Mem. S.A.It. Suppl. Vol. 16, 125
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Memorie della
Supplementi

DIAMOND: an impact sensor for the characterization of Martian dust tori

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Abstract. Dust is supposed to be present in several orbits around Mars. The sources of these hypothetical dust belts are expected to be the two Martian satellites Phobos and Deimos, due to their continuous hypervelocity bombardment by interplanetary micrometeoroids. Due to the low escape speeds from the surfaces of the two tiny moons and high ejecta yields, it is expected that a great amount of dust is ejected in areocentric orbit, forming tenuous tori around the orbits of the moons. Time of permanence of dust in the tori depends on grains mass and shape. Different models have been proposed in order to describe the process of generation and stabilization of dust in the tori but several uncertainties do exist about numerical density and size distribution of dust grains. In situ measurements are thus needed, in order to shed light on the extraction, escape and trap processes of particles in the tori.
The instrument DIAMOND (Direct In-situ Analyser and Monitor of Orbiting Natural Dust) has been designed for the detection and characterization of dust in the hypothetical tori of Mars. It has been accepted by the Russian space agency as part of the payload of the Russian Phobos-Soil mission to be launched in 2011. The project is now under evaluation by ASI.

Key words. Impact sensors – Piezoelectric sensors – Martian dust tori – Solar System: dust – dust detection – Phobos – Phobos-Soil mission

1. Introduction

The DIAMOND experiment is the dust detector proposed for the accommodation on the Russian *Phobos Soil* mission.

The Phobos Soil mission is mainly aimed at studying Phobos.

Goals of the mission are:

- Phobos regolith sample return;
- Phobos in situ study and remote sensing;
- Mars remote sensing;
- Martian environment study.

The main scientific objectives are:

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Table 1. Phobos-Soil mission schedule.

Launch	End of 2011
Arrival to Mars	August-September 2012
Elliptical orbits (initial and intermediate)	October 2012
Circular orbit	November 2012-January 2013
Landing on the Phobos surface	February-March 2013

- Study of the Phobos regolith and subsurface layers in situ and (after the sample return) in laboratory;
- The role of asteroidal impacts in forming terrestrial planets, in developing their atmospheres, crusts and volatiles;
- Peculiarities of Phobos orbital and proper motions;
- Study of the Martian environment (dust, plasma, radiation conditions);
- Search for methane and formaldehyde in the Martian atmosphere.

In order to achieve these objectives, the mission accommodates different instruments: infrared, gamma, neutron, laser and Moessbauer spectrometers, a secondary ions mass spectrometer, a gas-chromatograph complex, a thermodetector, a long wave radar, a seismometer, a plasma set, a solar sensor, an ultrastable oscillator, panoramic and stereo cameras, a navigation TV-system and the DIAMOND dust detector. The schedule of the mission is reported in Tab. 1.

The primary objective of the DIAMOND experiment is to search for dust belts around Mars.

2. Dust in the circum-Martian environment

In 1971 Soter was the first to suggest that the Martian moons could represent a source of dust for the circum-Martian space due to their continuous hypervelocity bombardment by interplanetary micro-meteoroids (Soter 1971). Due to the low escape speeds from the surfaces of Phobos and Deimos and high ejecta yields, it is expected that a great amount of dust is ejected in areocentric orbit, forming tenuous tori around the orbits of the moons.

So far, only 2 dedicated photometric measurements have been performed in order to observe the putative dust belts. The first was made by Viking Orbiter 1 in 1980 (Duxbury & Ocampo 1988) and the second by the Hubble Space Telescope (3000 times more sensitive than Viking cameras) in 2001 (Showalter et al. 2006). Both the attempts gave negative results. The upper limit of the normal optical depth of the putative tori has been set to $\tau \leq \sim 3{\cdot}10^{-8}$ for the Phobos torus and $\tau \leq \sim 10^{-7}$ for the Deimos torus. Some additional indication for the presence of dust around Phobos came from in situ measurements by the Phobos-2 spacecraft. In fact its magnetometer registered short-lasting fluctuations of the magnetic field and plasma parameters during a Phobos orbit crossing (Dubinin et al. 1990). Anyway, these events can be alternatively attributed to the presence of gaseous rather than dusty torus (Dubinin 1993),(Baumgärtel et al. 1996).

Theoretical studies have shown that the dynamics, sinks and lifetimes of dust debris lost by the Martian moons strongly depend on the grain size. So, the whole dust complex has been classified in 4 populations (Tab. 2).

According to recent models (Krivov et al. 2006), for population I_P particles in the Phobos torus (radius: 10 - 1000 μm) we should expect a number density n $\sim 10^3$ particles km^{-3}, while for population II_P we have n $\sim 10^4$ - 10^5 particles km^{-3}. This estimation is very uncertain because it is determined by poorly-known distributions of ejecta from hypervelocity impacts of interplanetary micrometeoroids onto the presumably loose, regolith-covered Phobos surface.

Table 2. Populations of circum-Martian dust. Extracted from (Krivov 1994) and (Krivov, & Hamilton 1997). P = Phobos; D = Deimos. Number density: high $\sim 10^4 - 10^5$ km^{-3}, medium $\sim 10^3$ km^{-3}, low $\lesssim 10^2$ km^{-3}.

Pop.	Radii (μm)	Number density
0	$\gtrsim 1000$	Low
I	10 – 1000 (P)	Med (P)
I	5 – 1000 (D)	High (D)
II	0.3 – 10 (P)	High (P)
II	0.3 – 5 (D)	Low (D)
III	$\lesssim 0.3$	High?

Shape and extension of both Phobos and Deimos tori vary with particle size and Martian season.

Here we consider for Phobos torus an internal radius $R_i = 2\ R_M$ and an external radius $R_e = 4\ R_M$, where R_M is the Martian radius, and all the radii are considered centered in the Mars center.

For Deimos we consider $R_i = 2.5\ R_M$ and $R_e = 10\ R_M$.

Particles in circular orbits around the tori have velocities ranging from $v_P(2R_M) = 2.5$ km/s to $v_P(4R_M) = 1.77$ km/s, in the case of Phobos torus, and from $v_D(2.5\ R_M) = 2.24$ km/s to $v_D(10\ R_M) = 1.12$ km/s, in the case of Deimos torus.

According to presently available information about mission profile, the spacecraft will have several orbits around Mars in the equatorial plane.

It is foreseen to have two elliptical orbits and two circular orbits. The first circular orbit will be at about 500 km above the orbit of Phobos (observational orbit), the second one will be a ”quasi-synchronous” orbit: moving along it, the spacecraft will be always near Phobos at a distance of 50 - 130 km.

Comparing spacecraft and particles velocities it results that their relative velocity v_{rel} is around 100 - 1000 m·s^{-1} in the elliptical orbits and much lower ($v_{rel} \sim 10 - 100$ m·s^{-1}) in the circular orbits.

During the elliptical orbits the spacecraft will cross the tori for a very little time, staying for about 2 – 3% of the orbital period in the Phobos torus and for about 6 - 9% of the orbital period in the Deimos torus. This is equivalent to a crossing time of about 2 days in the Phobos torus and about 8 days in the Deimos torus.

So, during elliptical orbits DIAMOND will have a little chance to detect impact events. Nevertheless, the elliptic orbit would have a major advantage: a part of it would lie within the probably dustier Deimos torus.

Most of the impact events are expected in the circular orbits. Moreover, during the synchronous orbit one could probably try to detect “fresh” ejecta from Phobos, or the Phobos “dust atmosphere”. So, assuming an impact velocity equal to v_{rel} in the circular orbits: v = 10 – 100 m·s^{-1}, we can estimate the impact rate over DIAMOND collecting area $S = 4 \cdot 0.01$ m^2 as:

- Pop $I_P \sim nvS \sim 4{\cdot}10^{-7} - 4{\cdot}10^{-6}$ hits s^{-1}, or 0.03 - 0.3 impacts / day when the spacecraft is in the Phobos torus.
- Pop $II_P \sim nvS \sim 4{\cdot}10^{-6} - 4{\cdot}10^{-4}$ hits s^{-1} , or 0.3 – 30 impacts / day when the spacecraft is in the Phobos torus.

Assuming the bulk density of tori particles $\rho = 2$ g·cm^{-3} and the impact velocity v = 100 m·s^{-1} we have:

- Population I_P grains have momentum between $\sim 8 \cdot 10^{-10}$ and $8 \cdot 10^{-4}$ Ns
- Population II_P grains have momentum between $\sim 2 \cdot 10^{-14}$ and $8 \cdot 10^{-10}$ Ns

3. DIAMOND experiment

The DIAMOND instrument is based on the use of the Impact Sensor (IS) concept developed for the GIADA instrument, presently flying onboard the ESA Rosetta mission. The selection of this detection system is mainly based on constraints about resource availability for the for Phobos-Soil mission. Other complementary or alternative detection methods, based on optical detection are, therefore, not considered here, as they would imply larger resource requests (mainly mass and power).

The Impact Sensor (IS) detection method is based on an aluminium square diaphragm

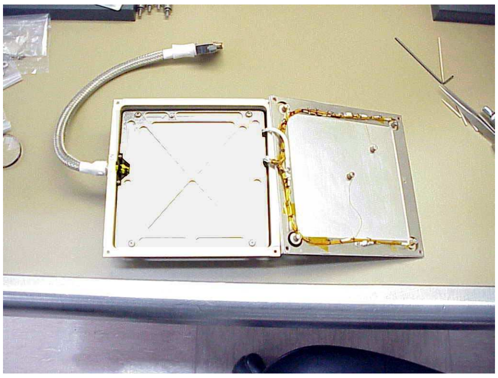

Fig. 1. The impact sensor developed for GIADA. The system is open to show the positioning of the piezoelectric sensors below the aluminium sensing plate. The proximity electronics is integrated below the sensor.

exposed to the impact of grains. The plate is equipped with five PZT sensors, placed below its corners and the centre (Fig. 1). When a grain impacts the sensing plate, flexural waves generated on the plate are detected by the piezoelectric crystals. The maximum displacement of these elements is directly related to the impulse imparted, and the displacement of the crystal produces a proportional potential. Through calibration, a known impulse may be equated with a specific charge produced on the electrodes of the PZT crystals. The detected signal is monotonically related to the momentum of the incident grain (Esposito et al. 2002). Thus, the impact sensor is capable to provide information about the flux and the momentum of the impacting particles. If the relative velocity of the sensor with respect to the local environment is known, the mass of each particle can be also derived.

The performances of the IS have been checked, during GIADA calibration sessions, with real grains with different velocities (from 1 $m{\cdot}s^{-1}$ up to some hundred $m{\cdot}s^{-1}$), sizes (up to some hundred μm) and composition (i.e. silicates, carbon). Thus, the system is fully calibrated and able to detect particles with momenta in the range $6.5{\cdot}10^{-10}$ – $4.0{\cdot}10^{-4}$ $kg{\cdot}m{\cdot}s^{-1}$ (Colangeli et al. 2004).

In the configuration of GIADA-IS it is already possible to fully detect particles in the Pop. I_P. For the DIAMOND experiment, the choise of new, more sensitive, piezoelectric sensors and the new design of the proximity electronics will shift the detection range of two orders of magnitude (10^{-12} – 10^{-6} $kg{\cdot}m{\cdot}s^{-1}$) in order to be able to detect also particle in the Pop. II_P.

4. Conclusions

The DIAMOND experiment is the dust detector selected to be accommodated on the Russian spacecraft Phobos-Soil to be launched in 2011.

DIAMOND is based on the design of the Impact Sensor of the instrument GIADA now on-board the ESA Rosetta mission. The expected performances of DIAMOND will allow the detection of particles in the Pop. I_P and Pop. II_P of putative Martian tori.

The instrument will be developed under a cooperation between INAF-Osservatorio Astronomico di Capodimonte (Naples, Italy) and the Moscow Space Research Institute (IKI) in Russia.

The DIAMOND project is now under evaluation by the Italian Space Agency.

Acknowledgements. This work has been supported by ASI in the framework of the contract n. I/015/07/0 ”Solar System exploration Studies” - subtask 3540.

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