OBSERVATIONS OF THE MARTIAN ATMOSPHERE FROM PHOBOS GRUNT MISSION.

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Phobos-Grunt project:

The main goal of the Phobos-Grunt project (Zelenyi et al., 2010) is to deliver samples of the material of Phobos to the Earth in order to perform comprehensive studies on them at ground laboratories. This aspect of the mission is considered in detail by Galimov (2010). The scenario of the Phobos mission is as follows (Akim et al., 2010): the launch is scheduled in the end of 2011 by Zenith rocket, followed by the 11-months interplanetary cruise to Mars, and insertion into the orbit around Mars. After the release of Chinese satellite YH-1 the orbit will be circularized and made close to the Phobos orbit. A period of remote observations of Phobos and Mars from this orbit is concluded with the approach and landing to Phobos. The collection of the Phobos samples, their loading into the return capsule, and the lift-off of the return rocket is planned within the shortest delay. The main spacecraft will then remain on the surface of Phobos to conduct in situ measurements on the surface, and other studies.

The scientific goals of the project cover a wide spectrum of problems related to the genesis of the Solar System. This task is primarily addressed by studying the relic material of Phobos. Other scientific problems are as follows: (i) to study the physicochemical properties of Phobos as a celestial body, to assess the origin of the Martian satellites and, possibly, satellite systems of other planets; (ii) to determine accurately the parameters of Phobos' orbit and proper motion, to study its internal structure and orbital evolution; (iii) to study the Mars environment: electric and magnetic fields, the interaction with the solar wind, the escape of oxygen ions from the atmosphere, to address the history of water on Mars; and (iv) to study the Martian atmosphere (to be addressed in detail in the present abstract).

The scientific problems and the science program of the project are presented by Zelenyi et al., (2010); Marov (2010). The most of scientific instruments are described in a special issue of Solar System Res. (see Zelenyi and Zakharov, 2010). The list of scientific experiments of the mission is given in Table 1. In addition to this list, two optional instruments are being prepared after the launch of Phobos-Grunt was shifted to 2011. These are the IR channel of the MicrOmega microscope, and TIMM-2 occultation spectrometer for the Mars atmosphere to be described later.

Phobos-Grunt Mars-related studies:

Although focused of the sample return, and in-situ studies of Phobos, the Phobos-Grunt mission provides opportunities for in-depth studies of Mars environment, atmosphere and climate. The orbit of the spacecraft around Mars, nearly synchronous with the Phobos orbit at 2 Mars radii, and 3 revolutions per sol allows on one hand traversing all the plasma boundaries, and on the other hand monitoring the diurnal and other short-scale atmospheric cycles, which escape detection from the mapping orbit or, e.g., the Mars-Express elliptical orbit. In turn, the studies of Mars from the Phobos mission will be limited in time to a few months before the landing, and the observed latitudes are limited to equatorial – low latitude range.

The observations of Mars, and the studies of its environment will start immediately after the insertion into the orbit around Mars. Few weeks in the first intermediate orbit with a period of 3d and a few months in the "observational" orbit, 540 km above the Phobos' orbit, and finally from the quasisynchronous orbit (Akim et al., 2010), provide the main opportunities for these studies. Solar occultation from these orbits occur 3 times per sol. The final scenario of the mission with exact dates is yet to be reported. Due to energy and radiovisibility constraints, the landing site is chosen on the outer side of Phobos, so the optical observations after the landing would be most likely impossible. Still certain plasma experiments could operate from the surface of Phobos as well, although Phobos will introduce biases, the SC resources would be limited, and the priority will be given to in-situ investigations. The leaving of Phobos with the entire spacecraft after the completion of the in-situ studies is technically feasible, and is not excluded. This is a question of prioritizing celestial mechanics and seismic experiments, which demand long lifetime on Phobos, and the observations of Mars.

Visual observations of Mars. The dedicated experiment of visual monitoring of Mars (multicolor TV camera) to observe seasonal cycles has been cancelled out of the payload after the landing site moved to the side of Phobos opposite to Mars. Still occasional observations of Mars before the landing will be possible with the service TV system TSNG, which consists of two narrow-angle cameras with a focal length of 500 mm and two wide-angle cameras with a focal length of 18 mm (Avanesov et al., 2010). All cameras are panchromatic (0.4-1 μm) and are based on Kodak 1020 1kx1k CCDs.

Spectrometers to study Mars.

The Mars atmosphere and climate will be studied from intermediate and observational orbits by means of two infrared spectrometers, AOST and TIMM-2, described in detail below. Both spectrometers have the solar occultation capability, and are complementary in spectral range and spectral resolution. AOST will be focused on the thermal structure of the atmosphere and diurnal cycles, while TIMM-2 is fully dedicated to sensitive measurements of minor constituents. The instruments will be redundant in terms of methane detection.

Mars ionosphere and escape will be characterized by several instruments onboard Phobos spacecraft. The FPMS suite consists of search-coil and flux-gate magnetometers (DC: ±1µT with an accuracy of 0.1 nT; AC: 10^{-6} nT at 10Hz-100kHz), ion composition analyzer for the energy range of 10eV-15 keV provided by Swedish IRF in Kiruna, and a panoramic ion sensor for the range of 3eV-3keV (Vaisberg et al., 2010). Also, the parameters of the Martian ionosphere will be studied by means of two-frequency radiooccultations between the Phobos-Grunt spacecraft and the YH-1 Chinese satellite (Breus et al., subm).

Radioccultations of the neutral atmosphere of Mars using the communication system of the Phobos-Grunt spacecraft and the ultrastable oscillator (USO) could be envisaged, but are not supported by any science team at this moment.

Table 1. The list of scientific instruments on board Phobos-Grunt spacecraft

Instruments	Objectives	Mass, kg	PI, cooperation
Instruments for investigation of regolith and Phobos inner structure			
Gas-Chromatograph package TDA, GC, MAL,	Thermo-Difference Analyzer, TDA Gas-Chromatograph, GC, TDLAS Mass-Spectrometer, MAL Volatiles in regolith	4.2 4.2 3.1	M. Gerasimov, IKI, Vernadsky Inst., LATMOS, MPS Lindau, Hong-Kong Univ.
Mossbauer Spectrometer, MIMOS	Phobos mineralogy	0.9	G. Klingelhofer, IAAC Mainz, D. Rodionov, IKI
Gamma-spectrometer, FOGS	Element composition of the surface	4.35	L. Moskaleva, Vernadsky Inst
Neutron Spectrometer, HEND	Hydrogen in the surface	3.8	I. Mitrofanov, IKI, ESTEC
IR Spectrometer, AOST	Mars atmosphere, Phobos mineralogy	4.0	O. Korablev, IKI, LATMOS, DLR, IFSI.
Laser time-of-flight Spectrometer, LASMA	Element composition of regolith	2.6	G. Managadze, IKI, UniBern
Secondary Ions Mass Spectrometer, MANAGA	Element composition of regolith	1.9	G. Managadze, IKI
Thermo-Detector, TERMOFOB	Regolith thermal properties	0.95	M. Marov, Vernadsky Inst, Polish Space Res Inst.
Long-wave Planetary Radar, LWR	Phobos inner structure, dielectric properties	3.28	V. Smirnov, Kotelnikov Inst.
Seismometer, SEISMO+GRAS	Phobos inner structure, gravimetry	1.05	A.Manukin, O. Khavroshkin, Schmidt Inst, IKI,Vernadsky Inst.
Instruments for Mars environment study and celestial mechanics experiments			
Dust counter, METEOR	Mars dust environment,	3.74	Vernadsky Inst., IKI
Plasma experiment, FPMS	Ion spectrometer, Electron spectrometer, Magnetometer	4.75	A. Skalsky, IKI IRF Kiruna, IKI Lvov
Star sensor, LIBRATION	Phobos libration study	0.5	A. Lipatov, IKI
Ultra-stable oscillator, USO	Celestial mechanic experiment	2.3	V. Gotlib, IKI
Total mass of science instruments		45.62	
Service subsystems related to science			
TV system, TSNG	Landing support Phobos surface mapping	3.0	G. Avanesov, IKI
Robotic arm	Regolith sampling; loading of samples for return, TDA, LASMA, MicrOmega; Mossbauer positioning	4.5	O. Kozlov, IKI Space Res Inst. Warsaw
Panoramic and Stereo TV Cameras, MicrOmega	Panoramic, stereo and close-up imaging, Microscope with color illumination	1.5	J.-P.Bibring, IAS O. Korablev, IKI

Fourier-Spectrometer AOST:

The AOST Fourier spectrometer developed for the Phobos-Soil project is intended for remote probing in the 2.5-25 μm region The experiment is dedicated to the investigation of the Martian atmosphere by solar eclipses and nadir observation, and investigating the surface characteristics of Mars and Phobos. The spectral range includes both solar, and thermal radiation of the celestial body being studied.

The design of the instrument is described in Korablev et al. (2009). The key element of AOST is double pendulum 25 mm aperture interferometer with cubic corner reflectors. The KBr beamsplitter determines the red boundary of the spectral range. The $LiTaO_3$ pyroelectic detector operates at ambient temperature. The field-of-view angle is 2.5°, and the time to record one interferogram ranges from 5 to 50s. The instrument (Fig. 1) consists f the electronic block and a rotating turret. The turret with the interferometer inside rotates around the "vertical" axis at 183°. The second degree of scanning is provided by the optical head with a flat mirror, rotatable at 360° around the "horizontal" axis. As a result the opening of the instrument can be pointed to any point of the sphere, including calibration blackbody simulator. The device includes double thermal-stabilization system. The mass of the device is 4kg, and its power requirement is 10W.

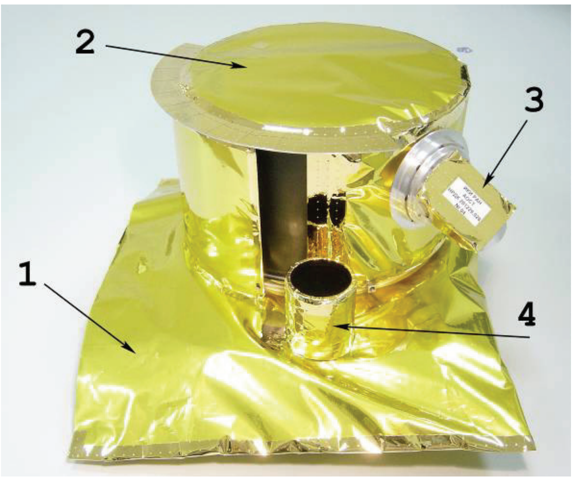

Fig. 1 AOST flight model. 1- electronic block; 2- rotatable turret containing thermally-stabilized interferometer; 3- scanner mirror head; 4- blackbody simulator.

The science goals and operations of the AOST experiment on Phobos-Grunt mission are described by Korablev et al. (2010).

In solar occultation, the main goal of the instrument is to measure the methane, and to assess the profiles of H_2O, D/H, and aerosols. The instrument observes the full disk of the sun (the disk is encompassed by the FOV of 2.5°), achieving the maximum apodized spectral resolution of $0.9cm^{-1}$. The time to measure one interferogram is 5s, and the expected S/N is ~500. During the ~100s occultation 20 spectra could be measure, allowing a theoretical detection threshold of ~1 ppb.

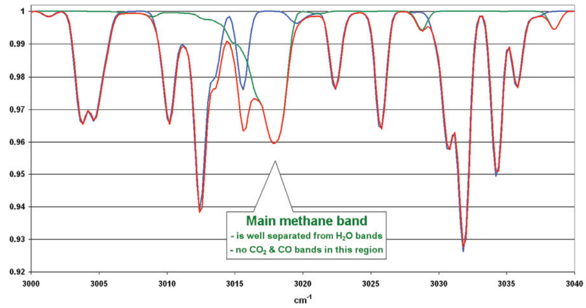

Fig. 2 Synthetic transmission of the Mars atmosphere on the limb at the altitude of 10 km (red). Methane at 10ppb (green) and H_2O at 300ppm are shown separately. Assumed spectral resolution is 0.9 cm^{-1}.

In nadir observations of Mars, the main goal is to study the diurnal variations, and, in the case of extended orbital mission seasonal variations of vertical profile of the atmosphere up to 55km, H_2O contents, dust and clouds. The projection of the instrument FOV on the surface will be about 290km. The scanner allows to extend the observation up to the mid-latitudes of Mars. With this limitation, any point of the Martian surface from the observational orbit (T = 7.65h) can be sounded twice per day, and the consecutive measurements will be separated by 10.77h in local time. Alternatively, scanning allows to observe the chosen location during 42 min to study short-term variations.

In nadir the spectral resolution of the instrument is $2cm^{-1}$, and the time to measure one interferogram is up to 50s. The relatively high spectral resolution allows accurate retrievals of the thermal structure of the atmosphere from the 15-μm band of CO_2 comparable to that of PFS or IRIS. The water vapor will be studied in the band at 6.3μm, and on the edge of the 40-μm band. Surface temperature can be retrieved from brightness temperature at 1300 cm^{-1}; aerosol absorption band allow to distinguish clouds and dust. The S/N for a single spectrum in nadir depends on the surface temperature and for the noon is estimated as 80-100 at 500 cm^{-1}, ~10 in the center of the 15-μm CO_2 band (680 cm^{-1}), 70-80 at 800 cm^{-1} and ~ 20 at 1300 cm^{-1}. At night the S/N is lower: 40-50, 10, 20 and 2, accordingly.

The infrared spectrum of Phobos, to study the mineralogy and the thermal properties of its surface is another task of AOST. The footprint of the FOV on Phobos from the quasisynchronous orbit will be ~2km; the scanning agility allows local measurements on the landing site.

The radiolink capacity of Phobos-Grunt limits the data volume of AOST to 4 Mbytes per day, allowing to transfer ~500 interferograms.

Echelle-spectrometer TIMM-2: TIMM-2 is the solar occultation spectrometer to study the atmosphere of Mars in a number of spectral ranges between 2.3 and 4.1 µm with a resolving power λ/Δλ exceeding 20 000 across the spectral range. On the Phobos-Grunt mission TIMM-2 complements end enhances the capabilities of the AOST interferometer in solar occultation, providing a factor of 10 better spectral resolution, and a narrow FOV for several limited spectral intervals. The experiment targets a sensitive measurements of methane, profiling of D/H, and other atmospheric gases (H_2O, O_3, CO, CO_2 isotopes, search for undetected species, potentially related to geophysical and exobiological activity), and the profiling and characterizing of aerosols.

TIMM-2, a late and still optional addition to the Phobos payload, occupies on the spacecraft the resources of the non-delivered thermal infrared imager, which explains its odd acronym. TIMM-2 is conceived on the basis of the flight-proven instruments (SOIR on Venus Express, and RUSALKA on ISS.), ensuring high heritage at all technical and management levels and phases of the development. TIMM-2 is built by IKI with the participation of LATMOS. The target date for the completion of the flight hardware is February 2011.

TIMM-2 consists of two key elements (see Fig. 3): an echelle-spectrometer, and an acousto-optic tunable filter (AOTF) used for preselection of the diffraction orders. Such type of an instrument was proposed for atmospheric studies by Korablev et al. (2002), first implemented on Venus Express (Nevejans et al., 2006) and then on the ISS (Korablev et al., subm). SOIR on VEX operates in the range of 2.3-4.3 µm with the resolution ~20 000. This is the only example of a deep space spectrometer attaining such resolving power. TIMM-2 is a compacted modification of SOIR with different grating (24.4 gr/mm blazed at 70°), allowing only a loose sampling of the spectral range (distant diffraction orders, see Fig. 4). The detector is similar to that of SOIR (SOFRADIR 256x320 MCT array with Ricor cooler). The instrument employs mostly reflective optics, and the custom AOTF. The FOV determined by the spectrometer slit is 0.5x40 arc min, to be oriented parallel to the limb. To extend the sounded spectral range towards the UV, mostly to characterize the optical properties of aerosol, the instrument includes 5 separate photometric channels at 250 (ozone), 340, 405, 520, and 700 nm. TIMM-2 weighs 3.5 kg, and requires 12W of power.

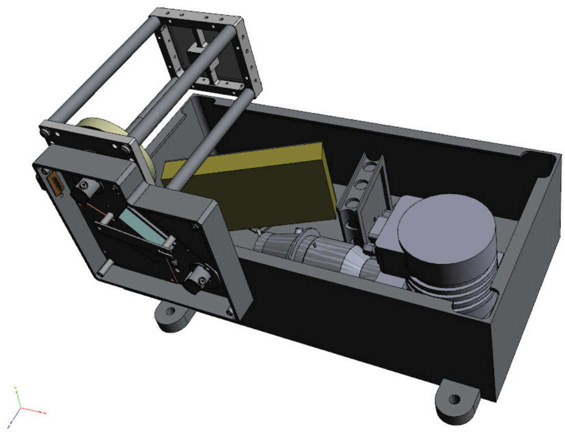

Fig. 3. 3D layout of TIMM-2. Photometric channels and the cover are not shown.

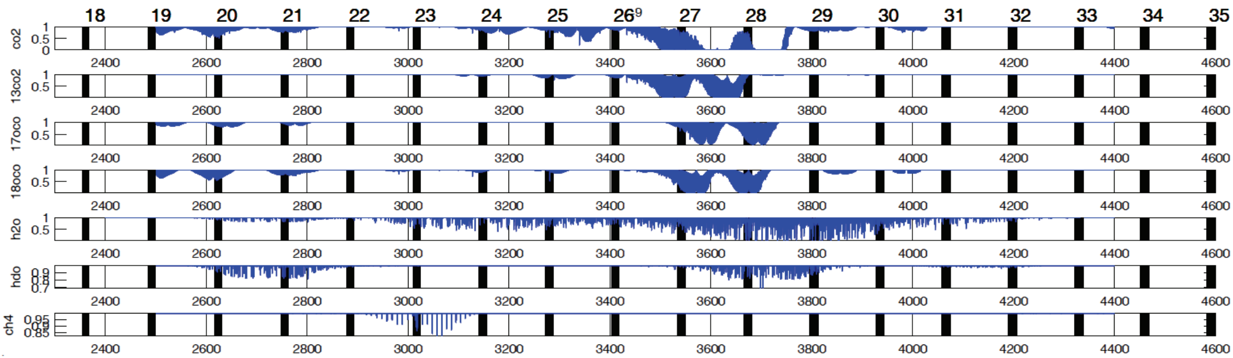

Fig. 4. Spectral coverage of TIMM-2 shown as solid vertical bars on the wavenumber horizontal scale, and a number of synthetic transmission spectra indicating some target atmospheric gases.

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