THE SYSTEM OF POLARIS

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ABSTRACT

Determinations of α and δ of Polaris made at Poulkovo, Washington, and Greenwich reveal an irregularity in the proper motion having a period of about 30 years, closely corresponding to the period of γ in the spectroscopic orbit. These give the following orbital elements of Polaris with respect to the center of gravity of the system $a''=0''.11$, $i=63°$, and $\Omega=147°$. A new spectroscopic orbit of long period in conjunction with the foregoing value of a'' gives $\pi=0''.025$ and $M_{\text{vis}}=-0.9$. The visual absolute magnitude of the secondary derived from the mass-luminosity relation is $+1.3$, and its mass is $2.4\odot$.

Polaris is a well-known Cepheid with an abnormally small variation in light and in velocity. Its visual range is only 0.08 mag., while the range in velocity does not exceed 6 km/sec. According to the period-luminosity relation, to a period of $3^{d}.968$ there corresponds a visual absolute magnitude of -1.6 and a parallax of $0''.018$, which, being six times larger than the adopted trigonometric parallax, is only slightly larger than the mean spectroscopic parallax ($0''.014$, Mount Wilson).

Since its discovery by W. W. Campbell, the variation in radial velocity during the four-day period has been thoroughly investigated both at Poulkovo and at Mount Hamilton. During the last 28 years Dr. Belopolsky[1] has derived 16 "orbits" for separate yearly cycles of observation, and has proved that the velocity curve undergoes some important progressive changes. At the same time the Lick observers secured seven hundred spectrograms and published some partial results of great interest. Campbell found that γ is variable, which indicated that Polaris is either a triple system or a real binary with a Cepheid-like bright component. On the basis of the first oscillation period of γ announced by Campbell in 1910, L. Courvoisier[2] found from the Poulkovo observations of α and δ a long-period oscillation ($P\sim 10$ years) in the mean place of Polaris. This result led me to undertake a special investigation of the Poulkovo

[1] *Zs. f. Ap.*, **5**, 294, 1932.

[2] *A.N.*, **203**, 85, 1917.

fundamental observations of the last century, which did not reveal periods of either 10 or 8 years in the mean places of Polaris.[3]

Since that time new extended series of spectroscopic observations of Polaris have been made both at Mount Hamilton and at Poulkovo, which proved that the period of γ is considerably longer than had been supposed. From the Lick data Moore found the period to be 29.6 years, and he derived the elements of the long-period orbit of Polaris,[4] this result being fully substantiated by Belopolsky.[5] Moore's period and the observed range in γ of about 8 km/sec, in conjunction with the Cepheid parallax of Polaris, correspond to an angular radius of the orbit of the bright component of about $0\rlap{.}''1$ (for $i=45°$) or more. Oscillations of this size should certainly be noticeable in the best series of numerous observations of Polaris made at Washington, Poulkovo, and Greenwich, and the detection of these oscillations would be interesting from various points of view. It would afford a unique occasion for determining the parallax of a Cepheid in a direct way, avoiding the spectroscopic and the Cepheid parallaxes, which, in the case under consideration, differ systematically from the trigonometric parallax. This would prove that Polaris is a binary, one component of which is a Cepheid—a rather curious mechanical system. On the other hand, Polaris is one of the most important fundamental stars (especially for the azimuth determinations), and the oscillations in its α and δ are by no means harmless to fundamental astronomy.

Oscillations in the mean places of Polaris.—Having in view the smallness of the expected changes in both co-ordinates, and taking into account the high declination of Polaris, it did not seem advisable to use the classical method of investigating variable proper motions, so brilliantly developed by Auwers. In the case of Polaris the only way open was that of using long series of the best observations, deriving from them portions of the curves of $\alpha-\alpha_0$ and $\delta-\delta_0$ and then properly adjusting these in case of the reality of the long-period oscillations. The Poulkovo and Washington data ("positions isolées") are given reduced to the system of a corresponding catalogue,

[3] *A.J.*, **35**, 181, 1924.

[4] *Pub. A.S.P.*, **41**, 254, 1929. [5] *Op. cit.*

smoothed and corrected for carefully investigated sources of errors. On the contrary, the Greenwich data are published in annual volumes of observations, not combined into catalogue form. Since observations of α of such a circumpolar star are known to be less accurate than observations of δ, it seemed advisable to avoid the use of the α data, which are not combined in catalogue form. To exclude all kind of seasonal influences and errors (including the parallax and the inaccuracy of the aberration), only the annual means have been used in this investigation. To get rid of the errors depending upon the kind of culmination and of some unexcluded latitude variations, the means "above the pole" have been combined with those "below the pole" with equal weights.

The final annual means $\alpha - \alpha_0$, $\delta - \delta_0$ (α_0, δ_0 are the mean data of the catalogue) can be considered as essentially free of seasonal and personal errors, the only remaining errors being progressive changes in personal equation, the inaccuracy of the constant of nutation and of the *variatio annua*. It should be, however, noticed that the last sources of error are easily controlled. In this manner the following fundamental series of observations have been investigated:

Right ascensions: Poulkovo, 1845; Poulkovo, 1865; Poulkovo, 1885; Nikolaieff, 1915; and Washington, 1915.

Declinations: Poulkovo, 1865; Poulkovo, 1885; Washington, 1915; Greenwich annual data (1890–1913).

Figures 1 and 2 give full account of the results obtained. They leave no doubt as to the reality of the 30-year oscillations in δ, those in α being not so clear, although their existence cannot be doubted. The separate series of data are adjusted by adding certain constants to the values of $\alpha - \alpha_0$ and $\delta - \delta_0$. The detailed results derived from the analysis of the catalogues will be published in *Poulkovo Circular No. 19.*

Orbit of the brighter component.—Plotting the x and y co-ordinates taken from the normal curves of Figures 1 and 2, it is possible to draw the apparent orbital ellipse. However, since the data of $\alpha - \alpha_0$ are very uncertain, it would be rather dangerous to give much weight to this apparent orbit and to derive from it the orbital elements in the usual way. The best we can do is to deduce the mean separation of the bright component from the center of gravity, a'', the inclination i, and the longitude of the ascending node Ω, which do not depend much upon the details of the curve of $\alpha - \alpha_0$ but only upon its range and general run. This gives

$$a'' = 0''.11$$
$$i = 63^\circ$$
$$\Omega = 147^\circ$$

The correctness of Ω can be indirectly checked by the spectroscopic orbit, which (see below) gives 1900.6 as the time of the ascend-

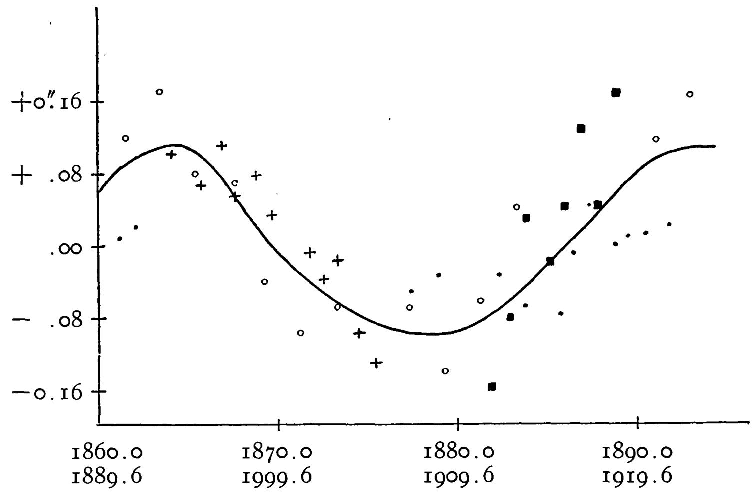

FIG. 1.—Orbital motion in the declination of Polaris. The ordinates are adjusted values of $\delta - \delta_0$, the zero-point being arbitrary. The abscissae are phases in time, reduced with Moore's period of 29.6 years. + = Poulkovo, 1865; · = Poulkovo, 1885; ▪ = Washington, 1915; o = Greenwich annual results (1891–1913).

ing node, while the corresponding time from the visual orbit is 1903.6 (or 1874.0).

The spectroscopic orbit.—The final long-period spectroscopic orbit as based upon the Lick observations was published by Moore in 1929.[6] In order to provide an independent set of elements I calculated the orbit on the basis of the Poulkovo data as published by Belopolsky, which start from 1900.2. Both sets of elements, as given in Table I, are quite similar. The value of the inclination gives

[6] *Op. cit.*

$a = 3.5$ astronomical units (Lick) and 4.4 astronomical units (Poulkovo).

Parallax and masses.—The combination of the angular separation with the values of a gives for the parallax $\pi = 0\overset{''}{.}031$ (Lick orbit) and

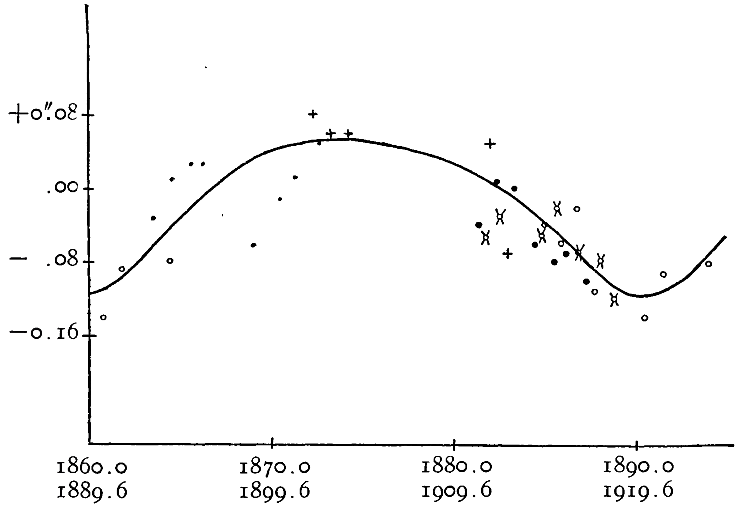

FIG. 2.—Orbital motion in the right ascension of Polaris. The ordinates are adjusted values of $\alpha - \alpha_0$, the zero-point being arbitrary. The abscissae are phases in time, reduced with Moore's period of 29.6 years + = Poulkovo, 1845; · = Poulkovo, 1865; • = Poulkovo, 1885; o = Nikolaieff, 1915; ¤ = Washington, 1915.

TABLE I

THE LONG-PERIOD SPECTROSCOPIC ORBIT

	Lick	Poulkovo
Period	$29^{y}.6$	$29^{y}.6$ (assumed)
K	4.05 km	4.35 km
e	0.63	0.50
ω	$332^{\circ}.0$	$315^{\circ}.8$
T_{π}	1899.5	1899.8
$a \sin i$	3.1 a.u.	3.9 a.u.
$m_2^3 \sin^3 i (m_1+m_2)^2$	0.035	0.075
γ	− 17.4 km	− 16.5 km

$\pi = 0\overset{''}{.}025$ (Poulkovo orbit). Both values are several times larger than the mean trigonometric parallax, which is much smaller than that derived from the period-luminosity relation with Shapley's revised zero-point ($\pi = 0\overset{''}{.}018$) and the recent Mount Wilson spectroscopic parallax ($\pi = 0\overset{''}{.}014$). The Poulkovo value of π ($0\overset{''}{.}025$) gives for the absolute visual magnitude $M = -0.9$, while the Cepheid parallax leads to $M = -1.6$. The difference of $+0.7$ mag. (which, incidentally, is close to the value of the zero-point correction as derived some years ago by the present writer) can result from (1) the inaccuracy of the observational data, (2) the zero-point correction, and (3) a deviation from the period-luminosity relation due to the individual properties of Polaris.

The value of π as derived from the visual and spectroscopic data is sufficiently close to the Cepheid parallax. It should, however, be clearly stated that all these indirect values of the parallax can by no means be reconciled with the vanishingly small value ($0\overset{''}{.}003$) of the mean trigonometric parallax, which leads to an impossible value, $M = -5.5$.

Adopting $a = 4.4$ astronomical units (which is in better agreement with the period-luminosity relation than the value $a = 3.5$ astronomical units) we derive for the ratio of masses (brighter to fainter component) $m_1/m_2 = 2.2$. On the basis of Eddington's mass-luminosity curve, there corresponds to $M = -0.9$ a mass of $m_1 = 5.2$, and therefore the mass and the absolute magnitude of the secondary are $m_2 = 2.4$ and $M_2 = +1.3$, which give a difference in magnitude of about 2.2 mag., the apparent visual magnitude of the secondary being 4.3. If the spectrum of the secondary is later than that of the primary, this difference should be slightly larger (for instance, for type $K0$ by $+0.21$ mag.). Adopting $M = -1.6$, we get the same value of the apparent magnitude of the secondary. The maximum angular separation of the two components being between $0\overset{''}{.}3$ and $0\overset{''}{.}4$, and the difference in magnitude being about 2.2, it is not impossible that the secondary could be observed visually. At present the secondary is not far from maximum separation, which occurred at about 1933, its position angle (referred to the classical Polaris), being 297° for 1936.2.

POULKOVO, U.S.S.R.
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