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YELLOW GIANTS: A NEW CLASS OF RADIAL VELOCITY VARIABLE?

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ABSTRACT

The five K giants and one K supergiant included in our precise (HF) radial velocity program all show significant long-term (~1 yr), low-amplitude (30–300 m s^{-1} rms) radial velocity variations which make them unsuitable as precise radial velocity standards. Arcturus has been discussed in detail elsewhere, and the supergiant ϵ Peg is probably a semiregular variable. The sampling in our 5 years of data is inadequate to say whether the giants are related to the Cepheid or Mira variables or form an independent class. The amplitudes of the long-term radial velocity variations of the giants and supergiant are correlated with the level of chromospheric activity shown by K line emission intensity and its fluctuation as seen in He I λ10830.
Subject headings: radial velocities — stars: late-type — stars: variables

I. INTRODUCTION

Late in 1980 we began to systematically monitor the radial velocities of the brightest available, single, solar-type stars using the hydrogen fluoride absorption cell technique developed by Campbell and Walker (1979). We were searching for small perturbations by low-mass companions. The first results of this work (Campbell, Walker, and Yang 1988) show that the majority of the dwarf and subgiant stars have remarkably constant velocities; the standard deviations (external errors) about at most a second-order secular trend are typically only 13 m s^{-1}. On the other hand, the five K giants and one K supergiant included in the program have all proved to be variable. They were included because they are all bright IAU velocity standards (Batten 1983; Batten *et al.* 1983), and we continued to monitor them until 1986. One of them, Arcturus, has been analyzed in detail in an earlier paper (Irwin *et al.* 1989) where we confirm the short-term variability (~days) found by Smith, McMillan, and Merline (1987) and demonstrate a long-term variability with the largest amplitude component having a period of 640 days or more.

Most regions of the H-R diagram above the main sequence contain variable stars, the great majority being pulsating variables. However, there is a conspicuous gap in reported radial velocity variability for K giants which lie between the red limit for the RR Lyrae and Cepheid variables, and the "blue" limit for the longer period Miras and red variables (Becker 1987). In this *Letter* we discuss the nature of the variations which we have detected for the five K giants and one supergiant included in our HF precision radial velocity program.

II. OBSERVATIONS

All of the observations were made with the HF absorption cell and f/8.2 coudé spectrograph at the Canada-France-Hawaii 3.6 m telescope. Details of the HF absorption cell technique for obtaining precise relative velocities have been given elsewhwere (Campbell, Walker, and Yang 1988). The K giants and K supergiant in the program are brighter than the dwarfs and subgiants so that exposure times are normally less than 500 s to achieve the required $S/N > 1000$. Although the HF absorption cell technique overcomes "guiding" errors, it does not eliminate *all* systematic errors; a small correction is applied to all the velocities in each observing run based on the average change in velocity of the nonvariable velocity dwarfs in that run. These observing run corrections, which are of the order of 10 m s^{-1}, are important for the dwarfs but less significant for the giants where the velocity variations can be >100 m s^{-1}.

III. THE RADIAL VELOCITY VARIATIONS

In Figure 1 the relative velocity, V (different zero points for each star), is plotted against time for each of the stars in Table 1. The bars associated with each point correspond to $\pm 2\sigma_k$, where σ_k (the internal error) is the standard deviation of the kth velocity estimated in the usual way from the dispersion of velocities derived from different stellar lines in the kth spectrum (see Campbell, Walker, and Yang 1988). For $\pm 2\sigma_k$ one would expect a line of constant velocity to intersect 95% of the points for any star of its velocity is nonvarying, but clearly, from Figure 1, this is not true for any of them particularly on long time scales. To quantify the variations, we follow the treatment in Irwin *et al.* (1989). The velocities are grouped by observing night (duration less than a day), observing run (durations from a day to a month), and observing season (durations from a month to a year) and also into one overall group. Table 1 lists for each star and each grouping

$$\chi^2/\nu = \left[\sum_k (V_k - \langle V \rangle_k)^2 \Big/ \sigma_k^2\right] \Big/ \nu , \qquad (1)$$

where V_k is the observed velocity, $\langle V \rangle_k$ is the weighted mean velocity of the group to which V_k belongs, σ_k is the estimated internal error of V_k, and ν is the number of velocities minus the number of independent group means used to fit those velocities. (V_k and σ_k have been slightly modified to account for the observing run corrections in the overall and observing season

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TABLE 1

χ^2/ν FROM THE VELOCITY SCATTER ABOUT GROUP MEANS

Name/ HR[c]	Group	ν	$(\chi^2/\nu)^a$	$(p_{\chi^2})^b$
	night[d]	8	0.52	8.4D-0001
α Ari	run[e]	13	1.12	3.4D-0001
HR 617	season[f]	19	6.12	5.4D-0016
	all[g]	25	7.02	1.4D-0024
	night[d]	13	0.83	6.2D-0001
α Tau	run[e]	18	2.81	6.2D-0005
HR 1457	season[f]	26	23.32	2.7D-0111
	all[g]	32	86.03	1.4D-0563
	night[d]	5	2.52	2.7D-0002
β Gem	run[e]	7	2.14	3.7D-0002
HR 2990	season[f]	14	5.87	1.1D-0011
	all[g]	20	6.29	2.3D-0017
	night[d]	6	0.88	5.1D-0001
α Hya	run[e]	14	3.48	1.0D-0005
HR 3748	season[f]	26	31.29	9.5D-0155
	all[g]	32	107.49	3.4D-0711
	night[d]	20	3.42	3.4D-0007
Arcturus	run[e]	28	18.34	1.0D-0090
HR 5340	season[f]	38	66.48	3.1D-0509
	all[g]	42	99.23	9.9D-0858
	night[d]	5	2.68	2.0D-0002
ε Peg	run[e]	7	7.01	2.2D-0008
HR 8308	season[f]	17	638.37	2.1D-2333
	all[g]	21	768.03	5.9D-3472

[a] Value of χ^2/ν calculated from eq. (1).
[b] False alarm probability calculated from χ^2 distribution.
[c] Bright Star number; Hoffleit 1982.
[d] Data grouped by observing night.
[e] Data grouped by observing run.
[f] Data grouped by observing season.
[g] All data included in group.

groupings.) Table 1 also gives false alarm probabilities p_{χ^2} calculated from the χ^2 distribution (Press *et al.* 1986, p. 165). Table 2 lists for each star spectral types (Garrison 1989), $V-K$ colors (Johnson *et al.* 1966), K line emission intensities (visual estimates) and widths (Wilson as reported by Zirin 1976), the standard deviations of our velocities about the overall mean, and the false alarm probabilities calculated from periodogram analysis. Defining a figure of merit by the maximum of the weighted periodogram (eq. [5] of Irwin *et al.* 1989) for all periods exceeding 25 days, these false alarm probabilities are calculated as the fraction of 100 randomized data sets having a figure of merit which exceeds that of the observed data.

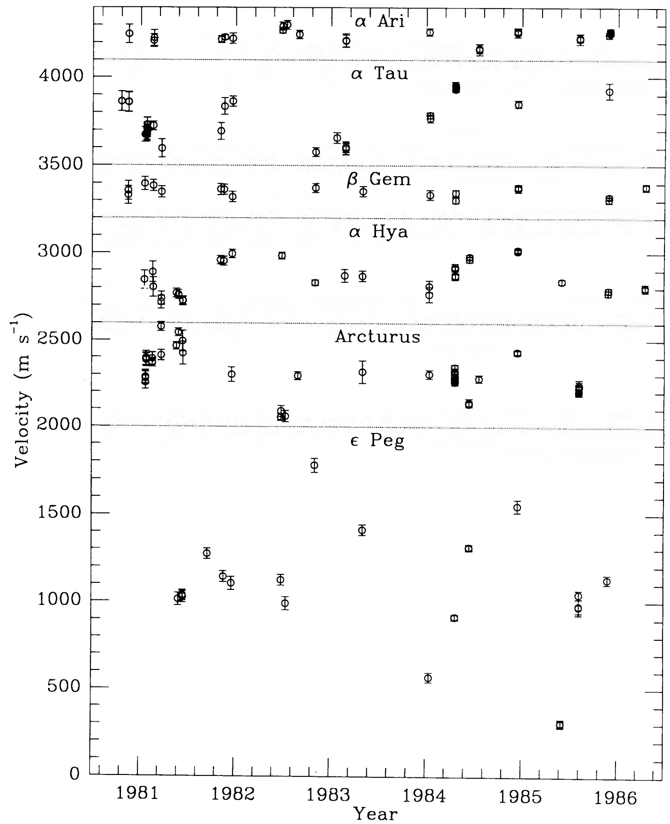

FIG. 1.—The variation of the radial velocities of the stars in Table 1 between 1980 and 1986. The zero points are arbitrary for each star. The bars correspond to ± 2 times the internally estimated standard deviations of the velocities.

IV. DISCUSSION

Several conclusions can be drawn from the χ^2/ν statistics in Table 1 and the periodogram false alarm probabilities of Table 2:

TABLE 2

ADDITIONAL DATA

NAME	SPECTRAL TYPE[a]	$(V-K)^b$	K LINE[c] Intensity	K LINE[c] Width (km s^{-1})	$(\sigma_V)^d$ (m s^{-1})	$(p_{per})^e$
α Ari	K2 IIIab	2.64	2	72	34	0.05
α Tau	K5 III	3.67	3	86	117	0.00
β Gem	K0 IIIb	2.23	1	74	26	0.00
α Hya	K3 II–III	3.16	3	100	102	0.00
Arcturus	K1.5 III Fe-0.5	2.95	3	80	116	0.00
ε Peg	K2 Ib	3.20	4	158	346	0.00

[a] Garrison 1989.
[b] Johnson *et al.* 1966
[c] Wilson as reported by Zirin 1976.
[d] Standard deviation of our velocities about long-term mean.
[e] False alarm probability calculated from the periodogram analysis. See text.

1. α Hya and α Tau show no significant variations in velocity on time scales less than a day, and α Ari shows no significant variations on time scales less than a month.

2. β Gem, Arcturus, and ϵ Peg show small but significant ($p_{\chi^2} < 3\%$) variations on time scales of less than a day.

3. All of the stars show significant variation on long time scales which, in all cases, exceeds the variations at shorter time intervals.

4. The variations show significant periodicity according to the false alarm probabilities.

Except for Arcturus which is discussed elsewhere, the observed data are too sparse to distinguish the correct period from aliases.

The σ_V statistics of Table 2 provide a measure of the suitability of these stars as radial velocity standards. With high resolution and a stable spectrograph, the external errors of a single photographically derived velocity can be reduced to the 150 m s^{-1} level (Scarfe 1985). For substantially higher errors we still confirm the suggestion (Batten *et al.* 1983) that ϵ Peg is not a suitable radial velocity standard. If errors slightly higher than Scarfe has obtained are acceptable, then α Tau, α Hya, and Arcturus are suitable standards. α Ari and β Gem are suitable standards for all but the most precise radial velocity determinations.

The velocity variations we see were not detected by Traub, Mariska, and Carleton (1978) who looked for stellar analogs of the solar 5 minute oscillations using a PEPSIOS scanner in a range of G, K, M giants and supergiants which included all but ϵ Peg and α Hya from Table 1. Their 3 σ confidence level varied from 9 m s^{-1} for Arcturus to 46 m s^{-1} for β Gem, but, while the total exposure time for Arcturus was 12 hr, it was only just over 1 hr for each of the other stars which would have prevented their detection of the variations we report here (although they must have been close to detection of the short-period variations in Arcturus).

The stars of Table 1 all vary in light according to Hoffleit (1982); α Tau has varied between 0.75 and 0.95 in V while ϵ Peg has varied between 0.7 and 3.5 in V and had a flare episode in 1972 (Wood 1972). All of the stars on the red side of the hot corona–massive cool wind dividing line (Ayres *et al.* 1981) have highly variable chromospheric He I λ10830; some of them, such as Arcturus, show a periodic variation which might be associated with rotation according to O'Brien and Lambert (1986) and Lambert (1987). One might expect rotation periods of about a year or more for some of our stars (Gray and Nagar 1985; Lambert 1987). In the presence of persistent surface features or large convection cells, this rotation could lead to quasi-periodic long-term variations of the type which we see. If the radial velocity and light variations are related to Cepheid or RR Lyrae–type pulsation, one would not expect periods greater than about 100 days, while the Mira episodes tend to be on time scales of years. The lack of large photometric variations for the giants makes a connection with the Mira variables doubtful. However, as Irwin *et al.* (1989) pointed out, the data, even in the case of Arcturus which has the best time coverage, are insufficient to identify pulsation with certainty as the cause of the velocity variations.

The chromospheric activity implies mechanical heating but it is not clear that the *short*-term velocity variations are the cause because the K line emission (Table 2) is not correlated with the presence or absence of short-term radial velocity variations; the three stars with no detected short-period variations have just as strong K line emission as those which do. On the other hand, the K line measurements were made over a decade before our velocity measurements, and the K line intensities show long-term variations.

There *is* a nice correlation (see Table 2) between σ_V, the stellar velocity scatter about the *long*-term mean, and both the K line intensity and the degree of variation in the He I λ10830 reported by Lambert (1987) and O'Brien and Lambert (1986) (the latter were observed during the time of our velocity measurements). These correlations may indicate the presence of *long*-period, nonradial pulsations (gravity modes) which, for giants and supergiants might transport mechanical energy into the chromospheres. Such a mechanism *cannot* explain dwarf chromospheric activity; 61 Cygni A (K5 V), for example has a K line emission intensity of 5 according to Wilson (Zirin 1976) but no detectable velocity variations (Campbell, Walker, and Yang 1988).

Without more extensive data, preferably supported by photometry, we cannot say whether these stars represent an extension of the Mira variables or the Cepheids and RR Lyrae stars or, whether they represent a new class of variable altogether. Indeed, we may not be dealing with a homogeneous group. The supergiant, ϵ Peg, is probably a semiregular variable. The possible relationship of the short-term variations to nonradial pulsations is not established, but there appears to be a link between long-term velocity variations and chromospheric activity.

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REFERENCES

Ayres, T. R., Linsky, J. L., Vaiana, G. S., Golub, L., and Rosner, R. 1981, *Ap. J.*, **250**, 293.

Batten, A. H. 1983, *Bull. Inf. Centre Donnèes Stellaires*, **24**, 3.

Batten, A. H., Harris, H. C., McClure, R. D., and Scarfe, C. D. 1983, *Pub. Dom. Ap. Obs.*, **16**, 143.

Becker, S. A. 1987, in *Stellar Pulsation*, ed. A. N. Cox, W. M. Sparks, and S. G. Starrfield (New York: Springer), p. 16.

Campbell, B., and Walker, G. A. H. 1979, *Pub. A.S.P.*, **91**, 540.

Campbell, B., Walker, G. A. H., and Yang, S. 1988, *Ap. J.*, **331**, 902.

Garrison, R. F. 1989, in *Observer's Handbook*, ed. R. L. Bishop (Toronto: The Royal Astronomical Society of Canada), p. 169.

Gray, D. F., and Nagar, P. 1985, *Ap. J.*, **298**, 756.

Hoffleit, D. 1982, *The Bright Star Catalogue* (New Haven: Yale University Observatory).

Irwin, A. W., Campbell, B., Morbey, C. L., Walker, G. A. H., and Yang, S. 1989, *Pub. A.S.P.*, **101**, 147.

Johnson, H. L., Mitchell, R. I., Iriarte, B., and Wisńiewski, W. Z. 1966, *Comm. Lunar Planet. Lab.*, **4**, 99.

Lambert, D. L. 1987, *Ap. J. Suppl.*, **65**, 255.

O'Brien, G. T., and Lambert, D. L. 1986, *Ap. J. Suppl.*, **62**, 899.

Press, W. H., Flannery, B. P., Teukolsky, S. A., and Vetterling, W. T. 1986, *Numerical Recipes* (Cambridge: Cambridge University Press).

Scarfe, C. D. 1985, in *IAU Symposium 111, Calibration of Fundamental Stellar Quantities*, ed. D. S. Hayes, L. E. Pasinetti, and A. G. Davis Philip (Dordrecht: Reidel), p. 583.
Smith, P. H., McMillan, R. S., and Merline, W. J. 1987, *Ap. J.* (*Letters*), **317**, L79.
Traub, W. A., Mariska, J. T., and Carleton, N. P. 1978, *Ap. J.*, **223**, 583.
Wood, R. J. 1972, *IAU Circ.*, No. 2450.
Zirin, H. 1976, *Ap. J.*, **208**, 414.

Note added in proof.—R. D. McClure *et al.* (*Pub. A.S.P.*, **97**, 740 [1985]) find an apparent orbit of 576 days with a semiamplitude of 0.7 km s^{-1} for the yellow giant (K5–M0 III) HR 152 which D. W. Latham *et al.* (*Nature*, **339**, 38 [1989]) suggest is evidence for a brown dwarf companion. In light of the results reported here, we think HR 152 is more likely to be a long-period velocity variable.

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