THE O-TYPE SPECTROSCOPIC BINARY SYSTEM HD 149404

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HD 149404 (HR 6164) was noted to have double lines by Conti, Leep and Lorre (1977). The spectrum has been previously classified as O9Ia, and shows strong Si IV λ4089, 4116 absorption, He I stronger than He II, N III λ4634,41 weakly in emission, He II λ4686 "filled in," and all the Balmer lines through H13 in absorption except Hα, which is strongly in emission.

PSC and Dr. Nancy Morrison obtained 40 coude spectrograms (18 Å/mm) of this star from Kitt Peak and Cerro-Tololo. Of these, 13 showed double lines. The orbit solution shown in Fig. 1 is based only on these double-lined plates, and only on the absorption lines. The formal elements are given below and were derived from a differential correction technique after the period was found using a program written by R. J. Wolff and N. Morrison based on the Lafler-Kinman (1965) search routine.

Elements of HD 149404

P = $9^{\mathrm{d}}.813$ (adopted)
e = 0 (assumed)
T = JD 2442498.7

	Primary	Secondary
Spectral type	O8.5I	O7III(f)
γ (km/s)	-37 ± 1	-28 ± 2
K (km/s)	101 ± 1	60 ± 2
a sin $\underline{i}$ (× 10^7 km)	1.37 ± 0.02	0.81 ± 0.01
m $\sin^3\underline{i}$ (solar masses)	1.6	2.7
mass ratio	1.68	

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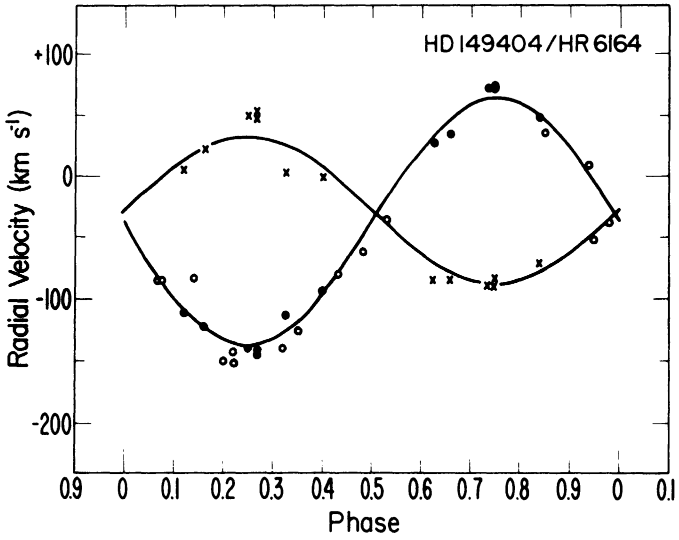

Fig. 1. Velocity curve HD 149404. The filled circle (primary) and the crosses (secondary) are from the double-lined plates; the open circles are from the single-lined plates and were not used in computing the orbit.

The brighter star is a late-O supergiant, which we call the primary; the secondary is a somewhat earlier giant. The N III λ4634,41 emission clearly shifts with the secondary. The primary is the less massive of the two. It should also be noted that the primary's γ velocity is blue-shifted relative to that of the secondary. This effect was seen in HDE 228766 and BD+40°4220 (Massey and Conti 1977) and is readily interpreted as evidence that mass is moving outwards even down deep in the line-forming photospheric regions.

Since the absorption lines are quite blended even at quadrature, we must consider how large an effect this has on the minimum masses. Wilson (1941) developed a simple method for obtaining the mass ratio of a double-lined binary without an orbit solution. When this approach is applied to the two sets of absorption lines, we find a mass ratio of 1.64, in excellent agreement with the formal solution as expected from the fact we used the same velocity data. However, when we use the secondary's N III λ4634,41 emission we find a mass ratio of 1.0. This would drive the minimum masses up to 4 for each star. It should be emphasized that this emission can occur even in a plane parallel geometry (Mihalas, Hummer and Conti 1972) and can be a good velocity indicator as shown by some WN stars (Conti, Niemela and Walborn 1979). Unfortunately, only 5 plates have measurable N III emission so an orbit solution is not possible.

We see evidence of mass loss from the supergiant in that (1) its γ velocity is more negative than its companion's, (2) it may be undermassive for its luminosity, and (3) there is very strong, broad Hα emission, indicating that mass is being lost somewhere in the system. We must now ask how the mass is being lost: does the supergiant fill its Roche lobe? We can argue that it does as follows:

We know the absolute luminosity of the system from its cluster membership in ARA OB1a (Humphreys 1978); after correcting for the contribution of the secondary we find $M_V \sim -6.8$. Using the effective temperature scale and bolometric corrections of Conti (1973), we compute that the supergiant should have radius of 27 R_O. We may estimate the size of the Roche radius r_1 following Paczyński (1970):

$$r_1 \sin \underline{i} = (a_1 + a_2) \sin \underline{i} \left(0.38 + 0.2 \log \frac{m_1}{m_2} \right) ,$$

or $r_1 \sin i = 13\ R_O$ from our orbital elements. Therefore, if the star did <u>not</u> fill its Roche lobe, $\underline{i} < 30°$. If the actual masses are about 20 M_O, then $i \geq 30°$. Furthermore, if the star is rotating synchronously in its orbit its equatorial velocity should be 140 km/s; we estimate $v \sin \underline{i}$ from the line widths to be 120 ± 30 km/s, implying that $i \gtrsim 40°$. These arguments are slightly <u>strengthened</u> if the mass ratio indicated by the N III emission is more nearly correct. We conclude that the supergiant probably fills its Roche lobe.

It should be mentioned that the Hα emission is usually double peaked, but is variable in the sense that it becomes single during phases near to quadrature; e.g., when the absorption lines become double. We do not know where the emission is produced; however, if we interpret it as coming from the supergiant we compute a mass loss rate from the models of Klein and Castor (1978) of $6 \times 10^{-6}\ M_O$/yr.

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DISCUSSION FOLLOWING MASSEY AND CONTI

Hutchings : Is there a light curve for this system? It should be an ellipsoidal variable, and the light curve should be analysed.

Massey : Yes, Nancy Morrison has done photometry for this system.

Morrison : I have obtained photometry of this star on the uvby photometric system, and the results are consistent with the brighter star filling its Roche lobe. The light curve is roughly sinusoidal between phase 0.0 (where the brighter star is in front) and phase 0.5, with maximum light at phase 0.25, where the velocity separation is a maximum, as would be expected on the basis of an ellipsoidal model. Phases are computed on the basis of the ephemeris from the velocity curve. At phases greater than 0.5, the light curve may show intrinsic variability, but the data are too fragmentary for definite conclusions to be drawn. The amplitude of the ellipsoidal variation is 0.03 mag.

Bidelman : How do you know whether so are the NIII emission lines on the absorption lines to determine the mass ratio in this system?

Massey : Well, we shouldn't be surprised if the absorption lines from the fainter stars are shifted towards the lines of the brighter star - this is the well known effect of pair blending. On the other hand, NIII λ4640 emission has been shown to be a surprising good velocity indicator. In HDE 228766, Conti and I found that the NIII emission from the Of star gave the same center-of-mass velocity as that determined from the absorption lines of the other star - a result we misinterpreted as the time. Niemela's work on the Wolf-Rayet star HD 97420, and Conti's work on other Of stars also support this contention. I believe that it is well known that NIII λ4640 can be formed in emission in a plane parallel atmosphere - it is not formed in the wind.

Bolton : In order to do pair-blending corrections properly it may be necessary to take a variety of photographic effects into account. If this not done, the correction will probably be underestimated. In other words, I doubt that it is possible to do the pair-blending correction properly for photographic data.

Massey : Let me just say that I do not believe blending corrections can be done correctly in any event. I personally don't think that photographic effects on IIa-O's taken at Coudé dispersions can be very significant, but I have not looked into it.

Cowley : In the X-ray binaries it is fairly common to find the emission lines indicate a smaller mass ratio than the true value. This is because the emission is partially formed between the stars. In this system perhaps the NIII emission gives a similarly too small velocity amplitude.

Massey : Our NIII emission gives a larger velocity amplitude than the absorption, as was also the case in HDE 228766. It is easy to see why the absorption line amplitude might be too small, due to the effects of blending. It is hard to see why the emission amplitude should be too big.