FUTURE RUSSIAN MAGNETOSPHERIC AND HELIOSPHERIC MISSIONS

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ABSTRACT

A number of missions, which are of interest for solar-terrestrial community, are now under implementation by Russian Space Agency. PLASMA-F experiment is a mission of opportunity onboard astronomy spacecraft SPECTR-R to be launched in late 2007. It's prime target is high-time resolution field and particle measurements in the solar wind. RESONANCE is the next primary solar-terrestrial mission with a launch in 2009. It includes two satellites at the inner magnetosphere orbit to study wave-particle interactions in subauroral region, outer radiation belt and ring current. INTERHELIOPROBE mission, currently under investigation, is targeted at solar wind observations in the inner heliosphere.

Key words: solar-terrestrial missions; solar wind; magnetosphere.

1. INTRODUCTION

Solar and solar-terrestrial physics is one of most important targets of the scientific part of the Russian Federal Space Program. Objects of this research: Sun, solar wind, plasma environments of the Earth and other planets are connected by the hierarchy of physical processes, transferring kinetic and electromagnetic energy from the Sun. Distinctive feature of such investigations is their integrated, multidisciplinary character, allowing to obtain substantially new knowledge of an operating physical mechanisms and response of the near-Earth environment to the state of the interplanetary space. Therefore, these studies are of a large practical interest for space weather applications.

In this paper we present a brief review of several space projects of the Russian Federal Space Program for 2006-2015, which will join the international space science fleet [1]:

- PLASMA-F/SPECTR-R, targeted at the studies of solar wind fine structure.
- RESONANCE, targeted at wave-particle interaction studies in the Earth's inner magnetosphere.
- INTERHELIOPROBE, planned to observe Sun and internal heliosphere.

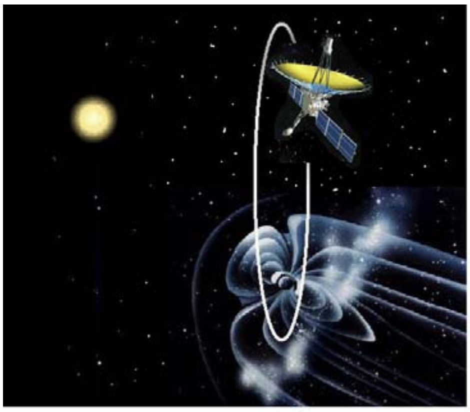

Figure 1. Artist view of SPECTR-R mission.

One more important related mission CORONAS-Photon, which is beyond the scope of this paper, will be devoted to remote observations of high-energy solar emissions. Its planned launch date is early 2007. Mission's web-site is http://iap.mephi.ru.

2. PLASMA-F/SPECTR-R

SPECTR-R is an international space VLBI project of Russian Space Agency, led by the Astro Space Center of Lebedev Physics Institute (http://www.asc.rssi.ru/radioastron) (Figure 1). A 10 meter radio telescope will be launched in late 2007 to an orbit with apogee about 350,000 km, perigee 5,000 km and inclination of 54^o. At this 9-day orbit, the spacecraft will spend 90% of time in the near-Earth interplanetary

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medium and thus it is a convenient platform for a solar wind experiment. PLASMA-F is the solar-terrestrial science payload of opportunity onboard SPECTR-R.

PLASMA-F primary scientific goal is to resolve small-scale solar wind structures down to 10-100 km, to track energy and momentum transformations below the scales of ion inertial length and gyro-radius and to understand role of small-scale processes in formation of solar wind discontinuities, boundaries and dissipation. Specially designed instruments will perform synchronized measurements of magnetic field, solar wind ions and energetic particles with temporal resolution up to 32 samples per second.

The secondary scientific goal is interplanetary medium monitoring in the interests of space weather research and forecast, participation in multi-spacecraft campaigns. The experiment will contribute to ILWS and International Heliophysical Year programs.

Scientific Leader of the experiment is Prof. L.M. Zelenyi and PLASMA-F Project scientist is G.N. Zastenker (Space Research Institute). Experiment is managed by Space Research Institute.

PLASMA-F experiment consists of four instruments:

Fast solar wind flow monitor BMSW includes 6 Faraday cups with different looking directions and retarding potentials, providing 32 solar wind flow measurements per sec. Combination of simultaneous data from all sensors allows to instantaneously determine direction, speed, density, temperature of solar wind ion flow in the Maxwellian approximation. Instrument PI is G.N. Zastenker (Space Research Institute). Instrument is built by Space Research Institute with participation of: OKB Aalam, Kyrgyzstan (sensors), Charles University, Czech Republic (analogue electronics), CSSAR, China (GSE).

Magnetic field instrument MMFF includes two DC magnetic field sensors, with +/-1000 nT range and two AC magnetic field sensors (10 Hz – 100 kHz) on a special boom. Instrument PI is A.A. Skalsky (Space Research Institute). DC sensors are provided by Institute of Metrology VNIIM, Russia, AC sensors - by Lviv space center, Ukraine.

Energetic particle instrument MEP-2 has large geometric factor to provide high-time resolution measurements of interplanetary and magnetospheric ions and electrons. Instrument measures electrons in 15–350 keV range, and ions in 15–3200 keV range with two pairs of telescopes looking in two directions. Time resolution is 1–32 samples/s depending on a number of program-defined energy levels. Instrument PI is K.Kudela (Institute of Experimental Physics, Slovakia). Detectors are provided by Space Research Laboratory, Democritus University of Thrace, Greece.

Data collection and processing unit SSNI-2 performs data collection from PLASMA-F instruments, on-board data storage and transmission to spacecraft telemetry along with some other tasks. SSNI-2 has 200 GB of onboard memory to perform intelligent onboard data treatment with possibility of data selection, averaging and compression. Instrument PI is L.S.Chesalin (Space Research Institute).

Expected data rate in case of permanent 32-Hz measurements is about 1 GByte per week. Browse and scientific data will be available for the broad scientific community within short time interval.

3. RESONANCE

The aim of the RESONANCE project is to study plasma dynamics and wave-particle interactions in the Earth's inner magnetosphere from an orbit, co-rotating with the magnetic flux tubes on L-shells around 5, which are rarely visited by scientific spacecraft [2, 3]. It is a joint project of Space Research Institute (IKI Moscow) and Institute of Applied Physics (IPF N.Novgorod) with participation of many other scientific institutions from Russia, France, Finland, Germany, USA, and Ukraine.

The scientific program of the project consists of two parts. The first, "passive", part, is aimed at the investigation of natural magnetospheric phenomena. Main goals of this part are as follows:

- Magnetospheric cyclotron maser and its long-term evolution.
- Role of small-scale phenomena in the global dynamics of magnetospheric plasma.
- Ring current and outer radiation belt formation and evolution, MeV electron dynamics.
- Plasmasphere dynamics and refilling, sub-auroral zone physics.
- Plasma injection development, magnetic field reconfigurations.
- Mid-altitude auroral zone, polar cap and cusp physics.

Investigations in the frame of the second, "active", part, will focus on the joint experiments of the RESONANCE satellite(s) with ground-based HF heating facilities (HAARP and/or MURMANSK). We expect that parameters of the natural magnetospheric oscillatory system will change, if powerful HF electromagnetic emissions heat the ionosphere and thus modulate the ionospheric mirrors. Phase and amplitude of magnetospheric oscillations, measured onboard the RESONANCE satellite, will be transmitted to the heating facility and used to modulate the HF radiation. In the case of in-phase modification, the amplitude of the natural oscillations should increase, whereas inverse anti-phase modification should decrease the oscillation. Such a unique experiment will help to investigate important underlying principles in cyclotron maser theory and clarify the role of ionospheric mirrors in wave generation.

The onboard instruments will include:

- DC and AC magnetometers.
- Electric field instrument.
- DC/ULF fields analyzer (0–35 Hz, dynamic range: DC - 120 dB, ULF - 80 dB).
- ELF/VLF fields analyzer (3 electric and 3 magnetic components, 0.01–30 kHz, dynamic range: 70 dB).
- HF fields analyzer (3 electric and 3 magnetic components, 0.01–30 MHz, dynamic range: 70 dB).
- Mutual impedance probe for plasma density and temperature measurements.
- Thermal plasma spectrometer (electrons and 3 sorts of ions (hydrogen, helium, oxygen) 1–100 eV, time resolution: 1–5 sec).
- Hot plasma spectrometer (electrons and 3 sorts of ions, 10–10^4 eV, time resolution: $\sim$1 sec).
- Fast electron spectrometer (5–50 keV, energy resolution 100 eV, time resolution 10 ms).
- Energetic particle instrument.

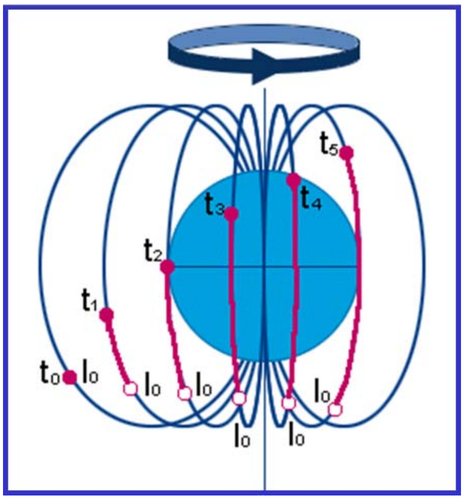

Figure 2. Magneto-synchronous trajectory of RESONANCE satellite.

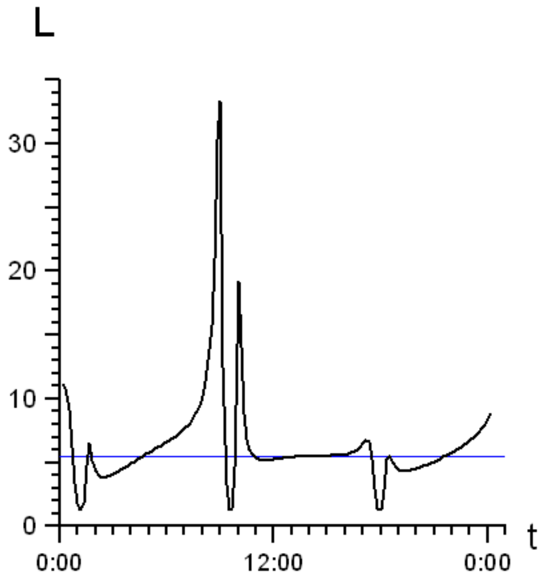

Figure 3. RESONANCE orbit L-shell vs time. Period of magneto-synchronous rotation is 12-15 hours.

The novel type of a magneto-synchronous orbit proposed and designed for this project will allow the satellite to conduct measurements within (approximately) the same magnetic flux tube for sufficiently long time intervals (Figures 2,3). Duration of the spacecraft and magnetic tube co-rotation near the equatorial plane might reach a couple of hours, if the transverse size of the flux tube at the ionospheric level is taken as 50–100 km (significantly longer than the maser characteristic time scales). An important constraint is the magnetic latitude of the orbit apogee, which must be in the inner magnetosphere not far from the plasmapause; otherwise reliable co-rotation is impossible. For active experiments the flux tube should map to the heating facility. Possibility of launching a pair of identical RESONANCE satellites is under investigation now and will provide additional opportunities to monitor dynamics of large-scale natural oscillating processes. Satellite locations will be determined with the onboard GPS/GLONASS navigation receivers. Preliminary orbital parameters are as follows: apogee: $\sim$28 000 km, perigee: $\sim$500 km, inclination: $\pm 63.4^\circ$ (for two satellites).

WWW site is http://www.resonance.romance.iki.rssi.ru.

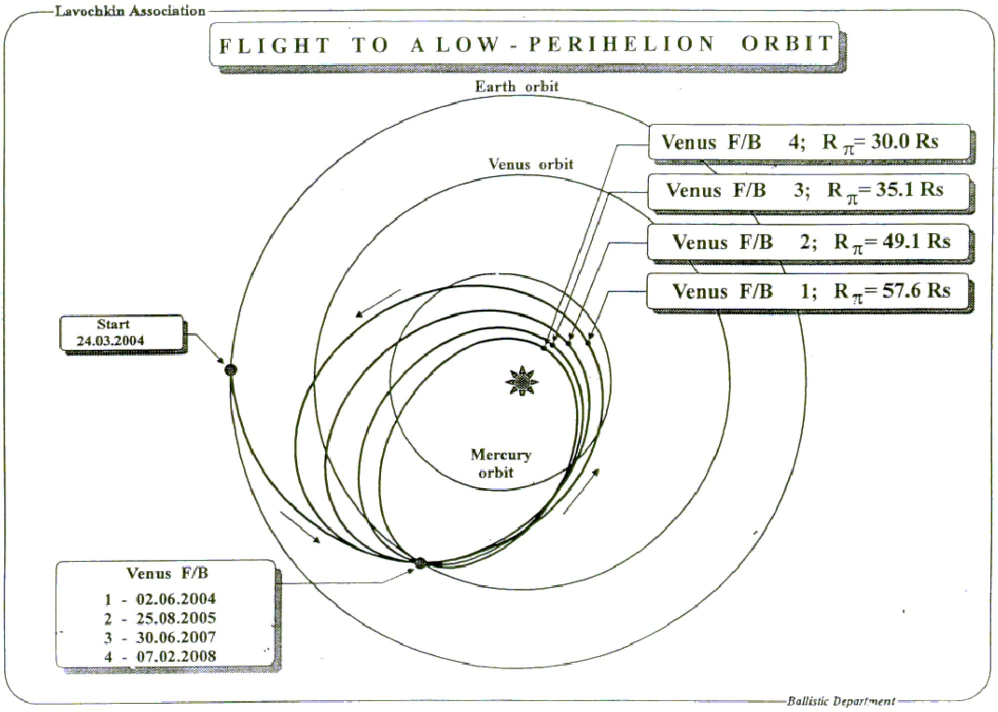

Figure 4. INTERHELIOPROBE orbital scenario.

4. INTERHELIOPROBE

The INTERHELIOPROBE mission is a part of the future solar program [4]. The Interhelios mission (a prototype of the INTERHELIOPROBE and the Solar Orbiter) was conceived in 1995 as a joint project of IZMIRAN and MPAE. In 1998, Russian Academy of Sciences and Russian Space Agency adopted the project for further development in stage A, and IZMIRAN and IKI institutes combined their efforts to design a joint mission INTERHELIOPROBE.

Proximity to the Sun will enable imaging of the solar surface with improved spatial resolution, correlated remote sensing observations of the solar surface and heliospheric in situ measurements in the co-rotation mode, unprecedented in situ measurements of fields and particles in the previously unvisited inner heliosphere, and observations of solar and heliospheric events undetectable from the Earth's orbit (micro-flares, neutrons, etc.).

Compared to previous missions, INTERHELIOPROBE provides the following significant advantages both for remote sensing and in situ measurements:

- Observation of the out-of-ecliptic solar surface and heliosphere in the high-latitude part of the orbit.
- Studies of the fine spatial structure and dynamics of the solar chromosphere.
- Observation of spatial properties of solar flares and coronal mass ejections.
- Investigations of mechanisms of coronal heating and solar wind acceleration, acceleration and transport of high-energy solar particles, generation of radio emission, waves, and turbulence.
- Determination of the relationship between heliospheric processes and surface magnetic structure and activity.
- Determination of composition and physical properties of near-solar heliospheric medium neutrals and dust, solar wind composition.

The basic trajectory of the INTERHELIOPROBE mission is illustrated in Fig.4. A series of gravity assisted manoeuvres at Venus (VGM), realized with a low-thrust engine, will place the spacecraft into the operational heliocentric orbit, that has a co-rotation interval near perihelion (30–40 solar radii). After at least two co-rotation intervals the following VGM will be used to incline the orbital plane with respect to the ecliptic plane. The remaining resources of the low-thrust engines will be used for lowering the perihelion of the inclined orbit.

To meet requirements of the research program, scientific payload of the INTERHELIOPROBE mission will comprise two units, designed for remote sensing and in situ measurements (Table 1). At the present stage, it is a tentative description of possible instruments, that meet scientific and other requirements. The spacecraft mass (at the final orbit) is estimated as 430 kg with 70 kg of scientific equipment.

Table 1. Payload of INTERHELIOPROBE.

Instrument	Measurement	Parameters
Optical telescope ”Photoscope”	Solar disc and photosphere imaging	4300 Å
X-ray imager ”Respect”	Imaging of solar disc	290–310, 185–195 Å
Coronagraph ”OKA”	Imaging of corona, CME	FOV 5°, resolution - 1”
Magnetograph	Photospheric magnetic field	6301 Å
Ion analyzer ”Helicon”	protons, He^{++}, heavy ions	30–6000 eV/q
Electron analyzer ”Helies”	Energy and angular spectra	0.002–30 keV
Dust and plasma analyzer ”PIPLS”	Dust velocity and composition	
	Mass composition of solar wind	$M/\Delta M \sim 10^3$
Wave complex ”IMWE”	Magnetic and electric fields	10 Hz – 1 MHz
Magnetometer ”Heliomag”	Magnetic field	±2048 nT
Charge particle telescope ”EPA-3”	Energetic e, p, He^{++}, heavy ions	10 keV – 100 MeV
Neutron detector ”Intersong”	Neutrons, X-rays and γ-rays	E_n = 0.1–100 Mev
		E_g = 0.03–10 Mev
Radio spectrometer ”RSD”	Coronal radio waves	30 kHz – 30 MHz
Electron gun	Active diagnostics of plasma	E = 1 kev, j = 200 mA

The mission WWW site is http://www.izmiran.rssi.ru/projects/INTERHELIOS.

5. CONCLUSIONS

Russian space science research during the last years has partially lost momentum due to the country’s economic problems. Missions, that are currently in operation or in the final stages of preparation, were actually planned during Soviet era. However, the potential demand for national solar-terrestrial and space weather research remains high thanks to the dense launch schedule, defense programs, and development of vast polar territories.

New projects need to be more compact, carefully targeted to fit smaller launchers and operations costs without compromising scientific return. Prospective directions are to implement micro-satellite technology, to install secondary payloads on other satellites and the international space station. An important aspect is diversification of funding sources. The national space weather program, that is now under development [5] will also include several space missions, that are devoted to magnetospheric and solar wind monitoring and other more practical aspects of the solar terrestrial research.

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