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OMICRON ANDROMEDAE IS QUADRUPLE

G. M. HILL,* G. A. H. WALKER,* N. DINSHAW, AND S. YANG*
Department of Geophysics and Astronomy, The University of British Columbia, Vancouver, BC V6T 1W5, Canada

AND

P. HARMANEC*
Astronomical Institute, Czechoslovak Academy of Sciences, 251 65 Ondrejov, Czechoslovakia

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ABSTRACT

The narrow absorption features superimposed on the rotationally broadened Mg II λ4481 line of o And A are almost certainly from the spectrum of o And B which is shown to be a 33.01-day double-lined spectroscopic binary. The speckle interferometrically measured separations of Aa and AB indicate that the system contains at least two doubles separated by some 25 AU with the periods of A–a and Aa–B on the order of four and 30 years, respectively, based on a parallax of 0.015 ± 0.008 arc seconds.

Key words: spectroscopic binaries–Be/shell stars

I. Introduction

The bright Be/shell star o Andromedae (HR 8762, HD 217675-6, B6 IIIpe) has been the object of spectroscopic and photometric observations for nearly a century. More recently it has become apparent that the star is at least triple. Interferometric and micrometric studies (Blazit *et al.* 1977; Heintz 1978; McAlister 1979; Tokovinin 1983, 1985; McAlister and Hartkopf 1984; Bonneau *et al.* 1986; McAlister *et al.* 1987) have revealed the presence of two companions, at separations of about 0.05 (Aa) and 0.3 (AB) arc seconds. The AB position angle changed steadily by about 10° between 1975 and 1985 with a decrease in separation from about 0.375 to 0.266 arc second. As B is only 0.5 to 1.0 magnitude fainter than the primary (McAlister, private communication) it may contribute up to 40% of the total flux from the system.

A variety of photometric variations are known or suspected to exist. The light curve has a 1.571272-day period but varies in both amplitude and shape (Harmanec 1984; Stagg *et al.* 1985; Stagg 1987; Harmanec *et al.* 1987). Harmanec (1984) suspects that the time scale for the variation in shape of the light curve is 11–15 days and that the amplitude of the 1.57-day light curve may vary in conjunction with a 3100-day periodic variation. The amplitude of the 3100-day periodic variations is about 0.1 magnitude and at maximum ($V = 3.61$) the amplitude of the 1.57-day light curve is almost zero while during the minima the amplitude of the short-term variations reaches a maximum of about 0.1 magnitude.

Spectroscopic investigations can be divided roughly into searches for short-term radial-velocity variations (about a day) and long-term (years) variations in radial velocity and shell strength. After analyzing radial velocities from 1900 to 1976, Fracassini and Pasinetti (1977) and Fracassini, Pasinetti, and Pastori (1977) reported the presence of a 23.5-year period and a 1.5845-day period. Horn *et al.* (1982) using a partially different set of radial velocities found a period of 25.9 years but found no periods in the range 0.5 to 1000 days. Gulliver and Bolton (1978) searched for radial-velocity periods in the range 0.5 to 1000 days with only a quasi-periodicity of 0.84 day being found. A period search by Baade *et al.* (1982) using plates taken during 1981 and 1982 found no periodicity in radial velocity.

Schmidt (1959), Pasinetti (1967, 1968), and Fracassini and Pasinetti (1975) have suggested that there are shell outbursts every 31 years. The occurrence of outbursts at more frequent intervals than 31 years has since made this period seem less likely than the 8.5-year (3100-day) period suggested by Harmanec (1984). Gulliver, Bolton, and Poeckert (1980) and Koubsky (1984) have shown that the overall behavior of the shell may be more complicated than simply periodic.

Strange variations of the Mg II λ4481 line profile of o And have been known for quite some time. Gulliver *et al.* (1980) showed that the narrow components superimposed on the broad underlying profile survived the disappearance of the shell and varied in velocity but found no periodicity in these variations. In an attempt to understand these profile variations and search for radial-veloc-

*Visiting Astronomer, Dominion Astrophysical Observatory, operated by the National Research Council of Canada.

ity variations we undertook a spectroscopic monitoring program using the University of British Columbia 0.42-m telescope.

II. Observations and Radial-Velocity Measurements

The University of British Columbia 0.42-m telescope was used to obtain 70 spectra on 63 nights between 1987 May 7 and September 1. An additional six spectra were obtained on 1986 June 1, 2, and 3. The spectra were taken with a liquid-nitrogen-cooled RL1872F/30 Reticon on the coudé spectrograph. A description of the detector and data-reduction procedures can be found in Walker, Johnson, and Yang (1985). The spectrograph was used in the second order to give a reciprocal dispersion of 17 Å mm^{-1}. This corresponds to about 0.26 Å per diode with a spectral coverge of 488 Å centered at 4460 Å. The exposure times were between 1.5 and 2 hours. For all spectra the signal-to-noise ratio per diode was 200 or greater. Figure 1 shows the region of the lines of Mg II λ4481 and He I λ4471 for all the 1987 UBC spectra. All the He I λ4388 profiles obtained at UBC in 1987 are shown in Figure 2. The spacing of the spectra along the vertical axis is scaled by the barycentric Julian Dates of their midexposure times.

In addition to the UBC observations, the Cassegrain spectrograph of the DAO 1.83-m telescope was used to obtain spectra of higher time and wavelength resolution. These observations were at 10 Å mm^{-1} (0.15 Å per diode) using an identical Reticon. Altogether 84 spectra were obtained on four nights in August and three nights in October 1986.

The principal lines present in both the DAO and UBC spectra are C II λ4267, Hγ λ4340, He I λλ4388, 4471, and Mg II λ4481. The spectra are dominated by the rotationally broadened ($v \sin i \sim 230$ km sec^{-1}) lines of the B6 III primary. Superimposed upon these are the narrower lines of a spectroscopic binary, probably B, the more distant of the two interferometrically resolved companions. These narrower components are most clearly visible in the Mg II λ4481 profile where their presence was first noted by Gulliver and Bolton (1978).

Only the Mg II lines of the spectroscopic binary were used for radial-velocity measurements. The He I lines of the binary are visible but not as strong or sharp compared to the underlying broad profile. The C II lines were not measured due to their weakness. The Stark broadening of Hγ prevented accurate measurement of radial velocities for the double-lined binary.

The average of all spectra in which the binary lines coalesced was used to determine the shape of the underlying broad profile and this was subtracted from all spectra prior to measuring the line positions. The line positions were measured using the weighted mean of the pixels in the line profiles of each of the narrow features with the depth below continuum acting as weights. The average of iron-argon hollow-cathode arc lamps taken before and after each exposure were used to set the wavelength calibration. The average of the doublet rest wavelengths, 4481.228 Å, was adopted as the rest wavelength. Radial velocities corrected to the solar-system barycenter, midexposure times, and phases are presented in Table I. In ten of the spectra the two components are too closely coalesced to yield useful radial velocities.

The DAO radial velocities are averages for each night. The standard deviation about the mean of the DAO velocities for each night are typically 5–6 km sec^{-1}. A small part of this represents phase smearing but the majority probably arises from variations in the underlying absorption profile. These variations, which seem to have a time scale of about one day, will be the subject of a forthcoming paper.

III. The Orbit

We identify the stronger of the two narrow components visible in the Mg II λ4481 profile with the primary and the weaker with the secondary. The radial velocities measured for these features are presented in Table I in the columns headed V_1 and V_2, respectively. The orbit was solved using the double-line option of the program RVORBIT, kindly supplied by Graham Hill. The velocities presented in Table I were given equal weights when determining the orbital elements of the double-line spectroscopic binary. The solution was obtained with respect to time of periastron passage using the method of Lehmann-Filhés. The observed minus calculated residuals are given in Table I.

The orbital elements are presented in Table II. The single-line option of RVORBIT was used to solve the orbit of each component separately. The double-line solution was adopted after finding that the single-line solutions agreed with it to within their mutual uncertainties. The period found by RVORBIT, 33.01 days, agrees with the period of 32.9 days found using the phase-dispersion-minimization (PDM) technique of Stellingwerf (1978). The fit of the solution to the data is shown in Figure 3.

IV. Discussion

The multiple nature of o And leads one to ask, which of the resolved components is the double-lined spectroscopic binary? The parallax for o And, 0.015 ± 0.008 arc sec (van Altena, private communication), yields a distance of 67 parsecs. At this distance the maximum observed separations of components a and B correspond to 3.9 and 25.1 AU, respectively. The spectroscopic binary must therefore be one of the three, as opposed to two of the three, resolved components. There must be a minimum of four stars present.

Table III presents masses for the spectroscopic binary stars for various values of the inclination. Since compo-

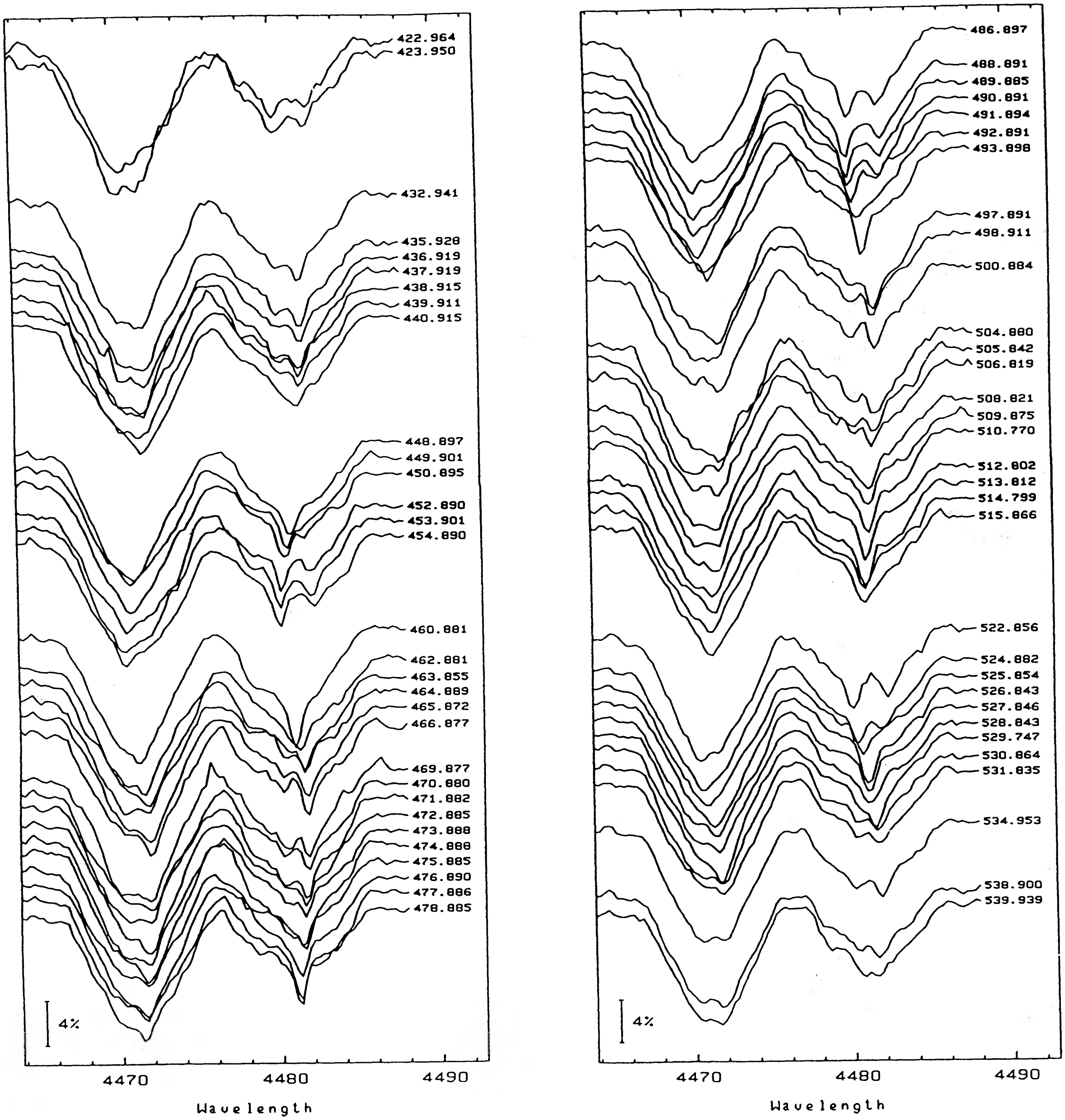

FIG. 1–Reticon spectra obtained with the UBC 0.42-m telescope showing He I λ4471 and Mg II λ4481. The resolution is 0.7 Å. For both lines $S/N \geq 200$. The midexposure time from BJD2446500 is indicated for each spectrum. Where two consecutive spectra were obtained on one night, the average is presented.

nent B is 0.5 to 1.0 magnitude fainter than component A and component a fainter still, one may determine an approximate lower limit to the inclination. Assuming component B contributes 40% of the total flux, the spectral type – M_v calibration of Balona and Crampton (1974) implies that the binary stars are around B8 IV–V and differ by about one spectral subclass. Assuming the two stars are B7 V and B8 V and using the spectral type – mass calibration of Popper (1980) implies $i \geq 65°$. Assigning late-B spectral types to the double-lined spectroscopic binary is compatible with the absence of reports of UV or IR excesses. That the lines of the binary are most visible in Mg II and visible but to a lesser degree in He I also agrees with this assignment. No 33-day photometric

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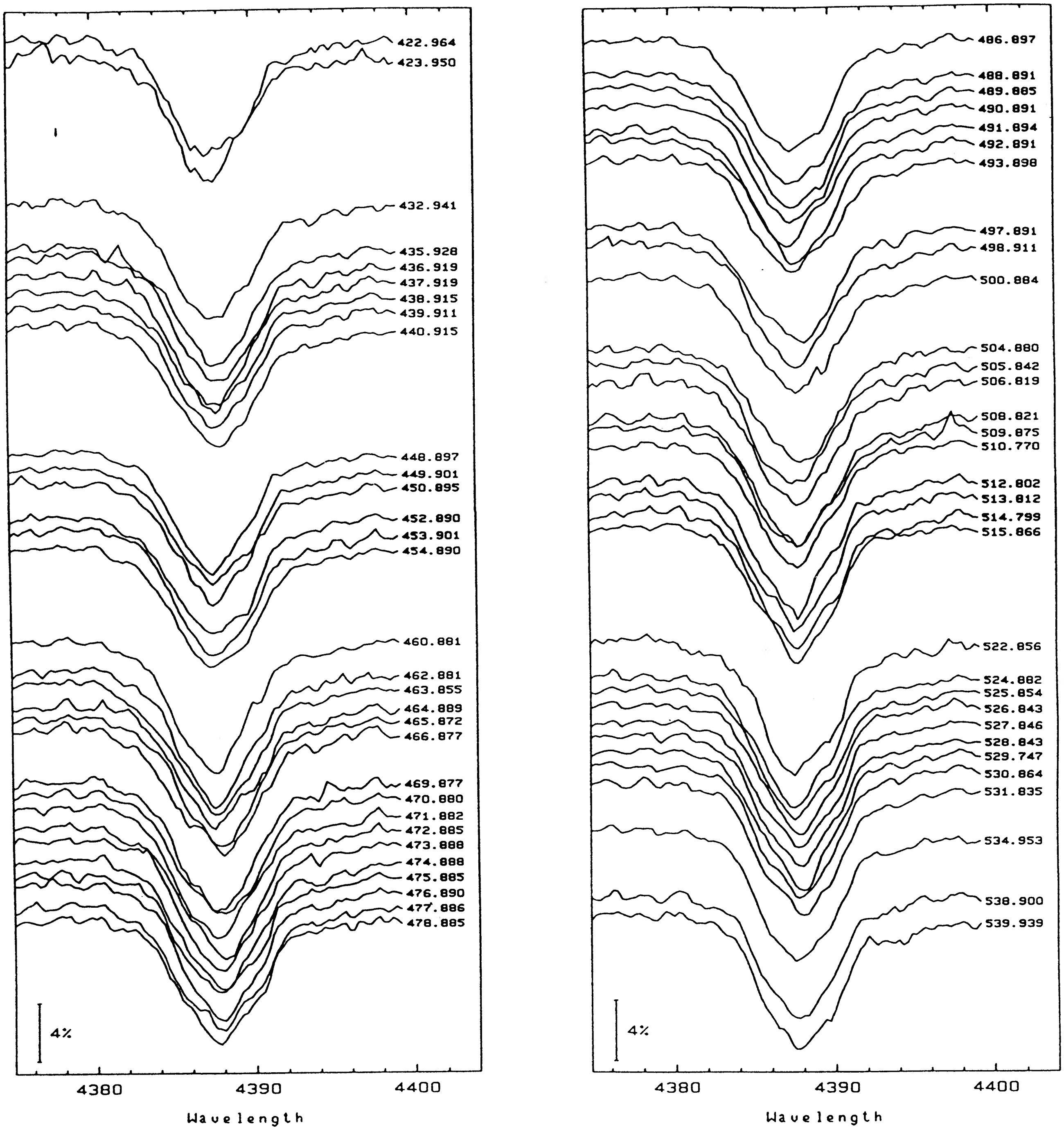

FIG. 2–Reticon spectra obtained with the UBC 0.42-m telescope showing He I λ4388. The resolution and *S/N* are the same as Figure 1. The midexposure time from BJD2446500 is indicated for each spectrum. Where two consecutive spectra were obtained on one night, the average is presented.

period arising from eclipses is known so $i < 89°$. It is also interesting that the time scale for suspected variations in the 1.57-day light curve, 11–15 days, is close to half of the period of the binary.

Of the two resolved companions to component A, component B seems the more likely candidate for the double-lined spectroscopic binary. We have detected no trace of component a in our data. Given its faintness this is not surprising. If component a were the binary, one would have to explain the absence of a contribution to the spectrum from the brighter component B. Further, in one year there has been no change in the systemic velocity. Omicron And would seem to be (at least) a double-double system.

TABLE I

o Andromedae Radial Velocity Measurements

BJD 2,440,000+	33.01 day binary phase	V_1 km/s	$(O-C)_1$ km/s	V_2 km/s	$(O-C)_2$ km/s
UBC 0.42m 1986					
6582.992	0.631	--	--	--	--
6583.925	0.660	--	--	--	--
6584.921	0.694	−21.1	+4.1	+7.8	+7.8
DAO 1.83m 1986					
6669.891	0.267	+26.8	−3.1	−61.4	+10.6
6671.777	0.324	+22.3	−8.8	−81.4	−7.8
6673.869	0.388	+20.4	−7.7	−64.8	+4.8
6674.833	0.417	+23.0	−2.5	−64.9	+1.4
6720.824	0.809	−54.6	+2.9	+39.9	−2.2
6722.950	0.874	−72.0	+1.1	+60.7	−1.9
6723.768	0.899	−74.9	+2.0	+68.6	+1.1
UBC 0.42m 1987					
6922.965	0.931	−68.8	+9.4	+75.0	+5.8
6923.951	0.961	−76.8	−2.3	+50.1	−14.4
6932.942	0.233	+24.5	−2.5	−67.5	+0.7
6935.929	0.323	+25.3	−5.8	−73.0	+0.6
6936.919	0.353	+25.8	−4.3	−72.9	−0.6
6937.919	0.384	+23.9	−4.4	−72.2	−2.4
6938.916	0.414	+27.1	+1.5	−72.8	−6.6
6939.912	0.444	+25.8	+3.5	−62.2	−0.1
6940.916	0.474	15.3	−3.1	−52.8	+4.1
6948.897	0.716	−37.8	−6.0	+17.8	+9.2
6949.901	0.746	−42.3	−2.1	+18.2	−1.4
6950.896	0.777	−55.6	−6.9	+30.2	−0.5
6952.890	0.837	−73.0	−7.7	+55.2	+2.8
6953.901	0.867	−73.9	−1.6	+52.3	−9.2
6954.890	0.897	−82.7	−5.8	+69.8	+2.2
6960.882	0.078	--	--	--	--
6962.882	0.139	+0.9	−4.3	−46.7	−7.0
6963.856	0.169	+12.0	−2.6	−51.3	+0.7
6964.889	0.200	+18.8	−3.1	−58.0	+3.6
6965.873	0.230	+30.5	+3.8	−69.8	−2.1
6966.877	0.260	+26.7	−2.9	−73.3	−1.7
6969.877	0.351	+30.5	+0.3	−65.7	+6.7
6970.880	0.382	+29.3	+0.9	−71.4	−1.4
6971.883	0.412	+20.9	−4.9	−68.7	−2.1
6972.886	0.442	+17.5	−5.0	−66.8	−4.6
6973.888	0.473	+18.5	−0.1	−61.0	−3.9
6974.888	0.503	+13.6	−0.5	−59.4	−8.1
6975.885	0.533	+8.7	−0.4	−46.9	−2.1
6976.890	0.564	−2.8	−6.3	−44.1	−6.6
6977.887	0.593	--	--	--	--

Using a reasonable estimate of the total mass of the system, Kepler's third law, and a separation of 25 AU we obtain a period for Aa-B of about 30 years. It is interesting to recall that various groups have suggested a 31-year periodicity in shell outbursts and radial-velocity periodicities of about 25 years have been reported. However, in

TABLE I (Continued)

BJD 2,440,000+	33.01 day binary phase	V_1 km/s	$(O-C)_1$ km/s	V_2 km/s	$(O-C)_2$ km/s
6978.886	0.623	––	––	––	––
6986.897	0.867	−66.9	+5.2	+62.0	+0.7
6988.892	0.927	−80.8	−2.5	+75.4	+6.1
6989.886	0.957	−77.7	−2.6	+66.1	+0.9
6990.892	0.988	−62.0	+4.7	+62.2	+8.0
6991.894	0.018	−55.9	−2.2	+40.9	+3.6
6992.892	0.048	−32.9	+5.2	+21.8	+5.0
6993.899	0.078	––	––	––	––
6997.892	0.200	+24.3	+2.4	−61.0	+0.5
6998.912	0.231	+24.3	−2.5	−68.5	−0.6
7000.880	0.290	+35.8	+4.8	−73.6	−0.2
7004.841	0.410	+25.4	−0.5	−61.4	+5.4
7004.918	0.412	+25.2	−0.5	−64.8	+1.7
7005.841	0.440	+23.7	+1.0	−60.6	+1.9
7006.823	0.470	+18.7	−0.2	−63.9	−6.3
7008.822	0.531	+16.1	+6.6	−37.7	+7.6
7009.875	0.562	+6.7	+3.0	−40.8	−3.1
7010.771	0.590	+1.8	+3.5	−24.4	+6.3
7012.802	0.650	––	––	––	––
7013.813	0.682	−31.6	−8.7	−1.8	+1.2
7014.800	0.712	−35.8	−5.0	+7.3	+0.0
7015.803	0.742	−42.7	−3.6	+26.2	+8.0
7015.928	0.746	−41.5	−1.3	+17.7	−1.9
7022.857	0.956	−85.0	−9.6	+71.5	+6.0
7024.843	0.016	−65.7	−11.0	+40.6	+2.1
7024.922	0.018	−48.5	+5.0	+41.3	+4.3
7025.793	0.045	−39.5	+0.4	+23.2	+4.0
7025.917	0.048	−37.9	+0.0	+8.7	−7.9
7026.843	0.076	––	––	––	––
7027.785	0.104	––	––	––	––
7027.909	0.108	––	––	––	––
7028.780	0.135	+13.7	+9.9	−39.2	−1.4
7028.906	0.139	+12.3	+7.1	−35.9	+3.8
7029.737	0.164	+16.6	+3.2	−42.2	+8.2
7029.817	0.166	+17.2	+3.1	−43.0	+8.3
7030.865	0.198	+24.1	+2.5	−59.4	+1.7
7031.836	0.228	+23.6	−2.8	−64.5	+2.9
7034.954	0.322	+39.1	+8.0	−79.0	−5.4
7038.900	0.441	+24.3	+1.8	−65.3	−3.0
7039.939	0.473	+14.4	−4.1	−44.9	+12.1

ten years of speckle interferometry measurements the AB position angle has only changed by about 10° and the separation has gone from about 0.375 to about 0.266 arc second. A much longer period than 30 years is possible if one adopts a smaller value for the parallax or the orbit is quite eccentric. Encounters at periastron due to an eccentric orbit are one possible mechanism to trigger shell outbursts.

Only four measurements of separation and position angle exist for Aa. Nevertheless, given the 180° indeterminacy of speckle interferometric position angle measurements, one can construct an orbit with a period of 3.7 years. If we take Kepler's third law, a separation of four AU, and reasonable mass estimates we obtain periods in

TABLE II

Orbital Elements For The Spectroscopic Binary

	Primary	Secondary
Period (days)	+33.01 ± 0.02	
T_{per} (2,440,000+)	+6925.3 ± 0.2	
V_o (km/sec)	−14.3 ± 0.5	
e	+0.24 ± 0.01	
ω (degrees)	+226.2 ± 2.3	
K (km/sec)	54.8 ± 0.8	71.6 ± 0.8
asini (AU)	0.161 ± 0.003	0.211 ± 0.002
m $\sin^3 i$ ($M_\odot$)	3.74 ± 0.05	2.86 ± 0.05
σ fit (km/sec)	4.6	5.2

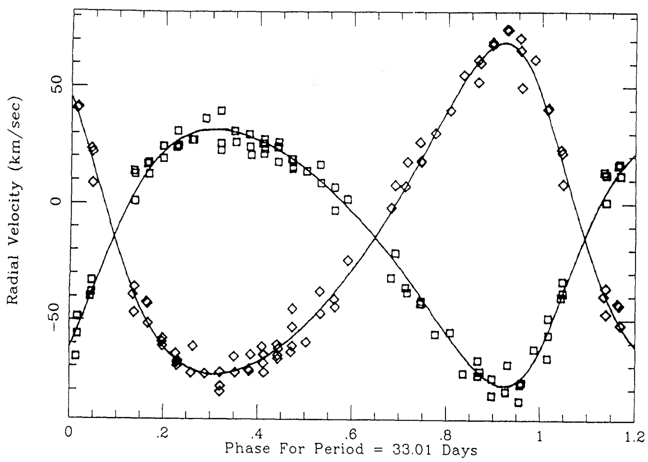

FIG. 3–Mg II narrow component radial velocities phased to a period of 33.01 days for o And. The solid line is the calculated curve corresponding to the orbital solution presented in Table II. Squares denote primary radial velocities and diamonds denote secondary radial velocities.

TABLE III

Masses of Spectroscopic Binary Stars

inclination (degrees)	M_1 ($M_\odot$)	M_2 ($M_\odot$)
50	8.32	6.36
55	6.80	5.20
60	5.76	4.40
65	5.02	3.84
70	4.51	3.45
75	4.15	3.17
80	3.92	2.99
85	3.78	2.89
90	3.74	2.86

the range three to four years. For a smaller parallax the period would be longer and could be on the order of the 8.5-year period advocated for shell outbursts by Harmanec (1984).

Omicron And has been the subject of considerable attention in recent years and in fact has been included in several photometric and spectroscopic campaigns. It is clear that certain medium-term spectral variations arise from its multiplicity. Some long-term variations may also be a result of this multiplicity. Continued interferometric measurements of the system will hopefully settle some of the questions regarding long-term variations.

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