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PHOTOELECTRIC PHOTOMETRY OF THE RED SUPERGIANT α^1 Her

The α Herculis star system (Rasalgethi = ADS 10418) is a visual binary that consists of a variable M5 Ib-II primary (α^1 Her; HR 6406; HD 156014) and a less luminous secondary (α^2 Her; HR 6407, HD 156015) which itself is a spectroscopic binary. Smith et al. (1989) carried out an analysis of AAVSO visual estimates made over the last 60 years and found α^1 Her to be a semi-regular variable star with a brightness range from about 3rd to 4th magnitude. They also found the star to have light variations on the short (30-100 day) and long (several years) time scales with variations that range from less than 0.1 mag to about 0.7 mag; however, the smaller 0.1 mag variations are more common. α^2 Her is a spectroscopic binary with an orbital period of P = 51.6 days which consists of G8 III and A9 V-IV stars; its combined visual magnitude is V=+5.39 (Deutsch, 1956; Thiering and Reimers, 1993). α^1 Her and α^2 Her have an angular separation of $4\farcs7$ and the star system is at a distance of about 70 pc (Thiering and Reimers, 1993). There is no evidence that α^2 Her is a light variable. Speckle interferometry by McAlister et al. (1989) has suggested that α^1 Her itself may be a binary with a fainter component $0\farcs19$ away, but this result is still tentative.

During the past several years pulsational variability studies have been conducted of α^1 Her, along with two other bright red supergiants, α Ori and α Sco A (Smith et al., 1989, 1995). Smith et al. (1989) reported a probable fundamental pulsational period for α^1 Her of 350 $\pm$ 40 days, obtained from radial velocity measures made at the McMath telescope (see Smith et al. 1995). Working with Smith, we carried out UBV photoelectric photometry of the star from 1989 and onwards to determine the characteristics of its light variations. Up to this time no systematic photoelectric study had been made on this important star. As pointed out by Smith et al. (1995), α^1 Her is an interesting star because it may be expected to exhibit hybrid features, falling between "normal" red supergiants (those classified spectroscopically by "I" like α Ori and α Sco A) and lower mass, highly evolved luminous red giants such as the Miras, located near the upper end of the red giant branch (Smith et al., 1995). In addition, the recent study of α^1 Her by Thiering and Reimers (1993) and Danchi et al. (1994) indicates that it has an extended circumstellar shell and a relatively large mass loss rate of about 1 to 3×10^{-7} $M_\odot$/yr.

UBV photoelectric photometry of α Her was carried out from 1989 to 1995 using the Phoenix-10 APT and the Four College Consortium 0.8m APT on Mt. Hopkins in Arizona; V-band photometry was also carried out by Wasatonic starting in 1993 using a 20-cm Schmidt-Cassegrain (SCT) located first in Maryland and then later in Pennsylvania. The photometry was carried out relative to nearby and check stars, adopting the usual observing sequence of sky-comp.-var.-comp.-sky-check-comp.-sky. The common comparison star was HD 154494 (A4 IV; V=+4.91 and B$-$V=+0.12); HD 154143 (M3 III; V=+4.98 and B$-$V=+1.60) served as the primary check star and was observed at least once on most nights. Several UBV standard stars were also observed. Typically the stars

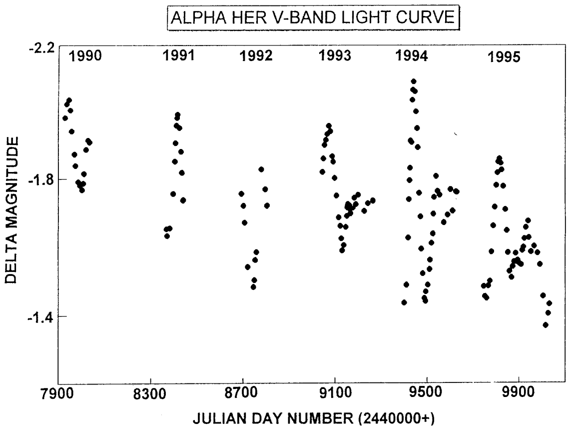

Figure 1. Visual light curve

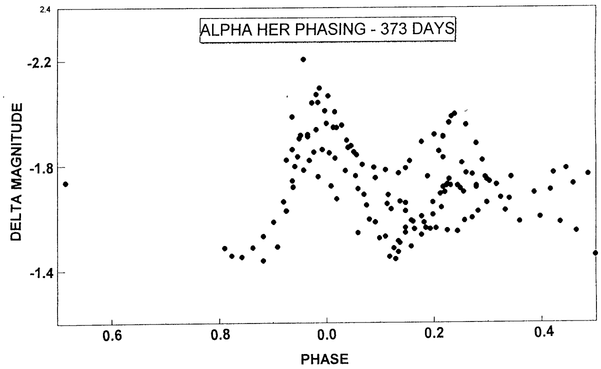

Figure 2. Phasing using 373 day period; scatter due to amplitude variation

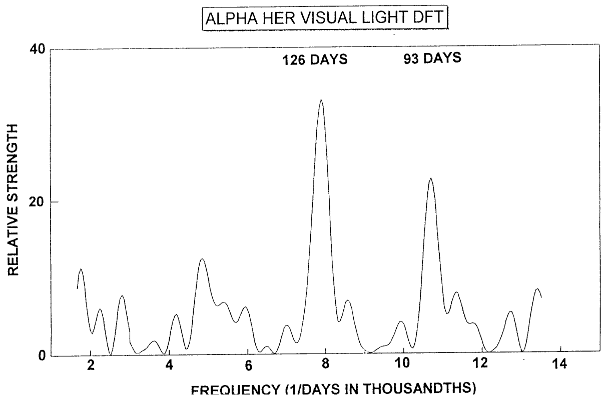

Figure 3. Discrete Fourier transform; note detected periods at frequencies 0.0079 and 0.0108 (126 and 93 days)

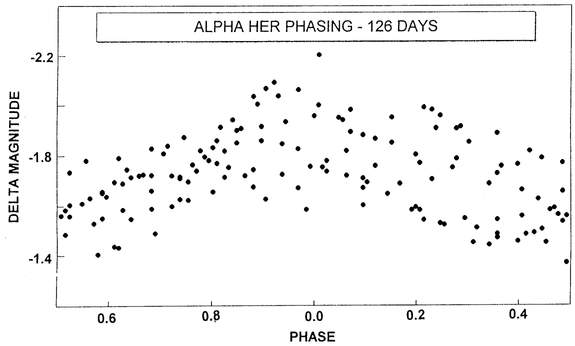

Figure 4. Phasing using 126 period; scattered due to amplitude variation

were observed for about 30 minutes each night. Other than what appears to be random scatter, the relative brightness of the comparison and check stars remained basically constant to within about $\pm$ 0.02 mag (V-band) over the time interval of the photometry. If small light variations do occur, they would be expected more from the M3 III check star rather than the A4 IV comparison star. For all the observations 10-sec integrations were used and the effects of differential atmospheric extinction were removed and heliocentric corrections were applied to the local times. Because of the relatively small angular separation of α^1 Her and α^2 Her, both stars were, out of necessity, included within the diaphragms of the photometers. Because of the large quantity of data, nightly means were computed to alleviate light curve clumpiness. The APT V-band observations were combined with the SCT photometry and are given in Table 1. The ΔV-magnitudes (in the sense of variable minus comparison star) are plotted against Julian Day number in Figure 1.

As shown in Figure 1, α^1 Her has a complicated light curve with short term (a few months) and long-term (several years) light variations. It displays irregular sinusoidal-like light variations on a time scale of about 90-130 days, and with brightness amplitudes that range from less than $0^{\mathrm{m}}.1$ up to $0^{\mathrm{m}}.7$. Because of the inclusion of α^2 Her in the light mea-

Table 1. Photometric data

JD244+	ΔV	JD244+	ΔV	JD244+	ΔV	JD244+	ΔV
7928.06	−1.982	8795.82	−1.769	9420.92	−1.740	9766.55	−1.486
7936.54	−2.023	8802.83	−1.721	9423.07	−1.795	9773.89	−1.500
7946.01	−2.036	9043.89	−1.820	9424.02	−1.832	9780.92	−1.585
7952.00	−2.004	9047.90	−1.860	9427.40	−1.913	9788.89	−1.662
7958.00	−1.942	9052.97	−1.900	9431.81	−1.908	9793.91	−1.717
7969.94	−1.873	9057.74	−1.915	9434.83	−2.035	9801.84	−1.781
7973.96	−1.839	9065.42	−1.933	9437.81	−2.066	9805.85	−1.818
7986.40	−1.791	9072.43	−1.957	9439.87	−2.091	9808.88	−1.850
7994.14	−1.781	9078.90	−1.941	9445.04	−2.061	9814.83	−1.859
8002.85	−1.768	9085.12	−1.866	9451.19	−2.000	9819.83	−1.846
8008.22	−1.787	9090.81	−1.850	9455.83	−1.950	9823.77	−1.826
8010.88	−1.815	9095.64	−1.795	9458.78	−1.893	9831.98	−1.778
8019.26	−1.887	9105.32	−1.751	9465.33	−1.758	9840.28	−1.710
8027.78	−1.914	9114.54	−1.687	9470.51	−1.689	9846.00	−1.648
8034.18	−1.908	9122.28	−1.662	9475.28	−1.594	9851.80	−1.583
8368.36	−1.653	9127.37	−1.625	9483.02	−1.522	9858.67	−1.528
8371.35	−1.633	9131.53	−1.589	9488.74	−1.450	9867.83	−1.510
8382.49	−1.656	9139.03	−1.605	9892.73	−1.441	9872.69	−1.542
8396.58	−1.756	9146.04	−1.659	9494.65	−1.469	9879.32	−1.556
8403.44	−1.852	9150.71	−1.691	9503.94	−1.489	9885.79	−1.561
8406.77	−1.906	9152.63	−1.716	9510.71	−1.534	9890.30	−1.556
8410.80	−1.958	9154.85	−1.722	9513.61	−1.561	9893.60	−1.560
8413.25	−1.981	9155.67	−1.726	9518.72	−1.611	9901.58	−1.551
8415.32	−1.991	9157.71	−1.723	9524.61	−1.639	9909.12	−1.569
8422.87	−1.951	9161.87	−1.722	9526.78	−1.697	9913.58	−1.589
8429.76	−1.881	9164.73	−1.711	9530.19	−1.746	9918.58	−1.599
8434.06	−1.818	9166.59	−1.698	9538.65	−1.808	9922.60	−1.624
8439.24	−1.737	9176.08	−1.715	9545.34	−1.764	9928.59	−1.657
8692.96	−1.756	9182.60	−1.744	9554.58	−1.753	9938.62	−1.676
8701.94	−1.721	9189.59	−1.725	9572.08	−1.672	9942.05	−1.627
8705.93	−1.672	9199.58	−1.753	9588.56	−1.694	9951.55	−1.585
8721.23	−1.542	9226.06	−1.705	9600.05	−1.769	9966.03	−1.602
8745.82	−1.483	9244.06	−1.728	9610.52	−1.706	9979.51	−1.582
8750.31	−1.503	9262.50	−1.736	9625.52	−1.762	9990.49	−1.547
8753.81	−1.532	9400.88	−1.436	9746.93	−1.485	10003.15	−1.455
8758.18	−1.585	9410.87	−1.489	9751.91	−1.455	10015.47	−1.368
8779.75	−1.828	9417.35	−1.627	9758.93	−1.450	10026.46	−1.404
						10031.45	−1.432

surement of the variable star, the light amplitudes (for the V-bandpass) are about 1.25 times larger than observed. Also, the star shows an irregular decrease in mean brightness from 1989 to 1995 of about 0.3 mag. This could be related to the long-term light variations seen in the earlier visual estimates. Observations obtained during the spring of 1996 indicate that the downward trend in brightness continues.

During 1993 to 1995 the addition of Wasatonic's photometry permitted the observing season to be extended from about 4 months with the APTs to over 8 months, revealing what appears to be a cyclic light variation with a period about 1 year. Based on the longer observing intervals, the light curve can be characterized by a large sinusoidal light pulse followed by smaller pulses in which the interval between successive maxima and minima is usually about 120-130 days. Examination of all the photometry indicates that the average interval between the occurrence of primary maxima is about 373 $\pm$ 30 days. This value is very close to the spectroscopic period of 350 $\pm$ 40 days from Smith et al. (1989), based on radial velocity observations. Thus, it could be related to the fundamental pulsation mode of the star. In Figure 2, the 1993/94 and 1994/95 photometry are plotted against phase using the 373 day period. Phasing with the 350 day spectroscopic period yields similar results.

To characterize quantitatively the possible periods in the light curve, a Discrete Fourier Transform (DFT) program from Sinnot (1988) was used to analyze the observations. Figure 3 shows the results of the DFT analysis in which two significant periodicities in the data were found, the most pronounced at about 126 days (frequency ≈ 0.0079) and a slightly less prominent period of 93 days (frequency ≈ 0.0106). Smith (1996) also found these periods in the photometry using the CLEAN periodogram routine (Roberts et al., 1987). In Figure 4 we show the data phased with the 126 day period. We did not correct the data for the long-term light decrease but the 126 day period is easily seen in the plot. Neither method showed a significant period near 373 days (or 350 days); this can be explained because the beat period from $P_1=126^d$ and $P_2=93^d$ is $P_{12}=355^d$, which is close (within the uncertainties) to the observed 373 day photometric period. The observed light curve is, however, more complex than can be represented by just these two periods. As noted by Bowen (1992) and Smith et al. (1995), shocks generated by the pulsations in the stellar atmosphere could produce further complex short term light variations. The long term light variations seen in our data and the earlier visual estimates could be a result of the growth and decay of supergranulations on or near the surface of the star.

With continued photometry (and radial velocity measures by Smith), we should be able to determine whether the 126 day and 93 day periods are persistent and stand the test of time. Also continued photometry may shed more on the nature of the long-term luminosity variations.

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