033	1.233	0.947	7821.350	4.995	1.076	0.746	8557.302	5.153	1.006
7040.462	5.000	1.242	0.949	7823.268	4.997	1.079	0.750	8559.333	5.149	1.007
7060.348	4.972	1.212	0.915	7824.277	5.021	1.079	0.745	8561.278	5.139	1.010
7062.354	4.976	1.215	0.940	7825.280	5.010	1.077	0.754	8562.310	5.145	1.007
7098.269	4.935	1.173	0.900	7840.256	5.018	1.093	0.762	8573.309	5.150	0.991
7100.345	4.935	1.173	0.858	7842.349	5.017	1.098	0.743	8592.260	5.138	1.006
7160.301	4.917	1.106		7843.257	5.030	1.070	0.831	8593.239	5.142	0.995
7207.242	4.966	1.155	0.747	7849.325	5.015	1.071	0.823	8597.240	5.107	1.024
7208.239	4.981	1.147		7854.270	5.033	1.067	0.807	8599.247	5.149	0.987
7213.249	5.007	1.162	0.773	7860.266	5.045	1.067	0.813	8600.264	5.135	0.990
7290.577	5.085	1.189	0.760	7919.224	5.049	1.115	0.774	8603.249	5.147	0.989
7334.515	5.022	1.216	0.860	8086.547	5.125	1.109				

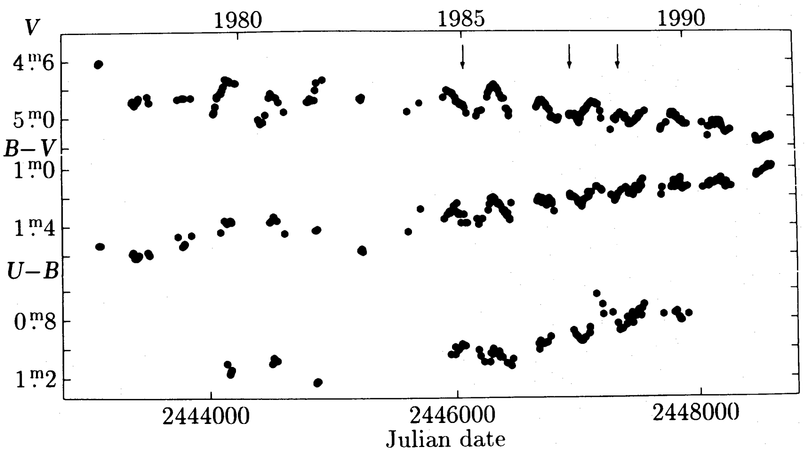

Fig. 1. Light and colour curves of HR 8752. The development of the hump is shown by the arrows

Table 1 lists the magnitudes and colours of HR 8752 observed in Piszkéstető and Budapest. The 1976–91 light curve of the star is plotted in Fig. 1 (the points are ten-day averages). Besides the data given in Table 1 and the AAVSO observations, Fig. 1 includes the measurements of Arellano Ferro (1985), Halbedel (1985, 1986, 1988, 1991), Mantegazza et al. (1988), Moffett & Barnes (1979), Parsons & Montemayor (1982), Percy & Ford (1985, unpublished), Percy & Welch (1981), Walker (1983, and unpublished), Zsoldos & Oláh (1985), Zsoldos (1986b), and those given in the Carlsberg Meridian Catalogue (1987). The agreement between the various observers is quite good, the differences are usually below $0^{\mathrm{m}}02$–$0^{\mathrm{m}}03$.

3. The light variation of HR 8752

The light variation of HR 8752 is rather complex. Its main features are (applying only to the portion of the light curve plotted in Fig. 1):

1. The average brightness is decreasing while the colours are getting bluer.
2. The 1976–78 part looks quite different from the rest: the star was at its brightest in 1976, it showed some slight variation in 1977, and it looked more or less constant in 1978.
3. Definite cyclic variation can be seen since 1979.
4. A hump appeared on the descending branch in 1985 which developed into a separate cycle (see arrows in Fig. 1).

The circumstellar shell of the star might also distort the appearance of the light curve. The shape of this distortion is, however, not obvious from Fig. 1, contrary to the case of ρ Cas (Zsoldos & Percy 1991). Shell activity might be the cause of the 1976–78 part since it is near the ejection of a shell (Lambert et al. 1981) but the lack of photometry before 1976 makes it impossible to decide. While the density of the shell might be insufficient to cause observable changes, the process of shell formation (expansion of the photosphere) may distort the light curve. The later part of the light curve (e.g. since 1984) might be unaffected by the above mentioned shell since the shell's infall has already been observed (Harmer et al. 1978).

3.1. Period analysis

The complexity of the light curve of HR 8752 makes the interpretation of its power spectrum quite difficult. It is shown in Fig. 2 together with the spectral window. This was made with the Deeming method the same way as in the previous paper (Zsoldos & Percy 1991). Because the light curve is best covered by observations between 1984 and 1991, Fig. 2 shows the spectrum and window of only these data. The analysis was repeated for the whole set and for the 1979–91 set, too.

Three peaks are identifiable in all spectra (they are indicated in Fig. 2), f_1 = 0.00492 (P=$203^{\mathrm{d}}3$), f_2 = 0.003342 (P=$299^{\mathrm{d}}2$) and f_3 = 0.002595 (P=$385^{\mathrm{d}}4$). The values given in the literature cluster around f_3: Percy & Welch (1981) gives about 1 year, Arellano Ferro (1985) gives 385^{d}, Zsoldos (1986c) gives about 400 days while Halbedel (1991) derives 409^{d}. On the other hand, Sheffer & Lambert (1987) gave two periods from radial velocity measurements: 421^{d} and 315^{d}. Though these latter values are larger than those derived from photometry (as in the case of ρ Cas, compare Sheffer & Lambert (1986) and Zsoldos & Percy (1991)), they probably correspond to f_3 and f_2, respectively.

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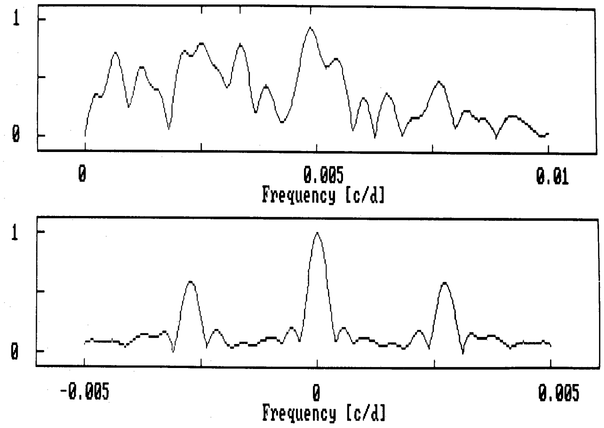

Fig. 2. The power spectrum and spectral window of the 1984–91 observations of HR 8752 after whitening with the peak caused by the decrease of brightness. The three peaks are indicated

Following Sheffer & Lambert (1987), these periods might belong to the fundamental and the first overtone mode, while the third period might be either a harmonic of the fundamental mode (since $f_1 \approx 2f_3$) or the second overtone.

Assume for the moment that HR 8752 is evolving to the red in the Hertzsprung-Russell diagram (HRD). Then the theoretical relations of Lovy et al. (1984) predict $\approx 150^{\mathrm{d}}$ as the first overtone period. This value depends only on the value of the fundamental period. Changing M_{bol} from $-9^{\mathrm{m}}0$ to $-9^{\mathrm{m}}5$ does not cause difference in the overtone period greater than one day (effective temperature was also calculated from the fundamental period using Eq. (2) of Lovy et al. (1984)). This value of the overtone period is too short, in fact it is about half of f_2. The most possible cause of this discrepancy is that the relations of Lovy et al. (1984) come from linear adiabatic theory while nonlinear effects might be important in supergiants like HR 8752.

It is evident from Fig. 1 that the amplitudes of these frequencies are variable. To investigate the amplitude variations various parts of the light curve were fitted with these three frequencies — the same procedure was used as in the case of UU Her (Zsoldos & Sasselov 1992). The 1984–91 light curve was divided into parts of three-years' duration each (e.g. 1984–86, 1985–87, etc.) and the above values of the frequencies were used. The frequencies were kept constant. Table 2 lists the amplitudes and the errors of the fits. When an amplitude is less than the error, its numerical value is uncertain.

Table 2. Amplitude changes

Years	f_1	f_2	f_3	s.d.
1984–86	0.018	0.047	0.063	0.023
1985–87	0.015	0.043	0.066	0.025
1986–88	0.042	0.010	0.032	0.025
1987–89	0.040	0.020	0.042	0.031
1988–90	0.034	0.032	0.007	0.023
1989–91	0.023	0.034	0.020	0.018

The amplitude variations are plotted in Fig. 3. It is clear that f_3 was the dominant frequency in 1984–85 but then its amplitude decreased dramatically. This behaviour is fully confirmed by the

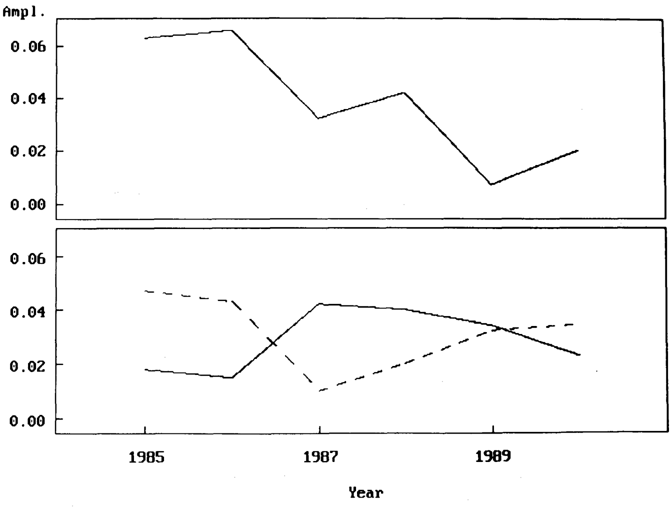

Fig. 3. Amplitude variations. The upper panel shows the amplitude decrease of f_3. The lower panel shows the amplitudes of the other two frequencies, the continuous and dashed lines correspond to f_1 and f_2, respectively

light curve (see Fig. 1). The amplitudes of f_1 and f_2 seem to alternate: when f_1 has greater amplitude then f_2 has a smaller one and vice versa. The time interval is, however, too short to derive the real character of the amplitude variations.

3.2. Colour and temperature changes

The decrease of the amplitude of f_3 (the fundamental mode) may be connected to the observed colour change of HR 8752. The colours of the star show an apparently secular decrease. Sheffer & Lambert (1987) explained this phenomenon as the result of an increase of ≈800 K in the star's effective temperature (from log $T_{\rm eff}$=3.69 to 3.75). It means a current temperature of about 5600 K which corresponds to a spectral type of G0 (Schmidt-Kaler 1982) or F6 (de Jager & Nieuwenhuijzen 1987). Contrary to this, Piters et al. (1988) derived an effective temperature of 4200 K! Possible causes for this disagreement are:

1. Piters et al. (1988) used measurements from widely differing epochs to derive the energy distribution of the star, reasoning that e.g. in 1984 the star was in a quiet state (but see Fig. 1).
2. They found that the best-fitting model atmosphere is that of Bell et al. (1976) which was made, however, for metal-deficient giants. HR 8752 is a hypergiant (luminosity class 0 instead of III), and Luck (1975) found normal Solar System composition.

This means that their conclusions must be used with caution. It must be mentioned here that Luck (1975) also found $T_{\rm eff}$ = 4000 K from spectra made in August, 1973. This will be discussed in Sect. 5.

The colour changes, if real, point to a change in spectral type. The only classification made in the 80's is that of Mantegazza (1988). He derived F6–F7, but he used the wavelength range 7500–9000 Å. This can be compared to the F9 type given by Bouw (1981), which was also derived from infrared spectra. According to Morgan et al. (1981) different regions may give different spectral types, so the above types may be too early. It shows, however, a possible spectral type change (from F9 to F6–7 from the infrared spectra) which can be connected to the colour change. As Sheffer & Lambert (1987) pointed out, this temperature change must be accompanied by a radius change, too. A temperature increase of 800 K may be caused by a 20–25% radius decrease depending on the change in luminosity. These changes must appear in the pulsational properties of the star.

3.3. Mode change or chaos?

As Fig. 1 shows, there are indeed changes in the pulsational behaviour of HR 8752. Some kind of change is expected: the high mass-loss rate (≈ $10^{-5} M_\odot$, Lambert & Luck 1978) and shell ejections decrease the mass of the star and might cause other changes, too (e.g. in the mean molecular weight, etc.). These are probably very small, so they are not suitable to explain the observations. The exact nature of these changes is not clear: is the amplitude change of the fundamental mode secular or periodic? Is there a connection between the three amplitudes? There are no answers to these questions as yet, so in the following the changes will be accepted at face value.

Another possibility is mode change: from the fundamental to overtone. It would be in agreement with the colour (and temperature) change since overtone pulsators are usually hotter than those pulsating in the fundamental mode, e.g. RRc stars are hotter and bluer than RRab stars. The length of the observations (eight years) is too short to state it with any certainty, but it is a possibility.

The next possibility is that the star's pulsation is chaotic. Buchler & Goupil (1988) suggested that the cause of the apparent irregularity of the variations of some supergiant stars may be an underlying chaotic attractor. The difficulty is the same here as before, i.e. the lack of long series of observations.

The above discussion refers only to the 1984–91 variations. The next problem is to fit the sporadic pre-1984 observations to any of these possibilities.

The 1979–81 light curve apparently supports the mode change interpretation since the cycle length was about 400 days at that time. It is very difficult (impossible) to get a reliable fit because almost only ascending branches were observed. The 1976–78 observations do not show any periodicity at all (Walker 1983). Its cause may be the effect on the light curve of the shell ejection or even the chaotic attractor suggested by Buchler & Goupil (1988).

4. The interstellar environment of HR 8752

A wide range of distance values can be found in the literature: from d=1.1 kpc (Stone 1978) to about 5 kpc (Sargent 1965). Fernie (1982) derived a colour excess of 0$^{\rm m}$48, while Arellano Ferro & Parrao (1990) derived it to be 0$^{\rm m}$42. These values correspond to a reddening of 1$^{\rm m}$5–1$^{\rm m}$6 and 1$^{\rm m}$3–1$^{\rm m}$4, respectively, depending on the value of R. Humphreys (1978) gave A_V=1$^{\rm m}$5–1$^{\rm m}$8 for the star, the reddening diagrams of Neckel & Klare (1980) indicate A_V ≈2$^{\rm m}$1 if HR 8752 is more distant than 2 kpc. With these values and assuming M_V = −9$^{\rm m}$2 one gets a lower limit of 2.6 kpc for the distance of HR 8752.

HR 8752 is a member of the Cep OB1 association (Humphreys 1978). Its membership is supported by its position, radial velocity and distance. There are interesting objects in the vicinity of the star: the supernova remnant G109.1−1.0 (Gregory & Fahlman 1980) and the H II zone S151 (Sharpless 1959). S151 is the more interesting one, since the radio map of this H II zone (Felli & Churchwell 1972) shows a curious depression near the position of HR 8752. This can mean a possible physical connection between HR 8752 and S151. These objects are very near on the sky, but since this does not necessarily mean physical nearness, the distance of S151 is needed. Fich & Blitz (1984) derived a kinematic distance of 5.37±0.84 kpc, which, at first glance, looks too great compared to the distance of HR 8752 (> 2.6 kpc). Sargent (1965), however, derived a distance of about 5 kpc for HR 8752 from kinematic considerations. On the other hand, Blitz et al. (1982) quoted a distance determination of S151 by Y. Georgelin which was only 2.4±0.8 kpc, so the limits of possible distances are approximately the same. Moreover, the radial velocities are very similar, -56.2 kms^{-1} for S151 (Blitz et al. 1982) and -58.3 kms^{-1} for HR 8752 (Humphreys 1978). Hence there is a clear possibility that the two objects are at the same distance.

Assuming that the they are really at the same distance from us, their separation can be estimated as about 20 pc (40 pc) if the distance is 2.6 kpc (5 kpc). This means that the above mentioned depression might be caused by the stellar wind of HR 8752 with the "help" of the B1 companion.

5. The evolutionary state of HR 8752

It has been shown that ρ Cas, the "spectroscopic twin" of HR 8752 is probably evolving to the red in the HRD (Zsoldos & Percy 1991). The evolutionary state of HR 8752 is more uncertain. One source of this uncertainty might be the companion. Lambert et al. (1981), however, argued that HR 8752 is a very wide binary, the companion having practically no effect on the variable.

The star's past is full of violent events. Lambert et al. (1981) inferred the occurence of a shell ejection based on the observations of Luck (1975), Harmer et al. (1978) and Lambert & Luck (1978). This is probably not the first (or last) such event. HR 8752 was about 1^{m} fainter 150 years ago than now (Zsoldos 1986a). The derived light curve can be compared to that of P Cyg (e.g. de Groot 1986) or even η Car (van Genderen & Thé 1984). De Groot & Lamers (1992) claim (based on an analysis of old observations) that P Cyg shows secular brightening. Since massive stars usually evolve at constant luminosity through the HRD, this brightening implies a decrease in effective temperature. This means that P Cyg is still evolving to the red part of the HRD, similarly to ρ Cas. Since HR 8752 has much in common with both stars, it is reasonable to assume that this star is also before the red-supergiant phase. The normal composition found by Luck (1975) also supports this interpretation.

In view of the above discussion one might be surprised to see that the observed $(B-V)$-colour of HR 8752 has shown a steady decrease since 1976 (see Fig. 1). An evolutionary cause, however, is unlikely because of the short time involved (only 16 years). More probably, this is connected to the above shell in the following way:

1. The whole process started in the early sixties with strong mass loss (probably with a higher rate than before). This might be the cause of the observed increase of the $(B-V)$-colour (Zsoldos 1986a).
2. Sometime around 1973 a shell was finally ejected. By this time the ejected mass probably had formed a false photosphere which had a cooler temperature and was responsible for the low temperature derived by Luck (1975).
3. At the late seventies or early eighties the enhanced mass loss stopped. The false photosphere might be dispersing and the colour returning to normal.

This interpretation of HR 8752 is somewhat speculative because of the scarcity of data (either spectroscopic or photometric) before 1976. For example, we cannot be sure of how many shell events are involved. Observations of the *differences* in the otherwise similar yellow hypergiant variables (not only ρ Cas, but e.g. V766 Cen (van Genderen 1992)) might lead to a better understanding of these objects.

6. Conclusions

A period analysis of eight years of continuous photometry revealed at least two (possibly three) periods in the light variation of HR 8752 between 1984 and 1991. They can be identified as the fundamental and first overtone (and the third as the second overtone). There are clear indications of amplitude variations though their nature is not clear. Two possible origins are suggested for these variations, mode change or chaos (though there might be others). It is clear that eight years of observations are not enough to arrive at a plausible model of HR 8752. The evolutionary state of the variable is probably the same as that of ρ Cas, i.e. still before the red-supergiant phase.

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