J. Astrophys. Astr. (1990) **11**, 255–263

The Spectroscopic Orbit of 6 Draconis*

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Received 1989 July 7; revised 1990 March 21; accepted 1990 April 10

Abstract. 6 Dra has long been known to show small variations in radial velocity, and there is photometric and spectroscopic evidence that its spectrum is composite. We show, largely on the basis of a generous number of photoelectric radial velocities mainly obtained at Cambridge and Fick observatories, that the orbit is of mild eccentricity and has a period of 562 days and a semi-amplitude of 7 km s^{-1}. *IUE* observations show that the spectrum between 1600 and 1800 Å is consistent with its arising from a late-A main-sequence companion.

Key words: radial velocities—spectroscopic binaries—orbits—stars, individual—6 Dra

1. Introduction

6 Draconis (HR 4795, HD 109551; $12^h34^m44^s$, + 70°1'18" (2000)) is a fifth-magnitude star and is therefore clearly identifiable by the naked eye that is sufficiently well backed up by a knowledge of the heavens: it is to be found only 15′ north-following the brighter star *k* Dra, with which it forms a pair reminiscent of Mizar and Alcor—from which system, indeed, it may be located, being nearly halfway from there to Polaris.

2. Spectral type, photometry, and duplicity

In the earliest days of spectral classification, 6 Dra was assigned by Miss Maury (1897) to Group XlVa, corresponding to what has subsequently become known as class G. The *Henry Draper Catalogue* (Cannon & Pickering 1920) calls its type K0. When spectroscopic criteria of stellar luminosity were developed (Adams 1916), 6 Dra was recognized as a giant star: Rimmer (1925) found its absolute magnitude to be + 1.1, and subsequently Adams *et al.* (1935) gave a value of + 0.3 and also revised the

* Based in part on observations made with the Cambridge radial-velocity spectrometer, in part on those made with the Erwin W. Fick Observatory spectrometer, and in part on those made by the International Ultraviolet Explorer and collected at the Villafranca Satellite Tracking Station of the European Space Agency.

spectral type to K2. Wilson (1976) obtained $M_V = -1.1$ from the K-line width criterion (Wilson & Bappu 1957); in a footnote he remarked "Moderate rotational broadening. Measured M_V(K) too bright". A referee, Dr D. M. Popper, has kindly explained that remark to us (we are ashamed of not having understood it ourselves when this paper was first submitted for publication): if the star shows significant rotation, the K line is broadened by it, and since the inferred luminosity increases with the width measured for that line the luminosity comes out too high. However, the comment on rotational broadening is actually inaccurate, since radial-velocity traces show line-widths in 6 Dra to be in the range typical of giant stars.

Photometry by Haggkvist & Oja (1966) yielded for 6 Dra the magnitude and colour $V = 4^m.94$, $(B-V) = 1^m.313$; Eggen (1966) gave $V = 4^m.89$, $(B-V) = 1^m.31$, $(U-B) = 1^m.13$:. Such a combination of colours immediately arouses curiosity: all normal K giants with $(B-V)$ as great as $1^m.3$ have $(U-B) > (B-V)$. The obvious explanation for the discrepancy in the colours is that the ultraviolet end of the spectrum is held up by a hot companion. Such a possibility is strongly supported by the very large value, $0^m.25$, of the quantity res(k) derived from Copenhagen photometry (Hansen & Kjaergaard 1971): the value is several times larger than the threshold at which res(k) definitely indicates abnormality in the distribution of light in the spectrum. Still further evidence pointing in the same direction is the detailed spectral classification given by Keenan (1983) and Keenan & Yorka (1985) for 6 Dra: K3 III CN – 1 CH – 1 H,K – 1 Fe – 1 Hδ 1. The classification shows that all the principal features in the violet part of the spectrum are weakened apart from Hδ which is strengthened—exactly what would be expected if the spectrum of a normal K giant were compounded with that of an A- or F-type main-sequence companion which is not quite bright enough for the composite nature of the spectrum to be explicitly apparent. That a companion of some sort does exist is rendered certain by the orbital motion documented in this paper; the best estimate that we can make of its type, on the basis of the evidence presented above, is late A. We view the still more recent classifications of 6 Dra by Keenan & Yorka (1988: K2.5 III Fe – 2 Hδ I) and Keenan & McNeil (1989: K2.5 III CN – 2 Hδ 1 Fe – 1) as indicating the continuing efforts of the classifiers to come to terms with a spectrum that is incipiently composite.

3. *IUE* spectroscopy

A low-resolution, short-wavelength *IUE* spectrum clarifies the nature of the companion. As displayed in Fig. 1, the composite ultraviolet spectrum has a sharp decline in the energy distribution between 1750 and 1700 Å. Since a fifth-magnitude K giant like 6 Dra would be expected to show barely any continuum flux between 1700 and 1900 Å in such a 120-minute exposure, we conclude that the observed flux in that range is due to the companion. We compared the spectrum with other *IUE* spectra of late-A to early-F main-sequence stars from the *IUE Ultraviolet Spectral Atlas* (Wu *et al.* 1983). According to the 1730-Å flux of about 1.4×10^{-13} erg cm^{-2} s^{-1} Å^{-1} and a distance modulus of $6^m.0$ (see below), and according to the shape of the spectrum between 1650 and 1750 Å, the companion of 6 Dra is an A8 to A9 main-sequence star. Since the flux at 1730 Å varies strongly with spectral type, the accuracy of our classification relies mainly on the closest comparison stars in the spectral atlas, namely 51 Tau (A8 V) and 44 Oph (A9 V).

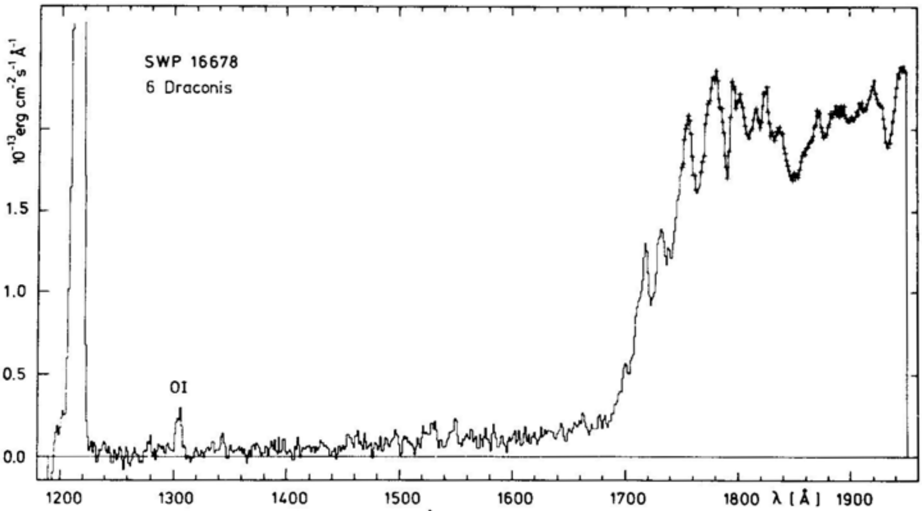

Figure 1. IUE spectrum of 6 Draconis (large aperture, 120 minutes' exposure). The flux at Earth is given. The spectrum is saturated at wavelengths above about 1750 Å, where it is denoted by crosses. Lyman-α emission is geocoronal.

The comparison with late-A main-sequence stars also shows that the 0 I 1300-Å emission blend is from the K giant. Its flux at Earth is about 8×10^{-14} erg cm^{-2} s^{-1}. With a distance modulus of 6^{m} and a K-giant radius of about 35 $R_{\odot}$ according to its spectral type and luminosity, 6 Dra is found to have an O I surface flux of about 3×10^{3} erg cm^{-2} s^{-1}, normal for a K giant with a relatively low activity level (*cf.* Ayres *et al.* 1981).

6 Dra has been observed to have circumstellar Ca II H and K lines (Reimers 1977), although the star is supposedly located in a region of the HR diagram where stars do not generally show circumstellar lines. A high-resolution long-wavelength *IUE* spectrum confirms that finding: 6 Dra has broad circumstellar Mg II absorption lines with a shortward edge at about – 60 km s^{-1}. Mg II emission is highly asymmetrical and apparently red-shifted owing to circumstellar absorption on the shortward side. It is difficult to see why the duplicity of 6 Dra should be the cause of the broad circumstellar absorption, since the companion star is not close in the sense in which that term is understood in connection with binary stars, and since rotation seems to be normal. One might suspect that, if circumstellar absorption were anything like as pronounced in the Ca II lines as it is in Mg II, it could so cut into the H and K profiles as to cause the Wilson–Bappu effect to underestimate the luminosity of 6 Dra. However, we do not think that that is really so. For one thing, even if 6 Dra were of absolute magnitude –2 or – 2.5, at which circumstellar Ca II and Mg II lines would be expected, the actual profiles of Mg II h and k would still be extremely peculiar. In a normal, single bright K giant the circumstellar line is far shifted shortwards, and the absorption never extends redwards to zero velocity, whereas in 6 Dra deep circumstellar absorption is found from – 60 all the way to 0 km s^{-1}. Furthermore, a high-resolution tracing of the violet spectrum of 6 Dra, kindly obtained for us on 1989 December 14 with the Lick 120-inch telescope and the Hamilton echelle spectrometer (Vogt 1987) by Mr. A. Misch, shows no unusual structure in the Ca II lines. Although

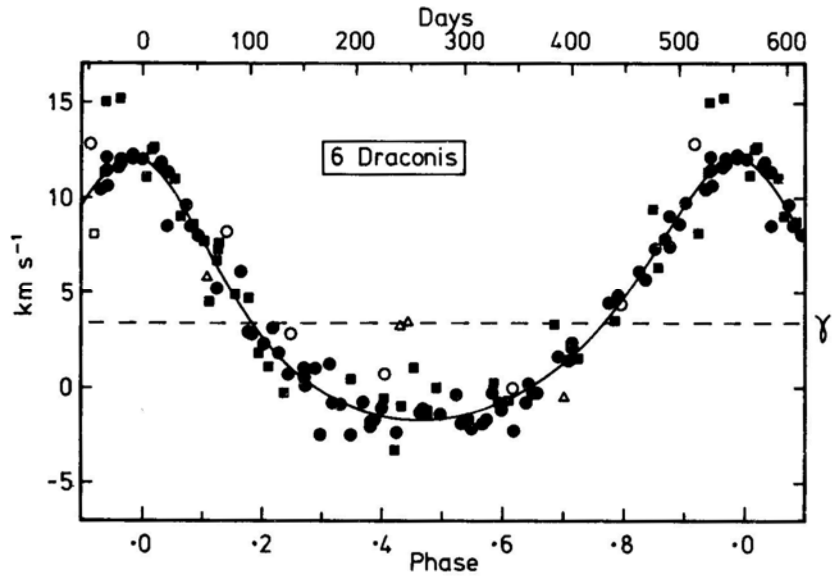

Figure 2. The computed radial-velocity curve of 6 Draconis, with the measured radial velocities plotted. Photoelectric observations from Cambridge, Coravel and the DAO are shown as filled circles, while those made at the Erwin W. Fick Observatory of Iowa State University are represented by filled squares. Open symbols are used for the published photographic data from Mount Wilson (triangles; not used in the solution of the orbit) and Lick (circles).

circumstellar absorption has been seen in the 6 Dra Ca II profiles, and such absorption has proved to be variable in other stars (Reimers 1977), it is doubtful whether it would ever be of such strength and extent to vitiate the K-line absolute magnitude determined for 6 Dra by the Wilson-Bappu method. In conclusion, we must admit that we have no good explanation for the peculiar circumstellar Mg II lines of 6 Dra, and no reason to dispute the absolute magnitude of $-1^{m}.1$ given by Wilson (1976). Such a luminosity would also be consistent with the fact that the A8 V companion appears to be detectable but not obtrusive in the violet part of the integrated spectrum of the system.

4. Radial velocities and orbit

The radial velocity of 6 Dra was first measured with the Mills Spectrograph on the 36-inch refractor of Lick Observatory, where its variability soon came to attention and was announced by Campbell (1922) but appears not to have been followed up. The mean velocity given by four low-dispersion Mount Wilson plates was published by Christie & Wilson (1938); the individual data have since been published by Abt (1973).

The present authors placed 6 Dra independently upon the observing programmes of the photoelectric radial-velocity spectrometers at Cambridge (Griffin 1967) and Fick (Beavers & Eitter 1977) observatories; they subsequently learnt of their shared interest in the object and agreed to join forces in this paper. Altogether there are 74 ‘‘Cambridge’’observations (included in that number are a few obtained by R.F.G.

Table 1. Radial-velocity measurements of 6 Draconics.

Date			MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}	Source*
1919	Apr	27.46	22075.46	+2.8	$\overline{38}.249$	+1.8	Lick
	July	24.45	163.45	+0.7	.406	+2.3	Lick
1920	May	6.32	22450.32	+12.8	$\overline{38}.916$	+2.5	Lick
1921	June	3.21	22843.21	0.0	$\overline{37}.616$	+0.5	Lick
1922	Mar	25.50	23138.50	+8.2	$\overline{36}.142$	+2.8	Lick
1923	Mar	27.50	23505.50	+4.4	$\overline{36}.795$	−0.1	Lick
1930	May	13.23	26109.23	+3.2	$\overline{31}.431$	+4.9	Mt. Wilson
		20.18	116.18	+3.4	.443	+5.1	Mt. Wilson
1931	May	29.18	26490.18	+5.8	$\overline{30}.109$	−1.4	Mt. Wilson
1935	May	24.17	27946.17	−0.5	$\overline{28}.702$	−1.8	Mt. Wilson
1978	Mar	29.99	43596.99	−1.9	0.567	−0.7	Cambridge
	Apr	14.97	612.97	−0.8	.595	0.0	Cambridge
	Nov	20.22	832.22	+12.2	.986	+0.1	Cambridge
1979	Jan	13.13	43886.13	+8.5	1.082	−0.3	Cambridge
	Mar	8.01	940.01	+2.9	.178	−0.8	Cambridge
	Apr	29.07	992.07	+0.5	.270	+0.1	Cambridge
	May	14.87	44007.87	−2.5	.299	−2.3	Cambridge
	June	11.91	035.91	−2.5	.348	−1.5	Cambridge
	Nov	28.22	205.22	−0.3	.650	−0.4	Cambridge
	Dec	31.14	238.14	+1.4	.708	−0.1	Cambridge
1980	Mar	10.02	44308.02	+5.7	1.833	−0.5	Cambridge
	Apr	29.19	358.19	+8.1	.922	−2.5	Fick C
	May	5.99	364.99	+10.4	.934	−0.6	Cambridge
		8.17	367.17	+11.3	.938	+0.1	Fick A
		9.17	368.17	+15.0	.940	+3.8	Fick B
		10.91	369.91	+12.1	.943	+0.8	Cambridge
		23.15	382.15	+15.2	.965	+3.3	Fick B
	July	22.88	442.88	+9.6	2.073	+0.3	Cambridge
1981	Jan	16.11	44620.11	−1.7	2.389	−0.2	Cambridge
	Feb	5.05	640.05	−2.4	.424	−0.7	Cambridge
		20.32	655.32	+1.0	.451	+2.7	Fick A
	Mar	6.29	669.29	−1.3	.476	+0.4	Fick A
	May	4.92	728.92	−0.3	.582	+0.7	Cambridge
		6.19	730.19	+0.2	.585	+1.2	Fick A
		20.13	744.13	−0.7	.609	−0.1	Fick A
		24.94	748.94	−2.3	.618	−1.8	Cambridge
	July	4.93	789.93	+1.6	.691	+0.6	Cambridge
1982	Mar	5.96	45033.96	+5.2	3.125	−1.1	Cambridge
		6.27	034.27	+7.3	.126	+1.0	Fick B
	Apr	7.89	066.89	+2.8	.184	−0.6	Cambridge
		14.23	073.23	+1.8	.195	−1.1	Fick B
		23.16	082.16	+1.1	.211	−1.2	Fick B
	May	7.15	096.15	−0.3	.236	−1.7	Fick A
		11.96	100.96	+0.7	.245	−0.4	Cambridge
		25.93	114.93	+1.0	.270	+0.6	Cambridge
	June	29.94	149.94	−0.9	.332	−0.1	Cambridge
	July	27.87	177.87	−1.8	.382	−0.4	Cambridge

Table 1. Continued.

Date			MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}	Source*
1983	Feb	4.44	45369.44	+1.6	3.723	−0.3	DAO
	Apr	20.24	444.24	+6.3	.856	−1.1	Fick A
		24.05	448.05	+6.3	.863	−1.4	Cambridge
	May	10.04	464.04	+8.6	.891	−0.5	Cambridge
	June	8.93	493.93	+10.6	.944	−0.8	Cambridge
		21.90	506.90	+11.8	.967	−0.1	Cambridge
	July	2.93	517.93	+12.1	.987	0.0	Cambridge
	Aug	3.87	549.87	+8.5	4.044	−2.2	Cambridge
1984	Jan	2.15	45701.15	+1.2	4.313	+1.7	Cambridge
	Feb	9.05	739.05	−2.1	.381	−0.7	Cambridge
		21.35	751.35	−0.6	.403	+1.0	Fick A
	Apr	13.95	803.95	−1.4	.496	+0.3	Cambridge
		29.06	819.06	−0.4	.523	+1.1	Cambridge
	May	13.01	833.01	−2.2	.548	−0.8	Cambridge
	June	8.93	859.93	−1.2	.596	−0.4	Cambridge
	July	11.91	892.91	−0.3	.655	−0.5	Cambridge
	Nov	8.57	46012.57	+7.8	.868	−0.1	DAO
	Dec	21.18	055.18	+11.4	.944	+0.1	Cambridge
1985	Jan	1.14	46066.14	+11.6	4.963	−0.2	Cambridge
		23.06	088.06	+12.0	5.002	0.0	Cambridge
		26.45	091.45	+11.1	.008	−0.8	Fick A
	Feb	8.46	104.46	+11.7	.031	+0.5	Cambridge
		27.38	123.38	+9.0	.065	−0.7	Fick A
	Mar	26.31	150.31	+4.5	.113	−2.5	Fick A
	May	2.20	187.20	+4.7	.179	+1.1	Fick A
		29.97	214.97	+1.8	.228	+0.1	Cambridge
	July	2.94	248.94	+1.0	.289	+1.0	Cambridge
1986	Jan	17.13	46447.13	+0.2	5.641	+0.3	Cambridge
	Feb	10.40	471.40	+3.3	.685	+2.4	Fick A
		14.01	475.01	+1.6	.691	+0.6	Cambridge
		26.99	487.99	+2.1	.714	+0.4	Cambridge
	Apr	7.25	527.25	+3.5	.784	−0.6	Fick A
		10.01	530.01	+4.8	.789	+0.5	Coravel
	May	12.13	562.13	+9.4	.846	+2.5	Fick A
		13.95	563.95	+7.3	.849	+0.3	Cambridge
		27.94	577.94	+7.4	.874	−0.9	Cambridge
	June	11.93	592.93	+9.7	.901	+0.1	Cambridge
	Aug	24.81	666.81	+11.8	6.033	+0.6	Coravel
	Dec	7.19	771.19	+3.1	.218	+1.1	Cambridge
1987	Jan	6.11	46801.11	+0.1	6.272	−0.3	Cambridge
	Feb	1.07	827.07	−0.8	.318	−0.2	Cambridge
		18.41	844.41	+0.4	.349	+1.5	Fick A
	Mar	1.23	855.23	−0.8	.368	+0.5	Coravel
		18.97	872.97	−1.1	.400	+0.4	Cambridge
		31.34	885.34	−3.3	.422	−1.6	Fick A
	Apr	6.25	891.25	−1.0	.432	+0.7	Fick A
		27.87	912.87	−1.2	.471	+0.5	Cambridge
	May	1.17	916.17	−1.4	.477	+0.3	Fick A
		8.16	923.16	0.0	.489	+1.7	Fick A
		31.98	946.98	−1.9	.531	−0.4	Cambridge

Table 1. Continued.

Date			MJD	Velocity km s⁻¹	Phase	(O – C) km s⁻¹	Source*
	June	24.90	970.90	−1.7	.574	−0.6	Cambridge
	Dec	10.21	47139.21	+9.0	.874	+0.8	Cambridge
1988	Jan	31.44	47191.44	+12.0	6.967	+0.1	DAO
	Feb	28.35	219.35	+12.5	7.016	+0.8	Fick A
	Mar	1.34	221.34	+12.6	.020	+1.0	Fick A
		14.95	234.95	+11.3	.044	+0.6	Coravel
		21.30	241.30	+11.0	.055	+0.8	Fick A
	Apr	7.27	258.27	+8.6	.086	0.0	Fick A
		12.88	263.88	+8.0	.096	0.0	Cambridge
		17.21	268.21	+7.7	.103	+0.1	Fick A
		30.17	281.17	+6.7	.126	+0.4	Fick A
	May	1.17	282.17	+7.6	.128	+1.4	Fick A
		16.13	297.13	+4.9	.155	+0.1	Fick A
		21.91	302.91	+6.1	.165	+1.9	Cambridge
	June	12.90	324.90	+2.3	.204	−0.2	Cambridge
	Nov	5.23	470.23	−1.3	.463	+0.4	Coravel
	Dec	20.13	515.13	−1.7	.543	−0.3	Cambridge
1989	Feb	11.03	47568.03	−0.8	7.637	−0.6	Cambridge
	Mar	26.87	611.87	+2.3	.715	+0.6	Coravel
	Apr	29.13	645.13	+4.4	.774	+0.7	Coravel
	May	26.98	672.98	+6.1	.824	+0.3	Cambridge

* Sources of radial velocities or descriptions of the equipment with which they were obtained, with the weights attributed in the 6 Dra orbit:

Lick: Campbell & Moore (1928); weight 0.15
Mt. Wilson: Christie & Wilson (1938); weight 0
Cambridge: Griffin (1967); weight 1
Fick: Beavers & Eitter (1977, 1986); weight 0.3 (A), 0.15 (B), 0.05 (C)
DAO: Fletcher et al. (1982); weight 1
Coravel: Baranne, Mayor & Poncet (1979); weight 1

with other spectrometers) and 34 Fick measurements, the first 14 of which have already been published by Beavers & Eitter (1986). The Fick data were already as nearly as possible on the IAU scale (Beavers & Eitter 1986); an effort has been made to place the Cambridge velocities on the same scale by the subtraction of 0.8 km s^{-1} from the raw values (*cf.* Griffin & Herbig 1981).

A preliminary orbit solution utilizing the photoelectric measurements alone yielded a period quite accurate enough to enable the six early Lick velocities to be phased to the correct cycle without ambiguity. The Lick data showed r.m.s. residuals of 2.0 km s^{-1} , which were in part systematic: their scatter was 1.3 km s^{-1} about a mean value of + 1.6 ± 0.6 km s^{-1}. We do not attach great significance to the systematic offset, which is in any case only just significant statistically. Not only is 6 Dra, whose declination is + 70°, in an unusual part of the sky, but most of the observations were made at unusual hour angles (10 hours west in one instance!), so atmospheric dispersion and possibly mechanical flexure may have had unusual effects. We have thought it safe to use the Lick velocities, as they stand, in the solution of the orbit and to attribute to them the weight to which their raw residuals entitle them: in that way some benefit to the period determination is gained from the greatly increased time base that they offer, but, since their combined weight only represents about one hundredth of that of the total data set, any systematic zero-point difference that they may show has negligible effect on the derived γ-velocity. The Mount Wilson velocities are not expected to be of high accuracy and have not been utilized in the solution.

All the velocities are listed in Table 1, with their respective sources noted. The Fick measurements are routinely graded A, B, or C at the time of reduction; typical Standard deviations for the three grades have been determined (Beavers & Eitter 1986). The corresponding relative weights have been attributed to them, and then they have been globally weighted to bring their weighted variance into equality with that of the Cambridge data. The final orbital solution has the following elements:

$P = 561.7 \pm 0.3$ days	$T = \mathrm{MJD}\ 45525 \pm 5$
$\gamma = +3.38 \pm 0.09\ \mathrm{km\,s^{-1}}$	$a \sin i = 51.4 \pm 0.9$ Gm
$K = 6.90 \pm 0.12\ \mathrm{km\,s^{-1}}$	$f(m) = 0.0172 \pm 0.0009\ M_\odot$
$e = 0.262 \pm 0.017$	
$\omega = 9 \pm 4$ degrees	R.m.s. residual (unit weight) $= 0.8\ \mathrm{km\,s^{-1}}$

Acknowledgements

We are very grateful to Mr A. Misch for obtaining a spectrum of 6 Dra. The Fick Observatory contribution to this paper owes a great deal to the work of Dr W. I. Beavers, and has been supported in part by the NSF and the Department of the Air Force. R.F.G. is grateful to the Geneva and Dominion Astrophysical observatories for the use of their radial-velocity instruments, and to SERC for travel grants. D. R. is pleased to acknowledge the use of the *IUE* satellite; his travelling to make the *IUE* observations has been supported by the Deutsche Forschungsgemeinschaft.

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