A SIMULTANEOUS ESTIMATION OF THE MASS OF MARS AND ITS NATURAL SATELLITES, PHOBOS AND DEIMOS, FROM THE ORBITAL PERTURBATIONS ON THE MARINER 9, VIKING 1, AND VIKING 2 ORBITERS; F. G. Lemoine[1,2], D. E. Smith, S. K. Fricke[3], and J. J. McCarthy[4], [1]Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [2]Dept. of Astronomy, University of Maryland, College Park, MD 20742-2421, [3]RMS Technologies, Inc., Landover, MD 20785, [4]Hughes STX Corporation, Lanham, MD 20706.

The natural satellites of Mars, Phobos and Deimos, caused perturbations on the orbits of the Mariner 9, and the Viking spacecraft that have been used to estimate the satellite masses. The Viking spacecraft were specifically targeted to make close flybys (within a few hundred kilometers) of Phobos in February 1977 and of Deimos in October 1977 [1,2]. These close encounters have been used to estimate the moons' gravitational constant, GM (the universal constant of gravitation multiplied by the satellite mass). However, the Viking and Mariner 9 spacecraft made numerous flybys of Phobos and Deimos at distances of a few thousand kilometers. The tracking data from these more 'distant' encounters have been processed to estimate the masses of Mars, Phobos, and Deimos.

The data include the Mariner 9 Doppler data from November 1971 through March 1972, and the Viking Orbiter Doppler data from orbit insertion in 1976 through January 1979. The data were processed in arcs three to six days in length using the GEODYN orbit determination program, which has been previously used in the analysis of planetary tracking data [3,4]. We processed the spacecraft-based optical observations of Phobos and Deimos [5,6] to produce the satellite ephemerides used in this study. In order to minimize the possibility of ephemeris error contaminating the GM estimates, we have specifically excluded the tracking data from the close flybys (less than 750 km).

During the Mariner 9 mission, the majority of the Phobos flybys were at distances of 3,750 to 4,500 km. In contrast, the flyby distances to the Viking-1 Orbiter ranged mostly from 1,000 to 4,000 km. The Viking-2 arcs while the spacecraft was at 300 km periapse altitude are only weakly sensitive to Phobos since no flybys occur at distances closer than 5,000 km.

In units of km^3/s^2, we find the following estimates for the GM of Mars and Phobos:

Data	Mars GM	Phobos GM
Mariner 9	42828.29 +/- 0.73	0.54 +/- 0.08
Viking 1	42828.32 +/- 0.04	0.54 +/- 0.02
Viking 2	42828.33 +/- 0.13	0.66 +/- 0.05
VO-1 + VO-2 + Mariner 9	42828.32 +/- 0.04	0.55 +/- 0.02

The Phobos GM estimates may be compared with the estimates obtained by Christensen et al. [1] using 14 Viking flybys within 213 km of 0.66 +/- 0.08 km^3/s^2, and by Kolyuka et al. [7] of 0.722 +/- 0.005 km^3/s^2 using the data from Soviet Phobos II Orbiter. Using the Phobos volume estimate of 5680 +/- 250 km^3 from Duxbury [8], our Phobos GM calculations indicate a bulk density of 1.44 to 1.74 g/cm^3. These values may have implications for both the models of the composition of Phobos and its origin since they can be accommodated only by presuming either a high porosity of the regolith or a high concentration of a low density material such as water ice within the moon [9].

Our estimates for the GM of Mars agree quite closely with the values determined from Null [10] using the Mariner 4 hyperbolic flyby tracking data of 42828.32 +/- 0.13 km^3/s^2; and from O'Neil et al. [11] using the Mariner 9 hyperbolic approach data of 42828.35 +/- 0.55 km^3/s^2. We find that the Mariner 9 Orbiter tracking data, and the Viking 2 Orbiter 1500 km periapse tracking data supply the weakest determinations for the Mars GM, whereas the Viking-1 Orbiter 1500 km and Viking-2 Orbiter 300 km periapse data make the strongest contributions.

The mass of Deimos is dependent on analysis of tracking data from only three close flybys of the moon in October 1977 [2]. During the interval from July 23, through October 30, 1977, the Viking-2 Orbiter made ten flybys between 1,000 and 3,500 km. These distant encounters may be used to obtain an independent estimate of the Deimos mass, as with Phobos.

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