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MEASUREMENTS OF PLANETARY DIMENSIONS

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June 1969

*TN-701-69-30
Supported in part by NASA Grants NGL 32-003-001 and NGL 32-003-027.

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INTRODUCTION

Some recent measurements of planetary dimensions are summarized in this note. The results are based on measurements of good quality photographs with a Mann measuring machine. The techniques used were essentially the same as those used by W. H. Wright (1925) and others; however, a few variables which were of concern to Wright have been eliminated. A good background to the problems involved in measuring planetary images can be found in an article and its accompanying references by R. A. Wells (1965).

The photographic plates used in this program were exposed at the *f*:75 Cassegranian focus of the NMSU 61-cm reflector. The all-mirror optical system of this instrument provides a plate scale which is the same for light of all wavelengths. The plate scale has been determined by photographing several pairs of stars in the Pleiades cluster whose separations are known with great accuracy. The photographic plates were Eastman spectroscopic plates, and were developed in a low-contrast, fine-grain developer: UFG for Jupiter and HC 110 for the other planets. The various spectral regions were isolated with the aid of Schott filters. Planets having bright limbs were given normal exposures which produced images having an optical density of about 0.60 above the plate background. Jupiter, which has pronounced limb darkening in most wavelengths, was given one and one-half times its normal exposure to obtain images having an optical density of about 0.90. Photographs of the outer planets used in this work were taken only within a very few days of opposition to avoid real and photographic phase effects.

The interpretation of the position of the true limb of the planet on its photographic image is, of course, the crux of the problem. The writer's technique has been to bring the micrometer web in until it appears solidly tangent to the limb of the planet. A measurer seems to acquire a subconscious ability to counteract the small effects of irradiation (turbidity) on images exposed in the normal to twice normal range by setting the micrometer web a little "harder" against the edge of a dense image than a less dense image. In all cases the tendency is to set the web at the point of maximum contrast. Irradiation from the limb of blue and ultraviolet images of the outer planets causes the point of maximum contrast to be halfway between the outermost edge of the image and the point inside the limb where maximum intensity is attained. On red and infrared images, however, limb darkening counteracts irradiation and the point of maximum contrast lies much nearer the extreme outer edge of the image. This technique should prevent the loss of limb in red light, and suppress the effects of irradiation in blue and ultraviolet light. Using this method of measuring, the diameter of Mars in blue light is a little less than 3% larger than it is in red light; however, when the micrometer web is set on the extreme outer edge of both the blue and red images, the diameter in blue light is nearly 7% larger.

When converting diameters in seconds of arc at unit distance to diameters in kilometers, the unit distance is taken as 149,600,000 kilometers. Since unknown systematic errors may be larger than the accidental measuring errors, the standard deviations given herein may not be a reliable indication of the accuracy of the measurements.

PLATES AND FILTERS

Plate	Filter	Wavelength	Planet
II-O	UG-2	3700 Å	Jupiter, Saturn
III-0	UG-2	3700 Å	Venus
III-0	N.F.	4300 Å	Jupiter, Saturn
III-0	GG-13	4400 Å	Mars, Venus
III-G	GG-14	5500 Å	Jupiter, Saturn
III-G	OG-5	5500 Å	Venus
III-F	OG-2	6200 Å	Jupiter, Saturn
IV-E	OG-2	6400 Å	Mercury, Mars, Venus
I-N	RG-5	7900 Å	Jupiter, Saturn

MERCURY

Date	Wavelength	Diameter at unit distance	Diameter and S.D.
1968, May 23	6400 Å (red)	6".723	4,876 ± 25 km
1968, Oct 29	6400 Å (red)	6.690	4,852 ± 11

The measured diameter of Mercury was the diameter joining the cusps. For comparison, the diameter adopted by the American Ephemeris is 4,845 km. The diameter obtained by radar measurements (O'Handley, 1969) is 4,878.2 ± 1.0 km.

VENUS

The diameter of Venus was measured under two different conditions of illumination: 1. Near dichotomy in February 1969 when the phase angle was near 90°. These photographs were given normal exposure. 2. Near the inferior conjunctions of 1967 (Fig. 1) and 1969 (Fig. 2) between phase angles 151° and 170° when the thin crescent subtended considerably more than a semicircle. These photographs were exposed to give the sky background an optical density of about 0.6 so that the faint extensions of the horns would be recorded to best advantage. Since the illuminated crescent must have been extremely thin along the measured diameter connecting the horns, it was assumed to have no thickness at all, and the micrometer web was set to bisect the thin rim of light at each limb. Thus, these measurements should be free from any effects of irradiation (Smith, 1964).

VENUS, NEAR DICHOTOMY (FEBRUARY, 1969)

Wavelength	Diameter at unit distance	Diameter and S. D.
6400 Å (red)	16".860	12,228 ± 8 km
4400 Å (blue)	16.890	12,250 ± 18
3700 Å (UV)	16.924	12,275 ± 15

VENUS, NEAR INFERIOR CONJUNCTION (1967)

Wavelength	Diameter at unit distance	Diameter and S. D.
7900 Å (infrared)	16".911	12,265 ± 13 km
6400 Å (red)	16.893	12,252 ± 11
5500 Å (green)	16.918	12,270 ± 17
Mean	16".904	12,260 ± 8 km

VENUS NEAR INFERIOR CONJUNCTION (1969)

Wavelength	Diameter at unit distance	Diameter and S. D.
7900 Å (infrared)	16".901	12,258 ± 8 km
6400 Å (red)	16.901	12,258 ± 6
5500 Å (green)	16.900	12,257 ± 8
3700 Å (ultraviolet)	16.913	12,267 ± 8
Mean	16".902	12,259 ± 4 km

The measured diameter of the scattering layer in the atmosphere of Venus near inferior conjunction is about 30 kilometers greater than the diameter of the reflecting layer in red light near dichotomy. This suggests that the middle of the scattering layer is about 15 kilometers above the opaque cloud deck. The diameter of the solid surface of the planet obtained from radar measurements (Melbourne, 1968), is 12,111.6 km. The top of the opaque cloud deck at dichotomy would be 58 kilometers above the solid surface.

MARS (15 APRIL 1967)

Wavelength	Diameter at unit distance	Diameter and S. D.
6400 Å (red)	9".336	6,771 ± 4 km
4400 Å (blue)	9.603	6,965 ± 19

The measured diameter was inclined about 25° to the planet's equator to avoid very bright cloud-like areas on the equatorial limb in photographs taken in blue light. Figure 3 illustrates the difference in size between the blue and red images of Mars. The writer feels rather confident that the difference in size is too great to be explained in its entirety by irradiation and turbidity on photographs taken in blue light. Loss of the true limb due to limb darkening in red light seems more probable. Opposed to this, however, is the fact that the measured diameter of Mars on photographs taken in red light is very near the generally accepted value. The measurements make the radius of the blue images 97 ± 10 km greater than the radius of the red images.

In order to test the effects of irridation and turbidity on the photographic emulsions used in taking the photographs of Mars in red and blue light, Thomas Kirby and Susan Dean made a number of photographs of the full moon with various exposures using the same or similar photographic plates and filters that were used for Mars. The photographs of the moon were taken at the primary focus of a 5-inch reflector of 20.3 inches focal length and gave images of the moon that were comparable in size to images of the planets taken with the 61-cm reflector. Measurements of the images of the moon photographed in red and blue light revealed no difference in diameter whatsoever, and this is rather convincingly illustrated in Figure 4. Also, there was no appreciable increase in diameter of the images of the moon in either red or blue light as the optical density of the images increased from 0.44 to 0.84. These results strongly indicate that turbidity and scattering in the blue emulsion were not responsible for the larger images of Mars in blue light.

The diameter of Mars adopted by the American Ephemeris is 6,790 km. The diameter obtained by radar measurements (Melbourne, 1968), is 6,750.6 km.

JUPITER (OPPOSITION, 1969)

	Equatorial diameter		Polar diameter		
Wavelength	Unit distance	Kilometers	Unit distance	Kilometers	Oblateness
7900 Å (infrared)	196".203	142,302±62	183".490	133,082±81	0.0648
6200 Å (orange)	195.843	142,041±87	182.888	132,645±63	0.0662
5500 Å (green)	195.964	142,129±94	182.656	132,477±132	0.0679
4300 Å (blue)	197.486	143,233±38	183.959	133,422±86	0.0685
3700 Å (ultraviolet)	197.518	143,256±58	183.887	133,370±76	0.0690

The equatorial diameter of Jupiter measures about 1% larger in blue light than in orange light. Photographs taken in rapid succession in red and blue light, when the satellites Io and Europa are being occulted by the limb of Jupiter, indicate that at least part of this apparent difference in diameter is caused by a loss of limb in red light. The measured oblateness of the planet remains greater in blue light than in red light by a nearly constant ratio even when the optical densities of the images are increased two or three times.

The diameters of Jupiter adopted by the American Ephemeris are 142,837 km for the equatorial diameter, and 133,322 km for the polar diameter. These ephemeris diameters give the planet an oblateness of 0.0667.

SATURN (OPPOSITION, 1968)

	Equatorial diameter		Polar diameter		
Wavelength	Unit distance	Kilometers	Unit distance	Kilometers	Oblateness
7900 Å (infrared)	166".759	120,947	---	---	---
62[illegible]0 Å (orange)	166.658	120,874±123	147".285	106,823±162	0.1132
5500 Å (green)	166.834	121,002±151	148.752	107,887±210	0.1084
4300 Å (blue)	167.106	121,199±119	149.856	108,688±212	0.1032

Unlike Jupiter, the oblateness of Saturn appears to increase with increasing wavelength.

The diameters of Saturn adopted by the American Ephemeris are 120,875 km for the equatorial diameter, and 108,168 km for the polar diameter. The ephemeris diameters give Saturn an oblateness of 0.1051.

SATURN'S RINGS (OPPOSITION, 1968)

Object	Diameter at unit distance	Diameter in kilometers	Ratio (A (outer) = 1)	Ratio (Cassini = 1)
Ring A, outer edge	376".756	273,254 ± 80	1.0000	1.1421
Ring A, inner edge	335.480	243,317 ± 134	0.8904	1.0170
Cassini's Division	329.869	239,248 ± 110	0.8755	1.0000
Ring B, outer edge	324.259	235,179 ± 117	0.8606	0.9829
Ring B, inner edge	252.883	183,411 ± 160	0.6712	0.7666
Ring C, inner edge	208.172	150,983 ± 328	0.5525	0.6310

Since the dimensions of Saturn's rings revealed no appreciable dependence on wavelength, the measurements made in infrared, orange, green, and blue light were averaged together. Measurements of Ring C, however, were made only in blue and green light since that ring appeared to be considerably brighter at the shorter wavelengths. From these measurements, the width of Cassini's Division is 4069 km. Ring C was measured only on photographs that were given twice the normal exposure, while the other rings were measured on photographs given a normal exposure.

JUPITER'S GREAT RED SPOT

Although somewhat out of context, this note will be concluded with a brief summary of the changing dimensions of Jupiter's Red Spot since it became a prominent object in 1878. Most references to the length of the Red Spot in astronomical publications give such values as 30,000 miles and 40,000 kilometers. Such values were occasionally applicable to the Red Spot prior to 1930; however, during the last 40 years the mean length has been 29,800 kilometers (18,500 miles) and the mean width about 13,000 kilometers (8,000 miles).

DIMENSIONS OF JUPITER'S RED SPOT

Interval	β" *	Length		Width		Source
1879-82	-24°.3	33°.7	38,670 km	11°.6	13,020 km	1
1887-88	-24.0	33.3	38,300	13.0	14,580	2
1890-92	-23.9	33.0	37,980	12.2	13,680	3
1893-97	-23.9	31.6	36,370	---	----	3
1914	-22.3	27.5	31,980	11.0	12,280	4
1918-20	-20.6	31.5	37,010	---	----	5
1925-28	-23.3	29.0	33,510	---	----	5
1925-30	-24.0	31.9	36,690	13.0	14,580	3
1930-39	-21.8	26.2	30,550	---	----	5
1930-39	-21.9	28.3	32,900	11.2	12,490	4
1940-49	-23.7	25.5	29,400	---	----	5,6
1950-59	-23.0	25.7	29,750	---	----	5,6
1960-66	-22.5	24.1	28,000	---	----	6
1960-69	-22.5	24.2	28,100	12.2	13,630	7

*Zenographic latitude of the center of the Red Spot.

The lengths and widths of the Red Spot tabulated above were obtained from the following sources:

1. Peek, B. M. (1958). "The Planet Jupiter." Chapter 15. Macmillan, New York.

2. Williams, A. S. (1909). "Zenographical Fragments, Volume II." Taylor and Francis, London.

3. Measurements of Lick Observatory photographs by H. G. Solberg and E. J. Reese.

4. Measurements of various photographs by H. G. Solberg and E. J. Reese.

5. Memoirs of the British Astronomical Association.

6. Journal of the Association of Lunar and Planetary Observers.

7. Measurements of New Mexico State University Observatory photographs by H. G. Solberg and E. J. Reese.

RECENT MEASUREMENTS OF JUPITER'S RED SPOT MADE BY

H. G. SOLBERG AND E. J. REESE AT NEW MEXICO STATE UNIVERSITY OBSERVATORY

Apparition	β'' *	Length		Width	
1961-62	-22.6	24.6	28,560 km	12.9	14,410 km
1962-63	-22.7	24.2	28,070	13.0	14,530
1963-64	-22.5	23.7	27,530	12.5	13,960
1964-65	-22.1	23.4	27,240	12.0	13,390
1965-66	-22.3	23.3	27,100	11.5	12,840
1967-68	-22.9	24.8	28,720	12.1	13,530

* Zenographic latitude of the center of the Red Spot.

NOTE: Measurements made from 1 February 1966 to 25 January 1968 were excluded because the true outline of the Red Spot apparently was concealed during this interval. All measurements of the length of the Red Spot made at the New Mexico State University Observatory pertain to the elliptical outline of the dark Red Spot as photographed in blue light. The extended tips or belt-like appendages sometimes visible at the preceding and following ends of the Red Spot were not included in the measured lengths.

REFERENCES

Melbourne, W. G., and O'Handley, D. A. (1968). Recent development ephemerides. Space Programs Summary 37-53, Vol. III, p.1.

O'Handley, D.A. (1969). Private communication to B. A. Smith.

Smith, B. A. (1964). A photographic optical semidiameter of Venus. Astronomical Journal 69, No. 2, 201-204.

Wells, R. A. (1965). A re-evaluation of W. H. Wright's plates of the 1924 and 1926 oppositions of Mars. Planetary Space Science 13, 261-263.

Wright, W. H. (1925). Photographs of Mars made with light of different colors. Lick Observatory Bulletin XII, No. 366, 48-61.

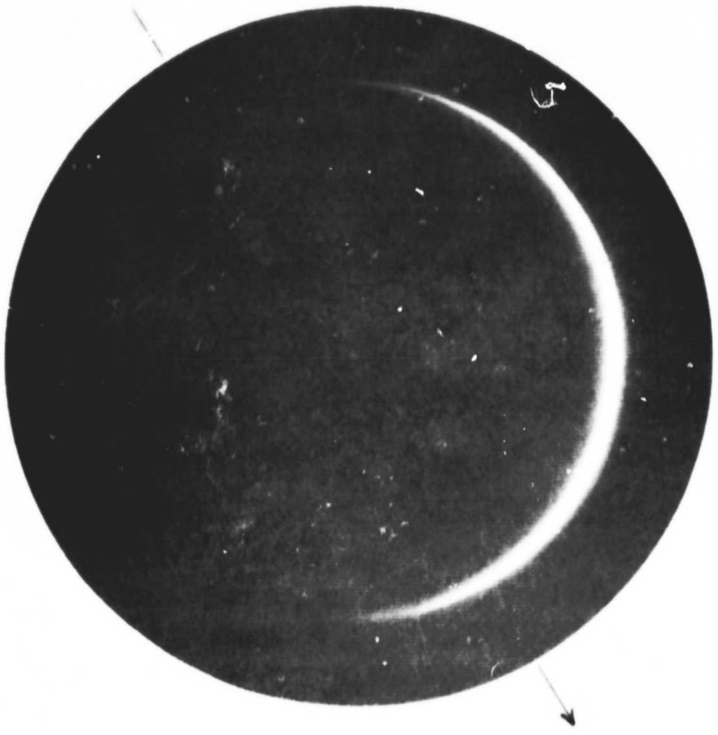

Fig. 1. Venus on 3 September 1967, 1533 UT, phase angle 163°.9. This photograph, which was taken in infrared light with an exposure of 0.08 second, shows the illuminated crescent subtending an arc of 191°. The greater twilight extension recorded in Fig. 2 was due to a longer exposure on a darker sky. The arrow indicates celestial north. Photograph taken by T. Pope with the 61-cm reflector at the NMSU Observatory.

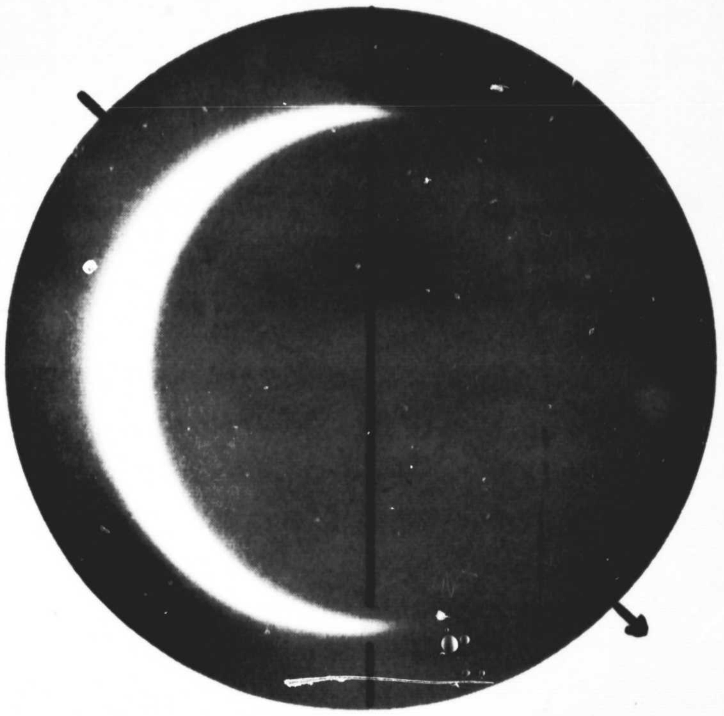

Fig. 2. Venus on 28 March 1969, 0125 UT, phase angle 152°.7. This 5 second exposure in red light shows the illuminated crescent subtending an arc of 203°. The arrow indicates celestial north. Photograph taken by C. F. Knuckles with the 61-cm reflector at the NMSU Observatory.

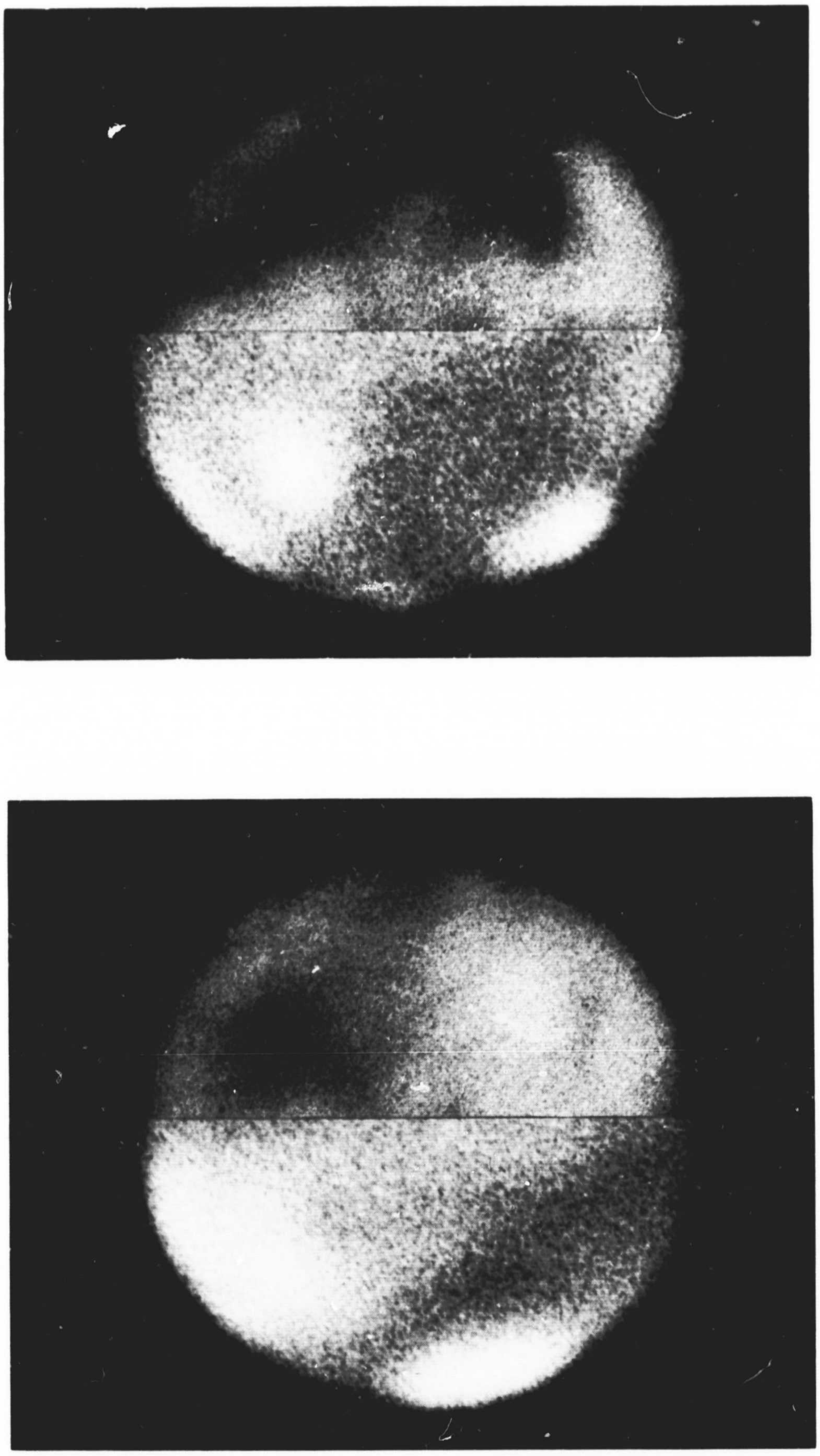

Fig. 3. Comparison photographs of Mars taken in red and blue light on 15 April 1967 at 0840 UT. The upper half of each spliced image was taken in red light using a IV-E plate with an OG-2 filter. The lower half of each image was taken in blue light using a III-O plate with a GG-13 filter.

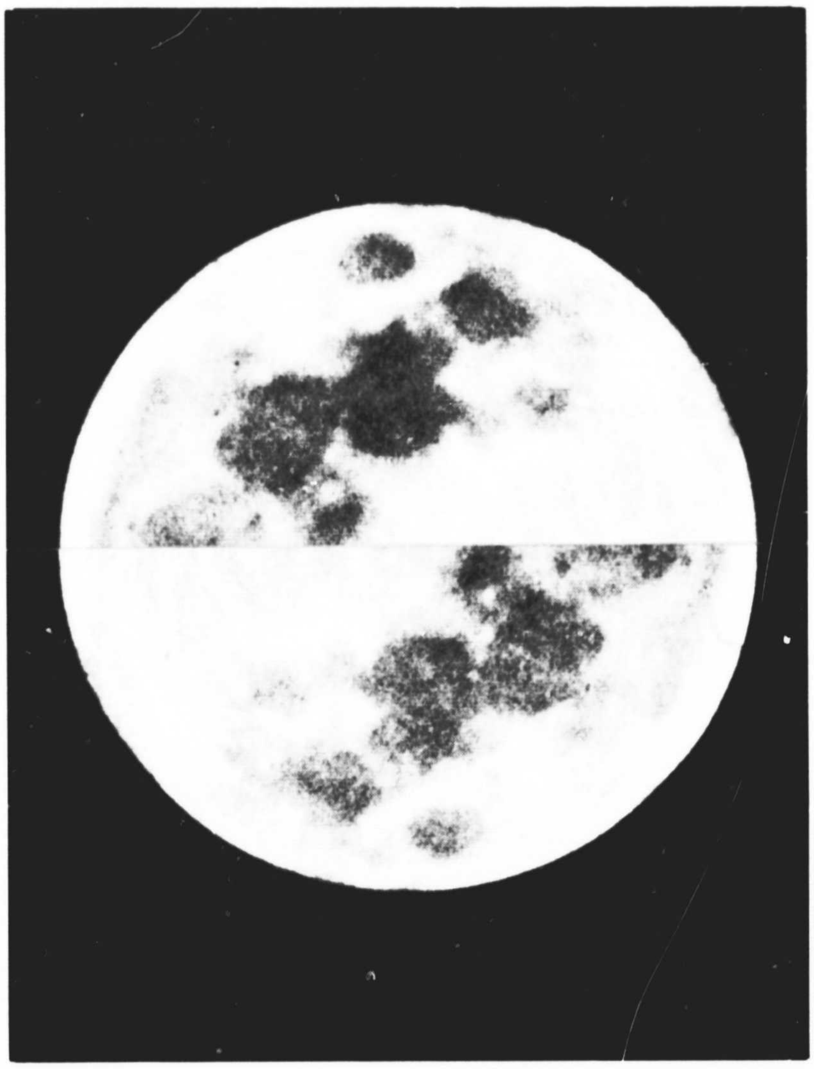

Fig. 4. Comparison photographs of the Moon taken in red and blue light. Two photographs of the same hemisphere of the moon spliced together. The upper half was taken in red light using a III-F Kodak spectroscopic plate with a Schott OG-3 filter. The lower half was taken 14 minutes later in blue light using a III-O plate with a Schott GG-13 filter. The photographs were taken at the primary focus of a 5-inch reflector of 20.3 inches focal length. Photographs by Thomas B. Kirby and Susan A. Dean.