Part I

Views of Mars, from the beginning to the present day

To put present and future Mars exploration in context we must first review the history of mankind's aspirations, investigations and knowledge regarding our planetary neighbour. The most basic facts about Mars, which are summarised in Appendix A, have been obtained as a result of observations spanning hundreds of years, during most of which researchers were limited to observations from the Earth, although latterly through telescopes of considerable size and sophistication. For the last half century, however, it has been possible to study Mars close up using instruments on space probes, and these too have been gradually increasing in size and complexity. Around 35 spacecraft have been dispatched (see the summary in Appendix B) and, while less than half of the total have been successful, no fewer than five are currently operational on and around Mars.

These current missions include the *Mars Exploration Rovers*, true robot geologists that, at the time of writing, have been crawling over the surface of Mars for more than two and a half years, covering more than ten miles between them. The discovery of sedimentary rocks and salt deposits has confirmed what was long suspected: liquid water played a major role on early Mars. Climate change has dried and cooled the planet, and depleted the Martian atmosphere to a thin remnant of its former, more Earth-like state. What may have been a good environment for life is no longer so benign. Any life that once existed on the surface may have been driven below ground, where explorers from Earth have yet to look.

Chapter 1
The dawn of Mars exploration

1.1 Early observations

Mars was known to the ancients as a planet, or wanderer, in the night sky. What they thought about it is the stuff of myths and legends: usually, the baleful blood-red planet personified the God of War. Mars became recognised as a world, a companion to the Earth in the cosmos, about the time of the ancient Greeks, and as a member of the Sun's family of orbiting planets when Kepler and Copernicus worked out its orbit in the Middle Ages.

Nicolaus Copernicus proposed in *De revolutionibus orbium coelestium* in 1543 that Mars, like Earth and the other planets, followed an orbit around the Sun, presumed on philosophical grounds to be a perfect circle. Stimulated by Copernicus' thinking, and some ideas of his own in which the orbits of the planets were related to the five regular 'Platonic' polyhedrons,[1] in 1600 Johannes Kepler joined Tycho Brahe in Prague. Here, and before that in his native Denmark, Brahe had been observing the movement of Mars in the sky with unprecedented precision. After Brahe died suddenly in 1601 (poisoned by Kepler, according to some accounts), Kepler spent nearly a decade with Tycho's data attempting to find a mathematical explanation for the apparent meanderings of the red planet. A true wanderer, Mars actually reverses its apparent direction of travel twice every two years, tracing a loop against the backdrop of 'fixed' stars as seen by an observer on the Earth. The Earth-centred plot of Mars' motion in Figure 1.1 shows how this occurs.

Kepler concluded that the orbit of Mars is not only not related to any of the five Platonic solids, it is not even circular, but must follow instead an elliptical

[1] Probably discovered by Pythagoras, but forming a cornerstone of Plato's philosophy, there are only five of these 'perfect' solids, ranging from four to twenty surfaces forming completely regular shapes. In his early thinking, Kepler proposed that they determined the geometry that separated the spheres containing the six planets. The shapes are, in the order Kepler placed them in distance from the Sun, the octahedron, the icosahedron, dodecahedron, tetrahedron and finally, framing the orbit of Saturn, the cube.

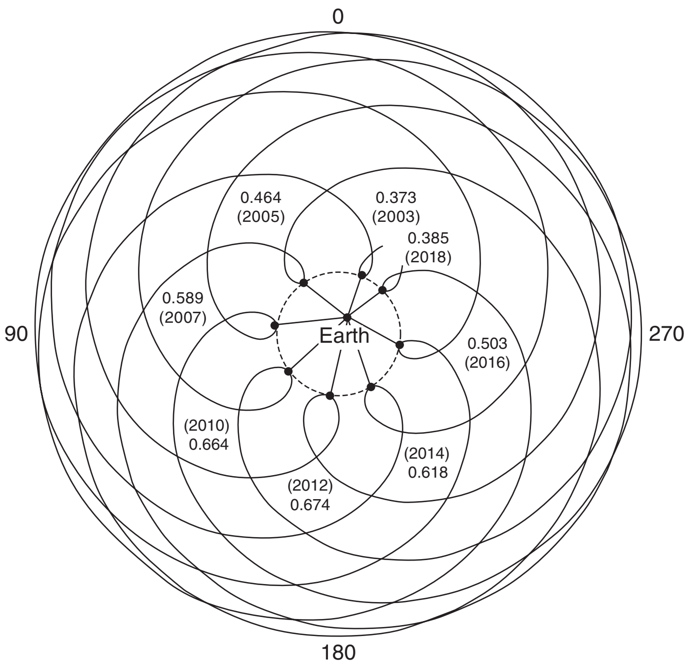


Figure 1.1 The elliptical orbit of Mars, plotted in a coordinate system that has the Earth at the centre. The dates, 2003, 2005 etc., are the years in which the closest approaches of Mars to Earth occur. The minimum distances are also shown; the closest is in 2003, when Mars was only 0.373 astronomical units (54.42 million kilometres) from Earth. This representation (based on plots by Tom Ruen using *Full Sky* software) makes it easier to understand why Mars periodically changes direction across the sky as viewed from Earth's surface. This apparently bizarre behaviour stimulated Kepler to develop his laws of planetary motion, which he published in 1609.

orbit with the Sun at one of its foci. This, and his second law of planetary motion, which states that a line from Mars to the Sun sweeps out equal areas in equal times as the planet moves, were published in *Astronomia Nova* in 1609. Three-quarters of a century later, in *Philosophiae Naturalis Principia Mathematica*, Isaac Newton showed that Kepler's laws were a specific application of more general laws of motion and of gravitation that applied to all objects at all times throughout the observable universe. This was one of the foundation stones of modern science, remaining essentially unchallenged until Einstein, with the Theory of Relativity, found deeper truths behind Newton's laws in the early 1900s. Today, the recent discoveries of apparently non-Newtonian behaviour in galaxies has led to concepts such as dark matter and dark energy that are understood by no one.

Most professional astronomers these days are cosmologists, wrestling with concepts of the nature and origin of the Universe at large, even discussing 'multiverses' ruled more by mathematics than observations. Planetary scientists are now a separate breed, often closer to Earth scientists than mainstream twenty-first-century astronomers because of a common interest in aspects of Solar System formation, geophysics and atmospheric science. Their tools are now more likely to be robotic spacecraft than telescopes on mountains, and data still rule over theory, just as in the time of Kepler and Tycho.

1.2 Another planet with an atmosphere

The scientific exploration of Mars as a planet like the Earth with a surface and an atmosphere started with the foundation of the great observatories, following the invention of the telescope *circa* 1610. In 1659 Christiaan Huygens made the sketch of Mars reproduced in Figure 1.2, which shows a glimpse of some features on the surface, while Giovanni Cassini was the first to record the bright polar cap at the Martian north pole in 1666. In 1672 Huygens saw its equivalent in the south. That same year, working with a colleague observing Mars from South America at the same time as he made his own observations in France, Cassini obtained a value for the parallax[2] of Mars and hence for its distance from the Earth, and that of the Earth from the Sun. This was the first reasonably accurate determination of these distances, less than ten per cent too small compared to modern values.

In 1781 William Herschel, observing both polar caps, wrote that he believed they were ice sheets like those on the Earth. In an address to the Royal Society in 1784, he went further:

> It appears that this planet is not without considerable atmosphere; for besides the permanent spots on the surface, I have often noticed occasional changes of partial bright belts; and also once a darkish one. These alterations we can hardly ascribe to any other cause

Figure 1.2 Huygens' 1659 sketch of Mars; on the left, is the earliest known record of markings on the surface. Thirteen years later, on 13 August 1672, he drew what seem to be the same features, but added the polar cap. The third drawing is dated 17 May 1683.

[2] Parallax is the apparent displacement of an object when viewed from different directions. In this case it refers to the apparent change in the position of Mars relative to the background stars when viewed from two locations on the Earth, or in principle when the Earth is at the two extremes of its orbit, either side of the Sun. This small angle is not simple to determine (particularly since Mars moves along its own orbit during the time of the measurement) but once it is available, the distance to Mars can be determined from simple triangulation.

than the variable disposition of clouds and vapours floating in the atmosphere of the planet. Mars has a considerable but modest atmosphere, so that its inhabitants probably enjoy a situation in many respects similar to ours.

Along with the idea that Mars had a substantial atmosphere came the assumption that it was likely to be more or less like that on the Earth, a not unreasonable starting point given the absence of quantitative measurements. Even less was known then than now about atmospheric evolution on the terrestrial planets, and today it is generally believed that the atmospheres of Earth, Mars, and indeed Venus, used to resemble each other more than they do now. It was not until 1908 that the first scientific attempt to quantify the surface pressure on Mars was made by Percival Lowell in the USA. As discussed below, he came up with less than one-tenth of the terrestrial value, but it was still ten times too large.

1.3 The Mountains of Mitchel

Mars studies surged in Victorian times, with the work of many keen amateur and professional observers using telescopes that had improved rapidly in availability and performance with the flourishing of technology that characterised this period. Along with the new observations came a rash of interpretations and speculations. In 1846, Ormsby Mitchel was the director of the recently completed observatory (shown in Figure 1.3), which still stands at what is now the University of Cincinnati in Ohio. He made drawings of Mars like those in Figure 1.4, in which he noted that a region of the south polar cap remained snow covered in the spring after the ice had receded all around it. He reasonably assumed that this meant a high elevation, and the region is still known as the Mountains of Mitchel, although observations from the recent *Mars Global Surveyor* spacecraft in orbit around Mars show that the terrain Mitchel saw, although rough, is only moderately hilly. Its long-lived brightness is probably due to the alignment of the outcrops of rock keeping much of the surface in shadow in the early spring, when the Sun is low in the sky, so that the winter frost is slower to clear than in surrounding regions at the same latitude. However, some other regions that look topographically quite similar do not stand out in this way, and the *Global Surveyor* camera team noted as recently as 1999 that the exceptional brightness of the region remains something of a mystery.

The infrared spectroscopy team on the same mission found that the carbon dioxide frost covering the 'Mountains' appeared to be unusually small-grained, making it very reflective and hence slower to sublime away in the spring (and, incidentally, easier for Mitchel himself to observe with his relatively primitive equipment). It seems that something about the local meteorological conditions provides the region with particularly heavy deposits of fresh, highly reflective snow each winter season. Whatever the reason, the phenomenon is a remarkable example of a very early study of localised behaviour on Mars that has stood the test of time without being shown to be illusory, even if the interpretation was wrong.

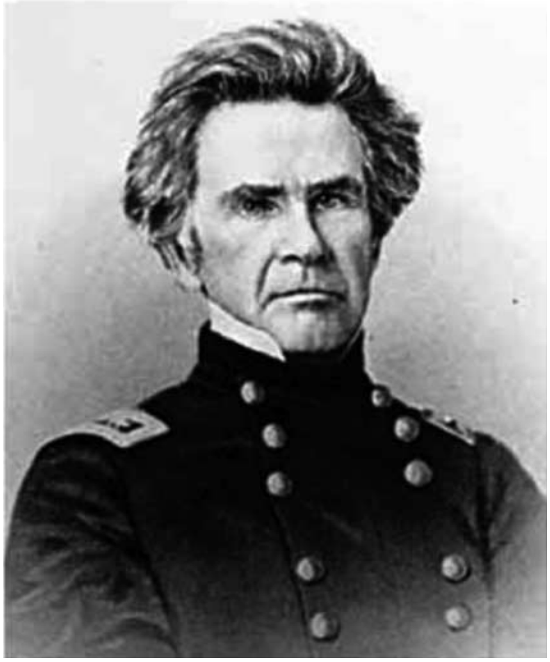


Figure 1.3 Ormsby M. Mitchel, in uniform as a general during the US Civil War, and the observatory in Cincinnati that housed his twelve-inch refracting telescope. (University of Cincinnati)

Mitchel made regular observations of Mars and wrote a book, *The Planetary and Stellar Worlds*, in which he said:

The reddish tint which marks the light of Mars has been attributed by Sir John Herschel to the prevailing colour of its soil, which he considers the greenish hue of certain tracts to

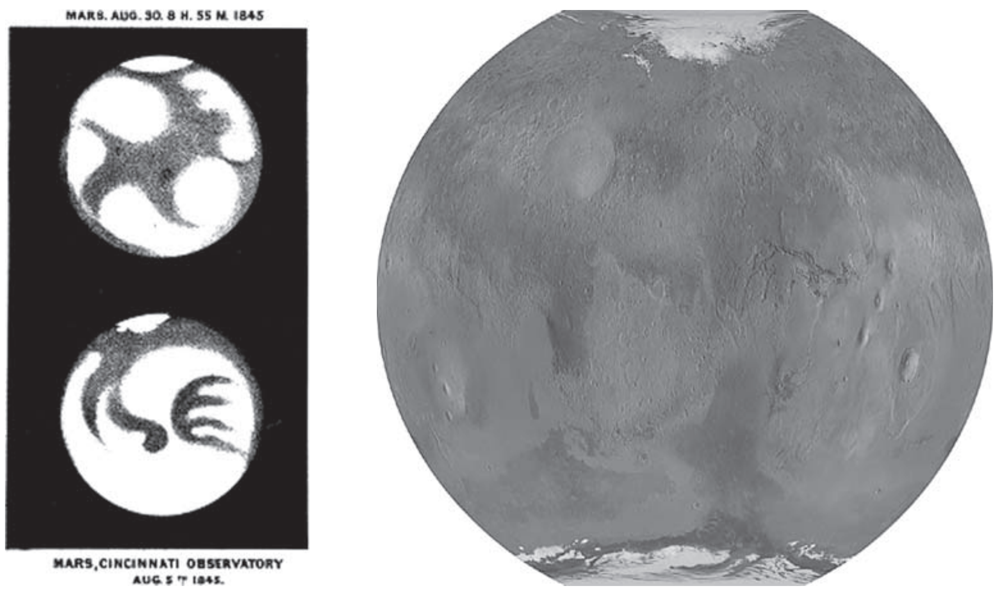


Figure 1.4 Early observers had to draw by hand what they saw through the telescope. The sketches of Mars on the left are by Ormsby Mitchel, who was one of the more reliable nineteenth-century observers. His discovery in 1846 of an isolated bright region as the polar cap receded in the Martian southern spring was confirmed by spacecraft observations more than a century and a half later. The 'Mountains of Mitchel' can be seen just to the left of the polar cap in both Mitchel's drawing and the modern photograph (taken through the twenty-four-inch telescope at Lowell Observatory by C. F. Capen) on the right. South is at the top of both pictures, since telescopic observers traditionally draw or photograph planets upside-down, which is the way they appear through their eyepieces. (University of Cincinnati, courtesy Mrs V. Grohe)

distinguish them as covered with water. This is all pure conjecture, based upon analogy and derived from our knowledge of what exists in our own planet. If we did not know of the existence of seas on the Earth, we could never conjecture or surmise their existence in any neighbouring world. Under what modification of circumstances sentient beings may be placed, who inhabit the neighbouring worlds, it is vain for us to imagine. It would be most incredible to assert, as some have done, that our planet, so small and insignificant in its proportions when compared with other planets with which it is allied, is the only world in the whole universe filled with sentient, rational, and intelligent beings capable of comprehending the grand mysteries of the physical universe.

1.4 The wave of darkening

Several nineteenth century astronomers observed a dark front that travelled from the pole towards the equator in the springtime, which became known as the 'wave of darkening'. The popular view, which persisted until relatively recently, attributed this to the seasonal advance of vegetation – 'herbage and plants' according to Camille Flammarion in 1873. In 1909 another French astronomer, Georges Fournier, wrote: 'As the spring advances, the dark shading progressively encroaches from the pole towards the equator across the seas. This advance, across wide expanses and along channels, takes place at a variable speed, but nearly always very rapidly; a few weeks only suffice to change the landscape completely.' E. M. Antoniadi in his book *La Planete Mars 1659–1929* wrote: 'It was almost exactly the colour of leaves which fall from trees in summer and autumn in our latitudes.'

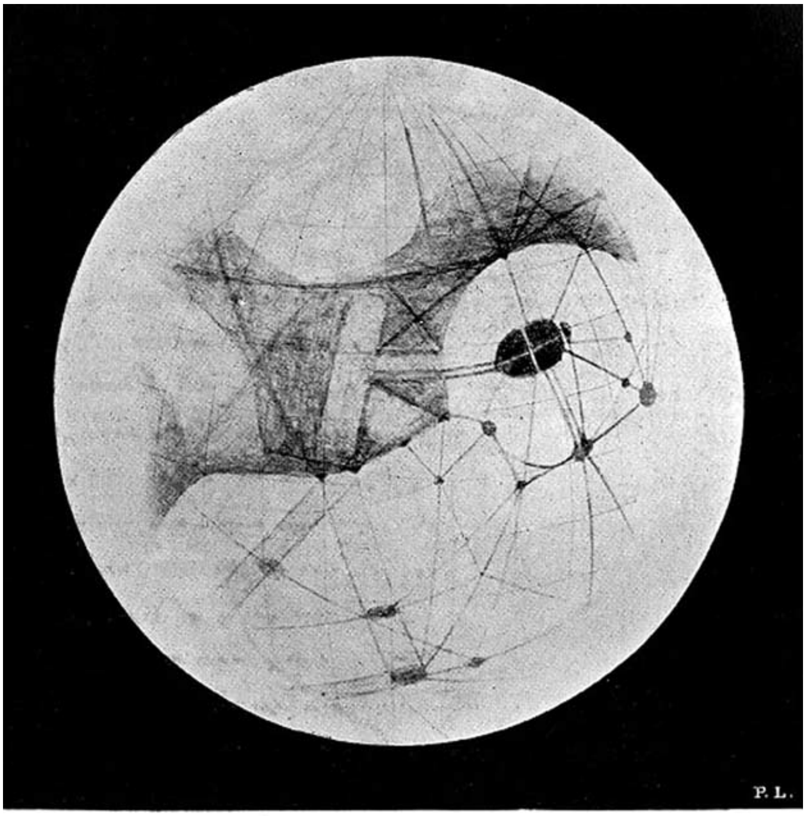
In fact, leaves were ruled out fairly early by infrared observations of Mars. The dark areas were found to lack the high reflectivity at infrared wavelengths that is characteristic of the chlorophyll in green vegetation. Those who wanted to save the life-based explanation proposed some sort of dark cactus or lichens instead; others considered that the non-biological possibilities needed to be ruled out first. The latter included the Swedish chemist Svante Arrhenius, who pointed out in 1918 that certain substances that could be present in the Martian soil might change colour as they absorbed moisture seasonally released from the polar caps. In 1954, Dean McLaughlin suggested drifting volcanic ash from active volcanoes, and in 1957 Gerard Kuiper proposed windblown dust. Carl Sagan and James Pollack, writing in the journal *Nature* in 1969, developed the dust hypothesis in convincing detail.

The phenomenon is real and still regularly observed by amateurs, but the greenish colours are illusory. Kuiper, Sagan and Pollack were right: the space missions of the 1970s observed vast dust storms moving across the planet, most frequently in the spring. The early optical observers, with small telescopes that delivered very limited spatial resolution, were detecting Martian meteorology, not biology.

1.5 Lowell and the canals

Today, when Mars explorers of the early telescopic era are discussed, the names that everyone remembers are those of Giovanni Schiaparelli and Percival Lowell. Lowell in particular is memorable as a serious observer who interpreted what he saw in dramatic and eloquent terms that turned out to be wrong. Schiaparelli was an astronomer at the Observatory of Milan and he was the first, in 1877, to observe channels or 'canali' on the surface of Mars. He did not claim that these were artificial, but many others thought they were evidence of large-scale engineering on Mars and hence must be the work of intelligent life. Lowell, who held a distinction in mathematics from Harvard University, had an early career as a diplomat and author working mainly in the Far East. In 1894, inspired in part by Schiaparelli's discovery, he decided to dedicate his time and his considerable personal wealth to building an observatory in Flagstaff, Arizona, specifically for the study of these and other interesting features on Mars. Figure 1.5 shows Lowell at work, and an example of his observations, recorded, as was still the practice at the time even for professional astronomers, as drawings.

Lowell's dedicated campaign, using instrumentation carefully selected and designed to be the best available at the time, revealed to him a network of artificial canals on Mars, the purpose of which was to irrigate the planet by supplying water from the melting polar caps. Lowell knew that he would not be



MARS
LONGITUDE 60° ON THE MERIDIAN

Figure 1.5 Percival Lowell in his observatory, and one of his drawings of Mars. (From *Mars and its Canals*, 1906)

able to see canals of any sensible width from the Earth, even if they existed, but he further surmised that the water would be bordered by fertile zones several miles wide, similar to those seen on Earth along the River Nile as it winds through otherwise arid desert.

Although 'unburdened with advanced degrees', Lowell was already an experienced author. He published, among others, books about Japanese culture, having lived in Japan as a young man. He was keen to communicate his insights on Mars to a receptive public, and wrote extensively about his findings in the scientific and the popular literature. Two of his books are still famous today: *Mars and its Canals* (1906) and *Mars as the Abode of Life* (1909), and they still convey the sense of excitement that Lowell felt over his discoveries:

In steady air the canals are perfectly distinct lines, not unlike the Fraunhofer ones of the Spectrum, pencil lines or gossamer filaments according to size. All the observers at Flagstaff concur in this. The photographs of them taken there also confirm it up to the limit of their ability. Careful experiments by the same observers on artificial lines show that if the canals had breaks amounting to 16 miles across, such breaks would be visible. None are; while the lines themselves are thousands of miles long and perfectly straight. Between expert observers representing the planet at the same epoch the accordance is striking; differences in drawings are differences of time and are due to seasonal and secular changes in the planet itself. These seasonal changes have been carefully followed at Flagstaff, and the law governing them detected. They are found to depend upon the melting of the polar caps. After the melting is under way the canals next to the cap proceed to darken, and the darkening thence progresses regularly down the latitudes. Twice this happens every Martian year, first from one cap and then six Martian months later from the other. The action reminds one of the quickening of the Nile valley after the melting of the snows in Abyssinia; only with planet-wide rhythm. Some of the canals are paired. The phenomenon is peculiar to certain canals, for only about one-tenth of the whole number, 56 out of 585, ever show double and these do so regularly. Each double has its special width; this width between the pair being 400 mi. in some cases, only 75 in others. Careful plotting has disclosed the fact that the doubles cluster round the planet's equator, rarely pass 40° Lat., and never occur at the poles, though the planet's axial tilt reveals all its latitudes to us in turn. They are thus features of those latitudes where the surface is greatest compared with the area of the polar cap, which is suggestive. Space precludes mention of many other equally striking peculiarities of the canals' positioning and development. At the junctions of the canals are small, dark round spots, which also wax and wane with the seasons. These facts and a host of others of like significance have led Lowell to the conclusion that the whole canal system is of artificial origin, first because of each appearance and secondly because of the laws governing its development. Every opposition has added to the assurance that the canals are artificial; both by disclosing their peculiarities better and better and by removing generic doubts as to the planet's habitability. The warmer temperature disclosed from Lowell's investigation on the subject, and the spectrographic detection[3] by Slipher[4] of water-vapour in the Martian air, are among the latest of these confirmations.

[3] 'Spectrography' is an early name for what is usually now called spectroscopy, see Figure 1.6.

[4] Vesto Slipher worked with Lowell at the Flagstaff Observatory. His work on Mars is discussed further below.