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SPECTROSCOPIC OBSERVATIONS OF HZ HERCULIS

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ABSTRACT

Spectroscopic observations of HZ Her obtained over a period of 1 year are presented. The velocity curve is distorted because of the shape of the star and the brightness distribution over its surface but preliminary estimates of the masses of HZ Her and the X-ray source are 2.2 ± 0.4 $M_\odot$ and 1.3 ± 0.4 $M_\odot$, respectively, assuming $i = 90°$. Apart from an absorption spectrum varying in type from BO to A8, only very weak variable emission at λλ4602, 4640, and 4686 is observed. The space motion and distance of HZ Her are briefly discussed.

Subject headings: binaries — stars, individual — X-ray sources

I. SPECTRAL AND RADIAL VELOCITY VARIATIONS

Observations of HZ Her, the optical counterpart of Her X-1 (Tananbaum *et al.* 1972; Giacconi *et al.* 1973) have been obtained with the *f*/1.4 spectrograph attached to the Cassegrain focus of the 1.84-m telescope. For consistency most of the observations were made with a grating giving a dispersion of 118 Å mm^{-1} at Hγ and an image slicer with a projected slit width of 22-μ (i.e., a resolution ≃ 2.5 Å producing a spectrum 0.2 mm wide). The same equipment was used to obtain 22 spectra of five standard velocity stars. A systematic error of only -1.8 ± 2.2 km s^{-1} is indicated; the standard error per spectrum is $= \pm 10$ km s^{-1} and the standard error per line is $\simeq \pm 30$ km s^{-1}. The length of the exposures on HZ Her ranged from about 1 to 3 hours.

The mean velocities listed in table 1 and plotted in figure 1*a* are the weighted (according to the reliability and appearance of the lines) mean velocities of all suitable lines in the spectra. It is obvious from the size of some of the standard errors that the agreement among the velocities of individual lines is sometimes very poor, and frequently this reflects differences among lines of different elements. A basic model in which a "normal" A star (HZ Her) is heated on one side by a compact object (Her X-1) orbiting with a period of 1.7 days should be kept in mind for the interpretation of the following descriptions. At phase 0, the A star is in front of the X-ray source.

a) *Mean Velocities*

A conventional Keplerian orbit fitted by least-squares to the mean velocities would be characterized by the usual binary-star parameters $K = 62 \pm 6$ km s^{-1}, $V_0 = -59 \pm 4$ km s^{-1}, $e = 0.34 \pm 0.06$, $\omega = 193° \pm 15°$, $T_0 = 2{,}441{,}507.86 \pm 0.06$, but the X-ray observations indicate that $e < 0.1$. If one assumes a circular orbit, a mass-ratio, $q = 0.5$ ($K = 85$ km s^{-1}), and $V_0 = -60$ km s^{-1}, the velocity of the center of *mass* of the A star would be represented by the sine curves (*solid lines*) in figure 1. Model calculations (Crampton and Hutchings 1972) of such a system indicate that the apparent velocity from strong spectral lines would be represented by the dashed line in figure 1*a*. It is apparent that the observed curve is distorted in this manner, although additional effects such as those due to gas streams must be present, particularly near phase 0.5. This type of behavior is known in other close binary systems (Batten 1973). It is obvious that the true amplitude of the velocity curve is difficult to estimate until more detailed models have been computed, but it is likely to be in the range 85–120 km s^{-1}.

Although the scatter about the mean curve is larger than expected, it is not correlated with the 35^d period. Large variations were observed to occur during a night (e.g., on JD 2,441,780, 2,441,829, 2,441,833, 2,441,838) and are presumably the result of gas streams.

b) *Helium lines*

The amplitude of the velocity variation (fig. 1*b*) is small; in fact there is little evidence for any variation with phase.

c) *Hydrogen lines*

The mean velocity of Hγ and Hδ (fig. 1*c*) may display the largest amplitude of all but more data are required, particularly near phase 0.2. Radial velocities of H9, H10, and H11 were frequently included in the mean, but H8 is apparently affected by He I λ3888 even at those phases when the other helium lines are weak or absent, and so it was not included in the mean. Asymmetric profiles, broad wings, and other structure of the hydrogen lines were suspected, particularly near phases 0.2 and 0.8.

d) *Ca* II *K-line*

The strong line characteristic of a late A star at phase 0.9 becomes shallower but broader near phase

TABLE 1

SPECTROSCOPIC OBSERVATIONS

Heliocentric Julian Date (2,440,000+)	35^d*, Orbital Phases†	Heliocentric Radial Velocities: Mean (km s^{-1})	Hγ and Hδ (km s^{-1})	He (km s^{-1})	K (km s^{-1})	Notes
1502.796	0.94, 0.88	−108 ± 23	− 86	...	−154	4, 5
1522.894	0.52, 0.71	−107 ± 9	−112	...	− 85	3, 4, 6
1531.787	0.77, 0.94	−126 ± 15	−106	...	−150	5
1540.746	0.03, 0.21	+ 20:	+ 44	...	+ 23	3, 6, 8
1552.745	0.38, 0.26	− 30 ± 9	− 34	− 30	− 14	3, 7
1554.735	0.43, 0.43	− 30 ± 5	− 42	− 26	− 26	7
1556.794	0.49, 0.64	− 58 ± 9	− 73	− 52	−243, −580	3, 4
1559.767	0.58, 0.39	− 13 ± 5	− 7	− 16	− 45:, −259	1, 6, 9
1560.746	0.60, 0.97	− 69 ± 25	− 50	...	− 30, −200	5
1561.730	0.63, 0.55	− 30 ± 10	− 22	− 3	− 70	3, 6
1750.015	0.03, 0.29	− 4 ± 9	+ 2	− 15	+ 19	1, 2, 9
1780.921	0.92, 0.47	− 17 ± 8	− 26	+ 6	+ 14	1
1780.998	0.92, 0.52	− 81 ± 11	− 60	− 67	+ 14, −102	1, 3, 4
1782.880	0.97, 0.62	− 50 ± 17	− 44	...	− 94	4, 8
1792.869	0.26, 0.50	− 28 ± 13	− 11	− 29	− 78	...
1792.931	0.26, 0.54	− 48 ± 11	− 37:	− 67	− 58	1, 9
1792.980	0.26, 0.56	− 49 ± 10	− 42	− 67	−153	1, 3, 4
1802.864	0.55, 0.38	− 22 ± 10	− 27	− 46	+ 75:	1
1802.944	0.55, 0.43	− 2 ± 7	+ 4	− 1	− 16	1, 7
1803.887	0.58, 0.98	− 53 ± 17	− 45	...	−112	5
1813.816	0.86, 0.82	−128 ± 20	−155	...	− 83, −205	2, 3, 4
1813.909	0.86, 0.87	−140 ± 14	−128	...	−151, −355	1, 2, 3
1823.919	0.15, 0.76	−108 ± 9	−120	...	− 67, −281	3, 4
1828.849	0.29, 0.66	− 83 ± 5	− 81	− 80	−114	1, 4, 6
1829.858	0.32, 0.26	− 30 ± 12	− 21	− 81	+ 20	1, 2
1829.931	0.32, 0.30	− 60 ± 4	− 53	− 62	− 30	1, 3
1831.773	0.38, 0.38	− 19 ± 10	− 19	− 22	+ 26:	...
1831.845	0.38, 0.42	− 8 ± 9	+ 6	− 9	+ 22, −120	...
1831.914	0.38, 0.46	− 41 ± 4	− 40	− 53	+107:	...
1833.764	0.43, 0.55	− 43 ± 8	− 43	− 24	0	1, 2, 9
1833.854	0.44, 0.61	− 36 ± 7	0	− 57	− 45, −356	1, 4, 6
1833.941	0.44, 0.66	− 80 ± 13	− 82	− 57	−171	4
1834.800	0.46, 0.16	− 2 ± 19	+ 55	− 84	− 42	1, 2, 3
1834.907	0.47, 0.22	− 10 ± 12	+ 30	− 20	− 4	1, 2, 3, 9
1835.867	0.49, 0.79	−115 ± 20	−108:	−107	−127	1, 3, 7
1837.839	0.55, 0.95	−119 ± 20	−140	...	− 90	3
1838.767	0.58, 0.50	− 29 ± 12	+ 13	− 41:	− 25:	1, 2, 3
1838.818	0.58, 0.53	− 1 ± 7	+ 3	+ 3	− 40	1, 2, 9
1838.882	0.58, 0.56	− 36 ± 8	− 24	...	− 31, −533	1, 4, 9
1838.934	0.58, 0.59	− 45 ± 5	− 50	− 35	− 89, −386	1, 4
1864.837	0.32, 0.83	−153 ± 5	−159	...	−128, −444	1, 2, 4, 5, 9

* Phase computed from epoch of peak X-ray intensity at JD 2,441,748.9, period 34.87 days (Levinson, private communication). The X-rays are "ON" from about phase 0.85 to 0.18.

† Phase computed from epoch of mid-eclipse at JD 2,441,506.3921, period 1.700165 days (Giacconi *et al.* 1973).

NOTES.—(1) Weak emission present at λ4640. (2) Weak emission present at λ4686. (3) The hydrogen-line profiles were asymmetric or showed evidence of structure. (4) The K-line profile was asymmetric or showed evidence of structure. (5) Weak metal lines present. (6) Spectrum obtained with an image slicer having a projected slit width of 12 μ and producing a spectrum 0.5 mm wide. (7) Spectrum obtained with a grating giving a dispersion of 78 Å mm^{-1} at Hγ. (8) Weak spectrum. (9) Weak emission present at λ4602?

0.5, and a weak secondary component with a radial velocity $\simeq -400$ km s^{-1} was observed between phases 0.5–0.7. Between phases 0.9–0.2 the velocity (fig. 1*d*) tends to be $\simeq -40$ km s^{-1} more negative than the mean of Hγ and Hδ.

e) *Metal lines*

As noted in table 1, weak metal lines, chiefly Mg II λ4481 and Fe I λλ3758, 3878, and 4383 were sometimes detected on spectra taken between phases 0.8–0.2.

f) *Emission lines*

Very weak wide emission in the λ4640 region (C III) is probably present on most spectra, although it has not been detected on any taken near phase 0.0. Rapid variations in the shape, strength, and velocity of the feature are suspected, confirming the observations by

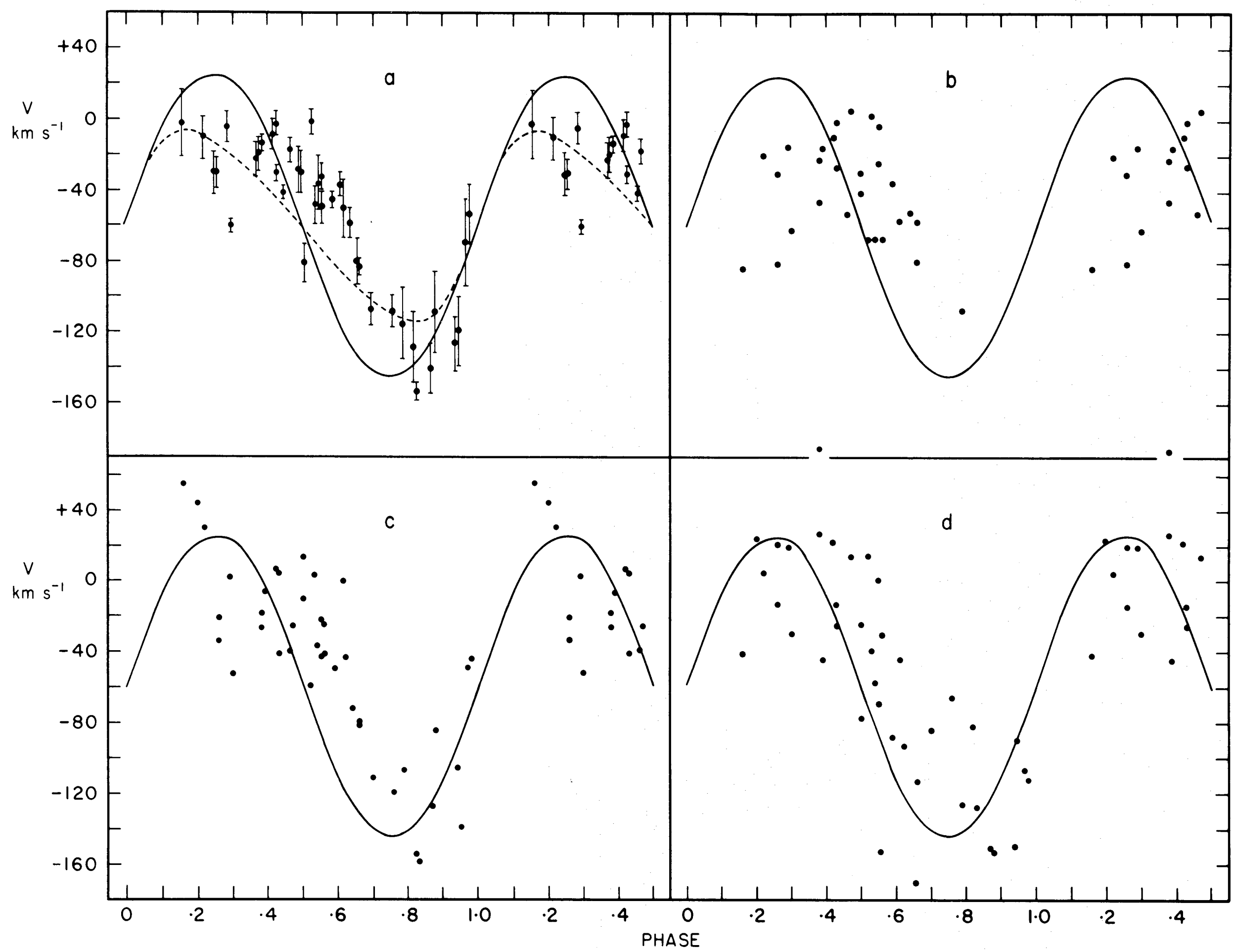

FIG. 1.—Variation with the 1.7-day phase of the radial velocity of (*a*) all lines, (*b*) helium lines, (*c*) mean of $H\gamma$ and $H\delta$, (*d*) calcium K-line. The solid line in each part represents the velocity of the center of mass of the A star if $K = 85$ km s^{-1}, $V_0 = -60$ km s^{-1}. The dashed line in fig. 1*a* represents the calculated velocity variation corresponding to the center of light of the A star.

Bopp, Grupsmith, and van den Bout 1972. Weak emission at λ4686 was detected less frequently, although it was the strongest feature on a recent spectrum (JD 2,441,887.866, orbital phase 0.38, 35-day phase 0.99). The very wide emission at λ4686 in combination with a narrower line at λ4602 (N v) gave the spectrum the appearance of a WN 5 star in this region (although the emission is very weak). A re-examination of the earlier spectra (table 1) indicates that perhaps this phenomena is not too infrequent.

No other emission features have been detected. Only an absorption feature is present at $H\beta$, although Bopp *et al.* (1972) reported $H\beta$ emission.

g) *Ultraviolet continuum*

The observations do not confirm the systematic disappearance (Crampton and Hutchings 1972) of the ultraviolet continuum during X-ray eclipse.

II. SPECTRAL TYPE

A selection of spectra taken at different phases are presented in figure 2 (plate 3) along with two standard stars of types O9.5 V (σ Ori) and A7 V (21 L Mi). At maximum light the spectrum of HZ Her resembles that of a B0 V star and the observed equivalent width of $H\gamma$ (4 Å) is appropriate to this type. At minimum light the ratio of K/H + Hϵ suggests a type $\simeq$A8. The hydrogen lines are more characteristic of spectral type A5, while the metal lines suggest a type of perhaps F0. Since the star is undoubtedly distorted, the cool "back" side will not be representative of the "underlying" star in any case. The present observations only allow the crude estimate that this star has a late A spectral type. Although a Population II object is indicated by the high galactic latitude, $b = 37^\circ.5$, the spectrum does not appear to be that of a subdwarf.

III. DISTANCE AND MASSES

A detailed interpretation of the results is postponed until better models are constructed, but it appears that the model proposed by Crampton and Hutchings (1973) is approximately correct. The amplitude of the center of mass of the A star is probably $\simeq$ 85–120 km s^{-1} corresponding to $q \simeq$ 0.5–0.7 or $M_1 \simeq 1.9$–$2.5\ M_\odot$, $M_x \simeq 1.0$–$1.7\ M_\odot$ for $i = 90°$. A value of i close to 90° is suggested by indications of a secondary minimum in the recent light curves (Petro and Hiltner 1973; Boynton *et al.* 1973). The value of $i \simeq 70°$ recently suggested by Basko and Sunyaev (1973) and by Strittmatter *et al.* (1973) would lead to a 20 percent increase in these masses. A star of "late A" spectral type has a typical mass $\simeq 1.5\ M_\odot$ if it is on the main sequence, but since HZ Her has been (and still is) losing mass to its companion, this estimate is very uncertain. Masses of $M_1 = 2.2 \pm 0.4\ M_\odot$ and $M_x = 1.3 \pm 0.4\ M_\odot$ seem to be compatible with the present data.

The intrinsic luminosity of HZ Her is likewise very uncertain, but an estimate of $M_v \simeq 1.5$ mag is in accord with the mass and spectral type. If cosecant law reddening [$E(B - V) = 0.06$ cosec b, Arp 1962] is assumed, the interstellar absorption is only 0.3 mag and so for $V \simeq 14$ mag a distance of 3 kpc is indicated. The system is then about 1800 pc above the galactic plane.

The proper motion of HZ Her was kindly measured by Dr. W. J. Luyten on a pair of plates taken with the Palomar 48-inch (1.2-m) telescope 12.86 years apart. The measured motion is +0″.015, −0″.041, or 0″.043 in 160° with errors of about 0″.020 in each coordinate. Dr. Luyten also blinked the plates and was able to detect the small southward motion. The proper motion is therefore very small, a marginal southward motion of 0″.04 per 12.86 years or 0″.003 per year being indicated. At a distance of kpc this corresponds to a tangential velocity of ~40 km s^{-1} in a direction nearly parallel to the galactic plane. The systemic radial velocity corrected for solar motion is also −40 km s^{-1}, and the component toward the plane is about 25 km s^{-1}. HZ Her is certainly not a "high-velocity" star, at least not at the present epoch, and its position so far from the plane is rather curious.

My thanks to all those DAO observers who relinquished telescope time at appropriate phases; particularly to C. Aikman, W. Fisher, G. Hill, S. Morris, and F. Younger. My thanks are due to Russell Redman, Ann Gower, G. Hill, and J. B. Hutchings for assistance and advice, and also to Dr. W. J. Luyten for kindly measuring the proper motion of HZ Her.

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Note added in proof.—The proper data supplied by Dr. Luyten was incorrectly interpreted to be displacements on the plate. The proper motion is 0″.043 per annum, which corresponds to a tangential velocity of the order of 600 km s^{-1} at 3 kpc. Since the errors are rather large and the radial velocity (corrected for solar motion) is only ~40 km s^{-1}, a more accurate determination of the proper motion should be made before speculating on the origin of such a velocity.