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Researches on the Diameter of Venus

made with the 26 inch Refractor of the U. S. Naval Observatory, Washington.

By T. J. J. See.

During the past two hundred years, the diameter of Venus has been determined by more than fifty separate investigators, and in the course of the present century has been carefully studied by the Government parties in the transits of 1874 and 1882, as well as by numerous individual observers equipped with Heliometers, filar and double-image Micrometers and other apparatus of special design; yet in spite of all the labor which has been bestowed upon the subject it appears that there is still no standard value in general use among astronomers.

The measurement of the diameter of Venus presents among others the following peculiar difficulties:

1) The enormous change in the geocentric distance of the planet renders the apparent diameter extremely variable. And unfortunately the phase is so arranged as to give merely a thin crescent when the body is nearest the Earth, and when the disc is more rounded out and diminished in angular diameter, the distance is so much increased that errors entering into the measures affect the reduced diameter greatly.

2) The line-like horns of the very thin crescent which the enlarged disc presents when near inferior conjunction, are so delicate that small atmospheric irregularities set them in violent motion, and it is difficult to locate their quiescent positions with the Micrometer wire. Even greater difficulty

is experienced in forming accurate contacts of the images produced by the Heliometer and double-image Micrometer.

3) When the crescent is enlarged the horns are broadened and more steady, but the apparent diameter is less, and an error in the setting enters with enlarged effect into the final result.

4) When the planet approaches superior conjunction, and the disc is nearly round, these difficulties diminish, but the diameter is then so small that the advantage sought is more than lost, through the enlargement of errors of observation in the final result. Practically these difficulties are augmented by the circumstance that the planet is then near the Sun, and must necessarily be observed at a time of day when the air is much disturbed by the heat.

5) During the transits across the Sun's disc, the image is both large and round, but its diameter is vitiated by unknown causes, like irradiation, a halo due to the planet's atmosphere, the black drop, etc., which, however, have been carefully investigated.

6) Venus is always extremely bright, and its light very white, which renders the irradiation large and the secondary spectrum troublesome.

The following table gives a brief summary of the principal investigations relative to the diameter of Venus.

Table I. Diameters of Venus. 1620-1895.

Authority	Source	Epoch	Diam.	Remarks
Galilei	Houzeau, V. M. 462	1620 [±]	17".2	From observations near superior conjunction
Horrocks	B. A. J. 1807, 165-6	1640	17.609	Calculated by Wurm; 2 days, by micrometer
La Hire	" " "	1700	17.610	By micrometer, 1 day, near inf. conj.
Short	" " "	1761	17.065	By micrometer, 4 days, near inf. conj.
Lalande	Houzeau, V. M. 463	1762	16.7	Measured during transit of 1761
Schroeter	B. A. J. 1807, 166-7	1789-94	16.835	7 days, micrometer
Herschel	" " "	1791	18.790	1 day, micrometer
Schroeter	Phil. Trans. 1792, 317	1792	16.7	Micrometer measures on 4 days; he sees hook on southern horn of Venus
Wurm	B. A. J. 1807, 167	1804	16.954	22 sets of micr. measures during transit of 1761
Wurm	" " "	1804	16.810	8 sets of micr. measures during transit of 1769
Arago	Oeuvres, XI, 1859, 346	1815	16.9	Double image micrometer
Encke	Entf. d. Sonne, 129	1822	16.611	From the transit of 1761
Ferrer	Mem. R. A. S., V, 281	1833	16.676	By duration of transit of 1769, at 15 stations
Beer & Mädler	A. N. 325	1837	17.134	Obs. on 66 days; corrected for various errors

Authority	Source	Epoch	Diam.	Remarks
Challis	Houzeau, V. M. 463	1839	17".51	2 sets of measures, double image micrometer
Challis	" " "	1841	17.57	Double image micrometer
Airy	Mem. Obs. Paris, 1861, 26	1845	16.566	Micrometer measures, $D = (8".283:4) + 0".60$
Lassell	Leiden Ann., III, 222	1849	17.15	By Heliometer, 2 days
Hartnup	" " " "	1849	17.92	Filar micrometer, 4 days
Hartnup	" " " "	"	17.13	Double image micrometer, 4 days
Thompson	" " " "	1849	17.77	1 day, filar micrometer
Thompson	" " " "	1849	17.58	1 day, double image micrometer
Wichmann	A. N. 749	1851	17.325	By Königsb. Heliometer, 11 days
Peirce	A. J. 50	1852	17.092	Wash. Mural Circle obs. 1845-6, 30 days, carefully discussed
Main	Mem. R. A. S., XXV, 46	1855	17.55	20 series of microm. measures, 1840-52, taking account of constant errors
Gilliss	U. S. N. Exp. to Chili, III. CCLXXXV	1856	16.70	Micrometer measures, carefully discussed by Gould
Secchi	A. N. 1089	1857	16.42	1 day, at inferior conjunction
Schmidt	A. N. 1543	1865	17.18	39 days, micr. meas. corr. for irradiation, 0".15
E. J. Stone	M. N. XXV, 59	1865	16.944	Mural Circle and Merid. obs. at Greenwich, 1839-62. 589 obs.
Powalky	A. N. 1841	1871	16.918	Transits of 1761 and 1769
Vogel	Bothk. Beob., II, 1873, 127	1871	16.867	8 days, by micrometer
Kaiser	Leiden Ann., III, 221	1872	17.516	34 days, in 1862 and 1865. Double image micr. of Airy
Plummer	M. N. XXXIII, 561	1873	17.321	26 days, Durham Observatory, irradiation 0".273
Auwers	Venus Durchg. 1874	1874	16.957	Discussion of observations at Luxor, &c.
Tennant	M. N. XXXV, 347	1875	16.903	Dbl. image micr. measures during transit, 1874. 6 inch telesc.
Downing	M. N. XXXVII, 399	1877	16.738	From Wash. Transit Circle obs. 1866-72. Well discussed
Hartwig	Publ. d. AG. XV, 10	1879	17.666	By Breslau Heliometer
Thackeray	M. N. XLVI, 336	1886	17.010	From Greenwich obs. 1873-84
Auwers	A. N. 3068	1891	16.801	Mean of results for 1874 and 1882, by Heliometer; diameter of solid planet
Auwers	A. N. 3214	1894	16.820	A correction in above leads to this final value. Fine determin.
Ambrohn	A. N. 3204	1893	17.711 $\pm 0".047$	34 obs. with Gött. Heliometer
Barnard	Pop. Astron., 1897-8, 287	1895	17.397	24 days near superior conj., when obs. D varied from 14" to 25"

The next table, No. II, shows the results of the micrometrical researches on the dimensions of Venus, carried out with the color screen on the 26 inch Refractor of the U. S. Naval Observatory during the recent passage of the planet from East to West elongation.

Table II. Diameters of Venus. Washington, 1900.

Wash. Mean Time 1900	s_o	s_c	$s_o - s_c$	D_o	Seeing = wt.	Cell	Power	Remarks
April 3 2 ^h 30 ^m	18".35	18".46	-0".11	16".70	4	1	400	Limb not quite steady, but conditions very good
7 0 45	19.41	19.08	+0.33	17.08	3	2	400	Tremulous
7 1 0	19.21	19.09	+0.12	16.91	2	1	400	Not very steady
19 1 39	20.85	21.36	-0.51	16.40	3	1	400	Image quite blurred
24 1 34	22.56	22.47	+0.09	16.86	3	1	400	Seeing variable, 2-3-4
28 1 4	22.94	23.46	-0.52	16.42	2	1	400	Terminator appears reddish; selective absorption?
May 13 7 50	28.86	28.27	+0.59	17.15	4	3	400	Limb very sharp; no markings of any kind
17 2 43	29.41	29.76	-0.35	16.60	5	1	600	Perfect seeing, never saw such sharp steady limb before. No trace of any markings whatever
17 6 37	29.71	29.83	-0.12	16.73	5	1	600	Limb a perfectly steady line; no trace of markings
17 6 45	29.96	29.83	+0.13	16.87	5	1	888	Excellent measures. Seeing perfect
June 1 2 57	37.10	37.25	-0.15	16.73	3	1	600	Somewhat unsteady
5 7 13	40.02	39.83	+0.19	16.88	4	1	600	Limb very good. No markings of any kind. Two cusps identical
20 0 18	51.11	50.19	+0.92	17.11	3	1	400	Image dancing at times, and unsteady
22 0 38	51.01	51.59	-0.58	16.61	4	1	400	Good measure
22 0 44	51.08	51.59	-0.51	16.63	4	1	400	Excellent observations

Wash. Mean Time 1900			s_o	s_c	$s_o - s_c$	D_o	Seeing = wt.	Cell	Power	Remarks
July	11	0 ^h 24 ^m	58".40	57".58	+0".82	17".04	4	3	600	Good measures
	11	0 32	58.30	57.57	+0.73	17.01	4	1	600	Excellent. Crescent very thin
	27	21 37	48.61	48.46	+0.15	16.85	4	2	600	Very good
	31	21 34	46.03	45.62	+0.41	16.95	4	2	400	Limb steady and sharp most of the time
	31	21 44	46.09	45.61	+0.48	16.97	4	2	600	
	31	21 58	45.77	45.60	+0.17	16.86	4	2	600	No certain markings of any kind
Aug.	1	22 43	45.04	44.88	+0.16	16.86	4	2	400	Quite good. A little tremulous
	2	22 30	44.32	44.19	+0.13	16.85	4	2	400	Very good, but occasionally tremulous
	4	0 19	43.55	43.46	+0.09	16.84	4	2	400	Quite good, but unsteady at moments
	10	0 11	38.72	39.54	-0.82	16.45	3	2	600	Sky very hazy, and planet faint
	13	0 18	36.76	37.79	-1.03	16.37	2	2	400	Very unsteady. Weather moist and hot
	13	21 52	37.80	37.22	+0.58	16.67	4	2	400	Very good seeing
	13	22 0	37.44	37.21	+0.23	16.90	5	2	600	Seeing nearly perfect
	13	22 5	37.27	37.21	+0.06	16.83	4	2	600	
	16	21 30	35.58	35.56	+0.02	16.81	4	2	600	Excellent seeing. Image perfectly sharp; no markings of any kind, neither lines, nor spots, nor terminator projections
	17	21 5	34.85	35.04	-0.19	16.71	3	2	600	Seeing tremulous. Sky white
	18	21 15	33.97	34.52	-0.55	16.53	3	2	600	Unsteady

Arithmetical mean = 16".787

Weighted mean = $16".800 \pm 0".022 = 12181.7 \pm 16$ kilometres.

The seeing is rated on a scale of five, and corresponding weights have been assigned to each day's work. The color screens have been explained in the paper on Neptune and Uranus, A. N. 3665, and in A. N. 3636.

In all large refractors the image of Venus is surrounded by a strong bluish halo, and when the seeing is unsteady, this secondary spectrum becomes so troublesome that diameter measures made under these conditions would be quite unsatisfactory. With good seeing, however, and the secondary spectrum removed by the color screen, the limb appears as sharp and definite as that of the Moon to the naked eye, and precise measures are easily obtained. On several occasions the writer has seen the limb perfectly sharp, and so quiescent that the micrometer wire could be set with the nicest accuracy.

The value 16".820 for the diameter of Venus, deduced by Dr. Auwers in 1894 from the transits of 1874 and 1882, is especially worthy of attention. Besides resting upon a most rigorous and exhaustive discussion of all available material, it has the advantage of resulting from observations taken when Venus had a diameter of 63".5. Under these circumstances errors in the observed diameters affect the value at the mean distance by only about one fourth of their original amount. Though the elimination of such influences as the irradiation is difficult and attended with some uncertainty, it hardly seems possible that his value of the diameter can depart from the truth to any great extent.

The mean of the above 32 sets of Micrometer measures on 22 days, gives $16".800 \pm 0".022$; which accords quite closely with the value found by Dr. Auwers, and also with the mean of the more central values in the above table.

In examining Table I, one cannot fail to be impressed with the large values given by several recent determinations with the Heliometer. This is the more singular, since in

the case of other planets like Jupiter and Saturn, the diameters found with this same instrument have usually come out abnormally small.

Is it possible that the crescent-like figure of Venus in an instrument whose images depend on half lenses is the source of this anomaly? Or is it due to the unsteadiness of the horns blurred by atmospheric irregularities into a violent quiver, which prevents strict tangency, and thus makes the measured diameter too large by an amount depending on the blurring, which is itself a function of the thickness of the crescent as well as of the seeing?

The latter view appears the more probable, but even if it be incorrect, and we admit that the cause is unknown, we shall still find it difficult to resist the conclusion that an instrument which diminishes the diameter of Jupiter and Saturn, and enlarges that of Venus, relative to the values found by the simple filar micrometer is not to be trusted in work on the planetary diameters. The constancy of the results found by the filar micrometer for different bodies, as well as the simplicity of the theory of this instrument, tends to strengthen one's confidence that it should be taken as the ultimate standard in all researches on the planetary discs.

In adjusting their observations, some previous investigators have formed equations of condition, arranged in such a way as to produce a term depending on an irradiation, which varies with the phase of the planet. Having followed Venus attentively from superior to inferior conjunction, the writer finds it difficult to believe that this procedure is well founded. The brightness at the horns appears always sensibly the same from East to West elongation. And the causes which produce the chief errors, are evidently those connected with the appearance of the horns of the crescent when disturbed by the irregularities of the terrestrial atmosphere.

The experience of the past year led to the following conclusions:

a) When the planet has a large angular diameter and the horns are very thin, they are tremulous and difficult to see sharply. Errors of observation under such conditions are increased, and produce in the reduced diameter an effect just about equivalent (within a certain range) to that due to the errors which arise when the horns are thicker and the planet apparently smaller and more remote from the Earth.

b) The irradiation at the horns of the crescent is sensibly the same while the planet moves from East to West elongation; but in order that the horns may be sufficiently thin to be similarly affected by the state of our atmosphere, observations should not be taken when the planet is more than about ten weeks from inferior conjunction.

c) When the observations are confined to this period of five months about inferior conjunction, the horns of the

crescent are so thin that with accurate bisections the irradiation may be entirely disregarded. It has the wellknown effect of blunting the point of the crescent, enlarging it inwardly, and outwardly by about equal angular amounts, and if the centre of the micrometer wire be accurately placed on the point of the horn, it will be tangent to the true limb of the planet, without any correction for irradiation whatever.

In view of these considerations no correction for irradiation has been applied to the above diameter; and all the individual determinations of diameter have been given equal weight, except as affected by the state of the seeing. The arithmetical mean of the 32 measures is $16''.787$; the weighted mean increases this quantity but slightly, and we have, as above, $D = 16''.800 \pm 0''.022$. Using $8''.796$ for the Solar parallax, this concluded angular diameter, at distance unity, makes the absolute diameter of Venus 12181.7 ± 16 kilometers.

U. S. Naval Observatory, Washington, D. C., 1900 Sept. 4.

T. J. J. See.

Observations of Titania and Oberon, the two outer Satellites of Uranus, made with the 26 inch Refractor of the U. S. Naval Observatory, Washington.

By *T. J. J. See.*

The following observations of the satellites Titania and Oberon, have been secured with a power of 606, and the new Clark Micrometer II (which is provided with a suitable electric illumination) attached to the 26 inch Refractor.

In the present position of Uranus the satellites are generally quite faint, and can be successfully measured with this telescope only when the sky is clear, and the Moon in the first and fourth quarters. On two or three occasions glimpses were obtained of the two inner satellites, Ariel and Umbriel, but they were too faint to admit of reliable measurement.

In the following table each recorded angle and distance is the mean of ten settings of the Micrometer, unless the contrary is indicated in the notes. The angles were obtained by placing the wire through the satellite and the centre of the planet's disc, and adjusting the color and intensity of the illumination to suit the faintness of the satellites. The distances were obtained by the usual method of

bisecting the ball of Uranus. The seeing is estimated on a scale of 5.

Mr. George Anderson, Assistant on the Great Equatorial, has been ill a considerable part of the time covered by these observations, and Mr. Geo. H. Peters, the Photographer, has voluntarily aided in the work on the satellites. The corrections for differential refraction indicated in the tables have been computed by Mr. W. Walter Dinwiddie, and checked by the writer.

These observations indicate that the places given in the American Ephemeris and Nautical Almanac, based upon the tables computed by Professor Newcomb in 1874, are now about 37° in advance of the observed places. The difference is probably due to an error in the tabular mean motion. The development of such a difference in the last 25 years, indicates that these tables cannot be relied upon for accurate places at epochs so remote as the time of Herschel, and that further researches on these satellites might be advantageously undertaken.

Observations of Titania.

Washington M. T. 1900	p_o	Refr.	p_o'	Wash. M. T.	s_o	Refr.	s_o'	Seeing = wt.	Remarks
April 25 $14^h 41^m 5$	138.26	+0.03	138.29	$14^h 41^m 7$	$32''.75$	+0.02	$32''.77$	2-3	Suspect Ariel and Umbriel, but [cannot measure]
26 14 8.6	178.46	+0.00	178.46	14 10.2	32.52	+0.04	32.56	4	
May 5 15 36.6	193.60	+0.02	193.62	15 36.5	32.90	+0.02	32.92	3-4	Hazy and moist, satellite difficult Clouds troubling Hazy
9 15 7.2	358.98	+0.03	359.01	15 8.0	33.44	+0.05	33.49	1-3	
17 13 47.4	326.89	-0.03	326.86	13 49.0	33.22	+0.02	33.24	4	
20 12 17.0	178.10	+0.01	178.11	12 17.0	33.58	+0.03	33.61	3-4	
21 13 14.7	211.60	-0.02	211.58	13 14.5	33.25	+0.03	33.28	2	Hazy
30 11 8.3	140.58	+0.03	140.61	11 9.0	33.25	+0.02	33.27	3-4	
June 1 10 27.5	221.88	-0.02	221.86	10 28.5	33.17	+0.04	33.21	2	