Phobos Sample Return Project

Space Research Institute
Vernadsky Institute of Geochemistry
Radioengineering and Electronics Institute
Apply Math Institute
Lavochkin Association
Goals of the Mission

- Phobos regolith sample return,
- Phobos in situ study and remote sensing,
- Martian environment study
- Mars monitoring

Peculiarities of the mission:

1. Samples return
2. Mars system science:
   - Martian moons (regolith, internal structure, origin, evolution),
   - Martian environment (dust, plasma, fields),
   - Mars (surface and atmosphere global dynamics)
Phobos and Deimos: similarity and difference

Problems driving to study the Martian satellites:
- origin of the Martian satellites,
- nature and characteristics of the regolith (relict matter?),
- difference in characteristics of the surfaces of Phobos and Deimos,
- low density,
- internal structure,
- peculiarity of the orbital and proper motion,
- dust tori?

<table>
<thead>
<tr>
<th></th>
<th>Phobos</th>
<th>Deimos</th>
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<tbody>
<tr>
<td>Dimensions</td>
<td>26.6x22.2x18.6 km</td>
<td>15.0x12.4x10.8 km</td>
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<tr>
<td>Density</td>
<td>1.9 ±0.1 g/cm³</td>
<td>1.8 ±0.3 g/cm³</td>
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<tr>
<td>Reflectance</td>
<td>0.071 ±0.012</td>
<td>0.068 ±0.007</td>
</tr>
<tr>
<td>Taxonomy</td>
<td>T (or B, or D)</td>
<td>D (?)</td>
</tr>
<tr>
<td>Morphology peculiarities</td>
<td>long fossas</td>
<td>no fossas</td>
</tr>
<tr>
<td>Gravity</td>
<td>0.54 cm/c²</td>
<td>0.31 cm/c²</td>
</tr>
<tr>
<td>Circular orbit</td>
<td>R=9378 km (2.76 Rₘ)</td>
<td>R=23459 km (6.9 Rₘ)</td>
</tr>
<tr>
<td></td>
<td>T=7h 39 min, i=24⁰</td>
<td>T=30h 21 min, i=24⁰</td>
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<tr>
<td>Proper motion</td>
<td>Synchronous rotation,</td>
<td>Synchronous rotation</td>
</tr>
<tr>
<td></td>
<td>libration: T=10h, A=7⁰</td>
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</tbody>
</table>
Scientific objections

- study physical and chemical characteristics of the Phobos regolith and subsurface layers *in situ* and under laboratory conditions - these data can provide information on properties of primordial matter of the Solar system;

- study of the role played by asteroidal impacts in the formation of terrestrial planets, in the evolution of their atmospheres, crusts, and inventories of volatiles;

- study of the origin of the Martian satellites and their relation to Mars - these data can help in our understanding of their evolution and the origin of satellite systems near other planets;

- search of possible trace of life or paleolife;

- study of peculiarities of orbital and proper motion of Phobos, what is important for understanding their origin, internal structure, celestial mechanics applications;

- study physical conditions of the Martian environment (dust, gas, plasma components) what is important to study of treatment processes of small body regolith under influence of external conditions and creation of engineering model of the Martian environment for future Martian missions;

- Monitoring of dynamic of the Martian atmosphere and seasons climate changing.
Injection into the Earth orbit (H=200 km)

SC deceleration by means of PS into 3-day Mars orbit

Observation orbit cruise. Rendezvous and landing maneuvers

Descent module braking

Descent module landing

PS 1st ignition, injection into the Earth parking orbit

PS separation injection phase

PS 2nd ignition, injection phase

Mars-Earth cruise TCMs

TCMs

Re-entry

Soil sampling

Observation orbit by means of PS

Wissenschaftliche Zeitschrift

Vol. 20, Sonderheft, 1971

PHOBOS SAMPLE RETURN MISSION PROFILE
Launch of the spacecraft and transfer into the interplanetary trajectory

**Launch:**
Baikonur

**Base orbit:**
circular, 200 km, 2.8 revolutions (4 h.)

**Intermediate orbit:**
A = 11100 km, p = 230 km, T = 3.65 h. 7 revolutions (26 h.)

**Interplanetary trajectory:**
Asymptotic velocity 3.3 km/s

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
The Earth-Mars Flight

interplanetary flight Earth-Mars
(7.10.2009 - 29.8.2010)

Mars orbit
Earth-Mars trajectory
launch from the Earth
the Earth position at the arrival of SC to Mars
arrival to Mars
corrections

Σ V = 45-60 m/s

DSN
Bear Lake (Moscow), Ussuriisk, Evpatoria

3 corrections

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
Insertion into the first Martian orbit

Deceleration
V~800 m/s

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
Orbits around Mars

1-st intermediate orbit
P=800 km, a=79000 km, T=3 d.

2-d intermediate orbit
P=9910 km, a=79000 km, T=3.3 d.

Observation orbit
Circular, 9910 km (about 500 km higher than the Phobos orbit), T=8.3 h.

Quasi synchronous orbit
Similar to the Phobos orbit

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
SC at the QSO

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
Approaching Phobos and landing

vertical descent

transfer trajectory

12 km

T ~40 min

turnoff from quasy-synchronous orbit

Phobos

-50,000

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
Shaping of the return sc orbits

LAVOCHKIN ASSOCIATION, APPLY MATH INSTITUTE
Entry into the atmosphere and landing at the surface of the Earth
# MAIN CHARACTERISTICS OF THE MISSION

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Launch site</td>
<td>Baikonur Cosmodrome</td>
</tr>
<tr>
<td>Interplanetary Earth – Mars cruise time</td>
<td>10 – 11.5 months</td>
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<tr>
<td>Interplanetary Mars – Earth cruise time</td>
<td>10.5 – 11.5 months</td>
</tr>
<tr>
<td>Mission total time</td>
<td>~ 33-34 months</td>
</tr>
<tr>
<td>SC mass</td>
<td>8,120 kg</td>
</tr>
<tr>
<td>Scientific equipment mass</td>
<td>50 kg</td>
</tr>
<tr>
<td>Phobos soil samples mass</td>
<td>0.2 kg</td>
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</tbody>
</table>
PHOBOS SAMPLE RETURN
SC MARS ORBIT INSERTION CONFIGURATION

Descent module
Return vehicle
Cruise module
Cruise module PS
Insertion PS
Payload

*Instruments for sc navigation and sampling*
- TV-system
- Mechanical device for sampling

*Instruments for study of Phobos regolith and internal structure*
- Panoramic camera
- Gas-chromatograph
- Messbauer spectrometer
- Gamma-spectrometer
- Neutron spectrometer
- Laser TOF spectrometer
- Mass-spectrometer of secondary ions
- IR spectrometers
- Thermoprobe
- Long wave radar
- Seismometer

*Instruments for Martian environment study*
- Plasma, waves and magnetic field detectors
- Dust particles detector
Manipulator Instrument

- Pointing ±5 mm
- Length – till 1000 mm
- Pressure – till 5 N
- Sample volume - 0.5–1.5 cm³
- Mass - 3.5 kg

Cooperation – IKI, “RAROS”, Lavochkin Association

MESSBAUER SPECTROMETER

- Source Fe⁵⁷
- Mass 0.3 kg
- Cooperation – Mainz University, Germany, IKI,
Investigation of the ability and chemical composition of volatile components in the soil of Phobos (bound water, organics, noble gases, etc.)

- to measure the quantity of individual gas components in a complex gas mixture, which is evolved from the soil sample by pyrolysis, due to their separation by the time of retention in a chromatographic columns and detection by TCD sensor.
- to identify chemical composition of gas components by their calibrated time of retention and by spectroscopy of specific absorption lines for H₂O, CO₂, and CH₄ gases.
- to measure isotopic composition of C, H, and O elements by spectroscopy of specific absorption lines for H₂O and CO₂ gases.

Objectives

Mass 0.5 kg
T till 1000⁰

Mass 4.5 kg
Sensitivity > 10⁻⁹

Mass 3.5 kg
Mass range 1-150 a.e.m.
Nucler – physical experiments

The study of the Phobos rocks chemical composition. The measurement of the chemical elements concentration on the Phobos surface: the rock-formed elements (from H to Fe) and the natural radioactive (K, Th, U) ones.

Range of measurements: 0.3 - 9.0 MeV
Resolution: 1-2%
Mass: 5.5 kg
Cooperation: GEOHI, SNIIP

**GAMMA-SPECTROMETER**
**PhGS**

**NEURTON SPECTROMETER**
**HEND**

Scientific tasks:
- studying composition of Phobos regolith;
- searching of hydrated materials or / and water ice on the subsurface of Phobos;
- development of physical model of radiation background on the surface of Phobos and on Martian orbits.

Range of measurement:
- Neutrons: 0.4 eV – 15.0 MeV
- Gamma-rays: 100 keV – 10 MeV

Energy resolution of LaBr3 crystal: 3% for 662 keV (size h=5.08cm d=5.08cm).

Cooperation: IKI
**Mass spectrometry**

**Laser Time-of-flight Mass Spectrometer**
**LASMA**

Quantitative analysis of elemental and isotopic composition of Phobos’ regolith at 30-50 µm

Mass range - 1-250 a.e.m.
resolution 300
Mass 1.4 kg

Cooperation – IKI, Belorussia

**Mass Spectrometer of secondary ions**
**MANAGA-F**

Mass range - 1-300 a.e.m.
resolution > 100
sensitivity 1 ppm
mass 1.4 kg.

Cooperation – IKI, «Polus»,...
IR - spectroscopy

<table>
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<tr>
<th>Thermal Infrared Multispectral Mapper</th>
<th>Fourier Spectrometer</th>
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<tr>
<td>TIMM</td>
<td>AOST</td>
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</table>

**Measurements of the Phobos thermal radiance in 35 spectral channels.** The instrument produces spectral images up to 40x40 pixels. Each pixel represents the interferogram of the corresponding surface on Phobos. By means of Fourier analysis, each interferogram is transformed to a spectrum.

- Study surface mineralogy and physical properties of Phobos using multi-spectral thermal-infrared images (7 - 15 µm).
- Mapping Phobos in both day and night multi-spectral infrared images at 0.4-1.0 km per pixel resolution.

**The specific objectives**

1. Determine the mineralogy and petrology of localized deposits
2. Study the surface temperature and thermal inertia.

**TIMM is imaging Fourier interferometre**

- Spectral range: 625 – 1333 cm⁻¹
- Resolution 20 cm⁻¹
- Mass 2,5 kg
- Cooperation IKI, Italy

**Spectral range 2,5 – 25 µ**
- resolution: 0.45 cm⁻¹
- Field of view - 2.3 deg
- Mass 4 kg

Кооперация: IKI, Italy, Germany, France
TV cameras

**TV system for observation and navigation**
**TSNN**

- **F = 500 и 18 мм**
- **Field of view 0,85x0,85 и 23,2 x 23,2**
- **mass 1,8 и 1,2 kg**

**Characteristics of the matrix**
- **Kodak-1020**
- **1004 x 1004**
- **Size of the elements, µm 7,4 x 7,4**
- **Spectral range, µm 0,4 – 1,0**

**Panoramic TV camera**
**PANCAM**

- **resolution 3 arc min.**
- **Dynamic range 1000**
- **Field of view 60x360 grad**
- **Spectral channels**
  - **0.45±0.05**
  - **0.65±0.05**
  - **0.95±0.05**
- **Matrix 1280x1024 pix**
- **mass 0,45 kg**

Cooperation – IKI, INFRATRON, LITMO
Sounding instruments

**Long waves planetary radar DPR**
- Frequency range $150\pm 25 \text{ MHz}$
- Vertical resolution 2 m
- Mass 3.5 kg

**Seismometer MUSS**
- Registration of seismic signals and wave fields of Phobos, measurement seismogravitational fluctuations on a surface of Phobos
- Internal structure and energy state of Phobos
- Spectral range, $\mu m$ 0.45, 0.55, 0.65
- Temperature range 160-380 K
- Mass 0.3 kg
- Cooperation IPhE, VNIIFTRI, NPO, IKI, GEOHI

**Termoprobe TERMOFOB**
- Active thermal measurements of Phobos surface based on the heat conductivity inverse problem solutions
- Spectral range, $\mu m$ 0.45, 0.55, 0.65
- Temperature range 160-380 K
- Mass 0.3 kg
- Cooperation AMI
Investigation of the Martian environment

Plasma-waves system FPMS

STUDY OF PLASMA-WAVE PROCESSES OF SOLAR WIND INTERACTION WITH THE MARTIAN PLASMA

Measurements: 3d distribution functions of protons, electrons and ion components; quasistatic and variable magnetic fields, electric field and plasma current fluctuations

Mass 3,0 kg

Cooperation – IKI, Hungary, Austria, Germany, France, Holland

Micrometeorites detector METEOR

Investigation of parameters of micrometeors (m, v).
Control micrometeor situation during the flight.
Velocity range 3 \( \leq \) 35 km/sec
Mass range \( 10^{-14} \leq 10^{-6} \) g

Mass 3,5 kg

Cooperation: GEOHI, ABEPC, NPO Lavochkin

Dust particle detector DIAMOND

Registration of dust particles in the Martian dust belts.
Area of the sensor \( 10^{-2} \) m²
Sensitivity \( 6.5 \times 10^{-10} \) kg·m/c
Max moment \( 4.0 \times 10^{-4} \) kg·m/c

Cooperation: Italy and IKI
Celestial mechanic experiments

INVESTIGATION OF PROPER AND FORCED LIBRATION OF PHOBOS

Investigation of internal structure of Phobos:
- Inhomogeneity of the body
- Center of mass and momentum of inertia
- Average density
- Proper and forced motion

Resolution:
- obscure camera 1 arc min.
- star sensor 10 min.
- dynamic range 1000
Number of obscure cameras 7
Field of view – half of sphere
matrix 1280 x 1024 pix
mass 0.5 kg
stability $10^{-12}$
mass 0.35 kg

ULTRASTABLE OSCILLATOR USO

- refinement of solar system parameters (astronomical unit, orbital parameters of Mars and Phobos);
- experimental estimation of Phobos lifetime on its orbit;
- determination of the mass distribution inside Phobos;
- refinement of masses of large asteroids from main belt;
- refinement of experimental limit of the constancy (or detection of time variations) of universal gravitational constant;
- refinement of the geometrical connection of dynamical coordinate system with origin in solar system center of mass and quasar coordinate system based on the measurements of relative angular coordinates of quasars.

Cooperation: – IKI, INFRATRON, LITMO

Cooperation: IKI, MARION
### Relevance of the instruments to the mission scientific objectives

<table>
<thead>
<tr>
<th>Science fields</th>
<th>Panoramic camera</th>
<th>Manipulator</th>
<th>Chromatograph</th>
<th>Gamma spectrom.</th>
<th>Neutron spectrom/</th>
<th>Seismometer</th>
<th>Long Wave Radar</th>
<th>Dust Detector</th>
<th>Plasma, waves, field</th>
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</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Geochemistry</td>
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<td>+</td>
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<td>Internal structure</td>
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<td>+</td>
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<td>+</td>
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<tr>
<td>Martian environment</td>
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<td>+</td>
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