Mars as been the focus of intense scientific interest and study throughout recorded history. Even before the advent of the telescope in 1609, astronomers carefully charted the motion of Mars across the sky. The planet's obviously reddish-orange color led many ancient civilizations to name the planet after war or warrior gods. Our current use of the name Mars comes from the Roman God of War. Large martian sinuous valleys (vallis) are named after the term for Mars in different languages: hence Ares Vallis (Greek name for Mars), Augakuh Vallis (Incan), and Nirgal Vallis (Babylonian). Careful observations of Mars' motion across the celestial sphere led early astronomers to deduce two things about the planet. First they determined that Mars' sidereal period (time to return to same position relative to the stars) is about 687 Earth days (1.88 Earth years). The Polish astronomer Nicolaus Copernicus found that the sidereal period (P) of a planet is related to its synodic period (S; time for planet to return to same Earth–Sun–planet configuration) by 1 P ¼ 1 □ 1 S : (1:1) Using this relationship, we can determine that the synodic period of Mars is 2.14 Earth years. The second thing that pre-telescopic observers noticed about Mars was its strange looping path across the sky. While planets tend to slowly travel from west to east across the background of stars over the period of several nights, occasionally they reverse course and travel east to west for a period of time before resuming their normal west-to-east motion. This retrograde (east-to-west) motion is most noticeable for planets closest to the Earth, and thus Mars' retrograde motion is apparent 1 NADBARLO: 9780521852265c01 7/11/07 16:57:53pm page 1 even to naked-eye observers. The geocentric model of the universe had extreme difficulty explaining retrograde motion, requiring the use of hundreds of small circles upon orbital circles (epicycles and deferents). However, retrograde motion was easily explained when Copernicus rearranged the view of the Solar System in 1543 by placing the Sun at the center and having Earth orbit the Sun along with the other planets. In the heliocentric model, retrograde motion results when one planet catches up to and overtakes another during their orbital motions. Mars also played a major role in determining the shapes of planetary orbits. It was Tycho Brahe's very accurate and voluminous observations of Mars' celestial positions that led Johannes Kepler in 1609 to deduce that planetary orbits were elliptical with the Sun at one focus of the orbit. Mars has the second most elliptical orbit of the eight major planets in the Solar System – Mercury's orbital eccentricity is higher but the planet is difficult to observe due to its proximity to the Sun. 1.1.2 Telescopic observations from Earth and space Although Galileo's small telescope was unable to reveal anything other than the reddish-orange disk of the planet in 1609, larger telescopes slowly coaxed more information from the planet. By 1610, Galileo reported that Mars can show a gibbous phase, which subsequent observers verified. The first report of albedo markings on the surface was published in 1659 by Christiaan Huygens, whose map showed a dark spot which was likely Syrtis Major. The identification of surface albedo markings allowed astronomers to determine that the rotation period of Mars was approximately 24 hours. The bright polar caps apparently were not noticed until Giovanni Cassini reported them in 1666. Cassini's nephew, Giacomo Maraldi, made detailed observations of the polar caps during several oppositions, including the favorable opposition of 1719. Among his discoveries were that the south polar cap was not centered on the rotation pole, that the polar caps and equatorial dark areas displayed temporal variations, and that a dark band occurs around the edge of the receding polar cap (which he interpreted as meltwater). Sir William Herschel observed Mars from 1777 to 1783 and was the first to determine that Mars' rotation axis was tipped approximately 30° from the perpendicular to its orbit. This result showed that Mars experiences four seasons, similar to the Earth. Herschel also determined the planet's rotation period to be 24 hours 39 minutes 21.67 seconds. Herschel deduced the presence of a thin atmosphere around Mars based on the changes he saw in the appearance of the planet, which he attributed to clouds. These were primarily the white clouds which are now known to be composed of ice particles. The yellow dust clouds were first reported by Honoré Flaugergues in 1809.

Major advances in our understanding of Mars began in 1830 during a close approach between Mars and Earth. The first complete map of Mars was derived from observations during this time and published in 1840 by Johan von Mädler and Wilhelm Beer – this was the first map to establish a latitude–longitude system for the planet, with the zero longitude line defined through a small, very dark spot. They also refined the rotation period of Mars to 24 hours 37 minutes 22.6 seconds (with 0.1 second of the currently accepted value). Numerous drawings of Mars were made between 1830 and the early twentieth century and these drawings were gradually incorporated into maps by William Dawes in 1864, Richard Proctor in 1867, Nicolas Flammarion (1876), and E.M. Antoniadi (between 1901 and 1930). Although Proctor and Flammarion both named features on their maps, the nomenclature system currently used for martian features is based on one proposed by Giovanni Schiaparelli on his 1877 map. Mars and Earth were very close in 1877, resulting in a surge of new discoveries. Principal among these was the discovery of Mars' two small moons, Phobos and Deimos, by Asaph Hall. High-altitude clouds were detected as white spots along the morning and evening limbs of the planet by Nathaniel Green and the first attempts to photograph the planet were also made this year by M. Gould. But it was another observation made in 1877 that would focus considerable attention on Mars for many years to come: Schiaparelli's observations of thin dark lines crossing the martian surface, which he called canali. Schiaparelli reported thin dark lines crossing the martian surface, but he was unsure of their origin. As a result, he used the generic term "channel" to describe these features. A channel is a natural feature which can be formed by flowing liquid/ ice, tectonics, or wind. The Italian word for channel is "canali," which unfortunately was mistranslated into English as "canal," a word that implies a waterway constructed by intelligent beings. The discovery of these "canals" on Mars simply augmented several other observations which people felt supported the idea of life on Mars. Mars displays a number of Earth-like characteristics which were already known in the nineteenth century. Mars' rotation period is about 37 minutes longer than an Earth day, and, due to the tilt of its rotation axis, it undergoes four seasons just like the Earth. Telescopic observations had revealed the presence of polar caps and an atmosphere, although their compositions were unknown. But one of the most intriguing observations for possible life on Mars was the "wave of darkening." Telescopic observations revealed that as one hemisphere's polar cap began to recede in the spring, the region immediately surrounding the polar cap became noticeably darker. As the polar cap continued to recede into summer, the area of darkening extended towards the equator. As fall arrived and the polar cap began to increase in size, the "wave of darkening" reversed itself and the hemisphere underwent a "wave of brightening" from the equator toward the poles. Most people attributed the wave of darkening to the melting of water ice at the polar caps in the spring and summer and the greening of surface vegetation as it absorbed this water. Schiaparelli's canali were quickly accepted as evidence that not only vegetation but also intelligent life existed on Mars. This idea was promulgated by Percival Lowell, a wealthy Bostonian who founded the Lowell Observatory in Flagstaff, AZ, in 1894 specifically to study the martian canals. Lowell observed hundreds of single and double canals using the 0.6-m Clark refracting telescope at the Observatory (Figure 1.1) and wrote several books describing his thoughts on the origin of these canals. According to Lowell, ancient Mars retained a thicker atmosphere, which led to temperate conditions on the surface, including abundant liquid water. A race of Martians arose under these conditions and settled the entire planet. But since Mars is only 52% the size of the Earth, the atmosphere gradually began to escape to space, cooling the surface and making liquid water less abundant. The Martians moved to the warm equatorial region of the planet and constructed the elaborate network of canals to bring water from the polar regions to the thirsty masses at the equator. Lowell realized that the canals themselves would likely be too small to be resolved with any Earth-based telescope, so he argued that the dark lines he observed were regions of vegetation bordering the canals. Lowell's books and public lectures always drew large, enthusiastic crowds and many science fiction books about Martians resulted from this discussion (e.g., The Martian Chronicles and The War of the Worlds). Most astronomers, however, were not convinced that martian canals existed. More powerful telescopes did not show dark lines but dark blotches across the surface. Scientists argued that the linear canals were optical illusions caused by the Figure 1.1 Image of the martian canals (dark lines) and putative lakes (round dots), drawn by Percival Lowell on the night of 9 November 1894. (Image courtesy of Lowell Observatory Archives.) 4 Introduction to Mars NADBARLO: 9780521852265c01 7/11/07 16:59:11pm page 4 human mind "connecting the dots" when observing at the limits of a telescope's ability. Such conditions are exacerbated by the turbulent atmospheres of both the Earth and Mars. Testing of human subjects confirmed these arguments. Lowell countered that the excellent seeing at his Flagstaff site allowed him to observe features that other telescopes did not reveal. The controversy continued after Lowell's death in 1916 and the development of large telescopes such as the 5-m telescope at Palomar Observatory in California in 1948. It was only after the advent of spacecraft exploration that astronomers were able to say definitively that canals do not exist on Mars and that the "wave of darkening" simply results from the movement of dust and sand across the planet by seasonal winds. Advances in telescope size and technology have greatly affected the quality and type of astronomical observations in recent years, and Mars studies have been one of the areas to reap these benefits. Infrared observations of Mars from Earth-based telescopes and the Hubble Space Telescope provided evidence of mineralogical variations across the surface, including the presence of hydrated minerals. The advent of adaptive optics, together with observations from the Hubble Space Telescope, have provided dramatic improvements in resolution and allow study of martian features which previously were only seen by orbiting spacecraft at Mars. Radar observations from ground-based radio telescopes have provided important constraints on surface roughness which have been important in the selection of landing sites for landers and rovers. These ground-based roughness measurements have only recently been surpassed by the acquisition of Mars Orbiter Laser Altimeter (MOLA) data from Mars orbit. Some people argue that ground-based observations of Mars are no longer needed because of the large number of orbiters and landers currently invading the planet (Section 1.2). Nothing could be further from the truth. Ground-based observations can provide the continuous or near-continuous monitoring of rapidly changing events, such as atmospheric phenomena (including dust storm formation and propagation) and polar cap changes. Due to orbital constraints, orbiting spacecraft cannot continuously monitor one location or event each day and landers/rovers are even more restricted in their observations. The wavelengths of observation also are restricted on spacecraft instrumentation. Hubble Space Telescope observations of Mars are few due to the demand for observing time. Thus, ground-based observations still fill an important niche in our ongoing observations of Mars