THE ASTROPHYSICAL JOURNAL, 194:637–643, 1974 December 15

A STUDY OF AN EARLY FLARE, RADIAL VELOCITIES, AND PARALLAX RESIDUALS FOR POSSIBLE ORBITAL MOTION OF HD 103095 (GROOMBRIDGE 1830)

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Received 1974 May 30; revised 1974 July 8

ABSTRACT

Measures of radial velocity are presented. Results suggest orbital motion with periastron occurring close to 1920 and an orbital inclination close to 90°. A flare was recorded on a Thaw refractor plate obtained on 1939 April 27. The increase in brightness amounted to 0.6 mag. Positional displacement of the flared images is very small if it exists at all. A revised parallax determination together with parallax residuals covering more than 50 years is also presented. Results again suggest orbital motion with periastron occurring close to 1920. We conclude that either the M dwarf component, which has been known to flare on one other occasion, was nearly aligned in the line of sight of the G8 VI component, or that it was this component itself that flared.

Subject headings: binaries — flare stars — radial velocities — stars, individual

I. INTRODUCTION

The star HD 103095 (Groombridge 1830) is a high-velocity halo subdwarf about 9 pc distant from the Sun. An interesting historical discussion of this has recently been published by Ashbrook (1974). Metals have been found to be about 10 times less abundant than in the Sun (Tomkin 1972). Van de Kamp (1969) has reported the existence of a companion 5 or 6 mag fainter with a separation of 1″.7 which flared on 1968 February 27. The existence of an extensive series of coudé spectrograms of HD 103095 was pointed out to one of the authors (W. R. B.) by Greenstein, who suggested that measurement of its radial velocity might reveal information concerning the period of revolution. In addition, astrometric material obtained at Allegheny Observatory is reported upon in this study.

II. RADIAL VELOCITIES

Table 1 presents a list of all radial velocities, including previously published as well as new determinations. Asterisks in column (1) indicate spectrograms measured by one of the authors (W. R. B.) on the Grant measuring engine at the Allegheny Observatory. Weighted mean velocities are listed in column (8). Weights judged to differ from 1 are listed in the Remarks column. The lines in the spectrum are extremely sharp and are capable of accurate measurement even on low dispersion. For this reason scatter in the velocities, particularly in the older observations, is puzzling. No attempt has been made to remeasure the old plates or to adjust for observatory differences. Such scatter may be an intrinsic property of this star. Annual and biennial means have been employed in an effort to minimize scatter and systematic errors.

A plot of mean radial velocity against time is presented in figure 1. The velocities from the late 1930s to date show a steady slow increase toward more positive values. The velocities of the early 1900s are strongly positive. A change in velocity is evident about 1920, suggesting that periastron passage occurred near that time. No reliable estimate of the period is possible; however, a comparison of the radial velocity variation with the parallax residuals, also shown in figure 1, suggests that the period may be close to 60 years. We conclude that orbital motion is present and that the system is a physical binary.

HD 103095 was included in the original IAU list of standard velocity stars (Plaskett 1935). Since then the rate of change of its radial velocity has been sufficiently slow and uniform that it may still be considered useful as a standard. Caution is advised for future observations, as the next periastron passage may occur soon.

III. THE 1939 FLARE

The series of parallax plates obtained with the Thaw refractor at the Allegheny Observatory was carefully examined by one of us (W. R. B.) for the possible existence of flares. An evident flare was indeed found on plate 57877 obtained by Burns on 1939 April 27. A reproduction of this plate appears in figure 2 (plate 15). Each image represents an exposure of 120 seconds. Star 4 is a field reference star which has remained constant in brightness. A gap in time of 10 minutes occurred between exposures 3 and 4.

A careful measurement of the magnitude of each of the six images on a Cuffey photometer was undertaken by W. R. B. The results are presented in table 2 together with a final parallax residual shift for each

TABLE 1

Radial Velocities of HD 103095

Reference† (1)	Observatory (2)	Plate No. (3)	Date (4)	Radial Velocity and p.e. (km s⁻¹) (5)	No. Lines Measured (6)	Dispersion (Å mm⁻¹) (7)	Mean Radial Velocity (8)	Mean Date (9)	Remarks‡ (10)
1..........	Lick		1901 Feb. 11	− 97	...	12.5			
			Mar. 18	− 93	...	57			wt. ½
			Apr. 1	− 98	...	57			wt. ½
			1903 Oct. 30	−108	...	57			wt. ¼
			Nov. 9	− 94	...	57			wt. ½
							− 96.9	1901 Nov. 26	
2..........	Mt. Wilson	β111	1910 Feb. 22	− 91.8 ± 1.4	...				wt. 0
		β127	Mar. 24	−105.3 ± 0.6	...				wt. 0
		β128	Apr. 23	−104.9 ± 0.9	...				wt. 0
		β135	Apr. 24	− 82.0 ± 1.9	...				wt. 0
		β174	May 14	− 85.2 ± 1.2	...				wt. 0
			17	− 99.7 ± 0.6	...				wt. 0
		γ247	1911 Feb. 22	− 99.2 ± 1.2	...				
		γ362	Apr. 15	− 96.2 ± 4.0	...				wt. ½
		γ399	May 12	− 95.8 ± 0.4	...				
							− 97.2	1911 Apr. 10	
2..........	Mt. Wilson	γ6455	1917 Dec. 6	− 96.2 ± 0.2	...				
		γ6635	1918 Jan. 29	− 98.4 ± 1.4	...	36			
		γ6784	Mar. 28	− 98.0 ± 0.9	...	36			
							− 97.5	1918 Jan. 30	
3..........	Victoria		1921 Feb. 21	−103.1	13				
			May 23	− 99.6	19				
							−101.4	1921 Apr. 8	
2..........	Mt. Wilson	D60	1926 May 26	−109.9	...	250?	−109.9	1926 May 26	wt. 0
2..........	Mt. Wilson	γ20343	1934 Apr. 22	−102.8 ± 1.1	...	36	−102.8	1934 Apr. 22	
2..........	Mt. Wilson	V1770	1937 Mar. 18	− 99.6 ± 0.4	...	38	− 99.6	1937 Mar. 18	
*..........	Mt. Wilson	Ce3742	1945 Mar. 28	− 99.3 ± 0.4	19	3			
2..........		Ce3791	May 21	− 98.8 ± 0.3	...	10			
2..........		Ce4268	1946 May 14	− 98.1	...	10			
							− 98.7	1945 Aug. 20	
*..........	Mt. Wilson	Ce5689	1949 June 15	− 99.7 ± 0.2	23	10			
*..........		Ce5708	June 17	− 99.5 ± 0.2	14	10			
*..........		Ce6278	1950 June 3	− 99.0 ± 0.2	13	5			
							− 99.4	1949 Oct. 11	
*..........	Palomar	Pa73b	1951 Mar. 26	−101.2 ± 0.1	11	2.1			wt. 0§
		Pe371	1952 July 7	− 99.0	12	10			
							− 99.0	1952 Jul. 7	
*..........	Palomar	Pb3236a	1957 June 18	− 98.7 ± 0.3	20	3.6	− 98.7	1957 June 18	
5..........	Haute Provence	W149	1960 Jan. 30	− 96.6 ± 0.5	...	10			
		W153	Jan. 31	− 99.3 ± 0.5	...	10			
		W202	Mar. 12	− 99.3 ± 0.5	...	10			
		W212	Mar. 18	− 98.3 ± 0.6	...	10			
		W230	Apr. 2	− 98.6 ± 0.5	...	10			
		W256	Apr. 13	− 99.2 ± 0.3	...	10			
							− 98.6	1960 Mar. 8	
*..........	Palomar	Pb5765a	1961 Apr. 5	− 98.8 ± 0.2	12	7			
*..........	Radcliffe	Pb5766a	Apr. 5	− 98.5 ± 0.3	7	7			
		W1186	Apr. 29	− 99.0 ± 0.3	...	10			
6..........		D2538	1962 Mar. 23	− 96.5 ± 0.4	...	16			
*..........	Mt. Wilson	Ce15343	Mar. 27	− 97.7 ± 0.1	13	5			
5..........	Haute Provence	W1185	1961 Dec. 29	− 98.2 ± 0.4	...	10			
							− 98.1	1961 Oct. 28	
5..........	Haute Provence	W2198	1964 Jan. 3	− 97.0 ± 0.7	...	10	− 97.0	1964 Jan. 3	
5..........	Haute Provence	GA585	1971 May 10	− 99.7 ± 0.6	...				
*..........	Allegheny	K5529	1972 Mar. 20	− 99.1 ± 0.6	13	40			
*..........		K5609	Apr. 28	− 96.5 ± 0.9	13	40			
*..........		K5611	Apr. 29	− 96.8 ± 0.5	13	40			
*..........		K5622	May 13	− 96.2 ± 0.5	13	40			
5..........	Haute Provence	GA1125	May 26	− 97.6 ± 0.7	...				
		GA1149	June 2	− 98.9 ± 0.7	...				
							− 97.8	1972 Mar. 14	

* See text.

† Numbers indicate the following references: (1) Campbell and Moore, J. H. 1928; (2) Abt 1970; (3) Wright 1951; (4) Harper 1933; (5) Fehrenbach 1972; (6) Evans 1963.

‡ All plates weight 1 unless noted.

§ Star lines strongly tilted with respect to comparison lines; spectrograph out of adjustment.

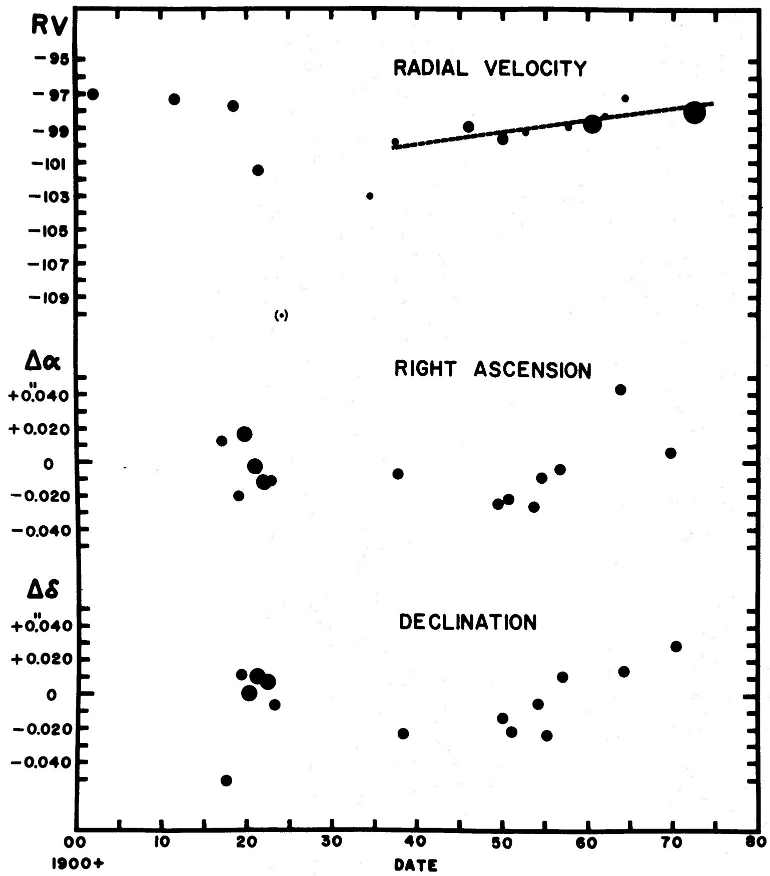

FIG. 1.—Mean radial velocity (km s^{-1}), and parallax residuals in right ascension and in declination (arc seconds) as a function of the date, beginning in 1900. The dotted line in the radial velocity plot is an eye-estimate only, showing slow uniform variation over the past 30 years.

image. It is evident that the star was of normal brightness in images 1 and 2. Images 3, 5, and 6 are about 0.2 mag brighter than normal. Image 4 is definitely flared, being 0.6 mag brighter, 6 times the mean standard deviation of 0.10 mag. It is impossible now to establish whether a slow flare occurred lasting in excess of 18 minutes or whether a series of short flares of large amplitude occurred. Evidently, the plate was never closely examined after being developed.

The question remains as to whether the primary or the secondary flared. A flare of the G8 primary would

TABLE 2

OBSERVED MINUS COMPUTED POSITION OF GROOMBRIDGE 1830 FOR THE SIX EXPOSURES OF PLATE 57877

No.	m_{pg}	Δα	Δα
1...........	7.25	+0.″066	+0.″016
2...........	7.24	−0.033	−0.018
3...........	7.04	−0.029	−0.044
4...........	6.62	−0.032	−0.027
5...........	7.02	+0.037	−0.044
6...........	7.04	+0.027	−0.008

be unusual, but a precedent case has been noted[1] (Weaver and Naftilan 1973). If it was the secondary that flared, then again we can say the flare was unusual due to the extreme brilliance required, since Worley (1972) has observed the secondary to be normally 5.0–5.5 mag fainter than the primary. We shall return to this question in the discussion section.

Figure 3 (plate 16) presents isophotometric contours of several images made by one of us (K. W. K.) with a Joyce-Loebl isophotometer at Van Vleck Observatory. Unlike the 1968 flare observed by van de Kamp the companion if indeed it was the companion that flared is not resolved nor is it possible to conclude that the flare image is elongated.

IV. ASTROMETRIC DATA AND REDUCTIONS

The astrometric material is comprised of 99 measurable exposures on 35 plates obtained with the Thaw

[1] Weaver and Naftilan report that H_{II} 230 is a normal-appearing G5 V star behind the Pleiades. Haro (see Haro and Chavira 1969, and Haro 1968) has observed this star to flare, but the same dilemma is present: Was it the G5 V star that flared or an unresolved M dwarf companion?

TABLE 3

RELATIVE POSITIONS, PROPER MOTIONS, AND ABSOLUTE PARALLAXES OF 14 STARS IN THE REGION OF GROOMBRIDGE 1830 ON THE SYSTEM OF THE FK4

No.	m_{pg}	π_{abs}	Standard Error in π	R.A. (1950)	Standard Error in R.A.	μ yr^{-1}	Standard Error in μ	Decl. (1950)	Standard Error in Decl.	μ' yr^{-1}	Standard Error in μ
23........	12.7	+0″005	7	11ʰ48ᵐ28ˢ9532	5	−0ˢ00132	2	38°10′34″428	8	−0″0133	3
24........	12.5	+0.010	5	11 48 36.8038	4	−0.00346	2	38 25 16.939	10	−0.0097	3
25........	12.5	−0.001	5	11 48 53.3233	4	−0.00137	2	38 04 12.465	6	−0.0101	2
26........	13.0	...	...	11 48 59.3624	12	−0.00459	9	38 20 38.464	30	−0.0195	20
27........	12.8	+0.007	5	11 49 02.2749	4	−0.00775	2	37 52 18.138	9	−0.0141	3
28........	12.6	+0.003	5	11 49 36.8721	4	−0.00372	2	37 54 17.031	6	−0.0045	2
29*.......	7.1	+0.107	6	11 50 06.1807	6	+0.33897	4	38 04 39.123	9	−5.8081	4
30........	12.7	−0.002	5	11 50 23.7726	4	+0.00002	2	38 15 50.629	6	−0.0141	2
31........	12.7	−0.008	7	11 50 25.2588	6	+0.00003	2	38 02 56.477	8	−0.0067	2
32........	11.0	...	...	11 50 28.0444	12	−0.00015	7	37 51 04.168	30	+0.0015	17
33........	12.9	+0.006	6	11 51 14.1825	5	+0.00026	2	37 50 56.271	7	+0.0098	2
34........	12.8	+0.011	5	11 51 23.3435	4	−0.00799	2	38 05 25.902	6	−0.0253	2
35........	9.4	...	...	11 51 29.7439	12	−0.00779	7	38 13 51.102	30	−0.0381	17
36........	10.4	...	...	11 51 49.2879	10	−0.00059	6	38 18 57.464	25	−0.0083	13

30-inch (76-cm) photographic refractor. Exposures were made on 21 nights in the years 1918 through 1924, two nights in 1939 and nine nights in the years 1951 through 1971. The plates were measured on the Strand Automatic Measuring Machine (SAMM) at the United States Naval Observatory and reduced by the central-overlap technique (Gatewood and Eichhorn 1973).

Table 3 lists the star number (a continuing sequence beginning in the above cited paper), estimated photographic magnitude, absolute parallax, standard error of the parallax, 1950.0 right ascension, internal standard error of the right ascension, proper motion in right ascension, the internal error of this component of the motion, the 1950.0 declination, the internal standard error of the declination, declination component of the proper motion, and the internal error of this component of the motion. The least significant unit of each standard error coincides with the least significant unit of the corresponding quantity. The absolute parallaxes listed here are equal to the relative parallaxes plus a correction of +0ʺ003. The system of the positions and motions given for the stars in this region is that of the AGK3 ostensibly that of the FK4 and was reduced from those stars common to table 3 and that catalog. Thus the systematic errors of these quantities should be similar to those of the AGK3 and FK4.

The parallax derived here supersedes the recent Allegheny value of 0ʺ121 ± 0ʺ017 standard error (Beardsley *et al.* 1973). No plates have been added to the series since this study; thus the increase of more than a factor of 8 in the weight of the parallax (similar to that observed in other studies in this series) must be attributed to the SAMM measuring machine and the central-overlap technique. We note that the new value is also in better agreement with the mean of all previous investigations 0ʺ110 ± 0ʺ007 (Woolley *et al.* 1970). For further calculations we adopt the weighted mean 0ʺ108 ± 0ʺ005.

The acceleration in position in right ascension and declination followed by their standard errors are +0ʺ000085 ± 0ʺ000024 and −0ʺ000019 ± 0ʺ000024 per year respectively. From these the adopted parallax and the proper motions listed in table 3 we find an astrometric radial velocity of −77 ± 25 km s^{-1}. We note that while this mean is well within its formal error of the spectroscopically determined radial velocity there is a considerable discordance between the values derived in the two coordinates. This is most likely due to the presence of orbital motion.

The residuals listed in table 4 are annual mean residuals to a least-squares solution with the equations of condition

$$\xi = \xi_{1950} + \mu_\xi t + P_\xi \pi$$

and

$$\eta = \eta_{1950} + \mu_\eta t + P_\eta \pi$$

after prereducing the observations for the acceleration predicted by a radial velocity of −98.3 km s^{-1}. These residuals are plotted in figure 1 and will be discussed below.

TABLE 4

YEARLY MEAN VALUES OF THE PARALLAX RESIDUALS FOR GROOMBRIDGE 1830

Epoch	Exposures	Δα (0ʺ001)	Δδ (0ʺ001)
1918.677........	6	15	−48
1920.373........	6	−15	14
1921.265........	12	19	3
1922.423........	15	0	13
1923.556........	15	−9	10
1924.190........	6	−8	−3
1939.322........	8	−4	−21
1951.271........	6	−22	−10
1952.298........	7	−18	−18
1955.243........	3	−23	−2
1956.234........	4	−6	−21
1958.293........	3	−2	14
1965.354........	4	47	18
1971.366........	3	10	33

Table 2 lists the individual residuals of the six exposures on plate number 57877 again utilizing these parameter adjustments.

V. DISCUSSION

It is evident that when one attempts to estimate curves through the three sets of points in figure 1, some discrepancy exists between the radial velocities and the parallax residuals. Both sets of material suffer weakness due to poor distribution in time. It also seems inescapable that the Δα and Δδ residuals are both positive in 1968 implying a third-quadrant position angle for the secondary. This does not agree with the position angle of 166° as observed by van de Kamp or 171° as observed by Worley. We believe that better astrometric and velocity data are needed before definitive results can be obtained. The 1939 position in each residual plot represents only those images for the two plates which were unflared.

The radial velocities in figure 1 suggest a total range ($2K$) of about 3 km s^{-1}. The line through the observations is presented only to show that a slow uniform variation has occurred during the past 30 years consistent with orbital motion. If the period is close to 60 years then it is apparent that the next periastron will occur soon.

We now return to the question of which star flared. In table 2 the flared images are 3, 4, 5, and 6 with 4 being particularly flared. Since no clear indication of a shift in position for the flared images is evident two conclusions are possible: either the primary flared (supported by the precedent G-star flare observed by Haro) or the secondary flared while closely aligned in the line of sight of the primary (an improbable event but supported by the previous evidence of a flare and by the observed range in radial velocity indicative of an orbital inclination close to 90°).

Should the second of the two cases be real then it is tempting to derive preliminary orbital parameters from a standard radial velocity curve using our previous assumptions concerning P, i, and K:

$$P = 60 \text{ years}, \quad e = 0.6, \quad \omega = 120°, \quad i = 90°.$$

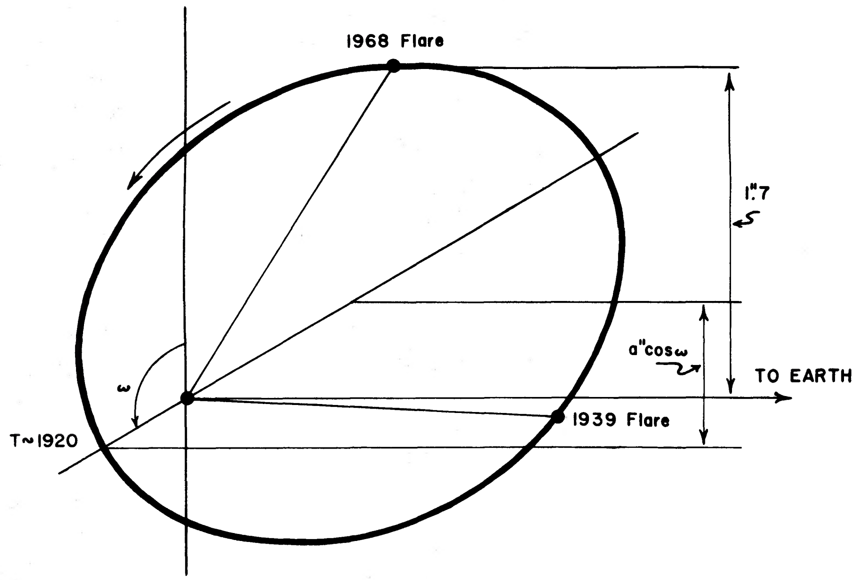

FIG. 4.—The apparent orbit constrained to lie perpendicular to the plane of the sky which is indicated by the vertical line through the primary. The Earth lies in the direction toward the right. The scaled ratio 1″.7 to a'' cos ω determines a in arc seconds.

It is possible to scale the orbit according to Crawford's method as shown in figure 4 (see Aitken 1935, p. 114) subject to the constraints (1) the companion have a separation of 1″.7 in 1968; (2) the companion be closely aligned with the primary in 1939. Using our absolute parallax of 0″.108, we obtain these preliminary parameters:

$$T \simeq 1920\,, \qquad a = 13 \text{ a.u.}\,, \qquad M_1 + M_2 = 0.6\,M_\odot\,.$$

Altering the value of the period or the eccentricity by any significant amount results in grossly smaller values for the sum of the masses. Again we stress the preliminary nature of the above values. They are presented as possible starting values for iterative solutions when better data become available.

VI. CONCLUSIONS

As we stated earlier, it is not possible to conclude which star actually flared, or whether a slow flare or a series of short intensive flares occurred. It is evident that an old Population II object, such as this star is, has flared—a result at variance with the conclusions of Haro and Chavira (1966) who would confine flares to young Population I stars. Conceivably, the M dwarf companion star is still gravitationally contracting even after a lifetime of 10^{10} years.

For either star the result is of great astrophysical interest, and further observations are particularly desirable.

We conclude also that orbital motion is present and that the next periastron passage will occur soon. We recommend that intensive astrometric, radial velocity, and visual observations be made over the next years to better define the orbital and physical parameters of the star—particularly for the sum of the masses, for in the next few years it will become possible to obtain reliable masses for this Population II object. We suspect that the secondary will be found to have an extremely low mass.

The authors express their appreciation to Dr. N. E. Wagman for valuable discussions, to Dr. K. Aa. Strand, Director of the U.S. Naval Observatory, to Dr. P. Routly for permission to use the SAMM measuring engine, and to Dr. Ch. Fehrenbach for permission to include a number of his unpublished radial velocities. This research was supported in part by the National Science Foundation grant GP-25224.

Note added 1974 June 25.—W. D. Heintz (private communication) reports that he has remeasured the 1968 flare plates and finds $\theta = 165°$ and $\rho = 2''.2$. Also, he observed the pair visually with the 24-inch Sproul refractor in 1968, estimating θ to be about 175° and ρ between 2″ and 2″.5.

REFERENCES

Abt, H. A. 1970, *Ap. J. Suppl.*, **19**, 387.
Aitken, R. G. 1935, *The Binary Stars* (New York: McGraw-Hill), p. 114.
Ashbrook, J. 1974, *Sky and Tel.*, **47**, 296.
Beardsley, W. R., Wagman, N. E., Erskine, E., Hubbel, E., and Gatewood, G. 1973, *A.J.*, **78**, 95.
Campbell, W. W., and Moore, J. H. 1928, *Pub. Lick Obs.*, **16**, 177.
Evans, D. S. 1963, *R.O.B.*, Series *E*, Vol. **77**.
Fehrenbach, Ch. 1972, private communication.
Gatewood, G., and Eichhorn, H. 1973, *A.J.*, **78**, 769.
Haro, G. 1968, in *Nebulae and Interstellar Matter*, ed. B. M. Middlehurst and L. H. Aller (Chicago: University of Chicago Press), p. 141.
Haro, G., and Chavira, E. 1966, in *Vistas in Astronomy*, ed. A. Beer and K. Aa. Strand (New York: Pergamon Press), **15**, 83.
———. 1969, *Bol. Obs. Tonantzintla y Tacubaya*, **5**, 23.

Harper, W. E. 1933, *Pub. Dom. Ap. Obs.*, **6**, 151.
Plaskett, J. S. 1935, *IAU Trans.*, **5**, 188.
Tomkin, J. 1972, *M.N.R.A.S.*, **156**, 349.
van de Kamp, P. 1968, *Low Luminosity Stars*, ed. S. Kumar (New York: Gordon & Breach), p. 199.
Weaver, W. B., and Naftilan, S. A. 1973, *Pub. A.S.P.*, **85**, 213.
Woolley, R. v. d. R., Epps, E. A., Penston, M. J., and Pocock, S. B. 1970, *Roy. Obs. Annals*, No. 5.
Worley, C. E. 1972, private communication.
Wright, K. O. 1951, *Pub. Dom. Ap. Obs.*, **9**, 197.

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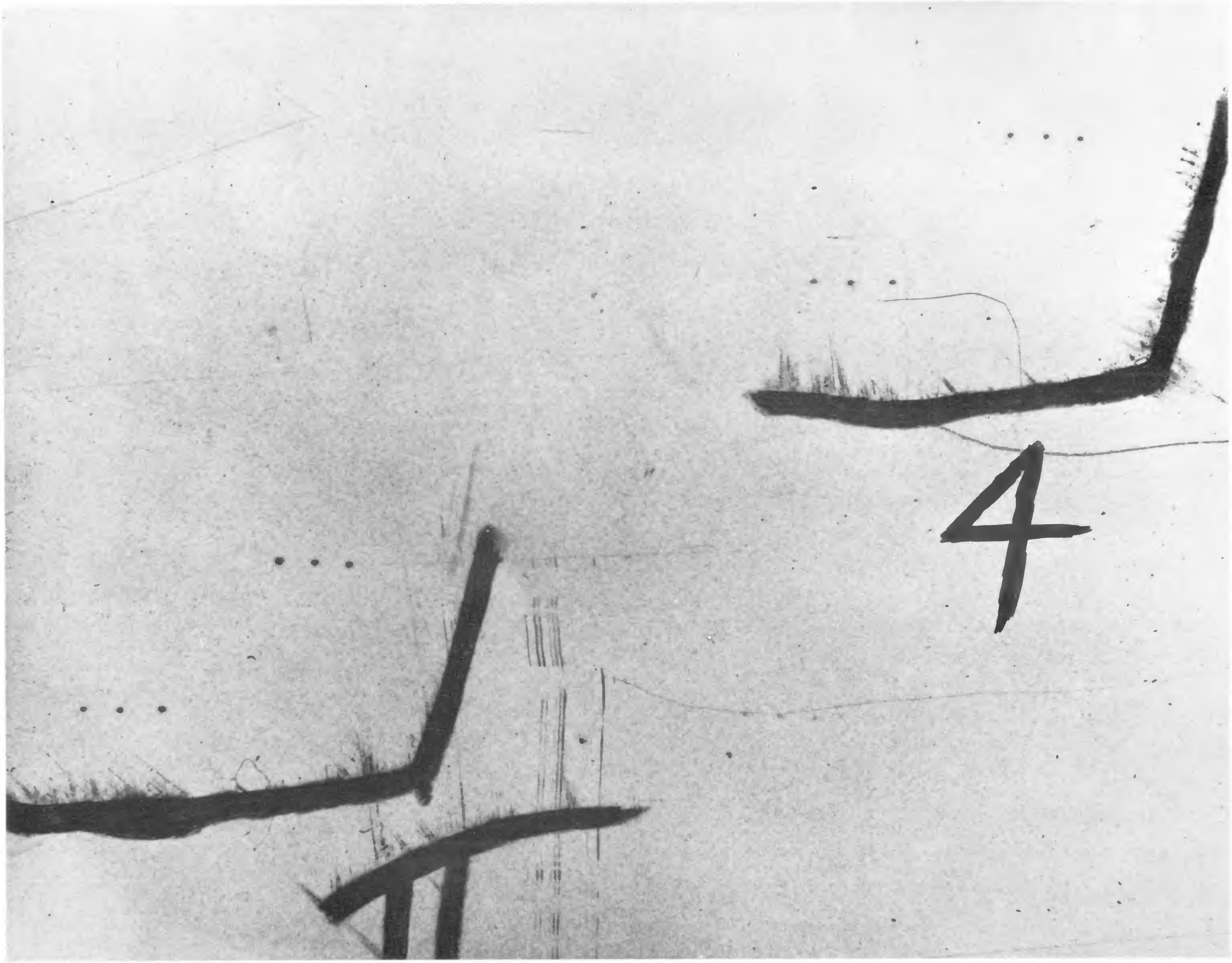

FIG. 2.—A reproduction of plate 57877 obtained by Burns on 1939 April 27 with the Thaw refractor when the star was on the meridian. The six images of Groombridge 1830 (star π) and of a field reference star (star 4) are numbered 1 to 6 successively, starting with the leftmost image. Image 4 of Groombridge 1830 is noticeably flared. All six images of star 4 are of uniform brightness. Each exposure was 2 minutes in duration. A gap of 10 minutes occurred between images 3 and 4.

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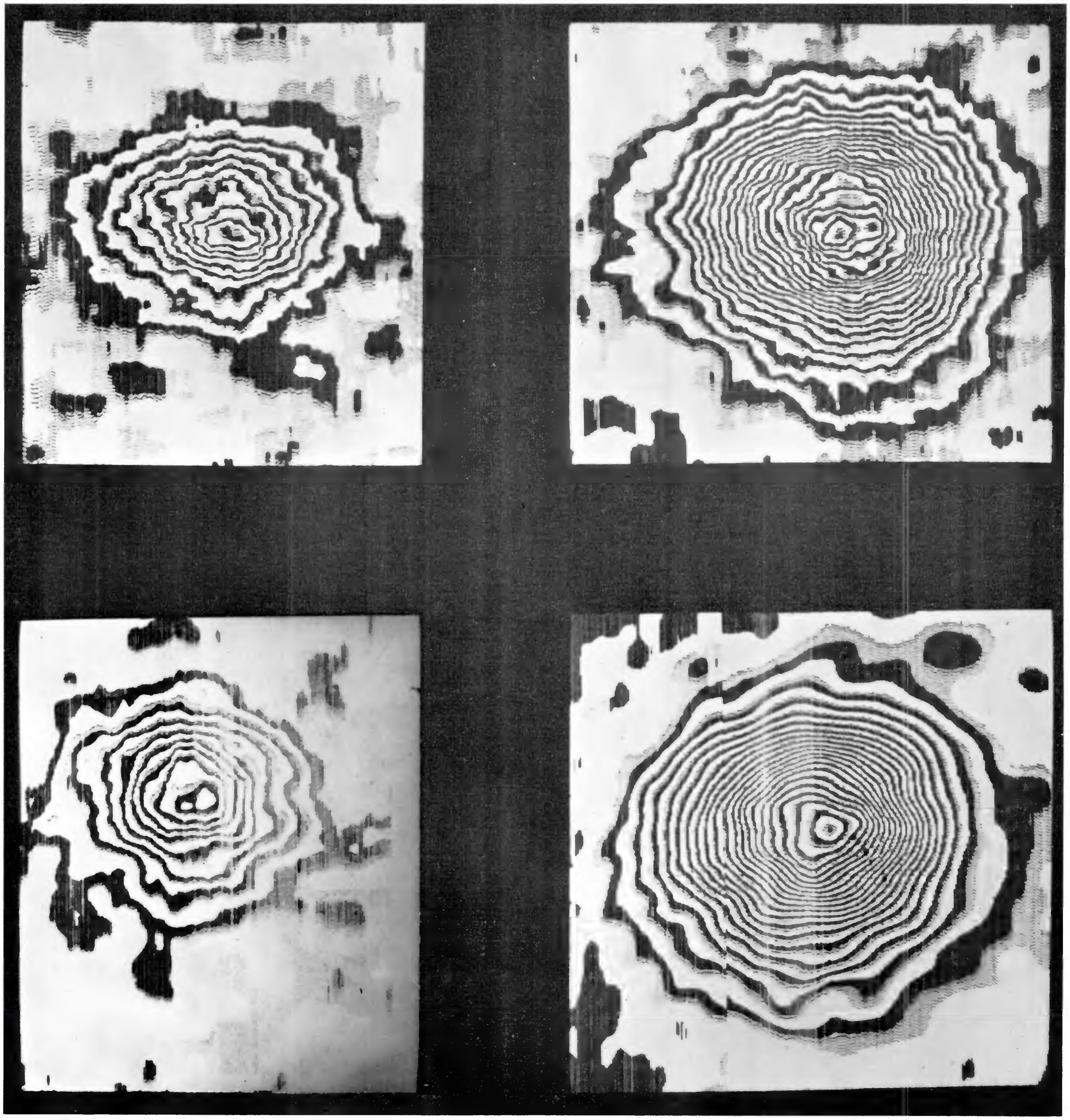

FIG. 3.—Isophotometric contours of Groombridge 1830 (*left*) and a field star (*right*). Image 4 (flared) is at the top, and image 1 (normal) is at the bottom. There is no obvious elongation of the flared image. Unfortunately no field star images on the plate matched the brightness of the flared image.

BEARDSLEY *et al.* (*see* page 639)