

Second Period, 1830–1877

The second period of our study begins with the great areographic work of Beer and Mädler, the first continuous observations that allowed the authors to draw up a geographical chart of Mars. With these observations, we also begin to gain some physical knowledge of the planet. The difficulties and uncertainties do not disappear; but science provides a solid basis for what follows.

Christopher Columbus was happy when he was halted by the American continent during his voyage of circumnavigation beyond Asia. Mars does not have its Christopher Columbus. He achieved fame by the simple fact of touching America; a phalanx of astronomers has been busy for more than a century studying their celestial continent. But Beer and Mädler deserve to be remembered as the true pioneers in this new conquest—though preceded by the eminent observers already discussed, among whom William Herschel and Schröter hold pride of place. Beer and Mädler published their observations of Mars in the *Astronomische Nachrichten* in 1831, 1834, 1835, 1838 and 1839, and combined their studies in a work entitled *Fragments sur les corps célestes du système solaire*, French edition (Paris, 1840) and *Beitrag zur physichen Kenntniss der himmlischen Körper im Sonnensysteme*, German edition (Weimar, 1841). These two editions are identical. From the French edition I have taken all the important data and drawings.

The instrument they used for their studies of Mars, as well as their great map of the Moon, Beer and Mädler's refractor was a 3-3/4-in (95^{mm}) refractor, analogous to that mentioned above when describing Arago's observations. This is a relatively modest instrument, but it was made by Fraunhofer and was therefore excellent; moreover the observers were particularly skilful, meticulous, and patient. We often say that the man is as important as his telescope.

1830–1841.—Beer and Mädler¹

In 1830 Mars made one of its closest approaches to the Earth. The opposition was perihelic. This was the main reason why the observers began their series of observations, which we will now examine. Here is a résumé of their great work:

Our chief aim (wrote the authors) has been to make an exact determination of the period of rotation, about which opinions differ appreciably. From his observations of 1778 to 1780, Herschel deduced a period of $24^{\text{h}} 39^{\text{m}} 21^{\text{s}}$. Huth of Mannheim gave $24^{\text{h}} 43^{\text{m}}$, and the observations made by Kunowsky in the winter of 1821–1822 gave $24^{\text{h}} 36^{\text{m}} 40^{\text{s}}$, though none of them achieved an exact determination of the period. In Herschel's observations, the number of complete rotations was doubtful, and in particular he did not take aberration and phase into account, while the data of the two others depended upon the results of one opposition only. From one opposition it is important to deduce the rotation period accurately enough to allow the number of complete rotations between one opposition and the next to be worked out with certainty. The mean error of the first result should not exceed 30 to 40 seconds, an accuracy which we hoped to exceed during the close approach of Mars to the Earth.

At the same time, prolonged observations ought to show whether or not the patches on the surface of Mars are variable in form, size, and colour; if they have individual movement, and if they should be regarded as condensations or shadings similar to our cloud or as features fixed to the surface. The preceding observations have already provided the important data listed above. As early as 1716 Maraldi, in Paris, made out the white patch at the north border of Mars; this has been confirmed by almost all subsequent observations. A patch is also seen at the south border of the planet, and sometimes it even happens that these two patches are visible at the same time.

Even before Herschel, it had been suggested that these patches are due to snows, similar to those at the poles of our planet. Several people have considered that the patches form on slight elevations which project from the mean border of the planet, while others have very reasonably regarded the great brightness of the patches as being due to this cause. Most observers also regard the other patches as variable; Kunowsky, at Berlin, maintains however that they are permanent. Several observers have called attention to particular brilliancy at the east and west limbs of the planet, and this suggests the idea of narrow menisci surrounding the globe, particularly in these areas. The contradictions shown by observations made with different instruments, or—if you like—the physical changes which take place over periods of time, are consequently very considerable.

From 10 September to 20 October 1830, we made observations on 17 nights of varying degrees of good seeing; during this period all the areas of Mars visible at this opposition were studied several times. We obtained 35 disk drawings. We did not use the micrometer, because the weakness of the patches made accurate measurements impossible; and an appreciation after the different parts of the disk had been studied made us certain that the great white patch at the south pole, which has been excellently seen ever since the start of our observations, could be used to show the meridian dividing the disk in half. A definite time elapsed before the main patches, at first vague and indeterminate, presented perfectly distinct forms. The drawings were made immediately, at the telescope. The co-ordinates of the most distinct points were determined and represented on the drawing; the rest of the detail was filled in later.

The most characteristic patch which struck the observers was a small round one, which appeared to be hanging from an undulating ribbon, and which is shown on drawings 1, 2, 3, 14, 15, and 16 of 1830 and 4 of 1832 (see Fig. 1). This patch is the

¹*Fragments sur les corps célestes du système solaire* (Paris, 1840), *Beiträge*, etc. (Weimar, 1841) and *Astr. Nach.*, 1831 to 1842.

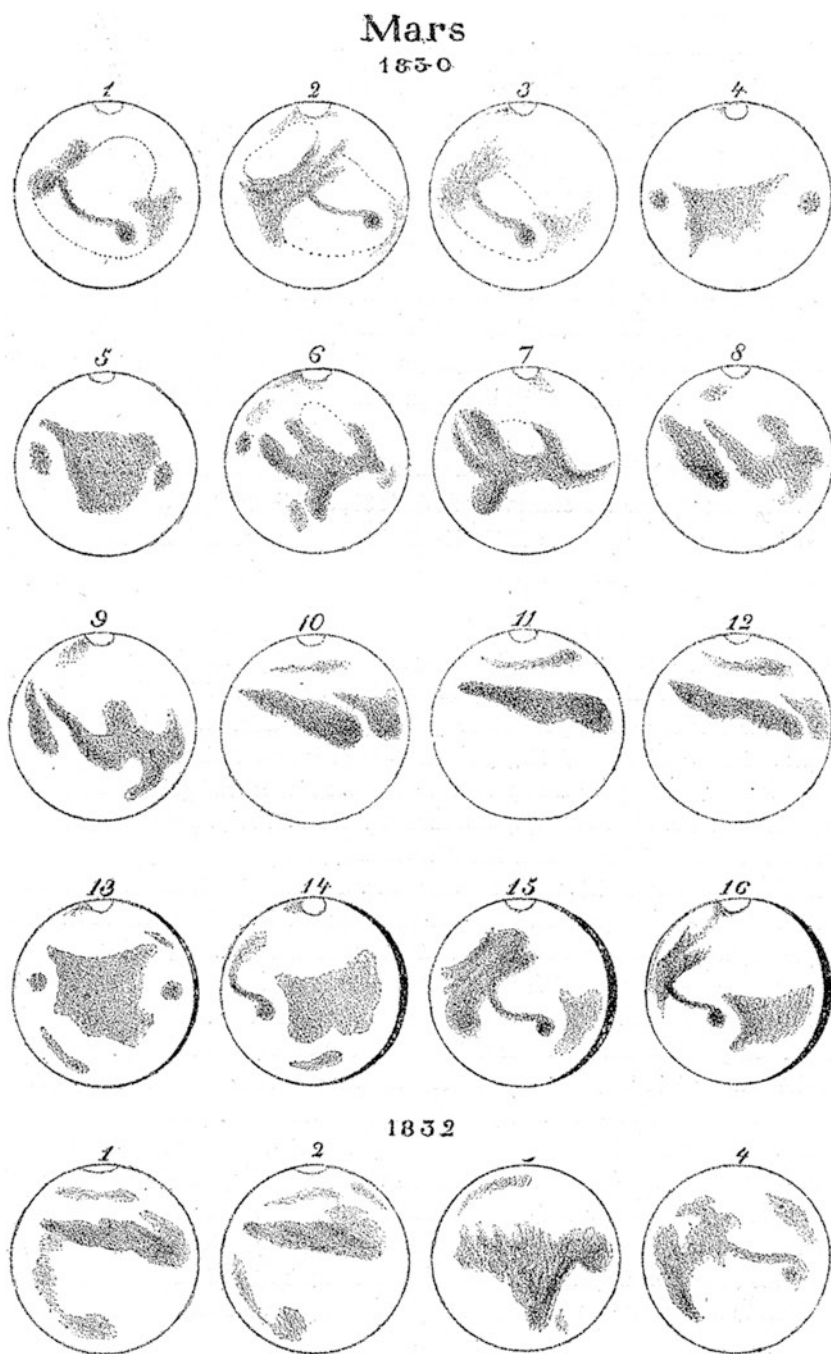


Fig. 1 Drawings of Mars by Beer and Mädler in 1830 and 1832

Meridian Bay of my own chart, near Herschel II Strait. But let us go back to the observers themselves.

[Note: the *fig.* numbers below refer to the small drawings in our Fig. 1.—WS]

A small patch of a very pronounced black was so strong—from the very first observations—and so well marked, and so near to the assumed equator, that we believe we should choose it as the reference point for the determination of the rotation period.² At 9^h 30^m (*fig.* 1) it appeared to be 7° of arc from the central meridian of Mars. On the 14th, we saw it from 10^h (*fig.* 2) to 15^h 15^m (*fig.* 4), advancing from the eastern hemisphere to the region of the western edge; five drawings of it were made. On the 15th, at 8^h 50^m (*fig.* 5). It was no longer visible; neither was it seen at 13^h 15^m. On the 16th, at 9^h, it was not visible; but at midnight it had returned, and was very distinct. We were then able to deduce the rotation period: it was clear that from the 19th and the following evenings, until the middle of October, the patch would not be observable during suitable hours at night. On the 19th (*figs.* 6 and 7), with a perfectly distinct image, it showed up as two reddish areas (bounded by these points in the general drawing), similar to the beautiful red colour of twilight on Earth. After an hour it had already become weaker; later it was again very clear, but never regained its former distinct red colour. Moreover, at 10^h 6^m it showed up as a small patch *g*, not really dark, by the side of the point *f*, but slightly later it ceased to be visible. Probably it had been seen only because of the great steadiness of the atmosphere; and when it reappeared it was always joined to *f*, since the gap separating them was always very difficult to distinguish.

In the observations from 26 September to 5 October (*figs.* 10 to 12), several reasonably dark patches were seen extended over the disk in the form of a zone; they were sharply bounded, particularly to the north, where they made a very pronounced contrast with the areas which were free of patches and showed up as purely bright. A salient from these patches at the point *m* was broad and distinct, particularly on the north side; to the south side; on the other hand, it was so narrow that we could scarcely see it. The patch *PM* was very black, particularly at the western extremity *p*, which was rounded. Between this patch and the white cap at the south pole we consistently saw a band *q*, quite broad, but of a pale tint. From 5 to 12 October clouds prevented us from making any observations. It was only on the 13th that we again saw a small dark patch near the west border (*fig.* 13); and in our observation of the 14th, at 7^h 37^m (*fig.* 14) we were confident that it was in fact the patch *a* of our first observation. During the following evenings it was particularly important to time its transit across the central meridian as accurately as possible; this we were able to do on the 19th and 20th, under remarkably steady atmospheric conditions (*figs.* 15 and 16).

These observations truly represent the first methodical attempt at studying Martian geography. The chart which Beer and Mädler constructed from these invaluable observations is given in Fig. 2. It reproduces the two hemispheres as they drew them, and presents an overall picture of the planet as obtained from their previous observations between 1830 and 1839. (This is the same diagram as is shown in the memoir which Beer and Mädler wrote.) It is, in fact, the first geographical chart ever drawn of the Martian world. It remained the only one for 30 years, and thus became the classical reference for all later observers.

The northern hemisphere chart seems to contain an error. The extremity of the patch *ehf* (the patch which is none other than the Hourglass Sea), which emerges from the southern hemisphere between longitude 62° and 73°, is traced in the

²This very distinctive spot was first seen by Schröter on 3 September 1798 (see his drawings in Fig. 52 above). It was also observed on the following day, 4 September (Fig. 53) and on 24 October. It was also shown on two drawings by Kunowsky in 1821–1822 (Fig. 65)—but what differences of aspect!

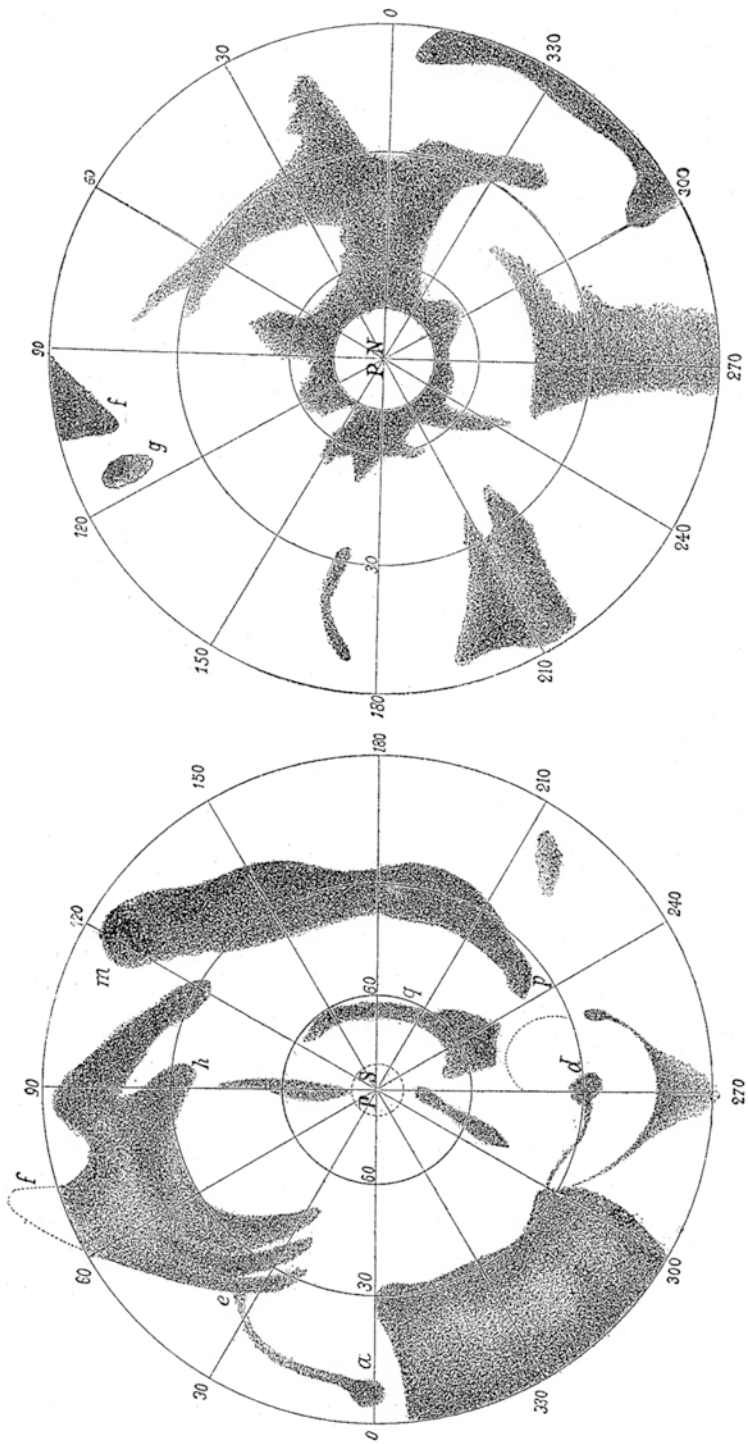


Fig. 2 General chart of the planet Mars, constructed by Beer and Mädler in 1840

northern hemisphere between 92° and 110° . Some mistake must have been made. It is necessary to trace the continuation between 62° and 73° to line up with the feature shown coming from the southern hemisphere.³

The Berlin astronomers chose the small round spot *a* as the zero meridian. I have followed this choice in drawing my chart, which is why I have proposed to name it the Meridian Bay.

Beer and Mädler reckoned longitude from right to left, assuming the south pole to be at the top. I reckon it in the contrary sense, i.e. from left to right, in the sense of the movement of rotation, meridian 0° passing in transit before meridian 10° .

These authors subsequently calculated the rotation period as derived from their observations. From the observations of 1830 they found $24^h 37^m 9^s.9$; from 1830 to 1832, $24^h 37^m 23^s.7$; 1830 to 1835, $24^h 37^m 20^s.4$. The second value seemed to them to be the best, and accordingly they adopted it. To resume their own account:

It is impossible to make an accurate comparison with the observations made nine years earlier by Kunowsky, in which the same patch was very distinct. And yet Kunowsky's work evidently confirms the consistency of the patches which we have seen, at least for *a* and also for the strongly curved arc which extends in a serpentine fashion from *a* to *e*. The patches further south were not seen when unfavourably placed, and some were not seen at all; also, Kunowsky showed others to the north which were no longer visible in 1830, while the usual patch was seen between November 1821 and March 1822 just as we observed it. The same was true between 10 September and 20 October 1830. Therefore, there is no chance of it being due to clouds.

For the rest—particularly if one observes the planet for the first time, and does not repeat the observations often—it is easy to imagine variations in the patches and attribute them to real physical changes in the atmospheric state of the Earth and perhaps also in that of Mars. This is why error of detection and drawing—small in themselves but considerable in relation to the object being studied—are inevitable. A patch approaching the limb may disappear before the moment when it actually reaches the limb (doubtless due to the effects of the planets atmosphere, as with Jupiter). Also, remember that during any opposition it is rare to have two absolutely identical views of the same hemisphere. Moreover, the opposition distance varies; the planet does not often approach the Earth as closely as it did in 1830, and with greater distances it is necessary to use higher magnifications and more powerful optics than most of the earlier observers had at their disposal.

The white south polar patch was clearly shown in each observation, even when the atmospheric conditions were unfavourable, but its size has been very variable. Before 31 August, when we made a superficial observation, it extended to $1/8$ to $1/10$ of the diameter of Mars. On 10 September, an estimate (made in the east–west direction) gave $1/10$; on 15 September $1/16$; on 2 October $1/18$; on 5 October $1/20$; and on 20 October $1/15$. Assuming a value of $1/9$ for 31 August, we have, for the days indicated, in the season corresponding to the months of June and July in our northern hemisphere, the following boundaries for the polar cap, assuming that the south pole lies in the centre of the cap:

31 August	$83^\circ 37'$	latitude corresponding to Earth	16 June
10 September	$84^\circ 15'$	latitude corresponding to Earth	23 June
15 September	$86^\circ 25'$	latitude corresponding to Earth	26 June
2 October	$86^\circ 50'$	latitude corresponding to Earth	7 July
5 October	$87^\circ 7'$	latitude corresponding to Earth	9 July
20 October	$85^\circ 59'$	latitude corresponding to Earth	19 July

³All astronomical treatises written since 1840—even Arago's excellent *Astronomie populaire*—have reproduced this chart without noticing the error.

This shows that the cap shrank until the Martian season corresponding to our mid-July, and then it began to increase again, which lends strong support to the hypothesis that the Martian pole is truly snow-covered. Moreover, almost all observers agree that the size of the patch is variable, and at times of greatest cold is considerably larger than we saw it in 1830.

The northern hemisphere of the planet, or rather as much of it as could be seen in 1830, showed no sign of any white patch, although it was midwinter in that hemisphere. This can be explained by the strong inclination of the axis of Mars, which, at the same time, receives indirect confirmation.

The observers here give a table of their drawings, and the aerographic longitudes of the patches.

At the opposition of 1832, atmospheric conditions were so consistently unfavourable, and the greater distance of the planet had so mischievous an influence, that the observations obtained were few in number and imperfect in quality. Of 16 attempts to draw details on the disk, only four merited comparison with those of 1830 (they are shown at the bottom of Fig. 1). The patch *a*, so remarkable and so characteristic two years earlier, could be recognized at once, even when it was well away from the centre (16 December).

However, these observations, even though not numerous, seem to be sufficient to show that the visible patches have not changed their positions since 1830. This was quite evident from the three principal patches, in particular the region *PM* and the weak band *q*. The latter was so close to the southern border that it was seen only with the greatest difficulty, and the features, which were even closer to the poles, included in the drawings of 1830, could not be seen at all—for reasons which are easy to understand. The south pole was not on the limb on 20 November, according to Herschel's elements, but 10° from the apparent border; and thus most of the bright part, so glittering in 1830 [the text says 1840, but this is surely a misprint for 1830.—*PM*] was only very feeble; it was seen with certainty only twice (20 November, 9 h, and 23 November, 8^h 14^m). During all other evenings it was uncertain or invisible. On the northern hemisphere, between approximate longitude 180° to 230° and latitude 0° to 35° N., we twice saw a weak band, broad and concave toward *PM*, but only its northern extremity was distinct. Red glimmers were often seen between this band and *PM*. In general the light of the northern hemisphere, in the part containing no patches, did not seem so clear and uniform as it had done in the two preceding years. No trace could be seen of the whiteness in the region of the north pole (this pole was still hidden from view).

The oppositions of 1834–1835 and 1837 were just as unfavourable as the two preceding ones from the point of view of atmospheric conditions; moreover, the opposition distance of Mars was approaching its maximum (Fig. 3).

The results of our observations would have been insignificant had we not had the use of the large telescope established in 1835 at the Royal Observatory in Berlin.

This instrument, in size exactly the same as that at Dorpat, allowed the use of a magnification at least double that of our telescope, and it collected six times as much light; a very convenient mechanism gave it a movement which, without any help from the observer, followed the planet in the sky. From 12 January until 22 March, over 15 partly clear nights, we obtained 32 drawings which related particularly to the northern hemisphere, though much less detail was shown than had been recorded in the southern hemisphere in 1830. In all the observations, without exception, the white patch at the north pole was visible with a degree of clarity which we never recalled having seen at the south pole; it was also considerably larger than the cap in 1830, and, particularly during the months of January and February appeared so much more distinct than the other parts of the globe that at first glance it was easy to suppose that in this place the planet was covered by another planet.

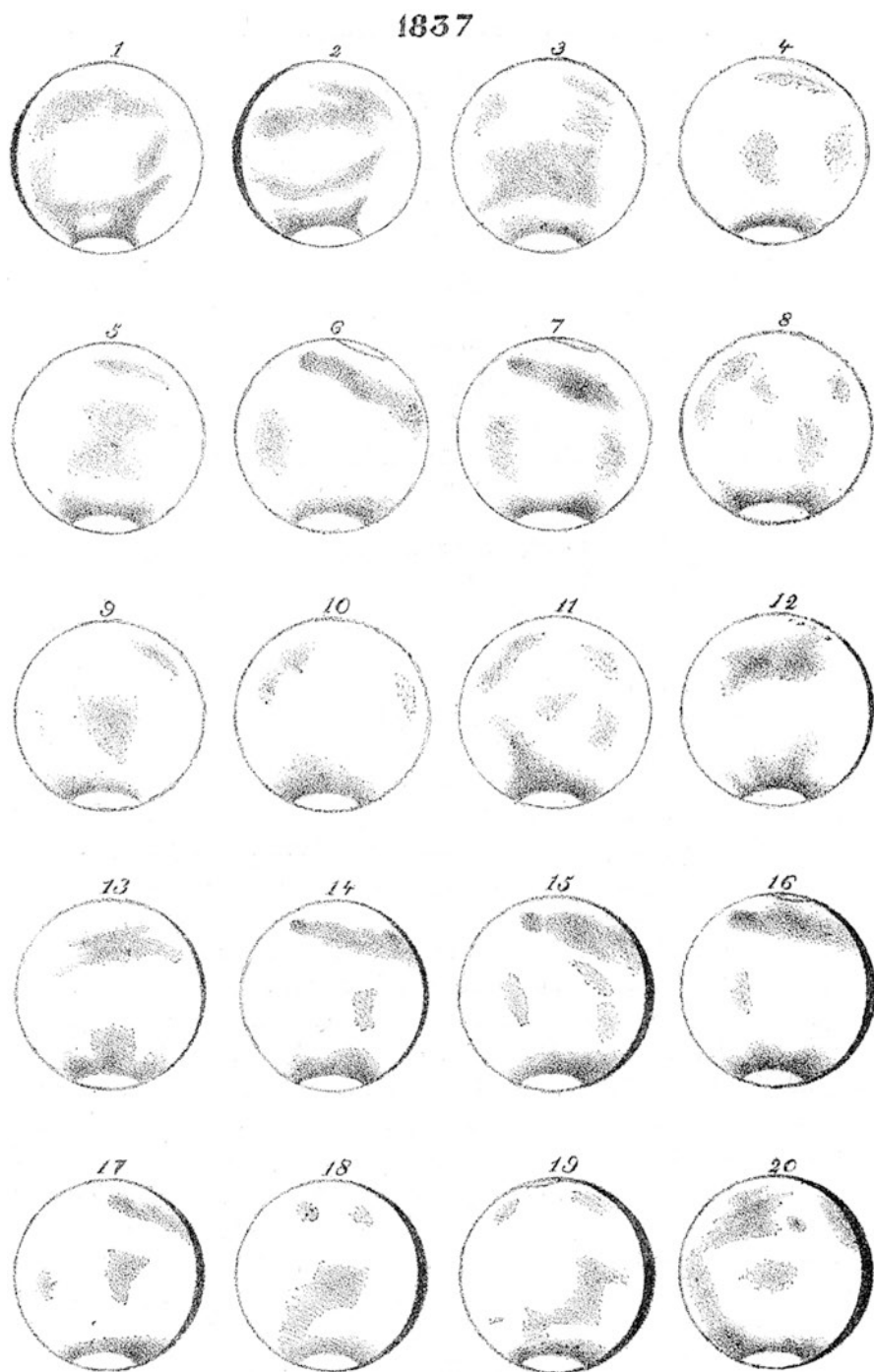


Fig. 3 Drawings of Mars, made by Beer and Mädler in 1837

The real size of the south polar patch, in February and March 1837, was several times greater than it had been in September and October 1830.

In the first observation, on 12 January, the north polar patch was so well marked that its size could be estimated with certainty; it covered 0.27 of the planets diameter along the border, and its breadth was 0.13. The first figure made us conclude that the semi-diameter was $15^{\circ}.7$ of the globe of Mars, or a limiting latitude of $74^{\circ}.3$; the second—adopting the elements of rotation given by Herschel, and assuming the pole to lie in the middle of the circular patch—gave a north latitude of $78^{\circ}.7$, since the north pole was $18^{\circ}.13$ inside. The first of these figures is less than half as reliable as the second. In any case, it is evident that at the opposition of 1837 the north polar patch was considerably larger than the south polar patch had been in 1830, and much smaller than the south polar patch in 1837. In the following observations its size does not seem to tend to lessen; this can be stated with certainty, and it is only the sharpness of its boundary in which there is any change; it becomes feeble after opposition.

With the micrometer, we set out to measure the position angle of the white patch, so as to obtain the data necessary for a direct examination of the position of the axis of Mars. The bad weather partly prevented this from being done. The few measurements, which we were able to make, showed only that in every case the eccentricity of the polar patch was very slight. The distance from the pole was estimated as 4° in 1837 for the northern patch and 8° for the southern, but with great uncertainty.

However, we cannot fail to mention that on the few occasions when we were able to distinguish a trace of the south polar patch, we found that it was not directly opposite to the north polar patch. On 7 February, at $16^h 14^m$, it was displaced by about 12° from the point opposite to the north patch, and a $18^h 16^m$ it was some 8° to the east; on 7 March, at $10^h 34^m$, it was displaced by 5° toward the east; finally, on 18 March at $7^h 56^m$, it was 3° to 5° to the west.

Of all the patches in the southern hemisphere observed with considerable precision in 1830, only one, marked *PM*, could be recognized with certainty. We first saw it on 7 February, at $16^h 4^m$ (fig. 6) with certainty; subsequently, on 28 February, at $6^h 49^m$ (fig. 7), and on three observations made during the night of 7 March (figs. 14, 15, and 16); finally, it was slightly less well marked on 10 March, from $7^h 7^m$ to $9^h 22^m$, and on 11 March, at $8^h 22^m$ (fig. 17). The aerographic latitude of the western extremity of *p* was determined, from eleven observations, as $+43^{\circ} 29'$; in 1830 we had found it to be between 39° and 42° from three observations, and this close agreement indicates that the two patches are identical. An attempt to link the longitude observed this year with that of 1830 gave a rotation period of $24^h 37^m 29^s.0$; This result, although sufficient to confirm the identity of the patches, cannot be used to correct the rotation period previously calculated, because of the strongly eccentric position of the patch. However, it is definite that there is no error in the number of complete rotations.

A second patch, marked *efh* on our chart, was recognized on 12 January and 22 February, and also on 12 March; but no point on it was sufficiently well marked for us to draw it with real accuracy.

This comment is curious, and worthy of close attention, because this patch *efh* is the Hourglass Sea, which is generally so clear and so distinctive. For instance, during the last opposition (1890) it was striking each time it lay on the hemisphere facing us.

As for the opposition of 1839, all the observations were made with the large telescope of the Royal Observatory. Mars requires a high magnification and, in consequence, great atmospheric calmness. This last condition was rarely met with in the winter of 1838–1839, which is why the observations were not numerous; 62 percent of the southern hemisphere was hidden from view, so that a great part of it was unobservable, and no patches in this hemisphere could be distinguished with precision.

The ten drawings published by Beer and Mädler for this year, 1839, are so pale and indefinite that to reproduce them here would be absolutely useless.

Here are the general conclusions, which they draw from their observations of the poles and of the seasons.

The colour of the polar patches, whenever they could be seen distinctly, was always a pure, brilliant white, in no way similar to the colour of the other parts of the planet. In 1837 there was a time, during the observing period, when Mars was completely concealed by cloud—apart from the polar patch—which remained distinctly in view. This great difference also means that the extent and figure of the polar patch can be evaluated with much more certainty than for any other part of the planet, and it may even be possible to make successful micrometrical measurements of it with powerful instruments.

We must also note the diminution and the growth of these patches, which however keep to the same form; this indicates that normally the polar patches are central over the true poles, or at least only a few degrees away. We have already indicated the variations of the southern cap; the seasons of Mars are repeated regularly, and we have expressed the Martian seasons in terms of the seasons of the Earth. The north polar cap showed the following variations:

1837	Jan. 12	Limit	74°18'	season corresponding to	4 May
"	Mar. 7	"	76°	"	4 June
1839	Feb. 26	"	78°33'	"	7 June
"	Apr. 1	"	80°48'	"	4 July
"	Apr. 16	"	82°20'	"	12 July
"	May 1	"	81°	"	20 July

According to this, the minimum for the two patches falls about 1/18 of a year after the summer solstice, which corresponds to our 12 July (and 12 January) on the Earth. But while the southern cap shrank to 6° diameter, that at the north pole never decreased below 12° to 14°, so that the surface area of the north cap was then five times as great as that of its southern counterpart.

Reciprocally, in 1837, during its winter (the days of observation corresponding to our 4 and 10 December) the south polar patch was so large that we could distinguish it even when the pole was 18° away from the limb. At that time the cap extended down to latitude 55° and had a diameter of 70°.

We have never seen the same thing at the north border, when the southern hemisphere is having its summer. The variations of the southern cap are considerably greater than those of the north cap.

Because of the position of the axis of Mars, the south pole is exposed more directly to the Sun during the period when the amount of light and heat which it receives is 0.52 of that which we receive on Earth; with the north pole, the corresponding figure is only 0.37. But over a full year this difference is completely compensated for by the greater length of the winter; but even for the other seasons we find partial compensation. The length of the summer half-year in the northern hemisphere is greater than that in the south in the ratio of 19 to 15; however at the points of greatest heat and greatest cold a very considerable difference still remains, because of the inclination of the axis. Accordingly, the south pole has hotter summers and colder winters than the north pole, and the difference is more marked than in the case of the Earth. With our world, the difference is scarcely appreciable—but the eccentricity of Mars orbit is five times greater than that of the Earth.

The differences, which we have noted, are in perfect accord with the idea that the white patches represent a precipitate analogous to our snow; it is indeed impossible to reject this explanation, which is confirmed in so convincing a manner. Seen from the distance of another planet, our Earth would show similar phenomena; with us, however, the two hemispheres are less unequal.

The other patches on the planet appear to be surface features. At the distance of Mars, we could under no circumstances make out the shadows produced by mountains, however great their heights (the spherical form of the disk is always preserved). These shadings must therefore be due to differences in reflecting power, which again recall the differences between the reflectivity of different places on the Earth. It was during the opposition of 1830 that we found it possible to delineate the patches in the southern hemisphere—those between the equator and latitude 45°—with the greatest precision; however, the darkness and relative clarity of the patches does not remain constant, as was shown, at least, in 1837 and 1839. Thus although the patches themselves are not analogous to our clouds, they sometimes present certain optical analogies to our own cloudy condensations—because they are better defined, sharper, and more intense during Martian summer, vaguer, paler and more ill-defined during the winter.

We have sometimes seen reddish colouration in certain particular regions on the disk. To the naked eye Mars appears as the reddest star in the sky. With the telescope, this ruddiness does not show up to the same degree; rather the general colour is more or less yellowish-red. The colour in these regions recalls that of a beautiful sunset on our Earth.

If all this has already led us on with certainty toward admitting that Mars has a very appreciable atmosphere, similar to that of the Earth, then it also explains the comment we have made that the patches seem to soften or completely vanish when approaching the limb. As we have often seen, the limb brightness appears to be due to the presence of the Martian atmosphere.

There is no objection to this idea from the contention that the atmosphere of Mars would produce refraction when the planet occults a star or other celestial body. At the times when Mars is closest to us, an arc of longitude of 20° on its globe would appear as an angle of 0".30. At such a distance the refraction would be completely undetectable, even if at the surface it were considerably greater than on the Earth.

The observations we have made indicate great variations in size, form, and intensity of the sombre patch adjoining the north polar zone, and there is probably a plausible explanation for this. If the polar patches are genuinely made up of snow, their shrinking with the onset of summer would be by continual melting and evaporation, if, as we may assume, the thickness of the polar snow is very considerable; but then those parts of the surface close to the evaporating snow will become extremely humid. Now, a wet, marshy soil is certainly liable to have low reflecting power, and will consequently appear to us as darker than the rest of the planet. The greatest darkness should occur at the time when the melting is most rapid, that is to say, in high latitudes between the equinox and the summer solstice. This explains why the dark patch which surrounds the north pole, which had not been seen in the summer, was so extended and prominent in 1837, whereas in 1839 it was very pale and at first very small.

It is not going too far to claim that Mars bears a very strong resemblance to the Earth, even with regard to physical conditions, and it appears as an image of the Earth in the firmament seen from a great distance. The most important differences between Mars and the Earth are the smaller volume of Mars and the strong eccentricity of its orbit. However, the length of the Martian day is practically the same as ours.

The orbital eccentricity causes inequalities in the lengths of the seasons, as follows; if we adopt Herschel's position for the axis and our own period of rotation:

A Martian year includes consequently,		669 ² / ₃ rotations
		668 ² / ₃ Martian solar days
The north hemisphere spring contains Summer		191 ¹ / ₃ days on Mars
		181 days on Mars
	total	372 ¹ / ₃
Autumn		149 ¹ / ₃ days on Mars
Winter		147 days on Mars
	total	293 ¹ / ₃

so that in the northern hemisphere spring and summer combined are 76 days longer than in the southern hemisphere. The two parts of the year separated by the equinoxes are in the ratio of 19 to 15.

Beer and Mädler ended their memoir with an examination of the length of the rotation of the planet, comparing their results with those obtained by Sir William Herschel. We have already seen that they derived $24^{\text{h}} 37^{\text{m}} 23^{\text{s}}.7$ for their most reliable estimate. They wrote:

The rotation period we have found (they remark) differs by two minutes from Herschel’s period, and it is Herschel’s value which has been accepted up to the present time; his period was also based on observations carried out over two oppositions, and therefore so great a difference is astonishing. However, the difference vanishes almost entirely if we admit that in one of the two years there is an error of one complete rotation—if we add one rotation to Herschel’s estimate or subtract one rotation from ours. Since a period of $23^{\text{h}} 39^{\text{m}} 22^{\text{s}}$ is irreconcilable with our observations as compared with each other, and we do not consider that we can have made such errors, it will perhaps be of interest to reconsider Herschel’s observations, and see what results can be drawn from them when they are reduced with greater accuracy.

In 1777, from 8 to 26 April, Herschel observed different patches, which however did not present any certain identifications—which is why he decided to re-observe during the following opposition. This fell on 12 May 1779, when the apparent diameter of Mars attained $13''.5$; this shrank, and by 19 June was reduced to $11''$. On 11 May, at $11^{\text{h}} 43^{\text{m}}$, he saw at the centre a patch that he had previously seen on 9 May at $11^{\text{h}} 43^{\text{m}}$, though on that occasion it had been slightly above the centre. The same patch was seen on 19 June, though Mars was then low. Here are his observations:

“June 19, $11^{\text{h}} 30^{\text{m}}$. The figure of 11 May has not come to the position; it was then at $11^{\text{h}} 43^{\text{m}}$, but cannot be far from it. I fear that as Mars approaches the horizon, I shall not be able to follow it until the marking comes to the centre.

“ $11^{\text{h}} 47^{\text{m}}$. The state of the air near the horizon is very unfavourable. With much difficulty, I can just see that the marking is not quite so far advanced as it was on 11 May at $11^{\text{h}} 44^{\text{m}}$, but can certainly not be more than two or three minutes from it.”

In three minutes a marking on Mars moves toward the centre by a distance equal to $1/153$ of the diameter of Mars; this amounts to only $1/14$ of a second of arc, and Mars was only 9° above the horizon. However, let us accept Herschel’s estimate that the marking reached the centre at $11^{\text{h}} 49^{\text{m}} 30^{\text{s}}$. The calculations then are as follows:

June	19	11^{h}	49^{m}	30^{s}	
May	11	11^{h}	43^{m}	0^{s}	
Interval	39^{d}	0^{h}	6^{m}	30^{s}	
Correction I			$+3^{\text{m}}$	36^{s}	(because of the change in geocentric long.)
Correction II			-16^{m}	14^{s}	(because of the phase of Mars)
Correction III			-0^{m}	49^{s}	(because of aberration)
	39^{d}	0^{h}	27^{m}	3^{s}	
38 rotations of			24^{h}	38^{m}	$36^{\text{s}}.4$

Herschel observed another patch on 11 May at $10^{\text{h}} 17^{\text{m}} 41^{\text{s}}$, and 13 May at $11^{\text{h}} 25^{\text{m}} 51^{\text{s}}$, after which it reappeared on 17 June at $9^{\text{h}} 12^{\text{m}} 20^{\text{s}}$. He then said:

“June 17, $9^{\text{h}} 12^{\text{m}}$ (clock 20^{s} slow). The dark spot is rather more advanced than it was on 11 May at $10^{\text{h}} 18^{\text{m}}$.”

Herschel also took into account a correction of three minutes, so that the true timing was given as 9^h 9^m 20^s. This gives the following results:

June	17	9 ^h	9 ^m	20 ^s
May	11	10 ^h	17 ^m	48 ^s
	36 ^d	22 ^h	51 ^m	32 ^s
Correction I				
Correction II				
Correction III			+37 ^m	28 ^s
			−15 ^m	0 ^s
			−0 ^m	44 ^s
	36 ^d	23 ^h	13 ^m	16 ^s
	36 ^d	24 ^h	38 ^m	42.9 ^s
June	17	9 ^h	9 ^m	20 ^s
May	13	11 ^h	25 ^m	51 ^s
	34 ^d	21 ^h	43 ^m	29 ^s
Correction I				
Correction II				
Correction III			+34 ^m	31 ^s
			−15 ^m	0 ^s
			−0 ^m	43 ^s
	34 ^d	22 ^h	2 ^m	17 ^s
	34 ^d	24 ^h	38 ^m	53.4 ^s

The mean of these three *extremely uncertain* determinations is therefore:
24^h 38^m 44^s.2.
But Herschel, not having allowed for the corrections needed because of the change in longitude, and paying no attention to the others, gave in 1779, as his final result:
24^h 39^m 22^s.1.

However, we must also consider something else. We calculate the amount of the phase at the mean of the angle made by the Earth and the Sun with the centre of Mars, but experience with Venus and Mercury had shown that the dark part is always slightly greater in extent than theory predicts. Moreover, with an instrument giving irradiation effects as strong as those in Herschel’s telescope, the whole bright border will seem to be shifted more to the dark part than to the opposite border. As on 11 and 13 May the full disk was visible, whereas on 17 and 19, June it showed a phase to the east from 28° 161’ to 29° 221’, it is necessary to increase Correction II in order to obtain a true value—that is to say, diminish the rotation period.

Taking his period of 24^h 39^m 22^s.1 as his basis, Herschel observed on the following days when the same markings appeared:

1777 April 8	1779 June 6	if we cover 768 rotations
1777 April 17	1779 June 15	if we cover 768 rotations
1777 April 26	1779 June 19	if we cover 763 rotations

He derived a period:

	24 ^h	39 ^m	23 ^s .03
	24 ^h	39 ^m	18 ^s .94
	24 ^h	39 ^m	23 ^s .04
Mean	24 ^h	39 ^m	21 ^s .67

Hereby the two minutes' difference between Herschel's result and our own is reduced to 2½ seconds.

It is clear that to give an exact result from these observations this explanation is admissible, while to reduce by two the number of rotations for our observations of 1830 and 1832, and to assume a mean error of 1^h 15^m in the intervals observed in 1830, is unthinkable.

Far be it from us to doubt the accuracy and observational skill of Herschel; but the extremely favourable conditions under which we were able to observe in 1830, and strict precision with which we have made the calculation, seem to decide in favour of our result—which, as we have seen, is in fact in agreement with Herschel's observations.

All the recent, very precise determinations confirm the period given by Beer and Mädler. With no possible doubt, the rotation period of Mars is 24^h 37^m 22^s.6, while the period given by Beer and Mädler was 24^h 37^m 23^s.7. Their value was thus correct to 1^s.1.

The observations were continued by Mädler from Dorpat Observatory during the opposition of 1841, and a résumé was published in the *Astronomische Nachrichten*, 1842, together with a plate of 40 drawings.

It is difficult to identify markings which had been shown on previous drawings. From this plate I have selected a series of nine sketches, which are among the best and which were made near opposition. These are here reproduced in facsimile. These are the ones that Mädler designates as *figs.* 6, 7, 8, 14, 15, 16, 22, 23 and 24 in his plate, and are reproduced here in our Fig. 4. The dates are as follows (opposition 1 April; distance from Earth = 0.591; diameter = 15" 1):

Fig. 6 or 1: 1 April 0^h 8^m Paris mean time.

Fig. 7 or 2 to the left: 5 Apr. 9^h 13^m Paris mean time.

Fig. 8 or 3: Same day 10^h 13^m Paris mean time.

Fig. 14 or 1 of 2nd row: 26 April at 9^h 12^m.

Fig. 15: Same day at 9^h 52^m.

Fig. 16: 29 April at 8^h 50^m.

Fig. 22 or 1st of 3rd row: 8 May at 8^h 41^m.

Fig. 23: 9 May at 8^h 11^m.

Fig. 24 or last: 11 May, at 7^h 54^m

These observations completed the previous series, though without adding much new information.

Such were the researches of Mädler, in many of them conducted together with his friend Wilhelm Beer—brother of Meyerbeer, the composer—who was no less an enthusiastic student of the sky. These researches were the most fruitful ever undertaken up to that time, and they really inaugurated our knowledge of Martian geography, or *areography*.

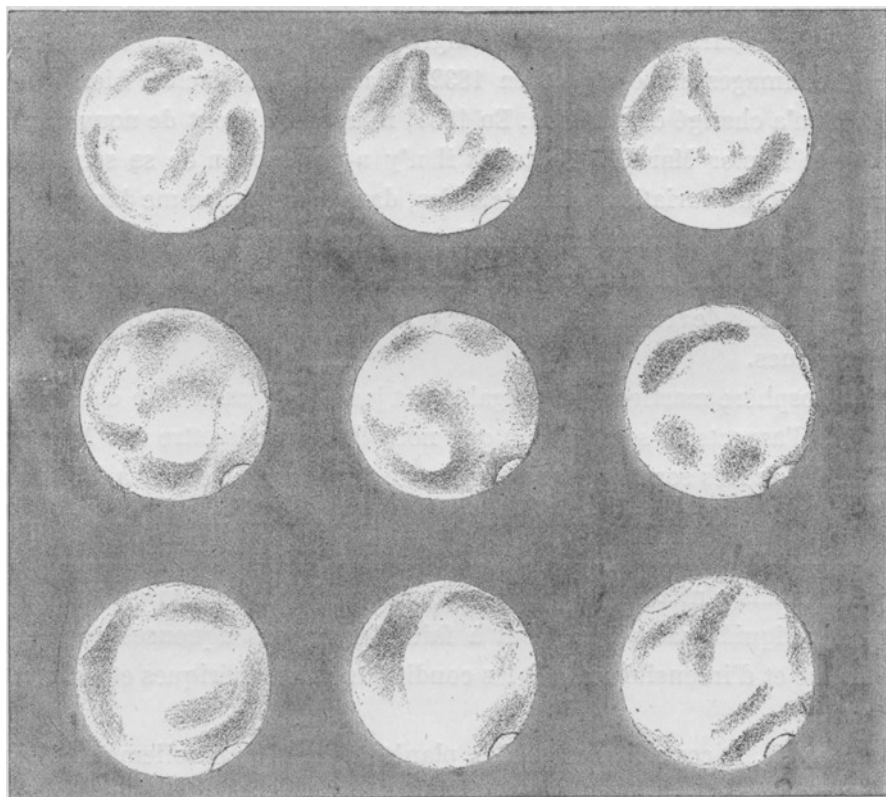


Fig. 4 Drawings of Mars, made by Mädler in 1841

The rotation period, determined with a precision superior to all previous measurements, is $24^{\text{h}} 37^{\text{m}} 23^{\text{s}}.7$.

The polar ices were studied with special care, as were the seasons in each hemisphere. Since then, we have known that the southern hemisphere has hotter summers and colder winters than the northern hemisphere, because of the greater orbital eccentricity and the inclination of the axis; the variations in the south polar ices are greater than those in the north, and they correspond to the seasons. The southern hemisphere has short, hot summers and long, rigorous winters; the northern hemisphere, on the contrary, has long, temperate summers and short, mild winters.

The measurements of the distance between the pole of cold and the geographical pole are not in accord with those of Herschel, although it is always found that the polar caps are not diametrically opposite to each other. Perhaps the poles of cold are not fixed.

The dark patches on the planet have certain fixity—certain permanence. However, there are undoubted changes. Those, which we have described in the earlier part of this work, are confirmed.

For stability, the spot *a*, the zero for longitude, is the most definite. It is the darkest and best-marked feature on the planet. (It is the Meridian Bay of my chart.) If readers will turn back to Figs. 16 and 30, Chap. 1, they will find this region to the right of the hemisphere containing the Hourglass Sea, and will note that the aspect is not the same as that shown on the chart by Beer and Mädler. The band is not clearly detached, and is less narrow; it shows that in this area *there have been incontestable changes*, perhaps of a periodical nature.

To Beer and Mädler, Herschel II. Strait appears stable, as it had also been observed by Kunowsky in 1821. Thus the serpentine arc *ac* and the patch *a*, seem to them to be definite surface features on the planet. The long broad patch *PM* of their chart is equally fixed (this is the Maraldi Sea). For the rest, despite the uncertainties and the confusion in some of their drawings, they wrote in 1832 that none of the patches observed in 1830 had changed in position. In 1837, they again recognized the Maraldi Sea with certainty. Sometimes they had the impression that considerable variations occurred in the tint, form, and extent of the dark patches. They were disposed to attribute these variations, at least in the high latitude features, to the effects of the melting of the snow, the soil becoming marshy and dark in the places where the snow had melted.

The Martian atmosphere should play an equally important role in these changes of aspect. It seems that on Mars we see two types of dark patches, those due to seas and those due to fogs or mists. Perhaps it may be that the water is not in the same state as ours, and does not form properly liquid seas, but blankets of very dense mists, which are viscous and come near the liquid state without actually being so. These aqueous blankets would show changes of extent and intensity according to the atmospheric conditions, and would follow the seasons.

We can see how our knowledge of the planet gradually advances, year by year, with the progress of the observations. We can now assert what before seemed only probable: stability, but with variations. The geographical study of Mars has become precise; Mars is a geographical globe like the Earth, not cloudy like Jupiter or Saturn; surely it has continents and seas, but these seas do not resemble our own; they show enigmatical variations which must be the object of future scientific studies.

1830.—Sir John Herschel

After having given his opinions about Mercury and Venus (*Outlines of Astronomy*), Herschel writes:

The most natural conclusion, from the very rare appearance and want of permanence in the spots, is that we do not see, as in the Moon, the real surface of these planets, but only their atmospheres, much loaded with clouds, and which may serve to mitigate the otherwise intense glare of their sunshine.

The case is very different with Mars. In this planet we frequently discern, with perfect distinctness, the outlines of what may be continents and seas. (See Fig. 5). Mars in its gibbous state, as seen on the 16th of August 1830, in the 20-ft reflector at Slough.) Of these, the former are distinguished by that ruddy colour which characterizes the light of this

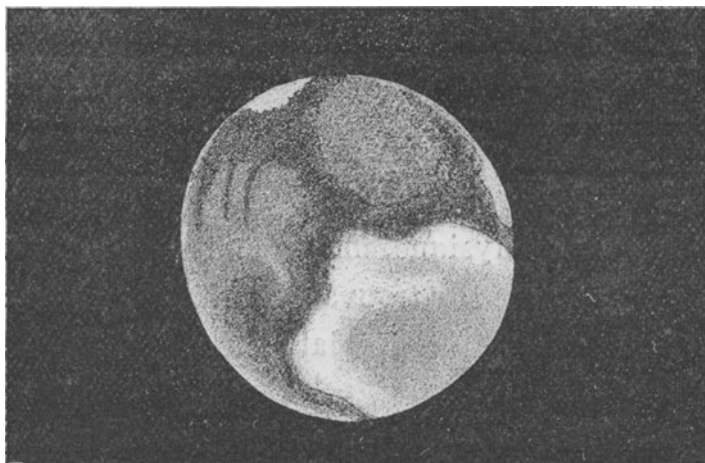


Fig. 5 View of Mars, by Sir John Herschel, on 16 August 1830

planet—which always appears red and fiery—and indicates an ochre tinge in the general soil—like what the red sandstone districts on the Earth may possibly offer to the inhabitants of Mars, only more decided. Contrasted with this (by a general law of optics), the seas, as we may well call them, appear greenish. These spots, however, are not always to be seen equally distinct, but, when seen, they offer the appearance of forms considerably definite and highly characteristic, brought successively into view by the rotation of the planet, from the assiduous observation of which it has even been found practicable to construct a rude chart of the surface of the planet. The variety in the spots may arise from the planet not being destitute of atmosphere and clouds; and what adds greatly to the probability of this is the appearance of brilliant white spots at its poles—which have been conjectured, with some probability, to be snow; as they disappear when they have been long exposed to the Sun, and are greatest when just emerging from the long night of the polar winter.

In 1828, on 22 June, Dr. Pearson observed on the disk of Mars a dark patch, vertically elongated, not far from the left or western border, and 4 days later he again saw this patch, no longer vertical, but horizontal and elongated along its upper edge. He wrote to Sir John Herschel, who in turn communicated the observation to Smyth. Smyth described it in his work *Cycle of Celestial Objects*, and reproduced the drawing. These patches were certainly not identical, because the planet does not rotate in this sense; we are not in the direction of the pole.

We must now consider two of Sir John Herschel's views. The first is his opinion that at that time (1830) the yellow regions represented continents and the grey regions seas; this was generally accepted. The second is that the yellow tone of the continents is that of the surface of the soil. But the explanations given by Sir William Herschel's son must be treated with caution. It would mean that there could be no kind of vegetation on the Martian soil. Such a suggestion can hardly be accepted, since there is air, water and sunshine. If the surface of the soil is reddish, can it not also mean that it is covered with vegetation of this tint? Besides, the colour is not everywhere red; it is usually a warm yellow, which can best be compared with ripe wheat.

1830–1837.—Bessel⁴

From 1830 to 1837 the great astronomer-mathematician Bessel, at the Königsberg Observatory, made a series of observations of Mars which were not concerned with its physical constitution, but only with measurements of its diameter and its flattening. He found that at unit distance (the distance between the Earth and the Sun) the diameter was 9".33. To him the polar flattening appeared insensible.

The same measurements gave the eccentricity of the southern polar patch as 6° 36'. We have seen that William Herschel had given a value of 8°.8 for this same southern polar patch in 1783, while the value given by Beer and Mädler was 8°.

In 1852 Oudemans of Leyden published a new reduction of these measurements.⁵ He gave a semi diameter of 4".664, which combined with the adopted solar parallax of 8".571, gave a diameter of 0.544 for Mars and a volume of 0.161, relative to the Earth. For these same observations by Bessel he found:

Celestial longitude of the north polar point of Mars	349°.1 ⁶
Or right ascension	317°.34
Latitude	61°.9
Or declination	50°.5

1831–1832.—Sir James South⁷

The English astronomer Sir James South, to whom we owe interesting measurements of double stars, presented to the Royal Society of London, on 16 June 1831 and subsequently on 13 December 1832, a series of observations of the *atmosphere of Mars*, showing that this atmosphere was not as extensive as had been supposed from the observations of the occultation of the star ϕ Aquarii by Mars on 1 October 1672. Cassini had observed at Briare: “On 1 October 1672, at 2.45 in the morning, Mars, seen with a 3–ft refractor, seemed to touch, with its western edge, the straight line drawn by joining the first and second stars of ϕ Aquarii, from which its distance was only six minutes. The star seemed to be so diminished and enfeebled that it could not be seen with the naked eye, or with a smaller telescope.”

The star ϕ Aquarii is of the fifth magnitude. This observation has already been described.

The same occultation was observed from Paris by Røemer: “Clouds did not allow me to see the beginning, and I do not know whether I would have been able to see it immediately, because three-quarters of an hour later, when the sky had cleared,

⁴*Königsberg Beobachtungen*, Vol. XXIII, 1847, p. 94, 95.
⁵*Astronomische Nachrichten*, no. 838, 1852, p. 351.
⁶We have seen that Herschel gave: Longitude 347°47', Latitude 59°42' and Schröter, longitude 352°55', latitude 60°33'.
⁷*On the extensive atmosphere of Mars. Philosophical Transactions*, 1831, p. 417. —*Id.* 1833, p. 15.

I searched carefully around Mars and only found the star after 2 minutes, when it was already $\frac{2}{3}$ of a diameter of Mars away from the eastern edge of the planet. I began to see it without difficulty only when the distance had increased to $\frac{3}{4}$ of a diameter.” (*Mem. de l’Acad.* Vol. VII, p. 359.)

Here we have a fifth-magnitude star whose brilliancy seemed to be reduced, by the influence of Mars, at a distance of 6 minutes.

There was considerable difficulty in seeing this fifth-magnitude star when it was very close to Mars, though there is no difficulty in seeing a star of the same magnitude when it is close to the limb of the Moon. From this, one can judge that Mars is surrounded by an atmosphere of some sort.

Sir James South noted that William Herschel had made a contrary observation on 27 October 1783, when he had followed a star of the 13th or 14th magnitude to a distance of $2''.56$ from the planet and found it “not otherwise affected by the approach of Mars than what the brightness of its superior light might account for.”

We have already noted this observation also.

On 19 February 1822, Sir James South wrote: “From Backgammon Street, London, I observed a star of the 9th to 10th magnitude whose brightness was not reduced at a distance of $143''$ from the limb of the planet.”

He continued:

On the following night, the star, 42 Leonis of the 6th magnitude, approached Mars; at 4 h in the morning it was very close, and looked a beautiful blue colour. It had been occulted. I could not time the precise moment of occultation, but at emersion I recovered the star about a minute and a half from the limb; it was clear, indigo blue, and made an exquisite contrast with the colour of Mars. The planet was only 47 hours from opposition, and its diameter was $16''.6$.

On 17 March 1831, South had made a similar observation with the occultation of 37 Tauri by Mars. The star showed no change in brightness or in colour. There was no colour-contrast, as in the case of 42 Leonis. No, for 37 Tauri is almost the same colour as Mars.

On 28 November 1832, Sir James South made yet another similar observation. A star of magnitude 6th or 7th preceded Mars to the south. It was of a beautiful blue colour, in striking contrast to the hue of the planet. The objective of the equatorial measured 11.85 English inches (301^{mm}), and stood a magnification of $520\times$. The star (RA. = $3^{\text{h}} 29^{\text{m}} 19^{\text{s}}$, decl. $+20^{\circ}22'$) was followed right up to the edge of the planet, and neither at immersion nor at emersion did it show any change in brilliancy or colour.

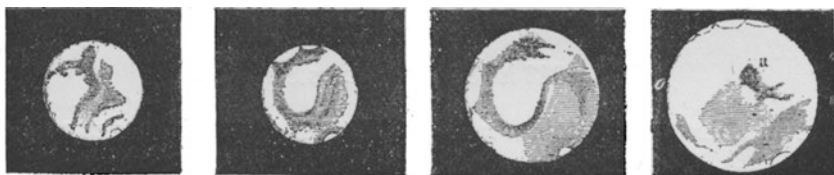
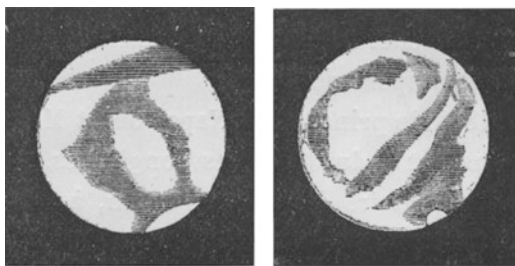
The planet had passed opposition just 9 days earlier.

South concluded that the old hypothesis of a considerable atmosphere was untenable, just as Flaugergues had concluded in 1796, from a similar observation.

1837–1839.—J.-G. Galle

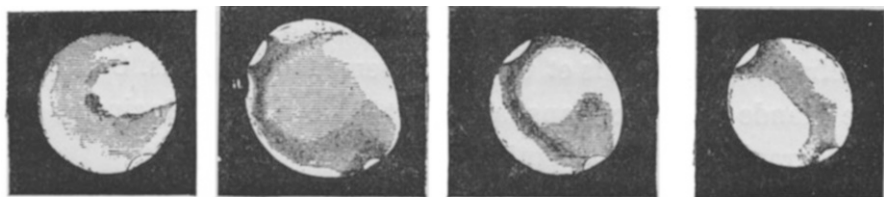
In 1837 and 1839 Galle, using the 9-in. refractor at the Berlin Observatory, made a series of observations and remarkable drawings. Eighteen of these drawings were reproduced by Löhse in Vol. I of the *Publications of the Astrophysical Observatory of Potsdam* (1878).

Fig. 6 Drawings of Mars by Galle, 1837–1839. A.—12 March 1837, at 10^h 37^m. B.—12 March 1839, at 10^h 0^m



C. — 12 mars, à 11^h 30^m. D. — 13 mars. E. — 14 mars. F. — 30 mars, à 9^m 40^m.

Fig. 7 Drawings of Mars by Galle, in 1839. C.—12 March, at 11^h 30^m. D.—13 March. E.—14 March. F.—30 March, at 9^h 40^m



G. — 30 mars, 11^h 10^m. H. — 31 mai. I. — 1^{er} juin. J. — 7 juin.

Fig. 8 Drawings of Mars by Galle, in 1839. G.—30 March, 11^h 10^m. H.—31 May. I.—1 June. J.—7 June

The following sketches are reproduced here:

Figure 6A: 12 March 1837, at 10^h 37^m.

Figure 6B: 12 March 1839, at 10^h 0^m.—In these two views we note the north polar cap at the bottom: in the second drawing it is very small. This 1839 drawing bears a remarkable resemblance to that made by Kunowsky on 15 March 1822; the upper patch represents Herschel II Strait and the Meridian Bay.

Figure 7C: 12 March, at 11^h 30^m.

Figure 7D: 13 March, at 9^h 41^m.

Figure 7E: 14 March 1839, at 10^h 0^m—The sort of duck's head also indicates the Meridian Bay; the forked aspect is noteworthy, and we will return to it later.

Figure 7F: 30 March—The black patch crossed the central meridian at 10^h 40^m. This drawing was made at 9^h 40^m—and the following one (Fig. 8G) at 11^h 10^m.

Figure 8H: 31 May, at 14^h 30^m —The two polar patches can be distinguished not opposite to each other. A singular hollowing-out can be seen. (A similar observation by Schröter has already been described.)

Figure 8I: 1 June, at 14^h 15^m —The sombre streak, which runs from one pole to the other, seems to correspond to the Hourglass Sea, which is better identifiable on drawings 6B, and 7D, E, H.

Figure 8J: 7 June, at 14^h 22^m.

These drawings by Galle indicate *stability; but also variations in tone.*

1839.—Napoleon III

I have discovered this observation in a work which has certainly not been examined by anyone else. I include it because of its curiosity rather than its importance.

In June 1839, Prince Louis-Napoleon and M. d’Abbadie, today a member of the Institute and of the Bureau des Longitudes, who accompanied him, were visiting Sir James South’s observatory in London; they observed Mars, and commented particularly on the upper polar cap, which was very prominent at the time. M. d’Abbadie made a little sketch, which it would be superfluous to reproduce, and Louis-Napoleon Bonaparte wrote a brief description *which he signed Napoleon III* (Thirteen years before he publicly began to use the name!). The planet showed a marked phase. The polar patch was so brilliant that it elongated the disk of Mars, forming a point and giving it the aspect of a pear.

This was undoubtedly a week or two after the first drawing, which preceded it.

1843–1873.—Julius Schmidt

The skilful Director of the Athens Observatory produced a collection of very numerous drawings of Mars, made in 1843, 1845, 1846, 1847, 1854, 1856, 1860, 1862, 1864, 1866, 1867, 1869, 1871, and 1873. But this beautiful series has not been published, and we know it only from the information which he gave to M. Terby. Schmidt’s drawings totaled 107. The observations were made successively at Hamburg in 1843, with a magnification of 90×; at Bilk, near Dusseldorf, in 1845; at Bonn, in 1846 and 1847, with a 5-foot refractor and a heliometer; at Olmütz in 1854 and 1856, with a 5-ft refractor; and, finally, at Athens, from 1860 to 1873, with a 6-ft refractor and a magnification of 550×. In most cases it is easy to recognize the principal geographical configurations of the planet.

The four drawings below, reproduced after Terby, give an idea of Julius Schmidts observations. Here are the dates; the drawings are published in chronological order.

Figure 9A	26 September 1862 at 8 ^h 36 ^m (Athens time)	
Figure 9B	1 October 1862 at 7 ^h 28 ^m	id.
Figure 9C	16 May 1873 at 8 ^h 15 ^m	id.
Figure 9D	23 May 1873 at 7 ^h 41 ^m	id.

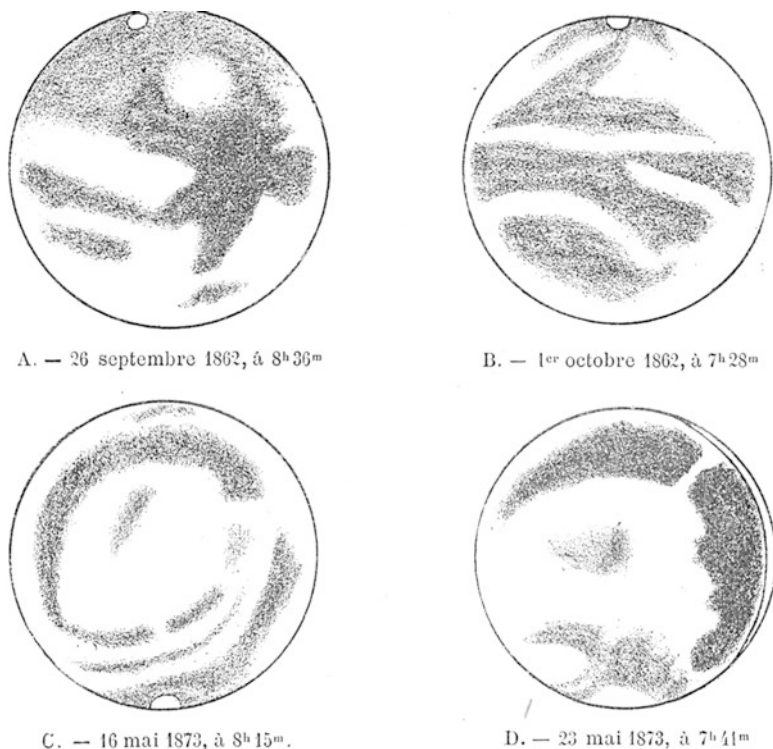


Fig. 9 Drawings of Mars, by Julius Schmidt, 1862 and 1873

Figure 9A shows the Hourglass Sea recognizably. Above, like a truly vast island, lies Lockyer Land.⁸ Above again is the south polar patch, clearly away from the limb. The rest is less certain. Figure 9B shows the Maraldi Sea, and above it a sombre band which cannot be identified. Figure 9C resembles Fig. 7 of 1841 by Mädler, but none of the patches can be identified with certainty. Figure 9D appears to represent the Flammarion Sea and the Hooke Sea, which are separated by an isthmus.

These observations equally militate in favor of notable variations in the aspects of Mars.

1845–1856.—Mitchel, Grant, Warren De La Rue, Jacob, Brodie, Webb

Observations of Mars became more numerous as astronomical knowledge grew and the urge to observe increased. In this study of the planet it would be useless to give full details of all the work; this would mean a great deal of repetition, without

⁸Hellas on Schiaparelli's chart.—WS.

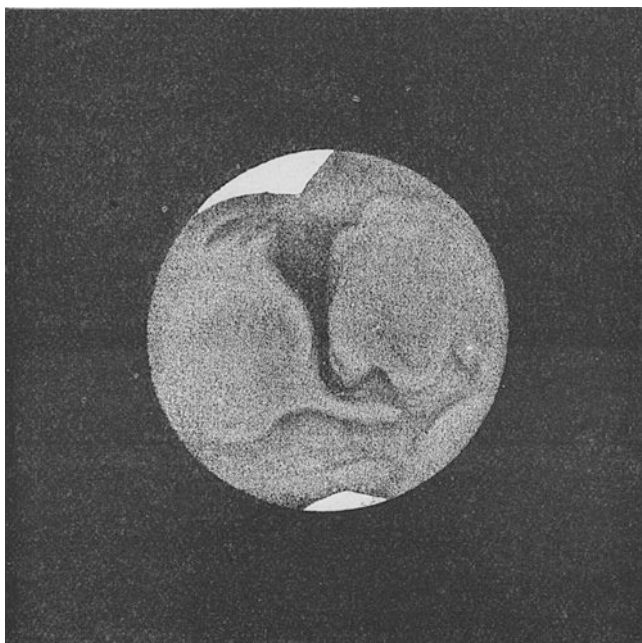


Fig. 10 Drawing of Mars, by Warren de la Rue, on 20 April 1856 at 9^h 40^m

adding much, which would be new. Therefore, I propose to omit work which is of no interest, and to give only the more important observations.

In 1845 Mitchel made several observations of the planet with the great Cincinnati equatorial, concentrating particularly upon the polar snows; he believed that on 12 July 1845 he detected a black point in the snow area, together with movements at the edges of the region covered with snow. James William Grant (not to be confused with Robert Grant, author of the *History of Physical Astronomy*, London 1852) presented to the Royal Astronomical Society of London two sketches made in October 1847 and March 1854 (*Monthly Notices*, 1854, p.165). The first sketch showed the southern polar patch, and the second showed the northern. In March 1854 Jacob made two drawings upon which the principal patches are recognizable. In 1856 Warren de la Rue merits the closest attention. Of his drawings, two—those of 20 April 1856, at 9^h 40^m and 11^h 45^m—are particularly notable, and are reproduced here. The first (Fig. 10) shows the Hourglass Sea as rather narrow. In the second (Fig. 11), made two hours later, the Hourglass Sea has reached the western or left edge of the disk, with Herschel II Strait occupying the upper part of the figure.

The Meridian Bay appears to the right, as a pointed tongue.

At both poles the white patches are very much in evidence. They are not diametrically opposite to each other. These two drawings are perhaps the best included in this book so far. They were obtained with the aid of an excellent Newtonian reflector of aperture 13 English inches (0^m.33), equatorially mounted.

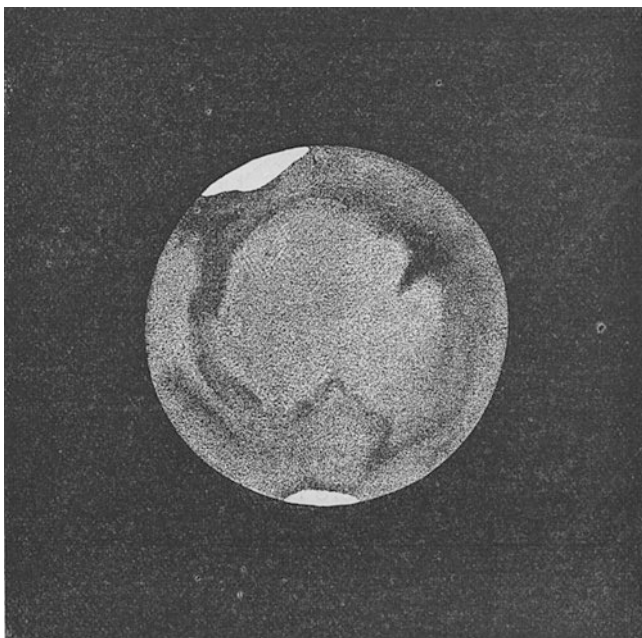


Fig. 11 Drawing made 2 hours later (at 11^h 45^m)

To these views of the planet may be added two more sketches made at almost the same date. The first, showing considerable detail, was made on the evening of the 18 April, 1856 by Fr. Brodie; the second, a straightforward sketch, made “near the 15th” by the Rev T.W. Webb. Here are the two observations (*Monthly Notices*, XVI, 204 and 188):

18 April, 10^h 10^m sidereal time: Mars near the Moon; image very good; 6 1/3 in. aperture, 396× and 578. The poles are splendidly white, especially the southern. Note also two other white regions, AB and CD (Fig. 12).

Webb’s sketch, although less detailed, gives a better representation than Brodie’s of these four white regions (the two poles and the areas AB and CD, making up a kind of equilateral pattern). This is a sketch remarkably like Cassini’s, published in the *Journal des Savants*, letter A (see Fig. 10, Chap. 1) and which was also in the front of Cassini’s memoir (Fig. 11, Chap. 1). The industrious Webb also made a large number of other drawings. These are to be found in his work on practical astronomy (Fig. 13).

A physical study of the planet was published by Taylor in the *Madras Spectator* for 26 August 1845. The observations were made with a Herschel telescope. Gruithuisen referred to them in the *Astronomische Jahrbach* for 1848. The planet had a broad equatorial band, and the surface, apart from this band, was very bright. This aspect recalls that of Jupiter.

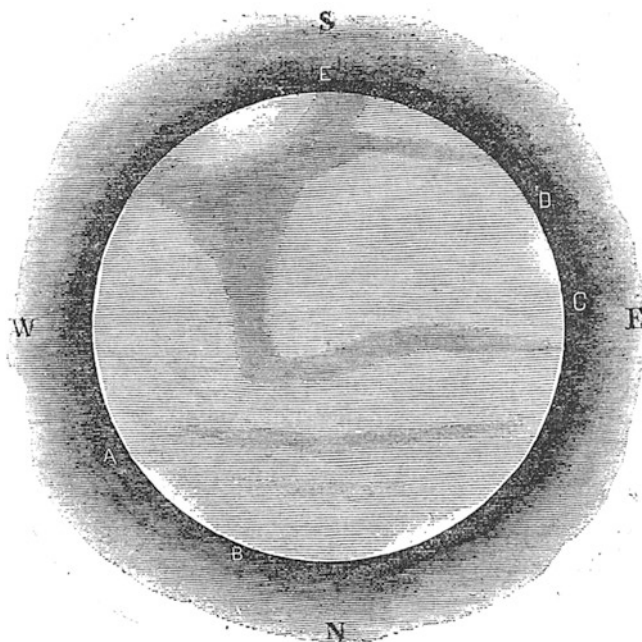
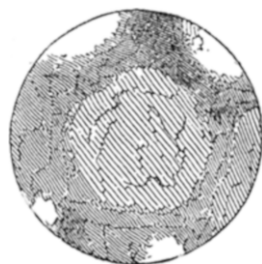


Fig. 12 Drawing of the planet Mars, 18 April 1856, by Fr. Brodie

Fig. 13 Sketch of the planet Mars by T.W. Webb, about 15 April 1856



1845–1875.—Main

At Greenwich and at Oxford, Main made various observations of Mars, principally with the object of measuring the diameter. In 1845 he also made some observations of the surface.⁹ On 22 August, at 11^h 30^m, at the time of opposition, he examined the Martian surface, in the company of the Astronomer Royal (George Biddell Airy):

About 10° to the west of the apparent north point, on the planets edge, can be seen a white cap which makes a striking contrast with the sombre zone immediately above it.

⁹*Examination of the surface of the planet Mars with the telescope of the South-East equatorial.* Royal Observatory, Greenwich, 1845, p. 172.

Slightly above this dark band there is a brighter band. The most prominent sombre patch on the disk lies to the left of the great dark mass, which occupies a considerable part of the upper disk; there is also another sombre patch to the right.

The best descriptions are not accompanied by even the simplest drawing.

22 August, 11^h—The appearance of the planet has changed considerably, with the exception of the polar cap. The colour was rich red earth; the sombre patches had a very light blue tint.

Main also made observations at Oxford.¹⁰ In particular, he made measurements of the polar flattening and the planet’s diameter, of which the results were as follows:

		Flattening			Flattening
1855	9".84	1/62	1871	9".25	1/71
1862	9".377	1/38	1875	9".185	1/36
1864	9".38	1/46			

1856.—Winnecke

Most of the present book has been devoted to studies of the physical constitution of Mars; I have not given here observations concerning the elements of the orbit, the parallax, the mass and the diameter. However, for the diameter I have included the most important measurements; those of Herschel, Schröter, Arago, and Bessel. We must also, then, note the measurements made by Winnecke in 1856, at the Bonn Observatory.¹¹ For unit distance, he found the diameter to be 9".213. There was no trace of flattening; on the contrary he found a polar diameter of 9".227 and an equatorial diameter of 9".186.

1853.—Arago¹²

We have already noted and discussed Arago’s observations of Mars given in his memoir. In Book XXIV of his *Astronomie populaire*, written in the last year of his life, when his sight—strained by overwork—was already failing, he again made studies of the seasons of Mars, together with the planet’s colour and its atmosphere.

The seasons which he adopted were those given by Beer and Mädler.

There is an interesting point about the orbital eccentricity, which I have already mentioned, and which Arago himself described as follows:

MM. Mädler and Beer have followed, and largely verified by means of their observations, the explanation that the brilliant polar patches of Mars are due to the accumulation of snow.

¹⁰*Memoirs of the Royal Astronomical Society*, Vol. XXV, p. 48; Id. Vol. XXXII, p. 112. *Radcliffe Observatory Results*, Vol. XXII, XXXI, and XXXIII.

¹¹*Astronomische Nachrichten*, No. 1135, 1858, p. 97.

¹²*Astronomie populaire*, published posthumously in 1854–1857. Arago had died on 3 October 1853.

During the 668 2/3 days which make up a Martian solar year, Mädler and Beer found that in the northern hemisphere of the planet, the summer lasts for 372 days, and the winter for 296 days. The same results apply to the southern hemisphere, except that the values for summer and for winter are reversed.

This inequality between the cold and warm seasons does not prevent the two hemispheres from having the same mean temperature. As for the extremes of these temperatures, it seems that the two hemispheres are very dissimilar.

Thus, at the summer solstice in the southern hemisphere of Mars, the planet is actually at its least distance from the Sun, and in consequence receives the maximum amount of solar heat that it can ever do. This heat is at its least at the time of the winter solstice.

It follows that if the material which produces the white patch at the south pole of Mars has properties analogous to those of our snows, then this patch ought to vary considerably more than the patch at the North Pole.

I will deal below with the theorem stating that the total quantity of solar heat received from the spring equinox to the autumn equinox is identical to that received from the autumn equinox to the spring equinox, the length of time of exposure to the Sun being exactly compensated for by the difference in distance. But even if the total quantity of heat received is the same, it is equally true that the hemisphere which is exposed to the Sun at the perihelic solstice receives at the moment more heat than the other hemisphere receives at aphelic solstice; consequently, its summer is hotter, and the polar snow will thus be more reduced.

We can imagine an orbit so elongated and an axial inclination such that the snow would never melt in the region of a pole having its winter at perihelion and its summer at aphelion.

With regard to the colour of the planet, and its atmosphere, Arago gave the following account:

Some astronomers, physicists and geologists have written in this connection about ochre landscapes of red sandstone, from which the sunlight would be reflected. To explain the same phenomena, Lambert supposed that on Mars all vegetation was red. Alternatively, recalling that at sunrise or sunset terrestrial objects are often reddened, it may be thought that the colour of Mars is the result of modifications introduced in the rays of light by the atmosphere which surrounds the planet.

But this explanation is inadmissible. If it were correct, then the colour would be most pronounced at the limb and in the polar regions, which is exactly the opposite of what we observe.

We note that the red colour of Mars is more intense to the naked eye than in the telescope. In my experience, it seems that telescopically the colour is less striking when high magnifications are used.

The permanent patches on Mars are never visible right up to the planet's limb, and the limb itself appears bright. These two facts are due to the presence of an atmosphere around Mars. The predominance of brilliancy of the east and west limbs is such that some observers have compared these two borders with two narrow, resplendent slices, between which the rest of the disk appears comparatively dark.

Some observers have noted that the sombre patches show a light greenish tint, but this colour is not genuine. It is a contrast effect, such as is always seen when a dim white object is placed beside a bright, strongly red object.¹³

¹³This is the effect first noted by the great French chemist Michel Eugène Chevreul (1786–1889), and now referred to as simultaneous contrast.—WS

The disposition of the permanent patches on Mars near the edge of the disk, considered as a proof of the existence of a Martian atmosphere, deserves further consideration here.

Without going into details about the principles of photometry, which could be relevant in our examination, we can accept the observational result that when the sunlight shines freely down upon the uneven surface of a spherical body, the edge and the centre of its apparent disk, viewed from afar, will have almost the same intensity. This is obvious enough simply from looking at the full moon.

This will not, however, be true if the rays which shine on the edges and the centre of the body do not have the same intensity.

If the solar rays which illuminate the edges of the body are weaker than those striking the centre, then the edges will appear less bright than the centre.

Now, if Mars is surrounded by an atmosphere which is not perfectly transparent, the rays which reach the planet's limb will be less intense than those reaching the centre, because they will have to pass through a greater thickness of atmosphere; therefore, for this reason, and even without taking into account the weakening of the light which must occur when it passes through the atmospheric layers for the second time, the solid or liquid parts of the regions near the edge should appear darker than the liquid or solid parts of the central regions.

A second effect can also have important optical consequences. In the direction of each material point on the planet, we ought to see simultaneously the light sent back by the area and the light which is reflected in the same direction by the corresponding parts by way of the intervening atmosphere....

Considerations of the same kind, combined with various photometric measurements of the darker and brighter areas at the centre of the disk and at different distances from the limb, lead us on to conclusions which cannot remain hidden by the optical properties of the Martian atmosphere.

From these comments of Arago—that the edges of the disk of Mars are really whiter than the interior regions, and that the patches are much less conspicuous there because of their brightness—we may conclude that the atmosphere of Mars is of considerable depth, and absorbs and reflects an appreciable part of the incoming sunlight. However, it is unquestionably more transparent than the atmosphere of the Earth and, moreover, less cloud-laden.

Arago also measured the intensity of the light reflected by the polar caps. He found it to be twice that coming from the edges of the disk.

1858.—Father A. Secchi¹⁴

During 1860 Mars was due to be very favourably placed for observation, and the eminent Director of the Observatory of the College of Rome prepared himself by making preliminary observations during the preceding opposition, that of 1858. He was interested as much in the physical condition of Mars as in his determination of the solar parallax. In this study he had the collaboration of his colleague P. Cappelletti, and the two astronomers made a large number of excellent drawings.

The instrument used was the fine equatorial at the Observatory, of aperture 0^m.244 and focal length 4^m.328. The magnifications used were 300× and 400×.

¹⁴*Osservazioni di Marte, fatte durante l'opposizione del 1858. Memorie dell'Osservatorio del Collegio romano. Roma, 1859.*

The best times for observing Mars from Rome are the 2 and 3 hours after sunset, and then only during spells of consistently fine weather.

On the planet they observed patches of various colours: reds, blues, yellows; even, perhaps due to contrast, greens. Secchi commented that the drawings could not give a real idea of these tints. Copper engravings could not reproduce them and even the attempts made with chromolithography were unsatisfactory. Only pastels were successful, and forty drawings of this kind are preserved in the Observatory of the College of Rome. (I saw them personally during my visit to Rome in 1872.) It was noted that Mars appeared less red to the naked eye when, in the telescope, important azure patches were on view. This may explain the variability of Mars to some extent.

The best method of judging the forms of the patches observed is, perhaps, not to describe them, but to examine the drawings directly.

The most characteristic are those of 13, 14, 15, and 16 June (Fig. 16), which show a great blue patch in the form of a triangle and which, in their notebooks, the observers named the *Scorpion*. It did indeed remind one of the form of this creature and of this constellation. Secchi also called it the *Atlantic Canal*. This characteristic patch is none other than our famous Hourglass Sea, as it had been known for such a long time. But let me give a literal translation of the author's description:

This Atlantic Canal is vast. Another canal,¹⁵ small in size and joining two broader patches, is shown on the drawings of 3, 4, 5, and 7 June; we have misnamed it the *isthmus*. (This isthmus, lying about 140° to the right of the preceding sea, is known to be the narrow sea which has been named the Channel on our chart, above Christie Bay, and which Schiaparelli calls the Ganges.—C.F.) The three bays are: 1. Meridian Bay, 2. Burton Bay, or the mouth of the Indus; 3. the Channel...

These two canals enclose a reddish continental area; altogether the two canals and the continent occupy about 150° of areographic longitude. The rest is covered with indefinite patches, very difficult to identify and draw.

The polar patches are bounded by contours which are ash-coloured and poorly defined, but between the reddish continent and the upper polar patch there is another very white region, which could easily be confused with the polar cap. The brilliancy of these regions is so striking that, by irradiation, they seem to project from the edge of the planet; this illusion will of course exaggerate the polar diameter.

The drawings of the polar hemisphere made by Secchi do not agree at all either with those of Beer and Mädler, or with those made later.

With regard to the numerous questions raised by studies of the physical constitution of the planet (continued the Roman astronomer), it seems that we cannot yet give definite solutions. For example, we cannot decide whether the blue patches are really blue, or whether their colour is merely due to contrast. I incline to the view that the colour is real, because I have been able to observe small parts of the area separately by using diaphragms; however, when observed in the daytime I see the areas as almost black. The other question to be decided—whether the dark regions represent water and the reddish areas continents and the white areas clouds—is equally difficult to answer; one must first decide whether the patches are permanent or variable. If the white patches change in form, we must regard them as clouds; if not, then they could be ice-plains or continents.

¹⁵This term *canal*, found in all Secchi's descriptions, could not have been worse chosen. The mer du Sablier, for instance, does not in the least correspond to such a description.

In support of the idea that the white regions are clouds, it is notable that we can sometimes see the great patch of the Atlantic Canal as though covered with cirrus, while at other times it is not. We must see whether these aspects recur.

The reddish regions, like the bluish ones, seem too permanent for their nature to be doubted; it is probable that the former are solid, the latter liquid. The tone of the former is not uniform, but markedly *scresziato*, as though filled with fine detail, about the nature of which we have no information.

A comparison of our drawings with those obtained by Mädler from 1830 to 1837 seems to establish the existence of very notable changes. However, bearing in mind the effect of the observations of differences in instrumentation and the quality of the atmosphere, we ought to reserve judgment. In particular, we have been very surprised not to recover the curious patch in the form of a bowl suspended from a thread, which was then so characteristic; and there seems to be a strong probability of change here, though perhaps this could be the lower patch of our isthmus. Was the great canal, so strong and so well-marked today, yet invisible then? But could it not be the great patch marked *pn* in the drawings made at that time? Later researchers will eventually resolve these enigma.¹⁶

Mars certainly seems to have an atmosphere. The brightness of the disk is much less at the limb than at the centre. Moreover, the sharpness of the outlines of the surface features decreases near the edge of the disk, which seems to demonstrate that an atmosphere exists, even if very feeble and certainly much less dense than that of Jupiter—probably even less dense than that of the Earth. It is worth drawing attention to the bright oval patch which we show on the drawings of 9 June and 10, 11, 13, 14, and 15 June, well separated from the neighbouring patch to the left. On the drawing of 8 June, however, the two patches are shown as joined together. This joining must have been only apparent, and due to a cloud in the planet's atmosphere lying about the division.¹⁷

From these observations, it is found that the axis of rotation is certainly not concentric with the polar patches. This conclusion had already been reached by Beer and Mädler who, however, did not regard it as definite. (The author ought to have said by Herschel, and demonstrated by him.)

Secchi was equally interested in the rotation of the planet. Using an observation made by him on 25 April 1856 at 11^h 20^m in the evening, and an identical one made on 24 July 1858 at 6^h 20^m, he deduced a rotation period of 24^h 37^m 35^s.

Here are a few extracts from his records:

1856 7 May, 11^h Rome mean time—In the middle of its disk Mars shows a large triangular patch, blue in colour, and above it a reddish patch. Seeing is bad, and it is not possible to make good observations. This patch is the Atlantic Canal, a name given for brevity to this large blue patch which seems to play the role of the Atlantic which, on Earth, separates the Old World from the New.

16 May—the disk is drawn with reddish stippling.

3 June, 9^h 45^m —Seeing good. The Isthmus is well seen. The upper polar cap is well-defined, but the lower is indefinite. The narrow canal which we call the Isthmus is well seen (Fig. 14A).

4 June, 9^h 30^m —View similar to yesterdays (Fig. 14B).

5 June, 9^h 40^m —Similar, The Isthmus is further across the disk, and so is the bright patch to the left (Fig. 14C).

¹⁶We can say that these changes definitely take place.

¹⁷This bright patch is called Phillips Island on my map. Its neighbour to the left is Lockyer Land, joining Dreyer Island to Kunowsky Land. We have here indications of important variations.

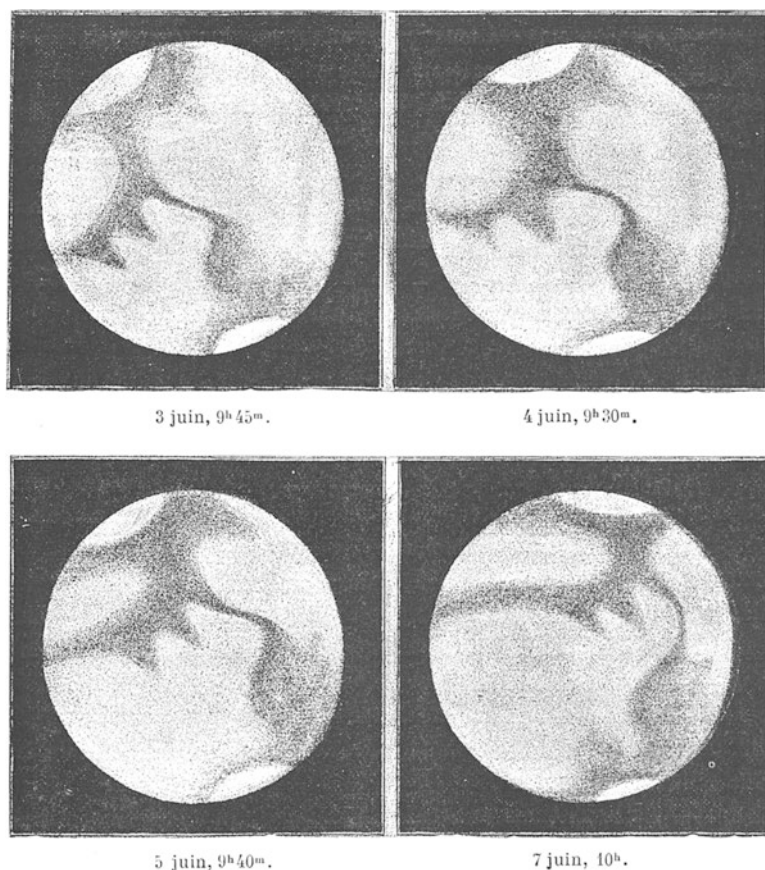


Fig. 14 Drawings of Mars made by P. Secchi. Rome, 1858

7 June, 10^h —A large reddish continent lies between the Isthmus and the Atlantic Canal (Fig. 14D).

8 June, 9^h 10^m and 9 June, 9^h 45^m —Observation of this reddish continent. In its lower part can be seen a sort of promontory, pointing toward the lower polar cap (Fig. 15A, B).

10 June, 9^h 0^m —The lower part of the figure merits special attention, because a region of bright cloud extends between the polar patch and the red continent (Fig. 15C).

11 June, 9^h 45^m —The planet presents prodigious and indescribable variety in tint. The green-blue canal is followed by a greenish fringe to the left, which extends as far as a yellow patch. At the lowermost boundary of the canal may be seen many very small white strips. These are very remarkable. Are they clouds? If they are not seen again under good conditions of seeing, one will be forced to believe that they have undergone change (Fig. 15D).

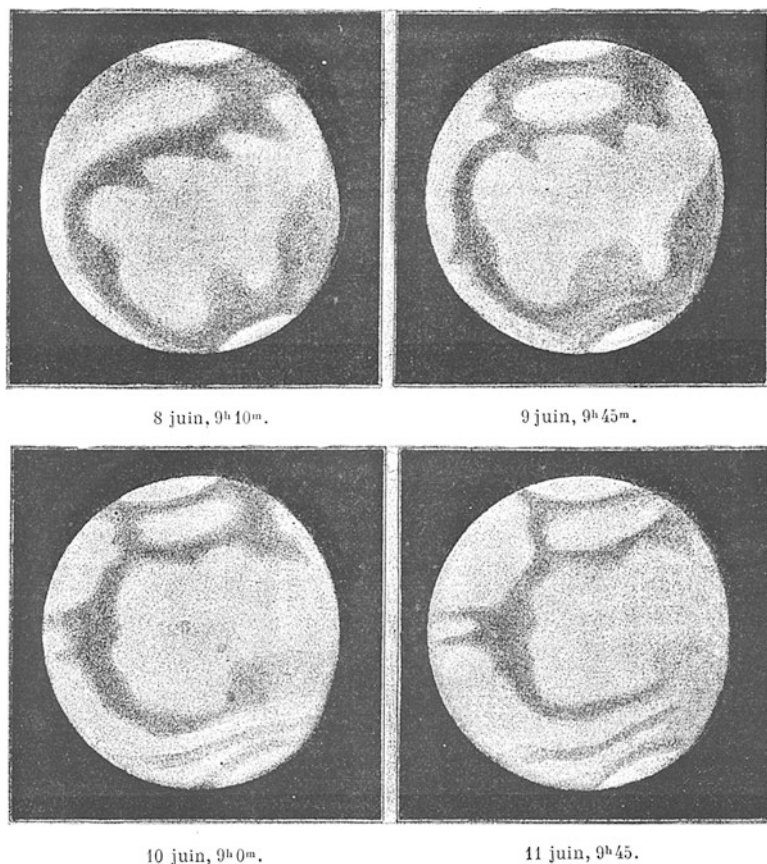


Fig. 15 Drawings of Mars made by P. Secchi. Rome, 1858

13 June, 9^h 30^m — The great blue canal (Fig. 16A) is almost in the middle of the disk; this patch is so vast that to the naked eye Mars appears less red than usual. The three principal arms of this patch make up the form of a γ or, rather a Scorpion:

Angle of the eccentric polar patches, 200°.5.

Angle of the axis of the triangular patch, 218°.

Right arm, 283°.

Left arm, 160°.5

Width of the black patch, 3".175.

Polar diameter of the planet, 18".371.

Distance of the patch from the upper pole, 7".304.

These measurements were made at 9^h. The drawing was made at 9^h 30^m.

14 June, 9^h 15^m—Same aspect as before. Very remarkable (Fig. 16B).

15 June—Same aspect as on the preceding evenings (Fig. 16C).

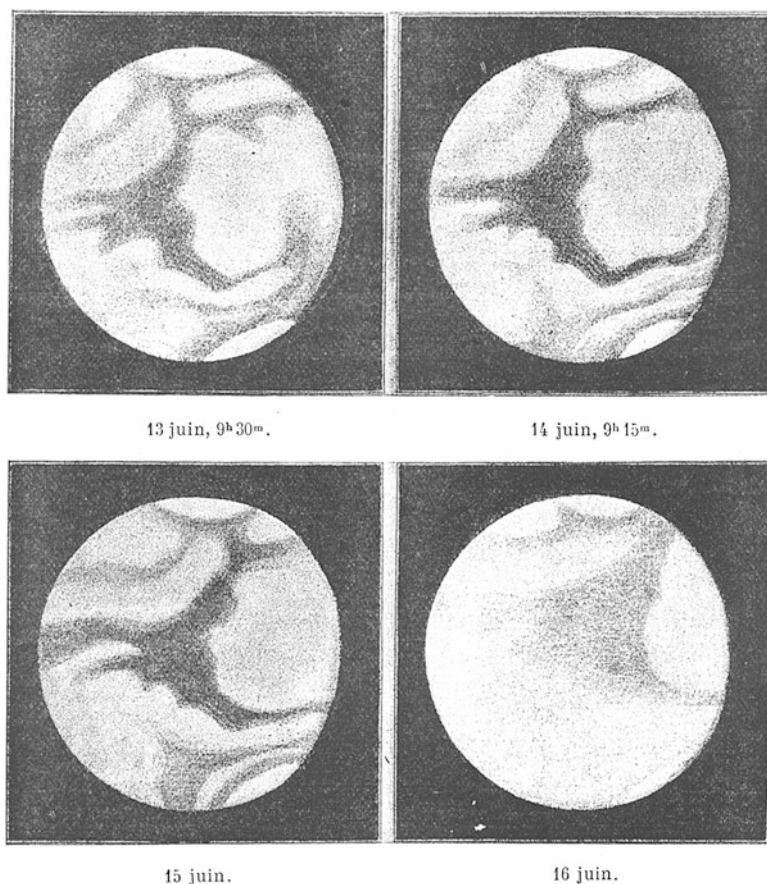


Fig. 16 Drawings of Mars made by P. Secchi. Rome, 1858

16 June—Atmosphere disturbed (Fig. 16D).

17 June, 9^h 36^m—Aspect (Fig. 17A) which is exactly like that of 25 April 1856, at 13^h 37^m sidereal time, which enables us to deduce (1) the rotation period of the planet and (2) the permanence of the Atlantic Canal, which appears on the right. The figure of the dark patch is crossed by several white veils. What are they? On the 15th they were not visible.

16 June, 9^h 20^m—Mars is particularly interesting. To the left may be seen the beginnings of a dark streak. In this area the planet is yellow, while all the rest of the disk is reddish and dappled. In this phase (Fig. 17B) the great canal tends to disappear and seems to be prolonged in the lower direction as far as the edge of the disk, but when it is seen in the middle of the disk, as from 13 to 15 June, it is obviously interrupted a long way before reaching the neighbourhood of the pole.

20 June, 9^h 40^m—The drawing was made when the canal had already almost reached the edge of the disk, and one could see only light ashy streaks on a red background (Fig. 17C).

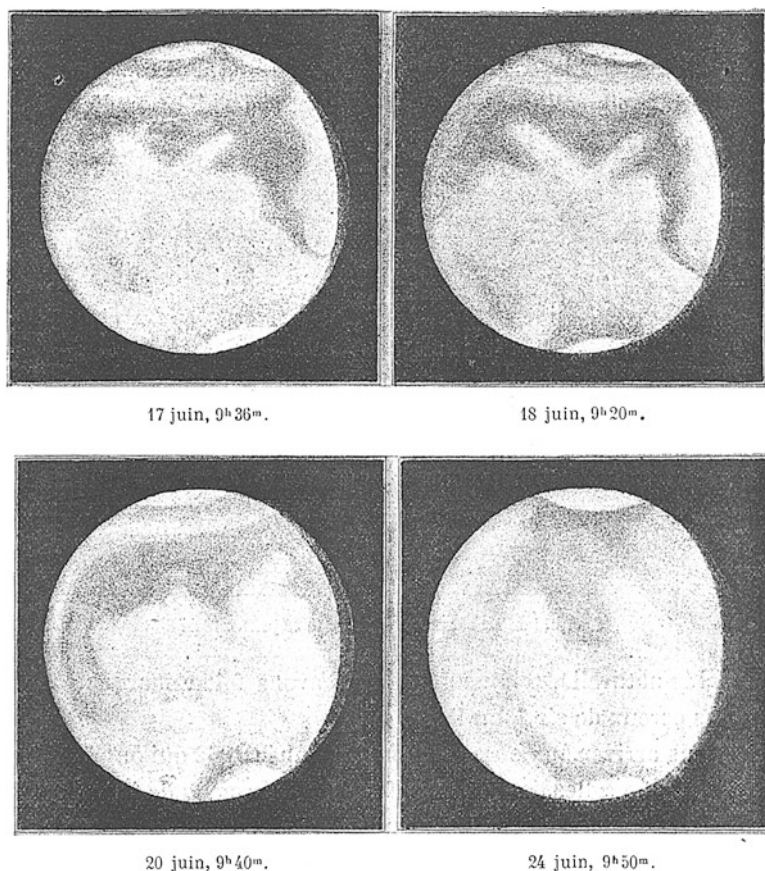


Fig. 17 Drawings of Mars made by P. Secchi. Rome, 1858

24 in June, 9^h 50^m—Thick atmosphere; the disk appeared chestnut colour (Fig. 17D).

1 and 2 July—Few patches. To the naked eye Mars appeared redder than usual.

23 July—The great blue patch strongly resembled a scorpion.

24 and 31 July, 5 and 13 August—Study of the lower polar patch; *it is certainly double*, made up of two patches in contrast with each other.

Such were the observations relating to the opposition of 1858. Father Secchi was unable to continue during the opposition of 1860, as he had intended, but he again observed in 1862 (see below). The observations just described were excellent, and among the best obtained up to that time. The later ones were even better.

1860.—Emmanuel Lias¹⁸

Emmanuel Liais, astronomer of the Paris Observatory and later nominated by the Emperor of Brazil to the directorship of the Observatory of Rio de Janeiro, observed Mars during the opposition of 1860, concentrating upon the physical aspect and the solar parallax. The mean of his measurements gave $25''35$, or $9''.91$ for unit distance. On 23 July he made the sketch of Mars which is reproduced here from his work *L'Espace cèleste*, published in 1865. In his sketch (Fig. 18), the south pole is turned toward us; while a little of the north pole can be seen below and what seems to be the Maraldi Sea.

Liais emphasized that—as Arago had shown—the reddish colour of the planet is not due to its atmosphere, but to the colour of the ground, and thought that *vegetation* was a likely cause. This latter explanation appeared to be an extremely natural one, as we have already noted when discussing Sir John Herschel's comments about the ochre lands.

We now come to the observations of 1862. Together with those of 1864, they are among the most valuable in the progress of our knowledge of Mars, because at these two oppositions, Mars was almost at its closest to the Earth. However, we had already a basic knowledge, sufficiently well-founded, to give a general idea of the constitution of our neighbour world. The following extract shows the state of opinion at this time.

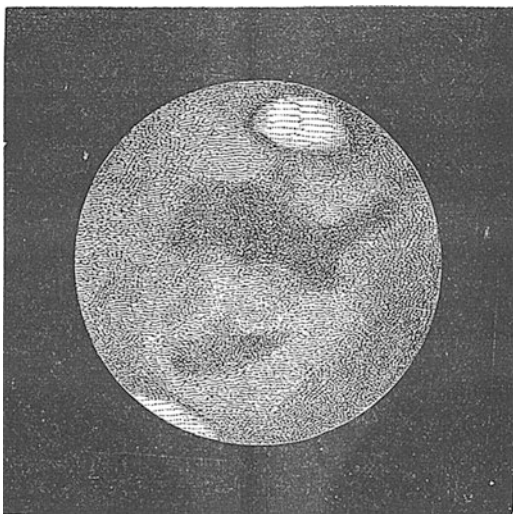


Fig. 18 Sketch of Mars, by M. Liais, on 23 July 1860

¹⁸*L'Espace cèleste*. Aspect and diameter of Mars.

1862.—C. Flammarion¹⁹

In the first edition of *La Pluralité des Mondes habités*, published in 1862, I gave the following résumé (at page 21) of the state of knowledge at the time concerning the conditions of habitability of Mars:

Around twenty million leagues from the Earth orbits the planet Mars; it presents some striking points of resemblance to the Earth. It is 58,178,600 leagues from the central star; its year is 687 days, and its diurnal rotation period is 24^h 39^m. The atmospheric envelopes which surround it and Earth; the snows which appear periodically over the poles of both planets; the clouds which extend from time to time in their atmospheres; the geographical arrangement of their surfaces in terms of continents and seas; the seasonal variations and the climates common to these two worlds; lead us to believe that both planets are inhabited by beings whose organization is of similar character. If one of them had been born in isolation, then the other, existing under the same conditions, should follow this same course.

From the second edition of this book (1864) to the sixteenth (1871) I have published the sketch given here (Fig. 19), made at the time from a comparison of the various observations of the better-known hemisphere of the planet. The little chart includes the Hourglass Sea and the surrounding seas and shows at a glance the difference between Martian geography and our own. At the end of the seventeenth edition (1872), I gave a coloured plate of the same hemisphere, drawn from more recent observations. The existence of continents, atmosphere, clouds, snows, seas, and polar ices is regarded as definitively proved.

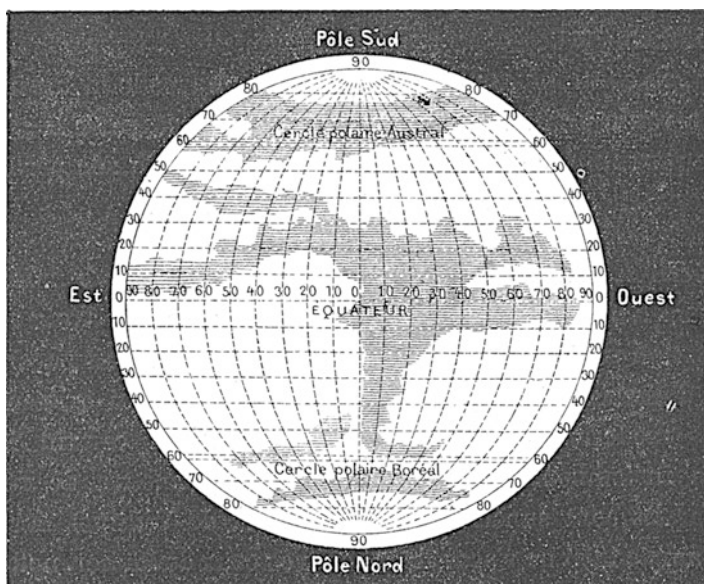


Fig. 19 The best-known hemisphere of Mars (1862–1864). (Figure reproduced from the 2nd edition of *la Pluralité des Mondes habités*)

¹⁹*La Pluralité des Mondes habités*.

In this figure I have indicated East and West as we use them on Earth—that is to say, as they would appear to an inhabitant of Mars.

We now come to the observations made by Father Secchi in 1862, and published in 1863.

1862.—A. Secchi²⁰

The following is a translation of the résumé of the memoir published by the eminent Italian astronomer. These observations were made at the Observatory of the Collegio Romano; they form a continuation of the series made in 1858, and the same instrument was used.

Secchi wanted to take full advantage of the perihelic opposition of the planet to continue his researches into its physical constitution:

Mars is the best-studied of all celestial bodies, except for the Moon. On it, Herschel and other astronomers have observed not only seas and continents, but also the effects of the seasons of winter and summer; however, the disagreements which exist between the modern observations and the old ones cause certain misgivings. Modern instruments ought to be able to resolve the problems, because they are superior even to those of William Herschel. Our drawings of 1858 are not in accord with those of Mädler, notably with regard to the white polar patch—Mädler showed it reduced to a small, brilliant circle, while we find it vast and complex. But at the last opposition, it reverted to the form shown by Mädler.

These differences are due to two causes. The first is the angle at which Mars is seen. In 1858, the two poles were equally visible, while now the north pole is hidden and the south pole is turned toward us. On 26 September 1862, at 9^h 45^m, the planet was seen in a position corresponding to that of 4 June 1858 (the one at the upper right of Fig. 14), but obliquely and foreshortened, with the upper pole tilted toward us, as in Mädler's third drawing of 1832.

The second cause of variation is that the polar patches really do change constantly. The vast white fields are shown as faint and restricted in the form of Mädler's small polar cap. It is clear that the variations can be explained only by a melting of the snow or a disappearance of the clouds covering the polar regions. And indeed the pole visible during the opposition of 1862 is also the pole turned toward the Sun; this pole is having its summer, and Mars is only 15° from perihelion; therefore the temperature of the pole is at its highest, corresponding to the middle of our month of July. Note also the strong inclination of the axis of Mars to the orbit, giving very marked seasons.

These aspects also proved that liquid water and seas exist on Mars; this is a natural result of the behavior of the snows. This conclusion is confirmed by the fact that the blue markings which we see in the equatorial regions do not change sensibly in form, whereas the white fields in the neighbourhood of the poles are adjacent to reddish fields which can only be continents. Thus, *the existence of seas and continents, and even the alternations of the seasons and the atmospheric variations, have been today conclusively proved.*

From these observations of 1862 it is found that the very characteristic features of the planet drawn by Beer and Mädler returned in an unequivocal manner. Thus, the patch that they lettered *efh* corresponds to that which I call the Cook Sea; their *np* is my Marco Polo; their patch *a* is the Franklin Canal. I have given no names to the reddish regions, and I have confined myself to giving names to the darkest, most certain and most constant of the dark patches.

²⁰ *Osservazioni del pianeta Marte, Memorie dell'Osservatorio del Collegio Romano*. Nuova Serie: Vol II. Roma, 1863.

From those researches I have come to the conclusion that as well as these permanent patches, there are variable ones, which should be studied closely and consistently. The existence of an atmosphere cannot be doubted, because of the limb brightening and also because of independent spectroscopic observations.

Extract From the Observations

21 September 1862, at 20^h 50^m sidereal time—Mars showed its upper polar cap, very reduced in size and fully turned toward us. Its angle is 145° from the centre. The blue patch in the form of a Y can be seen clearly; its form resembles that of a scorpion, but its narrow part is hidden. For brevity, I will call this blue canal the Cook Canal, applying to Mars the names of celebrated navigators, and I give the name of Cabot Continent to the reddish continent which extends to the right (Fig. 20A).

26 September, 9^h 45^m —The Cook Canal lies almost exactly in the middle of the disk. But, while in the 1858 drawings its broadest part, which I call the Scorpions body, is well

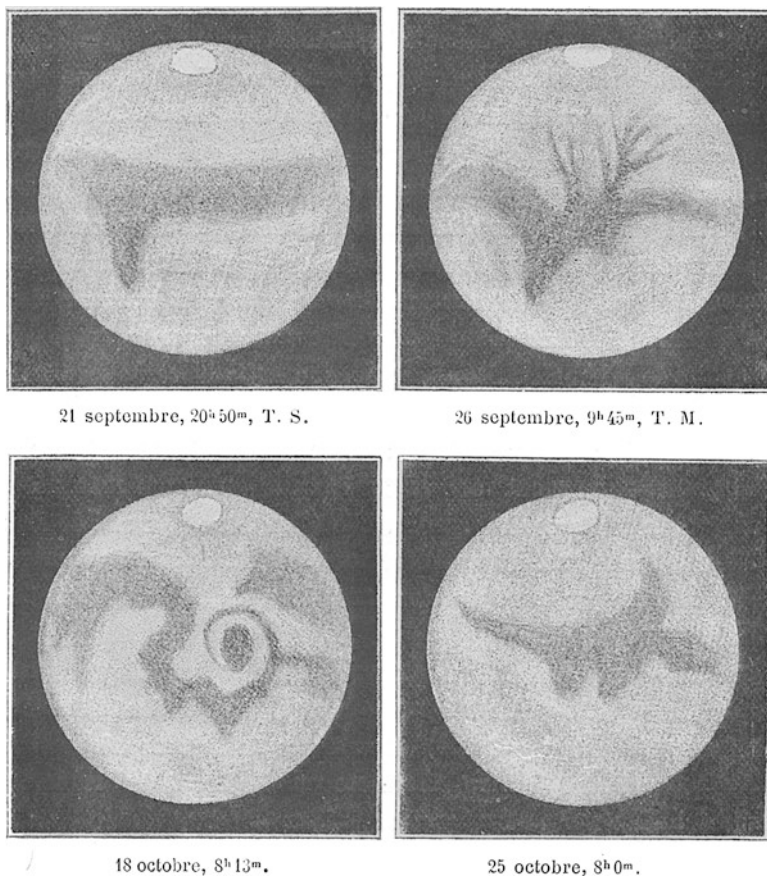


Fig. 20 Drawings of Mars made by P. Secchi. Rome, 1862

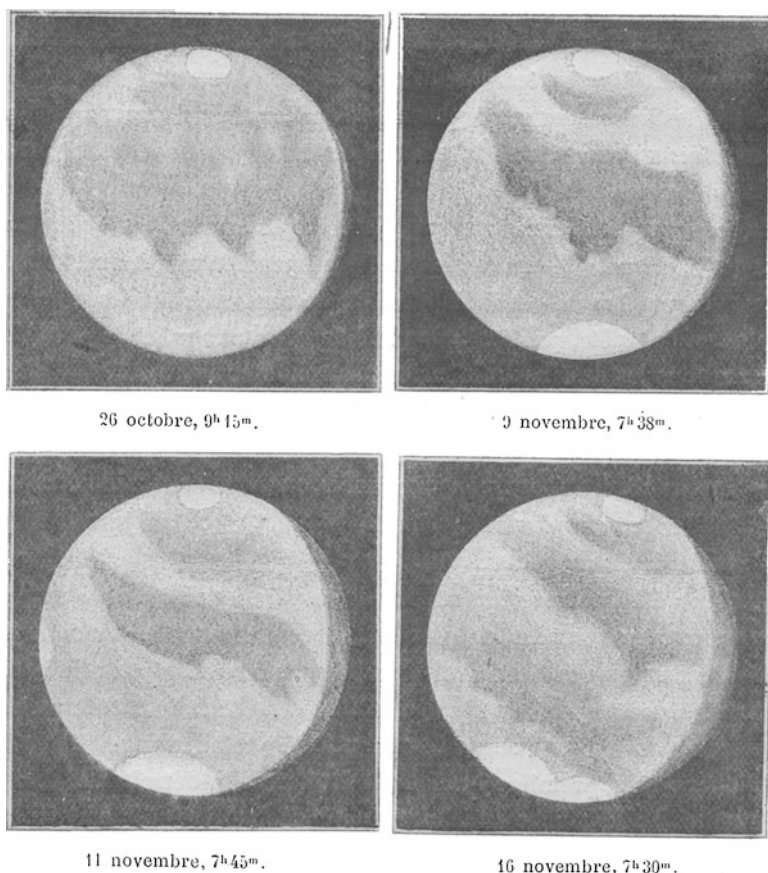


Fig. 21 Drawings of Mars made by P. Secchi. Rome, 1862

above the centre, it is now right at the centre. (See, in particular, the drawings of 14 and 16 June 1858 on p.140.) This is due to perspective. This year, the region shows exactly the aspect which Beer and Mädler drew in their Fig. 3 of 1832. Details near the limb cannot be distinguished, which proves that *the atmosphere of Mars is absorbing*. Between the polar patch and the Cook Sea may be noticed several shades of blue, and streaks shot through with yellow and red, difficult to draw. I believe we are looking at an archipelago (Fig. 20B).

18 October, 8^h 13^m—The polar cap is well away from the edge (Fig. 20C). I can note a dark patch different in tone from those to which I am accustomed; I have never seen it before. It seems to be surrounded by a ring, or a spiral cyclone. The regions near the pole are reddish; they were certainly white during the former year. I believe we are seeing a great squall on Mars.²¹

25 October 8^h 0^m—Polar patch well marked and well detached (Fig. 20D). Between it and the canal is a large reddish region which I call *Columbie*.

26 October, 9^h 1^m—The easiest feature to recognize is the Franklin Canal to the right (Fig. 21A). Between the pole and the sea which joins the Cook Canal to the Franklin Canal I see a reddish area speckled with curved lines (*Columbie*).

²¹This patch, compared here with a squall, is the Terby Sea of my chart. Secchi wrote: "*La credere una gran burrasca in Marte.*"

9 November, 7^h 38^m —The view this evening is remarkable because of a large blue patch which I have never seen in these proportions before (Fig. 21B). It is obviously a prolongation of the Cook Sea. It was not seen in 1858, no doubt because the real variations, rather than differences in perspective, or different conditions in the atmosphere of Mars. Very nebulous in this region, notably on 18 and 20 June 1858, this patch is similar in shape to the patch which Beer and Mädler lettered *PM*.

11 November, 7^h 46^m —The great patch *PM* which I call the Marco Polo Sea appears clearer and clearer (Fig. 21C). Between it and the white pole I can see a very curious dark cloud.

16 November, 7^h 30^m —The great blue sea is well seen (Fig. 21D). The lower or north polar cap is double.

18 and 26 December—The continuation of the observations proves that the upper or southern polar snows have diminished considerably, and are reduced to nothing more than a small white circle.

These observations by Father Secchi are as curious as they are important. They confirm our preceding views about the continents, the seas and the atmospheric influences on Mars, as well as the *certain variations* which occur on the surface of the planet with regard to the form and extent of the seas.

We can now, more completely than before, undertake a study of the determination of Martian geography. In order to tackle this more accurately, it is essential to refer to the base chart of Mars published in this book (fig. 31), and to compare it with the drawings made by the industrious Roman astronomer.

In the 1858 drawings, the celebrated Hourglass Sea can be recognized with certainty on five drawings, those of 10, 11, 13, 14, and 15 June (Figs. 15C, D and 16A–C). We may reason in the following manner:

As we have noted, the Hourglass Sea was called the *Scorpion* by the Roman astronomers, and the resemblance is indeed picturesque. The tail of the Scorpion is the Nasmyth Channel of my chart, and ends in a small sea called the Lassell Sea; the right tentacle, above the body, is the Dawes Ocean, which is prolonged toward the pole by the Lambert Sea. The first branch to the right is Herschel II Strait; the large tentacle to the left is the Flammarion Sea, which is prolonged by the Hooke Sea; the small tentacle above is probably the Main Sea, though exaggerated. This region is very variable in all the drawings. At the bottom of the figure, on all the five drawings, may be noted a white zone; the Laplace Canal, then a grey region (the Delambre Sea) and next a bright zone, followed by a dark zone surrounding the lower pole.

We again find the Hourglass Sea on the drawings of 21 and 26 September 1862 (Fig. 20A, B). Father Secchi gave no less than three names to this sea: the Scorpion, Atlantic, and Cook Sea.

In the drawings of 3, 4, 5, and 7 June 1858 (Fig. 14A–D), we see another side of the planet. This narrow elongated sea is the second characteristic aspect of Mars in these observations; the Roman astronomers called it sometimes the Isthmus, sometimes the Franklin Canal. It is almost 180° to the right of the Hourglass Sea, so that the two patches can never be seen at the same time. In my charts, I have given this sea the name of the Channel (*de Manche*, as the French refer to the *English Channel*—WS). Schiaparelli calls it the Ganges. The strait is not shown on Green's chart, which will be described further below.

If these four views of Mars are carefully studied, it seems that the first pointed tongue, going from left to right, is the Meridian Bay; the second, 20° to the right, is Burton Bay, called by Schiaparelli the Margaritifer Sinus and the mouth of the Indus; and the third, lying at the same distance below, seems to be made up of Christie Bay and the Channel. The identifications are not absolutely satisfactory. The drawings give longitude 25° for the mouth of the Indus; while the longitude of the Channel is not 50° , but 56° . However, it seems impossible to make any other identification. The Channel is absent on a great number of drawings, though we will find it again later. It is shown perfectly on two drawings made by Dawes on 12 and 14 November 1864, and on one made by Schiaparelli on 28 November 1879. The observations by Secchi and Dawes lead me to give greater emphasis to this Isthmus on my chart than it had on Schiaparelli's.

The 1862 drawings do not show it. On the eight drawings made at Rome in that year, the first two have—as we have seen—shown the Hourglass Sea. The third shows the Terby Sea, taken by Secchi to be a cyclone. The fourth enables us to identify the three bays on the 1858 drawings (Meridian, Burton, and the Channel), and it is the same on the fifth. The sixth, seventh and eighth show the Maraldi Sea, which Secchi calls the Marco Polo Sea and which Beer and Mädler lettered *PM*.

These drawings are sufficient to confirm the opinion that the Martian globe shows permanent geographical configurations, but show at the same time that these configurations are subject notable variations, which are in some measure due to the observers and to instruments, while many others—as, for example, the width of the Channel—are inherent in the physical constitution of the planet itself. This last point is of the greatest importance.

Secchi continued his observations in 1864. Among the drawings of that year, we may note, after Terby (Fig. 22), that of 1 December 1864, at 7^h , which at first appears to represent a very narrow form of the Hourglass Sea but actually shows the Maraldi Sea together with a strait going down from it in the form of an elongated triangle. This is evidence of the changes which occur on Mars in this particular region, because the elongation probably corresponds to Fig. 52B, Chap. 1, observed by Schröter on 2 November 1800, and to the left hand points of the marking shown in Figs. 51 and 53B, Chap. 1.



Fig. 22 Sketch made by P. Secchi, on 1 December 1864

1862.—Lockyer²²

We now enter a fruitful period in the study of Martian geography. During the very favourable opposition of 1862, several astronomers devoted themselves to the work, and we will examine, among others, the results obtained by Father Secchi in Italy, Lockyer in England, and Kaiser in Holland. First let us consider the work of the English astronomer, summarizing his important memoir as completely as possible.

The doubts and difficulties in connection with the permanence of the Martian features are due chiefly to the hopeless lack of accord between drawings made at different epochs. Opinions are remarkably contradictory; thus, to cite only two examples—Cassini in 1670 recognized the patches which he had discovered in 1666 with his Campani refractor of 16½ in. focal length and Maraldi in 1720 declared that it was impossible to reconcile them with drawings made in 1704, 1717, and 1719, while in our own time Secchi found in 1858 that his drawings were incompatible with those made by Beer and Mädler in 1830 and 1837.

The inclination of the planet can cause marked differences in aspect, because of the foreshortening effects; the features seem sometimes to be shifted in both latitude and longitude. It will therefore be convenient to compare drawings made under identical conditions of inclination. Thus the opposition of 5 October 1862, at heliocentric longitude 12°, is comparable with that of 19 September 1830 (heliocentric 356°) (Figs. 23 and 24).

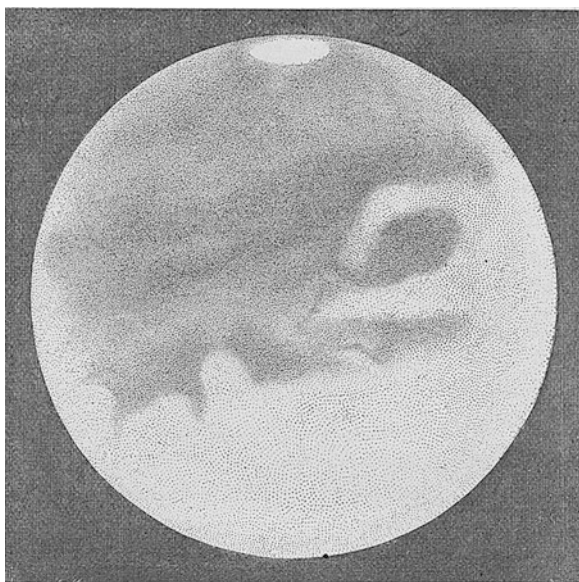
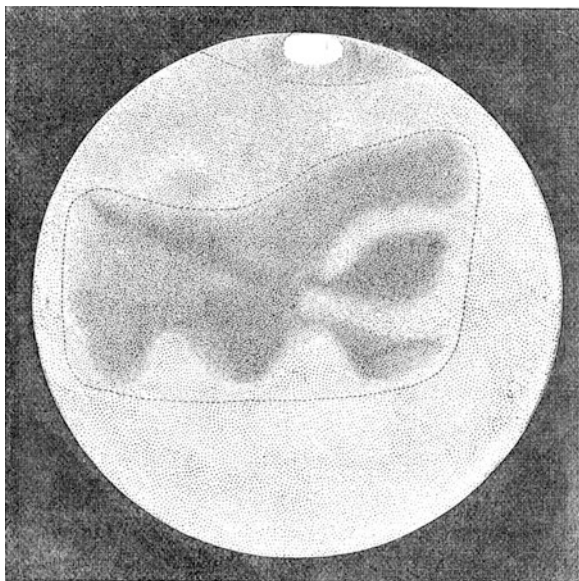


Fig. 23 Drawing by Lockyer, 17 September 1862, at 10^h 50^m

²²*Measures of the planet Mars, made at the opposition of 1862. Memoirs of the Royal Astronomical Society*, XXXII, p. 179–190.

Fig. 24 Drawing by Lockyer, 17 September 1862, about 10^h 50^m



Allowing for the fact that Lockyer's objective was of 6¼ in. aperture and 8½ ft focal length vs. Beer and Madler's 3¾ in. aperture and 4½ ft focal length, Lockyer claimed that his drawings agreed perfectly with those of 1830. (The larger instrument would, of course, show a correspondingly greater amount of detail.)

These observations of 1862 confirmed, in a most satisfactory manner, the absolute permanence of the configurations of the planet. There were nevertheless inexplicable disagreements between the observations made with different instruments, even in the hands of the most skilful observers (Figs. 25, 26, 27, and 28).

While the complete fixity of the general features was not in doubt, variations in the details and tones of the bright and dark regions were observed daily—one might even say from hour to hour. Lockyer did not doubt that these changes were caused by clouds passing over the different regions. He wrote:

These changes are, I doubt not, caused by the transit of clouds over the different features.

A clear, cloudless atmosphere, here as on Mars, would have the effect of rendering the dark regions of the planet darker and more distinct; the lines and coasts, if we may so call them, are so fine and so light that it is quite impossible to represent them exactly. Beer and Mädler have already commented that generally a definite time elapses before the patches—originally vague when observing begins,—become sharp and well-defined.

Clouds, on the other hand, have the effect of making the dark regions less dark, in proportion to the density of the clouds, and the bright regions less bright in the same ratio. *They can never make a bright region look dark.*²³ Thus when we see a dark patch as well-defined, we can be certain that there are no clouds above it, and that we are looking at the actual surface of the planet. However, we cannot be sure, at least in view of our information drawn from the old observations, that dark regions are not at a lower level than the bright areas.

²³Is this certain?

Fig. 25 Drawing by Lockyer
23 September 1862, at 9^h 40^m

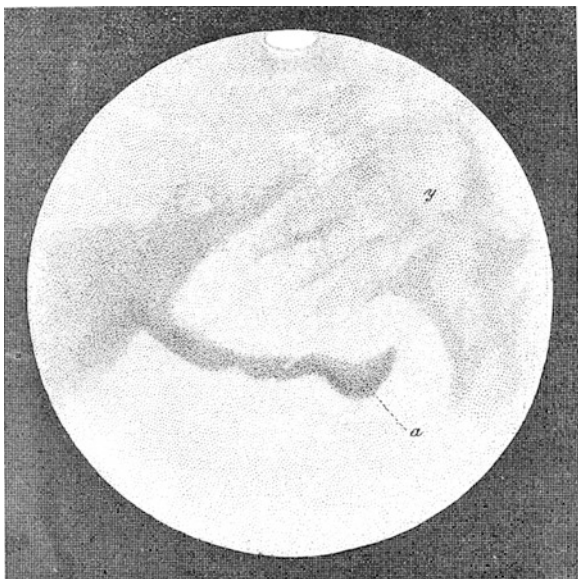
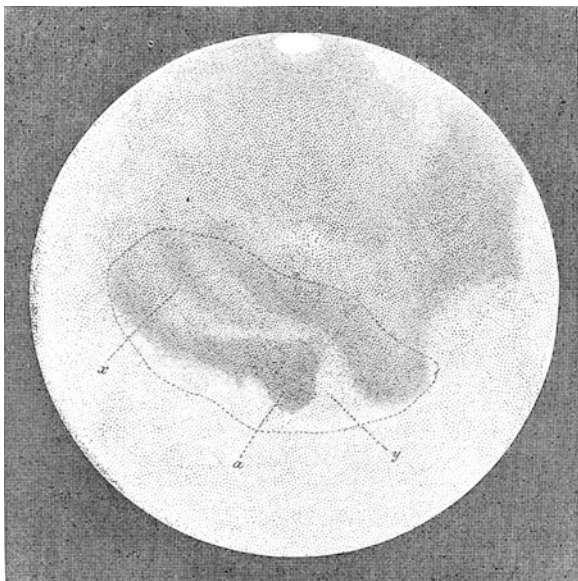


Fig. 26 Drawing by
Lockyer, 23 September 1862,
at 10^h 25^m



Several examples of clouds were suspected by Father Secchi in 1858. However, Lockyer presented some unmistakable cases. In the drawing made on 3 October, at 10^h 30^m (Fig. 31), the space stretching from *x* to *y* was lacking in any dark feature; in the sketch made on the same evening at 11^h 23^m (Fig. 32) a patch was seen near *y*,

Fig. 27 Drawing by Lockyer, 23 September 1862, at 11^h 55^m

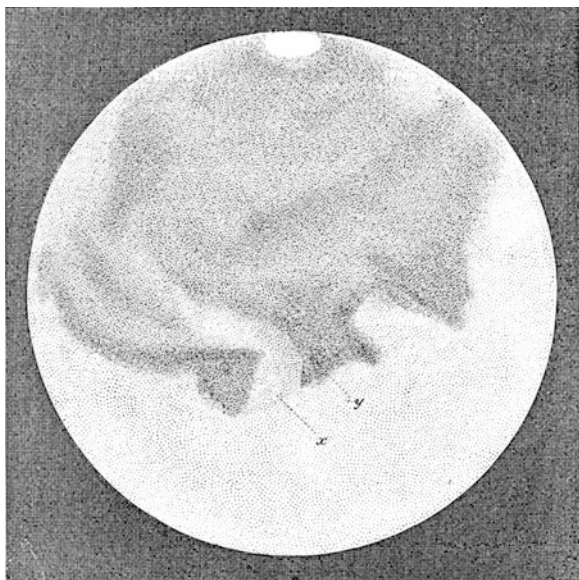
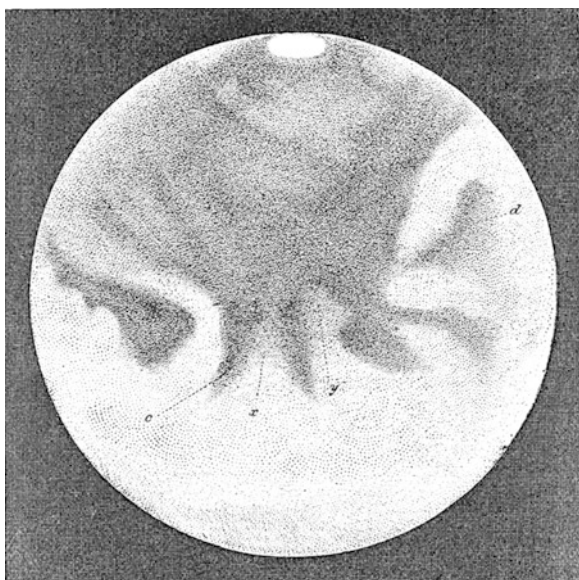


Fig. 28 Drawing by Lockyer, 23 September 1862, at 12^h 55^m



which spread out progressively and extended as far as *x* at 11^h 51^m, when the drawing in Fig. 33 was made. Lockyer wrote as follows:

Now, this region is one of those which we know best, because it has been excellently observed by Warren de la Rue, Father Secchi and others, and there is no doubt that Secchi's drawing no. 8 does not represent the normal aspect of this equatorial region at longitude 28°.

The observed changes can be easily explained by assuming that at the beginning of my observations the feature concerned, and which is persistent in Secchi's *fig.* 10, 11, 13, 14, 15, 17 and 18, was veiled by clouds which gradually dissipated up to the end of the observation; although the feature was not completely unveiled, it was much more clearly visible at the end of my observations.

He was referring to an area which our readers will know very well: that of the famous Hourglass Sea. Accepting, with Lockyer, the influence of white clouds, we can see that the zone marked *f* and *y* is very variable (further from the left border of the Hourglass Sea). Lockyer further wrote:

To take another example, in my drawing no. 14, Beer and Mädler's patch *a* is completely invisible, while in no. 15, made several minutes later, it is absolutely evident and very notable.

But quite apart from the clouds which, as we have seen, from time to time totally or partially obliterate the dark regions of the planet and give rise to variations of colour and tone which deform the appearance of the features, we must agree that an atmosphere as dense as that of Mars, with its mists and its fogs, must also play a definite role. I mention this fact particularly with the aim of establishing that although patches in the southern hemisphere can be observed with certainty in the middle of the summer, when they appear at the edge of the disk and as they are passing over the limb, we can see them even more distinctly in the northern hemisphere in the middle of the winter, blotting out the geographical features north of latitude $+30^\circ$ even when the features are on the central meridian. We have here new evidence of the *great intensity of the seasons* on Mars, an intensity already demonstrated by the great extent of the polar snows in winter and their rapid melting in summer. As Beer and Mädler have commented, the southern hemisphere of the planet is always the easier to study from our point of view, because it is turned toward us at the times when the planet is at its closest to us.

With regard to the red and green colours so often described for the geographical features of Mars, my observations lead me to the same opinion about their nature as that expressed by Father Secchi from his studies made in 1858. To me, also, *the red regions represent continents and the green regions seas*. I do not believe that the green colours are due to contrast effects; to me, they appear real.

The dark regions seem to me to be certainly green, as is agreed by all those who have observed Mars. Through my telescope, this colour is particularly marked in the feature lettered *PM* on the map by Beer and Mädler²⁴ (drawing made on 15 October, from 9^h 8^m to 9^h 20^m). This colouring is certainly not due to the object-glass of my telescope.

The patches which appeared darkest in 1862 are the same as those which had the same appearance in 1830; these seas are generally almost completely surrounded by lands.

The variation of the polar snows is a most interesting subject for observation. In 1830, the summer solstice in the southern hemisphere of Mars fell on 8 September, and the minimum of the polar snows (1/20 the apparent diameter of the planet) was observed on 5 October—that is to say, 27 days after the greatest altitude of the Sun in the southern hemisphere. In 1862 the solstice fell on 30 August; on the 23rd of that month the snowy zone showed a diameter equal to 1/5 of that of the planet, but on 25 September it was reduced to 1/10, and on 11 October to 1/13, so that it could barely be distinguished. After that, the snows began to increase again.

This very rapid melting of the south polar ices can be attributed to the great eccentricity of the orbit of Mars, and to the fact that summer in the southern hemisphere occurs when the planet is near perihelion. The centre of the snowy polar cap does not coincide with the pole, but lies at several degrees from the geographical pole, near longitude 20° ; on the other

²⁴This corresponds to Mare Sirenum and Mare Cimmerium on modern maps.—WS.

hand with the north or lower pole, visible in 1857, Father Secchi has stated that the ice-cap really is centred on the pole.

Sometimes the polar snow appears so brilliant that, like the crescent of the new moon, it seems to project beyond the planet. On one evening, as clouds passed in front of Mars, the polar snow remained visible, looking like a nebulous star. (This was noted as early as the 1700s.)

Finally, Lockyer commented that his 6¼-in. (0^m.16) refractor was equatorially mounted and clock-driven; the magnification generally used was 191×. The splitting of double stars such as χ Aquila, γ^2 Andromedæ and λ Cassiopeiæ was a guarantee of the power and definition of the telescope.

I have reproduced sixteen of Lockyer's drawings in facsimile. They are the most important, with regard to our knowledge of Mars, that we have yet encountered in this book. I have arranged them in chronological order.

In the first and second of these telescopic views, it is easy to recognize the circular feature which looks like an eye—which has been called the Terby Sea. Above it, and to the left, lies the De la Rue Ocean; below, a grey region subject to frequent variations; to the left, a little rounded bay, the Christie Bay; and a little further away a second, Burton Bay. The southern polar snows are brilliant and sharply-defined, as on all the drawings.

Lockyer himself calls this eye-like feature the Baltic Sea.

In the third drawing, we may note in particular Herschel II Strait and the patch *a* (the Meridian Bay). A little later in the evening this strait and this patch were slightly more advanced toward the left (Fig. 26) and an hour and a half afterwards, more advanced still (Fig. 27). There is a great resemblance between these drawings and those of Beer and Mädler. Above this elongated sea we may make out a second, the Arago Strait, and between the two there is a tongue of land which is white or rather grey. This is a variable country, which appears sometimes continental and sometimes maritime. Figure 28, still more advanced, shows the Arago Strait in the centre of the disk; it is bounded by two pointed tongues, one of which is Christie Bay; the other, somewhat deformed, is the Eye.

One senses, even at a glance, that the geographical features have been drawn with precision and certainty.

Figures 29 and 30, of 25 September, again show the Herschel II. Strait (the Meridian Bay is veiled in the first drawing; these dark clouds are presumably of atmospheric nature, as Lockyer maintains). At *e*, the Strait is joined on to the Hourglass Sea. The three drawings of 3 October (Figs. 31, 32 and 33) show, with complete certainty, the Hourglass Sea, Flammarion Sea, Hooke Sea, and below it, the Maraldi Sea. Zöllner Sea and Lockyer Land are equally easy to recognize. To the left of the Hourglass Sea, the region *xy* is misty.

The drawing made on 9 October shows the Hooke Sea and the Maraldi Sea. Above lies the Maunders Sea, between the Hooke Sea and the Maraldi Sea; also above the Niessen Isthmus; to the right, the Hooke Sea, Cassini Island and Dreyer Island; toward the edge, Zöllner Sea. Below the Maraldi Sea extends Herschel I. Continent (Fig. 34).

The drawing made on October 11 shows the same aspects, but to the left of the Maraldi Sea can be seen another—the Schiaparelli Sea, separated from the Maraldi Sea by Webb Land. (Green's chart is rather imperfect on this point.) (Fig. 35)

Fig. 29 Drawing by Lockyer, 25 September 1862, at 10^h 44^m

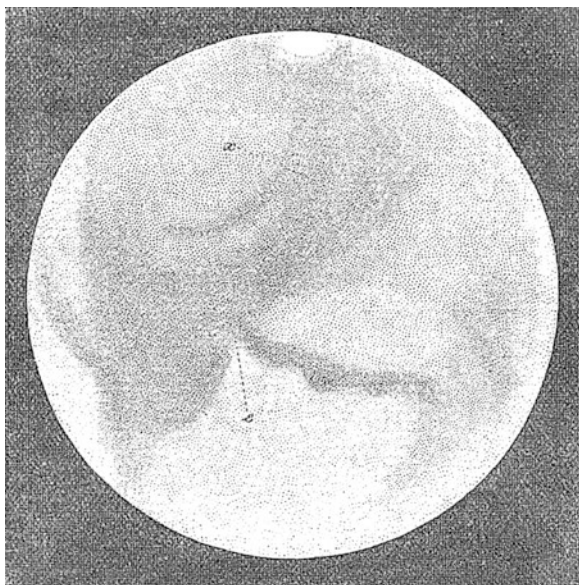
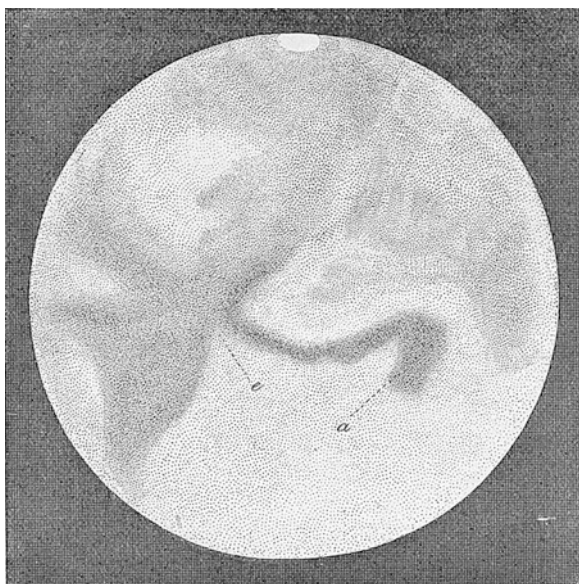


Fig. 30 Drawing by Lockyer, 25 September 1862, at 10^h 50^m



Finally, the two drawings of 15 October show the Schiaparelli Sea darker than the Maradli Sea to which it is joined (but this is not always the case); above, the Maunder Sea; to the left, the Eye or the Terby Sea in the middle of the disk, surrounded by the De la Rue Ocean, from which it is separated by Kepler Land. The region lying below the Terby Sea is less dark and less extended than it was on 17 September; this also is a very variable region (Figs. 36, 37, and 38).

On all the drawings, the lower or northern half of the disk is almost always devoid of features, except near the point of the Hourglass Sea.

Fig. 31 Drawing by Lockyer, 3 October 1862, at 10^h 30^m

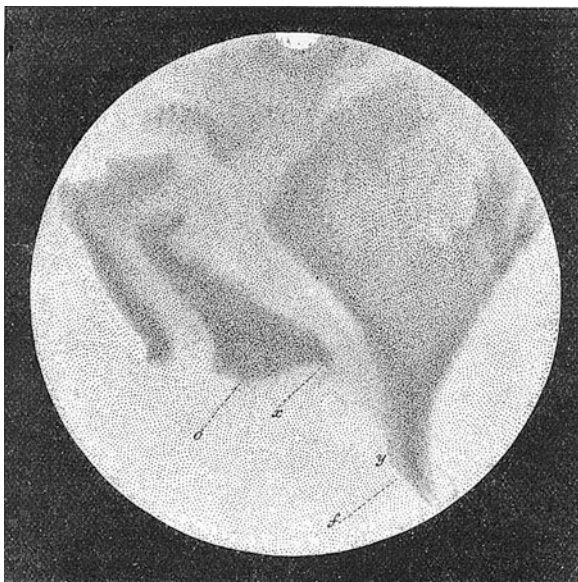
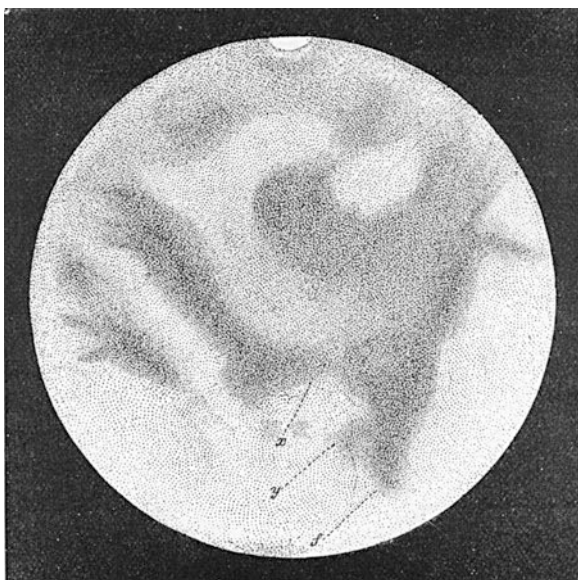


Fig. 32 Drawing by Lockyer, 3 October 1862, at 11^h 23^m



From this whole series of observations, we may conclude that the following points have been established:

1. Permanence of the position of the features;
2. Variations in the extent and darkness in tone of the features;
3. Various degrees of darkness in the seas; the Hourglass Sea, Herschel II Strait, Maraldi Sea and Schiaparelli Sea are generally the darkest.

Fig. 33 Drawing by
Lockyer, 3 October 1862, at
11^h 51^m

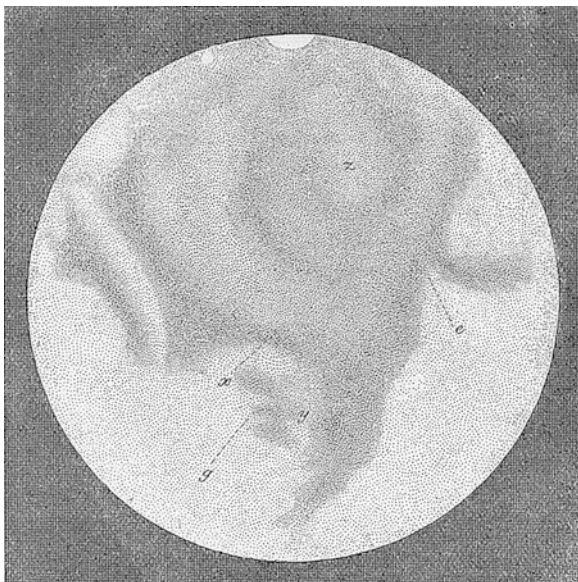
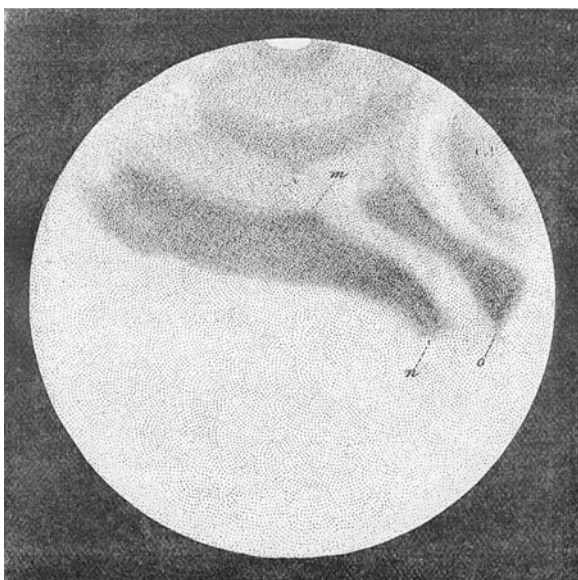


Fig. 34 Drawing by
Lockyer, 9 October 1862, at
10^h 47^m



To the Memoir we have just summarized, Lockyer has added the following note; it concerns the observations of Mars made during the same period by Professor Phillips and the Rev. W. R. Dawes:

Mr. Phillips concludes from his observations that, against a permanent background of bright and dark features, there is on Mars a variable atmospheric envelope which condenses and fluctuates, partly modifying the aspect of the basic configurations, and even disguising them to some extent and joining bright areas to dark ones;

Fig. 35 Drawing by Lockyer, 11 October 1862, at 11^h 4^m

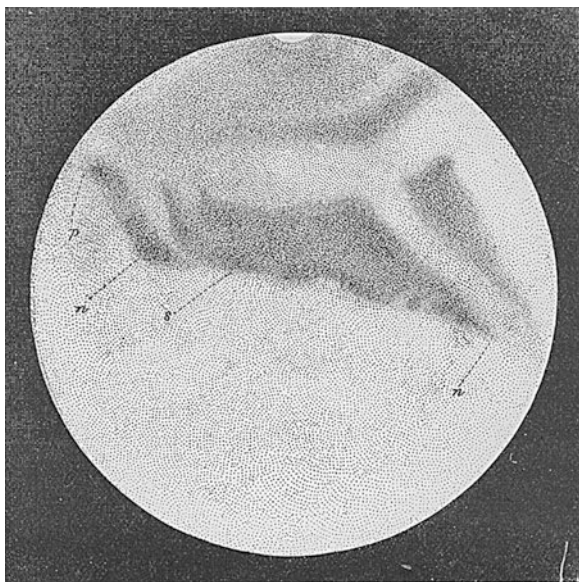
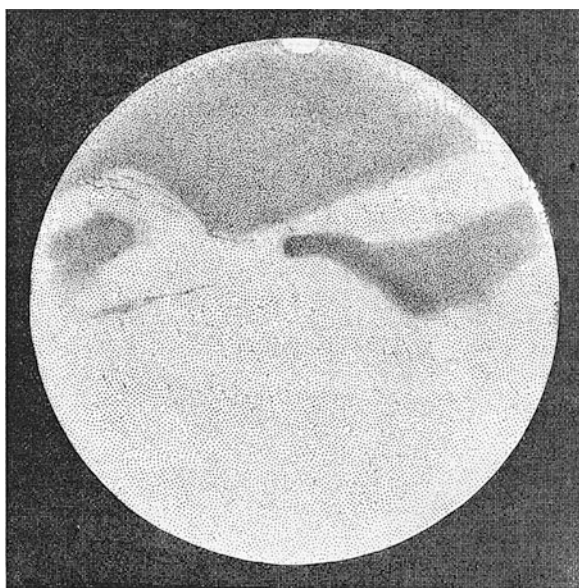


Fig. 36 Drawing by Lockyer, 15 October 1862, at 9^h 8^m



new lights and shades²⁵ which present no constancy, a thin, vaporous atmosphere, probably resting on a surface of lands, snow and water.

This inference is as remarkable as it is interesting, and it will be confirmed by later research.

²⁵This seems more probable to me than the assertion that Lockyer made above, that we can explain the phenomena more easily by black clouds seen from above and lit by the Sun.

Fig. 37 Drawing by Lockyer, 15 October 1862, at 9^h 20^m

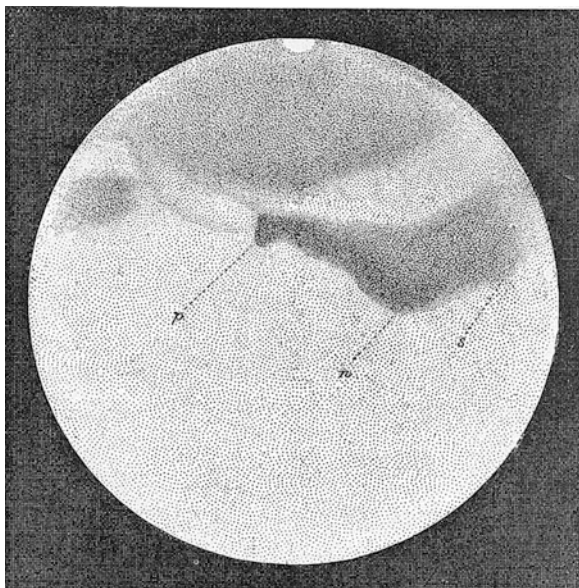
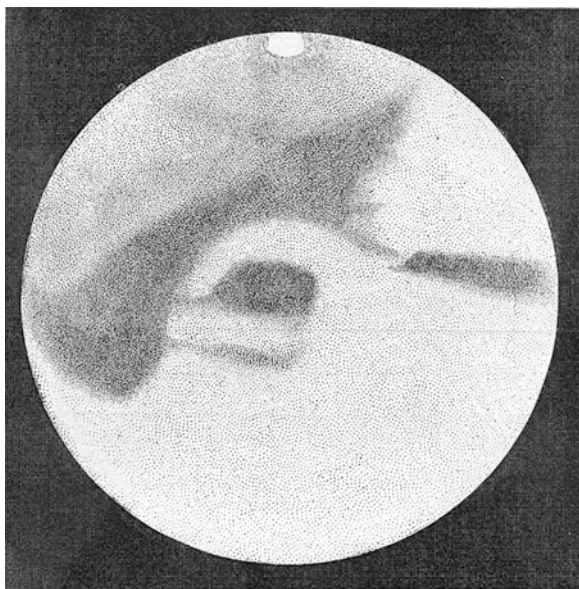


Fig. 38 Drawing by Lockyer, 18 October 1862, at 8^h 0^m



In reference to Dawes's observations, Lockyer remarks that they are in perfect agreement with his own. But one drawing made several minutes after his of 3 October at 11^h 51^m confirmed the passage of the clouds mentioned above, as at the time of Dawes's drawing the clouds had completely disappeared and the geographical features of the region had become clearly visible.

These excellent telescopic drawings by my learned friend Mr. Lockyer, whose name during this epoch has become unforgettable in the cause of the progress of contemporary astronomy, represent a very important advance in the physical study of Mars.

Same Year, 1862.—Phillips

During the same apparition, that of 1862, Professor Phillips at Oxford made some very detailed observations of the planet, communicated to the Royal Society of London on 12 February 1863. A résumé follows.

First, Phillips commented that the various views of Mars were mutually discordant, and that in comparing them he had been very perplexed. Were the patches permanent? Were they seas? Were they lands? The assertions given above by Secchi and Lockyer were in complete contrast to Phillips's uncertainty.

Reflectors are better than refractors for colour estimates; refractors give the sharper images. Phillips made his observations with a 6-in. (0^m.152) refractor, equatorially mounted and clock-driven.

From his various drawings Phillips chose three, which are reproduced here. The first shows the Hourglass Sea, Herschel II Strait, Dawes Ocean, Lambert Sea—which goes down toward the pole—and an upper polar sea. On the second, to the left we see the Hourglass Sea, Maraldi Sea, Hooke Sea and Zöllner Sea. The third drawing shows Maraldi Sea to the right, Schiaparelli Sea in the middle and Terby Sea to the left. The first of these drawings is very similar to that made by Sir John Herschel on 16 August 1830 (Figs. 39, 40, and 41).

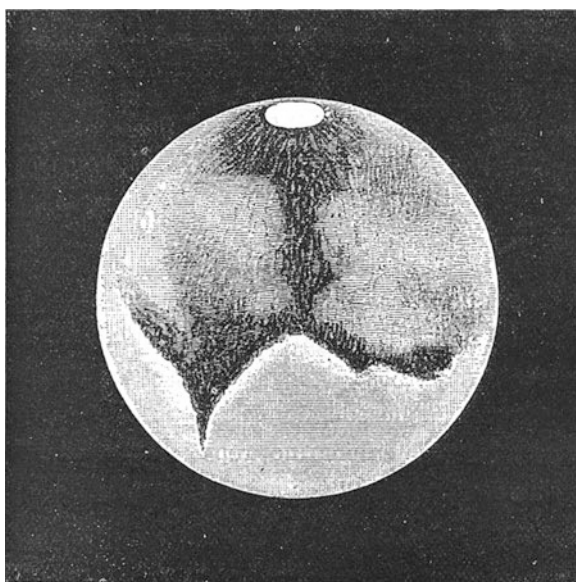


Fig. 39 Drawing of Mars by Phillips, 27 September 1862

Fig. 40 Drawing of Mars by Phillips, 11 November 1862

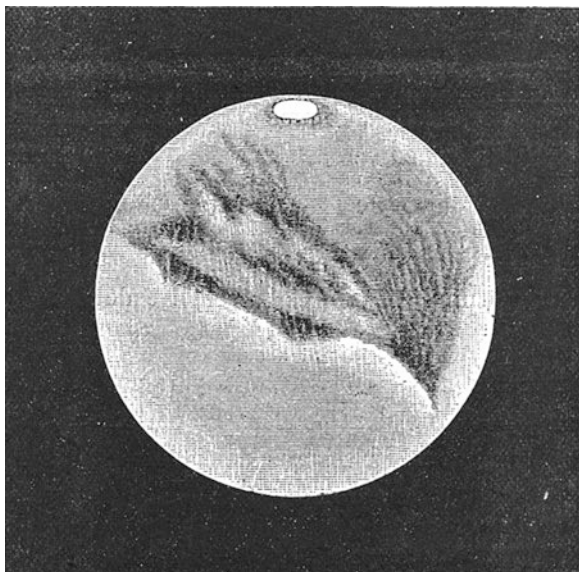
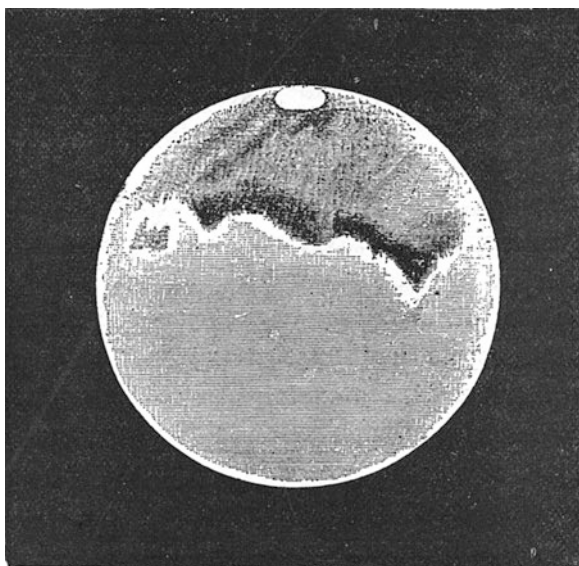


Fig. 41 Drawing of Mars by Phillips, 15 October 1862



Phillips expresses his regret that he cannot be sure whether the grey patches represent true seas, and not as with the Moon, merely grey plains. He commented that we would have positive proof in favour of the former idea if we could see there the image of the reflection of the Sun. Without taking irradiation into account, the Sun's image, reflected in the Martian seas, would be only $1/20$ of a second of arc across, but even so it would appear conspicuous. A thermometer bulb 1 in. (25^{mm}) in

diameter reflecting the sunlight is visible from 25 yd (22 m) as a star; the reflecting surface is scarcely $1/240$ of an inch in diameter, and consequently subtends, after an adjustment for irradiation, about 1^h of arc. Using a magnification of $300\times$ for observing Mars, $1/20$ of a second becomes 15^h . This would be perceptible. Phillips therefore concludes that under certain conditions we should see the image of the Sun reflected in the waters of Mars, whether the waters are calm or whether the image is diffused by the action of waves.

The Martian atmosphere should play a major role in modifying the geographical aspects which we observe.

The polar snow lies to the side of the pole, and some way from it.

With the telescope, the continents are red and the seas green.

Phillips adds, in conclusion, that the different aspects could be due to cloudiness. There is, he says, an enormous transport of moisture from one hemisphere where it is winter to the other where it is summer, giving rise to storm systems and vast cloudy masses. These are not distributed along the parallels of latitude as with the rapidly-rotating planet Jupiter but rather their arrangement depends upon the influence of lands and waters.

Same Year, 1862.—Observatory of Lord Rosse²⁶

Lord Rosse communicated to the Royal Society of London six drawings made by his assistant during the very favourable period in 1862. These drawings were made on the following dates with the great 6-ft ($1^m.83$) reflector (Fig. 42):

- 22 July, at $22^h 30^m$ sidereal time—Definition imperfect.
- 14 September, $6^h 26^m$ sidereal time—Definition quite good.
- 16 September, at $23^h 55^m$ sidereal time—Very good definition. Magnification $1,200\times$. There was light mist, and quite possibly the clarity was the best of the season.
- 6 October, $2^h 10^m$ sidereal time—Definition good.
- 29 October, $1^h 00^m$ sidereal time—Definition bad.
- 6 November, $1^h 40^m$ sidereal time—Definition very bad.

On the first and last of these drawings the Hourglass Sea may be recognized. The third clearly shows the circular Terby Sea. On the second, to the right of this lake, is Schiaparelli Sea. It seems that there are scattered clouds in each of these drawings made with Lord Rosse's great reflector.

If we compare these drawings with the preceding ones, we can see that they provide confirmation. Thus, for example, that of 16 September strongly resembles Secchi's of 18 October; also Lockyer's of 18 October and 17 September. That of 6 October gives the same aspect as Lockyer's of 3 October. All the features recognized above

²⁶Observations made at the Parsonstown Observatory (Ireland).

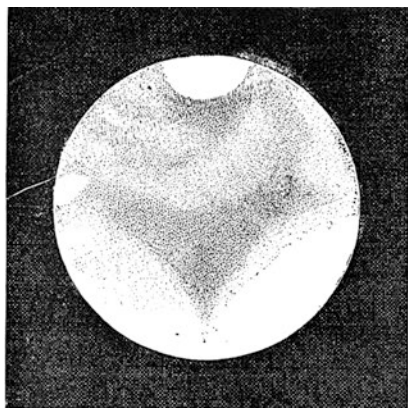
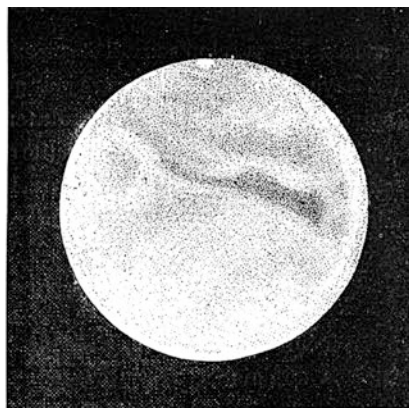
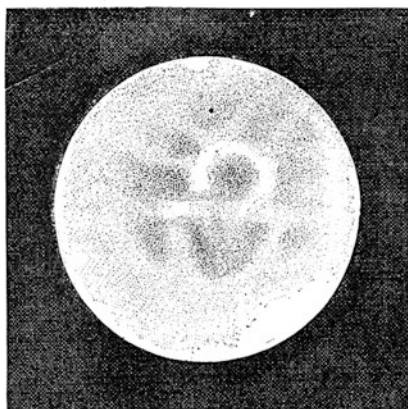
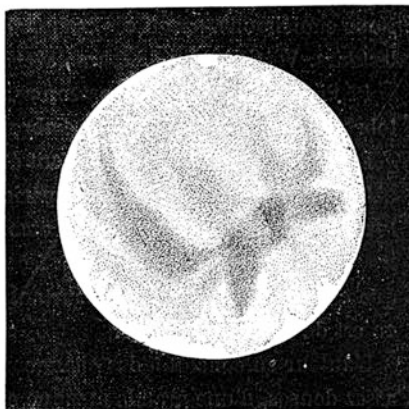
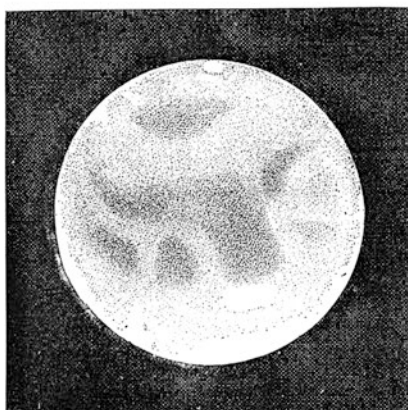
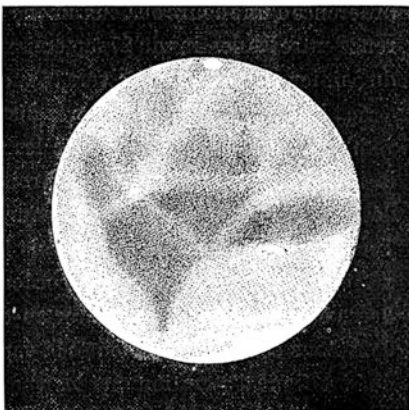
22 juillet, à 23^h 30^m. T. S.14 septembre, à 6^h 26^m. T. S.16 septembre, à 23^h 55^m. T. S.6 octobre, à 2^h 10^m. T. S.29 octobre, à 1^h 29^m. T. S.6 novembre, à 1^h 40^m. T. S.

Fig. 42 Telescopic views of Mars, obtained in 1862 at the Observatory of Lord Rosse

are represented in those drawings, depending of course on the hemisphere turned toward us.

They also show that each observer sees in his own particular way, according to his eye, his experience, and his method of drawing. M. Faye told me one day, that on a fine evening at the Paris Observatory, he had begun to draw Mars in the company of one of his colleagues (Goujon); this was in Arago's time. Comparing their drawings, made with the same instrument and within a quarter of an hour of each other, little resemblance was found. More than once I have made the same comment.

Same Year, 1862.—Lassell

In the same year Lassell, with his great 4-ft (1^m.20) reflector, made a remarkable series of observations, and communicated them to the Royal Astronomical Society of London. There were 24 drawings, from 13 September to 11 December 1862. From these sketches I have chosen eight of the most interesting to offer to my readers. Here are their dates, in order:

(1) 25 September; (2) 27 September; (3) 11 October; (4) 13 October; (5) 23 October; (6) 25 October; (7) 4 November; (8) 5 November.

Magnification used ranged between 474× and 760× (Fig. 43).

The snowy cap of the upper or south pole is clearly visible on all the drawings. The observer comments that the patches have varied during the observations. Thus, he says, the face presented on 27 September is the same as that of 5 November, and yet the drawings bear little resemblance to each other; it is the same with the others.

Lassell concludes that the changes are undoubtedly produced by clouds of sufficient density, great extent, and a wide variety of forms.

This conclusion is not really so unusual as Lassell believes, because even a difference of an hour or two can sometimes produce perceptible changes. The difference between the drawings of 27 September and 5 November is a case in point, where the Hourglass Sea is further to the left in the first drawing than in the second.

On the drawings of 4 and 5 November, our readers will recognize the Hourglass Sea very distinctly, with the Flammarion and Hooke Seas to the left, the Zöllner Sea above, Herschel II Strait to the right, and the Arago Strait and Lambert Sea above it; on the sketches of 23 and 25 October, the Terby Sea, De la Rue Ocean, and the bays (Christie, Burton and Meridian) appear. These two latter drawings are in good agreement with those of Lockyer, Lord Rosse and Secchi, since each shows a very dark region above the Eye, the variability of which will be discussed later.

It is worth noting that the views of the planet obtained with the gigantic telescopes of Lord Rosse and Lassell do not always contain much more detail than those made with instruments of average power.

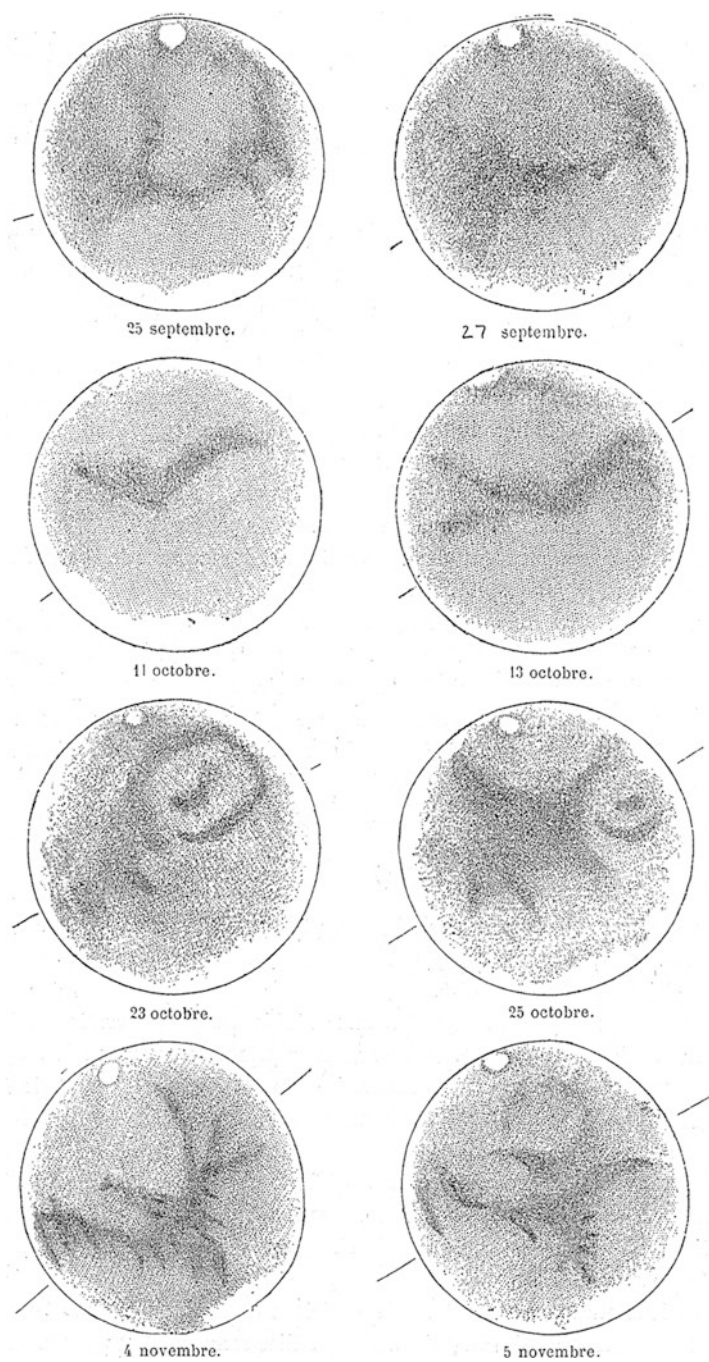


Fig. 43 Telescopic views of Mars, obtained in 1862 by Lassell

Same Year, 1862.—Main, Linsser, Nasmyth, Harkness, Grove, Knott, Ellery, Bulard, etc.

Almost all astronomers who had good instruments at their disposal made observations of the planet in the Martian year of 1862. In this book it is impossible to report all of them, or to reproduce all their drawings. Apart from the drawings made by Secchi, Lord Rosse, Lockyer, Phillip's and Lassell—already described—the observations made by Kaiser must be singled out as being particularly important; these will be discussed together with Kaiser's observations of 1864. But as a matter of principle we must also mention those of Main, Linsser, Grove, Knott, Harkness, Ellery, and Bulard.

The observations and measurements made by Main at Oxford have already been described.

Among the observations made in 1862, we must note those by Linsser at the Pulkova Observatory (Russia). In 1864, in Heis's *Wochenschrift für Astronomie*, he published an interesting paper in which he claimed that the drawings he had made agreed perfectly with those of Beer and Mädler. He asked whether the sombre patches could represent continents rather than seas, because of the various degrees of tone. He made a new calculation of the rotation period of Mars, and gave a value of

24^h 37^m 22^s.9.

Linsser's drawings do indeed confirm those of Beer and Mädler. He drew Herschel II Strait, which he called *Schlangen förmige Fleck* (the serpentine spot), as well as the Maraldi Sea (*pn*) and the Hourglass Sea.

The observations by Nasmyth in England must also be noted. On one drawing, made on 25 September, it is possible to recognize Herschel II Strait, with Phillips Island above. (*Memoirs of the Literary and Philosophical Society of Manchester*, 1862, 1863, page 303.)

Harkness, of the Washington Observatory, published the drawings he made on 6 and 30 September 1862 (*Annals*, 1862, p. 152). The first of these shows the Maraldi and Hooke Seas, the second the Herschel II Strait.

For 1862, note also the observations made by Knott in England and Ellery in Melbourne. These confirm the conclusions reached from earlier studies. Following Terby, I reproduce here four of Knott's drawings; they were made on 23 September at 8^h 20^m, the same time on 22 October, 9^h on 3 November and 7^h 15^m on 27 November. These drawings lead to conclusions different from Lockyer's, since they indicate rapid and considerable changes in the aspect of Mars. They were made with a 7 1/3-in. refractor.

In the *Monthly Notices*, XXIII, p.75, Grove describes a series of drawings which he made in October and November 1862 with a 4½-in. (114^{mm}) refractor; they demonstrate certain variations on the Martian surface. Grove maintained that there must be clouds condensing on vast aqueous areas (Fig. 44).

As we have seen, other observers also made drawings during the 1862 and 1864 oppositions.

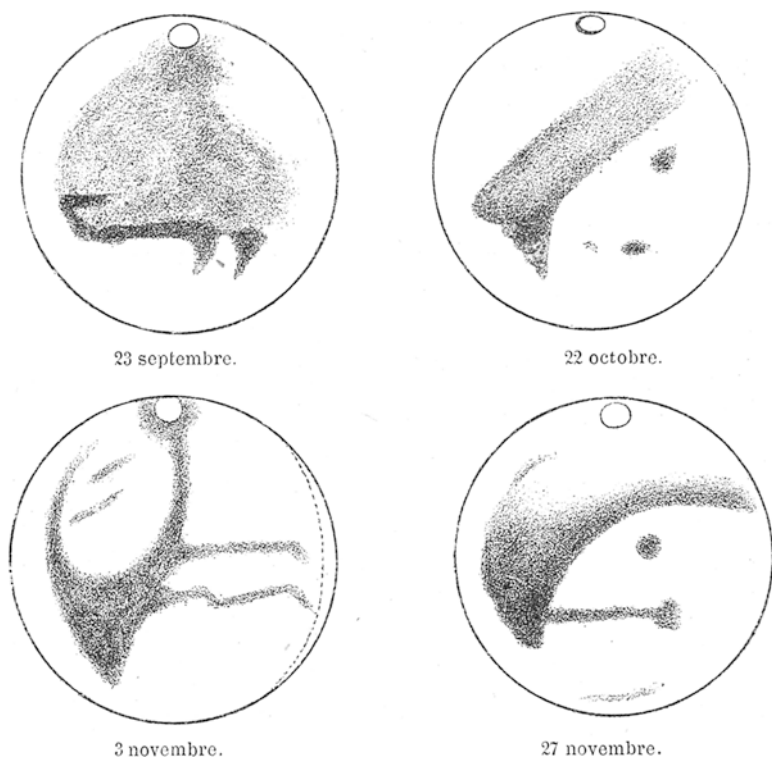


Fig. 44 Drawings of Mars, made by Knott in 1862

In France, at the meeting held on 15 December 1862, Bulard presented to the Academy of Sciences several drawings of Mars; they are not reproduced here, and of them I have no detailed information.

1862–1864.—Green and W.-L. Banks

Nathaniel Green and W.-L. Banks, both of whom were artists and amateur astronomers, lived in England; Green in St. John's Wood, Banks in Ealing. Both observed Mars during the oppositions of 1862 and 1864, the former with a French 4¼-in. (108^{mm}) refractor and eyepieces giving magnifications of 160×–240×, the latter with a 3¾-in. (95^{mm}) English refractor. They made a hundred drawings, of which 24 were published in the February 1865 issue of the old astronomical journal, the *Astronomical Register*.

These little drawings are charming, and I regret that I cannot reproduce them faithfully here. Comparisons of them bring out two incontestable facts: the first that despite the practical skill of the draughtsmen, they do not always agree in their representations of the planet; and the second, that the permanence of the Martian geographical configurations does not exclude considerable variations due, at least in

part, to effects of the Martian atmosphere, which can sometimes produce bright or dark streaks in the form of equatorial bands.

In several of these drawings the Hourglass Sea is excellently shown, and on one in particular, made by Green at 10^h 30^m on 24 March 1864, there is a vague misty region shown. Later, this has been regarded by many observers as being subject to variations, due possibly to flooding.

1862–1864.—J. Joynson, Noble, Williams

During the oppositions of 1862 and 1864, Joynson, whose observatory was situated at Waterloo, near Liverpool, presented to the Royal Astronomical Society of London a series of 92 drawings of Mars, made in 1862; there were 104 others made during 1864. The *Monthly Notices* (10 March 1865) reproduced only two sketches, showing a grey band going round the planet. These drawings were made on 8 and 12 December 1864. The Terby Sea is recognizable, and is very black; the band is formed by the succession of seas—Schiaparelli, Maraldi, Flammarion, Herschel II and de la Rue.

In 1862, Joynson used a 3½-in. refractor, and in 1864 a 6-in refractor. In each case the magnification was 350×. He believed that the band shown on these two drawings went right round the planet without interruption. At the same meeting of the Society, Lockyer commented that the sea is not continuous, but is crossed at many points by lands. He said that the different patches on the planet were of different degrees of intensity, with some of them darker than others. These differences were shown in 1862 by Joynson, and also by Phillips and Frankland, exactly as they had been drawn by Beer and Mädler in 1830. By correlating his 1862 sketches, Joynson found a rotation period of 24^h 37^m 37^s.

In England, Noble made some drawings with a 4-in (102^{mm}) refractor. He had begun studying the planet at the opposition of 1858, and continued until 1877. Williams obtained some drawings at the opposition of 1862, a dozen at that of 1864, and another dozen in 1867 (see *Monthly Notices*, XXV, p.170, and Terby, *Aréographie*, p.27). With his 4¼-in. refractor, he showed the principal patches on the planet, with their most striking characteristics. This period, from 1862 to 1864, was very fruitful. The most important work was carried out by Kaiser, Director of the Leyden Observatory, to whom we now turn.

1862–1864.—Kaiser²⁷

At the oppositions of 1862 and 1864, this energetic observer carried out the most important Martian researches that we have yet described in the present monograph. The memoir which he published in the *Annals of the Leiden Observatory* was

²⁷ *Untersuchungen über den planeten Mars bei dessen oppositionen in der Jahren 1862 und 1864.—Annalen der Sternwarte in Leiden, Dritter band, Haag 1872, p. 1–87.*

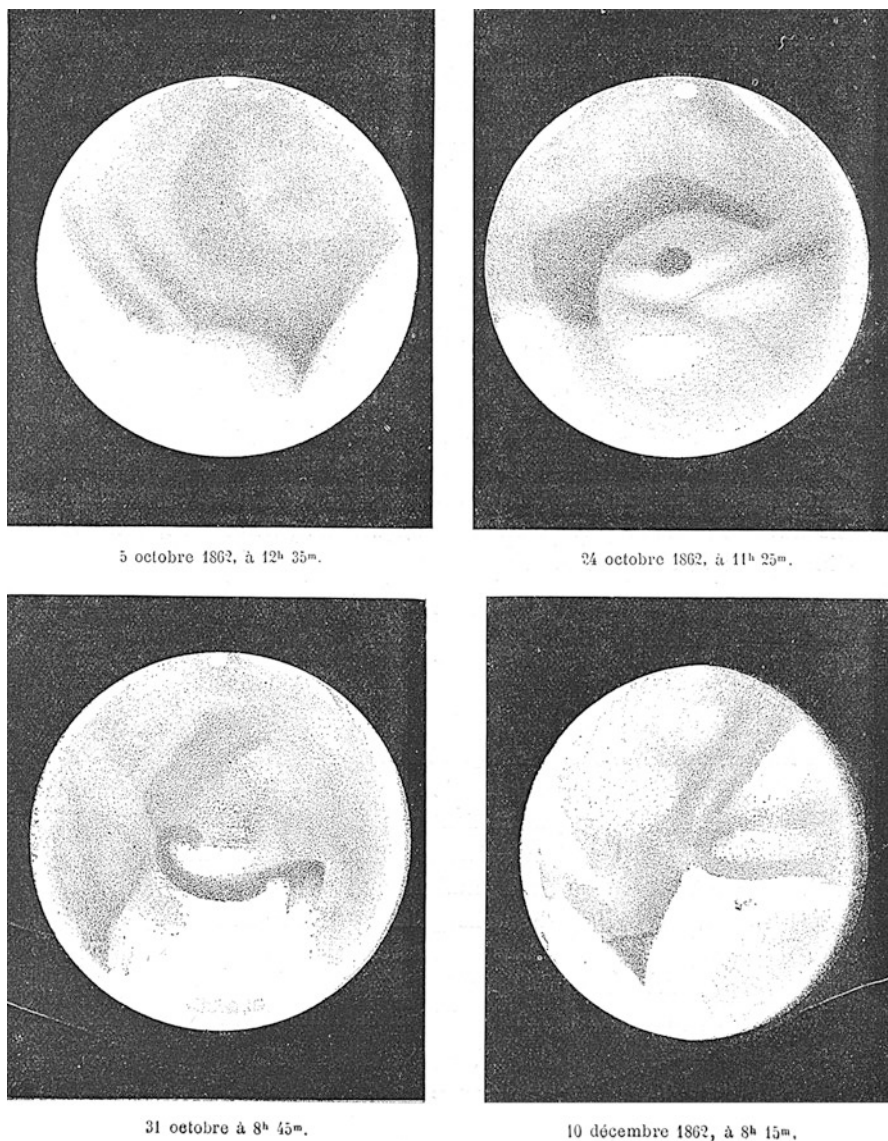


Fig. 45 Drawings of Mars, by Kaiser, in 1862

divided into several sections: the study of old drawings of Mars made from 1636 to 1864 and the observations made at Leiden with regard to the geographical configurations, the length or the rotation period, the polar caps, the flattening of the globe. The Memoir was accompanied by drawings and maps; the principal ones are reproduced here (Fig. 45).

There are four drawings made in 1862. The first shows the Hourglass, Flammarion, Hooke, and Maraldi Seas; Dawes Ocean, Zöllner Sea, Beer Continent, Herschel

Fig. 46 Telescopic view of Mars, by Kaiser, on 11 November 1864, at 10^h 30^m



I. Continent, Niesten Isthmus, and Cassini and Dreyer Lands; one can even make out Lockyer Land. The upper or southern pole is marked by a small circle or snow to the left of the Hourglass Sea; the whole area is misty. The drawing is complete, and in perfect agreement with the chart drawn from all the observations combined. It seems that at this time—5 October 1862, at 0^h 35^m—the aspect of the planet was not modified by any clouds at all. The tones themselves were noted.

The second drawing shows the Terby Sea, the De la Rue Ocean above it, and Schiaparelli Sea to the right. Instead of the Channel, a misty streak can be seen. The polar snow is detached from the edge of the disk (Figs. 46 and 47).

On the third drawing, we find Herschel II Strait and the Meridian Bay; the sombre ribbon is shown detached from the bright background, as in the time of Mädler, but instead of being circular the Bay is rectangular, ending in two points. The Bay was first seen as forked by Dawes on 22 September 1862, with an 8¼-in. Alvan Clark refractor. Above is the Lambert Sea; to the left, the Hourglass Sea. Phillips Island is very bright.

The fourth drawing seems to relate the first to the third.

It is interesting to compare Kaiser's *fig. 1* (5 October) to Fig. 32 made by Lockyer on 3 October at 11^h 23^m, and *fig. 4* to the drawing made by Lord Rosse on 6 October. All these agree well, allowing for the margin of error produced by different observers and their differences in drawing style. The same impression is had from comparing *fig. 2* with Lockyer's drawing made on 17 September. Without a shadow of doubt, all these features are real, but they are shown with different degrees of certainty.

Thus we are gradually becoming more precise in our knowledge of the real geographical form of the Martian surface. The analogy with the Earth with regard to the distribution of seas and continents becomes more and more evident with observational progress.

Fig. 47 Telescopic view of Mars, by Kaiser, on 22 November 1864, at 10^h 45^m



Fig. 48 Telescopic view of Mars, by Kaiser, on 10 December 1864, at 10^h 10^m



This precision was increased rapidly by the six excellent drawings made in 1864, reproduced here (Figs. 46, 47, 48, 49, 50 and 51).

In the first (Fig. 46), we again see the Meridian Bay, broadened and merged with the neighbouring sea; Burton Bay, broad and double; and Christie Bay. All these appear, apparently, too broad.

In the second (Fig. 47) the Hourglass Sea is very dark; and above Dawes Ocean is Lockyer Land. Below the Hourglass Sea there is the Nasmyth Channel.

Fig. 49 Telescopic view of Mars, by Kaiser, on 18 December 1864, at 10^h 0^m



Fig. 50 Telescopic view of Mars, by Kaiser, on 23 December 1864, at 9^h 25^m

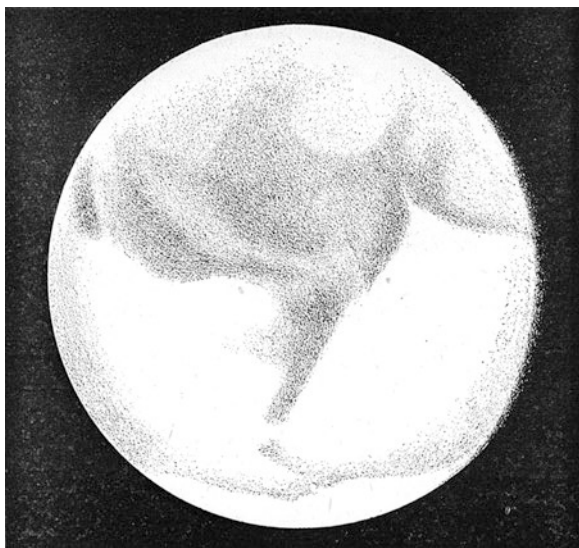


On the right of the disk, there is an unidentified streak which could be Schiaparelli's Euphrates, about which more will be said later.

In the third drawing (Fig. 48), the Eye is the Terby Sea; Copernicus land, beneath which lies a dark band; and to its right, the Schiaparelli Sea.

In the fourth drawing, the Terby Sea is shown to the right, with the sombre streak below it (to be discussed later); Kepler Land, De la Rue Ocean, Christie Bay, Arago Strait and the double Burton Bay, with the Meridian Bay to the left.

Fig. 51 Telescopic view of Mars, by Kaiser, on 28 December 1864, at 8^h 0^m



In the fifth sketch (Fig. 50) we see Herschel II Strait, appearing very dark and detached; Phillips Island (which is almost an actual island), and Arago Strait below the Delambre Sea.

In the sixth (Fig. 51) we see the Hourglass Sea, with its appendage; the Main Sea, diffuse; and all the features described above.

Henceforth, we can unmistakably affirm that the configurations on Mars are fixed and of a geographical nature, but are variable in aspect, no doubt because of changes in the atmosphere above them.

The Leiden astronomer compiled a geographical map of the planet by combining all his observations. This map is reproduced here in facsimile.

It is interesting to compare this map with my own (Fig. 3). Several differences are obvious at a glance. For instance, I have not separated Herschel II Strait, as Kaiser has, because in my view the sketch made by the Leiden observer does not represent a permanent configuration; generally the Strait is connected with the sea (Dawes Ocean). Generally, also, the Arago Strait is less broad at its extremity. These are two regions particularly noted for their variability, perhaps because the water of these seas retreats or evaporates, perhaps because of a change of tone—sometimes dark and blue, sometimes yellowish and bright. The more we progress in our studies, the more plausible becomes the idea of variations due to water: evaporation, flooding, and aqueous precipitation for various lengths of time.

In these observations by Kaiser, he recorded that for him the most remarkable and characteristic patch was the oval feature taken to mark the prime meridian; it lay at longitude 0°, latitude 26°S. Kaiser identified it with Beer and Mädler's spot *d* (see their map, Fig. 2). This is the circular lake which is called the Terby Sea on my map. Note its oval form on Kaiser's chart. This feature changes over the years. It is sometimes conspicuously oval, as here; sometimes perfectly circular. The area is equal to that of France.

The Hourglass Sea descends in a point below the equator, obliquely toward 150°. The round, circular spot taken by Beer and Mädler for the zero of longitude is shown as square in Kaiser’s drawing, and 90° to the left of the oval patch which he takes as the zero for longitudes. It is therefore seen that Kaiser’s longitudes differ by 90° from those which I have adopted, following Beer and Mädler (Fig. 52).

During 1862, 1863, 1864 and 1865, Kaiser used the 7–in. refractor at the Leiden Observatory, with Airy’s double ring micrometer, to make a series of measurements of the polar and equatorial diameters of Mars.²⁸ The measures gave the following values:

Equatorial diameter	9".468
Polar diameter	9".387
Flattening	1/117

As we have seen, measurements of the flattening of Mars are not in total agreement:

W. Herschel gave a value of	1/18
Schröter	1/81
Arago	1/30
Bessel	0
Main	1/62, 1/38, 1/46, 1/7 and 1/36
Winnecke, Dawes and Johnson found a polar elongation	

Kaiser was equally concerned with the rotation period of Mars, comparing his observations with the best chosen from those of his predecessors and, justifiably, identified the vertical patch drawn by Hooke in his two observations of 3 March 1666 with the feature lettered *f* in the observations made by Beer and Mädler in 1830, and now known as the Hourglass Sea.

Hooke’s observation of 3 March 1666 (old style) corresponds to 13 March in the Gregorian calendar, not adopted in England until 1752. The first sketch was made at 20^m, the second at 30^m. The patch had not yet reached the centre of the disk; it did so at 2^h 46^m. In his 1862 observations Kaiser noted the transit of the same patch across the central meridian of Mars on 1 November, at 6^h 10^m. He then made the following calculation:

Transit of the Hourglass Sea Across the Central Meridian of Mars:

Hooke	1666	Mar. 14	2 ^h 56 ^m
Kaiser	1862	Nov. 1	6 ^h 10 ^m
Difference:		71,821 ^d	3 ^h 14 ^m

During the interval, Mars rotated 70,004 times, giving a rotation period of:
24^h 37^m 22^s.735

²⁸*Durchmesser des Planeten Mars, gemessen im Jahre 1862–1863–1864, mit Airy’s Doppelbild Micrometer am 7 zölligen Refractor.—Annalen der Sternwarte in Leiden, Dritter Band.—Haag 1872, p. 227,227, 241, 65.*

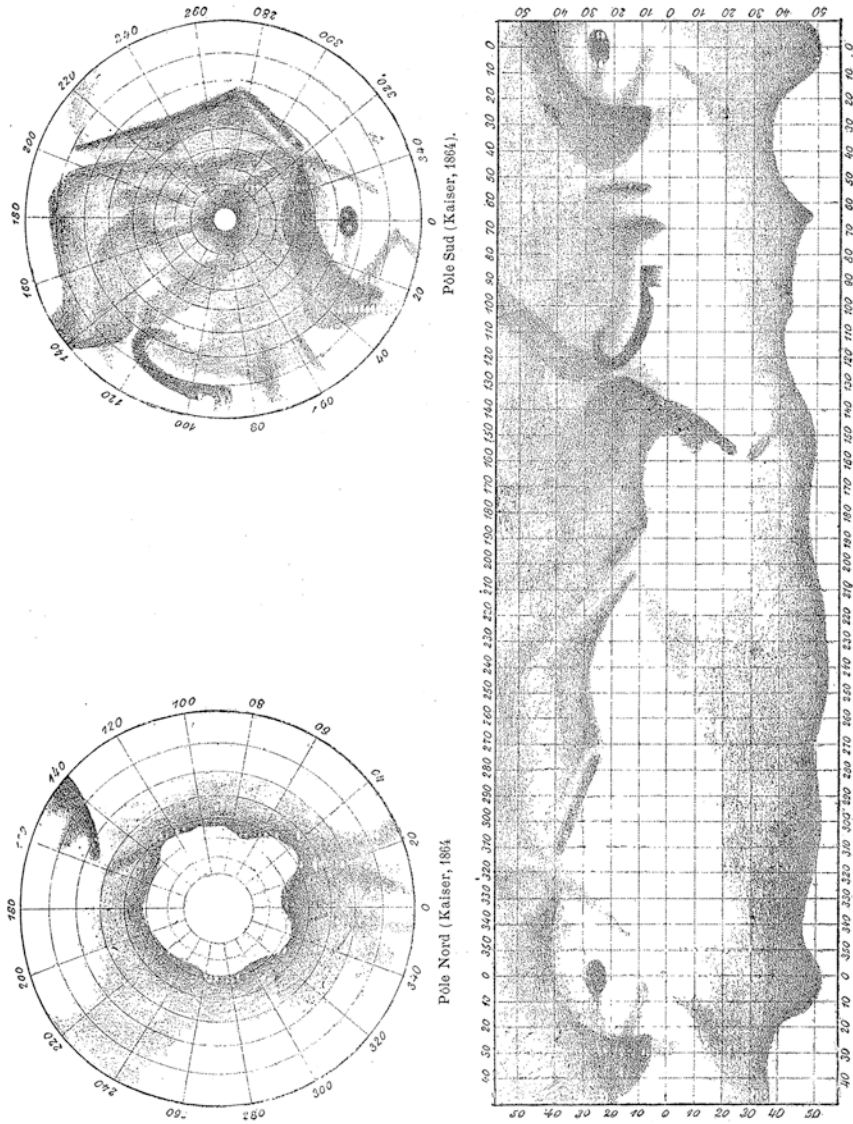


Fig. 52 Geographic chart of the planet Mars, constructed by Kaiser in 1864

From Hooke’s observation and that of Beer and Mädler on 30 September 1830, at 17^h 22^m, Kaiser obtained:

Difference 60,101^d 14^h 26^m, or 58,581 rotations;
Rotation period: 24^h 37^m 22^s.706

From Hooke’s observation and that of Huygens on 13 August 1672, at 0^h 11^m:
Difference 2,344^d 9^h 14^m or 2,285 rotations;
Rotation period: 24^h 37^m 22^s.62.

The agreement is remarkable, despite Kaiser’s doubts as to the identity of Hooke’s vertical feature with the Hourglass Sea. He did not doubt the identity of the sea with the triangular patch on Huygens drawing of 13 August 1672, from which he derived:

Huygens	1672	Aug.13	12 ^h 10 ^m
Kaiser	1862	Nov.1	6 ^h 10 ^m
Difference:	69,476 ^d 18 ^h		

During this interval the planet made 67,719 rotations, giving a period of:
24^h 37^m 22^s.643

The same observation by Huygens combined with that by Beer and Mädler on 30 September 1830, at 17^h 22^m, gave:
Difference 57,757^d 5^h 12^m, or 56,296 rotations;
Rotation period: 24^h 37^m 22^s.595

Summarizing, since 1864 the rotation period of Mars has been given as
24^h 37^m 22^s.6,
to an accuracy of about a tenth of a second.

**1862–1864,—Spectral Analysis of the Atmosphere of Mars:
Huggins, Miller, Rutherfurd and Vogel²⁹**

During 1862 William Huggins, member of the Royal Astronomical Society of London, and A. Miller, Professor of Chemistry at Kings College, made the first attempts to apply spectral analysis to studies of Venus, Jupiter, Mars and Saturn.

²⁹Rutherfurd, *Astronomical Observations with the Spectroscope* (*American Journal of Science*, January 1863). Miller and Huggins, *On the Spectrum of Mars* (*Philosophical Transactions*, 1864). Vogel, *Beobachtungen auf der Sternwarte zu Bothkamp*, Heft. I, p. 66 (*Astronomische Nachrichten*, 1864).

The results obtained were published in the *Philosophical Transactions* for 1864. In the United States, Rutherford began the same kind of research at the same time.

In this study, we are not concerned with the other planets. With Mars, the spectrum was observed 6 November 1862 and 17 April 1863; the principal lines of the solar spectrum were clearly seen, but no fainter lines were found.

Huggins and Miller again examined Mars on 10 and 29 August 1864, using an improved spectroscope. In the red part of the spectrum they found no absorption lines of the type known in the spectra of Jupiter and Saturn, but at the edge of the red, toward the B and *a* lines of the solar spectrum, they detected three strong lines.

Toward the F line in the solar spectrum—that is to say, at the beginning of the blue or immediately after the green—the spectrum of Mars showed a large number of absorption lines, which considerably reduced its brilliancy. These strong bands were almost equidistant, and continued up to the violet end of the spectrum. The absorption due to these bands is presumably the cause of the predominance of the red rays from the planet. Spectroscopic apparatus with high dispersive power resolves these bands into groups of lines.

From these experiments, it is shown that Mars shines only by the light reflected from the Sun, and reflects the solar spectrum in the manner of a mirror. Secondly, the atmosphere produces the absorption lines seen by Huggins and Miller. What do the spectral lines indicate? We will soon know.

In August 1864 Huggins and Miller commented that the brilliancy of the spectrum of Mars had diminished in a remarkable manner toward the F line, because of a series of groups of lines, strong and more or less equidistant, beginning near the F line and continuing toward the most refrangible lines in the spectrum. In November 1864, these lines were much weaker and could scarcely be distinguished from the numerous lines due to the solar spectrum. Huggins's impression was that on 10 and 27 August the light of Mars was reddened; he also found that the patches were more distinct than in November:

If this opinion is confirmed by other observations, we must agree that toward the end of the year the atmosphere of Mars was more heavily charged with mists and vapour. These mists reflected a considerable part of the incident light, and by shading and hiding the lower layers of the planets atmosphere—and hence the surface itself, which is probably responsible for the red colour—produce the absorption lines which weaken the blue and violet regions of the Martian spectrum. By a corresponding series of telescopic and spectroscopic observations, it will undoubtedly be possible to make effective studies of the meteorology of the planet.

Researches carried out in Germany by Vogel agreed well with those made in England and the United States with regard to the absorption lines in the spectrum of the atmosphere of Mars.

In reply to a question from Mr. Pritchard—whether a simple mist produces lines in the spectrum indicating the nature of the substances involved—Huggins replied that the mist could have no power of selective absorption to produce definite lines. The small particles making up the mist were large relative to the wavelength of light, thereby weakening the intensity of the blue and green rays to a greater extent than for the red. The light reflected from a mass of mist would be bluish in colour.

In this connection, Lockyer recalled that in 1862 Mars appeared redder to the naked eye than 1864. This observation is an agreement with Huggins's comments. It seems that when the Martian atmosphere is free from clouds and mists, the light from the planet is reddened, and the patches on the surface show up more distinctly. This point will be referred to again in a discussion of the 1867 observations.

We now come to the opposition of 1864, when conditions were similar to those of 1862 apart from the fact that Mars was a little less close. However, many astronomers were concentrating upon observations, and it was hoped that useful results would be obtained.

At this point, having completed our discussion of the observations by Kaiser and the spectroscopists, we pass on the work of the English observer Dawes, the astronomer with the eye of the eagle.

1864.—Observations by Rev. W.-R. Dawes³⁰

At the meeting of 9 June 1865, the skillful and energetic observer presented to the Royal Astronomical Society of London eight magnificent drawings which are reproduced here, and which represent considerable progress in our study of the planet. These observations were made from November 1864 to January 1865, with an excellent 8-in. (204^{mm}) refractor made by Thomas Cooke & Sons:

Many curious and interesting details which I have never recognized so distinctly were manifested during that opposition (of 1864). One of the most remarkable is a long, thin streak which runs in a NE-SW direction in the northern hemisphere, and which is shown distinctly on the drawings of 12 and 14 November and more weakly on that of 10 November, as well as that of 21 January. I have already noted and drawn this streak since the year 1852, when the north pole was similarly turn toward us, but although the planet was then excellently placed for observation (its declination was +24°) I have never seen it so distinctly with the 6 1/3-in (160^{mm}) Munich instrument which I then used, as with my present 8-in.

Another interesting object has been the forked shading, drawn in particular on 14 November as well as on the 20th and the 12th (less distinctly). I had previously noted it in 1852 in the form of an oval bay with a regular bank, and I did not once suspect that its contour was divided or irregular. But on 22 September 1862, I saw a forked aspect very clearly, and it has been the same all through the last opposition. This aspect gives the impression of two very broad *river mouths*, but I have never been able to recognize these rivers. The excellent drawings made by Mr. Lockyer in 1862 show the bay on several occasions, but do not show it divided into two points. It will be very interesting, at future oppositions, to find out whether this form is permanent or variable. *It is probable that the sea retreats from this part of the bank and leaves a tongue of land visible.*

It is very difficult to note, with certainty, variations in the aspects of the different patches which are due to atmospheric effects over the planet itself. The difficulty can no doubt be reduced if one takes care to compare the telescopic views with the configurations already known in the regions concerned; but to me it seems preferable to abstain from all reference and all preconceived ideas, so that the drawings made are absolutely independent.

³⁰Hopefield Observatory, Haddenham, Buckinghamshire.

Nevertheless, the atmosphere must play a certain role in the causes of the variations. Thus, during three consecutive nights—20, 21 and 22 January—I observed a very white patch exactly at the position marked *a* on the drawing of 21 January.³¹ This white patch was certainly not visible on 10 and 12 November. It gave the impression of being an enormous mass of snow, and was as brilliant as the south polar cap in 1862. Unfortunately, a series of cloudy nights prevented me from continuing these observations.

Nothing appears more certain, than that the red tint of Mars is not produced by the atmosphere of the planet; the reddish colour is always more pronounced toward the centre of the disk, precisely where the atmospheric envelope is thinnest. Toward the edges of the disk, the grey patches are almost entirely hidden by the denser atmosphere, and the colour reflected from these edges is white or greenish white; the latter colouration may be an effect of contrast with the red of the centre.

On 1 December, several hours after opposition, I obtained several measurements of the disk with an excellent double-image micrometer. It was not possible to recognize any trace of flattening; on the contrary, I found the polar diameter rather greater than the equatorial, though by an insignificant amount 0".02. This result recalls the measurements of Mars made by Mr. Johnson with the Oxford heliometer.

My impression is that the atmosphere of Mars is not generally very cloudy. During the last opposition, the principal configurations nearly always showed up brightly and sharply. I was not able to say, with certainty, that there were regions masked by mist and cloud. The sole exception to this permanence is found with the very white patches occasionally noticed, which gave the impression of being masses of snow or else cloudy masses whose surfaces reflected in the sunlight very efficiently. One can also note a remarkable fact about these variations by comparing the drawings of 14 November with those of the 10th and 12th of the lower pole; at the point mark *a* on the drawings of 10 and 12 of November there was a small grey streak, very evident at midnight on 14 November but certainly not existent on the other dates, though the neighboring details were seen perfectly.

To these extremely interesting observations, Dawes added the following postscript:

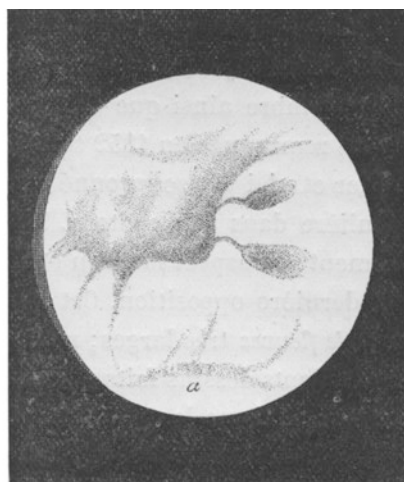
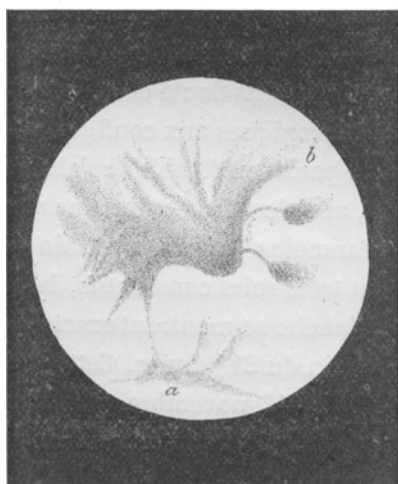
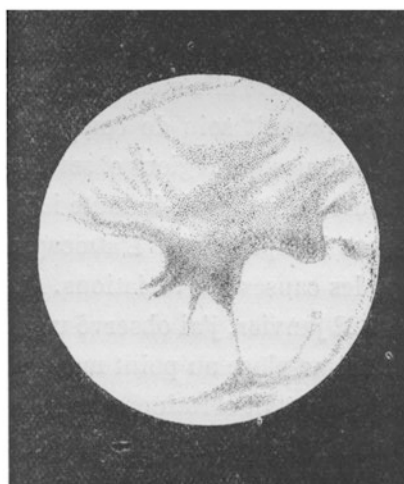
In looking back at my drawings of 1852, I saw in that year a particularly white streak along the bank marked *a* on the drawing of 20 November 1864. It attracted special attention because of its brilliant whiteness. It seems, therefore, that we have some effect which is either permanent or at least frequent, causing this exceptional brightness. However, since the region is in the neighborhood of the equator, it seems more reasonable to attribute the whitening to clouds rather than snow, at least if we are dealing with plateaux above the level of the sea (*Monthly Notices of the Royal Astronomical Society*, XXV, and *Memoirs of the Royal Astronomical Society*, XXXIV) (Figs. 53 and 54).

As noted above, these magnificent drawings by Dawes represent a considerable advance in our knowledge of Martian topography. The forked Meridian Bay was shown in its normal form, as well as Herschel II Strait, the banks of the Hourglass Sea, and most of the configurations shown on my map. At the Meridian Bay, which naturally gave rise to the idea of two broad river-mouths, Dawes looked for the rivers without being able to find them; Schiaparelli discovered them 13 years later, in 1877.

The white island observed on 21 January is shown on my chart, at the intersection of the 60° meridian with the south polar circle. It is not always visible, and neither are its surroundings.

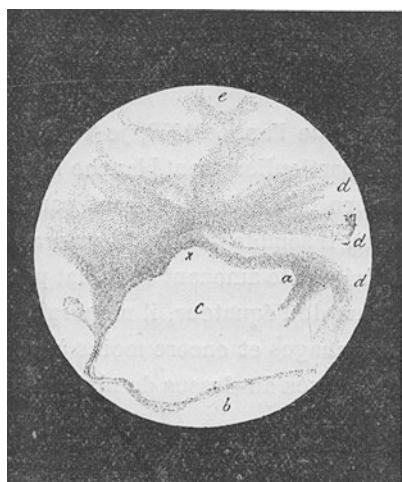
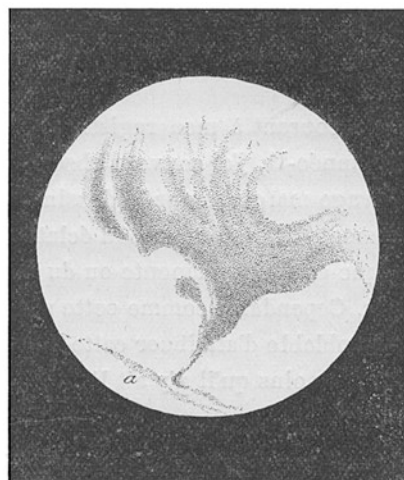
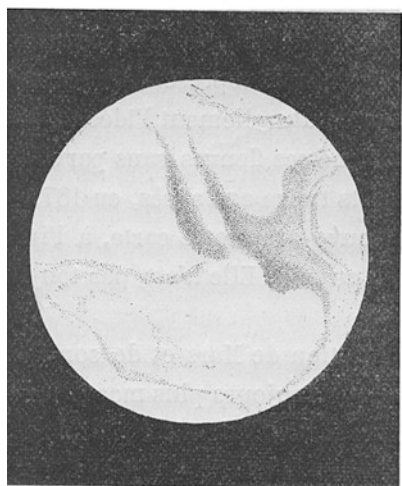
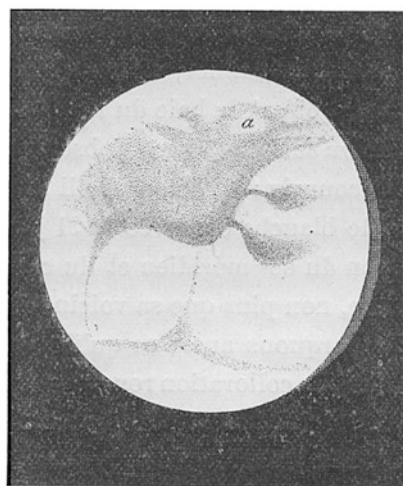
Note also what Dawes said about the colouration of Mars and its atmosphere. The reddish hue of the planet is always more marked in the central region of the disk

³¹This corresponds to the feature Schiaparelli later named *Argyre*.—WS.

3 novembre 1864. 12^h 24^m.10 novembre 1864. 12^h 6^m.29 octobre, à 1^h 29^m. T. S.6 novembre, à 1^h 40^m. T. S.**Fig. 53** Drawings of Mars, by Dawes, in 1864–1865

than at the edges. Therefore it cannot be produced by the atmosphere, because it is at the centre of the globe that the light reflected from the surface passes through the thinnest layer of the air. This had already been pointed out by Arago.

The almost constant visibility of the patches of Mars, the rarity of clouds, and the weakness of gravity at the surface of the globe lead us to believe that the atmosphere of Mars is very tenuous. That of the earth is so dense that details of the terrestrial surface would be less clearly visible, from a great distance, than those of Mars. According to researches by Langley, 40 out of every 100 solar rays which enter our

20 novembre 1864. 11^h 36^m.26 novembre 1864. 11^h 36^m.1^{er} décembre 1864. 12^h 0^m.21 janvier. 1865. 8^h 0.**Fig. 54** Drawings of Mars, by Dawes, in 1864–65

atmosphere vertically are absorbed by it. Of the 60 which reach ground level, perhaps less than a quarter are reflected even by yellow sand, and this quarter must again lose 40 out of 100 in passing through the atmosphere. For the Earth, then, only 8 or 9 of each 100 light-rays would reach the eye of an observer on the Moon. From afar, the Earth should appear whitish, even with the clearest sky.³²

³²*American Journal of Science*, Vol. XXVIII, p. 163.

The comparison of Dawes's drawings with my chart leads to conclusions identical with those drawn from the observations by Kaiser. The Terby Sea is elongated instead of being round; it resembles the underside of a leaf. A second patch, showing the same aspect, is much larger; the Herschel II Strait is clearly detached, but the Meridian Bay is not so round and isolated as in the observations by Beer and Mädler. *Everything indicates certain variations of geographical aspects.*

1864.—John Phillips³³

The Emeritus Professor at Oxford University, whose work for the 1862 opposition has already been described, continued his study of Mars during 1864, and presented his results to the Royal Society of London at the meeting of 12 January 1865.

First, he first he stated that the geographical aspects seen 1864 were nearly the same as those which he had drawn in 1862. He made several new drawings from 14 November to 13 December, and from them constructed the planisphere which is reproduced here. He regarded the orange regions as *land* and the greenish regions as *sea*, as is generally agreed; but in contrast to the more usual view, he noted the former as darker than the latter. A certain *fogginess* was noted under various circumstances, such as between 18 and 20 November and on other occasions. The seas were less green than in 1862, and in general everything was less sharp. However, the planet was further from the Earth in 1864 than it had been in 1862.

White patches, undoubtedly snows, were seen between 45° and 50° latitude on the 30° meridian on the map constructed by the author, and also at latitude 50°, longitude 225°. There was less snow round the south pole than in 1862.

Phillips next asked whether the lower layers of the atmosphere played a role in the colouration of the planet, which often resembled the colour of clouds lit up by the setting sun. He remarked:

There must, at least, be considerable transport of water vapour to take the snow from one pole to the other, following the sequence of the seasons.

Phillips observed snows down to 50° or even 40° S latitude; Warren De la Rue saw them extend up to 40° N latitude in April 1856. This is a little less than with the Earth in winter. The extent of the snows is not always the same in different Martian years, as can be seen by comparing the drawing made by Sir John Herschel on 16 August 1830 with that of Phillips on 27 September 1862.

The climates of Mars seem to be almost identical with those of our world, because there, as here, up to 50° latitude on the poles, water vapour should produce periodical snow, and from the equator to about latitude 40° the temperature remains high enough to produce normal evaporation; the atmosphere is generally clear in the equatorial and tropical regions, and the snows are variable out to a certain distance from the poles. It is undoubtedly the constitution of the atmosphere which has given rise to these quasi-terrestrial climates on a world which is more distant from the Sun than is the Earth by a ratio of 152 to 100, and on

³³*Proceedings of the Royal Society*, 1865, p. 42–46.

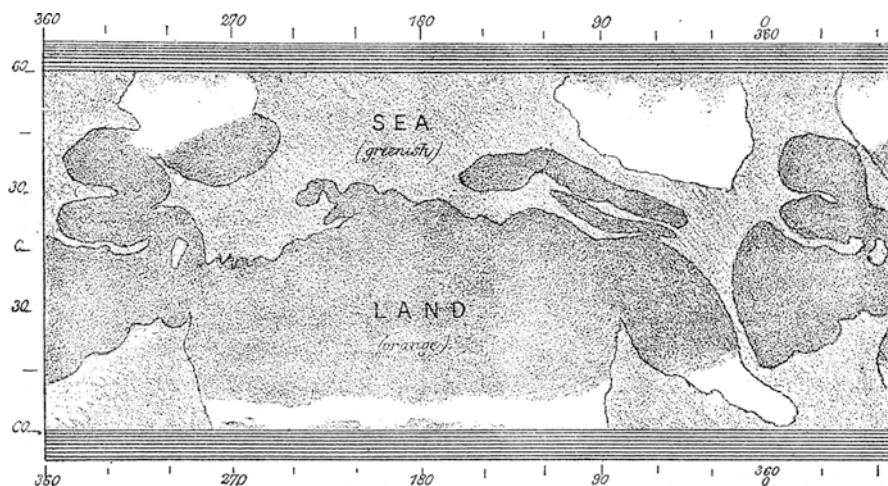


Fig. 55 Planisphere of Mars, equatorial projection, by Professor Phillips

which the heat received from the Sun is less in a ratio of 231 to 100. In preventing the radiation from escaping, and so conserving the Sun's heat, the atmosphere makes the winters and nights less cold than they would otherwise be. The influence of the atmosphere on Mars seems to be the same as with us, and is even more important. The result, according to all probability, is that we should regard Mars as habitable.

Such are the results of the observations by Professor Phillips. The planisphere which accompanies his Memoir is reproduced here in facsimile (Fig. 55).

The observations seem to have been made with the same instrument as those in 1862.

It is not easy to identify features on this chart. First, it seems that pale features were seen as dark, and vice versa. It may therefore be deduced that the Hourglass Sea is the pale triangular configuration which descends almost vertically from the 20th meridian. Above the sea, the large white patch is Lockyer Land. The continent upon which the word LAND is written is Herschel I Continent. The prime meridian 0° on this planisphere corresponds almost to longitude 315° on my chart. The meridians are reckoned from right to left, from east to west, instead of from west to east. My zero lies at longitude 315° on Phillips' chart, at the end of the bright ribbon which prolongs the Hourglass Sea into a long, narrow gulf to the right. There is a 45° difference between the two prime meridians.

Same Year, 1864. Félix Von Franzenau³⁴

At the Vatican Observatory, Von Franzenau made a very interesting study of Mars, accompanied by six remarkable drawings which are reproduced here.

³⁴Mars in November 1864. *Sitzungsberichte der K. K. Academie der Wissenschaften*. Wien, 1865, LIII Band, p. 509.

The following is a translation of the text of his short Memoir.

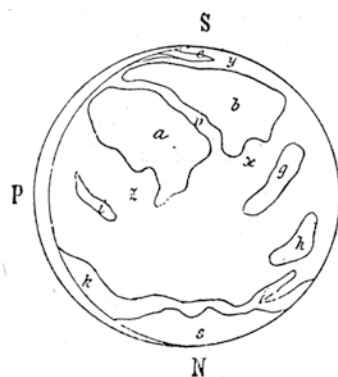
The favourable situation of the planet Mars during the last opposition led me to make the observations given here, which I made with the 6-in. (152^{mm}) refractor which was generously loaned to me by the Observatory. I set out to obtain representations of the planet which would be as faithful as possible with regard to the form of the patches and to the atmospheric conditions. Unfortunately, the extraordinarily bad weather, which persisted throughout, affected a large number of my observations. In all, I could make only seven drawings, and of these the last must be rejected as imperfect.

These several drawings allow me to confirm the permanence of the patches on Mars, and their striking resemblance to those shown on Mädler's drawings.

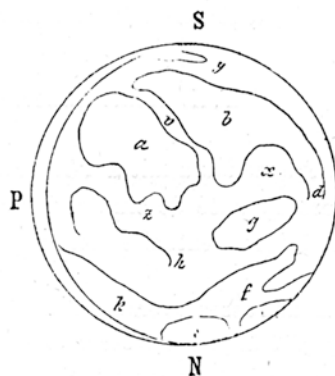
To explain the drawings, note that N S P indicate the North pole, the South pole, and Phase, respectively; by *s* I indicate the snow, or at least what resembles it, at the north pole (Figs. 56 and 57).

1. 8 November 1864, 9^h 30^m, Vienna time. *a*, *b* are the large very sombre patches separated by *v*. The blackness and sharpness of the contours of these three points of *a* is remarkable; the neighbouring regions *c*, *g*, *h*, *i*, *k* are grey shadings, scarcely perceptible, without well-defined contours; *x*, *y*, *z* are the bright red areas of the planet.
2. 10 November, 9^h 30^m —The patches remain the same, apart from a modification due to rotation. The patch *b* is considerably augmented at *d*; the band *f*, which I had previously only suspected, appeared very distinctly. As for the snow at the lower pole, it showed up as divided into two parts separated by a somber region.
3. 15 November 9^h 30^m —The progress of rotation begins to have a strong influence on the form of the patches. Patch *a* has completely lost its original aspect, and goes down well to the north; *b* is again enlarged towards *c*; as for the latter patch, it and *d* are very weakly illuminated in the region surrounding *b*; the reddish continent *x* has reached the middle of the disk, and has attained its greatest development. *s* seems almost to have disappeared, because the environs of the north pole are almost as sombre as *h* and *f*. All the northern hemisphere seems to be covered with innumerable small grey clouds.
4. 20 November, 7^h 45^m —Patch *a* has almost completely disappeared; *b* has reached centre of the disk, and in the west part *c* and *d* are more clearly visible than previously. *u* is a bright area between patches *b*, *c*, and *d*; *w* is a new bright red patch.
5. 20 November, 9^h 20^m —This drawing was made on the same evening, 2 hours later; the principal patches are closer to the central meridian of the planet, and consequently show up in more detail. *c* is even vaster and clearer; *u* can be easily distinguished, as a separation; *f* joins at *d* to the point *q*; a new patch, *p*, has appeared.
6. 22 November, 9^h —The interval between this drawing and IV covers almost two rotations of Mars. The only modification is at *r*; the snow at the north pole seems to extend further toward the south, but without well-defined limits. Note the sombre tint on the northern parts of patch *b* and the point *d*.

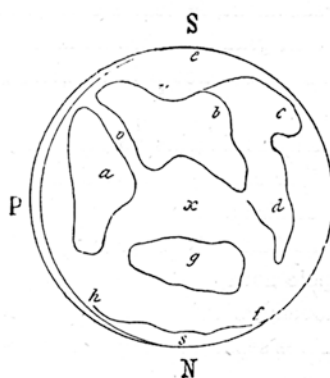
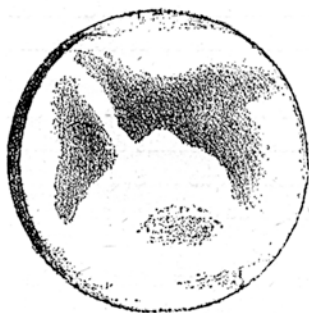
Such were the observations of von Franzenau. The most remarkable thing about them is their close agreement with the drawings of Beer and Mädler, giving extra proof of the permanence of the configurations. Another curious detail is the white isthmus above the Hourglass Sea, visible on drawings IV and VI, on 20 and 22 November. (Our readers will recognize this sea, as patch *d*.) Was it a band of clouds? This is not probable, because the same is shown on drawings on by Mädler in 1841, W. de la Rue in 1845, and Lord Rosse in 1862. Is it due to the variable depth of the sea? These topics will be discussed below. In any case, Von Franzenau's drawings lead us to a double conclusion: permanence and variations.



8 novembre, à 9^h 30^m.



10 novembre, à 3^h 30^m.



15 novembre, à 9^h 30^m.

Fig. 56 Observations of the planet Mars, by von Franzenau, in 1864

Same Year, 1864.—Talmage, Secchi, and Rudolf Wolf

During the same opposition, that of the 1864, the English observer Talmage noted³⁵—principally on 14 and 18 November—that the south pole seemed to project from the disk of the planet, an effect due doubtless to the irradiation caused by the brightness of the light reflected from the snow and which, measured with a micrometer, amounted to $2''.5$. Talmage commented that this observation was identical with those made by William Herschel on 17 April 1777 and 20 May 1783.

On 24 November, the patches on Mars appeared more distinct than ever, although on this date our own atmosphere was disturbed. Talmage believed that from this he could conclude that the clearer our atmosphere, the less well the details on Mars would be seen. (He had observed Mars without any great success in 1862, in the excellent climate of Nice.) I take leave to question this conclusion, which would certainly be paradoxical.

Father Secchi re-observed Mars during the same opposition. His observations have already been described.

Note also, among the studies of 1864, those of R. Wolf, of Zurich.³⁶ In the hope of determining a new value for the rotation period of the planet, the eminent Director of the Zurich Observatory compared a drawing made by him on 19 November 1864, at $10^h 30^m$, with a drawing made by Secchi on 26 September 1862, at $9^h 45^m$ (see Fig. 20B), and found a period of

$24^h 37^m 22^s.9$.

Same Year, 1864.—J.C. Zöllner, Seidel, Schmidt: Photometry

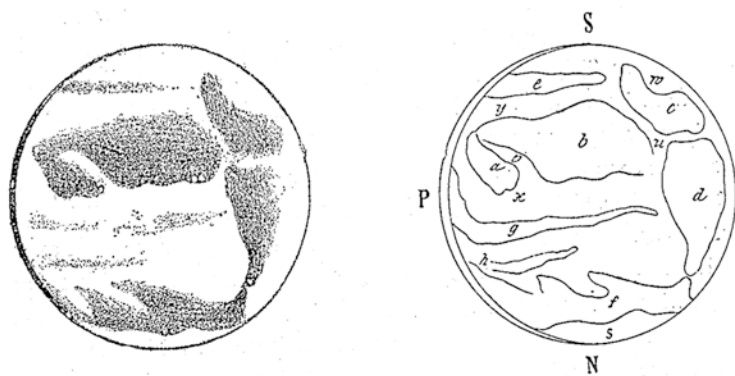
The German physicists Zöllner and Seidel made photometric observations³⁷ during this opposition, finding that Mars resembles the Moon with regard to the variation of light reflected during different phases, and also with respect to the great brilliancy of parts of the edge of the disk. Also, Zöllner found that the albedo of Mars is scarcely greater than that of the Moon. Jupiter and Saturn, on the other hand, have high reflecting power. The cause seems to be that on these two planets there are clouds in their atmospheres which reflect the sunlight, while on Mars the reflection comes from the actual globe of the planet. Jupiter and Saturn had albedoes respectively four and three times greater than that of the lunar surface.

The falling-off in brilliancy of the Moon after full, particularly with regard to the bright edge, can be explained by the irregularities on its surface. Zöllner found that

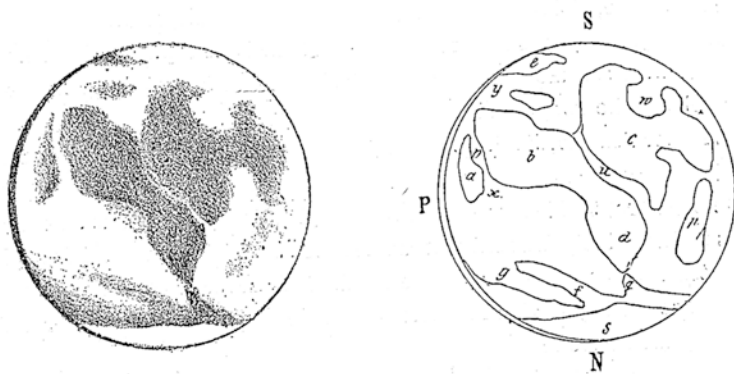
³⁵On an appearance presented by the spots on the planet Mars. *Monthly Notices of the Royal Astronomical Society*, 1865, p. 193.

³⁶*Astronomische Mittheilungen*, no. 22, p. 57.

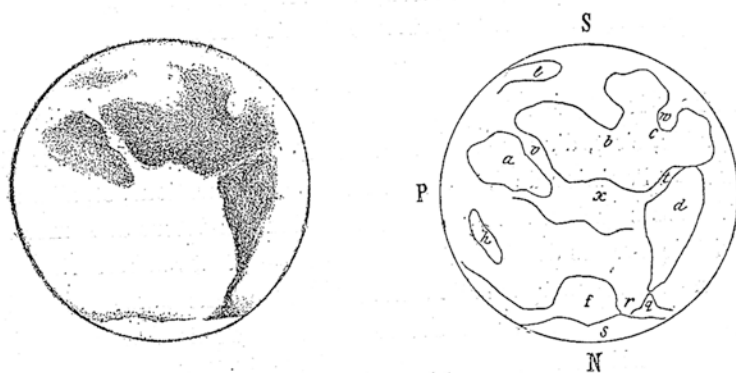
³⁷*Photometrische Untersuchungen*. Leipzig, 1865.



20 novembre, à 7^h 45^m.



20 novembre, à 9^h 20^m.



22 novembre, à 9^h.

Fig. 57 Observations of the planet Mars, by von Franzenau, in 1864

for these irregularities to produce the observed changes in brightness, the mean angle of elevation of the irregularities should be 52° for the Moons surface. According to the same hypothesis, the much more rapid changes in the brilliancy of Mars demand a mean angle of 76° for the mountains there.

Zöllner gives a table to explain the albedo—or mean brightness—of each planet:

	Albedo
The Moon	0.174
White sand	0.237
Mars	0.267
Saturn	0.498
Jupiter	0.624
White paper	0.700

It can be seen that according to these data, Mars absorbs 733/1,000 or more than 7/10 of the solar light which strikes it, while Jupiter, with its cloudy atmosphere, seems to be almost as reflective as white paper, and reflects more than 6/10 of the light which it receives. Mars thus absorbs much more of the Suns radiation than does Jupiter. Seidel³⁸ found for the brightness of Mars, relative to the star Vega:

Mars at opposition = $2.97 \times \text{Vega}$,

or almost three times the brightness of Vega. The observations were made with a Steinheil objective photometer. With his photometer, Zöllner found, relative to the Sun:

Mars at opposition = $1/699,400,000 \times \text{Sun}$.

This determination by Zöllner corresponds to a stellar magnitude of -2.25 .

From numerous observations, Julius Schmidt determined the dates when Mars should be equal to various stars of the first magnitude. Calling r the radius vector of the planet at a given moment, and D its distance from the Earth at the same moment, he found, for example, that:

Mars = Sirius, when $\log 1/\Delta^2 r^2 = 1.944$.

Mars = Aldebaran, when $\log 1/\Delta^2 r^2 = 1.258$.

1864–1875.—Dr. Terby

F. Terby, Doctor of Science at Louvain, to whose persevering and considerable work in areography we are so indebted, made a careful study of Mars from 1864 to the present time, and publishes his results in the Bulletin of the Academy of Sciences of Belgium. The first observations were made with an excellent Secrétan refractor, with an aperture at 108^{mm} and powers of 120 $\times$ and 180 $\times$, and sometimes even as

³⁸*Bayerische Akademie der Wissenschaften. München, 1859.*

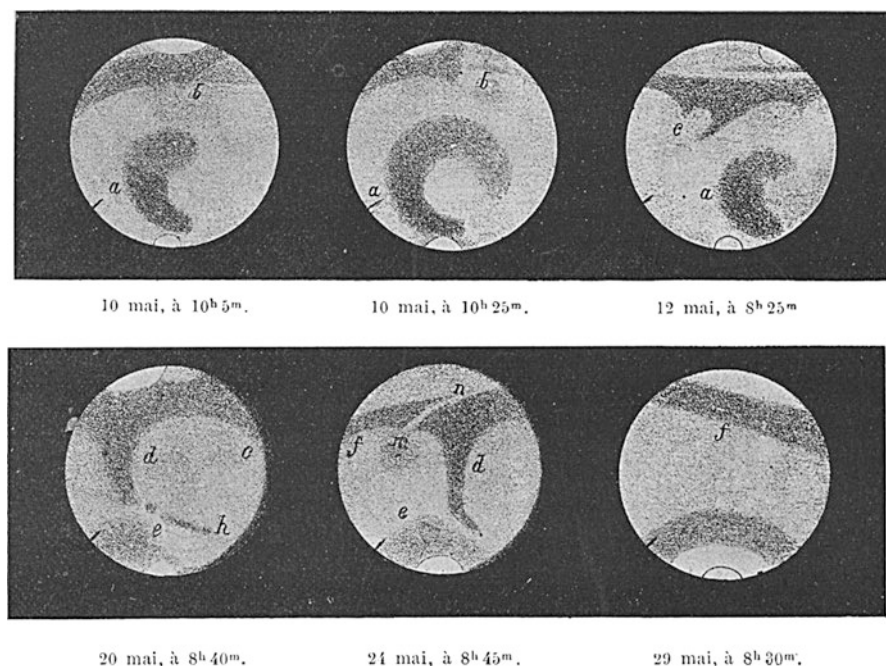


Fig. 58 Sketches of Mars, by M. Terby, in 1873

high as 240 $\times$. We will first discuss his observations made before 1877, the year which marked the start of the new cycle in our study of the planet. The Notices presented to the Belgian Academy by our eminent colleague are accompanied by 23 drawings for 1864 and 1867, 36 for 1871, 12 for 1873, and 22 for 1875. The sketches made during the two latter years are those which show the most detail. In particular, we can recognize the Hourglass Sea, Maraldi Sea, Herschel II Strait, and the north and south polar patches. From these numerous drawings, I first reproduce six particularly interesting ones made in 1873. The dates are given below each drawing (Fig. 58).

In these drawings, *a* indicates the Knobel Sea; *b*, the De la Rue Ocean; *c*, Meridian Bay and Herschel II Strait; *d*, the Hourglass Sea; *e*, the Delamare Sea and its surroundings; *f*, the Maraldi Sea. In the drawing of 24 May there is a curious separation *mn*, also seen on 22 May. This division is also shown on two drawings made in 1875, on July 20. On the drawing of 20 May 1873, the Nasmyth Channel is shown at *eh*.

In 1871 and 1873 the darkest and most easily visible patch was (as usual) the Hourglass Sea. The atmosphere of Mars sometimes seemed disturbed enough to hide the features and hinder studies of them, particularly in 1871.

Several of the 1875 drawings were of particular interest. The first, of 14 June (Fig. 59A), made at 11^h 30^m, shows at *m* an indentation, and at *d* a very dark angular point. The long grey patch, formed by the Hooke, Maraldi and Hourglass Seas,

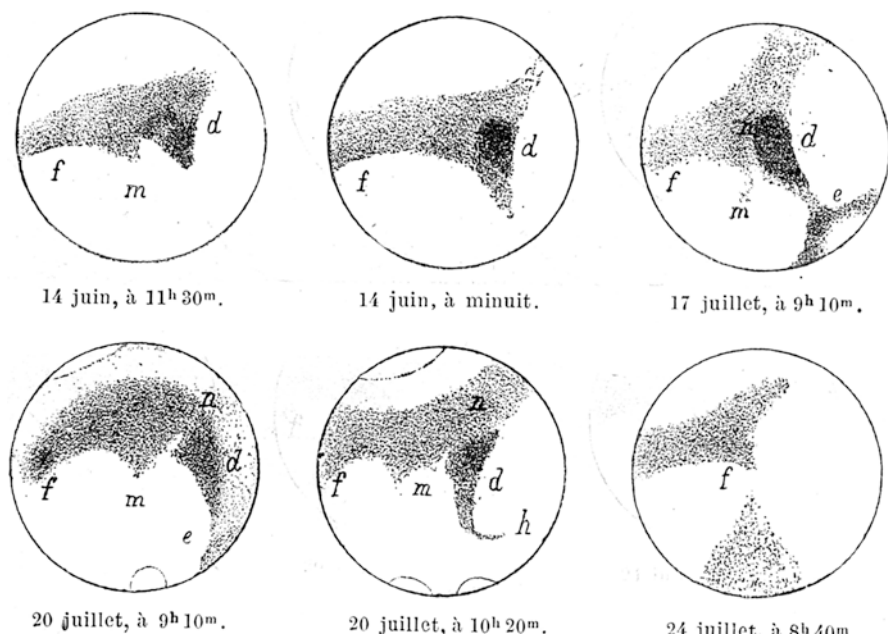


Fig. 59 Sketches of Mars, by M. Terby, in 1875

is also shown on an almost identical drawing made by Schröter on 9 September 1798, at 9^h 55^m (refer to Fig. 55, Chap. 1). The sombre angular point is the right-hand region of the Hourglass Sea, at that time appearing darker than the region below, as shown by Terby on the next drawing made half an hour later. We can also distinguish the lower part, which had not been seen earlier; this can be explained, on looking at this drawing from some distance, by assuming that the Hourglass Sea ends at this darker region, as in the first of the two drawings. This is irrefutable evidence in favour of variation in tone of the Martian seas, because the region is sometimes brighter than the vertical axis of the sea.

The third drawing shows, to the left of the Hourglass Sea *d*, an indentation *m* and a tongue of land at *n*, recalling the separation noted earlier in 1873 and which was also found in the drawings made by Von Franzenau. This same division is shown on the two drawings of 20 July.

The poles are marked by snowy patches; there are even two patches at the lower pole on 20 July at 10^h 20^m, recalling a drawing by Von Franzenau on 10 November 1864 and one by Secchi on 16 November 1862. The last sketch shows the Maraldi Sea and Huggins Bay recalling an observation made by Schröter.

These observations by Terby lead us to the usual conclusion: permanence of fundamental patches, real variations in their details.

Consulting my own map, we seem to trace a bank of sand as a dark line above the Hourglass Sea and running to the left obliquely across the Flammarion Sea. All in all, we have the impression that the water here must be very deep.

1865.—C. Flammarion.—Researches with Regard to the Planet Mars³⁹

The interpretation of observations of Mars is a matter of discussion. In the scientific review *Cosmos* of 26 June 1863, I discussed the observations of the polar snows and put forward the idea that the snow was chemically different from ours, and at the same time I expressed the hope that I could soon produce a complete Mercator map of Mars, succeeding the polar projections of Beer and Mädler (*Cosmos*, 1863, Vol. I, p. 751). In 1865, returning to the same subject, I claimed that according to the 1864 observations, the 0° isothermal line oscillates for both hemispheres, as with the Earth, up to latitude 45°; this indicates a mean temperature very little different from ours, despite the greater distance of Mars from the Sun. And yet it also assures us that the degree of condensation of terrestrial water and the crystallization of our snow can be duplicated on other planets. One might well think the contrary, because boiling depends upon the special relationship between the vapour of the liquid and the pressure of the atmosphere; it condenses according to the nature of the substances concerned. It is altogether too hasty to transfer terrestrial phenomena to an alien region (*Cosmos*, 1865, Vol. II, p. 315).

1867.—Huggins and Secchi: Spectral Analysis of the Atmosphere of Mars

We have already (1862) noted the first researches into the spectrum of Mars, made by Rutherfurd, Huggins, Miller, and Vogel. Huggins found that Mars shows the principal lines of the solar spectrum, and Rutherfurd detected the C, D, E, *b* and G Fraunhofer lines. At the Royal Astronomical Society meeting in London on 8 March 1867, William Huggins presented a new memoir on the subject, which will be summarized here.

Mars shines only by reflected sunlight. Its atmosphere absorbs part of this light, and its spectrum indicates which substances are present. In the blue and indigo part of the spectrum, the lines are too weak to be identified with certainty. In the red region, the Fraunhofer C line is easily visible, and its identity has been established by micrometrical measurements. Beyond this line, up to the end of the least refrangible part of the spectrum, can be seen a large number of dark lines. A very strong line has been micrometrically measured a quarter of the distance from C to B. As there is nothing analogous in this position in the solar spectrum, we must regard it as being due to absorption caused by the Martian atmosphere. The other lines in the red can be identified, at least in part, with B and *a*, the neighbouring lines in the solar spectrum.

³⁹ *Cosmos*: 6, 20 September and 11 October 1865.

On 14 February 1867, Huggins noticed weak lines to either side of the D line. Those to the more refrangible side were stronger than those on the other side. They occupied positions which appeared to coincide with the groups which we see when the sunlight passes through the lower layers of the atmosphere, and which are produced by absorption by gas or vapour, notably by water vapour. These lines probably indicate the existence of similar substances in the atmosphere of Mars. They are not caused by the terrestrial atmosphere, because under the same conditions they are absent from the spectrum of the Moon—even when observed at a lower altitude than Mars.

Huggins also observed the spectra of the darkest parts of the disk of Mars, that is to say the seas. Their spectra are much weaker throughout their length. The materials which form the dark regions absorb all the rays in the spectrum equally. We must conclude that in colour they are neutral, or nearly so.

The red colour of Mars cannot be attributed to selective absorption, i.e., the absorption of certain rays only, producing dark gaps in the spectrum. Moreover, it is not likely that this highly characteristic colouration has its origin in the atmosphere of the planet, because the light reflected from the polar regions remains white, even though it has passed through a greater thickness of the atmosphere than the light which comes to us from the central regions of the disk; it is in these central regions that the colour is most pronounced. Undoubtedly it originates at the surface of the planet.

The photometric observations by Seidel and Zöllner confirm this interpretation. They show that Mars resembles the Moon with regard to the abnormal value of the variation in reflected light according to the waxing or waning of the phase; also with regard to the great brightness of the regions at the edge of the disk. Moreover, Zöllner has found that the albedo of Mars, i.e., the reflecting power of different parts of the disk, is only $1\frac{1}{2}$ times greater than that of the lunar surface. These optical characteristics agree with telescopic observation in that with Mars the reflected sunlight comes almost entirely *from the true surface of the planet*, not from a cloudy envelope, as with Jupiter and Saturn. In these two latter planets, the disk is less brilliant near the edges than in the central region. We have also noted that Jupiter and Saturn have albedoes four and five times greater than that of our Moon.

At the same time Huggins was investigating this problem in England, and Zöllner in Germany, Father Secchi was studying the planets Jupiter, Saturn, Uranus, Mars, and Neptune in his researches into the spectra of these bodies.⁴⁰ He wrote:

Mars, shows terrestrial atmospheric lines weak toward the centre of the disk, but strong near the edge. These prove the existence of an atmosphere analogous to ours. He later gives two observations, of 11 February and 28 April 1869, which provide evidence of a nebulous zone near the C line and another in the extreme red. The atmosphere of Jupiter, Saturn and Uranus are very different from ours. The atmosphere of Mars seems a feeble and rarefied (*La sua atmosfera è assai piccola e sotile*).

⁴⁰*Sugli Spettri prismatici di Corpi celesti*. 1 br. in-8; Rome, 1868. 1 br. u-4; Rome, 1872.

The same research was carried out in 1872 by Vogel in Germany, and the results confirmed those of Huggins and Secchi with regard to the existence on Mars of an atmosphere analogous to ours from the viewpoint of water vapour, which gives rise to the lines observed. We will return later (1872) to Vogel's researches into the subject.

1867–1873.—John Browning, Barnes, Johnson, Elger, Grover, Knight, Backhouse, Noble and Williams

The first of these observers, John Browning, an excellent London maker of optical instruments, published in *The Intellectual Observer* eight chromo-lithographs of Mars, from drawings made between 8 January and 24 February 1867.

He also presented to the Astronomical Society of London, on 10 May 1867, a series of thirteen coloured drawings (including those referred to above), made by him between 29 December 1866 and 24 February 1867 with an 8½-in. (216^{mm}) silvered glass made by Barnes. The colour of the disk varied from rose to ochre, the tint being redder when our own atmosphere was rather humid. The edges of the disk were very pale. The sombre patches were bluish-grey or greenish.

Light white patches have frequently been said to appear on the disk, being carried across it by rotation and becoming almost as white as the polar snows on approaching the edge of the disk. These clouds were in general poorly defined at their edges, and of circular form. They were always observed in the region of the equator.

On 31 March, at 7 hours, Browning made a final drawing, which corresponds exactly to that which he had obtained on 23 February at 9 hours. He wrote: "On these two drawings, the patch usually known under the name of the Hourglass Sea is represented as passing across the centre of the planet's disk."

At the same time Barnes, an engineer by profession, made drawings that agree well with those of Browning. In this double series, the views seem to be almost identical with those of Warren De la Rue, reproduced above; but they bear only a slight resemblance to those of Secchi, still less to those of Beer and Mädler.

In 1868 Browning constructed a globe of Mars, based on Proctors chart (to be described below), and he produced some curious stereoscopic views. Over a period of several years, Warren De la Rue had obtained excellent stereoscopic views of the Moon, using different conditions of libration at the same phase and giving an impression of surface relief.

Among the other observations of 1867, let us note those of Joynson, Elger, Grover, and Knight in England. In *The Astronomical Register*, we found observations made by these observers in 1867. The first conclusion is that there is a permanent band near the south pole. Elger comments that the colour of the disk is always stronger in the central region than toward the edges, when the patches are obscured near the limb. This is nothing new.

The southern band which Joynson believed to be continuous is the same as that seen in the drawings made by Terby in 1875. It is formed by the near-continuity of the Maraldi, Hooke, Flammarion and Hourglass Seas, Dawes Ocean, De la Rue Ocean, Cottignez Sea and Schiaparelli Sea.

Fig. 60 Sketch of Mars, by Williams, on 11 January 1867, at 11^h 40^m



Let us also note in this period the observations by T.W. Backhouse, made during the oppositions of 1867, 1869, 1871 and 1873. They add nothing new to what has been given above.

Noble and Williams, who have already been referred to above, made new drawings in 1867, generally deficient in detail. Among those by Williams, note the one reproduced here; made on 11 January (Fig. 60) with a 4¼-in. telescope.

We can note a solution to the continuity problem in Herschel Strait, probably corresponding to that which is indicated when Kaiser's map at longitude 130°. The lower or northern snow is very extensive.

1867–1877.—R. A. Proctor⁴¹

We now come to Richard Anthony Proctor (1837–1888), whose work in areography was of great importance. In 1867 he began to construct a map, following the drawings by Dawes, whose principal sketches have already been given above.

We have already discussed the first attempt at Martian cartography, by Beer and Mädler, based on their drawings made in Germany between 1830 and 1837; also the planisphere of Kaiser, from his observations in Holland in 1862 and 1864, and that of Phillips, drawn from his observations made in England, in 1864. We note also the chart by Secchi, made from his Rome observations in 1858, which was reproduced in the second edition of my book *La Pluralité des Mondes habités* (1864).

The drawings by the English astronomer Dawes brought a new precision to studies of the Martian world. His contemporary, Proctor, wished to use them for a map which would be as complete as possible, and using them exclusively, drew up the chart reproduced here (Fig. 61), and which was the first chart to be published with a properly worked-out system of nomenclature.

A nomenclature, with settled names, was highly desirable, though from representations of the planet in the earliest drawings there were but a few objects shown, and a

⁴¹ *Chart of Mars from 27 drawings* by Mr. DAWES.—*Half-hours with the telescope*, London, 1869, pl. VI.—*Other Worlds than Ours*, London, 1870, p. 93.—*The orbs around us*, London, 1872, frontispiece.—*Essays on Astronomy*, London, 1872, p. 62.—*Flowers of the Sky*, p. 167.

Le Verrier, or observers of Mars, such as Galle, Schmidt, Lassell, Knott, Green, Von Franzenau, Vogel, etc. These defects in the nomenclature explain why some astronomers have been disposed to modify it.

But this consideration is unimportant from the point of view of the intrinsic geography of the planet, otherwise termed areography. Proctor rendered a signal service to science by constructing the first well-defined chart of Mars, and thereby laying the foundations of areography; and for this—together with his other very considerable work—Proctor's name is written indelibly in the history of astronomy.

In his original work on Mars, Proctor was concerned with obtaining a value for the rotation period which would be as accurate as possible. At the meeting of the Royal Astronomical Society of London on 14 June 1867, he presented his first paper on the subject. Making comparisons analogous to those described above by Cassini, Maraldi, Herschel, Schröter, Beer and Mädler, Kaiser, etc., and making use of Dawes's drawings, he gave the rotation period of

88,643 seconds, or $24^{\text{h}} 37^{\text{m}} 23^{\text{s}}$.

Confident that this value was near the truth, he compared Dawes's observations with those of Herschel and Hooke, and found:

$24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.745 \pm 0^{\text{s}}.005$.

Within an accuracy of 2 days, 79 rotations of the Earth are equal to 42 of Mars.

Proctor returned to the subject at the meeting of 10 January 1868. Comparing the drawings made by Browning in January and February 1867 with those of Dawes in 1864 and 1856, he selected three of the clearest and most precise (Dawes, 24 April 1856 and 26 November 1864, Browning, 23 February 1867), when the Hourglass Sea was near the central meridian. Comparing these drawings with those made by Hooke on 12 March 1666 (see Fig. 15, Chap. 1), he found a mean period of 88,642,735^s or:

$24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.735$.

The probable error does not exceed $0^{\text{s}}.005$.

Returning to the same question in 1869, Proctor found, with the help of a drawing made specially for the purpose by Browning on 4 February 1869, the value of $24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.736$. He concluded that the first value should be adopted.

Kaiser had found $24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.62$, but the difference of $0^{\text{s}}.115$ per rotation would produce a difference of $2^{\text{h}} 20^{\text{m}}$ going back all the way to the year 1666, and would put the Hourglass Sea 50° from the centre of the disk whereas Hooke's drawing showed it only 18° away; this sea was not visible on all of Hooke's drawings, and it could be lost in the foginess toward the edges of the disk.

Again Proctor came back to the question in 1873. This difference of 1/10 of a second was the subject of new research. He found that it was due to a slight error in calculation. In counting the number of days which had elapsed between 13 August 1672 and 1 November 1862, the Director of the Leyden Observatory had given 69,476 days; this is two days too many because he had forgotten that 1700 and 1800 were not Leap Years.

Moreover, Kaiser had taken Hooke's observation as having been made on 14 March instead of 13 March. He reproduced Huygens drawing, as we have seen, with the date (13 August 1672) and also those of Hooke (12 and 13 March 1666, at 20^m and 40^m). These new considerations showed that the Hourglass Sea could give a reliable value for the rotation period, and Proctor concluded that the true period must be between

24^h 37^m 22^s.71 and 24^h 37^m 22^s.72.

Therefore we adopt, as the best available period and to an accuracy of 1/10 of a second, a value of

24^h 37^m 22^s.7.

This is the sidereal day: it is the real period of rotation, not the solar day. Since the Earth's tropical sidereal day is 23^h 56^m 4^s.09, the Martian day is 41^m 18^s.6 longer than ours.

Proctor concentrated largely upon Mars in his books—apart from the very last, which was left incomplete at the time of his untimely death. More will be said of this later.

1871–1873.—Lehardelay, Crosley, Gledhill, Burton, Denning, Wilson, Guyon, Lowdon, Joynson, Spear

In 1871 Ledhardelay, observer at Fontenay (Normandy), made some observations with a 162^{mm} aperture Steinheil refractor.⁴² These observations were made on 2, 11, 13, 23, and 24 March and 23 April. The northern polar snow was well seen. The observation on 23 March was one of the best; the southern polar snow was also seen. The planet appeared to be covered with patches in the form of rounded lobes, some slightly festooned on their common borders, yellowish in colour and represented in separation by a very thin grey line. The drawing made on this occasion is reproduced here; it was published by Terby (*Aréographie*, p.111), and was made with a magnification of 547×. A curious feature is the river, or rather canal, which is called Burton Bay on my map or the *Isthmus* on Secchi's drawings (Figs. 62 and 63).

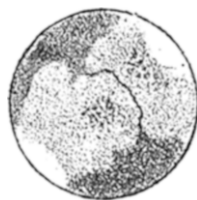
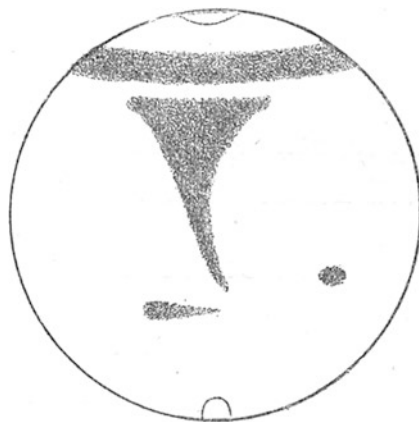


Fig. 62 Sketch of Mars by
M. Lehardelay, 23 March
1871, 10^h 30^m

⁴²*Bulletin de l'Association, Scientifique de France*, 31 December 1871, p. 219.

Fig. 63 Mars on 4 April 1871, at 11^h. Drawing by M. Gledhill



At the Halifax Observatory, Gledhill made observations on of Mars during the less favourable opposition of 1871, and published six sketches in *The Astronomical Register*.⁴³ The lower or northern polar patch was turned toward the Earth, and showed up as round and brilliant. The Hourglass Sea can be identified, and near latitude–30° the south circumpolar region shows a dark band, from which thin tongues extend northward. On two drawings, there may be seen, adjacent to the northern polar cap a dark patch in the form of a balloon, whose point touches the polar snow. (This drawing has a slight resemblance to Burton’s of 23 March 1871, already described; Gledhill’s feature was seen on the same day at the same time, and identification is therefore certain.) These six sketches are not reproduced here, but can be found in lithographic reproduction in the publication cited. I give only that of 4 April 1871, at 11^h (Fig. 63). The two polar caps are on view, and the Hourglass Sea is at the central meridian.

The summer solstice in the northern hemisphere of Mars fell on 2 March, opposition on 19 March.

At Loughlinstone in Ireland, C.E. Burton, using a 12-in. (305^{mm}) Newtonian reflector, made excellent the drawings in 1871 and 1873, and continued the series during the opposition of 1879.⁴⁴ In our third period of observation (1877–1892) the 1879 work will be described, together with the chart made from it. For the moment, let us discuss the drawings of 1871 and 1873.

The main point about Burton’s observations is that he concluded that considerable changes take place on the surface of the planet. Three drawings in 1871 and four in 1873—or, in general, all of those which represent this side of Mars—show an immense dark patch in the form of a pear or a balloon, corresponding to the Tycho Sea. It is in the neighbourhood of the north pole, and is contained inside the Martian Arctic Circle.

⁴³October 1871, p. 233.

⁴⁴*Transactions of the Royal Irish Academy*, XXVI, p. 427.

Fig. 64 Drawing of Mars, by Burton. The Tycho Sea in 1871

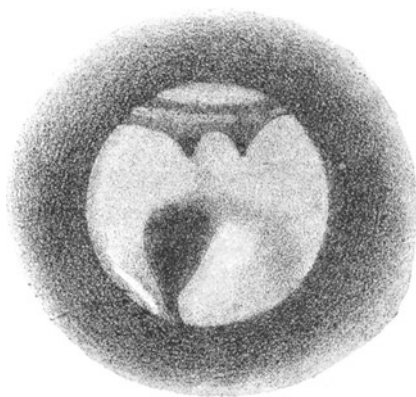
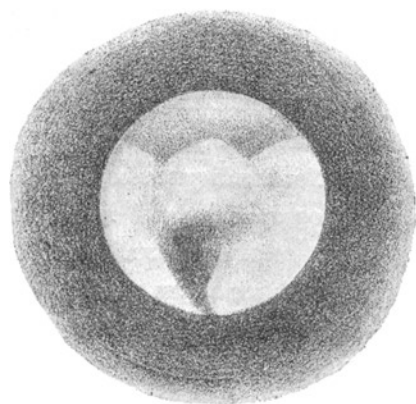


Fig. 65 Drawing of Mars, by Burton. The Tycho Sea in 1873



At the time when these observations were made, the Martian north pole was turned toward us. The balloon-shaped patch appeared very sombre, and of bluish green hue. Burton wrote:

If it is a sea, its decrease considerably surpasses, both in extent and speed, anything analogous which has occurred on the surface of the Earth in historical times.

This curious observation thus confirms our previous deductions.

I reproduce here (Figs. 64 and 65) two of Burton's drawings representing this sea, made on 23 March 1871 and 7 April 1873. Several other observers saw the same feature, notably Terby at Louvain on 12 May 1873, and Burton again saw it consistently during his 1873 observations. This patch, he commented, was as obvious and as distinctive as the celebrated Hourglass Sea.

Burton also drew the Hourglass Sea under excellent conditions; for example, see his sketches of 7 April and 4 May 1871, reproduced here (Fig. 66 and 67). In the first, to the left of the Hourglass Sea, may be noted a variable region which will be discussed later; to the right, a pointed cape (Banks Cape), which is generally shown as it is drawn in my chart.

Fig. 66 Drawings of Mars,
by Burton. The Hourglass
Sea in 1871

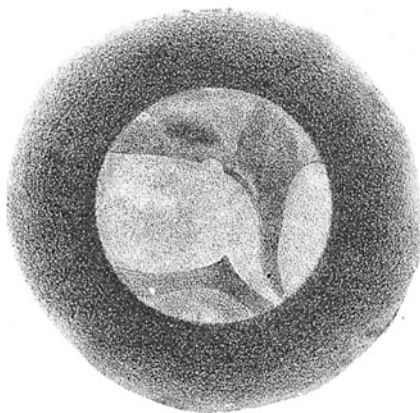


Fig. 67 Drawings of Mars,
by Burton. The Hourglass
Sea in 1871

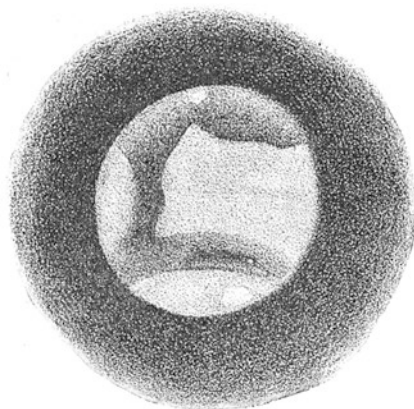
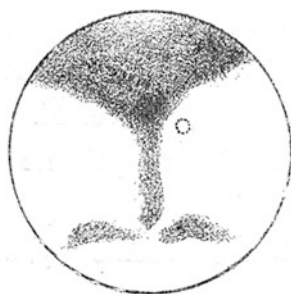


Fig. 68 Sketch of Mars, by
Burton, 24 May 1873,
indicating the position of a
snowy plateau in the tropics



Often, to the right of the shore of the Hourglass Sea, may be seen a point indicated by the dotted circle in Fig. 68—an extremely brilliant white patch. Burton considered that this indicated the presence of a very lofty plateau, lying not far from the tropics, yet covered with snow: *the summits of a cluster of lofty mountains, or a high table-land*. This Alpine plateau lies inside the tropical zone.

Fig. 69 View of Mars, on 29 May 1873 (Burton, showing the sand bank above the Hourglass Sea

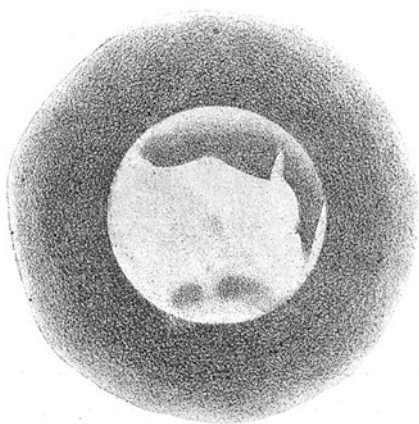


Fig. 70 Mars on 4 May 1871, at 9^h 30^m. Drawing by M. Wilson



Let us look now at the drawing made on 29 May 1873 (Fig. 69), on which may be seen a line separating the Hourglass Sea from the Hooke Sea, across the Flammarion Sea. This line has already been noted in connection with the drawings by Von Franzeneau and Terby, and can even be recognized on earlier drawings. It is certainly a sandbank, as it sometimes clears away.

In 1871, at the Rugby Observatory, Wilson made a certain number of very interesting drawings. In Fig. 70, one of these is reproduced; it was made on 4 May 1871, at 9^h 30^m. An 8¼-in. (210^{mm}) refractor was used, magnification 300×. During this opposition, and also in 1877, Wilson made many drawings of Mars which are reminiscent of those of Beer and Mädler.

To these studies made in 1871 and 1873, we must add those of Denning, Guyon, and Lowdon in England. In particular, Guyon made six drawings in 1871 and ten in 1873. The sketches add nothing really remarkable to the data already given.

During the same opposition, we must also note the observation made by John Joynson at Waterloo, near Liverpool, and one by J. Spear, at Churkrato, Bengal.⁴⁵

⁴⁵ *Monthly Notices of the Royal Astronomical Society*, 1871, p. 208 and 262.

Joynson commented that the north polar snow was much less extensive than in 1867, and was somewhat like the aspect of the south pole in 1862. He wrote: “The wine-glass-shaped channel is certainly permanent, as is the sea which dominates it.”

At Bengal, on 19 November 1870, Spear noted: “The snow at the north pole is of remarkably intense brilliancy.”

**1872–1873.—Dr. Vogel. Spectral Analysis
of the Atmosphere of Mars⁴⁶**

The skilful Bothkamp astrophysicist observed Mars on 19 November 1872, 2, 20, and 22 April, and 3 June 1873 with the object of continuing his spectroscopic researches, described earlier. In his memoir, he gives in detail the positions and wavelengths of 25 spectral lines. Here is a summary of the results obtained:

In the spectrum of Mars, we find a large number of the lines of the solar spectrum. In the less refrangible parts of the spectrum we find some bands which do not appear in the solar spectrum, but which coincide with lines due to absorption in our own atmosphere. We can conclude, with certainty, that Mars possesses an atmosphere which, in composition, does not differ essentially from ours, and which, in particular, is rich in water vapour. The red colour of Mars seems to be the result of absorption of the blue and violet rays; at least in this part of the spectrum it has not been possible to make out absorption bands. In the red, between C and B, we may deduce the presence of lines due to the actual spectrum of Mars, but it is not possible to fix their precise positions, because their intensities are too feeble.

Vogel gives a list identifying lines in the Martian spectrum with solar and telluric lines:

Wavelength		
570.0	}	Near Brewsters δ
580.0		
592.1	}	Telluric lines near D
594.9		
628.0		α
648.8		Fairly dark line
655.6		Telluric lines near C
687.8		B

This description will be continued later, with the spectroscopic researches into the atmosphere of Mars made in 1877. These 1877 results are more complete and more precise.

⁴⁶*Untersuchungen ueber die Spectra der Planeten, verfasst von Dr. H.C. Vogel. Sternwarte zu Bothkamp, Leipzig, 1874.*

1873.—C. Flammarion: Observations of the Planet Mars

During the opposition of spring 1873 the planet was well placed for observation. Here are the results of the studies I made of its surface with the Secrétan 108 mm refractor. The usual magnification was 202 $\times$, occasionally increased to 288 and often reduced to 150 because of the planet's low altitude over the horizon.

The résumé given here is that which was presented to the Academy of Sciences.⁴⁷

Around the time of opposition, Mars presented its northern hemisphere to us, which is less well known than the southern. The north pole, strongly tilted toward us, betrayed itself by a very brilliant white patch which under certain conditions of atmospheric transparency seemed to protrude from the contour of the disk.

The cap is not actually very extended; to the eye it sometimes gives the impression of a white pear which scintillates on the limb below the disk. Its position indicates that the pole lies about 40° from the lower limit of the vertical diameter, toward the east (image inverted, as in an astronomical telescope). The north polar snows do not actually extend beyond aerographic latitude 80°. However we know that at times the snows can be considerably more extensive, reaching down beyond 60°, while the variations in the southern snows are greater still.

There is probably a polar sea around the north pole, because a dark patch is constantly visible there, whichever hemisphere is turned toward us by the planet's rotation. This polar sea seems to extend to latitude 45°, and even beyond in certain points, but it is divided in two by the tongue of land which extends from the 65th to the 75th degree. Whatever may be this intermediate land (which can scarcely be distinguished), the sea extends in one direction as far as the ice, that is to say to at least latitude 80°, and in the other direction as far as 45° (Fig. 71).

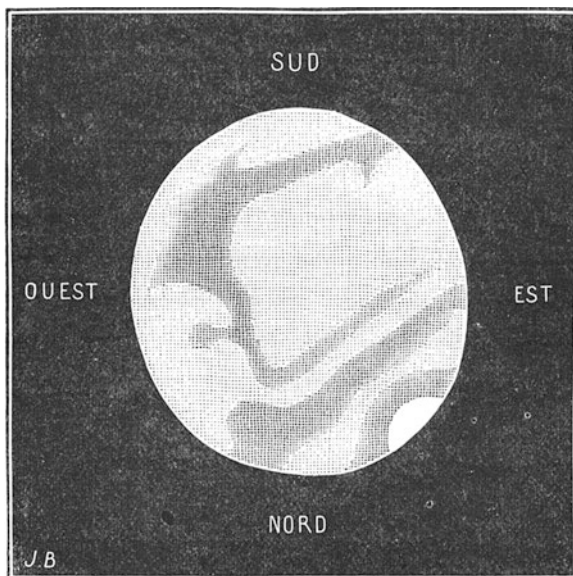
A long, narrow Mediterranean runs from north to south, and rejoins a vast sea which extends from beyond the equator into the southern hemisphere; between the western extremity of this Mediterranean and the northern sea referred to above, there is another enigmatical feature. Normally this Mediterranean channel seems to join the two patches. Sometimes, at the western end, there may be distinguished a sharply turned, even right-angled, feature, which does not, however, interfere with the general physical details already described: *a north pole* marked by a very white patch; *a north sea* extending from these latitudes; *a broad network of water* reaching in an east–west direction; and a considerable *southern sea*.

It was actually autumn in the northern hemisphere of Mars. The greater part of the north polar snows had melted, while snow was accumulating around the south pole, invisible to us. The southern region was marked by a white streak near its edge. Was this snow, extending down to latitude 40°? More probably it was due to clouds.

The detailed study of the planet showed that the surface was decidedly different from the Earth's with regard to lands and seas. On Earth, three-quarters of the globe are covered with water; with Mars, on the other hand, there is more continental than maritime surface.

⁴⁷ *Comptes rendus des séances de l'Académie des Sciences*, Vol. LXXVII, p. 278, séance, 28 July 1873.

Fig. 71 View of the planet Mars, on 29 June 1873, at 10^h in the evening



Nevertheless, evaporation on Mars produces effects analogous to those in terrestrial meteorology, and spectral analysis shows that the atmosphere of Mars is charged with *water vapour*, as is ours; also that the seas, snows and clouds are composed of the same water as our own seas.

It seemed to me that the red colour of the continents was less intense than usual this year. The cause of this colouration has often been discussed, and was at first attributed to the atmosphere; but this explanation has been rejected, because the edges of the disk of the planet are less strongly coloured than the centre; they are almost white. The opposite would be true if the colouration were due to the atmosphere; the redness would be greater at the edge, because of the greater thickness of atmosphere through which the reflected light-rays have passed. Is it due to the colour of the materials making up the planet? We can accept this if the Martian continents do not remain in the state of sterile deserts, but that, under the influence of the atmosphere, rains, the life-giving heat of the sun and the elements which on Earth lead to the *development of vegetation*, produce the same type of vegetation, suited to the physical and chemical state of Mars. Now, since it is the surface which we see, not the planet's interior, the red colour ought to be that of the Martian vegetation, since it is this species of vegetation which is produced there. It is true that while the seasons on Mars are of almost the same intensity as ours, we do not see variations in tone corresponding to those which we observe during the different seasons in terrestrial latitudes; but the vegetation which covers the surface of Mars is presumably very different from ours and less subject to variations over the course of the year.

However this may be, the studies made of our neighbour planet are numerous enough to allow us to form a general idea of its geography, and even of its meteorology. We can give a résumé of the facts which we have acquired with regard to the astronomical physics of the planet:

1. The polar regions are alternately covered with snow according to the seasons, and show variations due to the marked eccentricity of the orbit; the ices of the north pole do not extend beyond latitude 80 N.
2. Clouds and atmospheric currents exist there, as on the Earth; the atmosphere is cloudier in winter than in summer.
3. The geographical surface of Mars is more equally divided up into continents and seas than is that of the Earth; there is slightly more land than sea.
4. The meteorology of Mars is a little like that of the Earth; water exists in the same state as on our globe, but, without doubt, under different temperature conditions.
5. The continents seem to be covered with reddish vegetation.
6. Finally, reasoning analogous to that applicable to earth shows, without doubt, that organic conditions do not differ much from those which led to the appearance of the Earth.

Same Year, 1873.—F. Hoefer, Stan. Meunier

Some time after the presentation of these results to the Academy of Sciences, our learned friend Dr. Hoefer objected to the preceding explanation, maintaining that the colour of Mars is not due to vegetation because it does not vary with the seasons. According to Hoefer, it is simply the colour of the soil.

The colour of the soil? But then this soil would be bare! The sun, the rain, the air would allow it to remain sterile over the centuries! Dr. Hoefer, who is a fervent partisan of the doctrine of the plurality of worlds, cannot accept this sterility, which is contrary to all known effects of the forces of Nature. There must be *something* on the lands, whether it be moss or even less.

The objection about the invariability of the colour throughout the Martian year is not well-founded, and a broader examination will show its inadequacy. On Mars why restrict Nature to producing vegetation of the same type as ours? The mean conditions of temperature, density, gravity are opposed to this idea; therefore the marked difference which exists between the Martian and terrestrial vegetation can account for the variation in colour. But in addition, even on Earth we find that Nature meets this objection and shows us species of vegetation which do not change. In the tropics, olive-trees and orange-trees are as green in winter as in summer. In the North the fir, the cypress, the laurel, the spindle-tree, the box tree, the holly, rhododendron, etc., keep their greenness even in the middle of the snow. Even in our latitudes, grasses and almost a 1,000 species of vegetation scarcely vary at all. Why, then, reject an explanation which is so simple—when even on Earth we have the same examples, and when the differences in conditions of life on Mars and the Earth cannot have led to the same kind of vegetation on the two worlds?

A second objection has been put forward; that on Earth the continents are vegetation-covered only in limited areas, and that its colour dominates those of the lands, so that Mars should be ochre; but the deserts are exceptions. Only water will suffice to produce vegetation, and the sterile regions of Mars are those over which

no rain ever falls. The same agents which led to the appearance of the first vegetation on Earth—the natural forces of fertility—exist on Mars as well as on our planet. There, too, we can see actual clouds and rain. Therefore it is probable that the dominant colour of Mars is due to some kind of vegetation which covers the soil,

In one of the meetings following that in which I presented the preceding observations, M. St. Meunier made the following remarks concerning the forms of the Martian seas as compared with those of terrestrial oceans:

At the moment when the attention of observers is directed toward the planet Mars, I believe that it is of interest to submit to the academy a comment concerning this body—a comment which confirms the theory of cosmical evolution which has already been developed.

We know that, from this point of view, Mars as a globe is older than the terrestrial globe, and now offers conditions from which we are far removed. Many considerations support this idea, among them the thinness of the atmosphere and the smallness of the oceans relative to ours.

The fact which I want to discuss today concerns the forms of the Martian seas compared with the seas of Earth. I see here a new indication of the relative oldness, because it seems evident that our seas have taken up approximately the same proportions of those on Mars, but on Mars they have considerably diminished in size because of progressive absorption by the solid core.

One of the most remarkable characteristics of Mars is the presence of many long, narrow channels, and seas in the shape of *bottle-necks*. This disposition differs essentially from anything known on earth.

Now, if we take a marine chart such as that of the North Atlantic Ocean, and draw successive horizontal curves for greater and greater depths, we recognize that these curves tend progressively to delimit zones whose forms are more and more elongated. At 4000 metres, for example, we obtain forms which are comparable in every respect with those of the seas of Mars.

From this, it follows that we suppose the Atlantic to be absorbed by deep-seated masses on the way to solidification, so that the level of the ocean would drop by 4,000 m, we would have a much smaller area covered with water—in the form, that is to say, of a narrow elongated sea. These are precisely the conditions shown on Mars.

This comment by our colleague is ingenious, and must be noticed; but it is not certain that the geological form of Mars is analogous to that of the Earth, or that a diminution in the amount of water would lead to this configuration. On the Moon, for example, the orography indicates nothing of the kind, and all the deep plains are circular; this absence of water leads to another type of landscape. The orography of these two neighbour worlds is sharply contrasted. It is probable that Mars is rather flatter, because of its greater age, so that the sea-bottoms have been raised relative to the mountains, which have been reduced by rain, ice, winds and various atmospheric agents.

1873.—Nathaniel Green

This artist—already known to our readers—published in *The Astronomical Register* for 1873, p.179, a selection of six of his drawings of the planet made during this opposition, and a planisphere sketched according to those drawings.

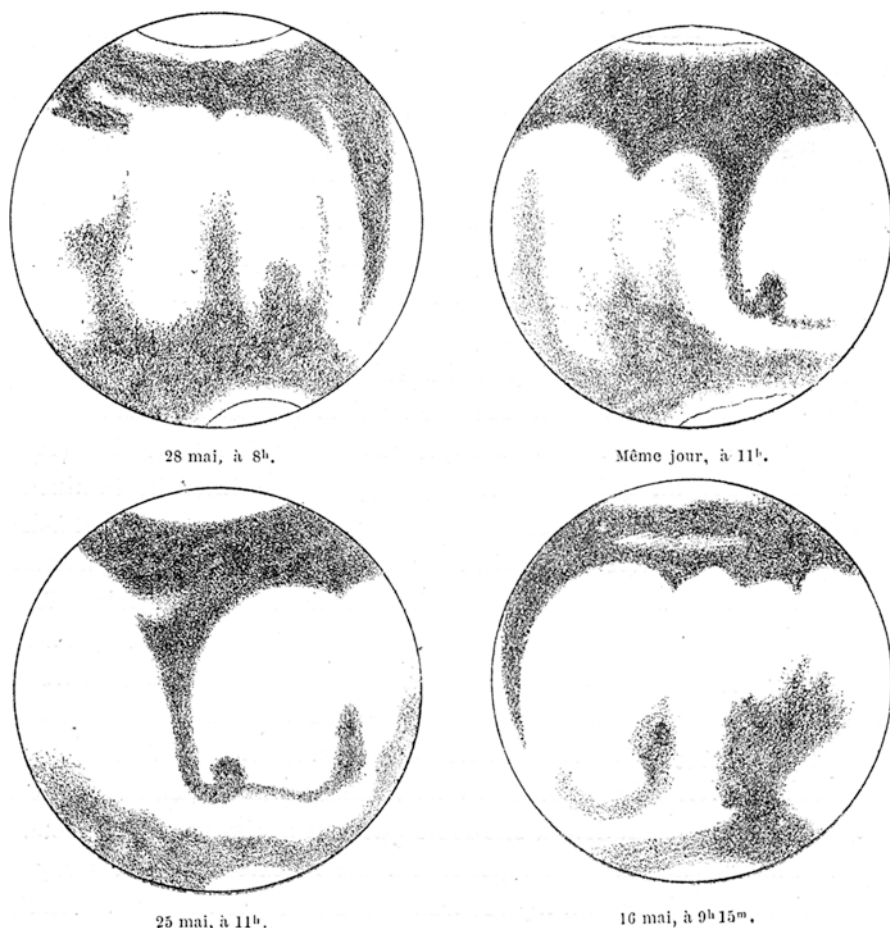


Fig. 72 Drawings of Mars, by M. Green, in 1873

The drawings themselves were made in London from 16 to 30 May 1873. The planet was low over the horizon, because of the southerly declination.

Four of the drawings are reproduced here (Fig. 72), together with the data and times for each. Our readers will recognize the advance of the Hourglass Sea from right to left, because of the planet's rotation.

The lower or north polar snow has been very marked; in December 1872 it was much more extensive than during spring at the time of opposition. After opposition, on the other hand, the southern snow increased considerably. Opposition took place on 27 April.

In the small planisphere reproduced below (Fig. 73), Green represented the features which he had been able to observe with certainty; each of the six views which we will discuss has, for its central meridian, the points given on the figure below. If we compare this planisphere with my map, we will find that point A.

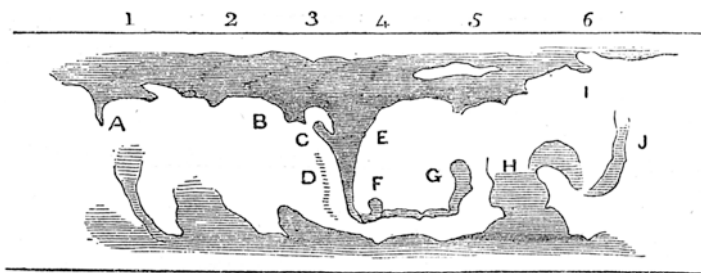


Fig. 73 Planisphere of Mars, by M. Green, from his observations of 1873

is the Maraldi Sea; B. the Flammarion sea; C. the Main Sea; E. the Hourglass sea, and the G. the Lassell Sea; H. is the upper Knobel Sea, I. the Christie Bay, and J. the Tycho Sea.

At D there is a grey streak parallel to the Hourglass Sea which does not appear on my map. "This was the most delicate streak observed in any of the drawings,"

wrote Green; he seemed to be certain of its existence. This aspect cannot surely be long-lived. Also note the feature F, which is hardly ever visible. Green wrote:

The Hourglass Sea is very dark near E. Generally, the dark areas are regarded as seas; but in this case should not one see a reflection of sunlight when the sun is on the meridian?

This question had already been asked, in 1862, by Phillips. In other words, he asked why we never see an image of the sun reflected from the Martian seas, and he could give no answer. In 1878 Schiaparelli asked the same question; he found that the diameter of the solar image should be $1/24$ of a second at closest approach, as on 5 September 1877 (Phillips had given a similar figure: $1/20$), and an intensity or luminosity 2,100,000,000 times less than that of the sun at unit distance, i.e. the distance between the Earth and the Sun. In his photometric researches, Zöllner (1865) had determined the amount of sunlight effectively reflected by the disk of Mars at mean opposition, and had found it is to be $1/6,994,000,000$, of sunlight at the distance of the Earth. From this it is found that the total light at a perihelic opposition, such as that of 1877, is $1/2,990,000,000$ of that of the Sun at unit distance. Therefore, the luminous image of the Sun reflected in the Martian seas at such an opposition should give more light than that from all the rest of the planet's disk.

This result is based on the assumption of total reflection of all these rays of the Sun. But in reality a transparent liquid, such as water, has a refractive index of $4/3$, and reflects only $1/49$ of the incident light. We must also take into account the absorption produced by the double passage of the rays through the atmosphere, which reduces their mean intensity. Instead of $1/49$, therefore, we have, in round numbers, $1/100$, the intensity of the solar image seen by reflection in the Martian seas should be:

$1/21 \times 10^{10}$ that of the Sun.

In the work already cited, Zöllner gave for Alpha Aurigae (Capella) a value of $1/5.57 \times 10^{10}$ that of the Sun.

Therefore, at the best opposition, the solar image should appear in the spherical surface of the Martian seas with a brilliancy equal to $\frac{1}{4}$ that of Alpha, that is to say as a beautiful star of the third magnitude.

Such an image ought to be visible against the sombre background of the Martian seas, despite the brightness of the disk. But this assumes a calm, mirror-like sea surface. Now, the observations of moving clouds, cloudy streaks, polar snows formed by vapours which are driven there—all these prove that there is wind across the surface of the planet. The surface of the water must, therefore, be normally distorted to a greater or lesser extent, and even the slightest waves will hinder the formation of a single solar image, giving instead a number of broken, smaller images. It is true that the total luminous intensity of these images would be the same as that of a single image, but they would be spread over a wide area of variable extent, and would become blurred, particularly if the crests of the waves were high. This nebulous light would become imperceptible to the observer.

Summarizing, it is not therefore impossible, under the best conditions, to detect the image of the Sun reflected from a sea surface on Mars, but this can be done only under exceptional circumstances.

Such is the answer to the question put forward by Green. We will return to this observer when discussing the work carried out in the year 1877.

Same Year, 1873.—E.B. Knobel, Webb, Grover

During the same period a skilful English observer, Knobel, at his observatory at Burton-on-Trent, made a series of observations, published by the Astronomical Society of London,⁴⁸ accompanied by 17 drawings. The observations were made with a reflector with a silver-on-glass mirror $8\frac{1}{2}$ in. (210^{mm}) aperture, of excellent quality, and with magnifications of 250× and 300×.

In general, the drawings agree perfectly with those of Dawes and with Proctors map constructed from them. However, certain exceptions are worthy of attention. Thus eight drawings, made from 11 to 22 May, very clearly show a dark circular patch in the lower or northern hemisphere, below the Meridian bay, which corresponds to Le Verrier Land or the Knobel Sea curved toward the left and continued upward after a sort of separating bulge. This separation may be traced obliquely from the SW to the NE, while on my chart (at longitude 30°) it runs from east to west; moreover, to the right of this sea, from 8 to 22 May, Knobel saw a patch as white as snow on 22 May, when the area lay on the terminator, brighter than the disk, so that it could be taken for polar snow. This snow sat at longitude 25°, latitude 50° N.

The Knobel Sea is the feature seen to the right in the fourth drawing by Green, reproduced above.

In these sketches, the oblique continuation of the Hourglass Sea—the Nasmyth channel—is also very marked, but the Lassell Sea is not, though it is very pronounced in Green's drawings.

⁴⁸*Monthly Notices of the Royal Astronomical Society*, 1873, p. 476.

During these observations, the coastline of the Meridian Bay was always seen with admirable clarity. The northern hemisphere of the planet was always clearer than the southern hemisphere; the north polar snow was better seen than that in the south. The Hourglass Sea was always very dark; the Main Sea was visible, but less dark.

The lamented English astronomer T.W. Webb, author of the *Celestial Objects for Common Telescopes*, made 85 drawings of Mars between 1839 and 1873, of which he communicated the principal ones to me; they have already been discussed (1856 opposition). Webb had keen eyesight, and was a skilful observer; his drawings, though of small size, are very precise with regard to many details. Also in England, Grover made five drawings in 1873, adding to the dozen he had made in 1867 and which have been referred to above.

Same Year, 1873.—Julius Schmidt: Rotation Period of Mars⁴⁹

In November 1873 Julius Schmidt, Director of the Athens Observatory, published a mathematical memoir about the rotation of Mars. He used his own drawings, extending from 1843 to 1873 (four of which have been reproduced here), and compared them with those of Kaiser, Mädler, Herschel and Huygens. The general result of this work gave a rotation period of:

$24^{\text{h}} 37^{\text{m}} 2^{\text{s}}.6027$.

Let us put aside, as of purely mathematical interest, the 10-millionths of a second and even the thousandths and hundredths, and give simply: $24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.6$.

We have already seen that the Martian rotation period had been given by Proctor as $24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.7$. Therefore we may now be confident that the period is known to an accuracy of 1/10 of a second.

These two series, by Proctor and Schmidt, were made with equal care, and are of equal value. Taking the approximation to 1/100 of a second, we can now give $22^{\text{s}}.65$ as being very close to the truth, if not absolutely precise.

This is the sidereal rotation. The Martian year, which is made up of $669 \frac{2}{3}$ rotations, has in corresponding Martian days a value of $668 \frac{2}{3}$ —namely, a rotation less, due to the orbital motion, which is in the same sense as the axial rotation. Therefore, the solar day of Mars is:

$24^{\text{h}} 37^{\text{m}} 35^{\text{s}}$.

During the opposition of 1873, Julius Schmidt, using the 9-in. (229^{mm}) refractor at Berlin Observatory, made an important series of observations and drawings, which appeared in Volume I of the *Publicationen des Astrophysikalischen Observatorium zu Potsdam* (1878). These six drawings of 1873 are not easy to interpret, except that of 25 May (10^h 5^m), which shows the Hourglass Sea. The others seem to disclose very large variations.

We will return to Schmidt's work in 1877 and 1879.

⁴⁹*Astronomische Nachrichten*, No. 1965.

Same Year, 1873.—Trouvelot: Drawings of Mars⁵⁰

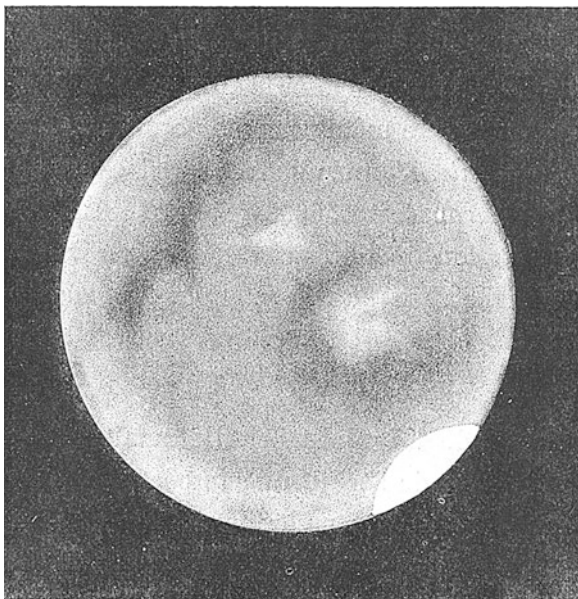
In Vol. VIII of the *Annals of Harvard College Observatory* (1876), Trouvelot published the four drawings of Mars which are reproduced here, made with the observatory's 15-in. equatorial. The first was made on 23 May, at 11^h 30^m; the second on the next day, at 9^h 30^m; the third on 26 May at 8^h 30^m, and the fourth on 29 May at 9^h 8^m (Figs. 74, 75, 76, and 77).

On the first two drawings, the Herschel II Strait is shown, and on the last two engravings the Meridian Bay and the Burton Bay; below, the Knobel Sea and the Tycho Sea. The Hourglass Sea, and its lower extensions toward the right (the Nasmyth Channel), are visible on the third and fourth drawings. The snows of the lower or northern pole are very evident. In a short note attached to these drawings, Trouvelot—a very skilful observer – was moved to write that the patches on Mars appeared to be surface features rather than clouds in the atmosphere. The whitish borders to the continents shown in his drawings do however suggest clouds.

In 1882 Trouvelot had an excellent general summary regarding his main astronomical drawings,⁵¹ in which he commented on the observations he had made of the different planets in our system. He summarized his studies of Mars as follows:

The sombre patterns showed different tones, from pale grey to deep black. The writer has never noticed green or blue coloration, and believes that these effects are due to complementary colour against the rosy tone of the continents.

Fig. 74 Drawing of Mars, by M. Trouvelot, in 1873



⁵⁰*Annals of the Astronomical Observatory of Harvard College*, Cambridge, Vol. VIII, 1876.

⁵¹*The Trouvelot Astronomical Drawings Manual*, New York 1882.

Fig. 75 Drawing of Mars, by M. Trouvelot, in 1873

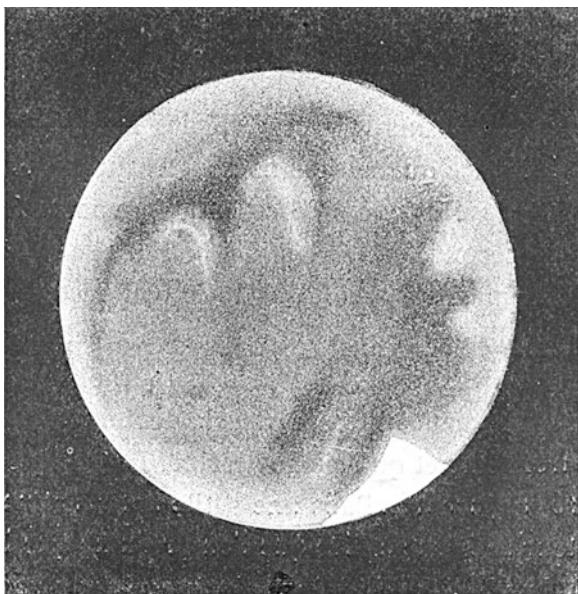
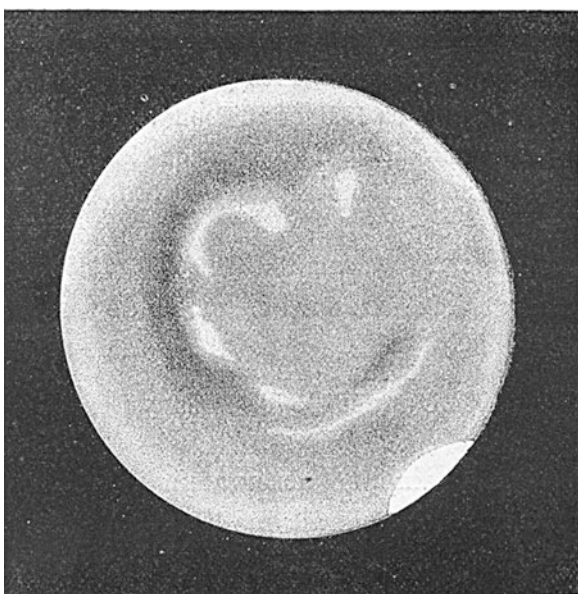


Fig. 76 Drawing of Mars, by M. Trouvelot, in 1873

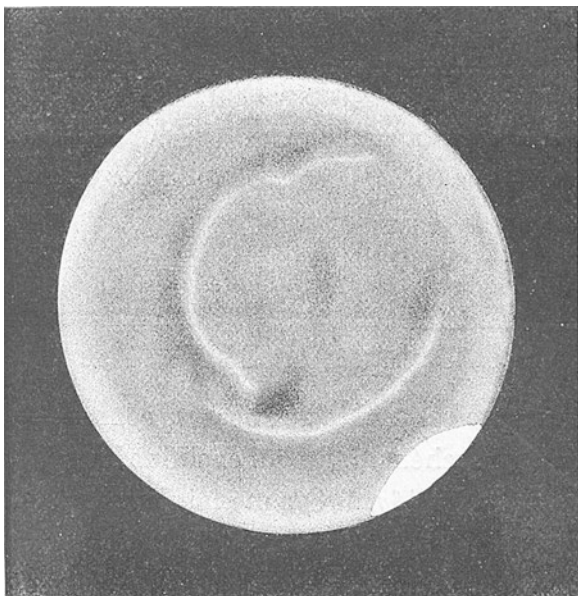


Several changes are certain, notably that of the sea represented by Beer and Mädler on the southern hemisphere at 230° longitude, below the circular sea d. This is the lake shown on my map, below the Terby Sea, at longitude 90° .

Trouvelot wrote in 1882:

In 1877, during one of the most favourable oppositions of the planet, I saw a strong dark patch there. There is not the least doubt about this change.

Fig. 77 Drawing of Mars, by M. Trouvelot, in 1873



This confirmed the opinion he had expressed in 1876 in *Les Terres du Ciel*.

More will be said about Trouvelot's work, and his deductions, in an account of the observations in 1882–1884.

Same Year, 1873.—Lohse⁵²

At the Bothkamp Observatory, Lohse made a series of studies and drawings, from which he concluded that Mars showed considerable variations in appearance. Six drawings were presented, which do not show details identifiable with known features. These are reproduced here, with a schematic tracing explaining the first.

The first of these drawings (Fig. 78) was made on 9 May 1873, at 10^h 10^m. The tracing which accompanies it (Fig. 79) was made to indicate the tones: *g*=deep grey, *dr*=dark red, *r*=pure red, *h*=white, *hh*=very white. The south polar patch *hh* is not diametrically opposed to the northern.

The second (Fig. 80) was made on 25 May at 10^h 5^m. I believe we can identify the Hourglass Sea, near which is a white elongated patch giving some impression of the Moon hiding behind a cloud.

The third (Fig. 81) was made on 2 June, at 9^h 45^m. Again shown is a sombre circle which recalls the ring in the first drawing. What can we conclude from these representations of the planet, except that each observer has his own personal manner of seeing, and that Lohse exaggerated features which were really vague and uncertain?

⁵²*Publicationen des astrophysikaleschen Observatorium zu Potsdam, 1878.*

Fig. 78 Drawing of Mars, by
O. Lohse, 9 May 1873



Fig. 79 Lohse's annotated
outline of the above

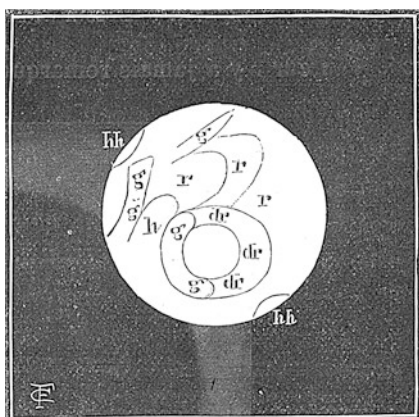


Fig. 80 Drawing of Mars, by
O. Lohse, on 25 May 1873

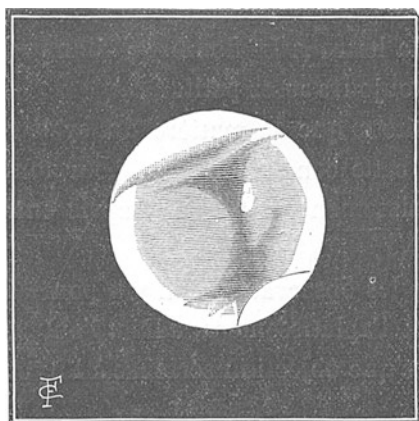
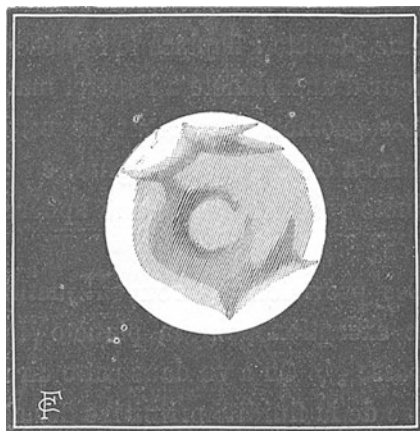


Fig. 81 Drawing of Mars, by
O. Lohse, on 2 June 1873



1872–1880.—Amigues, Hennesey, G.H. Darwin and Flammarion: Form of the Planet Mars

Most of the values found for the flattening of Mars seemed to be too great to be explained theoretically. The globe of Mars, smaller than that of the Earth and spinning less quickly, could develop an equatorial centrifugal force which is feeble compared with that of the Earth, and the polar flattening should be less than that of our globe, which amounts to $1/292$.

Laplace took this discrepancy into account by assuming that local irregularities, analogous to those whose effects may be seen in various parts of the Earth's globe, had a relatively greater influence upon the smaller globe of Mars. Arago challenged the validity of this explanation, and maintained that the shape of Mars was very regular; everything seemed similar at the poles and the centre of the equatorial region. His measurements of diameters at 45° gave him values intermediate between those of the poles and the equator, as exist in an elliptical body; however, Schröter, from his observations, had calculated that in the southern hemisphere there were mountains higher than those in the north. Amigues proposed, to the Academy of Sciences,⁵³ a different and highly original explanation, based upon a geometrical analysis of the problem.

Imagine a body placed on the equator of the planet. Let F be the attraction of the planet on the body, F' the centrifugal force due to the rotation. We know that the ratio F'/F is the same for all bodies on the equator of the same planet; Laplace represented it by the letter ϕ , which changes in value from one planet to another but is always small.

Geometers, assuming that the material of the Solar System was originally fluid, have concluded that for each planet approximating to a sphere, the flattening ought to lie between $1/2 \phi$ and $5/4 \phi$.

⁵³ *Comptes Rendus des séances de l'Académie des Sciences*, 1874, Vol. I, p. 1557.

These provisions are justified by the observations. However, Mars is an exception, since Amigues concludes that the flattening exceeds $5/4 \varphi$. This raises a serious objection to the hypothesis that the bodies were originally fluid.

However, it may be that the geometers have not considered the problem of spheroids with sufficient generality.

In effect, they all admit in their theories that the density of the layers diminished steadily from the centre of the spheroid up to its surface. Now, there is no proof that all the planets obey these conditions. Let us imagine, for example, that a planet cooled and solidified, taking up a certain form, and that later, because of circumstances impossible to define, a mass of cosmical materials passed in the neighbourhood of the planet and was disrupted by it, spreading out across the surface like a torrent of lava. We would be left with a spheroid in which the outer layers would be denser than the central layers. Amigues presented the general problem of spheroids as follows:

A spheroidal mass whose outer particles are fluid turns about an axis passing through its centre of gravity. The movement is slow; that is to say, the value of j is small. We assume a sphere having as its centre the centre of gravity of the spheroid, a sphere almost as large, but not exceeding it at any point on its surface. The material in the interior of the sphere is of mean density ρ (the mean density is the density of an homogeneous body of the same volume and the same mass). As for the material which is situated beyond the sphere, and which is spread out on the surface in a thin layer, it will presumably remain fluid, homogeneous, and of density ρ' . Under these conditions, assuming that we have an equilibrium figure very little different from that of a sphere, we can attempt to find out what this figure will be.

The problem is evidently indeterminate, and it is easy to see that the figure we are looking for, will depend upon the distribution of the material in the interior of the sphere. We can remove this indeterminacy either partially or completely. It is the latter which will be discussed here.

We assume that the sphere described above is made up of spherical layers, concentric with the sphere, and homogeneous. This hypothesis has several advantages:

1. It seems to depart only slightly from the present physical conditions:
2. It leads on to definite problems which will make up the law regulating to densities of the layers:
3. It allows for an easy calculation.

This calculation, by ordinary methods, that is to say, by applying Laplace's functions and neglecting quantities of the second order, gives the following result.

The mass takes up the form of an ellipsoid, whose flattening is given by the following formula:

$$\varphi / 2(1 - 3\rho' / 5\rho).$$

Do not forget that our calculation applies only to a spheroid and that, consequently, the formula is valid only if the flattening which it yields is positive and small. This means that the value of ρ' / ρ must not be too big.

Discussion:

1. for $\rho' = \rho$, we obtain $5/4 \varphi$, Newton's result.
2. for $\rho' = 0$, we obtain $1/2 \varphi$, Huygens's result.
3. when $0 < \rho'/\rho < 1$, the flattening lies between $1/2 \varphi$ and $3/4 \varphi$; this is what happens in the case discussed by Laplace and most geometers.
4. When $\rho'/\rho > 1$, the flattening exceeds $5/4 \varphi$; this is the case which has not yet been examined.

Let us apply the formula to Mars. Its probable flattening is $1/33$; this is low enough for us to use our formula. The value of φ relative to Mars being 0.0045866 , we obtain the following relation:

$$1/33 = 0.00045866 / 2(1 - 3\rho' / 5\rho).$$

We therefore have an equation of the first degree, which gives, without difficulty:

$$\rho' / \rho = 1.54.$$

Amigues' conclusions about the form of Mars are as follows:

1. The planet was formed in two or several stages;
2. The mean density of the outer layers is 1.54 times the mean density of the core, that is to say, of the planet.

The essential is to decide whether these premises are accurate—if the flattening of Mars really is $1/33$.

But this flattening is difficult to measure. It seems to be below $1/33$. The measurements made up to 1877 are:

1784	Herschel	1/16	1862	Main	1/38
1797	Schröter	1/81	1864	Main	1/46
1798	Köhler	1/81	1871	Main	1/71
1811–1847	Arago	1/30	1875	Main	1/36
1830–1837	Bessel	Insensible	1856	Winnecke	Insensible
1852	Oudemans	Insensible (after Bessel)	1864	Kaiser	1/117
			1864	Dawes	Insensible
1855	Main	1/62	1877	Young	11/219

(Of these, the last last value is probably the best.)

An English geometer, M. Hennessey, has replied to Amigues' paper.⁵⁴ He comments that the results obtained by Amigues seem to be a complete verification of those which Hennessey had reached much earlier. He wrote:

M. Amigues proposes to raise the important objection—the objection to the hypothesis of the original fluidity of the planets, because of the exceptionally large value for the flattening of Mars by saying: “The geometers have not discussed the problem of spheroids in a sufficiently generalized way”.

⁵⁴ *Comptes Rendus des séances de l'Académie des Sciences*, 1878, Vol. II, p. 590.

And after having indicated the method concerned, he adds:

This calculation, made by ordinary methods—that is to say, by using Laplace’s functions and neglecting the quantities of the second order—leads to the results which follow...

Hennessey comments that a very long time ago he had undertaken research into this very problem of spheroidal attractions (see *The Proceedings of the Royal Irish Academy*, Vol. IV, p.333). In the first case, he applied the results of his solutions to the question of the figure of the Earth, with the object of studying the basic parts of the theory which attempted to explain the spheroidal form by means of surface friction.

This theory was first proposed by Playfair in his *Commentaries on the System of Newton*, and was again put forward by Sir John Herschel in his *Outlines of Astronomy*. It was also cited by Sir Charles Lyell, serving as the basis for his views expressed in his *Principles of Geology*.

The results obtained by Hennessey did not confirm the theory, because the greatest compression of the Earth on the basis of surface friction would have been 1/404, which is in sharp disagreement with the results of observation. Hennessey wrote:

In 1864, for the first time, I applied my calculations to the problem of Mars, in a communication to the British Association, and a short extract from my work was published.

In February 1870, I published a memoir in Atlantis on the figure of Mars, and I applied to Mars the mathematical results of the preceding researches. I found an equation giving the ellipticity as a function of the mean density D_1 , and also the density D of the surface of the plane

$$e = 5q / (10 - 6D_1/D) = q / 2(1 - 3D_1/5D).$$

In the equation, q is the ratio of centrifugal force to gravity.

Now if we use Arago’s notation, replacing q by φ , D' by ρ' and D by ρ , we have

$$e = 5\varphi / (10 - 6\rho' / \rho) = \varphi / 2(1 - 3\rho' / 5\rho),$$

after which we have a formula exactly the same as that of Amigues.

From my formula, I have also deduced that if we accept the greater flattening attributed to Mars, we must conclude that the outer density is greater than the planets interior. But since such a situation appears contrary to the laws of physics, if the constitution of Mars resembles that of the Earth, I prefer to accept the conclusion of Bessel, Oudemans and Winnecke, who, after making very careful observations, are unanimous that the flattening of Mars is almost insensible.

An extract from my first researches into the theory of the form of the Earth, according to friction, has appeared in several scientific journals of some years ago. I am however convinced that the results obtained by Amigues with regard to Mars have been entirely independent, and made without any prior knowledge of my researches.

The complete agreement between the calculations of Hennessey and Amigues therefore confirms the opinion expressed above, in opposition to the theory of Playfair, Herschel and Lyell with regard to the form and structure of the Earth. (There is also a reference to these difficulties in Aragos memoir on Mars). Hennessey returned to the same question in 1880.⁵⁵

⁵⁵ *Comptes Rendus*, 1880, Vol. I, p. 1419.

C.A. Young, of the United States, has published a series of observations on the equatorial and polar diameter of Mars. These measurements seem to have been made with the greatest care and under the most favourable circumstances; the observations were reduced and corrected for the slight effects of aberration, and the final value for e or the polar flattening was $1/219$.

Hennessey comments that it is easy to see that this value agrees better with the hypothesis of the former fluidity of the planet than with the hypothesis of surface erosion by a liquid ocean having the same density as water.

If Mars were originally in a hot, fluid state, its mass would have been distributed in spheroidal surfaces of equal density, the density increasing from the surface to the centre.

The ellipticity would depend upon this law, and upon the rotation period of the planet, as is the case with the Earth. In such a liquid spheroid

$$e' = 5Q' / 2F(a'),$$

where Q' is the ratio of the centrifugal force to the gravity at the equator, and $F(a')$ is a function of the radius whose form depends on the law which regulates the variations of density going from the surface to the centre.

If T' is the rotation period of the planet, a' its mean radius, M' its mass and g' the intensity of the gravitational force at the surface, then

$$Q' = 4\pi^2 a' / T'^2 g', \quad g' = M' / a'^2$$

and consequently,

$$Q' = 4\pi^2 / T'^2 a'^3 / M';$$

For the Earth we have

$$Q = 4\pi^2 a / T^2 g \quad \text{and} \quad g = M / a^2;$$

and thence

$$g' = gM' / M (a / a')^2$$

and consequently,

$$Q' = Q(T / T')^2 (a' / a)^3 M / M'.$$

Astronomers generally agree that

$$a' / a = 54.$$

$T = 86164^s$, $T' = 24^h 37^m 22^s.7$ or 886427^s . If we accept that the mass values for the Earth and Mars given by Le Verrier, we have

$$M = 1/324439 \quad M' = 1/2812526 \quad Q = 1/289,$$

and it follows that

$$Q' = 1 / 224.07.$$

For the Earth $e = 5/2$ QF (a), and if F (a) has the same value for Mars, or more accurately the density varies from surface to centre in the same way as with the Earth, then

$$e' / e = (Q' / Q) e.$$

But, as the last determination of e gave $e = 1/293.46$, the calculation leads to $e' = 1/227.61$.

As Mars shows evidence on its surface of an aqueous fluid, we may go back to a theory previously advanced to explain the figure of Mars. It is suggested that erosion of the surface, combined with the centrifugal force which is produced by the planets rotation on its axis, will yield the observed result. This theory was suggested by Sir Charles Lyell.

Considering the theory of erosion by a moving liquid on the surface of a planet, I have found, for the ellipticity of the enveloping liquid,

$$e = 5QD + 6(D' - 1)\varepsilon / Q(5D - 3),$$

ε being the ellipticity of the solid surface, D the mean density, and D' the density of the solid material at the surface. The maximum possible value of e corresponds to $e = \varepsilon$, and then

$$e = 5QD / Q(5D - 3) - 6(D' - 1)s$$

With the Earth, the values generally agreed for the mean density of the globe and the density of the solid crust are in round figures $D = 5.6$ and $D' = 2.6$. With these numbers, it is evident that e cannot exceed $1/417$.

The smallest possible value which we can give D in the present state of our knowledge is about equal to twice D', and it follows that

$$e = 5 / 7Q = 1 / 404.6.$$

Hennesey concludes that the erosion theory cannot explain the figure of the Earth so satisfactorily as the theory of complete original fluidity.

If Mars were an homogeneous solid, the erosion theory could give as good an agreement with the observed ellipticity as the homogeneous fluid theory, because in either case e would be $5/4$ Q', whence $e = 1/179.24$, a value which is sensibly greater than the result obtained by observation.

The researches carried out by various astronomers have recently shown that the surface of Mars presents a well-defined distribution of solid material and liquid material. The lands appear to form groups of islands rather than large continents.

If the figure of the planet differs from that deduced from the theory of original fluidity, if its flattening is slightly or considerably greater, such a distribution of land

and water could not exist. With a strong flattening, the lands would form a great girdle near the equator; with maximum flattening or a spheroidal figure, the lands would form two continents round the poles with an intermediate equatorial ocean. All recent observers agree that the planet has a distribution different from that which would occur in the latter case.

To me, it seems more likely that the old determinations of the flattening of Mars (upon which Laplace’s reasoning was based) were too large, and that the real figure is close to the value given by Young, in accord with the rotation period and a gradual downward increase in density,

On the same question, the skilful mathematician G.H. Darwin⁵⁶ discussed Laplace’s formulae concerning the densities rotations and flattening of the planets. Calling ϕ the ratio of the centrifugal force produced by the rotation (at the extremity of the mean radius of the planet) to the gravity: Mars spins in 24^h 37^m 22^s.6 or 1.025956 sidereal days, while the density adopted by Darwin is 0.948 that of the Earth, and the sidereal Martian day is 0.997270. We have for the Earth

$$\phi=1 / 289.66$$

and for Mars
add equation

The measurements of the flattening must be affected by observational errors. Agreeing that the law of the interior density should be the same for Mars as for the Earth, the resulting flattening should be 1/298. But Darwin certainly adopted too great a value for the density of Mars; actually it is barely 0.70.

In 1872,⁵⁷ I examined the ratio of gravity to centrifugal force at the equator of Mars. Adopting a value of 24^h 37^m 22^s.7 or 8843^s for the rotation period, we have:

Speed	$\omega=2\pi/88643=0.0000709.$
	$\omega^2=0.000000050239.$
	$a=6371000m \times 0.53=3376630.$
Centrifugal force	$\omega^2a=0.1696$
Gravity	$g=9m8088 \times 0.376=3m688.$
	$g/\omega^2a=217.5.$
On the Earth	$g/\omega^2a=9.8088/0.033858=289.$
Flattening therefore = 1/292.	

The ratio of centrifugal force to gravity, which is 1/289 at the terrestrial equator, is 1/217.5 at the equator of Mars. The flattening should not differ much from this value, if, as is likely, the density of the globe increases from the surface to the centre, as with the Earth. It would then be in the region of 1/226.

If Mars rotated on itself solely by virtue of its own gravitational force, in the manner of a satellite over the equator moving around the mass of a planet which is

⁵⁶*Monthly Notices of the Royal Astronomical Society*, Dec.1876, p. 77.

⁵⁷*Études sur l’Astronomie*, vol. III, 1872.

condensed toward the centre, the rotation period would be only $1^h 40^m$. This figure must be multiplied by 14.77 to give the real rotation period of the planet. This number is also the square root of the number 217.5 found above, representing the ratio of centrifugal force to gravity at the equator of Mars.

We have the relationship

$$T / p = (g / \omega^2 a)^{-1/2},$$

where T =the length of the real rotation, p =the theoretical gravitational period, g =the surface velocity, ω =the angular velocity and a =the radius. But as

$$\omega = 2\pi / T, \quad \omega^2 = 2\pi^2 / T^2.$$

Therefore, for all the planets we have the equation

$$g / (2\pi^2 / T^2 a) = T^2 / p^2,$$

$$2\pi^2 / T^2 \times T^2 = gp^2,$$

and, finally,

$$2\pi^2 a = gp^2,$$

which links the radius of the planet to the satellite period.

1874. —Terby: Aréographie

On 6 June 1874, the eminent Louvain astronomer presented to the Belgian Academy of Sciences “A Comparative Study of Observations made of the physical aspect of the planet Mars between the time of Fontana (1636) and the present day (1873).”⁵⁸ This extremely important work begins by an account of all the observations, and continues with a comparison of the various representations given of each region of the planet. This is a meticulous study of areography, and a detailed, careful study of the most important drawings. The principal questions concerning the geography and meteorology of the planet are discussed. Terby’s aim is above all to help the observers. In conclusion he writes:

Directed to debatable points, they do not neglect to elucidate a great many questions asked in this book, and the accuracy of Martian maps is also essential. I will be happy if the points raised in this memoir, touching upon such matters, contribute something towards our knowledge of the physical state of Mars.

⁵⁸*Mémoires de l’Académie royale des Sciences de Belgique*, Vol. XXXIX, 1875.

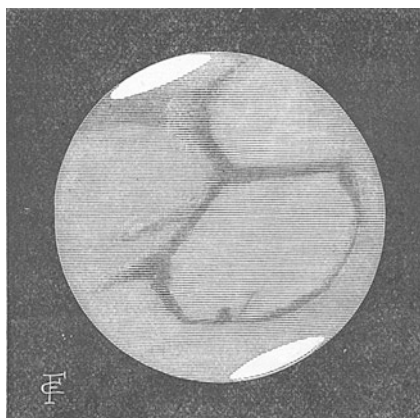
This monograph on Mars has been of the utmost value, not only to observers but to all students of the planet; and science is indebted to M. Terby for one of the best documents on this subject—one of those which has made the most progress toward our general knowledge of Mars.

Note also, in the same year (1874) an excellent study by the Rev. T.W. Webb,⁵⁹ summarizing the work of Kaiser, who died on 28 July 1872—a study accompanied by two drawings made by this skilful Dutch observer. One of the particular points made in this study is Kaiser's assertion that the differences in tone which characterize the various dark patches, and the lack of sharpness of their contours, indicate that the seas do not resemble our own. Webb concludes that their blue-green colour is real, not due merely to contrast with the yellow continents.

1875.—Holden, Bernaerts, Ellery, Flammarion

During the 1875 opposition Holden, at the National Observatory in Washington, used the great 26-in. (0^m.66) equatorial—the most powerful telescope then in existence—to make a number of drawings, of which six were communicated to the Royal Astronomical Society of London.⁶⁰ They were made on 14, 16, 21 and 23 June and 2 and 5 August; magnification used, 400×. Despite the size of the instrument, Holden's drawings do not agree with the known appearance of the planet, as can be seen from his sketches of 16 June, from 10^h 40^m to 11^h 15^m, and 23 June, from 10^h 20^m to 11^h 07^m (Figs. 82 and 83), which are the best of the series. This does not give much encouragement for the use of large instruments.

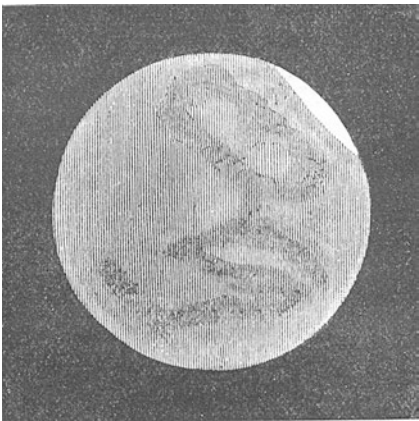
Fig. 82 Mars, by M. Holden, at Washington, on 16 June 1875



⁵⁹ *Nature*, 12 and 19 February 1874.

⁶⁰ *Monthly Notices of the Royal Astronomical Society*, November 1875.

Fig. 83 Mars, by M. Holden,
at Washington, on 23
June 1875



Holden made his drawings in pastels, stating that the colour best matching that of the Martian continents was salmon-red, and commenting that the principal belt on Jupiter was similar in hue; it had been drawn at the same time, and the same crayon had served for both.

On 12 August 1875, Mars was occulted by the Moon, and the phenomenon was observed at 2^h 58^m at the Windsor Observatory (New South Wales) by John Tebbutt. Nothing remarkable was seen.

During the same opposition Bernaerts, at Malines, made a series of observations and sketches, which add nothing of importance.⁶¹

Since 1875 we have been concerned with various comparisons between the different planets, stars, and luminous gas, with the help of a movable sextant mounted on a fixed pier, and bringing together the images of the different stars, or one star and a gas-jet.⁶² The stars were, as often as possible, at 40°–50° above the horizon, and about 1 km. to the south of the Paris Observatory. There is one essential provision: the thickness of the atmosphere tends to increase the rays at the red end of the spectrum, to the detriment of those at the blue end. The experiments which I conducted gave for the colours and the contrasts

Sirius	Bluish white
Moon	Clear yellow
Jupiter	Milky yellow
Mars	Orange yellow
Antarès	Orange
Gas	Reddish orange

⁶¹*Bulletin de l'Academie Belgique*, 2nd series, Vol. XLV, p. 39.
⁶²*Bulletin de la Société Astronomique de France*, 1st year, 1887, p. 50.

There were some very curious contrasts:

Mars and the Moon	Vivid orange and pale blue
Mars and Jupiter	Orange and pale sea green
Mars and Saturn	Orange and green
Mars and Véga	Red and blue
Gas and Mars	Orange and citron
Gas and Moon	Bright cherry red and glittering silver

Thus Mars, which to the naked eye appears as red as Antarès, its historic rival, is less red than a gas-jet seen from a distance of 1 km.

In the same year I also made many drawings of the planet.

1876.—C. Flammarion: *Les Terres du Ciel*

The first edition of this book, published in November 1876, was devoted to the planet Mars.⁶³

I reproduce here the following figure (Fig. 84) which gives the opposition positions for the cycle prior to 1877, and prepares us for the perihelic opposition of 1877. C is the centre of the orbit of Mars, P the perihelion point of Mars, *a* the aphelion of the Earth, *p* the perihelion of the Earth, Ω the line of intersection of the orbits. It is seen that since 1869, each opposition has brought Mars nearer to the Earth, and that the closest approach was due in 1877.

On this orbit I have marked the solstices and equinoxes of Mars; and with regard to Martian climatology, I wrote:

This world, as with ours, presents three very distinct zones; the torrid, temperate, and glacial. The first extends 28°42' to either side of the equator; the temperate zone extends to latitude 61°18', and the glacial zone from this latitude to each pole.

As with the Earth, the planet rotates in the plane of the Zodiac; similarly the Sun seems to move throughout the year in the Zodiacal constellations. However, the summer solstice in the northern hemisphere does not occur with the Sun in Cancer, as with us, but in Virgo while the winter solstice is in Leo, not Capricornus. On Mars, we should therefore refer to the Tropics of Virgo and Leo.

The existence of a Martian atmosphere is proved. When the surface patches are near the centre of the disk, they are clearly seen, but when they are carried by the planets rotation to near the edge of the disk, not only do they appear foreshortened due to the geometrical perspective of their position on the rotating sphere, but they also lose their sharpness, becoming pale and even invisible before reaching the limb. This effect is caused by the Martian atmosphere, which absorbs the light-rays, and interposes a veil of greater and greater thickness as the light comes from nearer and nearer the edge of the disk. Moreover, the edge of the planet is, overall, paler than the central region, because of the same atmospheric absorption.

In addition, the snows, the clouds, and the researches of spectral analysis prove that water vapour exists in the Martian atmosphere.

⁶³*Librarie Academique, Didier et Cie. Vol. I, Book VI, pp. 307–440.*

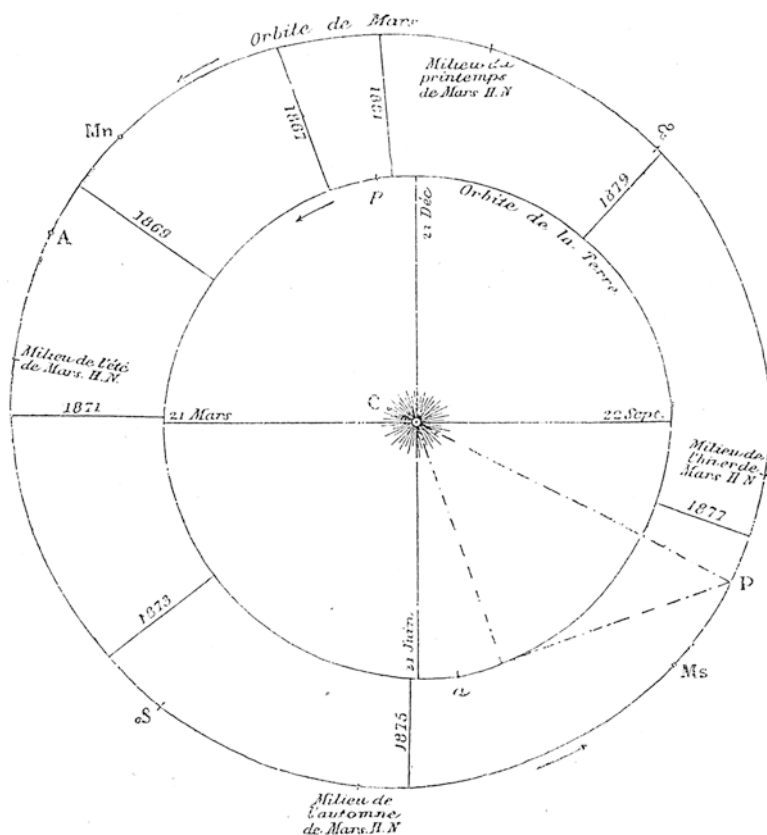


Fig. 84 Relation of the orbit of Mars to that of the Earth, from 1867 to 1877

The geography of Mars is dealt with in another chapter, where I consider all the observations made since 1636, and which are completed by a map showing the present extent of our knowledge. This map will be found below, as a preliminary to the opposition of 1877. It may be summarized as follows:

The examination of this planisphere shows us first that the geography of Mars does not resemble that of the Earth. While three-quarters of our globe is covered with water, the distribution of land and sea on Mars is practically equal. Instead of being islands emerging from the heart of the liquid element, the continents seem rather to reduce the oceans to simple inland seas, and to make them become veritable Mediterraneans. There is no Atlantic, no Pacific on Mars, and one could walk almost right round the globe on dry land. The seas are cut up by gulfs, variously prolonged in a large number of arms stretching out in the manner of our Red Sea over the closed land. Such is the essential character of areography. The second characteristic, which suffices for recognition of Mars from a great distance, is exemplified by the Hourglass Sea and the Channel.

We may also conclude that the dark patches do indeed represent stretches of water, while the bright areas represent continents—though this interpretation has

been discussed and challenged by more than one observer. (Liais, Cruls, Brett, Trouvelot, etc.).

In my own words:

It is evident that there is water on Mars, since we can see the state of the polar ices, the variable snows, and also the clouds floating in the atmosphere; moreover, the presence of water has been proved by the spectroscope. The seas, seen from afar, appear darker than the lands, because water absorbs a great part of the light and reflects very little.

We must, however, note that the seas of Mars are not equally dark; some are particularly dark (Hourglass Sea, Kaiser Gulf, Lockyer Sea, Maraldi Sea; see my chart). It may be thought that the less dark seas are sprinkled with islands, which we cannot distinguish because of their small size, and that some areas of the water are not very deep, as is the case with, for example, our Zuyder Zee. These differences are surprising; they cannot be explained by changes in the transparency of the atmosphere of Mars, but are real. So why is not the same thing evident in terrestrial waters? Yet the colour of sea-water is far from uniform. The Marne is yellow, the Seine pale green, the Rhine dark green, etc.

Moreover, it seems that the Martian seas are not changeless, because since 1830 there have been certain unquestionable variations. For instance, there is Kaiser Gulf, which since the end of the last century has presented the aspect of a thread ending in a disk, but after 1862 has become broader, ending not in an isolated black circle but in a forked bay. On the planet there may possibly be displacements of water, and variations in the colour of the water, which do not occur on Earth.

Such is a résumé of the knowledge derived from physical observations. For the first time (1876), the variations in the seas, in tone and in extent, has been established by adequate observational data.

To the long series of observations which makes up our second period, we must add the work of Capocci (1862), Schultz (1862), Vada (1863), Michez (1865), Folque (1867), Fabritius (1873), etc. But these detached contributions add nothing to our knowledge.

All the observations which we have examined have, assuredly, their intrinsic value, but on arriving at the close of our second period we must comment that the work of these last few years was essentially in preparation for the exceptionally favourable opposition of 1877. Astronomers prepared well ahead, as they had done in 1862; the planet was becoming better and better known, and the progress in optics was most encouraging.

Before coming to the third and last section of our examination, let us summarize the progress made during the second period, 1830–1877.

Conclusions of the Second Period 1830–1877

Refer back to an earlier section of this work, and recall the conclusions which had been reached in the first period.

The 13 points made in the first list have been confirmed. Many have been developed. New information has been obtained:

14. The length of the rotation period has now been fixed accurately at $24^{\text{h}} 37^{\text{m}} 22^{\text{s}}.65$, to within a few hundredths of a second; the true value certainly lies between $22^{\text{s}}.6$ and $22^{\text{s}}.7$. In 1830, we had still been far short of this accuracy.

15. The geography of the planet has been sketched in its principal characteristics. Several charts have been drawn up, first by Beer and Mädler in 1840, then by Kaiser in 1864, Phillips in the same year, Proctor in 1867, Green in 1873. To these geographical contributions must be added the map I published in 1864, showing the better-known hemisphere of the planet, that with the Hourglass Sea at the centre. The dark patches are essentially permanent, and we cannot agree with Schröter that they are atmospheric in nature. However, our first conclusion (point no. 8) is retained; the forms and aspects of the patches are variable. Two hundred new views of Mars have passed under our eyes during this second period. Joined to the earlier 191 of the first period, this makes a total of 391 different drawings of the planet, made by all the observers. Their study, by comparing them, establishes that each observer sees according to his eyes, his skill and his instruments; and he draws accordingly.
16. Therefore, for each drawing there is what we may call a personal equation, an individual interpretation, and as the details of a globe seen from the distance of Mars through two atmospheres are always vague and exceedingly delicate, there can be no single drawing which gives a rigorous and exact representation of Mars as it would appear to an observer close to the surface.
17. Nevertheless, despite all this variety, there is a definite basis represented in my general map. Moreover, the discrepancies between different observers cannot account for other kinds of changes, which must therefore be regarded as real. The Hourglass Sea certainly changes in breadth and tone; its left bank, particularly at the Hind Peninsula, seems to indicate lands which are sometimes dry and sometimes inundated; the circular Terby Sea has around it—particularly below it—regions which are sometimes bright and sometimes dark; the Flammarion Sea is sometimes crossed by a sort of sandbank; the Meridian Bay appears sometimes round, sometimes square, at still other times elongated and forked, and so on.
18. These aspects and their variations confirm the interpretation already put forward from the first period: the dark patches represent stretches of liquid, seas and lakes, and the bright areas are solid expanses, continents and islands.
19. The variations in the polar snows confirm that the water has the same properties as that on our own planet—susceptible to conversion into snow, ice, or clouds.
20. Spectral analysis, created during the second period, establishes that the waters are analogous to ours in chemical composition.
21. However, these aqueous stretches appear to be in a different physical state from our own seas: they may be less dense, less liquid, or covered with viscous fogs.
22. The atmosphere is less disturbed than ours, less charged with clouds and fogs, less productive of rain, more rarefied, more transparent. The water must evaporate and condense more easily than on Earth. Contrary to the views of Father Secchi, cyclones cannot be seen, but we can sometimes observe very extensive clouds (see the various drawings), at great distances from the poles—particularly in Lockyer Land, which is sometimes mistaken for a pole.
23. There is less water on Mars than on the Earth, both in extent (scarcely half the globe, instead of three-quarters, as with us) and also, no doubt, in depth, because the variation in tone of the seas seems to be due to the fact that the bottom is

sometimes visible; there is also frequent flooding across the vast plains, which, we assume, must be very flat.

24. The south or (as seen in the telescope) the upper hemisphere of Mars is primarily marine; the northern hemisphere is primarily continental. The level of the latter is therefore presumably higher than that of the former. The geological events leading from the formation of the planet have led to the development of an elevated northern hemisphere and a depressed southern. Let us note that it has been almost the same on Earth, where the great continents, Asia and Europe, North America and half of Africa, lie in the northern hemisphere; the southern hemisphere has South America, South Africa and Australia, but the level of the surface is much lower. The difference could be due to the Sun's attraction on the hemisphere of Mars which is closest to the Sun during the half-period of the revolution of the line of the apsides at the critical time when the planet's crust was solidifying; this attraction could have had the effect of lifting up the northern hemisphere slightly and obliquely. The continental centre seems to be in Huygens Continent, at longitude 150° latitude 20° ; the marine centre almost antipodal in Dawes Ocean, at 330° longitude, 30° latitude. For Earth, the analogous points are the Carpathians and their antipodes.
25. The polar flattening of Mars is certainly less than was believed by Herschel, Laplace, and Arago; objections to the theory are without foundation. The geometrical figure of the globe of Mars does not differ much from ours, if we accept greater flattening. The ratio of centrifugal force to gravity is $1/217.5$. The polar flattening should differ little from this value.
26. Rivers should exist on Mars, since there are clouds, seas and rains. The Meridian Bay seems to be the mouth of two great rivers.
27. Though the globe of Mars seems to be less irregular than ours in orographic relief, there certainly seem to be mountains of some height, and some elevated plateaux. Thus the two islands drawn on my chart at 47° and 297° longitude, are sometimes visible and sometimes not; they are undoubtedly mountains sometimes covered with snow. It also seems that there is a high plateau near the equator to the right of the Hourglass Sea, and another at the intersection of 185° longitude with 65° south latitude.

To sum up: the analogies between Mars and the Earth have been established by a series of observations. The climatic conditions seem remarkably similar to our own; the temperature on Mars is almost the same as ours, though the physical conditions of atmospheric pressure and density, and the lower gravity, produce effects analogous to a temperature difference.

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