THE RINGS OF MARS: AWAITING DISCOVERY?

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Summary: Phobos and Deimos have long been suspected of creating rings of dusty debris around Mars. Soter [1] first predicted that such rings should exist and numerous theoretical studies have been published since then. Several attempts have been made to directly detect the rings but none have been successful. Additionally, observations from the plasma instruments onboard the Phobos-2 spacecraft have been controversially attributed to Martian rings. We describe proposals to directly observe the rings using the Spitzer Space Telescope and indirectly detect them using data from the magnetometer (MAG/ER) onboard Mars Global Surveyor (MGS).

Theoretical expectations for the rings: Phobos and Deimos are both small, irregularly shaped satellites that orbit relatively close to Mars. Deimos has an approximate radius of 6 km and has a 23,000 km wide orbit (Mars' radius is 3393 km). Phobos has a radius of 10 km and has a 9400 km wide orbit (or within two Mars radii of the Martian surface). Based on their sizes, shapes, and spectral compositions they are thought to be captured asteroids, although dynamical models indicate that such a capture scenario is extremely unlikely; there is currently no resolution to this apparent paradox [2]. The basic mechanism for the origin of the putative rings is the impact of the moons by high speed interplanetary material which then lofts dust into orbit around Mars. Dynamical forces then distribute the dust into circumplanetary rings or tori. Similar dusty rings have been found to be produced by small satellites at Jupiter, Saturn, Uranus, and Neptune (cf. [3] for a recent review).

Krivov and Hamilton [4] give the most recent comprehensive description of the theoretical expectations for the rings. They find that the Deimos ring might be more accurately called a torus with a height of about 7000 km and a width of 50,000 km. The Phobos ring is expected to be much thinner (about 400 km) and only extend to a maximum of about 30,000 km. See Figure 1.

Beyond their basic shape, the rings are expected to have various morphological asymmetries due to the physics of their production and maintenance [5]. The dynamical interplay between the precession of particles due to Mars' oblateness, the originating bodies orbital distance from Mars, and the effects of solar radiation are expected to cause the Phobos ring to offset toward the Sun by approximately one Mars radius and the Deimos torus to be offset toward the Sun by a few Mars radii. The actual size of the offset depends on the dominant size of the grains. Furthermore, at the time of the observing opportunity described below, the Deimos torus is expected to tilted out of the equatorial plane by about 15°.

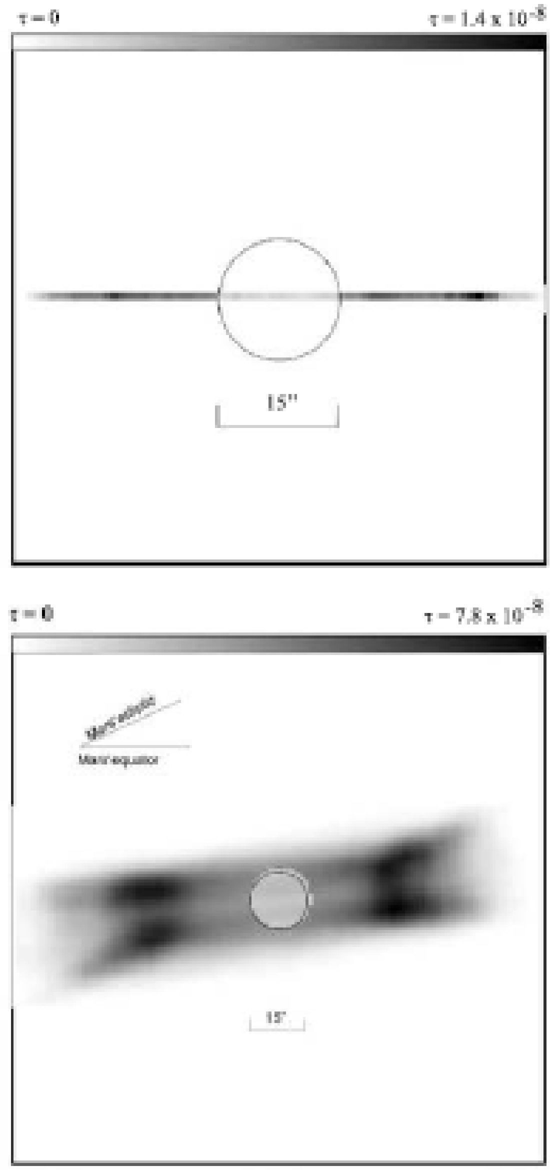

Figure 1 Distribution of optical fluxes from the Phobos ring (top) and the Deimos torus (bottom) as seen from Earth in December 2007. Adapted from [6].

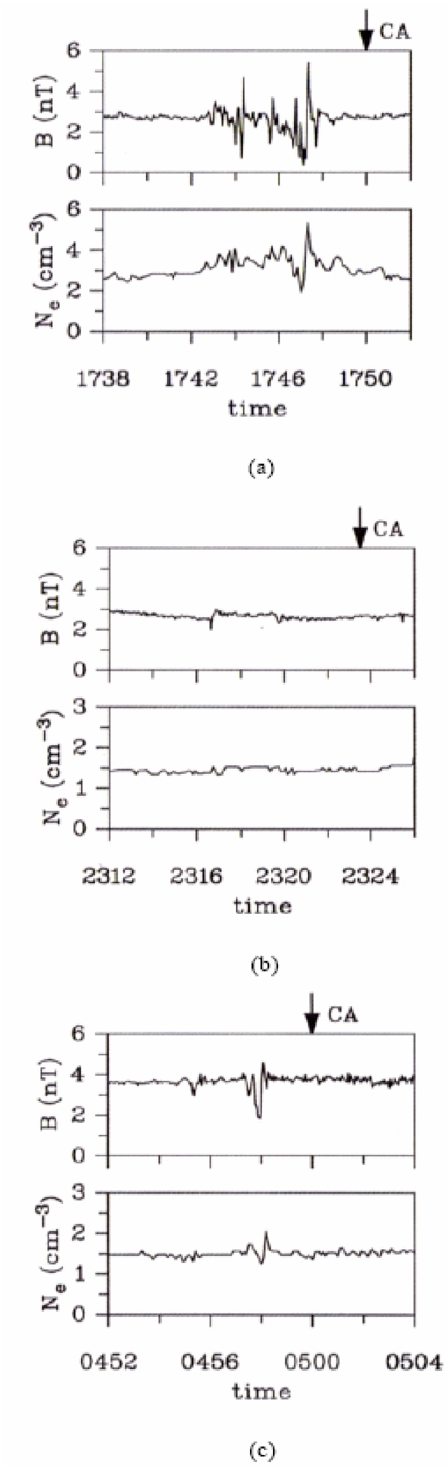

Figure 2 Magnetic field amplitudes and electron densities of the "Phobos events" as measured by Phobos-2 during its (a) first, (b) second, (c) and third elliptical orbits. The arrows marked by CA indicate the time of closet approach to Phobos' orbital path. From [7].

Another testable prediction from the theoretical work is which maintenance mechanism is primarily responsible for sustaining the dust population in faint rings. One scenario has nearly all the dust created and replenished solely interplanetary impactors on the moons. The other scenario has much of the dust in the Phobos ring created by reimpactment from the ring grains themselves onto Phobos. About an order of magnitude difference in τ is expected if the reimpactment mechanism is as expected [5].

Previous attempts at direct observations: Direct observations of the belts have been attempted several times but these attempts have hitherto only been successful at providing upper limits for the optical depths (τ) of the rings. Duxbury and Ocampo [8] used Viking images to put an upper limit of $\tau < 3 \times 10^{-5}$. Three attempts have been made with the Hubble Space Telescope (HST). Two remain unpublished but have been informally reported as negative results while the most recent attempt established upper limits of $\tau < 3 \times 10^{-8}$ for the Phobos ring and $\tau < 10^{-7}$ for the Deimos torus [9].

Previous Indirect Plasma Observations: Low frequency wave processes have played a prominent role in the controversy over the effects of Phobos and Deimos on the near Mars plasma environment. Glassmeier and Espley [10] review the literature regarding these fluctuations and we mirror their discussion in what follows. During the first three elliptical orbits of Phobos-2, the plasma instruments recorded low frequency disturbances in the plasma near the time that the spacecraft crossed the orbital path of Phobos (the "Phobos events") [11,12]. Additional periods of perturbations were observed when the spacecraft was behind Deimos and Phobos with respect to the solar wind flow (the "wake events"). Figure 2 shows magnetic field and electron density measurements for the three Phobos events.

Russell et al. [11] interpreted the magnetic field perturbations as being due to reflected ions in the foreshock region. Dubinin [12] expanded upon this interpretation to explain the perturbations as hot diamagnetic cavities produced by a high flux of backstreaming particles in the foreshock. On the other hand, Krymskii et al., [13] developed a fluid based model for describing the interaction of the solar wind with a torus of dust or neutral gas produced by Phobos. They concluded that there would be insufficient neutral gas to rise to the observed perturbations but that low frequency magnetic fluctuations would be produced by dust-solar wind interaction. Sauer et al. [14] and Baumgartel et al. [15] used fluid and hybrid models to reach a similar conclusion. However, in follow-up work, Baumgartel et al., [7] found that the most recent dust production models were not able to produce sufficient dust to create an observable solar wind interaction and hence they re-examined the interaction with a neutral gas torus. They used a hybrid model for low frequency instabilities related to ring-beam ion/ion wave modes and found that such modes could explain the observations. Similarly, Sauer et al. [16] used a fluid model to illustrate how a putative Deimosian magnetosphere could explain the "wake events". However, most recently, Simpson et al. [17] have performed initial analysis of the magnetometer electron reflectometer MAG/ER data from over 600 orbits of MGS and found no correlation with upstream fluctuations and the locations of Phobos, Deimos, their orbits, or their wakes. They concluded that any outgassing and dust escape from the moons must be too small to produce detectable fluctuations. We intend to verify and expand upon this analysis (see below).

In addition to the work done related to data from the elliptical orbits of Phobos-2, some groups have also used data from the circular orbits to report perturbations that were interpreted as an interaction between a dust torus created by Phobos and the solar wind [12,18] or by a putative Phobosian magnetosphere [19]. However, Verigin et al., [20] showed, using a bow shock model updated for very low solar wind conditions, that these perturbations are more likely to be unusually extreme bow shock excursions.

The December 2007 direct observation opportunity: Faint rings are easiest to see when the observer crosses the ring plane so that the maximum amount of ring material is present along the line of sight. Likewise, given the orbits of Mars and Earth, Mars is most easily observed when it is closest to Earth (i.e. near opposition). The most recent HST attempt (in 2001) took advantage of a rare circumstance where Earth crossed the Mars ring plane very close to opposition; this circumstance allowed the improved lower limits cited above.

These fortuitous circumstances are very rare. In December 2007 there will be another similar opportunity whereas the last comparable event prior to 2001 occurred in 1975 and next event after 2007 will occur in 2022. Thus December 2007 represents the only time for facilities with limited life spans (such as the Hubble or Spitzer telescopes) to attempt this type of observation. The best viewing circumstances depend on the ring opening angle, the Mars-Earth distance, and Mars-Earth angle. The week between 25 Dec. 2007 and 1 Jan. 2008 offers the best combination of observing parameters.

Proposed Spitzer observations: We have submitted a proposal to use the IRAC camera on Spitzer Space Telescope to attempt to photometrically observe the rings of Mars during the December 2007 opportunity described above. Since the rings have not been observed it is not possible to know for sure what their thermal properties will be. However, since they originate from Deimos and Phobos we can start with the assumption that they have properties similar to their parent bodies including a visual albedo of approximately 0.05. Furthermore, assuming that the dust grains act as perfect blackbodies then we can calculate their temperature to be ~ 220 K and to have a corresponding peak wavelength of emission at 13 μm. We find F_ν, the specific flux, by:

$$F_\nu = B_\nu(T)\, A\, (1-e^{-\tau}) \qquad (1)$$

where $B_\nu(T)$ is the monochromatic specific intensity for a blackbody at temperature T, A is the angular size of the emitting region, and τ is the optical depth the source. Using $\tau = 10^{-7}$ (the upper limit from the most recent HST attempt, a temperature of 220 K, and angular size of 30" by 25" for the observed portion of the Deimos torus (see Figure 1), we can calculate F_ν for particular observable wavelengths. At 8 μm (the highest channel of IRAC) we find that the expected flux is 60 mJy. These fluxes are well within the detectable limits of those instruments but extremely challenging for ground based instruments due to the added sky noise. Disentangling these ring-produced fluxes from the strong scattered light from Mars is an important problem that we discuss in detail in our proposal. At the time of writing we have not heard if our proposal will be accepted.

New plasma wave observations: We are also beginning to analyze observations from the MGS MAG/ER dataset to see whether there is a discernible effect from the predicted rings on the plasma environment. Espley et al. [21] have shown that high amplitude, low frequency (< 10 Hz) plasma waves are ubiquitous throughout the Martian system but especially in the magnetosheath region through which Phobos often orbits. Therefore, we will look for opportunities to observe possible Phobos dust effects in the far quieter magnetotail and during times of low solar activity. We will present initial results of this search in our presentation.

Signficance of their discovery: Besides the excitement that their discovery would create, the putative rings are interesting for several reasons. As we have just noted, observations of the rings would give constraints to the theories of ring dynamics. The ring grain production method and the rates of interplanetary impacts would be tested by knowledge of the optical depth of the rings. Confirming the existence of the rings would give insight into the effects on the plasma environment which, in turn, is a topic of great interest given its relation to atmospheric escape and hence climate at Mars. Finally, having knowledge of the dust and debris environment around Mars is a factor regarding spacecraft safety.

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