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The Interacting, Eclipsing Binary AU Monocerotis Revisited

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ABSTRACT. New spectrographic observations of the Algol binary AU Monocerotis have permitted the determination of the orbital elements of the two components of the system. They have further suggested that the image tube spectrograph that was attached to the CTIO 1-m-reflecting telescope in 1978 and 1979 was not quite suitable for radial-velocity work.

1. INTRODUCTION

AU Monocerotis (B5 V+ F0; P=11.1 days) is one of the binaries that was worked out spectrographically for the first time during the survey study carried at the McDonald Observatory with a dispersion of about 40 Å mm^{-1} at Ca II K and was the first investigated interacting binary to show in the spectrum the differential effect of the gaseous stream from the late-type component upon the H-line profiles and radial velocities. The discovery paper, which was published 52 years ago (Sahade and Cesco 1945), helped to clarify the puzzle posed by the spectroscopic behavior of U Cephei as compared with the photometric one (cf. Sahade and Wood 1978). A second spectrographic investigation of AU Mon was published 37 years later (Sahade and Ferrer 1982) and was based on spectrographic material (42 plates) secured in 1978 and 1979 with the image-tube spectrograph attached to the 1-m reflector of the Cerro Tololo Inter-American Observatory (CTIO), in Chile. The radial-velocity values that were derived from this material displayed quite a large scatter but, in the mean, they followed the general trend of Sahade and Cesco's radial velocities. In both studies only lines of the B5 V component were measured, lines arising in the late-type companion—the Na I D lines—having been measured by Popper (1989), whose work suggested a mass ratio of the B star relative to the F component of about 4.7.

2. THE NEW OBSERVATIONS

The large scatter in the radial velocities of AU Mon found on the material taken at the CTIO in the years 1978 and 1979 prompted the need to ascertain whether or not we were dealing with a new feature in AU Mon. As a result, a new series of observations (15 plates) of the object was taken at CTIO in February and December, 1984, by Sahade with the coudé spectrograph attached to the 1.5-m telescope, giving a dispersion of about 9 Å mm^{-1} in the second-order blue and about 18 Å mm^{-1} in the first-order red of the grating.

Additional material—eight images in total—was secured at El Leoncito Astronomical Complex (CASLEO), Argentina, by O. E. Ferrer and R. Barbá in 1995 August, and by O. E. Ferrer and E. Brandi in 1996 March, with the REOSC échelle spectrograph attached to the 2.15-m reflecting telescope, a 1024×1024 Tek CCD being the detector. The CTIO material covers the spectral regions of λλ3750–4600 Å and λλ5850–6400 Å, while the CASLEO observations cover the wavelength interval λλ4300–7300 Å with a resolution of 12,000.

Table 1 lists the material taken, together with the derived radial velocities, their mean errors and the indication of the observatory at which the corresponding spectrum has been secured. The phases have been computed by using the ephemeris given by Lorenzi (1980), namely,

$$\text{Pr. Min.} = \text{JD}2442801.3752 + 11.1130371\,E\ .$$

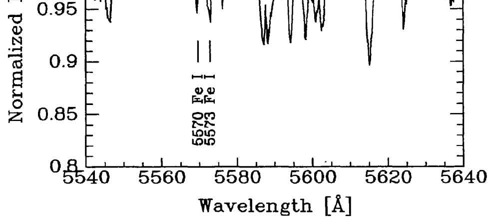

FIG. 1—Lines of Fe I from the secondary component of AU Mon.

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TABLE 1
Observational Material and Radial Velocities for AU Mon

H.J.D. 2400000+	Phase (P)	RV1 [a] (km s^{-1})	ME1[b] (km s^{-1})	RV2[c] (km s^{-1})	ME2[d] (km s^{-1})	OBS[e]
45750.5486	0.3796	−28 (6)	±5.4	+78 (1)		1
45751.6243	0.4764	+ 9 (6)	13.9			1
45751.7160	0.4847	+19 (5)	9.5			1
45752.6583	0.5695	+ 3 (6)	10.6			1
45753.5410	0.6489	+31 (5)	11.5			1
45754.6042	0.7446	+44 (6)	5.8			1
46045.6986	0.9385	+17 (6)	4.5			1
46045.8028	0.9479	+ 9 (6)	12.1			1
46046.6924	0.0279	−28 (4)	5.2	+ 33 (1)		1
46047.6875	0.1175	−33 (4)	9.8	+ 96 (2)	±0.5	1
46048.7125	0.2097	−37 (5)	9.5	+162 (2)	2.5	1
46049.6715	0.2960	−48 (5)	8.5	+129 (2)	4.0	1
46049.7833	0.3061	−38 (4)	8.7	+163 (2)	7.0	1
46050.6826	0.3869	−19 (5)	9.0			1
46051.6639	0.4753	−13 (4)	9.2			1
49943.9015	0.7160	+48 (3)	12.7	−141 (7)	5.3	2
49943.9125	0.7170	+48 (3)	7.8	−132 (7)	3.8	2
49944.8898	0.8049	+50 (3)	6.4	−119 (7)	2.5	2
49945.9072	0.8964	+39 (2)	11.0	−70 (7)	2.6	2
49946.8818	0.9841	+16 (2)	4.0	+ 4 (5)	1.5	2
49946.9092	0.9866	+13 (2)	8.0	+ 8 (5)	3.5	2
50166.4959	0.7460	+38 (3)	6.4	−139 (7)	3.3	2
50166.5456	0.7505	+31 (3)	5.7	−144 (7)	3.8	2

[a] RV1: Radial velocity from the He I lines of the brighter component of the system. The number of lines measured are given within parenthesis.
[b] ME1: Mean error of RV1.
[c] RV2: Radial velocity from the Fe I and Na I D lines of the late-type component of the system. The number of lines measured are given within parenthesis.
[d] ME2: Mean error of RV2.
[e] OBS: 1=CTIO; 2=CASLEO.

TABLE 2
Spectral Lines Measured

B5 component	Companion star
Hα	Na I 5890;5895
He I 3819	Fe I 4005
He I 4009	Fe I 4383
He I 4026	Fe I 4405
He I 4143	Fe I 4415
He I 4387	Fe I 5107
He I 4471	Fe I 5227
Ca II K	Fe I 5233
Mg II 4481	Fe I 5570
Si II 4130	Fe I 5573

3. THE ABSORPTION LINES

The CTIO spectrograms were first scrutinized by L. G. García and E. E. Brandi and later reanalyzed by O. E. Ferrer with the utilization of the IRAF[6] (Image Reduction Analysis Facilities) software, version 2.10. O. E. Ferrer also worked out the CASLEO material the same way.

One interesting and important result of the present work is the fact that lines of Fe I that arise in the component which is in front at the principal eclipse (see Fig. 1) have been identified and measured. The Na I D lines arising from the same component (see Fig. 2), have also been measured whenever they were well separated from the interstellar components.

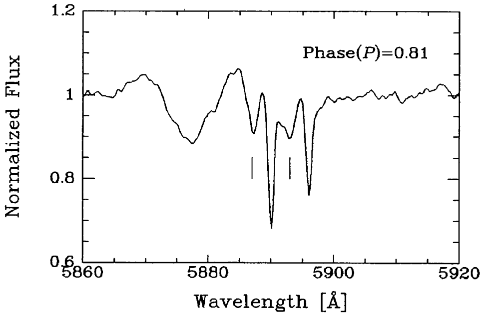

FIG. 2—Na I D lines from the secondary component of AU Mon.

Table 2 lists the spectral lines that have been measured for radial velocities of each one of the components. The velocity values are plotted in Fig. 3. The orbital elements, determined through Schlesinger's method, are listed in Table 3 for each component considered separately and for a joint solution of the two components. For comparison, we have also listed in this Table Popper's (1989) orbital elements that were derived by assuming zero eccentricity. In the derivation of the elements we have not considered the H lines because, as is well known (cf. Sahade and Cesco 1945; Sahade and Wood 1978; Sahade and Ferrer 1982; and Popper 1989), they are strongly distorted, particularly in the phase interval ~0.75 P to ~1.0 P, because of the gaseous stream from the late-type component. The values of the eccentricity, as derived for each component separately, suggest that we are likely dealing with a slightly eccentric orbit. As for the mass ratio, it actually turned out to be 3.4.

4. THE EMISSION LINES

Hα displays strong emission cut by an approximately central absorption, as reported by Popper (1962). From our

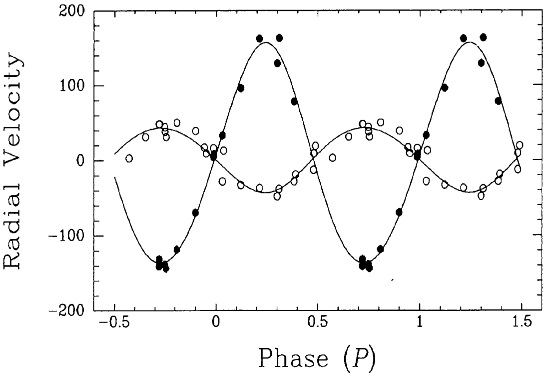

FIG. 3—Radial velocities and velocity curves of AU Mon. Two cycles are shown for continuity.

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[6] IRAF is distributed by the National Optical Astronomical Observatories, which is operated by AURA Inc. under contract to the National Science Foundation.

TABLE 3
Orbital Elements of AU Mon

	This paper			Popper (1989)		Sahade and Cesco (1945)
	Combined	He I	Fe I+Na I	He I	Na I	He I
$a_1 \sin i (10^6$ km)	6.6±0.39	6.6±0.44				4.9
$a_2 \sin i (10^6$ km)	2.2±0.41		2.3±0.73			
K_1 (km s^{-1})	43±2.5	44±2.7		32±4		32
K_2 (km s^{-1})	147±3.0		152±4.1		150±3	
e	0.06±0.02	0.09±0.06	0.12±0.04	0[a]	0[a]	0.13
ω (°)	204±22	119±35	47±12			340
γ (km s^{-1})	+2.1±1.5	+1.7±1.7	−4.4±3.9	+10±3	+17±2	+12
M_1 ($M_\odot$)	6.1±0.61					
M_2 ($M_\odot$)	1.8±0.53					

[a] Assumed.

material, it is clear that the profile is different at different cycles of the orbital period. This is illustrated in Fig. 4, which shows the profile of Hα at phases 0.38P and 0.31P on CTIO material taken at two different cycles, and for phases 0.72P and 0.74P on CASLEO material, also taken at two different cycles.

In our material, the emission borders behave in the following way, namely, at 0.03 P−0.21 P, $v>r$, ~0.3P−0.65P, $v=r$, 0.8P−0.95P, $v<r$, where v and r signify a violet and red border, respectively, a behavior that seems to be consistent with the fact that the stream from the late-type component flows from its advancing hemisphere.

In addition, the emission decrement turns out to be very steep: Hβ does not show the emission, as one could see in Fig. 5. Such behavior means that the emission arises in the outer edges of the extended gaseous envelope in which the system is embedded (Miyamoto 1952; see also Batten and Sahade 1973 for the case of β Lyrae).

Regarding the central absorption at Hα, both on the CASLEO and on the CTIO materials, we also find a different behavior at different times. On the spectra secured in 1984 February at CTIO, and in 1995 August at CASLEO, the central absorption is deeper than the level of the continuum. On the other hand, on the material taken in 1984 December at CTIO, and in 1996 March at CASLEO, the central absorptions are much fainter or reach to approximately the level of the continuum. Therefore, as would be expected, the amount/density of the material in the envelope in which the system is embedded does vary with time; in other words, mass ejection from the late-type component is a continuously varying phenomenon.

The central absorptions at Hα were measured for radial velocity and the results are listed in Table 4 and plotted in Fig. 6.

Last, in order to determine how the emission peaks behave velocity-wise, a Gaussian profile was fitted to the profile available whenever this procedure seemed to allow a result that could be trusted. Table 4 lists the figures thus derived, and Fig. 7 displays a plot of them. Both plots in Figs. 6 and 7 seem to be consistent with the general picture accepted for an Algol-type interacting binary.

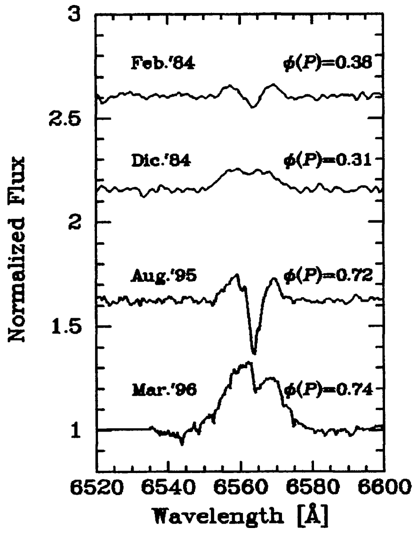

FIG. 4—Hα profiles in AU Mon for different cycles.

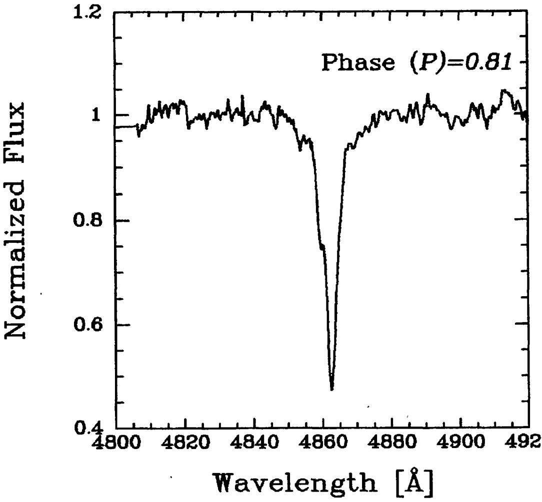

FIG. 5—Hβ profile.

Table 4
Radial Velocities Derived from Hα

HJD 2400000+	Phase (P)	RV(abs) (km s^{-1})	RV(em) (km s^{-1})
45750.5486	0.3796	+9	−34
45751.6243	0.4752	−7	−24
45751.7160	0.4764	+13	
45752.6583	0.5695	−11	
45754.6042	0.7446	−7	
46045.6986	0.9385	−75	+44
46046.6924	0.0279	+96	+63
46048.7125	0.2097	−18	−40
46049.7833	0.3061	−10	−10
46050.6826	0.3870	+34	
46051.6639	0.4847		−18
49943.9015	0.7160	+72	+50
49943.9125	0.7170	+63	+58
49944.8898	0.8049	+108:	+31
49945.9072	0.8964	+23	+70
49946.8818	0.9841	+17	+55
49946.9092	0.9866	+20	+45
50166.4959	0.7460	+57	−10
50166.5456	0.7505	+40	−40

5. CONCLUSIONS

One important feature of the new radial-velocity results is that they do not scatter all over the place as was the case for the observations carried out in 1979 with the spectrograph attached to the 1-m reflector at Tololo. Therefore, such a feature must have been the result of using a spectrograph that was not quite suitable for radial-velocity determinations rather than representing a change in the radial-velocity behavior of the system, as was thought at the time.

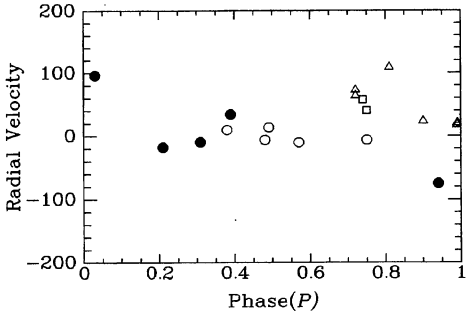

Fig. 6—Radial velocities from the central absorption of Hα. (○): CTIO, 1984 February; (●): CTIO, 1984 December; (△): CASLEO, 1995 August; (□): CASLEO, 1996 March.

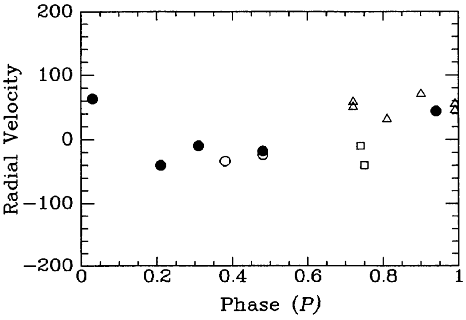

Fig. 7—Radial velocities from the emission profiles of Hα. (○): CTIO, 1984 February; (●): CTIO, 1984 December; (△): CASLEO,1995 August; (□): CASLEO, 1996 March.

Our material further suggests that we will reach a better understanding of the ejection mechanism at work in interacting binaries if we could follow the behavior of Hα, in systems like AU Mon, during a number of consecutive cycles. This also strongly indicates, once again, the need for a telescope exclusively devoted to continuously observing promising interacting binaries to find an answer to some of the questions that are still pending in this field of research, as was already stressed a few years ago (Sahade 1988).

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