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SPECTROSCOPIC BINARY ORBITS FROM ULTRAVIOLET RADIAL VELOCITIES

PAPER 19: μ^1 SCORPII (HD 151890)

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Introduction

In view of its brightness, $V = 3^{m}{\cdot}08$, the eclipsing binary μ^1 Sco has attracted relatively little detailed attention, a matter which is even more remarkable given that it was only the third spectroscopic binary to be discovered, by Bailey in 1896. The earliest set of orbital elements was derived from the relative velocities of the two components by Miss Maury[1] who measured 184 objective-prism spectra secured between 1892 and 1918. The long baseline permitted an accurate determination of the period, 1·44627 d, suggested a small eccentricity of 0·05, and yielded a combined $K_1 + K_2$ of 480 km s^{-1}.

There the matter rested until Struve[2] obtained the first series of prismatic slit spectrograms in 1939, with the Cassegrain spectrograph of the then-new 82-inch telescope of the McDonald Observatory. The 28 spectrograms were taken with a dispersion of 40 Å mm^{-1} at the Ca II K line, and even then the lines appeared to Struve "diffuse and ill-defined", which is perhaps not surprising considering the estimates for the projected rotational velocities[3]: 209 ± 9 km s^{-1} for the primary and 156 ± 8 km s^{-1} for the secondary. Struve considered the orbital eccentricity to be negligible (although it may be that his phase coverage was less than ideal for its determination) and found the amplitudes to be 185 and 280 km s^{-1} for the primary and secondary respectively, the sum of which represents a modest reduction over Miss Maury's result.

Since then, the only widely available published radial-velocity work appears to be the contribution of five velocities for the primary by Levato *et al.*[4] which are hard to tie in with Struve's data. However, the *Eighth Catalogue*[5] notes a preliminary study by Sahade & de Ferrer[6], the results of which were $K_1 = 144{\cdot}0 \pm 6{\cdot}1$ km s^{-1} and $K_2 = 243{\cdot}1 \pm 6{\cdot}2$ km s^{-1}, much smaller again than Struve's values.

IUE observations

The paucity of previous radial-velocity work prompted the authors to turn to the archive of *IUE* observations for data which might be valuable in improving upon the earlier work. In addition to three very early short-wavelength (SWP), high-resolution observations (one of which — SWP 5864 — was highly overexposed and has not been used), a series of 18 spectra spanning just over one cycle were taken at the end of July in 1990 by JS and HH; the journal of these observations is given in Table I. They have been dearchived and reduced in the usual way for papers in this series. Measurement of the relative velocity of the interstellar spectrum was accomplished by cross correlation against the usual mask, τ Sco, without difficulty. In order to put the stellar velocities on a near-absolute basis at a later stage, we note measurements by Hobbs[7,8], and by Crawford[9], which point to the D_1 line having a velocity of about -6 km s^{-1},

TABLE I

IUE radial-velocity observations of μ^1 Scorpii

SWP Image	*HJD* −2 440 000	*Phase*	V_1 *km s*$^{-1}$	*O−C* *km s*$^{-1}$	V_2 *km s*$^{-1}$	*O−C* *km s*$^{-1}$
5876	4075·710	2785·729	+136·0	+6·4	−202·7	+17·4
5879	4075·957	2785·892	−5·9	+4·8	−6·7	−4·0
39330	8103·367	0·585	+141·4	+5·2	−220·1	+10·3
39332	8103·462	0·651	+143·9	−4·3	−217·8	+31·2
39334	8103·554	0·714	+128·0	−7·7	−214·8	+14·8
39336	8103·655	0·784	+105·5	+9·7	−161·8	+6·1
39338	8103·746	0·847	+58·8	+17·1	−77·7	+6·2
39340	8103·831	0·906	−21·7	−4·5	−18·1	−25·4
39342	8103·923	0·970	−98·7	−18·9	+117·1	+12·7
39344	8104·022	1·038	−140·9	−7·0	+198·9	+10·8
39346	8104·122	1·108	−163·3	+0·4	+231·4	−3·0
33948	8104·220	1·175	−162·1	+1·0	+241·1	+7·6
39353	8104·461	1·342	−65·2	−8·9	+100·8	+32·8
39355	8104·549	1·402	−5·6	−7·2	−6·2	+15·6
39357	8104·657	1·477	+75·6	+6·3	−148·6	−21·9
39359	8104·764	1·551	+114·7	−6·0	−237·4	−31·1
39361	8104·860	1·617	+135·0	−10·2	−268·2	−23·9
39363	8104·950	1·680	+140·2	−5·3	−243·5	+1·3
39365	8105·039	1·741	+120·7	−2·7	−238·5	−27·9
39367	8105·131	1·805	+93·0	+13·3	−113·1	+29·7

while two similar-strength components of the K line appear at about −12 and −20 km s^{-1}. We take for our purpose an interstellar velocity of −12 km s^{-1}.

Measurement of the stellar radial velocities in μ^1 Sco was not so straightforward, largely on account of the relative lateness of the spectral types of the components in comparison with those of stars already treated in this series: the *Bright Star Catalogue* gives the primary type as B1·5V while the secondary is classified B6·5V. Cross-correlation tests were performed against a wide selection of sharp-lined reference stars, extending down to B6IV (ξ Oct). A strong signal for the primary was given against early B-type stars such as 1 Cas (HD 218376; B0·5IV) but the secondary's signal was weak, less than a third that of the primary. It improved somewhat with the later-type reference stars but, at the same time, the primary's cross-correlation function (ccf) became weaker and less well defined and thus modelling of the blended ccfs became problematical. The best compromise, which was finally adopted after much experimentation, was to use γ Peg (HD 886; B2IV) as the reference mask for both components.

The elements thus derived are listed in Table II. A separate solution is given for the primary star alone, while in the two-star computation, the secondary has been given one-fifth the weight of the primary in respect of the larger measuring error. Note that, following earlier papers in this series, velocities recorded within 0·1 cycles of the eclipse of a component have been given zero weight, although it is only fair to mention that, in the case of μ^1 Sco, their inclusion at full weight makes very little difference to the outcome. It is apparent that the velocity amplitudes derived for both components are considerably smaller than those found by Struve, implying a less massive system than generally considered hitherto, although the secondary amplitude is identical to that determined more recently by Sahade & García de Ferrer. Figure 1 shows the data and the eccentric solution; there are, however, good grounds for expecting that the orbit of such a close binary would be circular and any

TABLE II

Orbital elements of μ^1 Scorpii

	Primary		*Both*	
P (days)	1·446262	± 0·000011	1·4462710	± 0·0000044
γ (km s^{-1})	−8·1	± 1·9	−7·6	± 3·9
K_1 (km s^{-1})	158·2	± 2·2	157·6	± 3·1
K_2 (km s^{-1})			244·3	± 5·7
e	0·037	± 0·015	0·019	± 0·017
ω (degrees)	151·4	± 29·1	127·9	± 50·0
T (HJD)	2448102·622	± 0·119	2448102·521	± 0·202
R.m.s. residual (km s^{-1})	6·0		10·1	
f(m)	0·623	± 0·016		
q			1·55	± 0·05
$m_1 \sin^3 i$ ($M_\odot$)			5·92	± 0·32
$m_2 \sin^3 i$ ($M_\odot$)			3·82	± 0·17
$a_1 \sin i$ ($R_\odot$)			4·50	± 0·09
$a_2 \sin i$ ($R_\odot$)			6·98	± 0·16

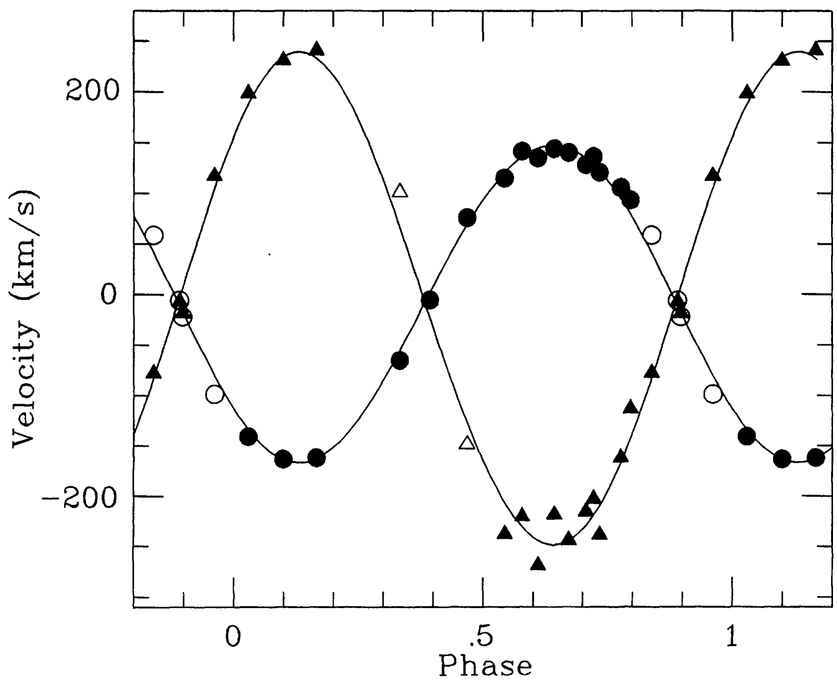

FIG. 1

The eccentric orbital solution for μ^1 Sco with the *IUE* radial velocities plotted: ●: primary, ▲: secondary; open symbols represent zero-weighted data.

observed departure may just be a manifestation of distortions produced by tides, gas streams, and gravity darkening. Accordingly, a circular solution was calculated but was found to be negligibly different from the slightly eccentric one in the important respect of the velocity amplitudes. The systemic velocity, −7·6 km s^{-1}, is more negative than was found by Struve (0 km s^{-1}) and slightly more negative than the mean of the four members of Sco OB2 listed by Humphreys[10] (−3 km s^{-1}), although not disturbingly so, given the uncertainty in the interstellar-line velocity of μ^1 Sco.

Discussion

If μ[1] Sco has been comparatively neglected by spectroscopists, neither has it received much recent attention by photometrists. Rudnick & Elvey[11] provided an early photoelectric light-curve while van Gent[12] produced a photovisual one. The definitive light-curve thus far was recorded almost half a century ago by Stibbs[13] with a broad-band photometer centered on 3970Å, and his data have since been re-examined by Cester *et al.*[14] and by Schneider *et al.*[15], applying more-modern analytical techniques. The conclusions of these studies point to μ[1] Sco being a semi-detached binary with the presently less-massive star being of comparable size to the more massive one and just filling its Roche lobe; they also suggest an effective temperature of the secondary indicative of a type earlier than B6, perhaps B2·5 or B3. All the investigators derived inclinations between 60° and 63°·2, from which we shall adopt a working average from the most recent studies of 62°. This leads to masses of 8·6 and 5·6 $M_{\odot}$, substantially lower than previous estimates and even somewhat lower than those of the comparable types in the well-studied α Vir system[16] (B1·5V + B4; 10·8 + 6·8 $M_{\odot}$).

The state of evolution of this member of the Sco OB2 association[17], age 10^7 years, has also been considered by the photometry analysis[11–15] and by Giannuzzi[18] among others. Their deliberations suggest, on the basis of the earlier photometric and spectroscopic results, that the binary has concluded a rapid phase of mass transfer, moving at least 3 $M_{\odot}$ from the presently less-massive star to the current primary, and is probably in a slow phase of Case A transfer at present. However, the fact that both stars appear to be located within the main-sequence band[14,15] and that the revised masses are not incompatible with the main-sequence types may argue instead that the system is not evolved, and could even be approaching the main sequence[15] for the first time.

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