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# History of telescopic observations of the Martian satellites☆

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ABSTRACT

This article intends to review the different studies of the Mars satellites Phobos and Deimos realized by means of ground-based telescopic observations as well in the astrometry and dynamics domain as in the physical one. This study spans the first period of investigations of the Martian satellites since their discovery in 1877 through the astrometry and the spectrometry methods, mainly before the modern period of the space era. It includes also some other observations performed thanks to the Hubble Space Telescope. The different techniques used and the main results obtained for the positionning, the size estimate, the albedo and surface composition are described.



## 1. Discovery

Gingerich (1970, 1978) informed us that in the 18th century the belief that Mars had two moons was pervasive, and justified on the basis of analogy, or by some form of harmonic progression. The argument went like this: If Mercury and Venus have no moons, Earth has one, Jupiter has four and Saturn has five, then Mars must have two moons. Such unscientific reasoning, and the failure of astronomers to find those satellites, caused satirists, such as Voltaire and Jonathan Swift, to ridicule the scientists of the day (Gingerich, 1970, 1978; Dick, 1988).

Asaph Hall, Sr., a highly experienced and motivated satellite observer, was in charge of the Alvan Clark 26-inch “Great Refractor” (Hall, 1878) of the United States Naval Observatory (USNO), the largest refractor in the world and effectively larger (more powerful) than the Grubb or Parsons speculum reflectors. In August, 1877, at the very favorable opposition of Mars, Hall turned the giant refractor to Mars with the express goal of finding a moon or two. His unique search technique was to place Mars on the rotation axis of his micrometer, move the eyepiece along its slide so that Mars was just out of the field of view, and then rotating the micrometer head. This scheme produced a search area in the shape of an annulus a few arcmin wide around Mars but absent the “dazzling” light of the planet (Hall, 1878).

With this technique the moons were discovered quickly – when they first became visible (from behind/in front of Mars). Once the light from the planet was blocked, it was not difficult to detect them by eye. In fact they have been seen and photographed with this telescope at every opposition from the favorable opposition of 1971 through the favorable opposition of 1988 and beyond, including all “unfavorable” oppositions.

The immediate significance of the discovery: (1) An accurate mass for Mars was determined, considerably improving Newcomb′s planetary theories, (2) the smallest moons yet, suggested the presence of small (faint) moons around the other planets and motivated observers to search for them, (3) Phobos, arguably the most peculiar and interesting satellite – it orbits Mars faster than Mars rotates, rising in the West (or setting in the East) three times in a Martian day – a first in the Solar System! Another first, Phobos orbited inside the stationary orbit, motivating theoreticians to look for a secular acceleration in the longitude of the moon (see discussion on the secular acceleration below) (Fig. 1).

## 2. Astrometric observations

From the time of their discovery, ground-based observations (measurements) of the Martian satellites have been almost exclusively astrometric (positional) except for a handful of photometric studies.

☆This article intends to review the different studies of the Mars satellites Phobos and Deimos realized by means of ground-based telescopic observations as well in the astrometry and dynamics domain as in the physical one. It includes also some others peformed thanks to the Hubble Space Telescope.

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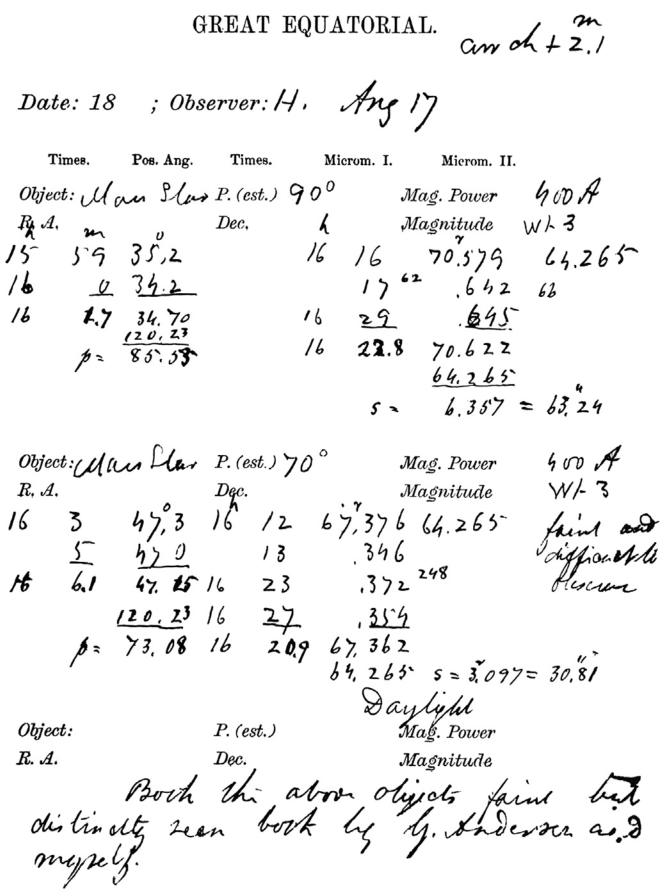


**Fig. 1.** Copy of the observer′s logbook for the 26-inch on the night of 17/18 August 1877. Asaph Hall′s comment at the bottom reads: "Both the above objects faint but distinctly seen both by G. Anderson and myself". While Deimos had been seen on the 11th, it was on the 17th that Phobos was discovered and it became clear that there were two satellites. George Anderson was the 26-inch night assistant (Courtesy USNO Library).

Observations of the satellites were carried out around the times of Martian opposition which occur on average every 26 months. Because Mars′ orbit has a significant eccentricity, Mars distance from Earth is about half the distance at a "favorable" opposition than at an "unfavorable" one. Favorable oppositions occur every 15 or 17 years.

Three distinct periods are identified based on the motivations giving rise to them and the observational techniques used.

### 2.1. First generation: visual observations

During the classical period, 1877–1941, visual astrometric observations were carried out, principally with the long-focus great equatorial refractors, constructed by the American optician, Alvan Clark. This included not only the USNO 26-inch, but also the Lick 36-inch, and the Pulkovo 30-inch. And it employed many of the eminent observers of the day, including Asaph Hall Sr., W. W. Campbell, and Hermann Struve. The filar micrometer was used to obtain separation and position angle measurements of each satellite relative to Mars, bisecting Mars for position angle, while making limb measurements for separation. Some observers, such as Asaph Hall, bisected Mars for both. Struve, however, advocated the use of rectangular coordinates ($x$,$y$) and tangential settings of the measuring crosshairs on the four planetary limbs as well – demonstrating their superior accuracy (Pascu, 1977, 1978).

Hermann Struve also introduced, into general practice, the measurement of intersatellite positions – the measurement of ($\Delta x$, $\Delta y$) or ($\Delta$PA, $\Delta$Sep) of one satellite relative to another. While the advantage of such observations was obvious – the large measuring errors on the disk of the planet were eliminated – the drawbacks were more subtle. In this scheme, the conditional equations included the orbital corrections for both satellites, which increased the correlations between the parameters, especially the eccentricities of the two satellites. This affected the accuracy of the semi-major axis and, thus, the resulting mass of Mars. Struve was aware of this problem and made observations of the satellites relative to Mars (Struve, 1888, 1898).

For the Martian moons, the classical period lasted until the favorable oppositions of 1939/1941. The last micrometer observations made with the USNO 26-inch were in 1941 (there is indication that the Soviet observers made micrometric observations as late as 1970). This 70-year period produced some 3000 "quality" observations of the satellites, with an external precision of about 0.5 arcsec, and resulted in a mass for Mars accurate to 0.1%, (compared to 0.0003% from Mariners 6 &7 (Anderson et al., 1970)), accurate orbital elements for Phobos and Deimos, a value for the dynamical oblateness of Mars, a value for $J2$, and the orientation of Mars′ pole of rotation. But most interestingly, it culminated in the report of a secular acceleration in the longitude of Phobos by Sharpless (1945).

Although the secular acceleration of Phobos was a first in the solar system, it was not a surprise. Struve understood the dynamics of a satellite orbiting inside the stationary orbit of Mars. Following the favorable opposition of 1909, Struve (1911) analyzed the residuals in longitude for Phobos, looking for an acceleration. While his results were not definitive, they were suggestive. Following the favorable opposition of 1926, Harold Burton (1929) of the USNO, repeated Struve′s analysis, using the observations made with Alvan Clark′s Great Refractors. He found evidence for the secular acceleration but, apparently, was not confident enough in his results to claim it. Plans were made for observations at the favorable opposition of 1939. Photographic observations were made by Bevan Sharpless with the USNO 40-inch Ritchy-Chretien while Burton made visual micrometer observations with the 26-inch. The observations were continued at the oppositions of 1941 and 1943. The photographic effort apparently was not very successful as there is no record of the observations, neither published nor in manuscript form. Part of the reason must have been the weather in 1939 since only one visual observation was recorded. Since Sharpless used Washington observations from both 1939 and 1941 in his new analysis, some of the 1939 photographic observations must have been used. In his 1945 paper, he reported an acceleration in the longitude of Phobos as +0.001882 deg/yr$^2$. Burton, in a memorandum to the Superintendent of the USNO (dated 9 August 1944) claimed that the reported acceleration was a confirmation of his own 1929 results. The irony is that Sharpless apparently did not believe that his (Sharpless) results indicated a true acceleration, but rather, part of a long period term in the longitude of Phobos (Reuning, 1981).

In the ensuing years, theoretical studies failed to find a plausible explanation for the acceleration, such as atmospheric drag or tidal effects (Burns, 1972), thus, the analysis and observations which led to those results became suspect. In the mid 1960 s, G. Wilkins, director of HMNAO (Her Majesty′s Nautical Almanac Office), reanalyzed all the observations, including the few Mt. Wilson 60-inch photographic observations made in 1956. He included an acceleration term in the solution for each satellite. Although Wilkins (1967, 1970) found a significant secular acceleration for Phobos, he also found a number of irregularities in the solutions. In particular, he found that an orbital fit to observations over a single opposition gave an rms residual of $\pm$ 0.3 arcsec, but when fit to the complete set of observations, the rms increased to $\pm$ 0.5 arcsec. Wilkins interpreted this to indicate that the Struve orbital theory was inadequate. His successor, Sinclair (1972), improved the theory, but it had little effect on the residuals, indicating systematic errors in the observations. Sinclair also found a well determined solution for the secular acceleration in Phobos′ longitude, but discovered that various subsets of the observations gave

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