attracted the attention of astronomers more than any other as the shadow traveled mostly over the land, and places along the central line were accessible.

The next eclipse was the one of August 9, 1896. This was visible mostly in northern Europe but if I remember correctly many of the observers were defeated by clouds and bad weather.

The eclipse of next August will be a most interesting one, especially so as we are now about at the end of a very long and drawn out period of sunspot minimum.

Boston, June 2, 1914.

MONTHLY REPORT ON MARS.—No. 6.

WILLIAM H. PICKERING.

Lunar Canals.

The present Report will be devoted chiefly to a study of the canals. By a canal in the astronomical sense of the word is meant any long narrow dark marking that is straight, or of large radius of curvature, and of fairly uniform breadth and density. The existence of the canals on Mars as objective realities must appear obvious to any one who has seen the planet under sufficiently favorable circumstances. They have been seen at this station with the 11-inch refractor by using a magnification of 660 when the diameter of the planet was but 5.″6. When well seen they can be held by the eye like any other real marking, for indefinite periods. The main cause of the controversy regarding them is that in northern latitudes, where most of the large telescopes are located, the seeing is not sufficiently good to show them well, and their existence therefore continues to be doubted in some quarters.

Another cause of doubt depends on the mistaken idea still held by the public, and also by many astronomers, that the larger the telescope the more you can see with it. If the seeing were good enough, or if the objects were very faint, this would obviously be true. But even with double stars there is a limiting size of aperture giving the best results, depending on the quality of the seeing, and with bright planetary detail this limit is very marked indeed. The statement once made in joke, that the 40-inch Yerkes lens is too powerful to show the canals of Mars, is literally true. There are too many air waves constantly passing in front of its great surface to permit of the necessary planetary definition.

For our north-eastern states the best results on a good night can be obtained with an 8-inch aperture. In the southwest 16 inches is perhaps the limit. The proper size for the tropics has not yet been reached by any instrument located there, and is still unknown. Any telescope intended for regular use on planetary detail should be provided with a cat's eye diaghragm placed over the objective, which can be adjusted instantly from the eye end of the telescope,—a device first used I believe at the Lowell Observatory.

As a means of studying the canals of Mars, it occurred to the writer that since the moon is a body closely resembling it, and of the same order of size, if we were to apply to it the same magnification in proportion to its distance, that we might get a similar effect. The average distance of Mars at opposition is fifty million miles. The average distance of the moon, one quarter of a million. The moon being at one-two hundredth the distance of Mars, we should use one-two hundredth the magnification, The Martian canals are well seen with a power of 500. An ordinary opera glass, giving a power of 2.5 would therefore be a proper instrument with which to view the moon. If we wish to have the moon appear of the same size as Mars, a field glass magnifying five times should be employed.

A preliminary sketch made with an opera glass on April 28, 1912 showed a number of long narrow canals crossing the face of the moon. Of these the most conspicuous was the broad double canal shown in Figure 1, extending north-westerly from Tycho. Next came the three canals to the west of it, and a few of those shown in Imbrium. All were narrow and quite uniform in appearance. The present sketch was made with a field glass magnifying four times, on October 14, 1913, colongitude 90°. The double canal extending from Tycho was now so broad that it had almost lost its canal like character, but numerous fine canals appeared, among them several exceeding 400 miles in length. Only the more conspicuous ones have been drawn, in order to avoid confusing the sketch. When near the terminator the canals are faint or invisible. They seem to be most conspicuous when the moon is full, and individually to vary more or less with the colongitude. It would seem as if a detailed study of them might repay the careful observer. Perhaps the best results are obtained on a slightly hazy evening, or with the moon not very far above the horizon, so it shall not be too dazzling. Even with an opera glass better results are obtained if it is steadied by holding it against a post. It is perhaps easier to see them in the first place with a field glass, but once seen, an opera glass gives them a more canal-like appearance. With the latter they are narrow straight and grey or black, with the former they show a slightly irregular structure, and are at times distinctly brownish. There are few canals on Mars more distinct than those between Copernicus and Aristarchus when seen under favorable conditions with an opera glass.

But it is not necessary to wait for a moonlight evening in order to see the lunar canal. The same result can be obtained, though in an inferior way, from any good photograph of the full moon. This should be placed against the wall in a strong light, and viewed with the naked eye from a distance of between twenty and forty times its diameter. If we get nearer than this, we see that the lakes, with the exception of Plato, are not sharply defined regions, but simply small dark areas of irregular shape and density, which are in reality much larger than they appear in the drawing. Similarly the canals, which are drawn as heavy fine lines, are in reality broader and less intense areas of the same length. They vary in general from 20 to 60 miles in breadth. The effect is clearly not due to areas of irregularly distributed and imperfectly seen fine detail. The surface is not necessarily irregular in density, nor spotted, nor filled with any detail at all. All that is required to produce a canal is a comparatively slight difference in density, a reasonable breadth, and a sufficient intrinsic brilliancy to render it visible.

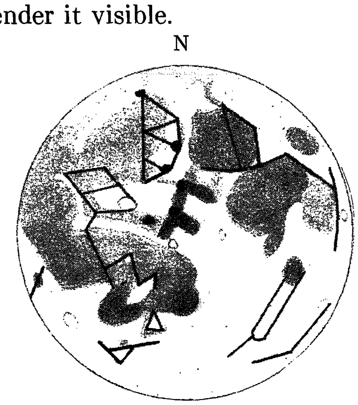

FIGURE 1.

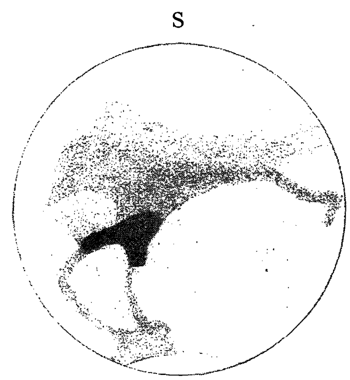

FIGURE 2.

Some of the canals are produced in a different manner however. Thus the little canal near the limb south of Crisium, as far south as its junction with the canal from Tranquillitatis, is due to a line of intensely black variable spots filling the bottoms of craters, and persisting in their blackness almost until the time of sunset on that region. The canals bordering Serenitatis and Tranquillitatis are perhaps due in part to contrast between the dark and bright regions, but in part also to dark variable spots lying at the foot of the elevated regions bounding the *maria*. In this double origin they resemble the Martian canal Triton, so well seen at the past opposition. It is instructive slowly to approach the photograph to within a couple of feet, and watch the changes,—especially in the regions of the double canals.

The writer cannot but feel that we have here an analogy, which may help us in explaining the so-called canals of Mars. That they have an objective reality is clear, but perhaps they are not the narrow, striking, artificial looking objects that our drawings represent them. Some of those that we see the best, like Sabaeus, Nilosyrtis, and Thoth, see Figure 2, are doubtless in reality very much as they are drawn, like the broad canal shown in the extreme north of Figure 1, which fairly represents the region when it is seen under a higher power. But it would appear that broad faint natural areas and narrow dark artificial ones present to the eye exactly the same appearance when viewed from a suitable distance, so unless we can increase our magnifying power sufficiently, there seems to be no way of distinguishing with certainty between them.

The three martian canals Sabaeus, Nilosyrtis, and Thoth can readily be identified by means of the map published in connection with the first Monthly Report. The first of these is not usually referred to as a canal, but it obviously differs little from the other two, and still less from Cerberus as it appeared at this opposition. It is conspicuous for a large portion of every martian year when sufficiently near us, but is at times invisible. Such was the case at this past opposition prior to November, that is, prior to longitude $\odot = 0°$. It is subject to considerable change in shape and is at times quite irregular; it is therefore possible that the others would be so also, could we see them sufficiently clearly. Nilosyrtis is often visible, and Thoth occasionally so, that is to say, it is sometimes invisible for several years at a time. See Bulletin 8 of the Lowell Observatory. This year all three of these canals were perfectly obvious, and the last two equally so. The drawing was made January 18, 1914, except for the two faint canals Orontes and Phison, which were inserted on it from drawings made upon January 10, 11, and 12. In order to make them clearly visible their conspicuousness is considerably exaggerated in the drawing. The case of Thoth is an unusual one. According to Schiaparelli it was visible at the oppositions of '77, '79, '82, '84, '86, and '88. It was not seen by the writer in '90 or '92, nor by Lowell in '94, '96, '99, or '01 but it was conspicuous to him in '03. It is not recorded by the observers of the Brit. Astron. Assoc. in '05 or '07 but was traced faintly by Lowell, and more conspicuously by Antoniadi in '09. It was clearly visible to M. Jarry Desloges and his assistants at the opposition of '11.

As far as the conspicuousness of the Martian canals is concerned when seen under favorable conditions, the more conspicuous ones are about as readily seen as the Mare Frigoris, the broad northern canal, upon the moon, when viewed with an opera glass. The two fainter canals, Figure 2, were less conspicuous than many of those shown in Figure 1. Other canals of intermediate visibility are found on Mars, and the writer feels therefore no question but that the two faint ones shown in the sketch were really there, as fairly uniform continuous markings.

A study of the lunar canals calls to our attention an unlooked for characteristic. We should naturally expect that as we approached nearer and nearer to the photograph, or used higher and higher powers upon the moon, that while the canals first seen would be resolved and exhibited in their true aspect, that other finer canals would appear, which a closer approach would in their turn resolve. On the moon, excepting with very low powers, this does not seem to be the case. It is true that with a power of several hundred diameters short uniform canals make their appearance, resembling in all respects the short stout canals in the Solis Lacus region of Mars, (Harvard Annals **53** 75), but the long narrow canals, hundreds of miles in length, so characteristic of Mars, are seen on the moon only with such low powers as we have just described. It must be noted that in the case of these canals, their size and appearance do not vary in any way with the aperture, but only with the magnification. Of this any one can readily satisfy himself.

As we reduce the aperture of the field-glass, a slight improvement in distinctness is noted when we reach a size of about one-quarter of an inch, on account of the reduction of the glare, but when the aperture gets below one-eighth, or a magnification of 32 to the inch, they become less distinct again. They continue to remain visible and to be of the same breadth and in the same place, until with failing light they gradually fade from view.

In the case of the moon an equivalent distance of 80,000 miles seems to produce the best effect. At less than 30,000, and at more than 150,000 miles, the canals disappear as such, and are replaced in the former case by more or less irregular, but still elongated markings.

On the moon, even with the naked eye, the dark canal shaped marking ending in the Mare Nectaris is obvious. Mare Frigoris too can easily be seen. Their appearance on a photograph of the full moon, and that of the F-shaped marking presently to be described indicates what the writer believes the canals of Mars would be like could we see them more clearly. It is perhaps worthy of remark in this connection that it is quite impossible to tell from a near inspection of a photograph of the moon, just where the canals will appear when it is seen from a distance. Thus, one might naturally expect that the F-mark would be prolonged as a canal nearly as far as Tycho. Such however is not the case. On the other hand one would never have expected the area lying between Tycho and Nectaris to appear from a distance as a double canal.

This canal so conspicuous in the opera glass, makes a severe test of acuteness of vision for the naked eye. If the moon is high, a shade glass will help one to distinguish it, but it can hardly be detected as a canal, earlier than a day or two before full moon. Few of the Martian lakes are ever as conspicuous as Mare Crisium to the naked eye, but they are comparable to some of the lakes shown in Figure 1 as seen with an opera glass, and their visibility might be recorded in that way. It is probable that the same law applies to the canals of Mars, and if we were only able to use a little higher power, when Mars was nearest to us, the canals would vanish, and be replaced by the real details which the canals merely indicate. During our Arequipa observations of Mars in 1892, when the planet was unusually near us, many of the canals presented a broad hazy appearance, which later, when more remote, was replaced by the effect of the very narrow dark lines. We used a low power of 350 most of the time, because we wanted to see the canals! Had we used a higher power, we should perhaps have seen what was really there.

The surface of Mars appears to be particularly well adapted to producing the canal effect. Only isolated areas upon the moon show it to advantage. This may be because the bright areas of the moon are too rough, and the smooth areas too dark,—for even on Mars the canal effect is conspicuous only in the bright regions. Again, on account of the more abundant vegetation on Mars, it is possible that stripes on the planet are more frequent, for it must be remembered that the basis of every canal is really a stripe, although the increase of blackness may be slight and the breadth great and irregular. The presence of lakes at the two ends of a canal will render it much more readily visible, though they will not produce a canal if there is no real shading between them. It might be suggested that a new and temporary canal on Mars might appear in any region if bounded on either side by a faint band of haze or cloud. At every opposition, by using the proper magnification, 300 to 600, some canals should be seen, and if they are not, it merely indicates that the definition is inferior. The better the definition, quite regardless of the aperture of the telescope, the more clearly will the canals appear.

In our sketch of the moon the shape and location of the *maria*, and the positions of a considerable number of the bright craters are in fair agreement with what we know to be the case, as based on photographs, and the use of higher telescopic powers. To the left and above the center of our figure, shaped like a letter F, are several short thick canals and a number of lakes, which are also in fair agreement with the facts. On the other hand our long thin canals give little or no information as to the real appearance of that portion of the surface. In spite of this fact the canals of Mars are well worth while observing, because they change with the seasons, and also differ from year to year at the same season on Mars. This is perhaps the most artificial feature. If the observer desires to study them to the best advantage, then the only way to do so is to draw them as they appear. Sometimes many of them appear as straight narrow dark lines. The fact that they may not really be narrow, or perfectly regular is no reason why they should not be carefully studied and named, and all honor should be given to Schiaparelli, who although not their discoverer, was the first to observe them in large numbers, and to draw general attention to their existence. Still we must remember, at the best they are only indications of detail, not the real thing. That is to say what they indicate is something that is actually beyond the power of the observer's telescope to correctly define.

If we had employed an eyepiece with our 11-inch telescope last January giving a magnification of 110, the more conspicuous canals, such as Nilosyrtis and Thoth would have been seen, and the emergent pencil of light would have been just one-tenth of an inch in diameter. The diameter of the planet at that time was 14″ and the breadth of these two canals was about one-thirtieth as great, or 0″.47 equivalent to 140 miles. In a well lighted room the diameter of the pupil of the eye is about one-tenth of an inch. If now we place Figure 2, which is 45 mm (1.75 inches) in diameter at a distance of six meters (20 feet) from the eye, it will be on the same scale that Mars would have appeared in the telescope, with a power of 110. The breadth of the canals will be $0''.47 \times 110$ or 52″. If we wish to see how the planet looked with a magnification of 330, we simply view the drawing at one-third the distance, but we must look at it through a large pin-hole 0.85mm (1/30-inch) in diameter. This should be made in a piece of black paper, and the drawing placed in a bright light in order to secure sufficient illumination. Since it is difficult to produce a pinhole of exactly the right size, without microscopic measurement, the reader may have to use a slightly different distance from that here given in order to get the proper effect. The writer usually prefers a magnification of 660 in his work, the effect of which may be produced by placing the drawing in the sunlight, and viewing it from a distance of 40 inches, through an aperture 1/60 of an inch in diameter.

In Figure 3 various lines have been drawn, the first one, A, to represent the canals as shown in Figure 2. When placed at the proper distance to represent the planet, however, it will be noticed that the second line B represents the canal quite as well as the first one, so we really do not know but that the canal may be one-quarter as wide again, and fainter. If it were wider than that however, and still fainter we should detect the difference. This drawing therefore gives us a maximum breadth for the canal. It may also be represented by a line C of three-quarters its breadth, and the proper density. It cannot however be darker than this and narrower. The martian canals therefore are not black.

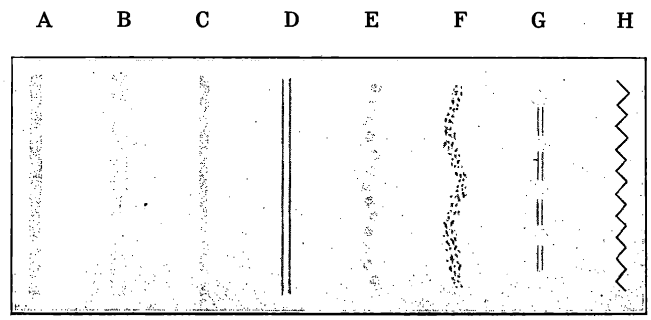

FIGURE 3.

It may be equally well represented by two narrow parallel lines whose centers are at a distance of two-thirds the breadth of A. These lines cannot be resolved into a pair until we approach within about half the distance. Provided the lines are dark enough to be easily seen, dark and light doubles are resolved with nearly equal ease. With an aperture of 1/30 of an inch, the ratio of separation to distance is as 1 to 1000 or an angular separation of 206″. With an 11-inch objective we may obtain an emergent pencil 1/30 of an inch in diameter, by using a magnification of 330. This would give 0″.62 as the smallest resolvable angle for parallel dark lines. This compares with a separation of 0″.42 found for a 15-inch telescope by actual trial on an artificial disk, (H. A. **32** 149), and is about fifty per cent greater than that usually accepted for double stars.

It is not likely therefore that the separation of the double canals upon Mars or in Aristillus was less than 0″.6 in place of 0″.5, as stated in Report No. 5. The fact that the Aristillus double was continued outside the crater as two diverging and easily separable canals would seem to indicate that the duplication was real in that case and not merely apparent, but the fact that the angular separation observed should be the same for both the moon and Mars is certainly a very suspicious circumstance.

Returning to Figure 3, the canal E is composed of a zigzag line of dots. The dots cannot be smaller or darker if a single row is employed, and unless they are placed more nearly in a straight line they cannot be confused with canal A. If there are more dots and they are scattered irregularly as in F, they cannot vary so much as these do from a straight line. The canals cannot therefore be very sinuous, nor indeed depart far from straight lines of uniform breadth. G shows the maximum possible size of the dots and H a continuous sinuous line like a river.

It therefore appears that the two canals Thoth and Nilosyrtis are not in reality more irregular than these later lines, and we have accordingly found an upper limit to any sinuosities or irregularities that they may contain. We see therefore that they are fairly uniform structures 1000 and 1500 miles in length by 150 miles in breadth, and are consequently quite unlike anything existing upon the earth. They cannot for instance be sinuous like our rivers, nor tapering, nor composed of dots accidentally located, so as to produce on us the impression of a continuous line.

On the other hand the finer canals, which may be represented by Figure 3 if we view it from double or treble the distance, cannot be distinguished from any of these irregular lines, and we consequently cannot say with certainty what their outlines are really like, or whether they are single or double. As there are canals of varying intermediate grades however, it seems fair to assume that all are of the same general structure, and all fairly uniform in shape. We may note one difference nevertheless. All of the larger and more conspicuous canals are curved. The fainter ones on the other hand usually appear straight.

The canals encircling Elysium were distinctly elliptical in outline this year, the major axis of the ellipse lying northeast and southwest in the terrestrial sense (*n. p.* and *s. f.*). The dimensions measured from four drawings were as follows:—December 15, 1450, 950 miles. December 16, 1450, 950 miles. December 17, 1200, 850 miles. January 20, 1250, 900 miles. The outline as drawn by the members of the British Astron. Assoc. at the oppositions of '99, '01, '03, '05 and '07 may be described in general as circular, but with a pronounced angle at the south. The diameter of the circle ranged from 1550 in 1901 to 1350 miles in 1903. It would appear therefore that the circle was flattened rather than lengthened this year. The loss of the angle, and the flattening noted are either of them sufficient to show that the canals do sometimes shift laterally from year to year. In 1911 M. Jarry Desloges and his assistants drew Elysium as a pentagon with straight sides, the southern and eastern angles being rather more marked than the other three. This would seem to make the case of lateral shift still stronger.

The most striking difference between the lunar and martian canals is that the latter are much more variable both in density and position, and often are entirely invisible. The former vary a little in density with the colongitude, which corresponds with the season upon the moon. Those lunar canals visible with a field-glass we shall designate as the coarser canals; those visible in the telescope we shall call the finer ones. With the latter we have the same difficulty as in the case of Mars, they appear perfectly straight and uniform, and as we saw in our last Report, in some cases they may even appear double.

The gradual narrowing of the canals with the progress of the season was well shown at this opposition. Nine canals were selected that were well seen at at least three presentations, and the breadth measured on the drawings. Where several drawings were available for the same presentation, which happened occasionally, the best one only was used. In Table I the first column gives the date, the second the longitude ⊙, the third the equivalent martian date, the fourth the measured breadth of the canal on the drawing in millimeters, the fifth the measured diameter of the planet, and the last the deduced breadth of the canal in miles.

TABLE I

BREADTH OF THE CANALS.

1913-4	⊙	M. D.	B	D	Miles
		CERBERUS.			
Sept. 2	312°.5	Jan. 30	0.7	21	140
Nov. 17	353.3	Mar. 13	2.5	34	310
Dec. 17	8.1	" 28	1.3	44	120
Jan. 20	24.1	Apr. 13	1.6	43	160
Feb. 25	40.4	" 29	1.2	31	160
Apr. 9	59.1	May 18	1.0	22	190
		NILOSYRTIS.			
Sept. 30	328.2	Feb. 15	1.0	25	170
Nov. 7	348.2	Mar. 8	2.6	33	330
Dec. 10	4.7	" 24	1.6	41	160
Jan. 17	22.7	Apr. 12	1.8	44	170
Feb. 24	40.0	" 29	0.4	34	50
Mar. 31	55.4	May 15	1.0	23	180
		THOTH.			
Sept. 30	328.2	Feb. 15	1.1	24	190
Nov. 7	348.2	Mar. 8	2.0	33	250
Dec. 10	4.7	" 24	1.8	41	180
Jan. 17	22.7	Apr. 12	1.9	44	180
Feb. 24	40.0	" 29	1.3	34	160
Mar. 31	55.4	May 15	0.9	23	160
		SABAEUS.			
Oct. 30	344.1	Mar. 3	3.0	30	420
Dec. 3	1.2	" 21	2.0	40	210
Jan. 10	19.4	Apr. 8	1.9	45	180
Feb. 14	35.2	" 24	2.0	35	240
Mar. 26	53.2	May 12	1.9	25	320

		HYBLAEUS.			
Nov. 7	348.2	Mar. 8	1.3	33	170
Dec. 16	7.6	" 27	1.0	43	100
Jan. 20	24.1	Apr. 13	1.1	43	110
Feb. 25	40.4	" 29	0.6	32	80
		HADES.			
Nov. 17	353.3	Mar. 13	1.9	34	240
Dec. 17	8.1	" 28	2.0	44	190
Jan. 21	24.6	Apr. 13	2.0	42	200
Feb. 25	40.4	" 29	0.8	32	100
		STYX.			
Dec. 17	8.1	Mar. 28	3.7	44	350
Jan. 20	24.1	Apr. 13	1.5	43	150
Feb. 25	40.4	" 29	0.6	32	80
Apr. 9	59.1	May 18	1.0	22	190
		TARTARUS.			
Oct. 12	334.6	Feb. 22	4.5	27	700
Dec. 18	8.5	Mar. 28	5.0	44	480
Feb. 1	29.6	Apr. 19	1.5	42	150
		ORONTES.			
Oct. 30	344.1	Mar. 3	1.6	30	224
Jan. 12	20.4	Apr. 9	1.1	45	100
Mar. 21	51.0	May 10	0.6	24	100

It is to be noted however that the narrowing is not continuous but fluctuating. One of the best illustrations of this occurred in the region bounded by the canals Ganges, Nilokeras, and Jamuna. This region lies between the chief of the northern marshes, Mare Acidalium, and the southern *maria*. It lies therefore exactly in the course that we should expect much of the water would take on its way from the northern polar cap to the southern hemisphere.

In Table II are given the date of observation, the diameter of the planet, the longitude of the Sun ⊙, and the breadth of the Ganges and Lunae Lacus in miles. Every observation made of this region is entered. When they were invisible, as indicated by the —, it was not from bad seeing, except perhaps at the very beginning and end, but from martian conditions, probably clouds. In the first observation of December 1, Ganges was narrower at its southern termination, and did not quite reach Aurorae Sinus, in the second, made a little over an hour later, it fell nearly 300 miles short of it. This change is ascribed to cloud. On December 4, January 5, and April 21 the narrowing near Aurora was very marked. February 5 it was invisible because too near the limb. Lunae Lacus was generally of well defined breadth and connected with Acidalium, but on September 17 it was large and indefinite in outline. On February 5 and 7 it was quite separate and brownish, and on April 21 was joined to Acidalium only by a narrow line. In the last two cases its equatorial diameter was greater than its polar.

The shading was generally too faint to show color. Possibly it was due to moist ground. As in a number of other cases, it will be noted that the canal first appears narrow, then rapidly broadens, and then slowly narrows again.

TABLE II.

GANGES AND LUNAE LACUS.

1913	Diam.	⊙	G	L	1914	Diam.	⊙	G	L
Aug. 6	6″.5	296.6	—	—	Jan. 5	15″.0	17.1	4-1200	1200
Sept. 13	7.6	318.7	50	—	Feb. 5	12.4	31.4	i	500
17	7.8	320.9	400	1	7	12.2	32.3	—	6-900
Oct. 19	9.5	338.3	—	—	8	12.0	32.8	50	800
Nov. 26	12.7	357.8	120	—	10	11.8	33.7	—	1000
28	12.9	358.8	—	600	12	11.6	34.6	300	700
Dec. 1	13.2	0.3	3-500	600	Mar. 13	8.8	48.3	600	300
"	"	"	700	800	20	8.4	50.6	700	700
2	13.3	0.8	1600	1600	21	8.3	51.0	—	—
3	13.4	1.2	600	900	Apr. 21	6.5	64.2	2-400	6-900
4	13.5	1.7	3-600	900	May 29	5.3	81.6	—	—
30	15.0	14.2	—	1100	June 3	5.2	83.4	—	—
31	"	14.7	700	700					

It now only remains for us to draw whatever conclusions may seem probable with regard to these interesting objects, since it does not seem likely that any further light on their nature will be gained, at least as far as Mars is concerned, before the next opposition. It is believed that Lambert was the first to suggest that the reddish areas of Mars owed their color to vegetation. The suggestion that they were simply desert regions, while the dark areas and canals were due to vegetation, instead of water, was of comparatively recent origin.*

The writer believes that both types of lunar, as well as the martian canals, are due to vegetation. Indeed no other explanation seems possible when we stop to consider the facts. It does not seem possible that the lunar canals can be artificial, but the martian ones act differently from them in some respects, notably in their great variability, and if we may so express it, their apparently unnatural conduct, some appearing during one martian year, and others during another, at the same season. They act indeed almost as if there were some guiding intelligence behind them. Their uniform breadth, straightness, and occasional circular or elliptical forms are waived as arguments, because perhaps they are not really quite as regular as they appear, and because we find something very similar upon the moon. It is to their changes that we should especially direct our attention, and regarding which future observers should secure all possible data.

* Science 1888 **12** 82.

The martian atmosphere as far as its permanent constituents are concerned we know to be more or less rarefied. The amount of water vapor it contains on the other hand, in the presence of ice or water, depends exclusively upon the temperature. When the polar caps are melting rapidly therefore, and large liquid surfaces present themselves in the marshes, the atmosphere may, at ordinary terrestrial temperatures, be composed in a very large part of water vapor. At other times it may contain very little. The question of the martian seasons should be considered very carefully in any future attempts to detect the presence of water vapor by means of the spectroscope. One of the most careful and painstaking attempts hitherto made to secure evidence of of the presence of water vapor upon Mars was made during the dry season upon the planet.

Assuming that the canals are due to vegetation, we must further assume either that they are, or are not artificial. Assuming first that they are, we shall find that three attempts have hitherto been made to explain them.

(*a*) They were formerly supposed to be fertilized by invisible irrigating ditches or conduits. The difficulty with this idea is to maintain the necessary circulation of water. Professor Lowell when he adopted it suggested that the circulation was maintained by pumping. To this it is replied that that would require altogether too great an expenditure of energy, when the problem is reduced to figures. Indeed the formation of the polar caps is sufficient of itself, as Professor Douglass long ago pointed out, to show that the planetary circulation must be in large part atmospheric, and not due, except at the very beginning, to artificial canals. If it is atmospheric in part, it might as well be wholly so.

(*b*) It was suggested a few years ago* that the canals consisted simply of a growth of dark vegetation like trees or bushes upon grassy or semi-arid plains of a lighter color, all being supported by water derived from the natural aerial circulation of the planet. The beauty of this plan consists in its extreme simplicity, and the fact that such canals actually exist upon the earth on a small scale, constructed in this manner for good and sufficient reasons, though presumably not the same ones, namely protection for herds of cattle against winter storms. The difficulty however is to account for the shifting of the canals.

(*c*) In an atmosphere saturated with moisture, fogs should readily form at night, which would disappear to a large extent in the daytime. This frequently occurs at certain seasons, notably the early autumn, upon the earth. Since the surface of Mars seems to be extremely flat, it is suggested that these fogs instead of being permitted to exhibit a

* Harper's Monthly Magazine 1908, 192.

general accidental distribution, might be localized night after night in certain selected regions artificially. It is known as a laboratory experiment that fog can be induced to form in a saturated atmosphere, if furnished with a sufficient number of minute solid nuclei on which it may condense. It is suggested that it might be practical to do this, either by electrifying the air in certain regions, night after night, or by some such similar means upon a large scale on Mars. Where the fogs condensed at night vegetation would appear by daylight, when the fog cleared away. As a matter of observation fog is often seen on the sunrise limb of the planet, and it does in general clear away as the sun rises higher upon it. Occasionally however it persists throughout the day, particularly near the northern boundary of certain dark areas, such as Sabaeus and Cerberus, as noted in our Report No. 3. A certain shifting of the fertilized areas from time to time would doubtless insure improved crops if the water supply were insufficient to fertilize the whole, so that we can readily see an object for it. If on account of accelerated growth due to greater moisture the vegetation ripened, dried up, and died first, along the medial line of the canal, we can account for the apparent duplications sometimes observed. In our Report No. 4 we saw that marshes did actually appear to advance and change their positions in this manner, following clouds or fogs produced by evaporation from their surfaces. The difficulty with this explanation is the question whether it would be possible in a saturated atmosphere overlying a uniform surface, to select any locality at will over which a fog should be produced.

Assuming now that the canals are due either to vegetation or to any other cause, but that they are *not* artificial, we find that to frame a plausible hypothesis that will explain the changes hitherto observed is a matter of extreme difficulty. The only natural agencies at our disposal capable of producing such changes, seem to be either volcanic or meteorological. The latter appear to be the more promising, although many of the lunar canals lie along volcanic cracks. We may modify either (*b*) or (*c*) by substituting for intelligent design the accidental shifting of the winds, bringing more moisture, and causing certain kinds of vegetation to flourish. To support a single canal 2000 miles long by 500 miles wide would seem to require too much volcanic activity. Such suggestions involve added hypothesis and are therefore unsatisfactory. It may fairly be said that no satisfactory explanation, based on purely natural causes, has as yet been suggested to account for the changes observed on Mars.

It is not considered by the writer however that any of these hypotheses are sufficiently well supported as yet, to justify us in such a momentous conclusion as the decision that intelligent animal life now exists upon Mars. To the majority of scientific men probably nothing short of the reception of a series of intelligible signals would be considered sufficient evidence to lead to such a decision. These theories of the canals are mentioned here, not because the writer feels assured that any one of them is right, but simply because (*b*) and (*c*), at least seem to him, to account for the observed facts more readily than any of the others, and because he feels that any theory, even a false one, is better than none at all. To the direct question so often asked, however, is Mars inhabited by intelligent beings, we must, and probably long shall be obliged to reply simply, possible but not proven.

Turning now from mere speculation to plain fact, the latitude of the southern boundary of the northern snow cap between March 20 and April 15 increased only from 71°.2 to 72°.5, showing a very slow rate of melting, of less than 50 miles in 26 days. There was thought to be a slight accession to its diameter between March 21 and 26. On the latter date at 12^h G.M.T. it was suspected that the southern polar cap was as bright, or almost as bright, as the northern. This might mean snow near the south pole. If so, it was the first we had seen. It lay in longitude 280°, latitude −60°, and the martian date corresponding was May 12, which for their southern hemisphere corresponds to our November. The south pole itself and all of the planet south of latitude −71° was hidden from view in the polar night:

Cloud was less marked in the extreme southern latitudes than during the previous months, and often the region was found to be perfectly clear. Indeed little cloud was seen anywhere excepting on a few dates. The southern *maria* retained their green color in some places, and Acidalium was occasionally reported as blue. Comparatively few canals were seen, doubtless on account of the great distance of the planet. The following however were observed.

Mar. 20 **1** Nilokeras, Jamuna, and Ganges as one broad hazy band.

Mar. 21 **1** Three broad very faint shadings radiating from Acidalium towards Sabaeus, Margaritifer and Aurora. Doubtless they will later concentrate into canals.

Mar. 26 **6** Orontes, Typhon, Euphrates, Hiddekel, Gehon, Deuteronilus, and Ismenius lacus.

Mar. 31 **5** Nilosyrtis, Thoth, Phison.

Apr. 9 **4** Cerberus, Hades, Eunostis, Tartarus and Trivium Charontis.

Apr. 15 **3** Titan.

This last drawing shows Sinus Titanum considerably to the south and east of Schiaparelli's position, in longitude 160°, latitude −32°.

TABLE OF DATA.

No.	1914	⊙	M.D.	Long.	Lat.	Sun	Diam.	Seeing
		°		°	°	°	″	
63	Mar. 20	50.6	May 10	60	+5	+18	8.4	7
64	21	51.0	"	43	"	"	8.3	8
65	26	53.2	12	328	+6	+19	7.9	10
66	"	"	"	342	"	"	"	10
67	"	"	"	0	"	"	"	8,9
68	31	55.4	15	296	+7	+20	7.6	11
69	Apr. 9	59.1	18	226	+8	"	7.1	9
70	12	60.6	20	160	+9	+21	7.0	—
71	15	62.0	21	160	"	"	6.8	8

AN INVESTIGATION OF THE 9.4-INCH OBJECTIVE OF THE SHATTUCK OBSERVATORY OF DARTMOUTH COLLEGE.

H. T. STETSON.

In the remounting of the equatorial telescope of the Shattuck Observatory provision was made for a new flint lens, interchangeable with the original flint, its use converting the Alvan Clark visual into a photographic objective of 320cm focal length. Shortly after the change was made a series of extra-focal plates was taken for an investigation of the aberration errors of the lens.

The now well known method devised by Hartmann for determining the zonal errors of astronomical objectives has been reviewed somewhat extensively in the *Astrophysical Journal* by Plaskett,* and by Fox,† and needs no detailed description in this connection.

For the investigation of the 9.4-inch (239mm) objective of the Shattuck Observatory the screen used in front of the lens had 44 holes distributed in zones ranging from 28mm to 115mm radii. The variations in the focal readings for the separate zones are shown in Table I, where the numbered columns represent the results for separate pairs of plates,—the final column giving the mean for each zone. These results are shown graphically in the curve of zonal errors, Fig. 1. The radii of the zones are drawn as abscissae and the corresponding focal readings as ordinates. The separate curves numbered 1, 2, 3, 4, represent the result of four independent determinations and are all in general agreement, giving the mean curve indicated in heavy line. Examining the mean curve we find the two widest departures occurring at R = 56mm and R = 84mm respectively. Otherwise a slight increase

* Ap. J. **25**, 195, 1907.
† Ibid **27**, 238, 1908.