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Orbit and mass of the visual binary L 726-8

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New observations permit a redetermination of the orbit of the red dwarf binary L 726-8. The resulting masses, assuming a reasonable mass-ratio, are 0.12 ⊙ and 0.10⊙ ; these values are about 2(1/2) times larger than those heretofore quoted. Consequently, it appears likely that the components are normal hydrogen-burning stars on the main sequence.

INTRODUCTION

SINCE its belated discovery in the course of the Bruce Proper Motion Survey, (Luyten 1949), the visual binary L 726-8 (1900:$01^h34^m.0$, $-18°28'$) has attracted attention because of its large parallax and proper motion, noticeable orbital motion, and the fact that the fainter component, UV Ceti, was one of the earliest flare stars discovered. As early as 1955, Protitch (1955) published a preliminary orbit with $P=31.9$ yr, and $a=1''.645$; these values, combined with the first accurate parallax, enabled Luyten (1956) to derive a total mass of only 0.08 ⊙, indicating that the components of L 726-8 were the least massive stars known. Three years later, van de Kamp (1959) published a quite different orbit, with $P=200$ yr and $a=5''.6$; still later Luyten (1961) obtained $P=54.54$ yr and $a=2''.38$. Despite these quite different elements, the calculated mass sums were nearly identical at about 0.08 ⊙, and seemed to lend weight to the conclusion that the components of L 726-8 were indeed the least-massive stars known. Shortly thereafter, theoretical models by Kumar (1963), based partly on results by Limber (1958) and Hayashi (1962), postulated that there existed a critical mass below which a star could not stabilize itself on the hydrogen-burning main sequence, but would instead continue its contraction until a degenerate configuration was reached. Theoretical work on this subject has been summarized by Grossman (1970), who currently finds a limiting critical mass at about 0.075 ⊙ for a composition of $X=0.68$, $Y=0.29$. As Grossman notes, however, it is possible to find higher limiting values, of the order of 0.1 ⊙, depending upon the initial chemical composition. Since the components of L 726-8 seemed to be comfortably below these limits, they became the "classical" examples of low-mass degenerate stars.

Greenstein, Neugebauer, and Becklin (1970) recently have expressed some qualms concerning the nature of the components of L 726-8. These writers have redetermined luminosities and temperatures for faint red dwarfs using modern infrared observations, and find that the bolometric corrections accepted earlier must be increased substantially. As a result, the components of L 726-8 appear to be overluminous for their masses. It is the purpose of this paper to show that previous mass determinations for L 726-8 are erroneous due to an incorrect interpretation of the orbital motion, and that the components of this system are, in all probability, normal main-sequence objects.

OBSERVATIONAL DATA

For all observers in the northern hemisphere, L 726-8 has, by virtue of its faintness and large zenith distance, proved to be a difficult object, and rather severe systematic errors are obvious in the observational material. Since the maximum separation only slightly exceeds 2 arcsec, these remarks apply to the photographic data as well as to the visual. Following its discovery, L 726-8 was observed visually with some frequency, and photographically upon occasion, but since 1964 few visual measures have been made. Fortunately, the pair has been under annual photographic observation since that time with the U. S. Naval Observatory's astrometric reflector. While Luyten's 1961 orbit represented the observations fairly well until about 1966, increasing deviations were noted subsequently, with the observed motion being much greater than that predicted. Worley (1972) obtained measures at Cerro Tololo in July 1970 which supported the rapid change noted on the plates; for a time in 1970–71 the pair had a separation <1 arcsec and was too close to photograph with any accuracy. A single plate taken in December 1972 shows the components once more clearly separated, and confirms a change in position angle of more than 180° since 1966. This rapid motion also has been noted and used by Luyten to compute a new orbit with a period of about 25 yr and $a=2''.13$ (van de Kamp 1971). Luyten's orbit has not been published in detail, but computation of residuals shows that it gives an unacceptable representation of both the early and the recent motion.

The visual measures used in this study were obtained from the Observation Catalogue maintained at the Naval Observatory, supplemented by a few positions quoted in Luyten's 1961 paper; these lists also contain a few photographic observations obtained with various telescopes. Later material includes 21 usable plates taken with the astrometric reflector, plus the Cerro Tololo visual measures. The plates obtained with the 61-in. were measured on the MANN measuring machine by Behall and reduced with the plate-constant program routinely used for the parallax program in order to

TABLE I. Normal points, weights, and residuals for L 726-8.

Date	θ	ρ	No. nights	Observers[b]	Weights θ	Weights ρ	Residuals θ	Residuals ρ
1948.77	118°1	1″58	5	3 VBS, 1 B[a], HUM	2.0,	1.0	−0°4,	+0″05
49.80	104.1	1.63	6	4 MRZ[a], 2 VBS	2.0,	1.0	−3.0,	+0.01
50.82	95.4	1.73	9	3 VBS, MRZ[a], 2 LUY, 1 BAA	3.0,	1.5	−1.4,	+0.05
51.78	86.9	1.67	5	3 VBS, 2 MRZ[a]	2.0,	1.0	−0.8,	−0.06
52.88	79.0	1.68	11	5 VBS, 4 DJU[a], 2 MRZ[a]	3.0,	1.5	+1.1,	−0.11
54.61	64.8	1.86	12	7 DJU[a], 4 VBS, 1 BAA	3.0,	1.5	+1.1,	−0.02
55.79	56.7	1.88	8	4 VBS, DJU[a]	2.0,	1.0	+1.8,	−0.08
56.79	49.1	1.95	6	4 DJU[a], 1 BAA, WOR	2.0,	1.0	+1.2,	−0.07
57.90	41.3	2.12	13	6 VBS, 4 DJU[a], 3 COU	3.0,	1.5	+0.6,	+0.03
58.77	37.0	2.14	8	3 COU[a], 2 KAM, VBS, 1 BAA	2.0,	1.0	+1.7,	0.00
59.73	30.9	2.34	10	5 WOR, 2 DJU[a], 1 BAA, COU[a], VBS	3.0,	1.5	+1.2,	+0.14
61.31	20.2	2.30	8	4 WOR, 3 DJU[a], 1 VBS	2.0,	1.0	−0.8,	+0.03
62.37	13.0	2.50	6	4 B, 2 VBS	2.0,	1.0	−2.4,	+0.20
64.60	3.4	2.34	5	2 VBS, 1 DJU[a], POP, WOR	2.0,	1.0	−0.4,	+0.05
64.903	2.5	2.22	2	2 USN	2.0,	2.0	+0.2,	−0.06
65.763	357.7	2.17	3	3 USN	4.0,	4.0	+0.1,	−0.06
66.783	350.7	2.08	2	2 USN	3.0,	3.0	−1.0,	−0.05
67.642	343.0	2.01	1	1 USN	2.0,	2.0	−3.2,	+0.01
68.786	335.8	1.74	3	2 USN, 1 DJU[c]	3.0,	3.0	−1.4,	0.00
69.646	325.1	1.46	2	2 USN	3.0,	3.0	−2.8,	+0.01
69.892	322.9	1.40	1	1 USN	1.0,	1.0	−1.5,	+0.06
70.56	316.5	1.02	3	3 WOR	1.0,	1.0	+5.4,	+0.01
70.897	303.9	0.7:	2	2 USN	2.0,	1.0	+3.9,	−0.12
71.705	256:	0.4:	2	2 USN	0.5,	0.5	+19.5,	−0.09
71.993	189:	0.6:	2	2 USN	0.5,	0.5	−16.4,	+0.06
72.920	157.5	1.02	1	1 USN	2.0,	2.0	−0.1,	+0.03

[a] Half-weight.
[b] Observer's designations are those used in the Index Catalog.
[c] Not used in the computation.

determine the orientation. In addition, the plates taken after 1969.89 were measured by both writers in polar coordinates, effected by rotating the measuring machine stage. Two of the reference stars were also measured in order to relate the measures to the equator. These measures by the two writers agree as well as might be expected, considering the slight elongations involved, which arise as much from dispersion, seeing, and guiding error as from the duplicity.

THE ORBIT

Table I lists the normal points formed from the visual and photographic observations of L 726-8. Observations made with telescopes having apertures <30-in. were given half-weight in forming the normal points. From the normal points a preliminary orbit was computed by the Thiele–van den Bos method. Experiments with slight variations in parameters showed that further improvement might be expected, so a differential correction was attempted. The differential corrector employed possesses the capability of treating position angles and separations independently, that is, one can assign different weights to each of the coordinates. This is a distinct advantage for visual pairs, where the angles are almost invariably observed with greater precision than the separations, and doubly so in the case of L 726-8. For this pair, weights were based simply on the number of nights, with the angles generally given twice the weight of the separations in the case of the visual observations, and equal weight in the case of the photographic measures. Three iterations converged to the final orbit listed in Table II, where an ephemeris is also given. Figure 1 illustrates the apparent orbit. Root-mean-square residuals were reduced from initial values of 0″082 in θ, and 0″118 in ρ, to final values of 0″068 and 0″072, respectively. Residuals from the final orbit are listed in columns 8 and 9 of Table I, and indicate that a satisfactory solution has been obtained despite the observational difficulty of this pair. The sizable residuals near periastron merely confirm the uncertainty of the

TABLE II. Orbital elements and ephemeris for L 726-8.

Campbell Elements			Thiele–Innes Elements			
P	26.52 years		A	−1″0665	F	−1″5653
T	1971.88		B	−0.7801	G	+1.2638
a	2″06		C	∓1.5778	H	±0.4332
e	0.615					
			pL	∓101.46	pN	±27.86
i	127°3	2000				
ω	285.4	2000				
Ω	150.5	2000				

Ephemeris

1970.0	322°7	1″29	1973.5	144°1	1″20
70.5	312.5	1.04	74.0	135.6	1.33
71.0	295.2	0.76	74.5	128.4	1.43
71.5	258.8	0.52	75.0	122.0	1.50
72.0	204.3	0.55	75.5	116.0	1.55
72.5	172.0	0.79	76.0	110.5	1.59
73.0	155.2	1.03	76.5	105.2	1.63

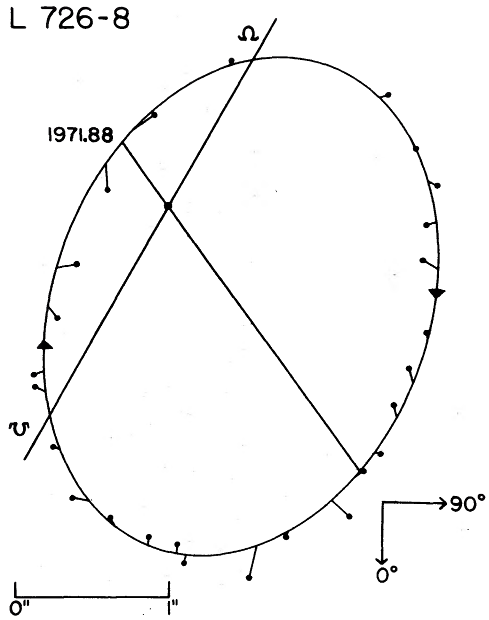

FIG. 1. The apparent orbit of L 726-8. The filled circles (●) indicate the normal points listed in Table I. Also shown are the semimajor axis, line of nodes, and point of periastron passage.

measures in this part of the orbit. Now that some 320° of the orbit has been described, the orbit is defined within tolerable limits, and we estimate its present grade on the Finsen–Worley (1970) scale as 2–3. As the ephemeris in Table II shows, L 726-8 is now opening out rather rapidly, and observations over the next few years should yield somewhat improved values of the elements. However, we do not at this point expect sizable changes from the tabulated elements.

THE MASSES

With the adoption of the values of P and a in Table II, the mass–sum for L 726-8 depends entirely on the value of the parallax used. The supplement to the parallax catalog (Jenkins 1963) lists Allegheny, Sproul, and Yerkes values; the latter value has been revised slightly (Strand and Riddle 1969). There is a subsequent published value from McCormick Observatory (Frederick and Shelus 1969), in which these writers also mention the possibility of a perturbation with $P=16$ yr. (While there is some indication of periodicity in the residuals from the present study, we feel these indications should be treated with extreme caution because of the existence of systematic errors.) Finally, there is a value derived from 24 plates taken with the astrometric reflector (Routly 1973). The five values of the parallax of L 726-8 are listed in Table III, together with the mean error of each determination. If we combine these values, weighted according to the stated errors, we obtain for the parallax of L 726-8

TABLE III. Relative parallaxes for L 726–8.

Allegheny	+0".333±0".028 (m.e.)
McCormick	0.448 0.044
Sproul	0.369 0.015
USNO	0.390 0.007
Yerkes	+0".378±0".022

TABLE IV. Variation in the mass–sum for L 726-8.

Parallax	Mass–sum
0".360	0.27 ⊙
0.370	0.25
0.380	0.23
0.390	0.21
0.400	0.19

$$\pi \text{ rel} = +0''.384 \pm 0''.016 \text{(s.d.)},$$

For a reasonable range in parallax, the variation in the mass-sum is shown in Table IV. Adopting an absolute parallax of 0".385, we then find that the mass–sum is 0.22 ⊙; that is, about $2\frac{1}{2}$ times larger than previously thought.

There exists no astrometric determination of the mass–ratio for L 726-8. However, the small visual Δm of 0.4–0.5 mag does not suggest any substantial difference in the individual masses. We might assign equal masses of 0.11 ⊙, or, following van de Kamp (1959, loc. cit.), we may invoke an empirical mass–luminosity relation, together with the observed Δm, to derive a mass–ratio. Using van de Kamp's value, we derive finally $M_A=0.12$ ⊙, $M_B=0.10$ ⊙. Of course, it is obvious that an actual mass–ratio determination should be made for this important pair.

THE MASS–LUMINOSITY RELATION

Since L 726-8 is one of the handful of low-mass stars available for defining the faint end of the mass-luminosity relation, the revised masses presented here obviously are of importance. While it is not our intent to provide such a redefinition at this point, we note that such a revision depends critically on the bolometric corrections adopted. Greenstein, Neugebauer, and Becklin advocate much larger corrections than heretofore accepted; if these authors are correct, then the increased mass of L 726-8 found by us considerably reduces the apparent overluminosity reported by them.

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