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Radial velocity observations of yellow supergiants

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Summary. Photoelectric radial velocities are presented for seven F–G supergiants suspected of Cepheid-like variations. Four of these stars have variable velocities with ranges from 5 to 11 km s^{-1}. No definite periodicity can be assigned to any member of the group.

1 Introduction

In recent years several photometric surveys of F and G supergiants have been carried out (Fernie & Hube 1971; Fernie 1976; Henrikson 1977; Percy, Baskerville & Trevorrow 1979; Ferro 1981; Percy & Welch 1981). These have had moderate success in discovering small-amplitude Cepheids or Cepheid-like supergiants as well as stable stars within the classical Cepheid instability strip of the H–R diagram. Many of the variable supergiants vary in a time-scale exceeding 50 day, although no case is known where the variations are strictly periodic with such long periods. Cepheids with periods longer than 50 day are relatively common in other galaxies, but unknown in our own Galaxy. Thus it is important to understand the nature of these long-period supergiant variables and their relationship to classical Cepheids. For this purpose we have been monitoring the radial velocities of seven F and G supergiants. In this paper we present these results and discuss the nature of these stars.

2 Observations

Radial velocity observations were obtained with the photoelectric radial velocity spectrophotometer attached to the coudé focus of the 1.88-m reflector at the Sutherland station of the South African Astronomical Observatory. A technical description of this instrument has been given by van Citters (1974). We used a copy of the spectrum of the G2II star δ TrA to construct the template for cross-correlation with the spectrum of the program star. The dispersion used was 13.4 Å mm^{-1} centred at 5800 Å.

The zero-point of the system was obtained by measuring many 'a'-quality radial velocity stars in the *Mount Wilson Catalogue of Radial Velocities*. The velocity of the iron arc was measured after each observation of the program star in order to correct for drifts in the system. The standard error per observation is about 2.5 km s^{-1}.

Table 1. Radial velocity observations for seven F–G supergiants.

R PUP		HR4337		HR4441		HR4511		HR5171		HR6392		HD159378	
JD2440000+	KM/S	JD2440000+	KM/S	JD2440000+	KM/S	JD2440000+	KM/S	JD2440000+	KM/S	JD2440[illegible]0+	KM/S	JD2440000+	KM/S
3940.382	63.3	3939.477	7.5	3939.485	-17.5	3939.518	-14.1	3940.522	-48.0	3939.627	-20.8	3941.645	-25.9
3945.419	62.2	3940.460	4.1	3940.464	-20.8	3945.525	-16.9	3945.550	-43.0	3945.616	-23.8	3945.645	-26.6
3969.293	60.4	3945.496	5.9	3945.501	-20.4	3969.369	-14.6	3969.403	-44.4	3967.654	-21.7	3967.669	-26.6
3972.368	66.1	3969.339	6.1	3969.363	-19.0	3973.354	-13.2	3972.568	-40.6	3973.598	-20.6	3973.610	-19.5
3976.276	61.8	3973.336	6.6	3973.348	-17.7	3976.402	-14.4	3977.447	-40.0	3977.608	-18.9	3977.615	-18.3
3978.340	63.2	3976.313	6.6	3976.399	-15.6	3978.535	-15.0	3979.519	-38.0	3979.607	-24.5	3979.628	-17.4
3980.278	62.5	3978.519	9.3	3978.418	-14.9	3980.437	-16.9	4025.488	-39.6	4025.540	-18.6	4026.525	-16.3
4023.225	64.5	3980.413	6.6	3980.420	-17.9	4026.311	-22.0	4298.582	-31.4	4177.257	-22.7	4177.269	-24.0
4235.595	61.3	4026.285	1.8	4026.289	-24.1	4246.624	-12.9	4302.590	-33.7	4183.253	-26.5	4183.260	-25.6
4237.582	65.4	4236.624	4.3	4236.620	-31.2	4298.556	-16.8	4331.564	-33.8	4298.616	-19.9	4302.629	-12.4
4239.568	60.4	4237.631	10.1	4238.630	-26.0	4302.531	-15.1	4333.603	-34.3	4302.621	-19.8	4331.673	-17.1
4241.481	62.6	4238.633	8.1	4239.612	-28.8	4331.503	-17.8	4335.637	-35.4	4331.661	-19.6	4363.525	-12.5
4242.475	55.1	4239.616	3.7	4240.626	-23.9	4335.577	-13.7	4336.632	-35.8	4332.521	-18.5	4299.650	-13.6
4246.492	63.0	4240.633	9.8	4241.624	-28.7	4336.567	-11.9	4363.471	-32.4	4335.677	-19.9	4415.474	- 9.7
4297.437	59.7	4241.629	3.2	4246.620	-23.7	4337.555	-14.0	4364.450	-35.0	4336.678	-20.6	4416.464	-10.0
4302.373	59.0	4246.632	4.5	4298.505	-17.3	4363.404	-14.0	3939.550	-39.3	4363.512	-18.5	4420.453	- 9.9
4331.309	62.0	4298.501	6.0	4302.501	-16.6	4416.300	-20.8	4416.316	-38.9	4415.431	-27.3	4424.410	- 9.3
4333.320	62.2	4302.496	10.2	4331.460	-14.4	4422.280	-23.2	4420.418	-38.4	4416.453	-22.9	4426.446	- 8.4
4335.350	63.1	4331.432	11.6	4333.510	-12.9	4424.271	-19.3	4422.287	-43.7	4420.431	-24.1	4428.456	- 9.1
4336.370	62.9	4333.505	10.1	4335.563	-14.8	4426.271	-18.1	4423.249	-37.9	4423.374	-22.9	4444.466	-13.0
4337.344	64.2	4335.520	8.2	4336.543	-14.8	4428.264	-19.9	4424.378	-37.4	4424.406	-23.9	4446.414	- 6.5
4363.226	58.3	4336.496	8.5	4337.526	-15.7	4444.296	-15.3	4425.257	-40.9	4425.278	-23.2	4449.437	-12.5
4591.506	61.6	4337.521	5.0	4363.389	-15.7	4445.301	-19.4	4426.376	-36.5	4426.440	-22.5	4511.290	-13.8
4596.468	69.7	4363.386	7.2	4364.392	-16.0	4447.266	-14.7	4427.265	-36.1	4428.383	-22.8	4512.237	-18.5
4637.335	64.2	4364.388	8.4	4415.314	-23.6	4591.572	-14.0	4428.329	-38.5	4443.489	-24.5	4536.263	-18.3
4638.384	60.4	4415.309	7.4	4416.239	-22.2	4654.658	-13.6	4443.361	-36.8	4444.418	-20.6		
4634.317	67.3	4416.255	0.9	4422.276	-26.0	4703.559	-15.4	4444.339	-39.6	4445.392	-21.7		
4655.318	65.1	4422.270	-2.2	4423.242	-23.8	4707.525	-16.7	4446.326	-37.5	4447.381	-24.6		
4656.316	63.7	4423.238	1.4	4424.268	-18.9	4711.454	-13.9	4447.325	-39.7	4449.418	-23.2		
4707.337	59.3	4424.262	2.2	4425.245	-16.9			4448.350	-37.4	4511.254	-21.7		
4708.326	65.1	4425.241	-1.9	4426.267	-21.1			4653.402	-34.6	4512.221	-23.3		
4711.283	60.6	4426.262	0.0	4427.248	-21.5			4654.650	-34.2	4707.687	-19.1		
4712.312	62.8	4427.243	-0.5	4428.261	-22.9			4703.597	-39.3	4709.593	-26.5		
4714.287	63.7	4428.256	2.7	4444.278	-20.5			4705.570	-40.6	4712.694	-23.7		
4715.260	62.1	4444.227	1.0	4445.295	-23.4			4707.604	-43.0	4713.642	-23.2		
		4445.274	1.4	4445.296	-24.6			4709.558	-39.2	4714.695	-30.5		
		4446.251	1.4	4446.273	-22.4			4772.496	-39.5	4772.601	-24.9		
		4447.257	0.1	4447.262	-21.0			4777.364	-39.5	4777.526	-27.0		
		4590.602	9.6	4590.598	-19.0								
		4591.557	8.3	4591.561	-17.0								
		4592.572	10.4	4595.575	-19.9								
		4593.558	10.1	4654.655	-21.4								
		4595.568	6.7	4703.550	-30.3								
		4596.576	6.5	4704.510	-24.4								
		4655.588	6.4	4711.437	-29.9								
		4703.506	6.7	4777.346	-22.1								
		4704.505	6.9										
		4707.490	6.2										

3 Results

Table 1 shows the results obtained during the period 1979 March to 1981 July.

R PUP (HR 2974)

Gould (1879) reported variability in the G0Ia supergiant R Pup of up to 0.6 mag. Since that time the star has been stable to within one or two hundredths of a magnitude (White 1975; Eggen 1980). However, Stift (1979) observed a variation with a range exceeding 0.05 mag in V. R Pup is a member of the open cluster NGC 2439 (White 1975) which makes it of particular interest should Cepheid-like variations be detected again.

The only published radial velocity measurements are those of Buscombe & Kennedy (1965) who obtain a mean velocity of $+68\,\mathrm{km\,s^{-1}}$ from four spectra. Our 35 observations of R Pup give $\langle V_r \rangle = 62.5 \pm 0.5\,\mathrm{km\,s^{-1}}$ with a rms error of $2.7\,\mathrm{km\,s^{-1}}$ per observation. Hence there is no indication of appreciable velocity variations, although a very long-term variation could be responsible for the discrepancy between our mean velocity and that of Buscombe & Kennedy.

HR 4337 (HD 96918)

Fernie (1976) observed this G2I a supergiant on six nights but found no evidence for variation. Stift (1979) observed a systematic brightening of 0.03 mag over a month. The photometric spectral type is K2 (Fernie 1976), which is probably a result of the surrounding dust shell inferred by Humphreys, Strecker & Ney (1971) from its infrared excess. It is possible that many other supergiants could be surrounded by dust shells, making the light variations difficult to interpret.

The radial velocity of HR 4337 is variable (Wright 1907; Hough 1928) with a range of 8 to $14\,\mathrm{km\,s^{-1}}$. The Cape observers (Hough 1928) obtain a mean velocity of $+5.5\,\mathrm{km\,s^{-1}}$ from 15 spectra. This agrees very well with our value of $+5.6 \pm 0.5\,\mathrm{km\,s^{-1}}$ from 49 observations. The rms error per observation is $3.6\,\mathrm{km\,s^{-1}}$ which is significantly larger than can be attributed to observational error. A periodogram analysis did not yield an unambiguous period, but a time-scale of about 330 day and a velocity range of about $5\,\mathrm{km\,s^{-1}}$ is indicated.

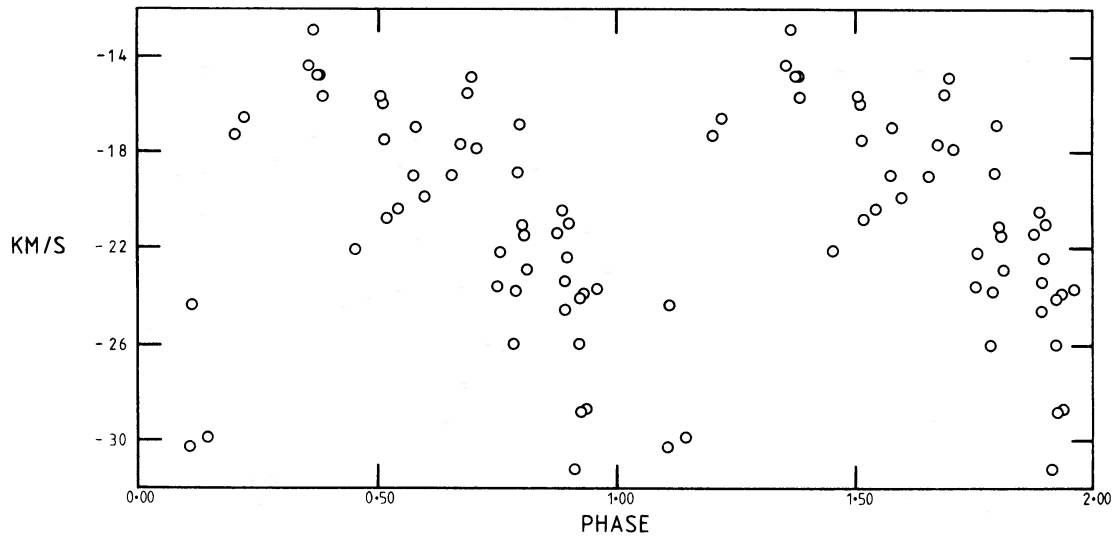

Figure 1. Radial velocities of HR 4441 using a period of 213 day. Phase zero corresponds to HJD 2440000.000.

HR 4441 (O^1 CEN, HD 100261)

From 1175 photographic plates, obtained between 1934 and 1952, O'Connell (1960) showed that O^1 Cen (F7 Ia/ab) is a semiregular variable with an extreme range of variation of about 0.8 mag. At times there are cycles of 200 days, at other times only small irregular fluctuations can be seen. Occasionally the brightness changes appreciably within a few days. Photoelectric observations by Stift (1979) on 20 nights showed a variation of 0.02 mag with a shallow minimum.

Campbell (1922) found a variable radial velocity from six spectra ranging from -12 to $-25\,\mathrm{km\,s^{-1}}$. Our 46 observations give a mean velocity of $-20.9 \pm 0.7\,\mathrm{km\,s^{-1}}$, but the standard error per observation of $4.6\,\mathrm{km\,s^{-1}}$ clearly shows that the star did indeed vary during this period. A periodogram analysis yielded a strong peak at 213 day, but other nearby peaks render this determination ambiguous. Fig. 1 shows a phase plot based on this period, indicating a velocity range of about $9\,\mathrm{km\,s^{-1}}$.

HR 4511 (HD 101947)

Fernie (1977) suspected this G0Ia supergiant to be a low-amplitude Cepheid with a period of about a month. Eichendorf & Reipurth (1979) obtained extensive photometric observations and deduced a period of 125 day and an amplitude of 0.2 mag. They supposed that it may be the longest period Cepheid known in our Galaxy, though the light curve is not regular. Of special interest is the fact that it is a probable member of the loose open cluster Stock 14. Dean (1980b) could find no evidence for the 125 day period, though it was certainly variable by as much as 0.1 mag. A periodogram analysis of the combined photometric data did not yield a meaningful period.

Bidelman, Sahade & Freiboes-Conde (1963) obtained spectra of HR 4511 with the intention of confirming the earlier Lick observations (Campbell 1928) which showed a variable radial velocity. Bidelman *et al.*'s data does not show much variability, though their mean velocity of $-15.8\,\mathrm{km\,s^{-1}}$ differs considerably from the Lick determination of $+10.1\,\mathrm{km\,s^{-1}}$. We obtain $\langle V_r \rangle = -16.1 \pm 0.5\,\mathrm{km\,s^{-1}}$ from 29 observations with a standard error of $2.9\,\mathrm{km\,s^{-1}}$ per observation. This is only slightly larger than expected from the observational error. If our results are combined with Bidelman's, a marginally significant 'period' of 126.26 day can be found, though it is unlikely that this represents a regular variation.

HR 5171 (HD 119796)

Dean (1980a) monitored this G8Ia/0 supergiant over several years using *UBVRI* photometry. A long term variation of about one magnitude in V and 0.3 mag in the colours was found.

This star has no published radial velocity. We obtained a mean velocity of $-38.3 \pm 0.6\,\mathrm{km\,s^{-1}}$ from 38 observations. The rms error is about $3.5\,\mathrm{km\,s^{-1}}$ which clearly indicates that the star has a variable radial velocity. The periodogram shows a strong peak at a period of 263.2 day and an amplitude of $9\,\mathrm{km\,s^{-1}}$ which is shown as a phase plot in Fig. 2. Since Dean's photometry does not support such a period, this may only indicate the approximate time-scale of the variation during the time when the observations were made.

HR 6392 (HD 115603)

From 16 *UBVRI* observations spread over one year, Dean (1980a) observed a general decrease in brightness of about 0.2 mag.

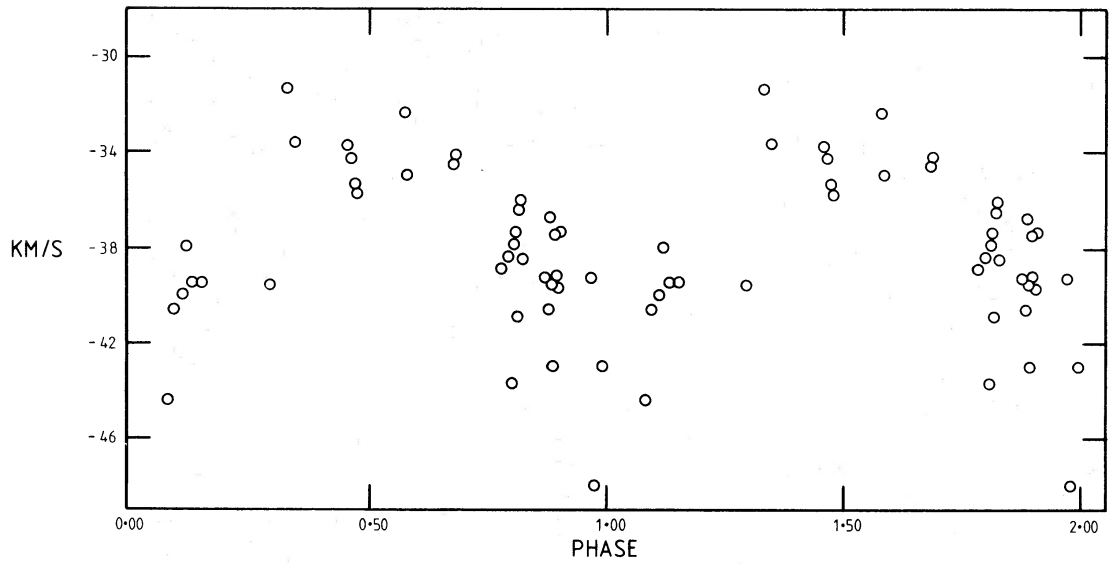

Figure 2. Radial velocities of HR 5171 using a period of 263.2 day. Phase zero corresponds to HJD 2440000.000.

Buscombe & Kennedy (1969) obtained a velocity of $-6\,\mathrm{km\,s^{-1}}$ from one spectrum of this G5Ia supergiant. From 38 observations we obtain a mean velocity of $-22.6 \pm 0.5\,\mathrm{km\,s^{-1}}$. This discrepancy could arise from a long-term variation, although the standard error per observation of $2.8\,\mathrm{km\,s^{-1}}$ shows that little if any variability occurred during our observations.

HD 159378

Van Genderen & Thé (1978) showed that this G0Ia supergiant varies in brightness and colour on a time-scale between 70 and 90 day with a light amplitude of 0.17 mag. It is probably a member of the open cluster Tr 27. Dean (1980b) confirmed the variability, but did not have enough data to check the supposed periodicity.

There are no published velocity observations of HD 159378. We obtain $\langle V_r \rangle = -15.8 \pm 1.3\,\mathrm{km\,s^{-1}}$, but the rms error of $6.2\,\mathrm{km\,s^{-1}}$ per observation shows that marked variability took place during this time. The periodogram shows peaks at 105.3 and 73.0 day which correspond roughly with the time-scale found by van Genderen & Thé (1978). However, somewhat higher peaks are found at 188.7 day and also at 312.5 day, so no unambiguous period can be found.

4 Conclusions

In our sample of seven F–G supergiants, four have definite radial velocity variations in excess of $4\,\mathrm{km\,s^{-1}}$, whereas all of them have shown light variations at one time or another. The velocity to light amplitude ratio for classical cepheids is of the order of $40\,\mathrm{km\,s^{-1}}$ per magnitude. This is the approximate ratio obtained from the three highest amplitude variables, HR 4441, 5171 and HD 159378, suggesting that Cepheid-like radial pulsations are probably responsible for the variations. On the other hand a part of the light variation may arise from a circumstellar shell as in the case of HR 4337.

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