Mars: The history of a master illusionist

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This paper presents a psychologically based history of Mars observation. We introduce the way that the perception of colours affected inferences about the nature of the planet, and describe the implications of the canals' tendency to appear in brief flashes, which severely challenged the performance of the eye-brain-hand system. Under such difficult conditions the effect of the personal equation of the observer looms large. We discuss a number of observers – Huygens in the early days, Schiaparelli and Green in the mid-19th century, and Lowell, Barnard, and Antoniadi at the turn of the last century – who achieved successive positions along what Schiaparelli regarded as a 'stairway of perception'. We have now reached the ultimate step in perceiving Mars, achieved through the eyes of robotic craft in orbit around and on the surface of the planet itself.

1. The stairway of perception

Whenever an observer peers intently at Mars through a telescope, under varying conditions of seeing, a series of images unfolds that presents in succession the history of observation of the planet. Giovanni Virginio Schiaparelli, perhaps the greatest observer of Mars of the 19th century, used the analogy of a printed page seen at various distances; at stage A the vision was confused and the page appeared as a grey square; at stage B this view was replaced with that of geometrical lines; only at stage C did one begin to suspect the breaks and irregularities, and at stage D to read the individual letters.

Thus, taking stock of the situation as it appeared in 1907, Schiaparelli wrote to a fellow scrutinizer of the red planet, Vincenzo Cerulli:

> The first observers of Mars, to 1860, lived in stage A. Since this epoch, Secchi, Kaiser, and Dawes came near to stage B, finding some lines… In the years after 1877 the view produced in me and others was stage B – a vision apparently complete and accurate of single and double lines on the planet. Now, thanks to you, we are entering stage C; the naïve faith in the regularity of the lines is shaken, and we have the prospect of yet another stage, D, in which the appearance of lines will resolve into forms of a different order – closer to the true structure of the Martian surface. But will this, then, be the final truth? No; for of course as optics continue to improve, the process will proceed to other stages of vision, or illusion. My thanks to you for the progress you have realized along this stairway.[1]

I can confirm what Schiaparelli is saying here from my own experience of observing Mars, with many different telescopes, over a span of fifty years (as of the time of writing). I began with only a 60-mm refractor of the department-store variety that everyone nowadays regards with contempt. It cost all of $30 and gave me countless hours of pleasure when I was ten. It was quite as powerful as the best of the telescopes used by Christiaan Huygens – indeed, his views of the planets were very much like mine.

I had become passionately interested in astronomy in early 1964, but had had to wait until 1965 March for a good first look at Mars, when it came to an unfavourable opposition, never much closer than 100 million km from Earth.

Despite that, the opposition was good enough to whet my appetite for all things Martian. I still remember 'how little it was, so silvery warm – a pin's-head of light!' (as the narrator says of the view through Ogilvie's telescope in H. G. Wells's *War of the Worlds*). Odd, but I was not disappointed. I peered insatiably at that brilliant pinpoint, small in itself, already portentous in its implications. As John Ruskin says in *Modern Painters*:

> The greatest thing a human soul ever does in this world is to *see* something, and tell what it *saw* in a plain way. Hundreds of people can talk for one who can think, but thousands think for one who can see. To see clearly is poetry, prophecy and religion, all in one.[2]

Mars did not, of course, then reveal to me the detail it would later when I had the chance to view it with more powerful means. The view was decidedly Huygensesque. Yet little as it was, it vouchsafed something momentous to me. It was a planet, another orb in space; it had a disk, and I was seeing it as if approaching it from the porthole of a spacecraft only a million miles away. That was something. Mars I had *seen*, and *seen* in a plain way. There was poetry, prophecy, and religion for me in that.

I longed to see more. If I could have seen Mars with a larger telescope, I did not doubt that I would catch a glimpse of the famous 'canals', with which I had become intimately acquainted almost as soon as I became astronomically literate, and in which I was at the time a true believer.

I had read the arguments pro and con in a number of books – and all of my favourite books at the time were books about Mars. I knew there were sceptics, and I knew their arguments about broken details being joined up by the eye. One version, called by Percival Lowell the 'small-boy theory', was based on experiments done at the Royal Hospital School under the supervision of Edward W. Maunder and J. E. Evans.[3] But they had as little effect on me as the arguments of sceptics against religion to the true believer.

At that moment, my religion was astronomy, and I was a particular devotee in the temple of the planet Mars. Men like Giovanni Schiaparelli and Camille Flammarion were high priests. Percival Lowell was the high-high priest.

1.1. *The books of Mars*

Naturally, all the books on Mars I read contained a smattering of Lowell's engaging prose, and I even managed to find, in the central library in Minneapolis, one of Lowell's own books, *The Evolution of Worlds*. I was enthralled, of course, with the burning questions Lowell posed: Is there life on Mars? Intelligent life? Are we, or are we not, alone in the Universe?

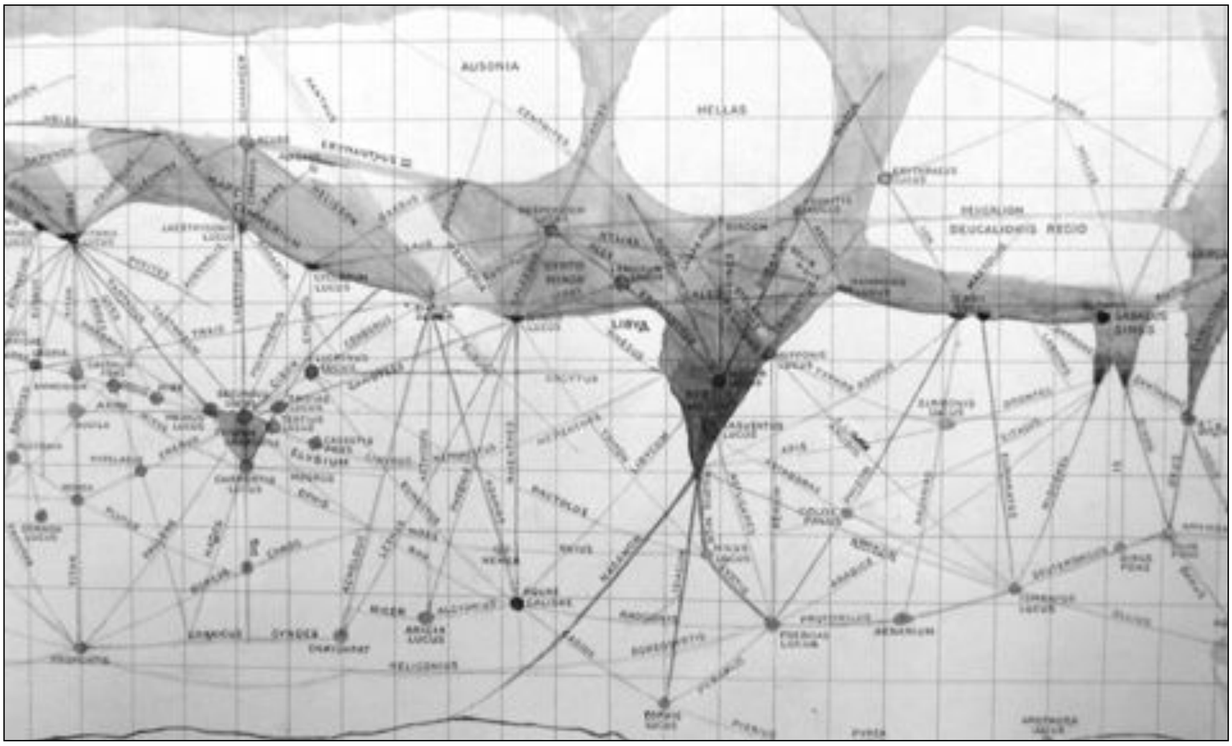
Lowell was an able champion. The objections of the skeptics melted like snow when I read stirring Lowellian stuff such as this:

> There are celestial sights more dazzling, spectacles that inspire more awe, but to the thoughtful observer who is privileged to see them well, there is nothing in the sky so profoundly impressive as these canals of Mars. Fine lines and little gossamer filaments only, cobwebbing the face of the Martian disc, but threads to draw one's mind after them across the millions of miles of intervening void.[4]

I will never forget the impact of those marvellous Mars books on my boyish sensibility. I was far from alone. They, or books derivative of them such as H. G. Wells's *War of the Worlds* or Edgar Rice Burroughs's *Princess of Mars*, had a similar impact on many other readers, at the same slender age. Thus Robert S. Richardson would write of his experiences as a boy growing up in Indiana:

> Lowell's theory of a neighboring world covered by canals and inhabited by intelligent beings can hardly fail to stir the imagination. It sounds, in

Fig. 1: *Detail from one of Percival Lowell's maps of Mars, criss-crossed with the delicate tracery of 'fine lines and little gossamer filaments' that he drew on the planet. (Lowell Observatory)*



addition, so very plausible. I remember the excitement with which I read Lowell's *Mars and Its Canals*. I was about twelve then, and the book made a profound impression upon me. I believed it absolutely. In fact, it was inconceivable to me that anyone could not believe it.[5]

Needless to say, there were no celestial sights I was more eager to see than those same 'fine lines and little gossamer filaments' (Fig. 1). My eye was more acute than it ever would be again: I could see at least 16 Pleiads from within the city limits and made out at least one of the satellites of Jupiter with the naked eye. I could even tell that Venus as it approached inferior conjunction was elongated not round, although I never saw the crescent as such, and doubt whether anyone can. I obviously had no chance at the canals with my 60-mm department-store refractor but I could participate vicariously by reading of others' exploits.

1.2. *Science as story*

Lowell himself attempted to appeal to his readers through the dramatic and personal way he presented his work, as his biographer David Strauss points out. 'No doubt,' says Strauss, 'his enthusiasm for the literary romances of Robert Louis Stevenson played an important role in Lowell's conceiving of science as a story that could… rival the adventures recounted in novels. Lowell's books thus appealed to the audience of men and boys who sought in literature, as in life, male heroes with whom they could identify.'[6]

Even though I hadn't yet seen the canals, Lowell had done so, and described the seeing so vividly that readers such as myself 'experienced a vicarious sense of participation through identification with the narrator or hero. Lowell insisted, for example, on the importance of the scientist writing about his own discoveries, to provide the reader with "an aroma of actuality" that would in turn make him a "co-discoverer".'[7]

2. Fine lines and little filaments

It was in consideration of the canals that I first came to appreciate just how much there is to 'seeing, and telling what one saw in a plain way', that Ruskin had waxed about in *Modern Painters*. This whole business of the intricacies of seeing has, in fact, become the overriding theme of all my work as a historian of astronomy. It has also informed, in significant ways, my professional work as a psychiatrist.

The first thing one notices about the canals is that they never appear clearly and all at once as one might imagine from examining the maps or globes that show them. Instead they show up fleetingly, and in glimpses. Here, for instance, is Percival Lowell's own classic description, from *Mars and Its Canals*:

When a fairly acute-eyed observer sets himself to scan the telescopic disk of the planet in steady air, he will, after noting the dazzling contour of the white polar cap and the sharp outlines of the blue-green seas, of a sudden be made aware of a vision as of thread stretched somewhere from the blue-green across the orange areas of the disk. Gone as quickly as it came he will instinctively doubt his own eyesight, and credit to illusion what can so unaccountably disappear. Gaze as hard as he will, no power of his can recall it, when, with the same starting abruptness, the thing stands before his eyes again. Convinced, after three or four such showings, that the vision is real, he will still be left wondering what and where it was. For so short and sudden are its appearances that the locating of it is dubiously hard. It is gone each time before one has got its bearings.

By persistent watch, however, for the best instants of definition, backed by the knowledge of what he is to see, he will find its comings more frequent, more certain and more detailed. At last some particularly propitious moment will disclose its relation to well known points and its position be assured. First one such thread and then another will make its presence evident; and then he will note that each always appears in place. Repetition *in situ* will convince him that these strange visitants are as real as the main markings, and are as permanent as they.[8]

2.1. *A microscopist at the telescope*

Lowell's friend Edward Sylvester Morse, whose lectures on Japan had first inspired Lowell's interest in and travels to the Far East that preceded his Mars obsession, spent nearly six weeks observing Mars on every clear night with the 24-inch (61-cm) Clark refractor around the time of its 1905 May opposition. No one has described better the process of learning to see the surface details on Mars than Morse in *Mars and Its Mystery* (1906). Although Morse was a microscopist by training, he was naive about matters Martian and struggled to get his bearings, as do all observers when they first try to come to terms with the subtle variegations of the Martian disk:

For years I had been familiar with different representations of Mars in which the surface features had been strongly depicted in black and white; in other words, photo-reliefs, or engravings incorporated with the printed page. I had unwittingly come to believe that these features were equally distinct when one observed Mars through the telescope… For a long time I had hoped for a chance to observe Mars through a large telescope in a clear and steady atmosphere. It seemed reasonable to me − knowing nothing about it − that one who had traced out under the microscope delicate lines and structural features in diaphanous membranes, who had, in fact, used a microscope with high powers for forty years,

> would find it child's play to make out the canals, oases, regions, etc., of Mars, as represented in the various publications on the subject. Professor Percival Lowell finally gave me the opportunity I so much desired… Imagine my surprise and chagrin when I first saw the beautiful disk of Mars through this superb telescope. Not a line! Not a marking! The object I saw could only be compared in appearance to the open mouth of a crucible filled with molten gold. Slight discolorations here and there and evanescent areas outlined for a tenth of a second, but not a determinate line or spot to be seen.[9]

On recalling, however, his own slow progress in learning to see details through the microscope, and also taking heart from a comment by the great British amateur A. Stanley Williams that he had had to observe continually for two months before he was sensitized to making out the more delicate markings on Mars, Morse gradually grew into the work, and before long was achieving results of interest:

> May 14. Midnight. Saw planet for the first time. A beautiful luminous disk with shades of tone dimly visible. Southern pole cap white and seen.
>
> May 15. Certain details sufficiently distinct to make out dark areas, and at times a line or two.
>
> May 16. Occasional flashes of a few lines, while broad darkened area and cuneiform area on right visible, and, in one flash, a line supporting the wedge as well as basal line… I saw enough to make my first drawing.
>
> May 20. Mr. Lowell informed me this morning that the luminous appearance around the south pole that I saw last night was the result of a snowstorm. Seeing fair. Considerable vibration of planet. Saw new snow field of the northern pole distinctly outlined and much confused markings. Looked in vain for spots but could not discern them.
>
> May 21. Seeing clearer, and for the first time I made out distinctly two spots, or oases. Mr. Lowell informed me that Schiaparelli had never seen them. The snow which fell on May 19 was still conspicuous.
>
> May 24. Am in despair of seeing anything when the others see so much. I must have an old and worn-out retina. In looking, lines flash out at times but it is impossible to locate them. I can certainly see more than Huyghens did, but not much more.
>
> May 30. To-night markings and more particularly shades seemed abundant yet so evanescent that only an intimate knowledge by long study could define them. I gave up in despair.
>
> May 31. Saw a little more than I saw last night but did not see a trace of things that Mr. Lowell and his assistants apparently saw without effort. I realize that it requires a special training to observe the flickering evanescent markings on Mars.
>
> June 5. I find a slow advance in my ability to see the markings though it is exasperating that the janitor of the Observatory [Harry Hussey] talks about plainly seeing certain details which he indicates to me by a sketch, and looking at the region I can see no trace of a canal or anything else.
>
> June 7. Seeing very good and in my observations tonight added another canal. It is a most difficult matter to catch the fleeting lines as they appear with startling distinctness to instantly vanish again.
>
> June 9. Seeing fairly good. Could make out but little more. Color of regions very strong and vivid.
>
> June 10. Seeing a little better than last night. Added three new canals, and these canals flashed out three or four times before I was willing to record them, and then I did not believe them till Mr. Lowell showed me a drawing he had made just before, and the two drawings corresponded.
>
> June 12. Rather poor seeing though some of the dark regions came out with remarkable distinctness. Every day I notice a very slight improvement in detecting lines. Markings formerly made out with great difficulty are now instantly recognized.
>
> June 13. In my observations to-night added one new canal and completed another, and was able to detect one that Mr. Lowell had not seen during the evening – a well-known one he says. It simply shows that one must continually observe as the lines flash out for a single instant.[10]

2.2. *Mars through the 100-inch*

Another case was Robert S. Richardson. A native of rural Indiana who was almost hired for the job at Lowell Observatory that went to the self-taught and (in the view of V. M. Slipher) more tractable Clyde Tombaugh, Richardson became a professional solar astronomer at Mt Wilson Observatory. He also became a prolific writer of popular astronomy books, science-fiction stories (under the pseudonym Philip Latham), and a celebrity astronomer at Griffith Observatory in Los Angeles.

Richardson wrote in *Exploring Mars* (1954): 'One of the things I hope to do before I die is to see the canals clearly and sharply, as Schiaparelli and Lowell saw them.' At the time he wrote this he had not done so, although he had a seemingly excellent chance in 1941 October when, with Mars at a better-than-average opposition, he had the opportunity to look at the planet through a series of telescopes, each bigger than the last. The first was a 6-inch, the last the 100-inch Hooker reflector:

> I had been on Mount Wilson taking observations of the sun, which left me free at night to look at Mars with a 6-inch telescope not otherwise in use.

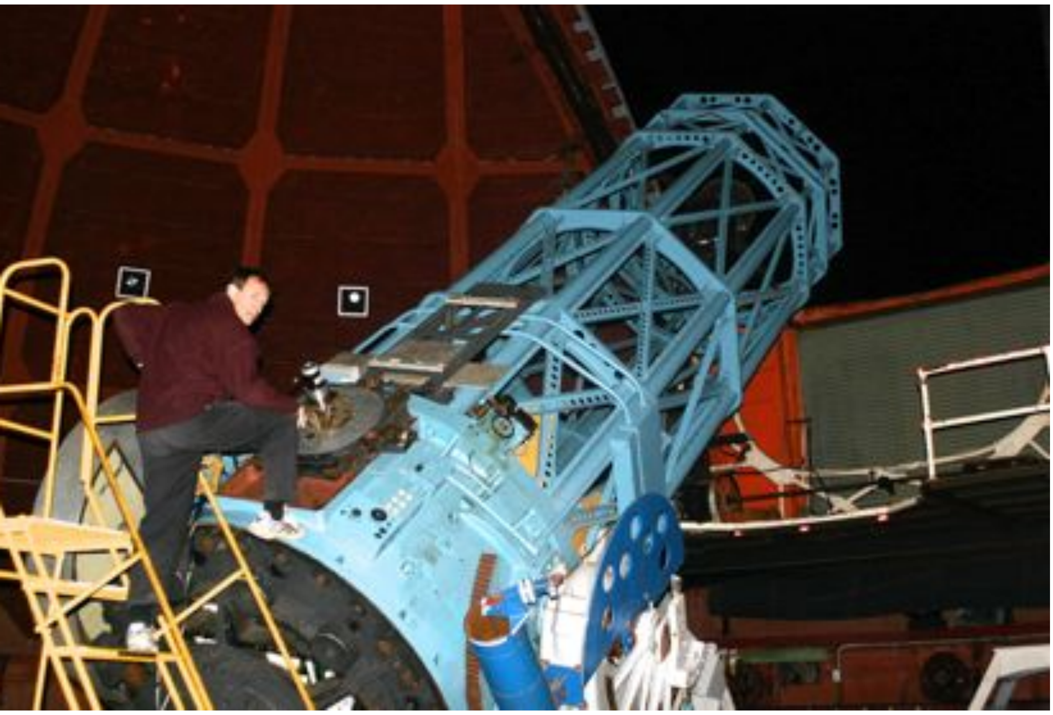


Fig. 2: *William Sheehan observing Mars at the modified Cassegrain focus of the Mt Wilson 60-inch reflector in 2005 October. Observing through the same telescope in 1911, E. E. Barnard described the planet as follows: 'There was a slight pinkish color on which the dark details had been painted with a grayish colored paint, supplied with a very poor brush, producing a shredded or streaky and wispy effect in the darkish regions.' (Photo by John Fletcher)*

> Every evening the seeing had been so poor that only the more prominent markings could be made out, to say nothing of such fine details as the canals. But on this evening I knew the instant I put my eye to the telescope that things were going to be different… I tried a magnification of about five hundred, and found the image still reasonably steady. Occasionally there would come flashes of fine seeing that made one gasp, but still nothing linelike. But I felt it was there, just below the threshold of visibility, and would be visible only if I had a larger telescope.[11]

Richardson next looked at Mars with a rather unusual instrument: the 12-inch lens at the top of the 60-foot solar tower. Still no canals! Next he managed to wangle time at the Newtonian focus of the 60-inch reflector, the masterpiece of George Willis Ritchey, a compact and powerful instrument I have had the opportunity to use myself, and to whose excellence I can testify (Fig. 2). Mars was 'a beautiful sight – an exquisite little pink-and-green globe with a bright polar cap'. Still there were no canals.

Finally, through the courtesy of Walter Baade, out for a smoke and a stroll while waiting for his extragalactic quarry, NGC 1285 in Eridanus, to rise, Richardson found himself seated in the observing cage of the famous 100-inch Hooker reflector. Surely now success? Hardly: 'Through the 100-inch the markings looked more hopeless than ever.' Richardson concluded that with each increase in aperture the canals 'seemed as far away as before'.

Perhaps, however, Mars was simply too close to the Earth! When Mars was far from opposition in 1954, Richardson reported seeing a network of 'bluish veins', which he identified with the canals.

3. Seeing red and blue

Mediterraneans… creep
Far into red hearts of continent
In landlocked peace to drop asleep;
Continents that lie content
By bluish arms of the winding deep…

Percival Lowell, unpublished poem, *Mars* (probably 1894 May/June)[12]

It is important to remind ourselves that the Martian canals did not appear in isolation. Moreover, for reasons I shall explain, it is unlikely they would have produced much of a stir had they been recorded on Mercury, Venus, or the satellites of Jupiter (as indeed they were; Lowell and his Flagstaff colleagues did record linear markings on all these bodies, yet no one paid much heed). It was only on Mars that one of the most curious psycho-sociological phenomena in the history of science could grow.

An important ingredient in all this is the very colour of Mars. It is the Red One, one of the few conspicuously red objects in the sky. At times its redness can be striking, although not equally so to all observers.

The varying degree of apparent redness is quite real. This is a consequence of the eccentricity of the planet's orbit, which makes its brightness fifty times greater when it is nearest to us than when it is at its most distant. When at its brightest – as in 2003 – it outshines Jupiter, and appears quite white, owing to saturation of the colour receptors of the eye. At not quite maximum brightness, as at the typical opposition, it appears wheat-coloured; at its faintest, it is a blood-red spark. (I would add that the reddishness is likely to be more vivid to children and younger individuals, since the lens of the eye has not yet yellowed with age as it inevitably does.)

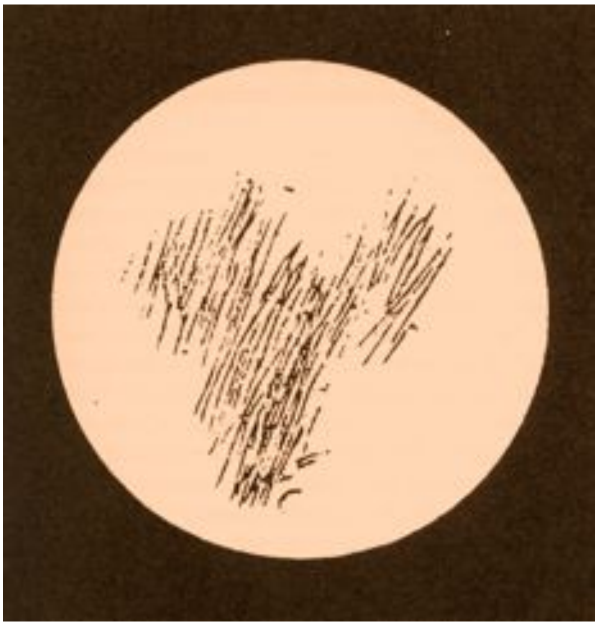
Red is the colour that most strongly seizes the attention and evokes the strongest emotional response. In fact, I would venture to say that were Mars not the Red Planet, its place in human imagination would not have loomed so large.

Through a telescope, as the disk is enlarged, the red fades into a more nuanced salmon-pink, and darker forms appear against the lighter background. As noted by Martha Evans Martins in *The Way of the Planets*, 'Seen through a telescope, Mars is not so red as it appears to the naked eye'.[13] As the darker forms shown crudely in Huygens's sketch begin to emerge (Fig. 3), other colours emerge with them, forming a more complex − and even more enticing and evocative − palette. The planet then resembles, in the different aspects presented to different observers, a 'fire opal'.

3.1. *The eye of the beholder*

Most of us soon learn that colour lies in the observer, rather than out there in the light. Neuroscientists have now worked out that the brain specializes in the detection of contrast. This, according to Stephen Macknik and Susana Martinez-Conde of the Barrow Neurological Institute in Phoenix, Arizona, 'forms the basis of all cognition, including your capacity to see, hear, feel, think, and pay attention. Without it, the world would have no boundaries and your brain could make no sense of itself or anything outside itself'.[14] Magicians recognize this, and capitalize on contrast detection in the illusion called Black Art. Explanations are needed to decode phenomena, and with changes of context a phenomenon may be seen in a quite different light.[15] Although context gives meaning, it can also mislead into illusions.

Fig. 3: *Huygens's view of Mars, 1659 November 18. From Camille Flammarion, La Planète Mars, vol. 1 (1892).*



When we see colours, we are sensing how information about wavelength varies across the image, but we will see nothing except where there are boundaries. Thus colours, too, depend on context. Seen against a red background, a neutral patch will assume its complementary colour, green (or blue-green), the phenomenon known as simultaneous contrast. This was first recognized by the French chemist Michel Eugène Chevreul at the Gobelins tapestry factory in Paris, as described in his book *The Principle of Harmony and Contrast of Colours, and their Application to the Arts* (1839). Soon after Chevreul discovered this, it was being applied to good effect by the Impressionists in their paintings.[16]

The context-dependence of colours makes the colours of a planet seen against a black surrounding even trickier. Such colours correspond to what is referred to as 'aperture' or 'film' mode (with no grey content), and are not what would be seen when standing beside the planet, with familiar objects available for context. Thus, as seen in the eyepiece, the Moon, although it is actually as dark as the average asphalt paving surface, appears bone-white. Mars, whose actual surface materials are dirty yellowish-brown, looks yellowish-orange or, as often described, ochre.

The dark areas of Mars consist of surface materials of similar hue but differing reflectivity and saturation. If we were actually standing on the surface of the planet everything would appear different degrees of brown, but in the eyepiece the 'unrelated' colours tend to expand to fill the colour space.[17] Apparently what is happening is that the visual system turns up the gain on the chroma when presented with a scene of very limited colour gamut. This, by the way, also plays a part in Edwin Land's well-known demonstration of producing a wide colour gamut from a scene that really just contains various shades of pink − an extreme example of the phenomenon made use of in the old colour movies shot in two rather than three colours, which used to be known as 'Tru-Color' Westerns. Similarly, Mars has been a kind of Tru-Color Western for visual observers.

3.2. *Blues for a red planet*

The blues and greens of the dark areas of Mars were noted by visual observers beginning with John Herschel in 1830 and reinforced a much older, perhaps unconscious, analogy between the markings on the disk and the lands and oceans of Earth. The blues and greens appear conspicuously in the first colour drawings and maps of the planet, as in the great map by John Phillips made in 1862–64 at Oxford[18] (Fig. 4).

The gifted English landscape painter and amateur astronomer Nathaniel Everett Green, using a 9-inch (23-cm) reflector at the opposition of 1873, produced a marvellous set of colour drawings of Mars (Fig. 5). This

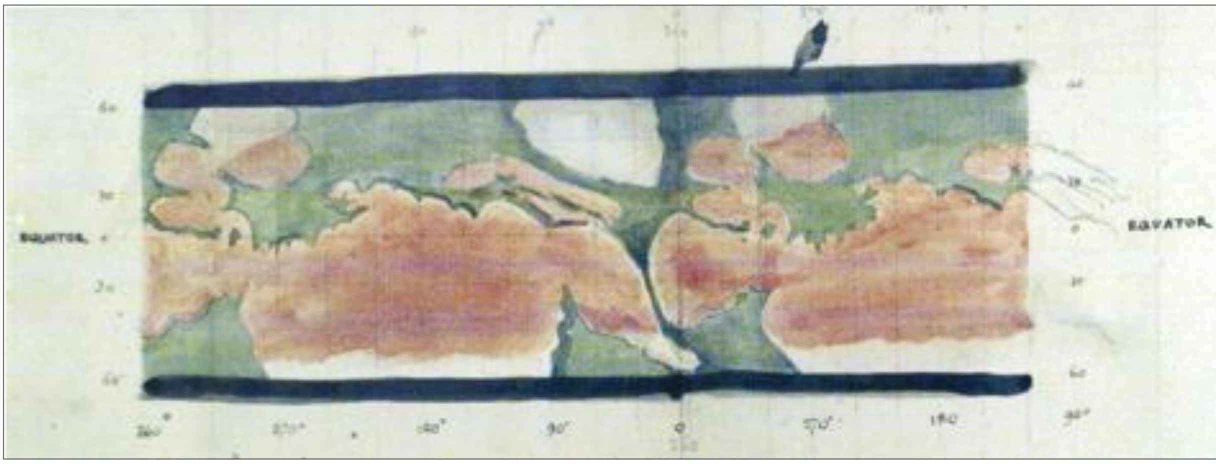
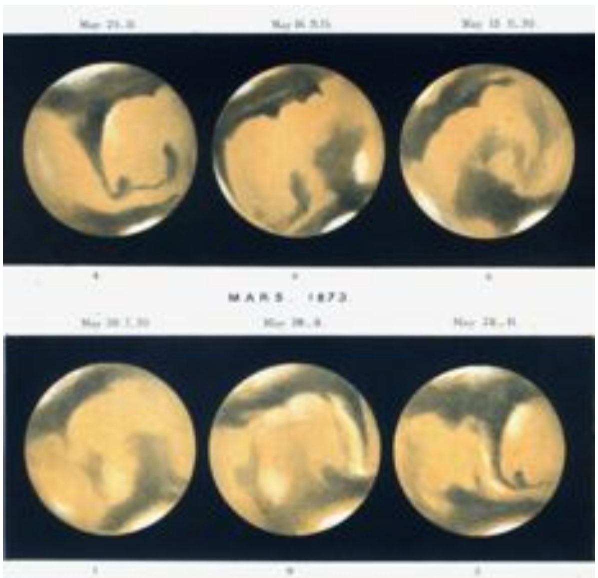


Fig. 4: *John Phillips's map of Mars, made from observations in 1862 and 1864 with a 6-inch Cooke refractor at the small observatory near the Museum of Natural History, Oxford. (Courtesy Roger Hutchins and Oxford University Museum of Natural History)*

artist-astronomer made even more remarkable drawings and a full-fledged map with a 13-inch (33-cm) reflector at Madeira at the great perihelic opposition of 1877 (Fig. 6). He had pointed out in 1873, 'With regard to the dark markings of this planet, they are generally considered to be oceans,' but in 1877 he added that the markings 'supposed to be water' actually appeared as various shades of greenish-grey and, artist that he was, fully recognized that these tints did not necessarily betray an aquatic nature but must be at least 'partly due to contrast with orange'.[19] (He was prudent to say 'partly', for sometimes the blues are very striking, and in fact are quite real.)

Over the years, observers have described the light areas of Mars as coral, salmon, orange-pink, reddish-yellow, red sandstone, and so on. Obviously, colour effects are exquisitely sensitive to seeing conditions, the telescope's aperture, the size of the disk, the Martian season (especially the presence or not of dust in the Martian atmosphere) and the personal equation. The looming effect of the latter is well-attested in the way that Green's great study of Mars was countered, at the same opposition of 1877 by the equally great study by the Italian astronomer Schiaparelli.

Fig. 5: *Nathaniel Green's drawings of Mars made in 1873 May through a 9-inch reflector with powers of ×200 to ×400 and published in The Astronomical Register. (Courtesy Richard McKim)*



4. Picture or plan?

Schiaparelli was, in contrast to Green, a professional astronomer. He had been well-trained by Encke at the Berlin Observatory and Struve at the Pulkovo Observatory. By the time of the 1877 opposition of Mars, he was already famous for his demonstration that the Perseid and Leonid meteor streams followed in the orbits of known comets. He was Director of the Royal Observatory of Brera in Milan, expert in the use of the micrometer for double-star observations, and (possibly relevant in the current context), a deuteranope, i.e. a sufferer from red–green colour blindness. Some of Schiaparelli's drawings of Mars can be seen in Fig. 7.

A comparison of Green's and Schiaparelli's drawings illustrates the 'personal equations' of the individuals better than any amount of description possibly could. Regarding the personal equation, the great American astronomer Henry Norris Russell wrote:

> Between the entrance of light into an observer's eye and his record of his observation, whatever this may be, intervenes a process of extreme complexity going on in the recesses of the brain, which we can follow only with difficulty, and mainly by its effects. In so simple a case as that when a man merely presses a telegraph key to record the time when he sees a thing happen one may be two or three tenths of a second ahead of another – not once, or by chance, but again and again – by almost the same amount. One man's nervous system works slowly, while his neighbor, perhaps,

Fig. 6: *Nathaniel Green's map of Mars, compiled from observations made at Madeira in 1877 and published in the Memoirs of the RAS in 1879. Green noted on the chart: 'The details of this chart have been compared with views of the planet by Schiaparelli, Trouvelot, Terby, De La Rue, Lockyer, Knobel, Christie, Maunder, Brett, Dreyer, and others. No form is introduced that has not been confirmed by the drawings of at least three observers.' (Courtesy Richard McKim)*

> anticipates the event. In the far more complex case of observations of planetary details, concerning which all observers agree that they can be seen only in the best moments for a few seconds at a time, similar principles are doubtless to be applied.[20]

Something of Green's general approach to extraterrestrial landscapes can be gleaned from his approach to terrestrial ones. An art reference book notes that he was 'an astronomer and landscape painter who studied at the Royal Academy Schools and exhibited from 1854. His work is pleasant, if lacking in detail, and he is fond of greens.'[21] In his own work, *Hints on Sketching from Nature*, where he emphasizes the importance of concentrating the attention upon a part of any general scene, Green insists:

> Yet, even when a small part has been selected for study, it will be found impossible to copy the whole of its details. Infinity is stamped upon every portion of nature – an infinity utterly beyond the power of the eye to follow, or the hand to imitate. Since it is so, our aim in sketching should be to suggest rather than to realize. From the first choice of the scene to the smallest mark of expressive character… judicious selection is the general principle upon which sketching must proceed.[22]

How different was the approach of his Italian counterpart. Desiring only to see whether the Brera Observatory's new 8.6-inch (22-cm) Merz refractor, 'which had given such good performances on double stars, possessed the necessary optical qualities to permit the study of the surfaces of the planets', and finding the result quite satisfactory, Schiaparelli determined to produce a map of the Martian surface detail. Green's instruments had been the sketchbook and the brush, Schiaparelli's the micrometer and the pencil. As he said,

> My basic plan was to describe the planet, not by making disc drawings or portraits of Mars based on eye estimates only, but by relying thoroughly on geometric methods. To this end I have first determined… the direction of the axis of rotation and the position of the south polar cap. In like manner I have measured micrometrically on the surface of Mars a certain number of fundamental points, from which to deduce the areographic coordinates of latitude and longitude. From these last, the topographical description of the regions in between can be inferred without too much uncertainty from the sketches, precisely in the way that a geographer finishes the description of a country on Earth by interpolating between the geometrically determined points.[23]

The landscape painter had produced a picture, the astronomer a plan. Hard as the different aspects were to reconcile, each captured part of the truth. The one was Mars from a left-hemisphere of the brain point of view, the other from a right-hemisphere perspective.

4.1. *The colour-blind astronomer*

In addition to the more marked features, the colour-blind astronomer, uniquely sensitive to slight nuances in the shadings on the Martian disk and thoroughly trained in the use of the micrometer, made out the delicate markings he represented schematically as the tracery of *canali*. 'As a record of fleeting impressions,' Antoniadi was to say, 'Schiaparelli's stands unrivalled.'

Green, on the other hand, had produced a dreamy landscape where, as with his terrestrial ones, only the main effects were given. This was consistent with what he had urged on the novice in *Sketching from Nature*. The pleasure of an outline was to be derived from the 'harmony' of general impressions, the subject was never to be bounded by the 'arbitrary line' but ought rather to shade imperceptibly into the 'region of indistinct vision'.[24]

That these two different, complementary points of view, appeared at the outset of the modern era of Mars observations is remarkable enough, and it also raises the interesting question − psychological or sociological − why the one view (Schiaparelli's) should have come to achieve dominance over the other (Green's) from the 1890s through the 1910s.

One was that Schiaparelli's map was more easily imitated. To copy an outline map required only modest artistic skill. Further, the nature of the instruments in use (mostly small refractors), combined with the canals' ability to command the selective attention of so many observers on the basis of hard facts of the physiology of vision, helps account for the near-universal appearance of tessellated maps during these years.

However, so dominant did the Schiaparellian paradigm become that even Green, near the end of his life, seems to have acquiesced to the existence of the general class of markings, perhaps because by then so many BAA members were drawing the canals. Even so, in his Presidential Address to the BAA in 1897, he still urged adoption of the term *channel* instead of *canal*.[25] By then, however, Percival Lowell had become the dominant figure on the Martian scene. Distinctions like Green's were going by the board, and the spider-webs were sweeping all before them.

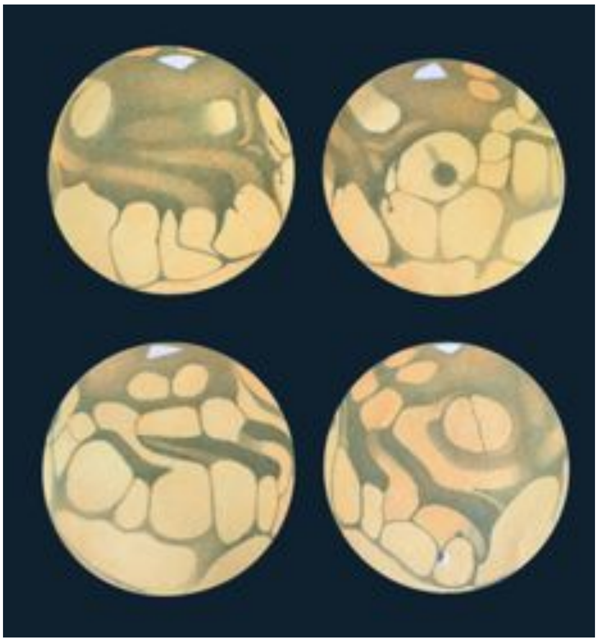


Fig. 7: *Four faces of Mars (longitudes 0°, 90°, 180°, and 270°), drawn by Giovanni Schiaparelli at Brera Observatory, Milan, from observations made 1877 September to 1878 March, and published in his first Memoir on the planet (1878).*

5. What spring is like on Mars

Whereas Schiaparelli's descriptions of Mars, given in his technical *Memoirs* (of which only the first, published in 1878, has been translated into English), are clinical and colourless, Percival Lowell's colourful prose found a fitting subject in the vividly coloured Martian disk. In 1894, his first season of observing at Flagstaff, he used a borrowed 18-inch (46-cm) Brashear refractor. (It is now in New Zealand, but remains in boxes and crates, as I found when I caught up with it in 1999.) Here are some notes from Lowell's observing log books:

> June 2. None of the dark parts really darker than a gray.
>
> Hellas and southern Ausonia one continuous rosy-orange band, distinct but fainter than equatorial continent. The rosy-orange tint of the land much more striking than the green-gray of the shaded parts.
>
> June 7. Nothing visible except pale-green tint of seas and orange of lands.
>
> June 9. Colors superb: brilliant rose-orange and livid [or vivid?] bluish green.
>
> June 15. Color of seas changed from green to blue with the dawn. Have previously noticed the change of color of the continental areas from rosy-orange to rosy-red on similar occasions of the turning of night into day. Our daylight, therefore, adds bluish light.
>
> June 20. It is worth noting again how faintly differentiated are the dark markings from the light all over the planet.
>
> [Lowell absent in Boston all of July and into late August]
>
> August 20. Colors beautiful: continent and island S[outh] rose-orange, seas blue.
>
> Cimmerium Sea greenish blue all over.
>
> August 22. Colors of the planet those of fire-opal.
>
> August 24. N[orth] region intense green.

Lowell's impressions were summed up as follows. In June, the high southern latitude containing the two Thyles and Argyre II were blue-green; by October, he found the same region yellowish. There were also numerous changes in smaller details. What it all added up to was, he claimed, 'a whole-sale transformation of the blue-green regions into orange-ochre ones… in progress upon that other world'. In October and November, 'Hesperia and all other markings [were] much fainter than at August presentation'. He added: 'The whole amount of the blue-green had diminished, and that of the orange ochre had proportionately increased.' Thus, 'Mars looked more Martian in November than he had in June.'[26]

5.1. *A matter of tone*

These changes, dramatic as they sound, were evidently less of tint than of tone (Fig. 8). Lowell would admit this in *Mars and Its Canals:* 'Usually the change in hue seems essentially to be one of tone; the blue-green fades out, getting less and less pronounced, until in extreme cases only ochre is left behind. It acts as if the darker color were superimposed upon the lighter and could be to a greater or less extent removed. This is what was seen in 1894 at Flagstaff.' [27]

During that first season of observing, Lowell had grown convinced that the blue-greenish dark areas were not seas, as had been supposed, but tracts of vegetation. He subsequently argued that the changes of tint occurred as these tracts were transformed from spring verdure to autumn sere – although it should be pointed out that this deduction rested on a hazardous extrapolation from the state of affairs on our aqueous globe, where photosynthesis is carried out by green plants which contain the green pigment chlorophyll.

The main forms of chlorophyll, chlorophylls a and b, have very strong absorption bands in the violet and red parts of the spectrum, but absorb very little in the yellow and green – hence plants look yellow-green. But a chlorophyll molecule with a different profile of absorption might equally well have been seized on by natural selection, in which case we might now have red meadows, brown glades, and purple fields, as in fact the French astronomer Camille Flammarion proposed; he thought the reddish colouring of Mars was due to the presence there of red vegetation, which was a perfectly reasonable supposition.

Lowell, with his eye for colour, was far from a singular case. The man who would become his canal nemesis, E. M. Antoniadi, not only confirmed the basic Lowellian colour scene but embellished it. As he wrote in 1924, 'Not only the green areas but also the greyish or blue surfaces turned under my eyes to brown, lilac-brown, or even carmine… It was almost exactly the colour of leaves which fall seasonally from trees in summer and autumn in our latitudes.'[28] Although he vehemently disputed Lowell's observations and theories about the canals, Antoniadi never doubted that Mars was the abode of abundant vegetative life – of the usual terrestrial (green-pigment chlorophyll) kind, apparently.

5.2. *Grand illusions*

The underlying basis in the colour changes was partly that the markings on Mars are variable, being frequently obscured by yellowish clouds, regional tempests, and even, from time to time, planet-encircling or global dust storms, which have been painstakingly culled from the historical record by Richard McKim.

The earliest planet-circling storm, as McKim and I found in 2009 during a visit to the Paris Observatory, was documented by E. L. Trouvelot, using only a 6-inch refractor at Cambridge, Massachusetts, in the grand Martian year of 1877. Trouvelot, a skilful artist who had begun observing Mars months before Green or Schiaparelli, produced a superb record of a storm that became planet-circling in scope; however, it died out just before Green's and Schiaparelli's observations began.

Obviously, dust strewn around the planet will alter the contrast between different albedo regions and, in combination with the complementary colour effects described above, suffices to explain how the Martian features could vary in tint, intensity, and hue. Darker tints would appear bluer and greener, fainter ones brownish or yellow. Like the colours themselves, the apparent seasonal changes were – at least partly – a grand illusion.

But only partly. The blue color of Syrtis Major can sometimes be very striking, as the author has often noted, and shows up as such even in modern images. The explanation for this lies in the seasonal aphelion cloud belt that straddles the equator. Covering near-equatorial markings such as the Syrtis Major, these white crystal clouds tend to scatter blue light preferentially, causing a bluish tint to the underlying markings in the same way that Rayleigh scattering makes our own sky blue. Around aphelion, it causes Syrtis Major to look more bluish than ever, particularly near the limb, where the optical thickness in the line of

Fig. 8: *Percival Lowell's views of Mars during his first observing season at Flagstaff in 1894, when he used a borrowed 18-inch refractor. The drawings were made on June 7, August 24, and October 30. The October drawing shows evidence of the dust storm that primarily affected Mare Cimmerium, although Lowell interpreted it as seasonal changes of vegetation. (Courtesy Lowell Observatory)*

sight is greater. Thus, the degree of blueness will change with the season as the aphelion cloud belt waxes and wanes, so Lowell's 'robin's egg blue' does have a basis in reality.[29]

Leaving aside the changes in colour for the moment, we suggest that the fading of the dark areas that so impressed Lowell in October–November 1894 was due to the emergence of a regional dust storm. Although Lowell noted the effects he failed to grasp the cause. He wrote: 'Toward the end of October, a strange, and, for observational purposes, a distressing phenomenon took place. What remained of the more southerly dark regions showed a desire to vanish, so completely did those regions proceed to fade in tint throughout. This was first noticeable in the Cimmerium Sea, then in the Sea of the Sirens, and in November in the Mare Erythraeum about the Lake of the Sun.'[30]

According to Lowell's prior belief, however, the fading was due to the autumnal yellowing of the Martian vegetation. He would never admit to major obscurations. Other observers, including Stanley Williams of the BAA and E. E. Barnard at Lick Observatory, produced more assured records that show a large regional dust storm was indeed underway, beginning in either Libya or Northern Ausonia, covering Mare Cimmerium, the southern deserts Ausonia through to Phaethontis (and part of Hellas), and at least thinly over Mare Sirenum, Mare Australe, and Aonius Sinus.[31]

6. Neuroscience interlude

Up to this point, we are still at Schiaparelli's Stage B. We have telescopic Mars, fascinating, alluring, ambiguous. By ambiguous, we mean that from the observer's point of view, the planet's colours and details could potentially be explained by different underlying causes. The dark areas might be oceans, they might be vegetation, or they might be volcanic plateaus scoured of finer dust by seasonal winds (which, as we now know, is the case).

In addition to these coarser features, there are subtle details – again, who could say what they might be? In flashes of seeing they appear line-like. One great observer, Schiaparelli himself, includes them on a map and calls them *canali* (canals). Other observers follow, notably Lowell, Barnard, Antoniadi, etc., with varying results and varying conjectures as to the true state of the Martian world.

It used to be thought that the way the brain builds its models was from the bottom up, through the amassing of low-level cues supplied by line-detectors, edge-maps, and so on. Recently, the concept of the 'predictive' or 'Bayesian' brain has become fashionable, building on ideas first proposed by the great 19th-century German physiologist Hermann Helmholtz. On this view, perception involves a bi-directional cascade of cortical processing. The brain thus becomes a statistical organ generating hypotheses or 'fantasies' that it then tests (and if necessary corrects) against sensory evidence.

'In other words,' write Brown and Friston, 'the brain is trying to infer the hidden causes and states of the world generating sensory information, using predictions based upon a generative model that includes prior beliefs.'[32] If a percept or inference turns out to be different from the true causes generating the stimuli, the inference is said to be illusory or false.

Lowell's 'prior beliefs' are laid out in rather striking detail in a poem he wrote early in the observing campaign of 1894.[33] Remarkably, he would find only a minimal need to change these prior beliefs from then until his death in 1916. His 'priors' can be summed up as follows:

Mars, being smaller than Earth, had evolved more quickly, and arrived at an advanced state of desiccation. The only significant remaining source of water was in the polar caps, and this water was released with the onset of spring each year. It was inhabited by a dying race which clung to survival by building a system of irrigation canals – the set of features that Schiaparelli had mapped – to distribute water around the planet. As this water sluiced through the system, the dry areas became verdant and productive with vegetation.

Despite Lowell's certainty, Mars remained an ambiguous stimulus. Under the conditions in which he observed the planet, inferences about the true causes of the impressions produced through the eyepiece were necessarily uncertain. Lowell, however, had 'locked in' his prior beliefs early, and managed to explain away, at least to his own satisfaction, any inconsistencies (errors). This was itself a result of his personal equation. He was an obsessive personality, markedly lacking in Negative Capability; he liked things clear-cut and sharply delineated. Ambiguity was something he had little tolerance for.

7. Disambiguation statements

Although Lowell would remain at Schiaparelli's Stage B (the canal stage), other observers during Lowell's lifetime were ascending Schiaparelli's stairway of perception from Stage B to Stage C, and even to the threshold of Stage D.

Before following their progress, let's conclude our comments about Stage B by throwing out a hypothesis of our own: the canal illusion appeared only under certain conditions. Clyde Tombaugh, who observed Mars with the same 24-inch (61-cm) refractor that Lowell himself used from 1896 onwards, noted that the canals were 'as extraordinary as they are puzzling and that he had never seen anything like them on any other planet's disk. He [felt] quite sure that if some of the critics could have seen the canals as he has seen them,

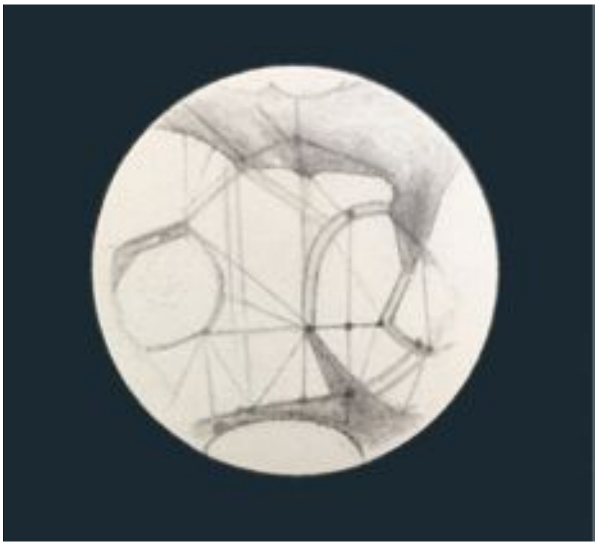


Fig. 9: *Mars 1916 February 10, drawn by Earl C. Slipher using the 24-inch refractor at Lowell Observatory ×400, showing that a skilful observer, under conditions similar to those employed by Lowell, experienced very similar perceptions of 'canals'. (Lowell Observatory)*

they would never have advanced the explanations they have'.[34] Those explanations no doubt included the 'small-boy' theory of Maunder and Evans.

7.1. *Stopping down*

A combination of chromatic aberration of the Clark lens and atmospheric seeing led Lowell to diaphragm his 24-inch refractor to 16 or even 12 inches. He also used relatively low magnifying powers of 310 to 400 times. There were good reasons for these choices. As Clyde Tombaugh wrote to me:

> For best definition the air cells of uniform refraction in front of the telescope should be nearly as large as the aperture used, and the air cells should be about 15 inches across. This was one of the reasons Lowell used 16 inches most of the time. The other was the serious secondary or residual chromatic aberration for the f/16 refractor. Lowell's views were deceiving because he used too low a magnifying power of 310 to 400, and irradiation bled in on the dark stripes, etc., making them appear more narrow than they really were. When I used the same telescope parameters, as Lowell used, I saw the canals much as he drew them![35]

According to Tombaugh, the canals were not irrigation channels so much as irradiation channels − and he would have appreciated the pun.

There can be no disputing his testimony. Despite Mariner 4, whose flyby on 1965 July 14 showed craters but no canals and left at least one 11-year-old boy crushed with disappointment, the canals still exist − and will always exist − in the subjective realm of illusion, making their appearances when Mars is viewed under the right conditions. Thus Lowell, Earl C. Slipher, Tombaugh, and others using the same telescope parameters saw canals (Fig. 9). And I can add myself to the list, since even post-Mariner 4, when I have used the Lowell telescope, stopped down and with the same magnifying powers, I too have had canal-like impressions, in flashes, which startled me at the time.

On the other hand, observers using different telescope parameters, such as E. M. Antoniadi with the 83-cm (32¾-inch) refractor at Meudon, at the still comparatively low magnifications of ×320 to ×540, or E. E. Barnard with the 36-inch (91-cm) refractor at Lick, at ×360 to ×540 (although sometimes as much as ×1000), saw a different Mars.

Lowell and his colleagues chose the best arrangement for showing the blue-green tints and the canals. When Antoniadi, then serving also as Director of the BAA Mars Section, looked into the eyepiece of Meudon's Grand Lunette on 1909 September 20 he saw, as he recounted to his BAA colleagues, an utterly different kind of world unfold (Fig. 10):

> At the first glance… the Director thought he was dreaming and scanning Mars from his outer satellite. The planet revealed a prodigious and bewildering amount of sharp or diffused natural, irregular, detail, all held steadily; and it was at once obvious that the geometrical network of single and double canals discovered by Schiaparelli was a gross illusion.[36]

He was harking back to what E. E. Barnard had said when he was observing Mars from Mt Hamilton, 1100 km west of Flagstaff, with the great 36-inch refractor at Lick Observatory. Barnard obtained splendid views during the summer and autumn of 1894 (Fig. 11), and some of his sketches were made at almost the exact same moments when Lowell was busily sketching the canal system (another case where the personal equation of the two observers can be compared). Barnard wrote to Simon Newcomb on September 11:

> I have been watching and drawing the surface of Mars. It is wonderfully full of detail. There is certainly no question about there being mountains and large greatly elevated plateaus. To save my soul I can't believe in the canals as Schiaparelli draws them. I see details where some of his canals are, but they are not straight lines at all. When best seen these details are very irregular and broken up − that is, some of the regions of his canals; I verily believe − for all the verifications − that the canals as depicted by Schiaparelli are a fallacy and that they will be so proved before many oppositions are past.[37]

7.2. *Observing at Lick Observatory*

Having had the opportunity to view Mars with a range of instruments, from the 60-mm refractor I first used in 1965 to the great telescope Barnard used, I have experienced the gamut of what Huygens, Schiaparelli, Lowell, and Barnard experienced. My best views of Mars were in 2003 and 2005, with the Lick refractor.

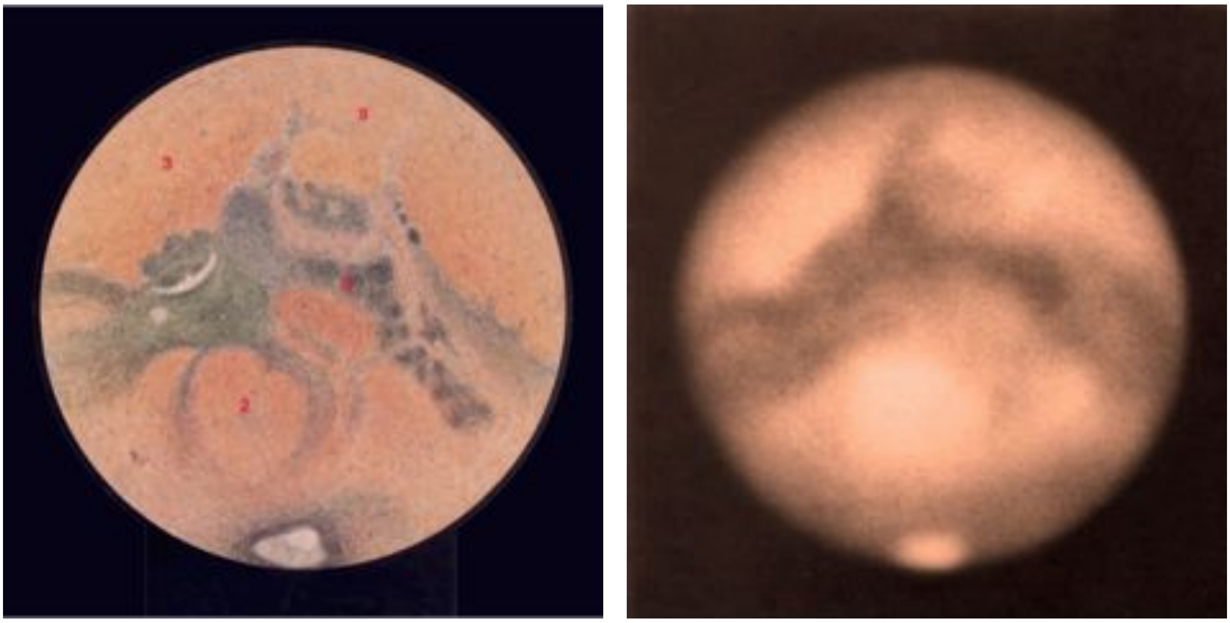


Fig. 10: *Mars drawn on 1909 September 20 by E. M. Antoniadi at Meudon, and a near-simultaneous photograph by E. E. Barnard at Yerkes Observatory, showing general agreement in the representation of the features. (William Sheehan collection)*

As a member of a team including Laurie Hatch, Remington Stone, and Tony Misch in 2003, and with the Japanese Mars observer Masatsugu Minami joining us in 2005, we had, thanks to the kind auspices of Lick Observatory Director-emeritus Donald E. Osterbrock, uninterrupted weeks of telescope time to study the planet, under excellent conditions.

Because of chromatic aberration, we stopped the 36-inch lens usually to 20 inches, and used either a Plössl eyepiece magnifying ×486 or a Plössl binocular eyepiece magnifying ×750. There was a marked advantage to using the binocular eyepiece since, with only a little practice, we succeeded in fusing the images so as to produce a pseudo three-dimensional effect – the planet appeared like a globe suspended in space. Under that circumstance there was a dramatic increase in the eye's ability to resolve detail, not least because of suppression by the brain of such nuisances as 'floaters'. Higher powers were used occasionally up to ×1000.

Two of the observers – Hatch and Misch – were professionally trained artists, but neither had had much experience observing Mars, and were naive about the observational history, even the nomenclature, of the planet. This did not matter in the result. We attempted to approach the subject with something of an artistic temperament, taking as our preceptors Green and John Ruskin, the latter having recommended the would-be artist to:

> Take the commonest, closest, most familiar thing, and strive to draw it verily as you see it. Be sure of this last fact, for otherwise you will find yourself continually drawing, not what you *see*, but what you *know*. Try to draw a bank of grass, with all its blades; or a bush, with all its leaves; and you will soon begin to understand what a universal law of obscurity we live, and perceive that all *distinct* drawing must be bad drawing, and that nothing can be right, till it is unintelligible.[38]

Lowell and the other canalists were on the small-telescope side of the small-versus-large telescope debate of the late 19th century. They used comparatively small telescopes and low powers and seemed to see Mars more distinctly – or at least harder and sharper – than those who used larger telescopes and higher powers. They were also guilty of drawing what they knew. Had Ruskin seen the drawings they produced, he would likely have pronounced them bad drawings, as Green actually did.

7.3. *Artist and astronomer*

I readily admit that my artistic talent is modest, so I cannot really say that my own drawings were good. On the other hand, those by Tony Misch and Laurie Hatch certainly were – perhaps better than any made since Antoniadi's day. Laurie in particular saw the world of Mars as if for the first time (Fig. 12). She was not, however, a naive observer; naive about Mars, perhaps, but as a trained artist, she took her artist's eye and training to the eyepiece and drew Mars as she might a bank of grass, with all its blades; or a bush, with all its leaves.

For that matter, the dome of the Great Refractor became a kind of makeshift artist's studio during the two weeks around Mars's close approach that we were there, with easels and pencils and paints and drop-cloths all around, and many of the professional astronomers couldn't resist desisting briefly from their research to find out what was going on.

I remember in particular Debra Fischer, the accomplished discoverer of exoplanets then at San Francisco

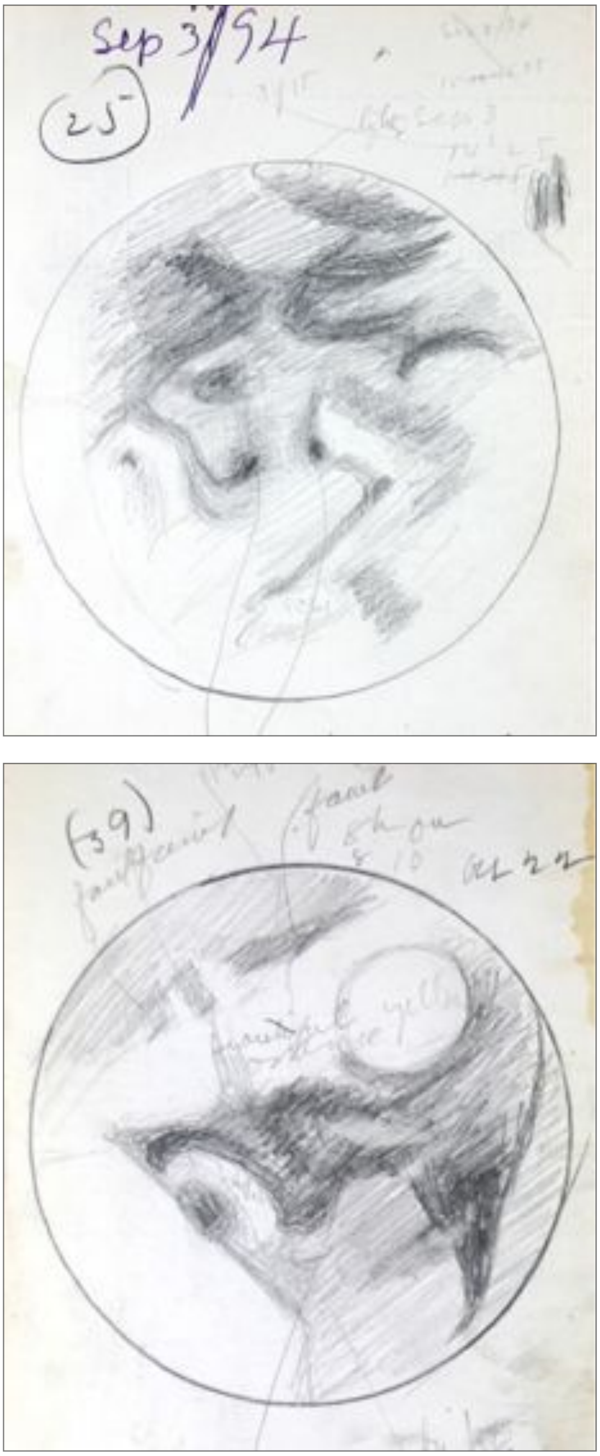


Fig. 11: *Pages from the observing books of E. E. Barnard, containing drawings of Mars made with the Lick 36-inch refractor on 1894 September 3 (top) and October 22. The top image shows the Solis Lacus ('Eye of Mars') region, with Tharsis to the south. Barnard wrote that, despite excellent seeing, 'I have failed to see anything of Schiaparelli's canals as narrow straight lines'.*
The lower drawing shows a regional dust storm in progress, evident in the anomalous appearance of the west end of Mare Cimmerium, with parts of the mare obscured; Barnard scribbled 'beautiful orange' on the drawing. Lowell made observations on the same date which show similar effects, but he failed to grasp that he was seeing an obscuration. (William Sheehan/Lick Observatory)

State University, dropping by with her daughter, who tried her own hand at sketching Mars. We also had the founder of Sun Microsystems and his family up for a visit, as well as many others of the Silicon Valley set. Despite being the most high-tech of the high-tech, they each, to a person, seemed intrigued and even charmed by our old-fashioned methods and results.

After one night of superb viewing, before I dozed off for a few hours in the small room in which I stayed beneath the Shane reflector, I wrote:

> Night after night, for hours on end, the planet appeared as if it had been painted onto the eyepiece. Initially, the region on Mars presented to our view extended from Tharsis through Solis Lacus, across the broad expanse of Mare Erythraeum, to the forked bay, Meridiani Sinus. The colors were subtle, and ranged (on the yellow-brown side of the palette) from dull brownish grey (Hellas), to vivid ochre (Isidis) and pale ochre (Xanthe), to brownish (Arabia); on the cooler side, from blue-green (Syrtis Major) to intensely blue-green (Acidalia) to dull olive-green (Noachis). Evidently these colors – estimated by comparison with Munsell Color System standards – were largely subjective, and when isolated regions were viewed through a small aperture, disappeared, and gave way to a swath of lighter and darker browns. There were some broad streaky markings – for instance, the brightish band between Juventae Fons and Coprates – but nothing truly canal-like. Mare Erythraeum broke into an intricately striped and mottled expanse; along Margaritifer Sinus and Aurorae Sinus a series of round spots hung, pendant-like, and straggled into windblown wispy streaks. The Solis Lacus region presented a remarkable tangle of thready wisps, splotches, and trails. We expended much effort in attempting to delineate the structure at the complex intersection where the Mare Erythraeum, Coprates, and Aurorae Sinus came together. The Coprates-Tithonius Lacus region was heartbreakingly complex; it broke up into tiny fissures, flecks, and spots, corresponding to structures along the intricate Valles Marineris canyon system. All of the desert regions appeared covered with bright knots, pale streaks and other features.

Antoniadi had believed that just such details were the substratum of real features that had produced, under imperfect viewing conditions, the illusion of the canal network. His testimony is not necessarily inconsistent with Tombaugh's:

> My experience in observing the canals is that they do come out in brief flashes (less than a second of time) when larger air-cells of uniform refractive index pass in front of the telescope aperture. These flashes are generally too short to be caught on the photographic plate, which requires a few seconds of exposure.[39]

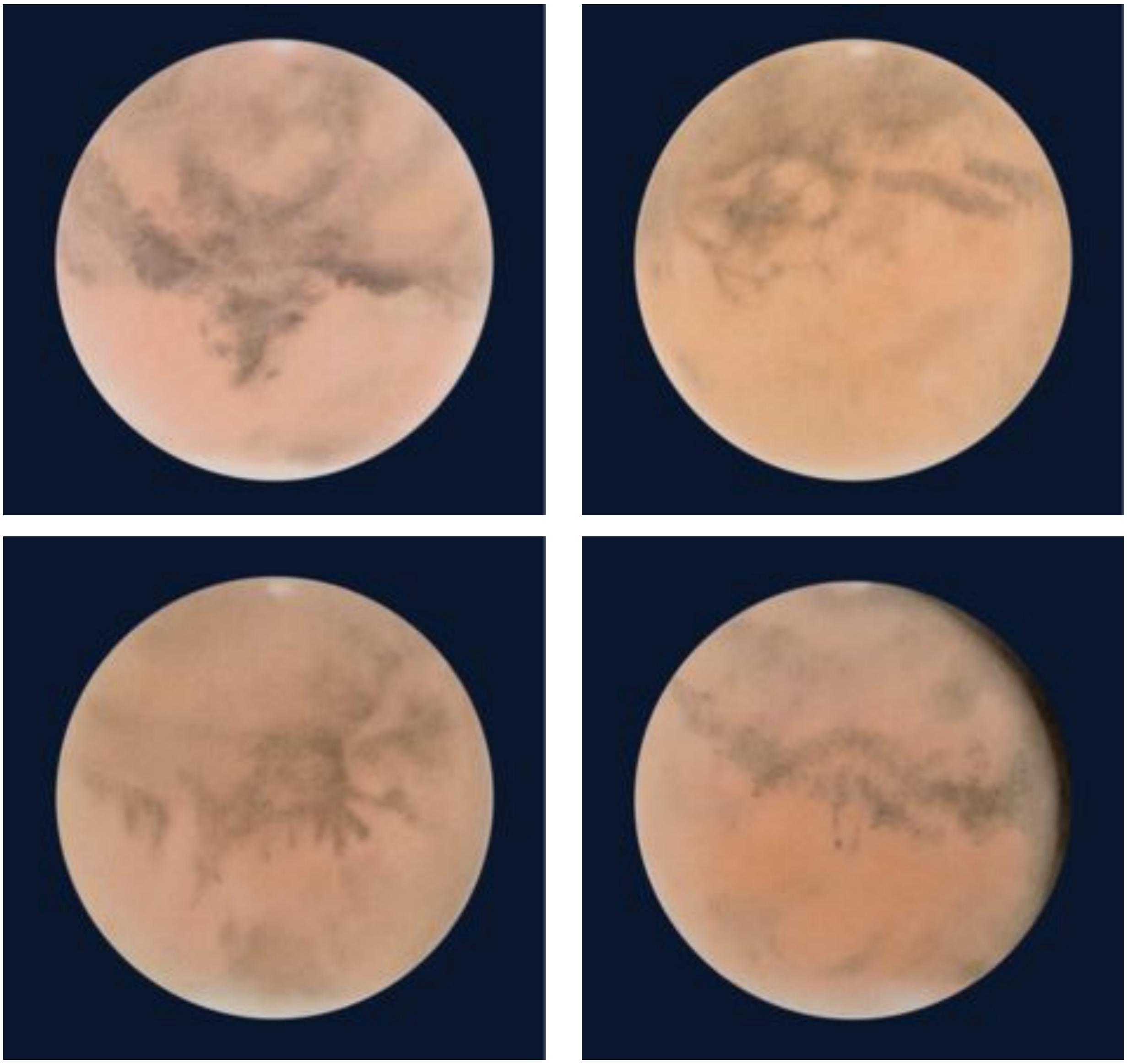


Fig. 12: *Four drawings of Mars by artist Laurie Hatch, made with the 36-inch Lick refractor in 2005 using a binocular eyepiece magnifying ×750. At upper left (November 1) Syrtis Major is at the centre of the disk. At upper right (November 18) the Solis Lacus region is shown. The lower left (November 28) shows Mare Erythraeum and Margaritifer Sinus, while at lower right (December 15) Mare Cimmerium and Mare Sirenum cut a swath above the center of the planet. The dark areas were greatly broken up, with subtle details in the deserts, but under these conditions of observation the features appeared completely natural, with no hint of a canal. (Laurie Hatch)*

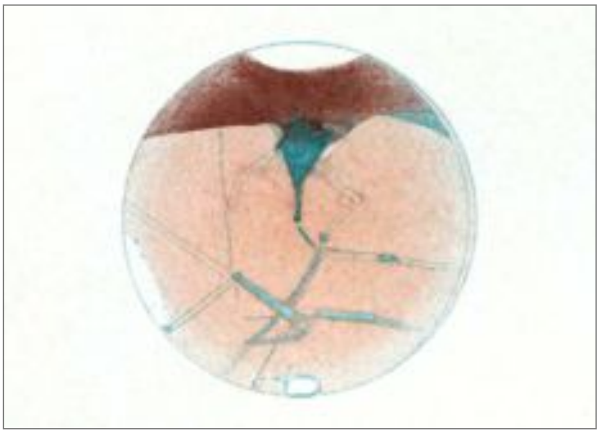
8. The tachistoscope effect

Tombaugh mentions the 'brief flashes' in which the canals appeared (less than a second of time). Many years ago I referred to this as the *tachistoscope effect*, and the term has caught on.[40] Generally, observers who saw canals reported their tendency to come and go in such brief flashes. This is another clue to the nature of the canal illusion.

Illusory the canals surely were. But Mars is the master illusionist among the planets. R. L. Gregory, the great British authority on perception, has written: 'Illusions are discrepancies from truths. All kinds of perceptions are subject to illusions, but generally they are unnoticed, except when there are marked internal inconsistencies, or clear departures from what is believed to be true.'[41]

In Lowell's day, the illusory character of the canals was not obvious, since the canals fitted so well with the world of vegetation and inhabitants that Lowell believed in and made so compelling for others to believe. But, as Gregory adds, 'Though beliefs largely determine what is accepted as true... conceptual understanding seldom destroys perceptual illusions [because] perceptions and conceptions are remarkably separate in the brain, and so we continue to experience illusions though they are recognized as such, and even explained.'[42]

Even in the aftermath of all we know from the modern-day Mars orbiters and landers, there will still be times when the observer, under suitable conditions, will



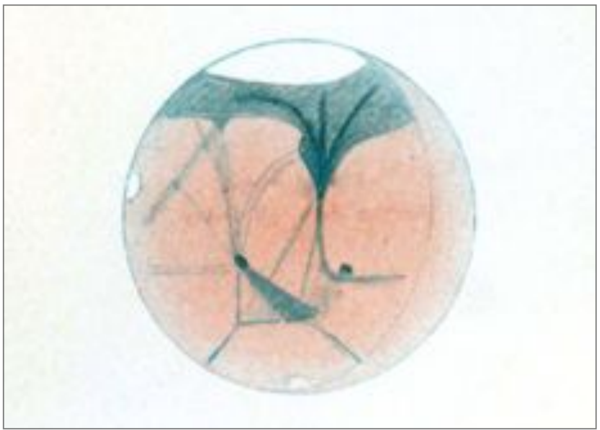


Fig. 13: *Colour renderings of Mars by Percival Lowell, from his book Mars and its Canals (1906), illustrating supposed seasonal changes due to burgeoning vegetation. The first shows the predominant chocolate-brown tints of the southern hemisphere winter; the second, made three months later, the lush blue-green of early spring. Lowell failed to understand the nature of the colour changes he recorded. The bluish hue of the Syrtis Major in the top drawing results from the Syrtis Major Blue Cloud. However, the other colours are due mostly (or totally) to the effects of simultaneous contrast, in which a neutral-coloured area takes on the complementary hue of its bright background.*

be startled as the canals flash into view − something that is sure to evoke in even the most jaded a sudden exclamation of 'Ah!'.

The illusion preyed on the old observers − and can still do so, when the canals deign to make one of these startling visitations. Macknik and Martinez-Conde write: 'Humans have a hardwired process of attention and awareness that is hackable.'[43] Rather easily hackable, I might add.

8.1. *The slowness of vision*

One of the things that make it so easily hackable is the fact that vision is such a slow process. The elaboration of a perception from the retina where photoreceptors in the eye convert light into electrochemical signals, then from the retina via the bundle of fibres in the optic nerve to the brain, involves processing. In the visual cortex alone, that processing involves at least thirty different cortical regions. Such extensive processing takes time.

Until recently, astronomers were rather blissfully unaware of this. The eye's perception seemed instantaneous, and its vaunted speed of perception was long cited as the chief advantage the eye over the photographic plate in the field of planetary observation where speed rather than light-gathering ability was needed, at which the photographic plate has long excelled. Thus Robert S. Richardson wrote:

> The trouble with photography when applied to the canals of Mars, is that the photographic plate requires an appreciable time to 'see' the planet. In the past this exposure time has ranged from about 0.5 seconds to 5 seconds and longer. Now the eye does not function like the photographic plate. We see an object immediately or usually not at all. Thus, when the air is steady, we catch a glimpse of the canals. Then it blurs, and the canals shimmer and vanish. An instant later the air steadies and the canals flash out again.[44]

Richardson's statement 'we see immediately or not at all' is sort of true. If an image is registered on the retina for less than a tenth of a second, it does not register at all. On the other hand − recalling that an image is made up of information − if the registration of an image is interrupted before the brain's processing is complete, it may contain ambiguities that are not resolvable. This is the sense in which attention and awareness is hackable, and has been exploited by magicians for ages; everyone knows that the hand is quicker than the eye.

Eadweard Muybridge was the pioneer of stop-action photographs (which indeed were quicker than the eye) and the developer of the zoopraxiscope for projecting motion pictures. He was an early explorer of the eye's imperfect ability to see fast-moving things, such as galloping horses, and the way that the brain filled things in to make us generally as unaware of the finite speed of vision as we are of the blindspot. Only under specific experimental conditions are these shortcomings exposed to scrutiny.

Of course, even before Muybridge, astronomers themselves had discovered discrepancies among their 'eye and ear' estimates of star-transits across the wires of their transit telescopes. Each observer had a personal equation that was significantly longer than the 0.1 second associated with the 'reaction time', the time required for a nerve impulse to go from the eye to the brain to the hand which touched the key of a chronograph. These were quantitative observations, and the delays were measurable − they varied in a consistent way from observer to observer, forming an individual personal equation that could be taken into account and corrected for. The lessons learned from these experiments were, however, largely forgotten a few years later when it came to Mars observations.

8.2. *The basis of the canal illusion*

At a conference in Milan I attended, the Italian physiologist Giovanni Berlucchi stated:

> Schiaparelli aimed at describing Mars by means of geometrical principles and methods… It must be kept in mind that even under excellent conditions of seeing, details from Mars's surface can only be glimpsed in flashes, similar to tachistoscopic stimulus exposures in the experimental psychology laboratory. After each such glimpse, Schiaparelli recorded the seen image by quickly sketching it, hopefully before the memory could fade. In addition the sketches were corrected and retouched at a later time upon better seeing conditions, so that the final maps were composites of many sketches performed in the course of several nights. Therefore potential sources of error were not limited to faulty perception, but may have had to do with false memories or with imprecise and unfaithful sketching. Already in the 19th century Helmholtz had shown that during a tachistoscopic exposure of a visual scene, one tends to see only those parts of the scene that are in spatial register with the direction of attention… In an unattended part of the visual field, observers reported many illusory conjunctions. By focusing attention on one part of the Mars surface during a brief moment of seeing, Schiaparelli may have misperceived, and thus erroneously sketched, illusory conjunctions on other, unattended parts of the planet.[45]

Here, then, we have the basis of the canal illusion. The image of Mars revealed in tachistoscope flashes of seeing in Lowell's telescope was ambiguous, and the signal-to-noise ratio was low.

The Martian surface features were shown at too low temporal and spatial resolutions to reveal anything of the nature of the surface features except as lines (this was Schiaparelli's Stage B). In larger instruments – those used by Barnard, Antoniadi, and the author and his colleagues at Lick Observatory in 2003 and 2005, for example – there was an increase in contrast; higher spatial frequencies were accessible, the signal-to-noise ratio was better. Thus there was a decisive improvement in the level of precision, and instead of an image at Schiaparelli's Stage B, these observations climbed the perceptual stairway to Stage C and even to Stage D. The information density of the images increased and the ambiguity decreased.

In closing, I cannot resist recalling Lowell's invocation of the 'fine lines and little gossamer filaments that draw the mind after them across the intervening void'. They perforce draw the mind after them. After all, they were spun out of the mind's own stuff.

How strange. We started out to study Mars. We ended up learning about the observer, our selves.

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References and notes

1. Quoted in Sheehan, William, *The Planet Mars: A History of Observation and Discovery* (Tucson: University of Arizona Press, 1996), p 130.
2. Ruskin, John, *Modern Painters* (London: George Allen, 1906), vol. III, Part IV, Chapter XVI.
3. Maunder, E. Walter, and Evans, J. E., 'Experiments as to the Actuality of the "Canals" of Mars', *MNRAS*, 63 (1903), 488–499.
4. Lowell, Percival, *Mars as the Abode of Life* (New York: MacMillan, 1908), p. 228.
5. Richardson, Robert S., *Exploring Mars* (New York: McGraw-Hill, 1954), pp. 154–155.
6. Strauss, David, *Percival Lowell: The Culture of a Boston Brahmin* (Cambridge, Mass.: Harvard University Press, 2001), p. 74.
7. Ibid., p. 75.
8. Lowell, Percival, *Mars and Its Canals* (New York: Macmillan, 1906), pp. 174–175.
9. Morse, Edward Sylvester, *Mars and Its Mystery* (Boston: Little, Brown & Co., 1906), p. 79.
10. Ibid., p. 160 ff.
11. Richardson, *Exploring Mars*, p. 158.
12. This poem will be published, with a commentary, in a forthcoming edition of the SHA *Bulletin*.
13. Martins, Martha Evans, *The Way of the Planets* (New York: Harper & Brothers, 1912), p. 172.
14. Macknik, Stephen L. and Martinez-Conde, Susana, *Sleights of Mind: What the Neuroscience of Magic Reveals about our Everyday Deceptions* (New York: Henry Holt & Co., 2010), p. 11.
15. Gregory, Richard L., 'Illusions', in *Oxford Companion to the Mind*, R. L. Gregory, ed. (Oxford: Oxford University Press, 2nd ed., 2004), p. 428.
16. As described by Phoebe Pool in her book *Impressionism* (London: Thames & Hudson, 1967), pp. 14–15. I am indebted to Richard McKim for calling this to my attention.
17. Young, Andrew T., 'What color is the solar system?' *Sky & Tel.*, 69 (1985), 399–403. I wish to thank Dr

Young for sharing with me a much longer, unpublished, manuscript on this subject.

18. See Hutchins, Roger, 'John Phillips's astronomy 1852–67, a pioneering contribution to comparative planetology', *The Antiquarian Astronomer*, 6 (January 2012), 44–57.
19. See McKim, Richard J., 'Nathaniel Everett Green: artist and astronomer', *J. Brit. Astron. Assoc.*, 114 (2004), 13–23.
20. Russell, Henry Norris, 'Percival Lowell and his work', *The Outlook* (1916 December 6), 781–783.
21. Quoted in McKim, 'Nathaniel Everett Green', p. 14.
22. Green, Nathaniel Everett, *Hints on Sketching from Nature* (London: George Rowney & Co., 1871), p. 17 and p. 20.
23. Schiaparelli, Giovanni Virginio, *Astronomical and Physical Observations of the Axis of Rotation and the Topography of the Planet Mars, First Memoir, 1877–1878*, William Sheehan, trans. A.L.P.O. Monograph No. 5 (1996), p. 1.
24. Green, *Sketching from Nature*, p. 27.
25. Green, Nathaniel Everett, 'Presidential Address', *J. Brit. Astron. Assoc*. 8 (1897), 3–7.
26. Lowell, Percival, 'Seasonal Changes in the Surface of the Planet', *Annals of the Lowell Observatory*, vol. 1 (1898), p. 83.
27. Lowell, *Mars and Its Canals*, p. 121.
28. Quoted in Sheehan, William, and O'Meara, Stephen James, *Mars: The Lure of the Red Planet* (Amherst, New York: 2001), pp. 341–342.
29. The discussion in this paragraph is due to Richard J. McKim, who raised these points while refereeing the paper. References to the aphelion cloud belt can be found in the B.A.A. Mars Section Reports. In particular, see: McKim, Richard J., 'The Opposition of Mars, 1997', *J. Brit. Astron. Assoc.* 116, 4 (2003), 169–186, and 'The Opposition of Mars, 1999', *J. Brit. Astron. Assoc.,* 117 (2007), 314–330.
30. Lowell, Percival, *Mars* (Boston: Houghton-Mifflin, 1895), p. 120.
31. See McKim, Richard J., 'Telescopic martian dust storms', *Memoirs of the British Astronomical Association*, 44 (1999), 28–31. This work is an outstanding example of the way that careful gleaning of historical observations can contribute to our ongoing understanding of Martian conditions.
32. Brown, Harriet and Friston, Karl J., 'Free-energy and Illusions: the Cornsweet Effect', *Frontiers in Psychology*, 3 (Feb. 2012), 1–13.
33. This poem will be published in a forthcoming SHA *Bulletin*.
34. Quoted in Richardson, *Exploring Mars*, p. 149.
35. Tombaugh, Clyde; personal communication to William Sheehan, 1986 December 5.
36. Antoniadi, E. M., 'Report of Mars Section, 1909', *Memoirs of the BAA*, 20 (1916), p. 32.
37. Quoted in Sheehan, William *The Immortal Fire Within: The life and work of Edward Emerson Barnard* (Cambridge: Cambridge University Press, 1995), p. 246.
38. Ruskin, *Modern Painters*, vol. IV, ch. 4.
39. Tombaugh, personal communication.
40. Sheehan, William, *Planets and Perception: Telescopic views and interpretations, 1609–1909* (Tucson: University of Arizona Press, 1988).
41. Gregory, 'Illusions', pp. 426–427.
42. Ibid.
43. Macknik and Martinez-Conde, *Sleights of Mind*, p. 6.
44. Richardson, *Exploring Mars*, pp. 155–156.
45. Berlucchi, G., 'Some Historical Crossroads between Astronomy and Visual Neuroscience', *Memorie della Società Astronomica Italiana*, 82 (2011), 225–231.

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