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Alpha Cygni as a Radial-Velocity Variable

M. Parthasarathy* & David L. Lambert *Department of Astronomy, University of Texas, Austin, Texas 78712-1083, USA*

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Abstract One hundred and twentythree radial velocities for α Cyg are derived between December 1977 and October 1982. These photospheric velocities are derived from N I lines near 8700 Å. Semiregular variations in radial velocities are present with periods of 7 to 20 days. The range of variation of 14.3 kms^{-1} observed in the present radial velocities of α Cyg is close to the sum of the amplitudes (10.44 kms^{-1}) of all the pulsation periods from 7 to 101 days (Lucy 1976a) and is also approximately equal to micro and macro-turbulent velocities.

Key words: stars, radial velocities—supergiants—stars, pulsation

1. Introduction

Alpha Cygni (Deneb, spectral type A2 Iae) shows quasi-periodic variations of radial velocity (Paddock 1935). Such variations are characteristic of early-type Ia supergiants for which Abt (1957) showed that the time scale of variations was 10–100 days with an amplitude of about 10 km s^{-1}. For α Cyg, Paddock found a mean quasi-period of 11.7 days and an amplitude of ± 4.2 km s^{-1}. Lucy's (1976a) analysis of more than 400 radial velocities obtained by Paddock between 1927 and 1935 provided 16 modes with periods from 6.9 to 100.8 days, as well as a longer-term (~ 800 days) variation suggestive of orbital motion. Lucy (1976b) proposed that the 'macroturbulence' in the atmospheres of these supergiants is due to multiperiodic nonradial oscillations. Other recent studies of the radial velocity of α Cyg include those by Rosendhal (1972) and Inoue (1979).

Our study, which began as an attempt to monitor α Cyg's radial velocity during selected intervals of 14 to 21 days, was motivated by two factors. First, α Cyg is so bright that a spectrum of excellent quality is obtainable in a few minutes and, hence, regular observations of the star are possible without any interference with other observing programs. Second, since observations in the near-infrared are possible in daytime, the star may now be observed throughout the year from the northern hemisphere. In this paper we report the radial velocities of α Cyg derived from near-infrared N I lines.

2. Observations

Alpha Cygni was observed at the McDonald Observatory with the 2.7 m reflector and the coudé spectrometer. A spectral interval of about 100 Å centred at 8700 Å was

* Present address: Indian Institute of Astrophysics, Bangalore 560034

recorded with a Reticon detector (Vogt, Tull & Kelton 1978). For daytime observations our observing procedure was to follow the short (about 5 minutes) exposure on α Cyg with an exposure of equal length on the adjacent sky. The latter was subtracted from the former (star plus sky) and the difference (stellar) spectrum was recorded. In typical seeing conditions, the sky brightness was about 10 to 20 per cent of the stellar continuum. Day time observations were made only when the sky was devoid of clouds. Observations of Vega were made to check on systematic errors.

The 8700 Å region was chosen because it provides several high excitation lines of N I which are strong in Deneb (and Vega), but weak in the solar spectrum. Hence, all but major fluctuations of the sky brightness change the apparent continuum level of the 'stellar' spectrum, but not the stellar radial velocity. The radial velocities are based on the N I lines at 8680.283, 8683.401, 8686.149, 8703.248, 8711.707, and 8718.826 Å.

Radial velocities were derived using a cross-correlation program written by Dr. J. Tomkin. Velocities for Vega were determined by cross-correlation against a spectrum obtained on 1977 December 23. The velocity for that date was derived using the stellar N I lines and lines from a Fe-Ne hollow cathode lamp observed following the stellar observations. This reference spectrum of Vega was adopted for the cross-correlations with the Deneb spectra. Small changes in the instrumental setting were measured by cross-correlating the Fe-Ne spectra obtained following each observation of Deneb. Heliocentric radial velocities for Vega and Deneb are given in Table 1 and Table 2 respectively.

3. Discussion

The 13 observations of Vega give a mean radial velocity of = –13.67 kms $^{-1}$ (the standard deviation of an individual radial velocity measurement is 0.88 km s^{-1}), a value consistent with the velocity (–13.9 kms^{-1}) recommended by Wilson (1953) in his catalogue. Our observations of Vega during the period 1977 December to 1980 June show that the radial velocity is constant. However there have been reports on the

Table 1. Radial velocities of Vega from N I lines near 8700 Å.

	Date	Time (UT) h	m	Radial velocity (km s^{-1})
1977	December 23	22	21.5	–13.9
	December 25	00	13.0	–14.7
	December 30	00	33.5	–12.4
1978	May 16	11	41.0	–13.4
	November 25	00	38.0	–15.0
	November 26	22	12.0	–14.9
	November 27	01	02.0	–12.6
1979	December 31	19	35.0	–14.5
1980	May 28	12	36.0	–13.4
	May 29	12	39.0	–13.6
	May 30	12	52.0	–12.6
	June 2	12	21.0	–13.6
	June 25	10	24.0	–13.2

Table 2. Radial velocities (V_r) of Deneb from N I lines near 8700 Å.

Date JD 2440000+	V_r km s^{-1}	Date JD 2440000+	V_r km s^{-1}	Date JD 2440000+	V_r km s^{-1}
3501.441	−2.6	4537.612	−5.5	4677.409	−9.0
3502.514	−3.6	4539.598	−4.6	4681.023	−4.2
3507.526	−3.1	4540.566	−4.4	4683.025	−3.3
3644.976	−3.6	4542.530	−5.5	4683.976	−3.1
3837.539	−4.2	4543.529	−4.5	4704.115	−8.8
3839.415	−6.3	4572.551	−4.2	4704.234	−7.8
3839.554	−6.0	4573.545	−3.6	4720.150	−8.6
4239.323	−5.9	4574.562	−3.2	4741.981	−9.8
4241.309	−3.3	4575.526	−2.5	4742.976	−5.7
4379.975	0.0	4576.517	−2.2	4744.985	−8.6
4388.043	−5.9	4600.517	−6.8	4745.971	−8.8
4389.037	−3.8	4602.550	−8.1	4746.980	−7.8
4390.047	−2.0	4604.550	−5.2	4771.921	−2.4
4393.023	−2.7	4606.549	−3.5	4772.865	−4.5
4394.025	−3.4	4632.202	−3.7	4773.902	−4.0
4415.941	−4.2	4632.217	−3.5	4774.913	−4.0
4439.977	−2.2	4632.234	−5.5	4805.812	−6.8
4441.004	−0.2	4632.299	−4.4	4807.856	+3.2
4441.987	−0.7	4632.372	−3.7	4838.763	+2.2
4442.901	−1.6	4632.404	−4.1	4862.813	+0.2
4444.979	−4.4	4632.415	−4.2	4865.592	−2.9
4446.000	−6.2	4632.439	−4.4	5207.647	−0.2
4446.990	−3.2	4633.200	−3.4	5207.665	−0.5
4447.818	−1.7	4634.334	−5.7	5208.901	+0.8
4448.899	−1.5	4634.397	−3.3	5210.629	+1.1
4448.979	−1.8	4634.467	−2.2	5212.594	−1.3
4455.812	−4.2	4650.328	−5.2	5215.659	−1.2
4455.877	−3.8	4652.323	−5.4	5216.827	−1.3
4474.819	−6.0	4657.355	−8.0	5217.695	−0.9
4475.905	−4.2	4657.411	−8.0	5218.679	+0.6
4476.892	−5.4	4658.030	−7.8	5219.682	+3.1
4477.722	−5.3	4658.046	−8.0	5220.609	+3.2
4478.862	−4.3	4659.310	−7.7	5221.644	+4.5
4480.740	−7.3	4660.183	−6.7	5224.577	+2.1
4481.759	−7.9	4660.234	−5.9	5225.592	+1.6
4482.780	−6.8	4660.276	−5.3	5247.557	−0.9
4483.779	−5.2	4660.319	−5.1	5249.572	+0.2
4484.694	−2.9	4660.359	−4.7	5250.786	+1.1
4484.934	−3.8	4661.251	−5.0	5251.555	+0.9
4502.661	−1.5	4665.026	−4.2	5252.551	+1.8
4503.613	−0.9	4666.032	−1.7	5253.544	+1.9

possibilities of variations in radial velocity and spectrum of Vega. Wisniewski & Johnson (1979), and more recently Hayes (1985, p. 238), have summarized all the observations on the variability of Vega. Johnson & Wisniewski (1978) reported the detection of violet-shifted emission components in the near-infrared lines of O I and Ca II. However, Griffins (1978) have obtained very-high-dispersion (0.8Å–1.8Å mm^{-1}) spectrum of Vega and found no trace of emission in the lines. Barker *et al.,* (1978) also found no evidence for emission components in their Reticon spectra of the O I and Ca II near-infrared lines. There appear to be no emission lines in the spectrum of Vega and the features seen by Johnson & Wisniewski (1978) are probably introduced by their instrument. In summarizing all the observations of Vega, Hayes (1985, p. 238) concluded that there is no evidence for variability in Vega. Our standard deviation of 0.88 km s^{-1} in a radial-velocity observation corresponds to about one-quarter of a Reticon diode and is a plausible value for our spectra with 8 useful stellar lines in the window adopted for the cross-correlation, each line having a width (FWHM) of about 13 diodes. The N I lines are far stronger in Deneb's spectrum, and hence the stronger signal from a cross-correlation provides an even smaller uncertainty.

The Radial velocities for Deneb between JD 2444440 and JD 2445260 are plotted in Fig. 1. Solid lines connect points which appear to belong to a common pulsation; broken lines appear where a bolder interpolation seems necessary. Radial-velocity variations with the characteristics described by Paddock are obviously present. The

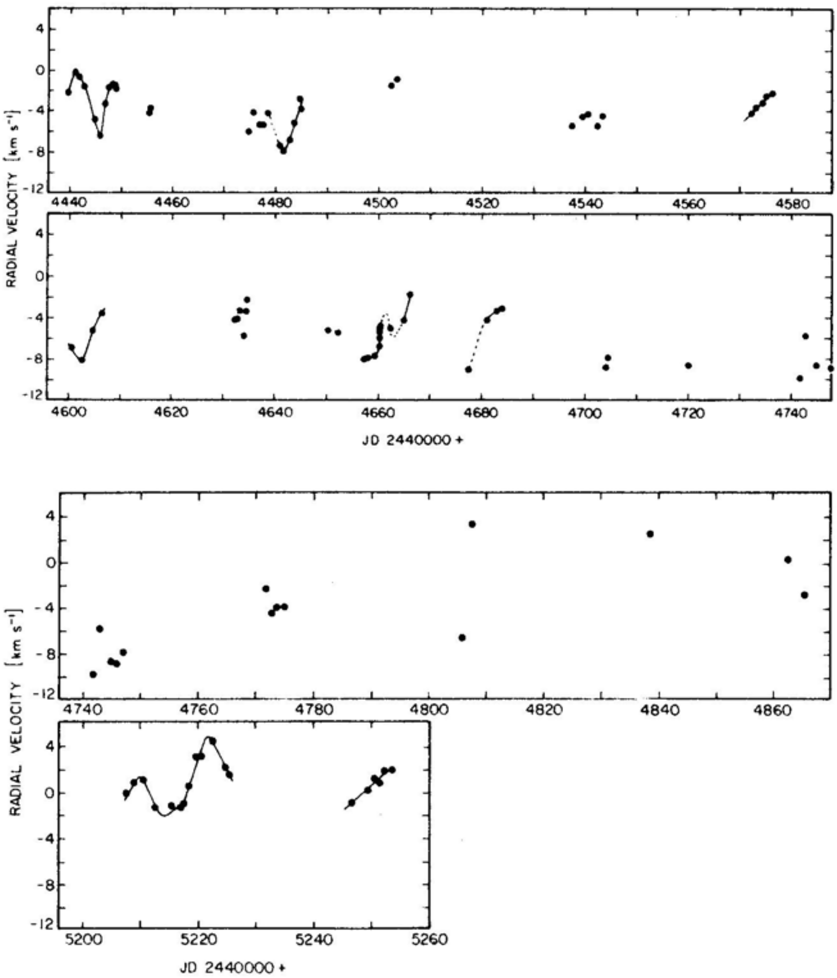

Figure 1. The radial velocity of α Cyg from JD 2444440 to JD 2445260.

mean velocity of the pulsation is apparently varying reaching a minimum around JD 2444700 and a maximum around JD 2445222.

The predominant feature of the radial velocities is the quasi-periodic pulsation with periods of 5 to 20 days documented by Paddock (1935), and analysed by Lucy (1976a). Lucy found 16 significant modes with periods from 6.9 to 100.8 days. As our coverage is less intensive than Paddock's, we have not attempted to mimic Lucy's analysis, but it may be safely asserted that several modes must again be invoked. Our radial velocity observations of Deneb are nearly continuous during the interval JD 2444440 to JD 2444449 and JD 2445207 to JD 2445226, and show the periods of 7 and 12 days (Fig. 1) respectively. In addition to identifying 7–101 day pulsation periods, Lucy (1976a) also proposed that α Cyg is a spectroscopic binary, with an orbital period of 850 days. We find that the long-period radial-velocity variation of Deneb in our data is similar to that shown in Fig. 2 of Lucy's (1976a) paper.

On the timescale of one day or less, the regular pulsations may provide a detectable variation of the radial velocity: a 1 km s^{-1} day^{-1} change is fairly characteristic of the pulsations. We found two occasions on which this acceleration was exceeded. On JD 2444446 and JD 2444741, 3–4 km s^{-1} variation occurred in one day. On JD 2444634, a 3.5 k m s^{-1} change occurred in 3 hours. On JD 2444660, a 2.0 k m s^{-1} change took 4 hours. There are similar intervals when no significant change of velocity was detected: e.g., on JD 2444632, 8 observations combine for a mean velocity of – 4.2 km s^{-1} and 6 of the 8 are within –0.2 to + 0.7 km s^{-1} of the mean. To establish conclusively that the rapid accelerations are not, in part, of instrumental origin, either spectra should be acquired with an imposed set of absorption lines (Campbell & Walker 1979) or observations of Deneb and Vega (or another radial velocity standard star) should be interlaced.

The unweighted mean of our 123 velocities is – 3.6 km s^{-1}. Our radial velocity observations of Deneb show a minimum value of — 9.8 k m s^{-1} and a maximum value of + 4.5 kms^{-1}(a range of 14 kms^{-1}). This value is close to the sum of the amplitudes (10.44 kms^{-1}) of all the pulsation periods from 6.9 to 100.8 days (Lucy 1976a). Recently, de Jager, Mulder & Kondo (1984) derived micro- and macro-turbulent velocities in the atmosphere of Deneb to be 15.0 ±0.5 km s^{-1} and 14.2 ± 2.5 km s^{-1} respectively. They find that the larger macroturbulent velocities determined by Groth (1961:28 kms^{-1}), Gray(1975:36 kms^{-1}), and others, are in compatible with their data. Lucy (1976b) suggested the possibility of variation in macroturbulent velocity as due to the multiperiodic nonradial oscillations corresponding to surface harmonics of degree 3–4. A measurement of the radial velocity from a cross-correlation provides a one parameter description of the profile changes induced by pulsations/oscillations. Analysis of accurate line profiles for lines formed at differing depths may provide more detailed information on the pulsations. Inspection of our profiles shows no major features such as have been seen in the B stars experiencing nonradial oscillations (cf., Smith 1986).

4. Concluding Remarks

Supergiants such as α Cyg with a complex pattern of radial-velocity variations continue to present a considerable challenge to the observer. The present and earlier series of observations show that the radial-velocity variations need to be monitored continuously for a longer period of time on a variety of spectral lines in order to understand the atmospheric pulsations and velocity field effects of the Ia supergiants of all spectral types (*cf.* Abt 1957; Maeder 1980; Sterken 1977; de Jager 1980).

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