NO. 174 MULTICOLOR PHOTOGRAPHY OF JUPITER

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ABSTRACT

Examples of wide-band filter photography of Jupiter between 1965 and 1970 are reviewed, describing the basic wavelength dependence of the cloud features. The initial results of photography in the 0.89μ methane band are discussed.

1. Introduction

Direct photography of Jupiter provides much information on the nature and circulation of cloud patterns. Because of the planet's large angular size, its major features can be easily recorded and under the best conditions complex, fine structure is seen. The changing nature of the clouds requires photography at frequent intervals to follow their evolution. Most of the data on the appearance of Jupiter before this century are drawings by visual observers, but with the application of photography, reliable, objective records provide the opportunity for systematic and quantitative studies of the visible clouds. It has been generally maintained that the visual observer can see more detail than the photograph can record, but this is only partly true. Under "average" seeing conditions the visual observer *might* be able to detect a small feature (given enough time to pick out moments of better seeing) not resolved on a photograph, but in the fraction of a second of the photographic exposure, a permanent, objective, geometrically and photometrically consistent record is obtained; and if many photographs are taken, a few may approach "visual" resolution. Under excellent seeing conditions, the photography may show all the detail that the observer can see and may actually excel in resolving broad, low-contrast features because of the higher contrast detection capability of the emulsion. (The relative merits may be different for small telescopes).

In the early experiments of A. A. Common in 1879 and others, photographic emulsions were not very efficient; but with systematic programs that started about 1905, especially at Lowell Observatory (Slipher 1964), it was shown that the major changes could be followed successfully. Since then, Lyot (1943, 1953), Camichel (1946), and Humason (1961) have provided improved results with better techniques, emulsions and telescopes. More recently the New Mexico State Observatory has achieved excellent resolution and coverage with modest aperture, and the NASA IPP has provided unprecedented patrol data.

A major milestone was reached in W. H. Wright's (1929) studies of the wavelength dependency of the clouds on Jupiter from 0.36-0.76μ. With the use of selected broadband glass filters,he produced the first objective records of the spatial distribution of the colors that at that time had been described only by visual observers.

2. The Program

In October 1965, Dr. Kuiper initiated a program of direct photography of the Moon and planets with the newly completed 154-cm telescope at the Catalina Observatory (32°.4 N latitude, 2520m altitude). Every effort was made to optimize the optical performance of the telescope, and minimize local seeing effects. F/13.5 (10 arc-sec mm^{-1}), and f/45 (3 arc-sec mm^{-1}) Cassegrain secondaries are available. About one fourth of the telescope time has been used for lunar and planetary photography, with lunar photography having first priority during the period up to mid-1967 in preparation for the CONSOLIDATED LUNAR ATLAS (1967). Initially, D. Milon experimented with several black-and-white, and color emulsions and scales to optimize results for the side conditions. The present authors became the principal observers in 1967 and initiated the use of filters and many more emulsions. In the continuing effort to refine our techniques, new emulsions are considered and adopted when the results are improved. Over the years we have been assisted by C. Campbell, D. McLean, J. Barrett, R. B. Minton, and others.

The primary objective of the program has been to obtain the highest possible resolution; however, orientation trails and photometric calibration are applied routinely to make the data more useful for future studies. The exposure times are recorded on paper tape with 1 sec accuracy, and other pertinent data are recorded in a log.

For efficiency in storage, handling, and processing, and because of the diversity of available emulsions, 35mm roll films have been used almost exclusively. The camera is a Nikon F, which permits the image quality to be monitored in a reflex viewer; no exposures are made when the seeing is below average for the night. This greatly reduces the number of images which would not be used because of their low quality. Further improvements in image quality are realized with the use of a non-deviating, low-dispersion prism to compensate for atmospheric dispersion (allowing better coverage because observations may be extended to greater zenith angles) and sometimes by reducing the aperture in inferior seeing conditions with appropriate diaphragms either at the end of the telescope or at the secondary mirror.

Normally, 15-20 exposures are made within a short interval, to provide adequate material for compositing 2 to 10 images (Jupiter's rotation causes 0.2 arc-sec smear at the center of the disk during 45 sec). At our site a composite of selected high-quality images of short exposure is usually better than a single longer exposure on a slower, fine-grain emulsion. Only during the best seeing is the gain in quality negligible, for exposures up to several seconds. The result of compositing is an enlarged (to a constant scale) positive copy that can be further copied to adjust contrast or intensity gradients.

The selection of plate scale was determined primarily by the width of the passband filters and emulsions used. For wide effective passbands, large plate scales on fast emulsions were found preferable; thus f/45 to f/80 was most common. For narrow bands requiring long exposures, smaller plate scales, such as provided by the f/13.5 secondary, were necessary. Sometimes the image size was adjusted for the seeing; but since visual assessment of the (photographic) seeing is often unreliable, the optimum scale for average conditions was found most practical.

Processing of the black-and-white films is done manually or by the LPL's Itek Transflo automatic film processor. The exposure times for Jupiter at the f/45 focus are 1/30 to 1/15 sec for panchromatic film without filter; 1/8 to 1/4 sec, with broadband filters (1500Å); 1/2 to 1 sec for color films; and with the 8975Å interference filter at the f/13.5 focus, 60-90 sec.

This filter was obtained by Dr. Kuiper in October 1968. It passed a band 200Å wide centered on λ8975Å. The transmission curve is shown on page 311. It was obtained to cover the strong 200Å wide CH_4 band (e.g. Kuiper 1952, Plate 12), for the photography of the Jovian planets. The intensity of a portion of the planet in the photograph measures the methane absorption above it, and is thus interpreted as a measure of the height of that feature in the Jupiter atmosphere. Our records show that some of the bright belts, the Red Spot, and polar hoods, are higher than the other clouds. In 1970 an ammonia filter for λ6445Å (8Å wide) was used. The images appeared essentially the same as those taken through broadband red filters, apparently because the continuum between the rather sharp NH_3 lines dominated in the transmitted light.

3. Selection of Reproductions

We have selected representative records for the apparitions 1965-70. The black-and-white images shown are composites, produced as follows: the original telescopic negatives were composited on film (as positives), without photometric compensations (such as shading). Second negatives of appropriate scale on film

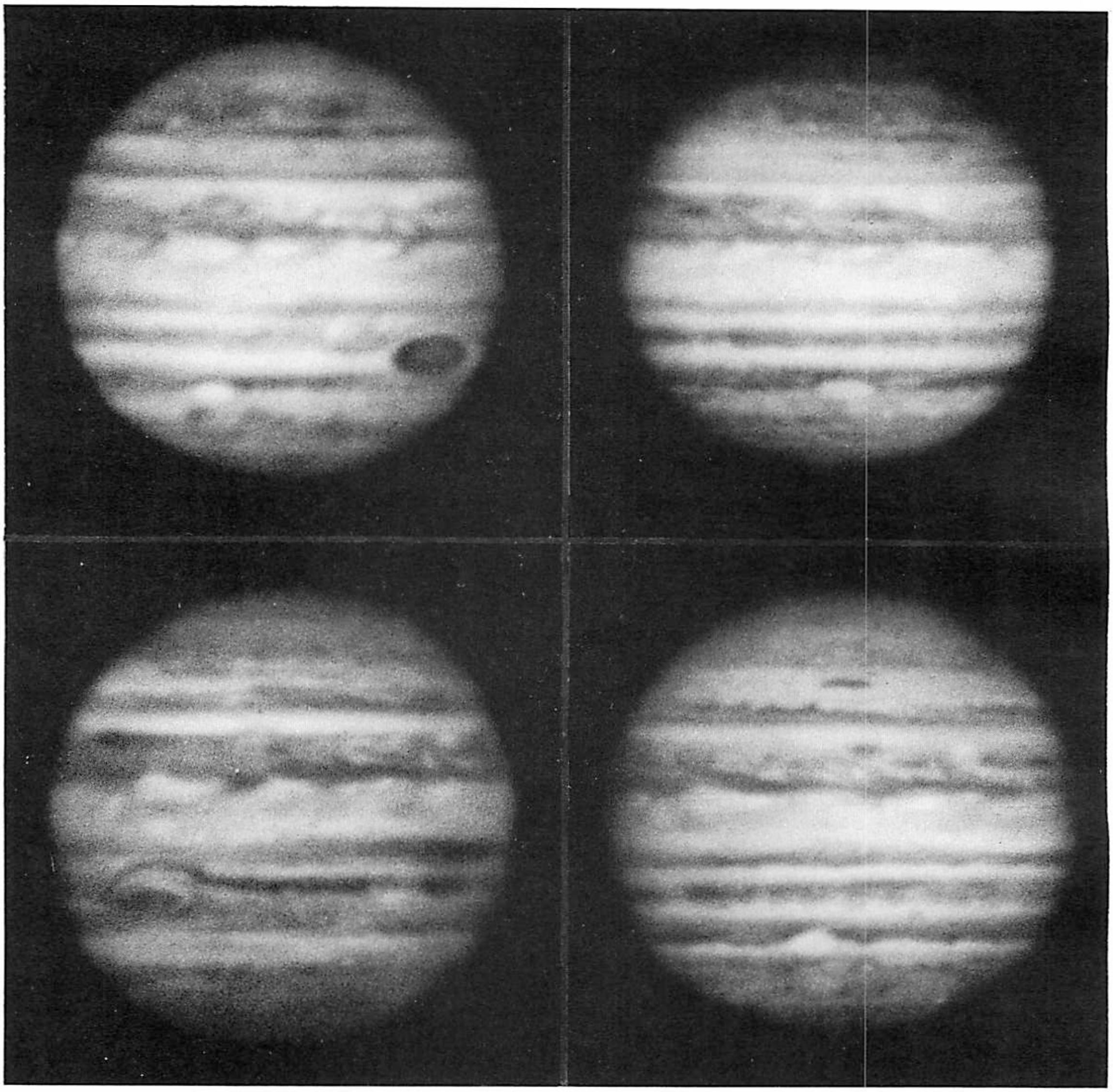

Fig. 1*a*. 1965 Oct 30, 08:35:07 UT. Panchromatic. RS prominent on limb. White oval visible South of STeB; smaller dark spots at high latitudes. Prominent festoons adjacent to NEB.
b. 1966 Feb 4, 05:39:45 UT. Panchromatic. Many small high-latitude spots visible, and mottling in belts. NTeB has faded since Oct 30; also diminishing festoon activity.
c. 1966 Dec 23, 08:35:22 UT. Panchromatic. All zones except NTrZ filled with darker material. Belts, e.g. NTeB and NEB, still prominent. SEBs is very dark and in vicinity of RS displaced toward equator. Size and shape of RS changed with appearance of light material between it and SEBs.
d. 1967 Jan 20, 05:52:37 UT. Panchromatic. Zones have lightened; many high-latitude spots and small detail in belts. On central meridian NTeZ is isolated dark bar. Note double nature of NTeB over most of its length and break near center of disk. Irregular belt edges.

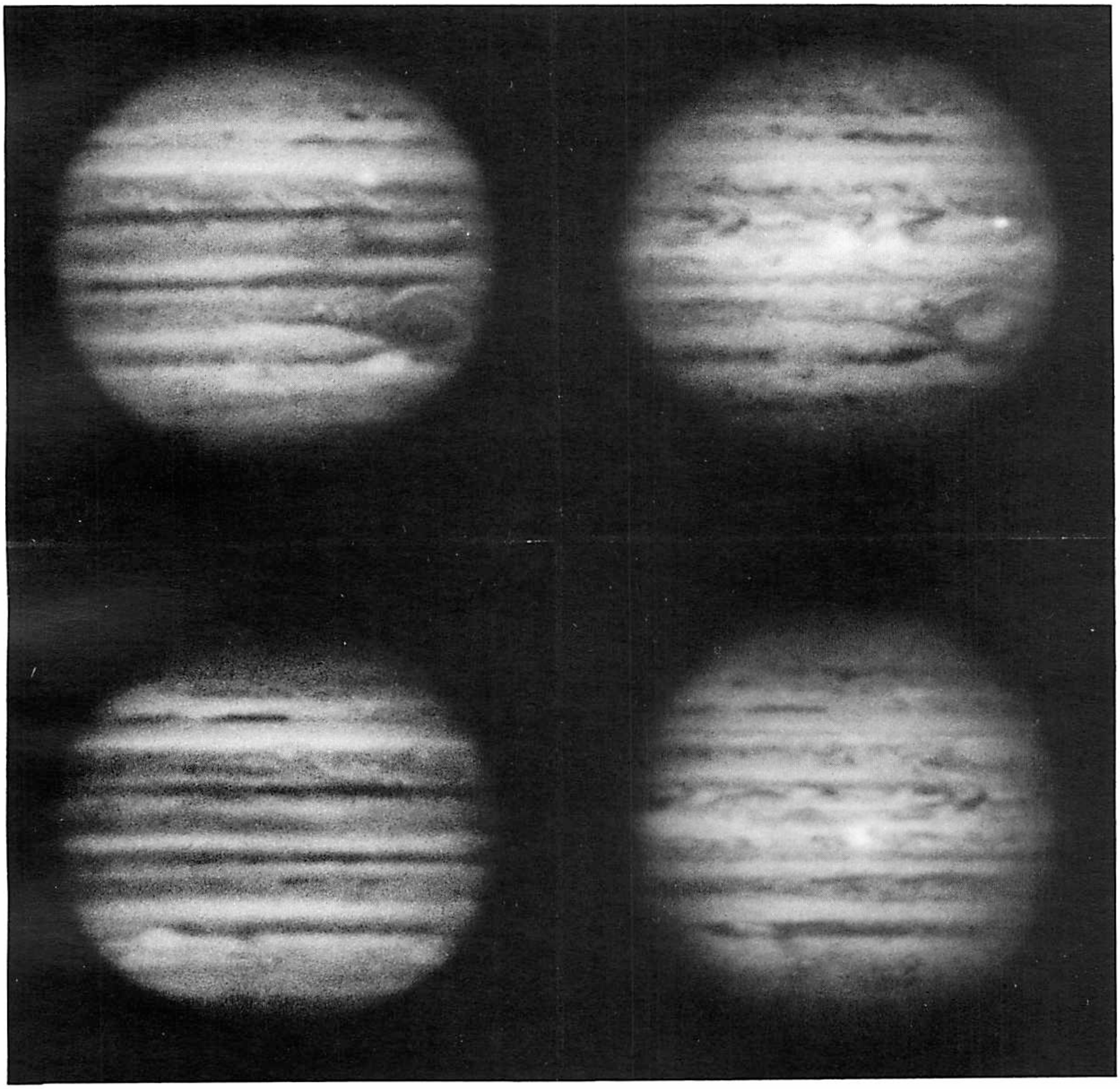

Fig. 2*a*. 1968 Jan 25, 10:09:57 UT, 0.35-0.48μ.
b. 1968 Jan 25, 10:01:29 UT, 0.70-0.89μ.
a and *b* show typical differences between blue and red: greater prominence of banded structure in blue and irregular structure in red. Sections of NTeB indicate peculiar colorations. Broken-up appearance of SEBs immediately following RS. Small spot within RS, darker in red and brighter in blue than RS. Io near right side of disk, brighter in red; elongated appearance due to lower albedo of poles.
c. 1968 Jan 25, 11:46:52 UT, 0.35-0.48μ.
d. 1968 Jan 25, 11:32:09 UT, 0.70-0.89μ.
Compare with *a* and *b*. Light spot near center of red image may be defect.

were produced from these positives, again without shading. Paper positives were made by contact printing from the second negatives, with appropriate shading applied in order to bring out local contrasts to maximum advantage; in general, that meant only a reduction of the limb darkening, but sometimes a compensation for the Red Spot or an unusually dark belt showing detail on the film copies (paper having a small dynamic range). The shading was never done manually, but always with an appropriate mask placed between the negative and the light source; and the resulting print was always carefully inspected against the original film positive. This method was used, after much experimentation, since it allowed maximum control and repeatability, and minimized spurious halos, etc., introduced by some methods. For a given day the images have the same scale (depending on the image quality); North is up.

The limb darkening has been reduced in the reproductions of the red-filter images, which should be borne in mind in their use. Table I lists the relevant observational data for each of the reproductions here included.

TABLE I

Figure	Date	Time (UT)	Film	Filter	Images in Composite	λ_I	λ_{II}	Comp. No.
1*a*	1965 Oct 30	08:35:07	TRI-X	NF*	12	250.9	64.5	1102
1*b*	1966 Feb 4	05:39:45	TRI-X	NF	1	355.3	143.7	1205
1*c*	1966 Dec 23	08:35:22	4-X	NF	8	145.7	356.3	1104
1*d*	1967 Jan 20	05:52:37	4-X	NF	8	151.5	149.3	1173
2*a*	1968 Jan 25	10:09:57	103-O	NF	3	15.9	69.3	214
2*b*	1968 Jan 25	10:01:29	HSIR	RG-5	4	10.7	64.2	210
2*c*	1968 Jan 25	11:46:52	103-O	NF	3	74.9	127.8	218
2*d*	1968 Jan 25	11:32:09	HSIR	RG-5	11	66.0	118.9	997
3*a*	1968 Dec 6	11:37:36	103-O	NF	8	251.2	53.0	381
3*b*	1968 Dec 6	12:00:41	HSIR	RG-5	7	265.3	66.9	385
3*c*	1968 Dec 6	12:14:07	HSIR	0.9μ	4	273.5	75.1	386
3*d*	1970 Apr 3	7:17:08	103-O	NF	8	13.3	91.2	1169
3*e*	1970 Apr 3	7:07:49	HSIR	RG-5	4	7.6	85.6	921
3*f*	1970 Apr 3	6:58:50	HSIR	0.9μ	3	2.2	80.1	916
4*a*	1969 May 30	4:00:19	103-O	NF	11	253.9	163.0	984
4*b*	1969 May 30	3:54:47	4-X	GG-14	9	250.6	159.6	982
4*c*	1969 May 30	3:48:27	HSIR	GG-14	12	246.7	155.8	983
5*a*	1968 Mar 22	5:58:44	103-O	UG-11	3	229.3	209.1	1092
5*b*	1968 Mar 22	5:53:01	103-O	NF	3	225.8	205.5	1093
5*c*	1970 May 16	7:25:27	103-O	UG-5	5	333.1	82.8	1028
5*d*	1970 May 16	7:21:55	103-O	NF	6	330.9	80.6	1031
6*a*	1970 May 16	7:31:04	4-X	GG-14	6	336.5	86.2	1033
6*b*	1970 May 16	7:34:40	HSIR	GG-14	9	338.7	88.4	1034
6*c*	1970 May 16	5:40:32	HSIR	RG-5	3	269.1	19.4	1112
6*d*	1970 May 16	5:50:07	HSIR	0.9μ	4	275.0	25.2	914
7*a*	1970 Jun 19	4:03:00	103-O	NF	10	178.1	29.7	1204
7*b*	1970 Jun 19	3:56:59	HSIR	GG-14	12	174.5	26.0	946

* NF = No filter

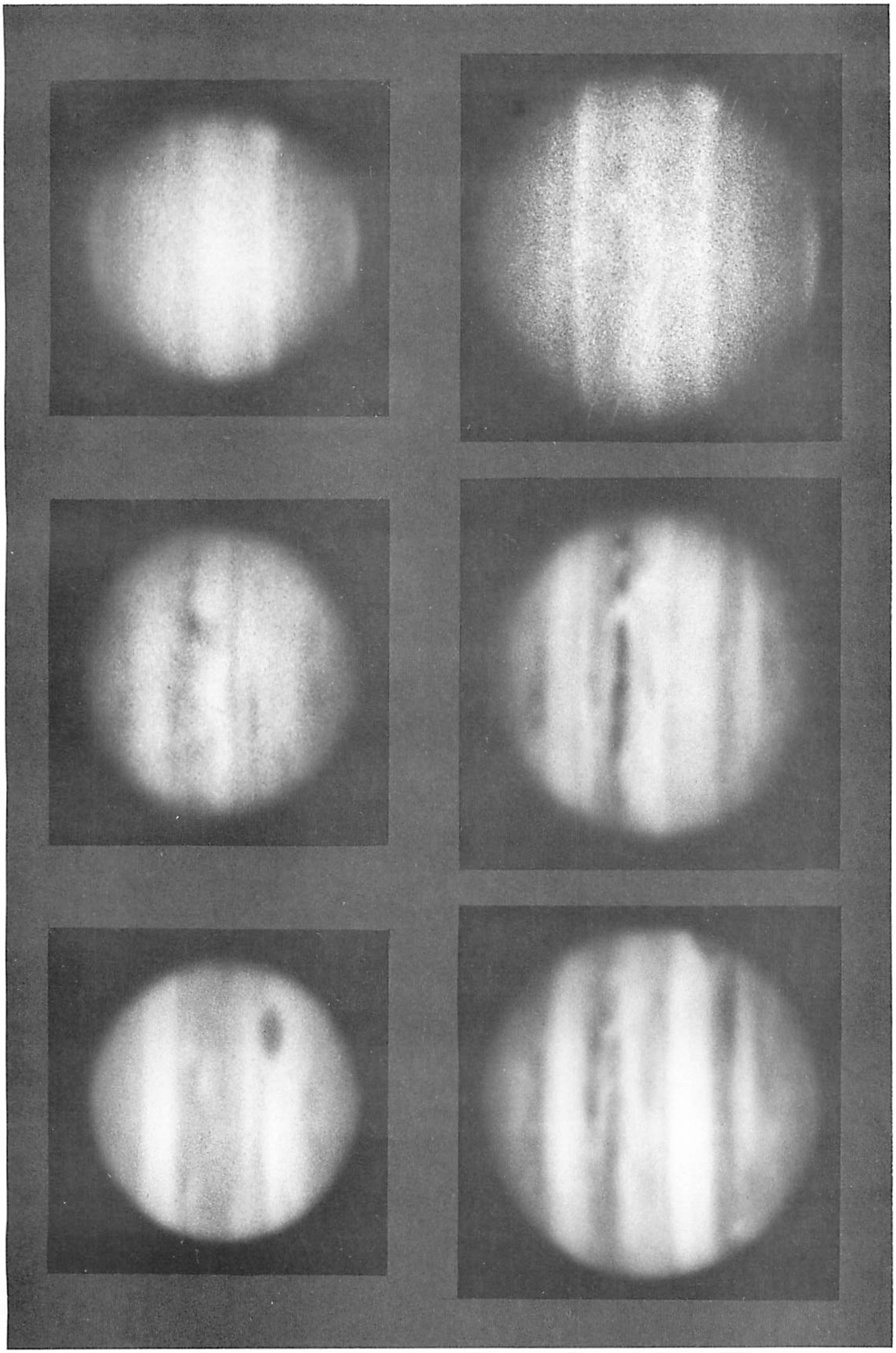

Fig. 3*a*. 1968 Dec 6, 11:37:36 UT; 0.35–0.48μ.
b. 1968 Dec 6, 12:00:41 UT; 0.70–0.89μ.
c. 1968 Dec 6, 12:14:07 UT; 0.90μ (CH_4). Light polar hoods, RS, EZ, and Tropical Zones; Io at right.
d. 1970 Apr 3, 7:17:08 UT, 0.35–0.48μ.
e. 1970 Apr 3, 7:07:49 UT, 0.70–0.89μ.
f. 1970 Apr 3, 6:58:50 UT, 0.90μ (CH_4). Changes since 1968.

4. Discussion

The nomenclature used herein is basically the same as adopted by the BAA, but it should be noted that there are many difficulties in describing features in different wavelengths. The qualitative manner in which some features are referred to is due to lack of standardization. With minor exceptions Jupiter's appearance from 0.3-0.5μ is fairly constant, as it true longward of 0.5μ. Near 0.5μ the relative brightness of the belts and zones often changes considerably. In blue light the banded structure of the planet is promiment, and the limb darkening is small. In red light the appearance of the planet is less ordered and

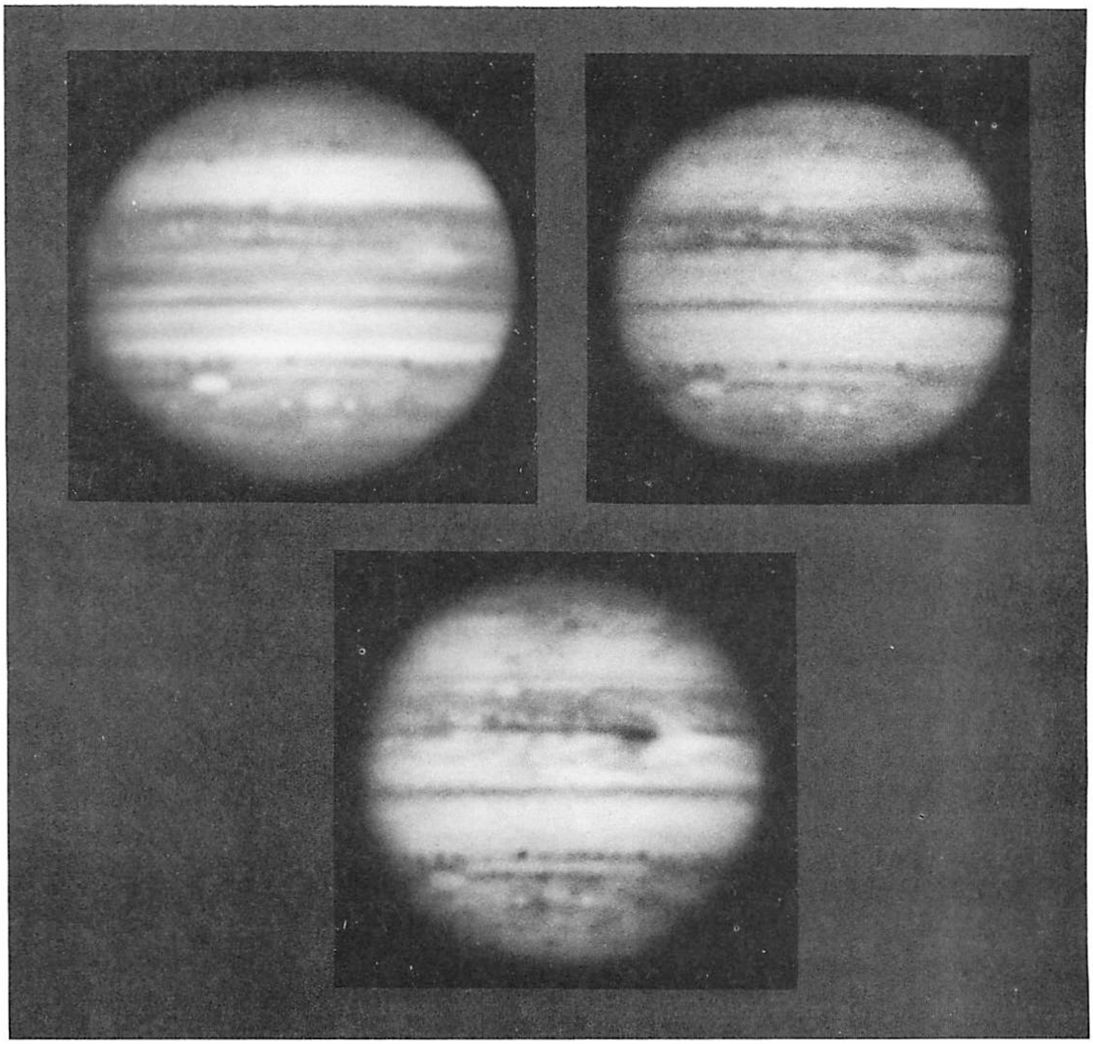

Fig. 4*a* 1969 May 30, 4:00:19 UT, 0.35-0.48μ.
b 1969 May 30, 3:54:47 UT, 0.51-0.63μ.
c 1969 May 30, 3:48:27 UT, 0.70-0.89μ.
An unusual number of spots: dark spots in STrZ, prominent in all three wavelengths; white spots in NEB and SPR. Unusually high-latitude festoons in Northern hemisphere of red image.

limb darkening is more severe, contrast between the belts and zones is reduced, and much of the visible structure no longer tends to be parallel to the equator. This is largely due to the intrinsic colors of the features, the belts often being somewhat reddish and the festoon-like features bluish. Green photographs of Jupiter are rarely taken since they contain contributions from these two distinctive appearances.

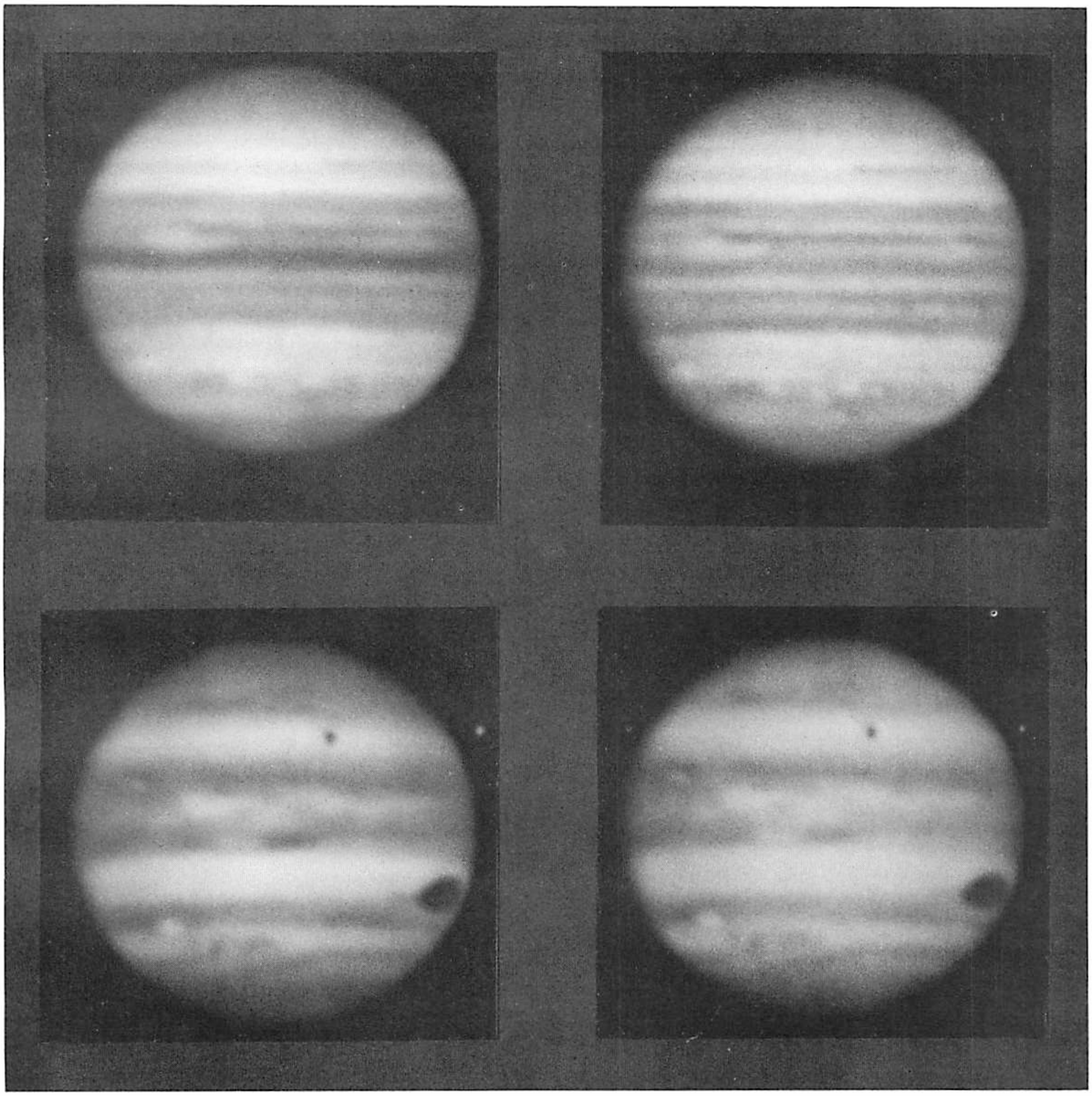

Fig. 5*a* 1968 Mar 22, 5:58:44 UT, 0.33-0.38μ.
b 1968 Mar 22, 5:53:01 UT, 0.35-0.58μ.
c 1970 May 16, 7:25:27 UT, 0.33-0.40μ.
d 1970 May 16, 7:21:55 UT, 0.35-0.48μ.
Representing differences in UV and blue. In *a*, *b*, belt near equator is much darker in UV than in blue; the lower pair shows a more common difference - one of contrast.

The most dominant single feature on Jupiter is the Red Spot, and since it shows color and boundary changes, it demands coverage in both blue and red light. Because of its reddish color it appears dark on blue light photographs and often shows interesting structure in red. When our photography commenced in 1965, the RS was prominent (Fig. 1*a*) and had a darker border. By late 1966 (Fig. 1*c*) the Northern edge was light, reducing its overall prominence. In 1968 (Figs. 2*a*, *b*) it had returned to a more normal appearance and remained so until 1970 when it had become very red (Fig. 7*a*). At that time, the red images showed much interior detail.

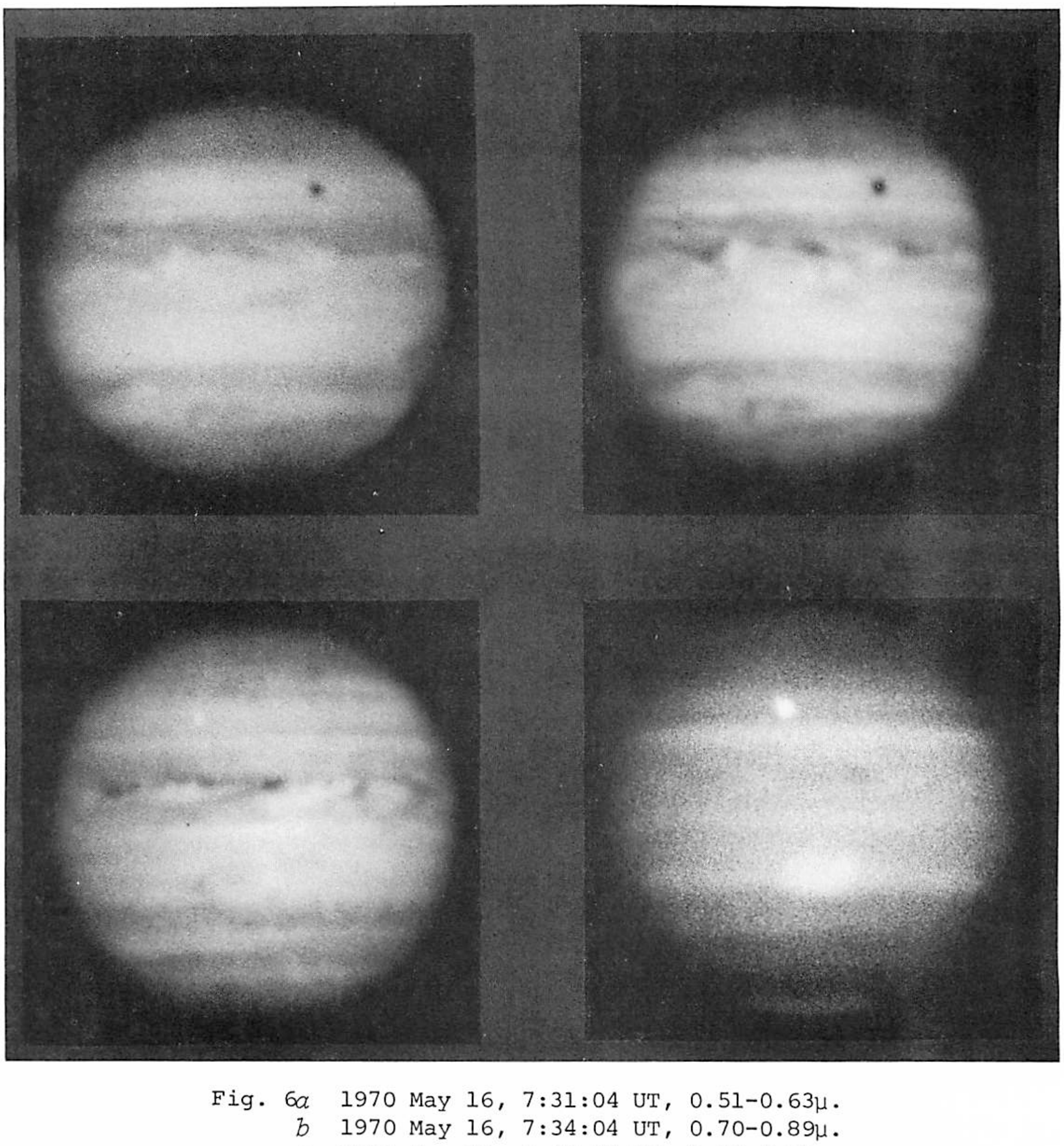

Fig. 6*a* 1970 May 16, 7:31:04 UT, 0.51-0.63μ.
b 1970 May 16, 7:34:04 UT, 0.70-0.89μ.
c 1970 May 16, 5:40:32 UT, 0.70-0.89μ.
d 1970 May 16, 5:50:07 UT, 0.90μ (CH_4).
Compare with Fig. 5*c*, *d*, taken on same date. Europa's shadow on disk. Note structure around and in RS in *c*, and strong Tropical Zones in *d*. Brightness of Europa in *d* indicative of amount of methane absorption on planet.

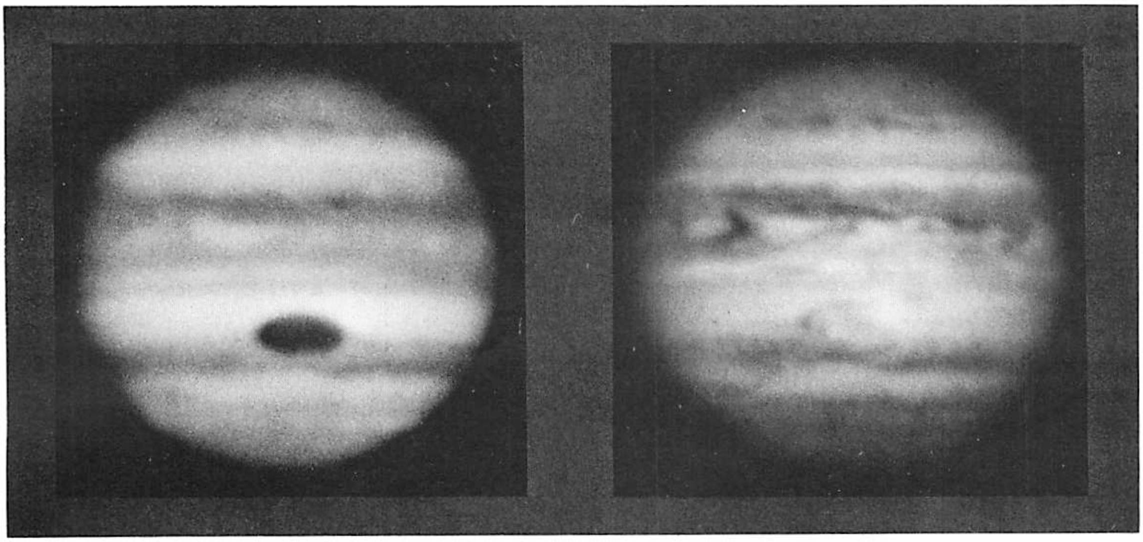

Fig. *7a* 1970 June 19, 4:03:00 UT, 0.35-0.58μ.
b 1970 June 19, 3:56:59 UT, 0.70-0.89μ.
Note prominence of RS in blue, and intricate structure within RS in red.

There are many examples of belts that have changed their intensity, extent, and color in the interval 1965-70. E.g., the NTeB appeared orange in 1965, grey in 1966, broken in 1968, and hardly present in 1970.

North of the latitude of the RS, higher resolution photographs often show numerous light and dark spots whose lifetimes are on the order of weeks. From 1965 to 1970 the spots appear to have a higher frequency of appearance in the Southern hemisphere.

Photographs of Jupiter at 0.89μ show several distinctive characteristics attributed to differences in methane absorption above the clouds, since there are no important color changes on the planet in this part of the spectrum (*LPL Comm. No. 175*). The South pole shows a bright hood compared with the adjacent polar region, a much weaker hood is seen at the North pole, and the contrast of the bright zones against the rest of the planet is much greater than in the comparison images. We stress that the actual contrast between the bright and dark portions of the planet at 0.89μ is very great; it has been reduced here so that the full range of tones may be reproduced. Bright zones in the methane images are seen to correspond to bright zones in the comparison images; however, the relative brightnesses are not preserved. The North and South Tropical Zones are nearly always the most prominent zones in the methane images, and the Red Spot is the brightest feature. The limb darkening in the darker portions of the methane image appears to be greater than in the bright zones. In the higher-resolution methane images some of the dark festoons are resolved. It is uncertain whether their presence is a result of contamination by the continuum from the wings of the filter or if this accurately reflects the methane distribution. In the latter case the dark features must be lower than any other features observed in methane.

Acknowledgments. The planetary photography program with the 154-cm telescope was organized by Dr. Kuiper in 1965. He and D. Milon obtained the results during most of the first year. R. B. Minton produced the composites here published and participated in the observing program. Several other assistants contributed during shorter periods. The planetary photography program is supported by NASA Grant No. NGL-03-002-002.

REFERENCES

Camichel, M. H. 1946, "Le Developpement de la Station Astronomique de l'Observatoire du Pic du Midi", *l'Astronomie, 60*, 160.

Dollfus, A. 1961, "Visual and Photographic Studies of the Planets at the Pic du Midi", THE SOLAR SYSTEM (U. of Chicago Press), ed. G. P. Kuiper and B. Middlehurst, Vol. III, Chap. 15, pp. 534-571.

Humason, M. L. 1961, "Photographs of Planets with the 200-inch Telescope", *Ibid*, Chap. 16, pp. 572-574.

Kuiper, G. P. 1952, THE ATMOSPHERES OF THE EARTH AND PLANETS, (U. of Chicago Press), Chap. 12, Plate 12.

Lyot, B. 1943, "Observations Planétaires au Pic du Midi, en 1941", *l'Astronomie, 57*.

Lyot, B. 1953, "Photographies de Jupiter en 1945", *l'Astronomie, 67*, Figs. 1-6, 21.

Owen, T. C. 1969, "The Spectra of Jupiter and Saturn in the Photographic Infrared", *Icarus, 10*, 355-364.

Peek, B. M. 1958, THE PLANET JUPITER (London: Faber and Faber).

Reese, E. J. 1972, "Jupiter: Its Red Spot and Disturbances in 1970-1971", *Icarus, 17*, 57-72.

Slipher, E. C. 1964, A PHOTOGRAPHIC STUDY OF THE BRIGHTER PLANETS, (National Geographic Society and Northland Press).

Wright, W. H. 1929, "Photographic Observations of Certain Jovian Phenomena Reported by Messrs. Hargreaves, Peek, and Phillips", *MN, 89*, 703-708.