PUBLICATIONS OF THE
ASTRONOMICAL SOCIETY OF THE PACIFIC

Vol. 62 August 1950 No. 367

THE DIAMETER OF PLUTO

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Through the courtesy of Dr. I. S. Bowen and the close co-operation of M. L. Humason, the writer was able to measure the diameter of Pluto with the 200-inch telescope in March 1950. In view of the interest attached to this problem, largely in connection with its bearing on Pluto's mass, the steps leading up to this measurement are recorded below, together with a discussion of some implications of the new result.

On repeated occasions, during 1948 and 1949, the writer has attempted to measure the diameter of Pluto with the 82-inch telescope. A disk meter, designed to produce a small artificial luminous disk of controllable brightness, color, and diameter, was placed at the Cassegrain focus. With the aid of small diaphragms the F ratio of the lens forming the artificial image is always made equal to the F ratio of the main telescope. Diffraction effects in the two images to be compared are then identical so that they are eliminated in the comparison. The limits of the instrument are set, of course, by the size of the Airy disk itself, 0".06 for the 82-inch telescope; and by obvious intensity requirements (very faint disks, smaller than about 0".5, look like stars).[1]

Owing to the faintness of Pluto no reliable results were obtained, in spite of very considerable efforts. The nearest approach to an actual measurement was made on November 4–5, 1949, when the seeing was 9 on a scale of 10 for several hours and the mirror was essentially free from distortions. The writer then derived 0".4 for the diameter, and A. Shatzel, who was called in

[1] G. P. Kuiper, *The Atmospheres of the Earth and Planets*, chap. xii, p. 305, 1949.

because of the exceptional conditions, got the same value, independently. But it was obvious that the measurement was on the very threshold of the capabilities of the telescope (if not beyond it), even with the exceptional conditions prevailing on that night. It was concluded that further efforts would be futile and that the observation could be successful only with the 200-inch telescope —which would give six times the intensity.

There seemed to be one indirect argument in support of the tentative value, 0\'\'4. Pluto's mass had been determined at 1.0 ± 0.23 earth masses by S. B. Nicholson and N. U. Mayall;[2] and, later, at 1.0 ± 0.1 (p.e.) earth masses by L. R. Wylie.[3] If $d = 0\overset{\prime\prime}{.}4$, the true diameter would be 0.8 times the earth, and the volume 0.51 earth. Since for a mass smaller than the earth, degeneracy cannot set in, the mean density of Pluto can hardly be greater than that of the earth; the expected mass would therefore be no greater than $(0.8)^3 = 0.5$ earth. If the diameter estimate were uncertain by 10 percent, which seemed reasonable, the mass would be uncertain by 30 percent. The rough determinations for the diameter and the mass would then be just barely consistent; but a diameter smaller than 0\'\'4 would definitely conflict with the present value for the mass.

A brief account of the 82-inch observation was given in December 1949 at the Tucson meeting of the American Astronomical Society; but because publication was regarded as premature, the abstract was withheld.[4] At the same time the feasibility of attaching the disk meter to the 200-inch telescope was explored with Dr. Walter Baade, who pointed out that the instrument would have to be folded vertically before it could go into the cage. After this modification was made, the final adaptations of the instrument and the actual observations were made possible through the personal interest of Dr. Bowen.

On March 14 the disk meter was fitted to the prime focus mount of the Hale telescope and on March 21 the observation of Pluto was made. On both occasions the writer had the benefit of

[2] *Pub. A.A.S.*, **7**, 11, 1931.

[3] *A.J.*, **49**, 106, 1940.

[4] Reference to the verbal remarks was made, however, by Dr. D. Brouwer in *Sky and Telescope,* March 1950.

the expert advice and help of Humason, who gave some of his own observing time to make the observation of Pluto possible. The first hour or two of March 21 were favored with fine seeing, about 6 on a scale of 10. The F/3.6 Ross corrector, which was in place because of Mr. Humason's photographic program, was left in for reasons of safety. Since it was not known what its effect might be on the visual resolving power of the telescope (except, of course, that the photographic images taken with it are very good), the diameter of an eleventh-magnitude star was measured also. The calibration for scale follows from the geometry of the disk meter plus the focal length of the telescope used. The latter was obtained from a plate of the Pleiades taken by Mr. Humason. On a later occasion the writer took the same field with the 82-inch telescope as a check on the calibration; this at the same time determined the effective magnification used on the 200-inch telescope, 1140 diameters.

The observation was made on March 22, 1950, 4^h UT. Pluto's distance was then 35.56 astronomical units. The diameter of Pluto was found to be 0.021 mm, or $0\rlap{.}''23$; that of the comparison star 0.010 mm, or $0\rlap{.}''11$. Mr. Humason made independent settings on Pluto and got the same result. The zenith distance of Pluto was only about 20° during the observations. Neither Mr. Humason nor the writer regarded the measurement of Pluto as especially difficult, although it would have been, had the seeing or the figure of the mirror been less satisfactory. The comparison included artificial disks down to about one-half Pluto's diameter; it was established beyond doubt that the 200-inch result was a real measure and not merely an upper limit. From previous experience with the disk meter the writer estimated the uncertainty of the measured diameter to be about 5 percent, or $0\rlap{.}''01$; this may be regarded to be in the nature of a mean error. On the other hand, the derived diameter of the star may be somewhat too large. The power of 1140 is insufficient to decide this (it makes the apparent disk as viewed at the eyepiece $2\rlap{.}'0$ in diameter); but because it was definitely not larger—and because of the pressure of time—the matter was not further pursued. It is at present uncertain whether the uncorrected value, $0\rlap{.}''23 \pm 0\rlap{.}''01$, should be used; or whether the maximum correction found for the presence of the corrector lens should be applied, making Pluto's observed diameter $0''.20 \pm 0''.01$.

The albedo may be computed from Baade's value of the photovisual magnitude[5] on the assumption that the uncorrected value, $0''.23$, is the diameter and that the phase function is the same as that of Mars. The resulting albedo is 0.17, a value much more reasonable than the extremely low value of 0.04 based on the assumption that Pluto equals the earth in size. The new diameter is 0.46 times the earth, midway between Mars's and and Mercury's.

Such a body must have some atmosphere, though most of its original atmosphere will have frozen out owing to the low equilibrium temperature for Pluto, 40°–50° K. Both the atmosphere and the condensation products will prevent the albedo from being extremely low: nearly all snows are white, the crystals being small (H_2O, CO_2, CH_4, etc.). On the other hand, the albedo need not be that of freshly fallen snow, 0.7–0.8, because several effects, including grit deposited by comets and meteors, will darken snows over the ages. However, the rocky surface of Pluto would be expected to be invisible, which may explain why its color index is only slightly different from that of the sun, quite contrary to the results for Mercury, Mars, and the moon. These three bodies are known to show their rocky surfaces, and their color indices are in each case 0.5 mag., or more, greater than that of the sun. For Pluto the difference of only 0.1 mag. is consistent with a gritty-snow surface.[6] Recent observations by the writer of the ultraviolet spectrum of Pluto with the 82-inch telescope show the absence or near-absence of an excess near 3000 A attributable to Rayleigh scattering by molecules; from an incomplete reduction of the plates it is estimated that the atmospheric content is less than 0.1 terrestrial atmospheres.

With the diameter of Pluto 0.46 times the earth's, the volume is 0.10 earth and the probable mass slightly below 0.10 earth. If the mass derived from the Neptune observations were correct, the density of Pluto would be nearly ten times the earth, or 50 cgs.

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[5] *Pub. A.S.P.*, **46**, 218, 1934.

[6] The color index derived by Baade, footnote 5, being 0.67 mag., was recently confirmed photoelectrically by the writer.

This does not seem physically possible. The mass determination is therefore not regarded as real, though no obvious explanation of the Neptune residuals is at hand. The resulting residual of 8″ for Lalande's two observations in 1795 might perhaps be accepted, but the unexplained residuals of 0.″5 in Neptune's latitude are somewhat larger than the errors normally suspected. On the other hand, the diameter measurement is so comparatively simple and direct that the possibility of a serious systematic error seems excluded.[7]

The writer wishes to record his gratitude to Dr. Bowen for giving him access to the Hale telescope; and to Mr. Humason whose help in the observation was so vital that he may well be considered co-author of the principal result of this article.

[7] For further discussions on the mass of Pluto, reference is made to E. W. Brown, *Proc. Nat. Acad. Sci.*, **16**, 364–71, 1930; *M.N. of the R.A.S.*, **92**, 99–101, 1931; *Pub. A.S.P.*, **44**, 24–27, 1932; as well as V. Kourganoff, *Bull. Astronomique*, **12**, 147, 153, 271, and 303, 1940.