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PHOTOGRAPHS OF MARS AND OF JUPITER TAKEN BY LIGHT OF
DIFFERENT COLORS DURING 1926

BY

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This paper is a preliminary report on photographs of *Mars* and of *Jupiter* taken by light of different colors during the opposition of 1926. The observations are in continuation of some made of *Mars* in 1924 which are described in two earlier papers.¹ A general account of the purpose of the work will be found in these, so that it will suffice here to describe only the modifications in apparatus and observing procedure that were made for the present observations.

The most important of the changes is the addition of a number of colors to those used in 1924. Four were then used: ultra-violet, violet, orange, and infra-red; and of these the first and third were employed only occasionally, which left but two in systematic use. During 1926 six colors were regularly employed, so that the present series is, in that respect, more complete. The approximate wave-lengths of the colors, and the plates and filters by which they were isolated, are given in Table 1.

ally in the comparative study of the diameters of images rendered in the several colors, to have the plates as uniform in quality as possible, and to this end Dr. Mees had a special emulsion prepared, parts of which were sensitized separately, in the process of manufacture, with erythrosine (for green and orange), pinacyanol (for red) and kryptocyanine (for infra-red). Two separate treatments with erythrosine were adopted, one of which gives the maximum in sensitivity in the orange which is usually provided by this dye. The other gives a very remarkable extension from the ordinary region of sensitivity in the blue, which falls gradually to zero in the red. The emulsion prepared by the second of these processes was used exclusively in taking the "green photographs," and very largely in the orange. Ordinary erythrosine plates are perhaps better for the latter color, but it was more convenient, in observing, to use the others. The wave-lengths of effective sensitivity given in

TABLE 1

Wave-length (approximate)	Plate	Filter
3700	Eastman Special Process No. 4407 A	Chance ultra-violet glass
4400	Eastman Special Process No. 4407 A	Chance clear glass
5300	Eastman Process Green No. 4407 D	Chance green glass
5700	Eastman Process Green No. 4407 D	Chance orange glass
6500	Eastman Process Pinacyanol No. 4407 B	Selenium glass
7600	Eastman Process Kryptocyanine No. 4407 C	Selenium glass

The plates used were especially manufactured by the Eastman Research Laboratory under the direction of Dr. C. E. K. Mees, whose interest and cooperation in the prosecution of this work is acknowledged with the greatest pleasure. It seemed desirable, especially

column 1 of Table 1 are only approximate. The range in wave-length is quite wide for each color, except in the infra-red, where kryptocyanine provides a narrow, isolated maximum.

The filters used in 1926 were of colored glass, surfaced to a degree of excellence which is specified by opticians as grade A. The glass was supplied by

¹ *Lick Obs. Bull.*, 12, 48, 1925; *Publ. Ast. Soc. Pac.*, 36, 239, 1924.

Messrs. Chance Bros., of Birmingham, England, and the surfaces were worked by Hilger. The filters employed in 1924 were of the gelatine-in-glass kind popularly used in general photography. There were two reasons for making this change. One is explained on page 49 of the *Lick Observatory Bulletin* already cited; the other was that better color stability was hoped for in glass than is obtainable in gelatine, a matter of much importance where observations taken years apart are to be compared. In 1924 the filters were placed between the telescopic focus and the enlarging lens. In the present observations they were moved forward to a position within the telescopic focus—in the converging pencil of rays coming from the mirror. Ultra-violet photographs were made in the same manner as the others. It is believed that the absorption of ultra-violet light (of the wave-length used) by the small glass enlarging lens is not a serious matter.

In essentially all of the present observations standard intensity areas were photographed on the plates by light of the color used in making the picture. There are six of these areas, graded in intensity steps of 1:2, the total range provided being thus 1:64. A positive check on the contrast factor of each negative is therefore supplied, and means are at hand for the measurement of relative intensities of different parts of the planet's surface.

Except with respect to the changes indicated above, the observing technique was the same as that employed in the observations of 1924.

PHOTOGRAPHS OF MARS

The general purpose of the work in 1926 may conveniently be indicated in categorical form as follows:

I. The general development of the methods used in 1924, and further exploration of the field opened through their application. Under this head may be considered the employment of additional colors, and other matters referred to in the foregoing paragraphs.

II. The systematic observation of special phenomena observed at the earlier opposition.

These phenomena include:

- a) The dependence of diameter on color. The measurements here contemplated were of two kinds:
 - (1) The direct measurement of diameter on photographs taken in different colors, on plates as nearly uniform in quality as possible; and
 - (2) The determination of diameter by timed measurements of markings, to be reduced in conjunction with the

known period of rotation of the planet. This method was proposed in the earlier papers as an independent means of determining the diameter of the solid surface of *Mars*.

- b) The further interpretation of the impermanent configurations or markings found on the violet and ultra-violet photographs of *Mars*. For a description of these, reference may be had to the *Lick Observatory Bulletin* already cited. The restricted interpretation adopted in that paper is that the several types of configuration there described are cloud formations which differ in certain essential respects from terrestrial clouds.
- c) The investigation of the changes in form of the above described objects by cinematography.

* With respect to II (a), the dependence of diameter on color, it may be recalled that the observations of 1924 showed that *Mars* is photographed larger by violet and ultra-violet than by infra-red light. The explanation advanced was that the difference represented the thickness of the atmospheric shell, which was photographically recorded by short-waved light, but not by long-waved. The measurements necessary for the continuation of this branch of the investigation will take a great deal of time, and they have not yet been begun. The material available for the inquiry seems to be of reasonably satisfactory quality. The "seeing" for the opposition was, on the whole, very disappointing, especially near midnights, when the planet was in the best position for observation; and there was a great deal of cloudy weather. On the other hand the plates used were of uniform quality, as has been mentioned, and, profiting by the experience had in 1924, a "softer" developer was used, which very much reduces limb fading in the infra-red images, and makes them more suitable for measurement.

While there is nothing to report in relation to this important division of the work, it may not be out of place to refer here to two recently published observations of diameter. In a recent paper² Professor Frank E. Ross has given measurements of relative diameters of photographs of *Mars* secured in several colors, and has found inequalities similar to those referred to above. The other observation is by Professor R. J. Trumpler,³ who in his discussion of photographs of *Mars* taken in 1924, has determined the diameter of the planet's solid surface by the method mentioned above of timed measurements of the surface markings. He finds the diameter, as thus determined, to be appreciably smaller than that directly measured by the usual method, on photographs taken by yellow light.

² *Astrophys. Jour.*, **64**, 243, 1926.

³ *Lick Obs. Bull.*, **13**, 32, 1927.

The differences found by Ross and by Trumpler are of the same order of magnitude as those reported by me, and while the three observers will probably agree that it will be unprofitable to attempt a numerical comparison of the several results until the material for both oppositions shall have been fully reduced and discussed, there appears to be no reason to question that there is an excess in the diameter of *Mars* as photographed by short-waved light over the actual surface diameter. My own disposition is now, as formerly, to interpret this difference in terms of the atmospheric over-layer.

Item II (b) will be passed for the moment because it is treated in a later part of the paper.

Item II (c) relates to an attempt to secure "motion pictures" of the variable markings shown on the violet and ultra-violet photographs. These objects, severally referred to in the account of the 1924 observations as limb light, mottlings, blotches, and streaks, according to their appearance on the photographs, are subject to pronounced change during intervals of, let us say, an hour or more. It was believed that by taking photographs close together in point of time (three minutes was the interval adopted) the behavior of these peculiar things, as they formed, changed or dissolved in their daily journey across the illuminated disk of the planet, could be advantageously studied by the use of a cinema projector. A portrayal secured by this means of the brilliant clouds of mid October, especially on October 18 when they formed, or burst through the underlying envelope of haze shortly after noon, could not well have been other than fascinating and instructive. There are no technical difficulties in the taking of the photographs, and the period of approximately eight hours during which *Mars* was accessible for observation during this opposition lent some hope that such an undertaking might be successful. Three favorable factors are obviously required for the success of a night's run of these observations: the occurrence on *Mars* of fairly conspicuous objects to be studied, uniformly good seeing, and finally, uniformly transparent atmosphere during the night. As supplementary to the violet photographs, others (showing the surface markings) were taken in the infra-red, the purpose being to throw both sets on the screen, properly synchronized, so that the exact areographic position of every cloud or atmospheric peculiarity would be seen. Because of the approximate equality in length of the Martian and the terrestrial day the photography had to be repeated at intervals of about ten days in order to cover the planet. Furthermore the photographs had to be made as close to opposition as possible.

Many photographs were made with this end in view, I cannot say at present with what success. Suit-

able objects were, fortunately, common enough, but the seeing was seldom good, and clouds, which are to be expected in this locality in the fall, proved very annoying. Frequently, after two or three hours of painstaking work on the part of the observer, they covered the sky, perhaps to vanish in an hour, having spoiled the run of the evening's observations. Whatever the outcome of the cinema project, the photographs will retain their value as "stills." It is hoped that this method will prove useful in the study of some of the phenomena of *Jupiter* at the coming opposition.

While a complete report upon the observations can obviously not be made at the present time it will perhaps not be inappropriate to reproduce a few representative photographs. These will serve to show the general character of the material available for study and may, in addition, prove suggestive of some of the physical conditions existing on the surface and in the atmosphere of *Mars*.

Remarks on the illustrations relating to Mars (Plates VI, VII, and VIII). The methods used in making the prints which were provided the engraver for reproduction in half-tone are described under a separate head, since they relate to photographs of *Jupiter* as well as to those of *Mars*. It is quite essential to an understanding of the illustrations that these methods be understood.

The photographs in the upper two rows of Plate VI were taken during the evening of October 15-16, Mount Hamilton Civil reckoning. Those in the upper row are reproduced approximately in normal contrast, as photographed, except that the red image, No. 5, has, in the process of reproduction, been made a little strong. A fair idea of the natural gradation in contrast is had in the sequence, figures 4, 11, 3, 2, 6, 1. Due to the planet's rotation the photographs give somewhat different presentations (see column 7 of Table 2). In the second row, with the exception of figure 10, the same subjects are shown with some modification in the character of the reproduction. To be specific, figures 7, 8, and 9 are substantially repetitions in exaggerated contrast of the images directly above them, and are introduced for the purpose of bringing out more clearly the cloud on the left side of the planet. In 8 and 9 the picture has been completely sacrificed to this end. The cloud is not visible in red and infra-red pictures. No. 10 has been introduced principally to perfect symmetry in the arrangement of the cuts, and No. 11 as an illustration of the composition of several photographs, three in this instance (compare with No. 5, above). Figure 12, is a composite photograph in which three originals are combined in double contrast. This subject is, furthermore, diffusely printed in order to subdue photographic grain. As stated elsewhere a

number of different methods of printing are here being tried experimentally for the purpose of testing their respective merits for reproduction in half tone. The group of illustrations shows the progressive fading of the features which characterize the violet and ultra-violet images, on the one hand, and the development of the known features of the surface, on the other, as the wave-length of the light used in observation is increased. The phenomenon was fully described in the 1924 observations and need not be dwelt upon here. A curious feature of most of the violet and ultra-violet images, which was not then referred to but which persists in the photographs for both oppositions, is a wedge-like dark area extending inward from the terminator in the north temperate zone, which for these presentations is the winter hemisphere. The pairs: figures 13-14, 16-17, and the group of four at the top of Plate VII, provide records on other days of the cloud group shown in figures 1, 7, 6, and 12. These clouds were first photographed on the evening of October 13-14 (figures 13-14) and appear to have changed little in general character during the following two days. No photographs were taken on October 16-17, but a number were secured on the following night which are of exceptional interest because on that occasion the clouds formed shortly after noon. This was the fifth day after the clouds were first photographed, and in that time the lag in the daily rotation of *Mars* relative to that of the Earth brought the planet under observation several hours earlier by Martian time, and thus afforded the opportunity of observing, during the morning hours, the area in which these clouds occurred. The upper row of Plate VII consists of reproductions in exaggerated contrast of four photographs taken on October 17-18. In the second row the same photographs are diffusely printed. The first three do not record the cloud group in question. There are lighter cloud areas on the disk, but nothing in the position of the objects especially under consideration. The group is however very conspicuous on the fourth photograph. It is necessary to bear in mind, in comparing the pictures of this group, that the planet rotated approximately 60° between the first and last. The presentation of the planet in figure 4 is substantially the same as in figures 7, 13, and 16 of the preceding plate, as may be seen by consulting the central meridian longitudes in the last column of Table 2. In the paper already cited, Professor Ross has published some excellent photographs of this cloud group, taken on October 16. So far as one can judge from his illustrations, the cloud was much stronger after meridian passage than before, and it therefore seems not unlikely that it had just formed. Afternoon clouds are common enough on the Earth, especially in equatorial regions, and, while one hesitates to press the analogy too far, the

explanation in the more familiar case is so simple that it may stand in some relation to that in the other.

The cloudy region just described is without doubt related to the persistent equatorial cloudy area noted during the 1924 opposition as lying north of *Mare Sirenum* and *Mare Cimmerium*.⁴ A photograph of the region is given in Plate II, figure 6, of the earlier Bulletin. It is reproduced here in exaggerated contrast (Plate VI, figure 15) for comparison with the clouds of 1926. The areographic longitude of the center of the disk is 196° , as against approximately 130° for the photographs we have been discussing (or 160° for figures 6 and 12 of Plate VI), so that the clouds of 1926 lie farther to the west (in the direction of diminishing areographic longitude) though there is a considerable overlap. While the 1926 clouds were the stronger, the two cloud groups strikingly resembled one another in general appearance, and this taken in conjunction with the proximity of their locations can be taken as evidence that they are closely related in origin and development. However, the one of September 21-22, 1924, extended clear across the illuminated disk, and could therefore not have been an affair of the afternoons only.

The three pairs of images, Plate VII, figures 9 to 14, show cloud forms over various parts of the planet. Figures 5 and 9 present almost the same face, 5 showing it turned 8° farther toward the left. Figure 9 shows one vertical and two horizontal streaks on the left half of the image. The vertical one is perhaps that seen in figure 5, which can be traced, with some alterations in appearance due principally to perspective, in figures 6 and 7, as it is carried over by the planet's rotation. The crossed cloud streaks of figure 9 are of interest by reason of their complexity. Crossed cirrus clouds are familiar enough on the Earth where they are separate objects at different atmospheric levels. I am not sure that the relation between the Martian objects and terrestrial clouds is sufficiently close to make this comparison a significant one.

The foregoing comments refer to the objects, interpreted as clouds, which are conspicuous in the violet photographs and fade to invisibility in the red. Figure 15 shows a temporary object of a very different kind. The presentation shows the *Syrtis Major*. By turning the plate so that the rows are vertical (the ordinary reading position of the paper) it will be seen that this cut provides a fair representation of a deer's head. The purpose in suggesting the resemblance is not altogether frivolous, for the anatomy of the suggested animal provides a system of reference in the discussion

⁴ In one of the references to this cloud it was mistakenly referred to as being close to the equator and south of these *maria* (*Lick Obs. Bull.*, 12, 61, ¶5). The *maria* in question are in the southern hemisphere, so the error in direction is obvious, especially as a photograph of the object was given.

of special features of this part of the Martian surface which is at once unambiguous and free from the rather forbidding nomenclature of areography. The marking to which it is especially desired to call attention is the white spot directly in front of the deer's throat. This is a temporary feature observed only on the evening of November 1-2. My attention was drawn to it by Dr. Trumpler who was observing *Mars* with the 36-inch refractor, and whom I visited on the way to my instrument. In the telescope it was the brightest part of the planet, at least equaling the polar cap, but it was decidedly yellow—as nearly as one could tell of the same color as the brighter areas which give the characteristic color to *Mars*. It is unquestionably the same sort of object as has repeatedly been seen and described by observers with the telescope. The three photographs, 15, 16, and 17, were taken consecutively. No. 17 is by orange light. The quality of the picture is poor, but the spot is shown near the limb, and is thereby proved to have been on the visible disk when the ultra-violet photograph No. 16 was taken. That photograph shows not a trace of the spot. This observation duplicates in all essential respects one by E. C. Slipher of the great temporary marking of July 9, 1922. In that instance the marking photographed well in orange light, but was lost in the blue image. The mobility and change in appearance of Slipher's object leaves little doubt that his interpretation of it as a cloud of some kind is correct. After the color reaction of the object of last November had been detected, Trumpler, from a comparison of photographs taken by both of us in 1924, found a number of similar instances, and has reported them in his recent paper.⁵ *Mars* therefore seems to present to us clouds, or impermanent markings, of two classes:

- I. Those which are visible by light of short wave-length, and become gradually invisible as the wave-length of the observing light is increased, and
- II. Those which are visible by light of long wave-length and fade into invisibility when the wave-length of the viewing light is decreased.

The observational basis for Class II is somewhat fragmentary, it must be admitted, but it seems fairly secure. There are three cases supported by photographic evidence (the only cases in which such evidence appears to be available), and there is the corroborative fact that observers consistently report the temporary areas of great brightness as being yellowish in color. Objects of the kind designated above as Class I, when they have been bright enough to be seen in the telescope, are described as white, or greenish white.

⁵ *Lick Obs. Bull.*, 13, 43, 1927.

Clouds of Class I, which will be referred to as "blue" clouds, are shown in substantially all of the violet and ultra-violet photographs accompanying this paper. The object at the "deer's throat" in figure 15 of Plate VII had the color reaction of a yellow cloud, and probably was one.

Returning to a consideration of the illustrations, Plate VII, figure 18 is a photograph, of unsatisfactory quality, taken on the night of November 2-3. It is reproduced merely for the purpose of showing that the bright spot of the day before had disappeared. Figure 19 is the violet counterpart of 18, while 20 is essentially a reproduction of 19 in heightened contrast. Attention is especially called to these two photographs because there is a certain similarity between 18 and 19, which when first noticed led to the belief that the latter recorded very dimly the image of the *Syrtis Major*. The exaggerated contrast provided in figure 20 makes it clear that the resemblance is due in part to a large cloud⁶ which outlines approximately the deer's forehead and forward antler, and there is little resemblance between figures 18 and 20 in the general region of the south pole. The dark area extending from the middle of 20, in a direction upward to the left, probably corresponds with the somewhat similar one in 18. In describing the 1924 observations the statement was made that surface detail had not been photographed by violet, that is to say, by unscreened light. Commenting on this, Professor Pickering recalls⁷ that the *Syrtis Major* and some of the other markings are recorded on a few of the photographs taken by him in 1888 and 1890. Professor Ross in his recent paper also reports that surface features are dimly seen on unscreened photographs. I believe that traces of these markings are to be found on unscreened pictures of the present series taken between October 23 and November 9, 1926, though interference by "blue" clouds makes the observation difficult in any one instance. This interval included the date of opposition, November 4, and the conditions for seeing the surface were then probably more favorable than at any other time. Judging from their descriptions of their plates the observers mentioned appear to have less difficulty than I in seeing surface detail on unscreened photographs, and this is probably to be attributed very largely to the fact that my photographs were made almost exclusively on plates quite insensitive to the blue-green region of the spectrum, namely: "Eastman Lantern Slide" and "Eastman Process" plates. Possibly cloud formations have, on occasion, provided the basis for resemblance to surface features, as in figure 20. However that may

⁶ Figures 11 and 19-20 are in longitude nearly 180° apart, so that the cloud on the left of figure 11 has approximately the same areographic position as the one appearing at the lower right side in 19-20.

⁷ *Pop. Astron.*, 33, 437, 1925.

be, the question of visibility or invisibility of surface markings on ordinary "violet" or "blue-violet" photographs can hardly be one of great consequence, because they can be plainly photographed by green light (Plate VI, figure 2), and very probably have not been photographed by ultra-violet light. Blue-violet would appear to be the limiting color by which they can be observed.

Plate VIII is devoted to a number of miscellaneous illustrations. The photographs in the upper row are a few shown in Plate VI, further enlarged as an experiment in scale of reproduction, to determine whether the increase in size would be of advantage. Figures 1 of Plate VIII and 12 of Plate VI are identical, except that the latter is diffusely printed. Figure 2 of Plate VIII matches 11 of Plate VI, and 3 of Plate VIII, 16 of Plate VI, except that VIII 3 is diffusely printed. The large pictures do not appear to possess especial merit. Figures 4, 5, and 6 depict the *Syrtis Major* at three separate oppositions. No. 4 was taken by Barnard at the Yerkes Observatory with the use of a yellow, or orange, color screen,⁸ and is here reproduced through the courtesy of Director Frost of the Yerkes Observatory. While figure 4 was made by light of a different color than that used for the other two, the very great differences shown undoubtedly represent actual changes of a kind that have generally been recognized as seasonal. Referring to the stag-head configuration in figure 5, the back part of the neck is much fuller here than in figure 4, and the "beard" (if one may take so great a liberty with the facts of natural history) is better developed. In these respects figure 6 shows an intermediate condition. However, in 6 one antler, strong in the other two photographs, is extremely faint. The bright spot at the throat in figure 5 is a temporary feature referred to elsewhere. Except with respect to the latter feature these seem all to be recognized seasonal changes, and the photographs are given merely as immediate illustrations of the well-known fact, to which there will later be occasion to refer, that changes do take place on the planet's surface.

Interpretations. In the two earlier papers to which reference has been made there was proposed a general explanation of the outstanding phenomena exhibited by such photographs as these, based on the assumption that *Mars* possesses an atmosphere of considerable absorbing and light scattering power.⁹ There is no occasion to repeat the arguments there presented except in regard to an aspect of the interpretation on which light has been shed by the detection of the two classes of clouds, or impermanent markings, described above. The matter I have in mind has to do with the sugges-

tion that the non-appearance of the well known surface markings, in photographs taken by violet and ultra-violet light, is due to the chance matching in reflectivity in those colors, of the substances which compose the Martian surface. This hypothesis was considered in both of my early papers, and perhaps I may be permitted to write in a quotation from one of them:¹⁰

"The violet pictures from their very uniformity offer a startling contrast to the lively presentation made by those taken in the infra-red. In seeking for an explanation of this great difference, two possible hypotheses naturally occur to one. The first is that the several materials of which the surface of *Mars* is composed, while they have very different reflectivities for infra-red light, may have equal reflectivities for light of the violet end of the spectrum. If that were true the violet images would, of course, present no contrasts whatever. The second is that the atmosphere, the existence of which we have inferred from the edge effect of the infra-red photographs, may be obliterating the details. With respect to the first of the proposed explanations we recall that differences in relative reflectivity of substances, corresponding to the several parts of the spectrum, are common enough, and furnish, in fact, the basis of color in ordinary objects. It would, therefore, be physically possible to have a number of materials that would stand out in contrast when viewed by light of one wave-length and could not be distinguished by that of another. Arrangements of the sort can be made artificially, but they are not to be expected in nature. We may photograph a landscape by red and by violet light and the relative values will, in general, be different in the two pictures, but there will be contrast in both pictures though it may be differently distributed. The chance that for a single region of the spectrum the intensities of all the elements of the picture would match exactly seems remote.

"Nevertheless it has been urged in personal conversation that the possibility of the surface of *Mars* being composed of only two kinds of material should not be overlooked, and that if it were, the probability of a chance matching by violet light would not be negligible. * * * * There is nothing in the observations to exclude the possibility implied in the above suggestion. On the other hand I can think of no good reason for assuming that there are exposed on the surface of *Mars* only two materials and that they match in ultra-violet light. Photographs of *Jupiter*, *Saturn*, the Moon, and the Earth's surface show contrast and detail quite as well by violet as by infra-red light of the wave-length used in these observations. On the whole the first of the alternative explanations advanced to

⁸ *M. N. R. A. S.*, **71**, 471, 1911.

⁹ See especially *Lick Obs. Bull.*, **12**, pp. 57 to 60.

¹⁰ *Loc. cit.*, p. 57.

account for the quality of the violet images hardly seems a probable one."

With respect to the suggestion that there are only two different kinds of substance on the Martian surface, let us consider the bright spot of November 2 (Plate VII, figure 15) and assume that *Mars* has an atmosphere of high transparency to light of all colors, a premise that has been entertained by those who question the adequacy of the theory of atmospheric obliteration as an explanation of the flatness of the short-wave photographs. The spot may have been a surface marking or a cloud. It has been suggested that such objects are dust clouds, and that they derive their color from the surface material from which they originate. This does not appear to be a tenable assumption. Dust which is sufficiently fine to float in the atmosphere is visible by scattered light,¹¹ and that fact determines its color, which will have a considerable bluish content. The Martian object was yellow, and could not be photographed by light of short wavelengths. It could not, therefore, have been a cloud of fine dust. If the dust is coarse enough to show its color, and is kept afloat by whatever process one wills, the particles will be large enough to intercept light, since color is a residual phenomenon of absorption. A cloud of such small bodies constitutes a fairly effective light trap, and if sufficiently dense or extensive to cast a black shadow, may readily be shown to reflect only half of the light which would be sent back by a solid surface of the same material, unless the cloud be, in the strictest mathematical sense, at opposition,¹² when the reflectivity will approach that of the solid surface. In no case, however, could reflectivity of the kind we are now considering equal that of the surface. This object was, however, *brighter* than the brightest part of the surface. It could not therefore, have been a dust cloud composed of particles of the surface material sufficiently large to confer their natural color. We have considered two cases, the one of dust sufficiently fine to scatter light, the other of dust sufficiently coarse to show its natural color, and find that neither of these will fit the observed facts. There remains the possibility of dust of intermediate size. While this is a condition not so easy to discuss in a qualitative way, I think we may, without serious danger of error, consider the light returned by such material as made up of two parts: that which is reflected or diffused

as colored light, and that which is returned as scattered light. The same considerations refer to the diffused light as before; it cannot equal in strength the light from the surface. If the brightness of the cloud is greater than that of the surface, as it is observed to be, the extra light necessary to make it so must be the contribution of the returning beam which is due to scattering. Now there is an excellent reason for believing this not to have been the case with the object observed. The component of the returned light which has its origin in scattering would necessarily be relatively strong in the spectral regions of short wavelength, and could be regarded as negligible in the infra-red. If it were sufficiently strong to add materially to the visibility of the cloud by yellow light, and make the cloud appear brighter in that color than the surrounding surface, we should expect a considerable increase in the blue content of the cloud light, while in the infra-red, assuming negligible scattering, the cloud should appear darker than the surface. As a matter of fact the object could not be seen on ultra-violet photographs, and was bright and more conspicuous on the infra-red than on the yellow (or orange) photographs. If the above analysis is correct, the object could not under the assumption of a homogeneously transparent atmosphere, have been a dust cloud.

Let us now assume that the spot was actually on the surface. In that case it could hardly have been composed of the permanent surface material for two very obvious reasons: it did not stay there, and it was brighter than any other part of the surface. It seems difficult to escape the conclusion that in addition to the two hypothetical materials on *Mars*, the dark and the light, we had for a while at least a third, and this had the same peculiarity which characterizes the other two: it was easily photographed by long-waved light and faded out in light of short wave-lengths. But is there any valid ground for limiting our assumption to three substances on the Martian surface? Consideration of changes, probably seasonal, such as are reported by essentially all observers, and are illustrated in figures 4, 5, and 6 of Plate VIII, certainly suggests a wealth of variety in the material exposed to our view. With the spectroscope proclaiming the distribution of the chemical elements throughout the universe, the assumption that a surface, so subject to alteration as that of *Mars*, possesses a limited number of their combinations, and only those which have the same reflective action on violet and ultra-violet light does not seem especially attractive. One is therefore disposed to discard the explanation that the flattening out of detail in the violet and ultra-violet photographs of *Mars* is due to a chance matching in reflectivity at those colors of all the materials of which *Mars* is com-

¹¹ This should be especially true with respect to *Mars* because of the low surface gravity of the planet. The density of the supporting atmosphere varies with gravity, but the density of a solid particle remains constant. Dust of a size that floats in the Earth's atmosphere might therefore be expected to sink if the force of gravity were reduced.

¹² This happens to have been pretty nearly the case when the spot referred to was seen, the planetocentric angle between the Earth and Sun being, at the time, about 2°. But the argument relates equally well to the cloud of July 9, 1922, when this condition did not obtain.

posed, and to accept the obvious alternative that it is the effect of an overlying atmosphere.

Let us now revert to the temporary yellow markings, and consider specifically the one of July, 1922. The color of this object is variously described as "creamy white" and "yellow." Because of its changes in form and its mobility, the object in question was interpreted by W. H. Pickering, E. C. Slipher, and no doubt others as a cloud. Slipher photographed it by yellow-light, but it was invisible in his photographs taken by blue. In this respect it paralleled the behavior of the temporary yellow spot of November 2, 1926, referred to in preceding paragraphs, and we shall assume that the color reactions of the two objects were similar throughout the spectrum. There appears to be little reason to doubt that both of these objects are examples of the "yellowish clouds" which, though they are not usual features of the telescopic view, have in the course of years frequently been seen by all systematic observers of *Mars*. Therefore, while the following comments are made with the cloud of July, 1922, especially in mind, and under the assumption with respect to its color just stated, it is believed that they refer equally to all of that class of temporary yellow markings whose general behavior permits of their interpretation as clouds.

For reasons which have been sketched in previous paragraphs we shall assume that this object was not a dust cloud. If it was not that, what was it? So far as we can estimate probabilities in such a matter on the basis of terrestrial experience, I think we must regard as reasonable the assumption which observers of *Mars* seem usually to have made with respect to similar objects, that it was an aqueous cloud. The temperature of *Mars* appears to be favorable to this assumption. We shall therefore, for the purpose of getting on with our interpretation, take the ground that this was an aqueous cloud. Now aqueous clouds as we know them, are white, and it is hard to understand how one could appear yellow, unless it were viewed through the equivalent of a yellow screen. The implication of this comment is that the atmosphere of *Mars* is not homogeneously transparent to light of all colors, but that it has optical properties which make it the equivalent of such a screen.¹³ The yellowness cannot be due to selective absorption in the upper (shorter wave-length) part of the visible spectrum, because the

¹³ Until this paper was practically ready for the press I did not know that Professor W. H. Pickering had offered such an explanation of the yellowness of Martian clouds. This was due entirely to my own negligence. The reference was caught in a search for a description of the color of the polar caps, undertaken in relation to a later part of this paper (see footnote 18). The explanation is such an obvious one that it must have occurred to others besides Professor Pickering. The possibility of a "yellow" atmosphere was also suggested in my paper of 1924. It has seemed best to let the present phrasing of the text stand, and make the acknowledgment to Professor Pickering in this way.

line absorption of *Mars* is, so far as has been found, a replica of that of the Sun. The only available explanation is in terms of a progressively increasing general absorption in the direction of shorter wave-lengths. Since several of the phenomena presented by color photographs of *Mars* have suggested a similar property on the part of its atmosphere, it seems worth while to entertain the suggestion, tentatively at least, as an hypothesis, for the purpose of inquiring whether it is capable of explaining any of the other curious things which the planet presents for our interpretation.

It is well at the outset to emphasize the seriousness of the assumption of this property on the part of an atmosphere. Such an hypothesis, as suggested in an earlier paper, has been criticized by a number of astronomers, notably Menzel,¹⁴ as not being a consequence of the phenomenon of light scattering which is usually taken to explain the yellow screening effect of our own atmosphere when, for example, we observe the Sun through it. It was pointed out by Langley that the Earth's atmosphere causes the Sun to appear to us yellower than it is, and a yellow tinge is consequently imparted to the landscape. This is relieved to a certain degree by blue illumination from the sky, though, since the latter undoubtedly returns blue light to space, the net effect on the color of the landscape, as seen by the terrestrial observer, is still yellow. An observer outside the atmosphere would see the blue sky projected against the landscape, and Menzel, by assuming that there is no true absorption in the atmosphere (as distinguished from depletion by scattering), shows that the net result should be to make the landscape appear, to such an observer, bluer than it actually is, not yellower. In order for the atmosphere to impart a yellow tinge it would seem necessary that it possess absorptive properties for which he is unable to account. Dr. Menzel's paper and others on the subject¹⁵ are undoubtedly valuable contributions to the theory of planetary atmospheres, and help in putting to rights certain matters of cause and effect, but they deal with the subject in an academic manner, and make use of assumptions which one does not feel sure are justified either by the state of our understanding of light scattering, or that of our knowledge of conditions to be expected in the atmosphere of a planet. In fact it seems questionable whether our present knowledge of the optical properties of atmospheres is sufficiently well grounded to serve as the basis of exact quantitative predictions of what will or will not occur under conditions which have not been realized, approximately at least, in observation. In taking this view I am perhaps not uninfluenced by the historical fact that the principal optical properties of the Earth's atmosphere,

¹⁴ *Astrophys. Jour.*, **63**, pp. 48 and 58, 1926.

¹⁵ See also a paper by Fessenkoff, *A. N.*, **228**, 25, 1926.

1 Ultra-violet

2 Green

3 Orange

4 Red

5 Infra-red

6 Violet

7 (High contrast)

8 (High contrast)

9 (High contrast)

10 Infra-red

11 Red

12 (High contrast)

13 Ultra-violet

14 Violet

15 Violet

16 Ultra-violet

17 Violet

1926 October 14

1924 September 22

1926 October 15

Photographs of *Mars*

1 5^h 57^m

2 7^h 40^m

3 8^h 3^m

4 9^h 51^m

5 Violet

6 Ultra-violet

7 Violet

8 Violet

October 18

9 Violet

10 Infra-red

11 Violet

12 Red

13 Ultra-violet

14 Infra-red

October 20

November 17

15 Infra-red

16 Ultra-violet

November 2

17 Orange

18 Infra-red

19 Violet

November 3

20 Violet (High Contrast)

Photographs of *Mars*, 1926

VOL. XIII

PLATE VII

L. O. BULLETIN

1 Violet
1926, October 16

2 Red
1926, October 16

3 Ultra-violet
1926, October 15

4 Orange
1909, September 29

5 Infra-red
1926, November 2

6 Infra-red
1924, September 12

Photographs of *Mars*

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PLATE VIII

L. O. BULLETIN

1 Ultra-violet

2 Violet

3 Green

4 Orange

5 Red

6 Infra-red

7 Infra-red

8 Infra-red

(Exaggerated contrast)

9 Ultra-violet

10 Infra-red

October 14

October 18

11 Violet

12 Infra-red

October 20

13 Ultra-violet

14 Infra-red

October 22

Photographs of *Jupiter*, 1926

1 ultra-violet

2 green

3 orange

4 red

5 infra-red

6 violet

7 [high contrast]

8 [high contrast]

9 [high contrast]

10 infra-red

11 red

12 [high contrast]

1926 October 16

13 ultra-violet

14 violet

15 violet

16 ultra-violet

17 violet

1926 October 14

1924 September 22

1926 October 15

Photographs of Mars

VOL. XIII.

PLATE VI.

L.O. BULLETIN

4 9^h 51^m

3 8^h 3^m

2 7^h 40^m

1 5^h 57^m

8 violet

7 violet

6 ultra-violet

5 violet

October 18

14 infra-red

13 ultra-violet

12 red

11 violet

10 infra-red

9 violet

November 17

October 23

October 20

20 violet
[high contrast]

19 violet

18 infra-red

17 orange

16 ultra-violet

15 infra-red

November 3

November 2

Photographs of Mars 1926

PLATE VII.

L.O. BULLETIN

VOL. XIII.

1 violet
1926, October 16

2 red
1926, October 16

3 ultra-violet
1926, October 15

4 orange
1909 September 29

5 infra-red
1926 November 2

6 infra-red
1924 September 12

Photographs of Mars

VOL. XIII.

PLATE VIII.

L.O. BULLETIN

1 ultra-violet

2 violet

3 green

4 orange

5 red

6 infra-red

7 infra-red
[exaggerated contrast]

8 infra-red
[exaggerated contrast]

9 ultra-violet

10 infra-red

October 14

11 violet

12 infra-red

October 20

13 ultra-violet

14 infra-red

October 22

Photographs of Jupiter 1926 PLATE IX.

excepting refraction, have been discovered, not through deduction and prediction from well established physical laws, but in spite of such ratiocinative processes. Knowledge of these properties has on each occasion come as a surprise, and in order to account for them, theory has had to be improved, or special assumptions made with respect to the constitution of the atmosphere. To illustrate, let us recall that the peculiar polarization of skylight observed by Tyndall was in his opinion out of harmony with the theory of polarization by reflection. After its detection the phenomenon was explained by Rayleigh. Another case is the opacity of the upper air to light of wave-length less than λ 2900. This would never have been suspected from known phenomena of the atmospheric region to which we have access. We explain it now by a layer of ozone at unexplored altitudes. Consider finally that remarkable property of the atmosphere which permits the transmission of signals, and of speech, over large areas of the curved surface of the Earth, through the agency of electro-magnetic radiation. Those who derive pleasure or profit from the art based on this property do so, it is said, by virtue of a layer of ionized gas inconveniently (or perhaps that is not the correct word) located in a region which forbids its being made the subject of direct study. Perhaps when we have more light on such matters as these, and can explain, among other things, the strong absorption phenomena in the spectra of the major planets, we shall know enough about atmospheres to support fairly secure inferences as to what a planet enclosed by one ought to look like from the outside. These comments are regarded as applying to all theoretical discussions of atmospheres, including the present one. Until such a time as we have a better understanding of such matters, conjecture, or plausible explanations of what we see, would seem to be permissible even though they may appear to run counter in some respects to the apparent implications of incompletely understood laws acting in assumed environments.

We shall admit that the hypothesis of an atmosphere with relatively great absorbing power for light of shorter wave-lengths requires further study in relation to its physical probability, but there can be no harm done if, in the emergency, we ticket it for consideration at some future time, and proceed to follow up some of its consequences. If these prove to be sufficiently consistent with phenomena observed on *Mars*, zest will be lent to an investigation of a possible property of its atmosphere which might otherwise seem of no especial consequence. Suggestion respecting a possible constituent of the atmosphere which might confer such a property is purposely avoided.

To sum up, the suggested hypothesis permits a qualitative explanation of:

1) Why the albedo of *Mars* in blue and violet light is low for a planet having so extensive an atmosphere as that indicated by the inequality in size of the violet and infra-red images. We get the light principally from the upper atmosphere. Incident light is reduced in strength on its way in, and being scattered at depth is again subject to absorption on its way out.

2) Why surface details cannot be photographed by light of the shorter wave-lengths.—That light is heavily absorbed and the little which is returned from the surface is masked by light scattered at high levels of the atmosphere.

3) Why the brighter parts of the surface (which give the planet its characteristic color) appear yellow.

4) Why the dark areas appear bluish green.—The areas are dark because they reflect little light of any kind. We therefore see the Martian sky projected upon them. Our own sky is blue, and would, presumably, appear that color from without if projected against an absolutely black area. But with such an atmosphere as has been assumed for *Mars* rays of somewhat longer wave-length would penetrate farther and therefore provide an effectively greater "thickness" of sky. This would displace the effective color toward the green. Furthermore it is not likely that the dark areas of *Mars* are absolutely black. By our assumption they probably return a small amount of light, which, by the time it reaches the outer atmosphere of the planet, may be assumed to be yellowish. This should effect an additional alteration of the sky color in the direction of longer wave-lengths, and emphasize the green tinge. The dark markings are subject to alteration in strength (a number of instances have already been referred to and are illustrated in Plate VIII). By such changes the content of yellow light from the planet would be altered, and the apparent color of these markings changed. Variation in the color of these markings has been reported, and is conceivably due to this cause; in fact a test of this explanation might be made by comparing observed color changes of a marking with changes in its strength. The darker the marking, the bluer one would expect to find it. Clouds, as a possible source of interference, would of course have to be considered in such a test, as every observer knows. It seems not unlikely that there are records of observations which might bear on this question. It is, of course, impossible to say whether the cause here suggested of the color is complete or contributory. That the effect of the Martian skylight on the color of the dark areas is far from negligible follows from the assumption made in this paper that the blue-violet photographs are due in greater part to the atmosphere. From this point of view most of the blue content of their light, which must unquestionably affect their apparent hue, is

atmospheric. The difficulty is not in accounting for as much blue light as is seen, but in explaining why there is not more of it if the atmosphere is so extensive as we are assuming it to be. To what extent the undoubted greenish cast of the markings may have its origin in the considerations sketched above it is impossible to estimate, especially in the absence of numerical photometric data. Their color is of especial interest in view of the fact that they are very commonly interpreted as areas covered with vegetation. The more critical observers of *Mars* appear to have recognized the influence of Martian skylight on the color of the markings, but the magnitude of the effect has, perhaps, not generally been appreciated. While there is, of course, nothing here to suggest that the markings are not actually green, it seems likely that their appearance to us is determined, very largely at least, by the atmospheric veil.

5) Polar caps. It may well be asked why the polar caps do not look yellow, since they are on the surface and are, as well, observed through a great thickness of this hypothetical yellow atmosphere. The explanation is that the caps are shown by photographs taken by violet and ultra-violet light to be surrounded by a halo, which is visible also by light of a somewhat less refrangible part of the spectrum. When the surface cap, as photographed by infra-red light, is absent, or extremely small, this halo is faintly visible in the orange photographs, and becomes progressively stronger in photographs of shorter wave-length. In partial verification of this see Plate VI, figures 3, 2, 6, 1 in order. There was at the time these photographs were taken an extremely small cap on infra-red images, but because of its eccentricity (with respect to the planet's pole) the presentation on figure 4 is unfavorable for showing it. However on 6 the presentation is still more unfavorable, but the halo shows plainly. What is here called the halo was referred to in the earlier papers as the "atmospheric cap," but the term halo has been adopted as both less awkward and more appropriate. The yellow of the surface cap is corrected by the bluish light of the halo, and produces the impression of white. In my own limited experience in the photography of *Mars* the south pole only has been in position for observation and the halo has persisted even when no record of a cap could be found on the infra-red images, that is to say, when the surface-cap was presumably not present, or was at least extremely small. Under such circumstances one would expect the color of the object seen in the telescope to tend toward blue. That a halo is not always present is shown by some photographs obtained in violet light by W. H. Pickering during the oppositions of 1888 and 1890.¹⁶ Some of these show no polar whitening,

¹⁶ *Ann. Harv. Obs.*, **53**, 170, 1905.

that is to say, under the interpretation here adopted there was, at times, no halo. Had a surface cap existed under such circumstances it might have been expected to appear yellow, and generally speaking the apparent color of the cap would depend on the relative brightness of cap and halo. In this connection we are able to quote a terse description of the appearance of both caps and clouds by Professor Pickering:

"For some unknown reason the clouds of *Mars* are always of a light yellow color, while the planet's poles are sometimes yellow, sometimes pure white, and sometimes a light but vivid green."¹⁷

And later:

"On *Mars* the clouds are distinctly yellow, as has been noted by many observers. Dr. Lowell even went so far as to describe them as dust clouds. Nevertheless they are of all grades of whitish yellow and yellowish white. On rather rare occasions they appear to be as white as our own. The polar caps never appear as white as snow near at hand, although whiter than the snow upon distant mountains."¹⁸

There seems to be enough variation in the color of the cap as observed by this indefatigable student of *Mars* to allow for a great range in relative intensity of cap and halo. The green color mentioned by Pickering would be explained by the dominance of the halo, the yellow by that of the surface cap. Should a yellow cap again be observed it would be well worth while to take photographs of it by violet, and if possible by red or infra-red light. The explanation of color here given would be substantiated or disproved according as the halo were weak or strong.

The presence of the polar halo seems to be quite positively established by the color photographs, but it is of interest to note that it affords an explanation of, and is therefore corroborated by, some observations relating to the color of the cap. As is generally known, the south polar cap is eccentrically situated, and is consequently carried to and from the limb by the rotation of the planet. The travel, at the two past oppositions, has been between limits of approximately 10° and 23° from the limb. When near the limb the cap, as photographed by infra-red light, becomes relatively faint; by violet light it suffers slight diminution, but not nearly so much as by infra-red. Trumpler has recently remarked upon the same effect in respect to photographs made by red and orange light.¹⁹ On approach to the limb the decrease in visibility is greater for the red than for the orange cap. In other words, as the cap approaches the limb the "effective wave-length" of its light becomes smaller; as it sets it gets "bluer." This is to be explained by the fact that the halo, which contributes the light of shorter wave-lengths, is high in the atmosphere, and its visibility does not suffer commensurably with that of the

¹⁷ *Ibid.*, p. 155.

¹⁸ Report on *Mars* No. 30. *Pop. Astron.*, **33**, 439, 1925.

¹⁹ *Lick Obs. Bull.*, **13**, 43, 1927.

surface cap, which must be seen through a greatly increased atmospheric thickness. It would be rather difficult to explain these observations on the assumption that the polar cap of *Mars* consists of a surface layer only. In order to do so it would seem necessary to invert our hypothesis regarding the absorption characteristics of the atmosphere and assume its transparency to be greater for violet than for red light. This would lead us to insuperable difficulties elsewhere. The change in relative strength of red and blue photographs is so marked that it seems likely the alteration in color would be perceptible to the eye. It would probably best be seen with a cap sufficiently small to clear the pole (12° in diameter) and yet large enough to insure that the surface cap (which appears to be smaller than the halo) would contribute a substantial share of the total light. The observation should be made when there is no interference from limb light (as in figure 14 of Plate VI). Possibly observations of this kind are already available. At the next opposition (1928-29), the south pole of *Mars* will be close to the limb, and the polar cap, if present at that season, will be carried over the edge: it will actually rise and set. It will be important to observe its color changes and record its visibility under these conditions.

6) Clouds. The clouds belonging to Class I described above (blue clouds) are interpreted as being due to finely divided material condensed out of the upper atmosphere. The particles of which they are composed must be smaller than the water droplets, or ice crystals, as the case may be, of terrestrial clouds because they appear to be visible by scattered light. The drops or crystals in terrestrial clouds refract and reflect light, and are altogether too large to serve as scatterers; consequently terrestrial clouds have a high reflectivity for light of all colors, including red light. The reason for believing the light of Martian clouds of Class I to be due to scattering lies in their high and progressively increasing visibility by light of short wave-lengths, and their seeming transparency to infra-red light. A position near the surface of the atmosphere is assigned to them because they are photographed by light to which the atmosphere is regarded as relatively opaque. When they are exceptionally bright, as they were, for example, during October, 1926, they are visible in the telescope, and are undoubtedly the rare "white" clouds mentioned by Pickering. As a matter of fact these clouds are not rare in their occurrence, they are frequently photographed, but, on account of their color, they are not easily seen. They are rarely bright enough to be seen in the telescope. The clouds observed by E. C. Slipher in the spring of 1920²⁰ appear from his general description of them to belong to this class.

²⁰ *Pop. Astron.*, 29, 69, 1921.

Clouds of Class II. Yellow clouds are, according to this system of explanation, comparatively low lying affairs. They are regarded as aqueous clouds, like those of the Earth. It ought not, however, to be assumed that they occur invariably at the same level. The higher of them would be seen through less atmosphere, and might therefore be expected to appear lighter in color. This would account for the observed variations in shade reported by all observers. The difficulty in photographing them by violet light is occasioned by the assumed absorptive properties of the atmosphere.

In the foregoing paragraphs I have attempted to formulate a hypothesis suggested by the observed color of Martian clouds, and to sketch some of its consequences. In discussions of this kind one is frequently forced, in order to avoid the embarrassment of continual qualification, to treat assumptions as though they were facts, and an impression of assurance is sometimes conveyed which does not truly reflect the outlook of the author. It is a source of great regret to me that it is not possible at this time to apply numerical tests to some of the explanations offered in this paper. Qualitative reasoning, uncontrolled by quantitative check, is notoriously treacherous. It is hoped that photometric measurements of the photographs will eventually provide data of the kind desired. By measuring the visibility of a marking in its travel across the disk, information bearing on the amount of diffusion and absorption by the planet's atmosphere should be yielded. For this purpose the cinema pictures, taken at three-minute intervals throughout the night, may be of value. It would have been my preference to reserve comment on this whole subject until a digest of all of the available material had ripened it for discussion; but that would have occasioned a very great delay, and it is believed that the photographs possess a general interest, which warrants their prompt publication. Having decided to present them, it is difficult to avoid mentioning some of the obvious, and more or less plausible interpretations which differences in registry by light of different colors suggest.

METHOD OF MAKING THE PHOTOGRAPHS OF MARS AND JUPITER FOR ILLUSTRATION

The photographs were taken with the Crossley reflecting telescope, to which was attached an enlarging camera having an amplifying factor of approximately 5.4. The arrangement is the same as that previously described.²¹ The size of the image of *Mars*, at closest

²¹ *Pub. Ast. Soc. Pac.*, 36, 239, 1924; *Lick Obs. Bull.*, 12, 48, 1925.

approach for the opposition, is 2.7 mm. and of *Jupiter*, at the time of taking most of the photographs, 5.7 mm. The further enlargement to the scale of the illustrations was secured in copying. Positive copies were made from the original negatives and secondary negatives were taken from these, in some instances by special methods presently to be described. The secondary negatives were used in making the prints supplied the engraver.

The special methods referred to are the outcome of reflections indulged in from time to time on the possible advantages of combining separate photographs of an astronomical subject for the purpose of suppressing or mitigating the effect of peculiarities of single images. Such peculiarities may be due to almost innumerable causes, but result principally from poor seeing, faulty following of the telescope, and the chance distribution of silver grains on the photographic plate. The idea of compositing photographs is a sufficiently familiar one, but I am not aware of its having been used in scientific observation, at least for the purpose here described.²² In the system here employed the positive enlargements of the pictures it is desired to combine are mounted in a manner which ensures accurate registry, and are successively photographed on a single plate, or film. A variation of this procedure, which augments contrast, is to superpose one positive on another and photograph through the combination thus secured. If the positives are on glass the number which can be so utilized is limited to two, and one of these must of course be "reversed," but if they are on thin films reversal is not necessary, and as many as desired may be placed in series. In some instances the above described methods have been combined, that is to say, several original photographs have been brought into one, of double, or of triple contrast as the case may be. If double contrast is desired and three pictures are to be used, they are combined in pairs in three different ways, and each pair is photographed, for a third of the total exposure. The technique of the process of registry and superposition is extremely simple, and need hardly be described here.

Experience with this method of combining photographs has, on the whole, been satisfactory. When three or four photographs of an equal degree of excellence are combined in normal contrast some advantage in detail may be expected to result, while photographic grain, which in an enlargement is displeasing to the eye, is appreciably reduced. If, however, one of the photographs is noticeably better than the others it is usually found that the advantages of combination are insufficient to compensate for the poorer quality of the companion pictures, although because of the modified

grain, the composite may be more sightly. Where increased contrast is sought there is a positive advantage in combination: faint shadings which might easily escape the eye can be built up until they dominate the picture. A check on the reality of such features can be provided, where it seems necessary, by building up two independent sets of photographs, and whenever this has been done the features in question have been verified.

It is a matter of common knowledge that contrast in a subject can be enhanced to a very great degree by purely photographic methods; for example, by copying on plates and papers of suitable quality, by control of exposure and development, and by repeated copying; and it may well be asked what advantage the procedure here described has over the more familiar methods. One advantage lies in the freedom from exaggerated grain, and from magnified imperfections of the single original plate; another in the fact that any desired contrast factor can be had in one simple operation. If the necessary number of original photographs is available the method is to be recommended in preference to the older one.

In order still further to eliminate the appearance of grain, experiments were tried with diffuse printing. This was done by placing a piece of glass between the negative and the paper. A more pleasing picture is sometimes secured in this way, and one which provides a better half-tone. (Compare figures 1 and 3 of Plate VIII; figure 3 is diffusely printed.)

Shading. A familiar difficulty which attends the enhancement of contrast in any pictorial subject is that detail in the fainter or stronger parts may be lost through insufficient latitude in the recording agency. In order to mitigate this as much as possible, artificial shading of a part of the picture has been resorted to in instances where it was believed it would not be deceptive. Where any of the above described devices, namely composition, reinforcement of contrast, diffuse printing, or shading, have been employed the fact is noted in Table 2.

Description of Table 2: This is a tabulation of data relating to illustrations. The first two columns require no explanation. Column 3 gives the number of the negative from which the illustration is taken. There are several images on each negative, and the numbers in column 4 are the distinguishing marks by which the ones used may be identified. Where more than one figure is recorded the illustration is a composite photograph. Column 5 gives the contrast factor of the negative used in printing. Where the printing negative is made from positives in single thickness the contrast is termed 1, where several positives are placed one over the other, the number used is taken to indicate the degree of contrast. For example, in Plate VI,

²² This comment refers to its general use. I have employed the method on several occasions, for example, in *Lick Obs. Bull.*, 7, Plate I, figure 2, 1912.

TABLE 2. DATA RELATING TO ILLUSTRATIONS

Plate	Fig.	Negative No.	Image No.	Contrast	Gr. Univ. Time 1926	Long. of* Cent. Merid.	Remarks
VI (Mars)	1	4679	1	1	Oct. 16, 8 ^h 35 ^m	127°	
	2	4687	4	1	9 8	134	
	3	4688	1	1	9 16	137	
	4	4689	1	1—	9 26	138	
	5	4691	4	1	10 46	159	
	6	4692	2	1	10 52	160	
	7	4679	1, 2, 3	2	8 41	128	a
	8	4687	2, 3, 4	3	9 7	134	
	9	4688	1, 1, 2	3	9 16	137	
	10	4690	5	1	10 33	155	
	11	4691	2, 3, 4	2—	10 46	159	
	12	4692	1, 2, 3	2—	10 52	160	c
	13	4665	1, 2	2	Oct. 14, 7 32	129	a
	14	4666	1, 2	2	7 49	133	a
	15	4409-10	3, 4, 7, 8	4		196	a, b
	16	4672	1, 2	2	Oct. 15, 8 21	132	a
	17	4673	3, 5	2	8 33	135	a
VII (Mars)	1	4699	1, 2, 3	3	Oct. 18, 5 57	70	a
	2	4700	1, 2	2	7 40	96	a
	3	4701	2, 3, 4, 5	2	8 3	101	a
	4	4706	1	2	9 51	127	a
	5 to 8						d
	9	4715	1, 2, 3, 4	4	Oct. 20, 7 43	78	a, c
	10	4716	2, 3, 4	2	7 49	79	e
	11	4731	1, 2, 4	3	11 22	106	a
	12	4730	1, 2	2	11 9	102	e
	13	4828	1, 2, 3	2	6 4	168	
	14	4829	1	1	6 8	168	
	15	4763	1	1	Nov. 2, 6 12	302	
	16	4764	1	2	6 57	313	
	17	4765	1, 2	2	7 31	321	
	18	4770	0, 1	2	Nov. 3, 5 2	276	
	19	4771	1	1	5 28	282	
	20	4771	2, 3, 4	3	5 32	283	a, c
VIII (Mars)	1	4692	1, 2, 3	3	Oct. 16, 10 53	160	a
	2	4691	2, 3, 4	2—	10 46	159	
	3	4672	1, 2	2	Oct. 15, 8 21	132	c
	4					301	f
	5	4763	1	1	Nov. 2, 6 12	302	
	6	4397	3	1		299	h
IX (Jupiter)	1	4693	1	1	Oct. 18, 3 9	339	
	2	4694	5	1	3 23	348	
	3	4695	3	1	3 31	352	
	4	4696	5	1	3 47	3	
	5	4697	3	1	3 57	8	
	6	4698	4	1	4 26	24	
	7	4698	3, 4	2	4 25	24	g
	8	4698	5, 6	2	4 30	28	g
	9	4660	4	1	Oct. 14, 4 56	159	
	10	4664	4	1	5 51	192	
	11	4709	3	1	Oct. 20, 4 37	331	
	12	4708	4	1	4 19	320	
	13	4717	3	1	Oct. 22, 3 45	241	
	14	4718	2	1	4 0	248	

* Not corrected for phase. Longitudes for *Jupiter* are based on System II, as tabulated in the *American Ephemeris*.

a Terminator shaded in printing.

b This is the photograph, rendered in higher contrast, which is shown in *Lick Obs. Bull.*, 12, Plate II, fig. 6. The date as given there, 1924, Sept. 21, 17^h 37^m (G.M.T.), corresponds to 1924, Sept. 22, 5^h 37^m (U.T.).

c Diffusely printed.

d Figures 5, 6, 7, and 8 are repetitions of those immediately above except that they are diffusely printed.

e Shaded on southern limb in printing.

f A photograph by Barnard, taken with the Yerkes 40-inch refractor; G.M.T. 1909, Sept. 28, 16^h 24^m = U.T. 1909, Sept. 29, 4^h 24^m.

g Shaded around edge to reduce fading.

h Photograph made during preceding opposition; 1924, Sept. 11, 18^h 30^m = U.T. Sept. 12, 6^h 30^m.

figure 7, three separate images, designated on the original plate as numbers 1, 2, and 3, were combined three ways in pairs, and a partial exposure made to each pair. In this way three images were brought into the illustration with contrast 2. In Plate VII, figure 16, double contrast was desired, but only one image of passable quality was available. Two positives were made from this image and placed one over the other. In a few instances prints were made on a soft grade of paper, and that fact is indicated in each case by the sign (—). The remainder of the table does not require explanation.

PHOTOGRAPHS OF JUPITER

The photographs of *Jupiter* were made rather casually, as time could be spared from the work on *Mars*. During the summer, while *Mars* was not within reach in the early evening, there was little interference of the one object with the other, but as *Mars* approached opposition it received the greater share of attention. Indeed, the observations of *Jupiter* were regarded as of secondary importance because the low declination of the planet placed it in an unfavorable position for observation. At the time of observation it had a zenith distance, when on the meridian, of about 52° . Better photographs should be obtainable in 1927, and the position will improve during succeeding years as the planet works its way northward.

Notwithstanding the unfavorable position, some of the photographs are of very good quality, and they show variations with change in the color by which the planet is pictured which are quite striking. In Plate IX there are reproduced a complete set of photographs taken in the six colors employed, ranging from ultra-violet to infra-red, and several pairs of photographs consisting in each case of an infra-red member and one taken either by violet or by ultra-violet light.

The complete set is given in the upper row of illustrations, the photographs being arranged in the spectral order of the colors used, which happens as well to be the time sequence in which they were taken. It will be noticed that there is a very considerable difference between the images at the extremities of the row, notably in the structure of the heavy lower belt, which in the right hand photograph exhibits curious inclined streaks, or filaments, as though a pen and ink drawing had, while still wet, been brushed in a direction upward to the right. The contrast between belt and background is rather low in the photographs taken in the longer-waved colors, and, in order to insure a representation in the half-tone engraving of the infra-red image, two prints made in exaggerated contrast are inserted just below the left-hand members of the series.

The means employed to magnify contrast are described in the section of this paper relating especially to the illustrations.

It is necessary to bear in mind, in comparing the several images of the series, that, because of the rapid rotation of *Jupiter*, approximately equivalent presentations are had only in successive photographs. The interval between the taking of the pictures at the extremities of the row was one hour and seventeen minutes, during which *Jupiter* turned 45° on its axis. The direction of motion due to rotation is from right to left on the paper, and the displacement is, of course, progressive through the series.

Most of the changes with color are so obvious that attention need hardly be directed to them. The remarkable difference in the structure of the heavy northern (lower) belt has already been alluded to. There are changes in the relative strengths of some of the other belts. A pronounced fading in the higher latitudes is shown by the images of short wave-lengths, and this imparts to those images an exaggerated appearance of ellipticity. The general edge fading, which is so marked a phenomenon in *Jupiter*, is much more pronounced in the long than in the short wave images; in fact the limb of the planet is quite invisible in infra-red photographs of normal exposure. It was therefore necessary, in making the two prints pictured on the second line in magnified contrast, to shade the edge strongly in order to prevent it from being completely lost. Limb darkening is hardly appreciable in the ultra-violet photographs. Possibly it might have been a little more pronounced had they been taken closer to opposition, though the relatively strong terminator indicates that it would not have approached that of the long-wave photographs. In respect to this fading my observations are altogether at variance with those of Professor R. W. Wood, who reported, on the basis of his pioneer work on the photography of *Jupiter* by light of different colors,²³ that the fading is more pronounced in the images of shorter wave-length. The present observations indicate that the change in limb fading is progressive as the color used in observation passes from one end of the spectrum to the other. Some of the changes here mentioned, as well as the invisibility of the red spot in colors of longer wave-length, were referred to in an earlier note.²⁴ The red spot is shown on the ultra-violet and violet images, just emerging on the disk at the upper right side. It was well on the disk when the infra-red pictures were taken.

Reverting to the inclined filaments, which in the infra-red images reach out from the strong north equatorial belt, it is to be noted that they are bordered

²³ *Astrophys. Jour.*, **43**, 317, 1916.

²⁴ *Publ. Astron. Soc. Pac.*, **38**, 334, 1926.

on their southern (upper) edges by patches of extreme brilliancy, which are, in fact, the brightest parts of the planet as photographed by infra-red light. The filaments are terminated by short dark lines, or cross bars, which lie approximately on the planet's equator. These terminal lines are probably regions of exceptional density in the faint, narrow, dark belt in that position. On the infra-red image of October 22 (figure 14) one of the stronger filaments divides into a broadly spread italic Y, one branch of which recurves sharply. The upper terminals of the Y merge either with the south equatorial belt, or with an extremely faint belt lying just below it. Most of the filaments are attached to the north equatorial belt and extend upward to the right in the illustrations. There are a few, however, reaching in the same direction from the south equatorial belt, and perhaps one extremely faint one directed upward to the left.

These filaments are unquestionably the wisps, or faint diagonal lacings, which have been seen by many observers with the telescope, but of which I had no knowledge when writing the above description. The reader's indulgence must be begged for the display here and elsewhere of very great ignorance regarding planetary matters. It seems well enough, however, to let the account stand as written, because it tallies so closely with the descriptions given by eye observers, and thus establishes conclusively the identity of the extremely strong markings of the infra-red photographs with the delicate tracings seen in the telescope. Attention has been especially directed to these wisps, as observed visually, by Scriven Bolton, W. F. Denning, and Rev. T. E. R. Phillips, though they appear to have been known since the early days of planetary observation. Excellent descriptions of them are available especially in the *Journal* and *Memoirs* of the British Astronomical Association, and in *Lowell Observatory Bulletin No. 38*. E. C. Slipher at Lowell Observatory and Pease at Mount Wilson have photographed them by yellow light. Their appearance in the yellow photographs is probably not very different from the telescopic aspect. They have been aptly described by one observer as resembling driven showers of rain. The curious thing about them is that, while to the eye they are not at all conspicuous, on the infra-red photographs they compare favorably in visibility with the belts themselves. Professor Pease has kindly sent me copies of some of his photographs taken with a yellow screen. On one of them the wisps reach downward to the right and in another upward to the right. Observers with the telescope describe them as favoring an inclination of approximately 45° , but as having no especial preference in the matter of quadrants; and they are occasionally reported as going straight across from one belt to another. The bright patches noted

as accompanying the filaments in the photographs have usually been found to be present in the telescopic view.

Wisp-like markings such as these were seen on *Saturn* in 1909 by Lowell and Slipher.²⁵ It is possible that infra-red light will prove as advantageous in observing them there as it is on *Jupiter*.

When one looks at *Jupiter* through the telescope the eye perceives, of course, the integrated effect of different designs in different colors. The multitude of shades, which make this planet colorful beyond all others, is therefore undoubtedly due in part to the crisscrossing of detail in the elementary color images, and the intricacy of the resulting pattern is largely provided by light of the redward end of the spectrum.

Regarding interpretation. It is feared that the following discussion does not justify the noun of its introductory phrase; speculation would have been a more suitable word and one of none too wide a connotation. The one used was chosen rather to make the form of this paper match that of others in which the observational data are perhaps better able to support a conclusion. The phenomena presented by these curious photographs of *Jupiter* appear to be so complex, the observational material is so limited, and the conditions on the great planet are so unlike those on the Earth, where our intuitions are bred, that I feel that a serious attempt at interpretation would now be premature. There is the further fact that the spectrum of *Jupiter* provides a powerful and as yet little utilized means of studying its atmosphere. In the case of *Mars*, where a tentative attempt at explanation has been made, we have a body obviously not very different from the Earth; in that of *Jupiter* the conditions are not at all comparable. The following paragraph, quoted from a note by Mr. Edwin Holmes, epitomizes some very important implications of the high superficial gravity of *Jupiter*:

"We must not forget that on *Jupiter* gravity doubles the pressure (or halves it) every 1.6 miles. M. Flammarion calculated that if his atmosphere had a depth of only 100 kilometers, or about 63 miles, the density at 37 miles from the surface would be the density of platinum, and 'yet there are 25 more doublings of density in the remaining descent.' He adds: 'It is perfectly monstrous.' The atmosphere at the surface would be 17 millions of times more dense than platinum. I think this amounts to telling us that long before we reached 37 miles down, the atmosphere would be compressed into a solid body, and would be in no reasonable sense an atmosphere at all. And the clouds in any case under the conditions must be extremely thin, and *Jupiter's* beauty only skin-deep."²⁶

For the purpose of illustrating how little agreement there is in views respecting conditions on *Jupiter* let us compare with the above paragraph the following excerpt from a paper by Dr. Harold Jeffreys:

²⁵ *Lowell Observatory Bulletin*, 1, 241, 1910.

²⁶ *Journal Brit. Astron. Assoc.*, 27, 85, 1916.

"To sum up, the available evidence regarding *Jupiter* and *Saturn* is consistent with the hypothesis that each is composed of a rocky core, surrounded by a thick layer of ice, which is covered by an atmosphere whose depth is in the one case about 9 per cent. and in the other 23 per cent. of the radius of the planet."²⁷

Nine per cent. of the radius of *Jupiter* is, in round numbers, 380 miles. There is evidently a divergence of opinion among authorities relative to the atmosphere of this enigmatical planet.

The problem presented by *Jupiter* is one of such surpassing difficulty that it is doubtful whether it can be reduced to simple terms without mustering to our service every possible means of attack. It may not, however, be out of place to trace the steps of a small reconnaissance undertaken along lines suggested by the color work on *Mars*. The approach adopted is through a consideration of the phenomenon of edge fading. Failing visibility at the limb in observations made by light of a given color may well be caused, or at least influenced, by the occurrence of Jovian atmospheric absorption bands within the range of color used. This is a consideration of vital consequence in interpreting any phenomenon of absorption. A comparison of the colors used and their respective ranges, with the spectrum of *Jupiter* as photographed by V. M. Slipher,²⁸ does not suggest serious interference by the selective absorption of these bands or rather broad lines, though a few weak Jovian absorption lines do occur in several of the regions used. Apparent freedom from such interference is also indicated by the continuity of the change in character of the image with change in color. It will be well, eventually, to examine the ultra-violet and infra-red sections of the spectrum, but it seems safe for the present to assume that, in the changes here described, we are dealing with a general color effect and not with the consequences of isolated or uncontinuous absorption.

That there is general atmospheric absorption in the lower spectrum of *Jupiter* will be taken as established by the pronounced edge fading in the red and infra-red photographs. If we assume that the general absorptive power at short wave-length is not less than in the red,²⁹ it follows from the almost negligible darkening at the limb of the violet photographs, that these depict on the whole, phenomena of *Jupiter's* upper atmosphere. Absence of edge fading in the case of a planet which receives its illumination from without and has an atmosphere of appreciable absorbing power does not necessarily imply that there is negligible penetration of the atmosphere. Possibly subject to certain

limitations discussed by Fessenkoff,³⁰ which are not trespassed upon here, it means that the light's effective penetration (into and out of the atmosphere) is not greatly in excess of the atmosphere's vertical thickness; in other words that we cannot see to the bottom.

Figure 1

Figure 1 will be of convenience in illustrating this. It is supposed to represent a planet illuminated and observed from the direction 0. The atmosphere of the planet is assumed to be able to scatter and to absorb light. Let the outer circle represent the outer atmospheric layer of appreciable density, and the inner one the surface of the planet. We shall assume that violet rays are effective in photographing only to the depth *D*, while red rays have an effective penetration considerably in excess of the atmosphere's vertical thickness. The effective depth to which violet rays penetrate and return at points away from the center is indicated by the curve *EDW* and the part of the atmosphere photographed is the lune-like section *EDWSE*. To a degree of approximation which is sufficient for present purposes this limited volume of the atmosphere will be seen, or photographed, as a uniformly illuminated disk, provided only the ratio of scattering to absorption is constant throughout the volume considered.³¹ On the other hand the red rays, as a result of their greater penetration, will be able to take advantage of the less thickness of the atmosphere

³⁰ As the result of an elaborate analysis of the problem of planetary reflection, in which is introduced the assumption that atmospheric absorption occurs only through scattering, Fessenkoff (*A. N.*, 228, 30, 1926) concludes that a planet having an albedo of approximately 0.2 will present a disk of uniform brightness, whatever the atmospheric absorption. The analysis is quite complex, and will bear study. Whether or not the conclusion is correct, it does not apply in the present case because the photographic albedo of *Jupiter* (0.73 according to Russell) is greatly in excess of Fessenkoff's critical value.

³¹ Uniformity will result only when the planet is approximately at opposition. With illumination from one side there should be an increase in brightness from terminator to limb.

²⁷ *M. N. R. A. S.*, 84, 538, 1924.

²⁸ *Lowell Obs. Bull.*, 1, 231, 1909.

²⁹ The photographs taken by red and infra-red light in the one case, and by violet and ultra-violet light in the other, are so similar that in what follows the somewhat awkward prefixes will not be used.

near the middle of the disk, and will show the well known phenomenon of edge fading.

It is quite clear, on a little reflection, that the violet photographs cannot be explained on the unmodified assumption that they are due to scattered light. Generally speaking, light of that kind is not especially influenced by the composition of particles which do the scattering. By way of illustration let us consider the phenomenon of our own sky. The part of the light of the sky which is due to fine suspended dust, while it is undoubtedly less blue than that scattered by molecules of air, is, on the whole, not every different from it. A fairly uniform surface might therefore be expected in the ultra-violet photographs of *Jupiter*, even though the scattering particles might differ considerably in size and composition at different parts of the planet's surface. The observed fact is that the variations in intensity—the contrasts between belt and background—are quite as great in these short-wave photographs as in any of the others.

A path out of the difficulty is perhaps provided by the following considerations. The brightness of our hypothetical atmosphere of figure 1, for a given intensity of illumination, depends on the ratio of scattering efficiency to absorption. If therefore, we have a medium in which this ratio is low (as, for example, is suggested for *Mars*) a uniformly darker disk will result. If such a medium were distributed in zones, like the belts of *Jupiter*, it would seem to meet our requirements, for it would maintain constancy in brightness (or darkness) to the planet's limb. It is to be noted that the medium must extend clear to the surface of the atmosphere in order to fulfill the condition named, i.e., constancy of ratio of scattering to absorption, for that condition merely implies homogeneity. If we were to assume the contrary to be the case, namely that the belt material (as just interpreted) falls short of the atmospheric surface, the increased thickness of the free atmospheric layer through which we should have to look at the belt when near the limb would result in the superposition of light over the dark area and consequently in a reduction of contrast. To put the matter a little differently suppose the upper surface of the belt to lie between *D* and *S* (figure 1). (It must lie above *D* because that is the greatest depth to which one sees by violet light.) As the portion of the belt under consideration is carried toward *E* by the planet's rotation it will eventually fall below the curve *DE*, and therefore become invisible. Since the belts apparently persist to the limb with little alteration in strength it is necessary to assume that they extend clear to the surface *S*.

The statement here made that the belts persist in normal intensity to the edge is based only on casual inspection of the photographs. It may, of course, not

be more than approximately true. On photographs taken close to opposition (August 22 and 25), when the phase angle was less than 2° , the dark belts appear to be lost in a peripheral line of brightness at the limb. These were the first photographs taken, and they were not made under the best conditions. On October 14 (see Plate IX, figure 9), with a phase angle of 10° , the comparatively narrow South Equatorial and North Temperate belts apparently extend to the limb, but it is not certain that the wide North Equatorial belt reaches it on any of the photographs. The structure of this belt varies so from point to point that a true idea of the effect upon it of proximity to the limb can be had only by studying the appearance of one or more of its configurations in their diurnal travel across the disk and on their approach to the limb. This will be done it is hoped, at the coming opposition, with the aid of cinematography. For the present we shall have to content ourselves with the approximate statement that, relatively to their appearance on photographs taken by light of longer wave-length, the equatorial regions of the planet, as recorded on ultra-violet photographs, are free from limb effect, and from this fact the provisional inference of the preceding paragraph, respecting the upward extension of the belts, is drawn.

Several assumptions regarding the nature of our hypothetical belt medium seem to be permissible as far as the violet photographs are concerned. One is that it consists of small absorbing bodies homogeneously distributed in the atmosphere. If that be the case, one is tempted to assign to them a reddish color, for that is the color of the belts, and since they are near the surface it does not appear that their color can be affected by absorption. The red color accounts for falling off of contrast of the belts in the red images. If these particles have a density distribution homogeneous with that of the atmosphere in which they float, the optical conditions necessary for our belt medium are fulfilled. It is to be remarked that the high value of gravity on *Jupiter* would favor the flotation of solid particles of considerable size.

Our alternative hypothesis is that the medium of which the belts are composed is a gas whose ratio of scattering to absorbing power is low.

These two hypotheses have been examined rather sketchily in relation to the red images. The phenomena there are very complex and I should prefer not to embark on a discussion of them without the photometric data which the plates will eventually provide. The red images seem to favor the explanation in terms of an absorbing gas as against absorption by suspended particles, because darkening at the limb, which is strong in the red images and affects the belts as well as the bright surface, seems to be better taken care of by it.

In regard to the depth to which the violet photographs extend—the position of the point *D* in figure 1—a general inference seems possible. If we assume that the photographs 1 and 7–8 of Plate IX actually represent different average levels, and that 7 is lower than 1, it seems reasonable to assume that the inclined filaments of the latter photograph are completely below the level of figure 1, because there is no trace of them there. From this it is judged that the point *D* must be situated fairly well up in the atmosphere, in order to leave room for the development of these very conspicuous features below it. In this connection the rather puzzling behavior of the red spot may be mentioned. Diminished visibility of that object on the red photographs is to be expected, since it is a dark marking of reddish hue seen against a white background; but if it is a phenomenon of the upper levels, as its occurrence in the violet photographs would seem to indicate, we must be looking *through* it in the red photographs. One would, therefore, expect to find

some trace of it on them. The ultimate visibility of the characteristic markings of one color on photographs taken in the other, may eventually settle the question of which level is the higher.

It will be understood that none of the inferences which are here tentatively drawn are regarded in any sense as conclusions. These notes are mere comments accompanying what are believed to be unique photographs of *Jupiter*. Future interpretation, based on more observational material and competent photometric data, may lead in a very different direction than that taken in this exploratory ramble.

I am indebted to Mr. J. F. Chappell, Lick Observatory photographer, for his painstaking care in making the prints which illustrate this paper.

April, 1927.

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