6. AN ASTROMETRIC STUDY OF VAN MAANEN'S STAR

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Van Maanen's star (1950: $0^h46\overset{m}{.}5$, $+5\overset{\circ}{.}09'$) is a white dwarf (visual magnitude 12.4, spectrum DF) with a proper motion of $2\overset{''}{.}95$ in $155\overset{\circ}{.}5$ and parallax $0\overset{''}{.}234$. An early determination of radial velocity yielded +238 km/sec (Adams and Joy, 1926). It was suggested by Russell and Atkinson (1931) that van Maanen's star might show a very large Einstein shift of at least +700 km/sec. Oort (1932) pointed out that the observed value of +238 km/sec is incompatible with the theory of galactic rotation: this would support the Einstein shift interpretation.

Meanwhile radial velocity and Einstein shift have been drastically revised. According to Greenstein (1954) radial velocity results appear to depend on dispersion and exposure time; low dispersion spectra yield a range of +21 to +216 km/sec. Observations by Greenstein and Trimble (private communication) yield +54 km/sec; neutral iron lines yield about −50 km/sec, while a mass of 0.68 ○ and radius $\frac{1}{78}$ $R_{\odot}$ would yield an Einstein shift of +34 km/sec.

Oort (1932) proposed that a determination of secular change in proper motion would eventually provide a direct geometric determination of the radial velocity. The yearly secular perspective acceleration is given by

$$\Delta\mu = -\,2\overset{''}{.}05 \times 10^{-6} V\mu p \tag{1}$$

Conversely the radial velocity is given by

$$V = -\,4.88 \times 10^{5}\,(\Delta\mu/\mu p)\ \text{km/sec} \tag{2}$$

or, for van Maanen's star

$$V = -\,2.08 \times 10^{6}\,(\Delta\mu/\mu)\ \text{km/sec} \tag{3}$$

A first attempt at determining the acceleration is presented here. van Maanen's star was put on the observing program of the Sproul 24-inch refractor (1 mm = $18\overset{''}{.}87$) in 1937. Results for parallax and proper motion from plates up to and including 1948 have been published (van de Kamp and Lippincott, 1949). The additional material obtained since 1948, together with a number of earlier plates, was measured by Mrs. Betty Kuhlman on the St. Clair-Kasten machine, and again reduced to the standard frame based on three reference stars. The distribution of the material is uneven, which is partly explained by the change in exposure times which averaged 50 min in 1937 and 1938, about 20 min from 1939 to 1944, and gradually decreased to the current value of about 4 min.

A solution for parallax, proper motion and acceleration was made from 281 plates with 511 exposures and a total night weight 174 taken on 137 nights spread over the

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interval 1937.0–1970.0. The nightly mean positions are represented by

$$X = c_x + \mu_x t + q_x t^2 + \pi P_\alpha$$
$$Y = c_y + \mu_y t + q_y t^2 + \pi P_\delta$$

where t is counted in years from 1950.000. A least squares solution combining x and y gives

$$\begin{aligned}
\mu_x &= +\,1''\!.2214 && \pm\,0''\!.0009 \quad \text{(p.e.)}\\
\mu_y &= -\,2.6843 && 0.0009\\
\pi &= +\,0.2231 && 0.0042\\
q_x &= +\,0.000052 && 0.000032\\
q_y &= -\,0.000162 && 0.000032\\
\text{p.e. } 1 &= \pm\,0^{\text{mm}}\!.00187 = \pm\,0''\!.0352
\end{aligned}$$

Separate solutions yield

$$\begin{aligned}
\pi_x &= +\,0''\!.2294 && \pm\,0''\!.0046\\
\pi_y &= +\,0.1879 && 0.0104\\
\text{p.e. } 1_x &= \pm\,0^{\text{mm}}\!.00188 = \pm\,0''\!.0355\\
\text{p.e. } 1_y &= \pm\,0.00182 \quad = \pm\,0.0343
\end{aligned}$$

The residuals from the least squares solution indicate a possible perturbation with a period of some two decades and an amplitude too small to have a sensible effect on the measured acceleration.

The observed acceleration is affected by a spurious acceleration caused by the proper motions of the reference stars and their changing influence, with time, on the reduced position of the central star (van de Kamp, 1935). We were fortunate in being able to measure the proper motions of the three reference stars on a background of 60 stars, using four pairs of plates with an average interval of 28.6 years. The probable errors of the resulting proper motions are $\pm''\!.0015$ and $\pm''\!.0012$ in x and y, respectively.

The relative proper motions and annual dependence changes for the reference stars are as given in Table I.

TABLE I

	μ_x	μ_y	ΔD
1	$+0''.0210$	$-0''.0295$	-0.00348
2	$-$ 160	$-$ 137	$+$ 260
3	$-$ 23	$+$ 44	$+$ 88

The corresponding corrections for spurious acceleration are:

$$+\,2\,[\Delta D \mu_x] = -\,0''\!.000234 \pm 0''\!.000007$$
$$+\,2\,[\Delta D \mu_y] = +\,0.000132 \pm 0.000005$$

We thus obtain the values as given in Table II for the acceleration components and the radial velocity using formula (3).

TABLE II

	x		y	
Observed acceleration	$+0''.000104$	$\pm 0''.000064$	$-0''.000326$	$\pm 0''.000064$
Correction for spurious acceleration	$-0''.000234$	0.000007	$+0''.000132$	0.000005
True perspective acceleration	-0.000130	0.000064	-0.000194	0.000064
Radial velocity	$+220$	± 110 km/sec	$+150$	± 50 km/sec

Assigning relative weights of 1 and 5 to the determinations in x and y, we find a resultant value of $+160 \pm 45$ km/sec for the radial velocity determined by the present geometric method. Although this value must be considered provisional, it appears to exclude very large values either a large positive value for the radial velocity or the Einstein red shift.

The present result is not anywhere near as accurate as the corresponding determination recently made for Barnard's star from some 3500 plates taken over the interval 1916–1919 and 1938–1969, resulting in a probable error of only 2.6 km/sec (van de Kamp, 1970). In that study the obtainable accuracy was limited by the accuracy of the spurious acceleration, which had the much larger probable error of $0''.00003$, due to the large annual dependence changes. For van Maanen's star the spurious acceleration is very accurately determined. In the not too distant future we shall be able to make a much more accurate geometric determination of the radial velocity of van Maanen's star. Observational material, distributed uniformly in time, yields an acceleration whose weight increases with the fifth power of the time interval. In the present case the material has a far from uniform distribution in time, observations between 1953 and 1962 being very scarce. With the current short exposure time extensive future material appears to be assured and a vast improvement of the perspective acceleration, and hence the radial velocity, is expected within the decade.

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