0254-6124/2008/28(5)-395–07 *Chin. J. Space Sci.*

Zhao Hua. YingHuo-1——Martian space environment exploration orbiter. *Chin. J. Space Sci.*, 2008, **28**(5): 395~401

YingHuo-1——Martian Space Environment Exploration Orbiter

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Abstract This paper gives a brief introduction of YingHuo-1 (YH-1), a Chinese Martian Space Environment Exploration Orbiter. YH-1 is a micro-satellite developed by Chinese Aerospace Industry, and will be launched together with Russian spacecraft, Phobos-Grunt, to orbit Mars in September, 2009. Four payloads are selected for the mission, plasma package, including of electron analyzer, ion energy and mass analyzer; sat-sat occultation receiver; flux-gate magnetometer; and optical monitor. YH-1 mission focus on the investigation of the characteristics and its evolution of the Martian space Environment, and identifying major plasma processes, which provide channels for Martian volatiles escaping.

Key words Mars exploration, Mars orbiter, Martian space environment

1 Introduction

Planetary Exploration has attracted many interests from Chinese space community. Mars exploration mission is regarded as an important milestone for the advances of space research and technology in China. YH-1, Martian Space Environmental Exploration Orbiter, is a micro-satellite mission focused on investigating the Martian space environment and the solar wind-planet interaction.

YH-1 is planned to be launched with Phobos-Grunt and inserted into the orbit around Mars. YH-1 and Phobos-Grunt forms a two-point measurement configuration in the Martian space environment. Equipped with similar plasma and magnetic field detecting payload on two spacecraft would give some coordinated exploration around Mars. Especially the long wave (800/400 MHz) occultation between the two spacecraft would tap some Martian ionosphere regions which were rarely touched by previous Mars missions.

2 Scientific Objectives of the Mission

Solar wind-Mars interaction forms a special environment around Mars, which affects the energy transfer from the Sun to Mars. The escape of Mars' atmosphere driven by solar wind is critical for understanding the habitability in Mars in the past. YH-1 mission focus on the investigation of the characteristics and its evolution of the Martian space Environment, and identifying major plasma processes, which provide channels for Martian volatiles escaping. The main scientific objectives of YH-1 are as follows:

- to investigate the magnetosphere and ionosphere in the Mars magnetosheath;
- to investigate the loss mechanism of water on Mars;
- to carry out the comparative studies of planets and understand how the space environment of Earth-like planets evolve.

The main research subjects include:

- Martian space environmental structure, plasma distribution and characteristic in the regions;
- solar wind-atmosphere coupling and energy deposition processes;
- Martian ion escaping processes and possible mechanisms;
- ionosphere occultation, focusing on sub-solar and midnight regions.

Received 2008-05-10

The coordinated measurement between YH-1 and Phobos-Grunt would provide a deep view of the plasma evolution and dynamic processes around Mars.

3 YH-1 Mission Overview

YH-1 is a micro-satellite developed by Chinese Aerospace Industry, and will be launched together with Russian spacecraft, Phobos-Grunt, to orbit Mars in September, 2009 to explore the Martian space environment. The micro-satellite will cross Martian bow shock, magnetosheath, magnetic pile-up region and ionosphere. The magnetic field and particle instruments on the micro-satellite will coordinate with the instruments on Phobos-Grunt to form two-point measurement around Mars. A sat-sat occultation experiment has been planned for the collaboration, Radio-frequency wave at 400 MHz and 800 MHz would beam away from Phobos-Grunt and a receiver installed on the micro-satellite to carry out the occultation experiment.

Chinese micro-satellite would be inserted into the orbit around Mars with apoapsis height of 800 km, and preasis of 80 000 km, the orbit plane is about 0∼7° to the Mars equator. The period of the orbit is about 72.8 hours. The orbit of the micro-satellite, YH-1, is schematically shown in Fig.1.

The mechanical structure of the micro-satellite is a cubic 900 mm × 700 mm × 700 mm, with deployable solar penal as shown in Fig.2. The total mass of the micro-satellite is 115 kg, and power supply is about 110 W in average and 190 W for instance. A high gain antenna with 950 mm diameter is used for the data transmission from the spacecraft to the earth, with 8∼16 000 bit/s.

The communication of HY-1 is designed as directly to the earth via X-band which also used for orbit determination with VLBI technology, and the accuracy of the orbit determination is about 1 km.

4 Payload

To achieve the scientific objectives of YH-1 and with the limitation of mass and power consummation, four payloads are selected for the mission, plasma package, including of electron analyzer, ion energy and mass

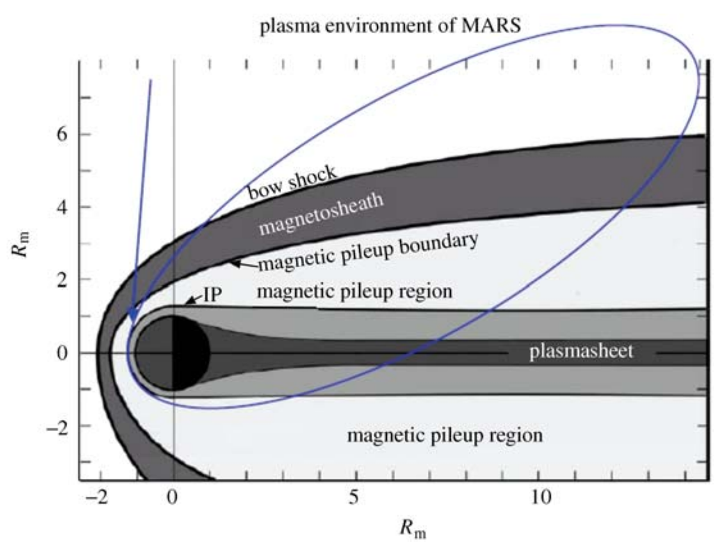

Fig.1 Operating orbit of YH-1 around Mars

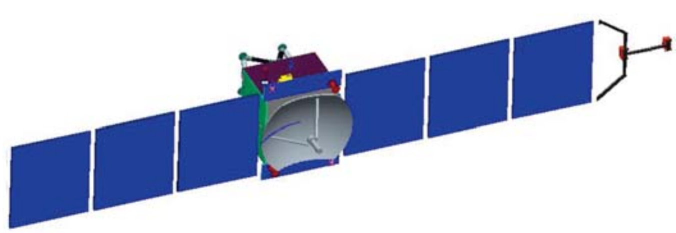

Fig.2 HY-1 micro-satellite structure

analyzer; sat-sat occultation receiver; flux-gate magnetometer; and optical monitor.

4.1 Plasma Package

In order to address the science objectives linked to the interaction of the solar wind with the Martian environment, a plasma package will fly on YH-1, devoting to the observations of low to moderate high energy plasma, which will determine the composition, temperature, and bulk velocity of the plasma in the Martian space.

The objectives of the plasma experiment on YH-1 are focused the effects of the solar wind interaction with the Martian environment. The key objectives of the instrument are:

(1) to investigate the constitution of the solar wind/Mars interaction regions and boundary layers, and its evolution with the dynamic solar wind, and define local plasma characteristics there;

(2) to study the interaction of the solar wind with the ionosphere of Mars: momentum, energy, and mass deposition from the solar wind to the upper atmosphere and ionosphere;

(3) to determine the total ion escape (particles/s) for the major ion species (O^+, O_2^+, CO_2^+), and study the mechanism of ion heating and escaping.

To address these objectives, electron and ion in situ measurements will be carried out on YH-1. Together with the magnetic field measurement, YH-1 plasma experiment will give new insight into the solar wind interaction with the Martian environment.

The plasma package consists of 4 main electrical subsystems: two identical ion analyzers, one electron analyzer, and one electronic box containing 2 independent Data Processing Units (DPU) for the ion and electron analyzer respectively (see Fig.3).

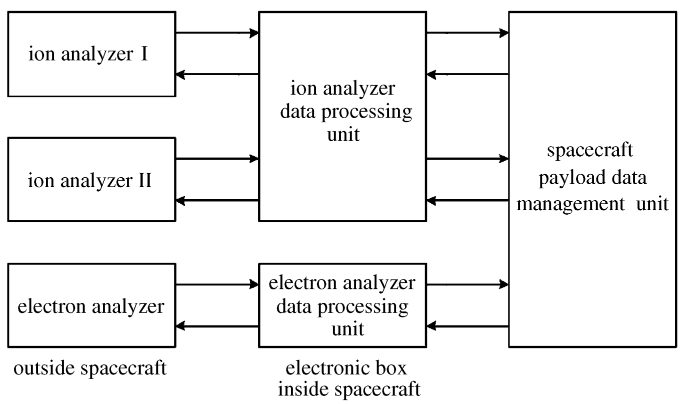

Fig.3 System constitutes of the plasma package

The design of the ion/electron analyzers incorporates standard electrostatic analyzer technique. As shown in Fig.4, at the entrance is a defector, bounded by two deflection plates which steer the filed of view of the analyzer. The electric field established between the deflection plates selects incoming particles of specific angle. Sweeping the voltage effectively sweeps the look direction. After the deflector, the electrostatic analyzer sets the energy resolution for the instrument. Changing the voltage applied to the walls of the electrostatic analyzer, only particles in the required energy range can reach the detector. For ions, the mass analyzer will further determine their mass according to the Time of Flight (TOF) technique.

The ion analyzer consists of sensor and electronics. As shown in Fig.5, ions enter the ion optics through a bell-shaped electrostatic deflector. The electric field applied to the wall of the entrance de-

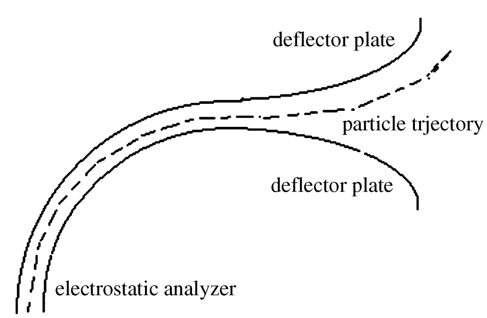

Fig.4 Conceptual drawing of the plasma package with two of its main components: the deflector, and the electrostatic analyzer

flector sets the Field of View (FOV) of the analyzer. Sweeping the voltage from -3500 V to 0 V, the sensor can measure ions in $360^\circ \times 160^\circ$, with angle analysis in the polar viewing direction, but not in the azimuth direction. The inner wall of the electrostatic analyzer is biased -3500~20 V relative to the outer wall (0 V), allowing the passage of ions with energies within a passband of 20 eV~15 keV. The ions exiting the energy analyzer are post accelerated by a voltage applied to the TOF cell consisting of START and STOP surfaces and two Ceramic Channel Electron Multipliers (CCEM). The ions hit the START surface, knocking out secondary electrons and are then reflected towards a STOP surface. The secondary electrons are collected by a START CCEM and produce a START pulse. Secondary electrons from the STOP surface are collected by the STOP CCEM and provide the STOP pulse. The timing of the event gives the ion velocity and, in combination with known energy, the mass. The counts of the ions can also be obtained from the pulse height in CCEM. The sensor also comprises a specially designed UV trap to avoid the interference of the solar photons.

The specification of the ion analyzer is summarized as follows.

- Field of view: $360^\circ \times 160^\circ$ with 8 angular sectors in the polar direction.
- Energy range: 20 eV~15 keV.
- Energy resolution: 7% with 96 energy bins.
- Mass resolution: sufficient to resolve mass groups 1, 2, 4, 8, 16, >32.

As described above, according to the current design, one ion analyzer can only make angle analysis in the polar viewing direction, or the analyzer has no resolving power in the 360° azimuth direction. Since the ion distribution might be highly anisotropic in the Martian environment due to the possible presence of ion beams[1], to get better angular resolution of the measurement, the plasma package adopts 2 identical ion sensors. When mounted on the spacecraft, there is some overlap in the FOV of the 2 sensors, as seen from Fig.6. These two sensors not only give better angular coverage in the polar direction, but can also resolve the azimuth direction of the incident ion through simultaneous measurements.

Like the ion sensor, basically the electron sensor also adopts the design as sketched in Fig.4, with deflector, electrostatic analyzer and CCEM as the detector. Since the electron distribution is more isotropic compared with the ion distribution, the electron sensor is simplified to a 2D configuration, concentrating on the measurement of the electron distribution approximately in the ecliptic plane of Mars. Sweeping the high voltage on the plates from 0~3000 V, the sensor measures electrons in a FOV of $9^\circ \times 60^\circ$. With the inner of the electrostatic analyzer behind the deflector can be biased to 20~3000 V relative to the outer wall (0 V), the sensor makes electron energy analysis in the range of 20 eV~15 keV. The electrons from the electrostatic analyzer are collected by CCEM to give the total counts. A UV trap is also mounted between the deflector and the electrostatic analyzer to absorb the solar UV photons to minimize the background counts. As shown in Fig.7, the electron analyzer integrates 2 identical sensors to achieve a FOV of $9^\circ \times 120^\circ$. The following is the main features of the electron analyzer.

- Field of view: $9^\circ \times 120^\circ$, with 8 angular sectors in the azimuth direction.
- Energy range: 20 eV~15 keV.
- Energy resolution: 15% with 32 energy bins.

The ion and electron analyzers are self-contained: front-end electronics, TOF measurement system (ion analyzer only), high voltage power supplies, HV monitors, and Amplifier/Discriminations, A/D converters, etc. are all located within the analyzer units. Both the ion and electron analyzer have interfaces for connection with the instrument electronic box, the Data Processing Unit (DPU). The ion and electron analyzer has its own DPU board. The DPUs provides +5 V, +12 V, -12 V power supply to the electron and ion analyzer through DC-DC converters. DPUs also manage operation of the analyzers, collect and process the data from the analyzers, and send the data to the spacecraft Payload Data Management Unit for downlink to Earth.

Nominally, the plasma package operates under a prescribed mode, in which each ion analyzer sweeps 96 energy bins, 8 directions in 24 s (32.15 ms each step), producing 32 mass group data in a constant rate of 18.5 kbit/s; while the electron analyzer sweeps 32 energy bins, 8 directions every 8 s, producing data in a rate of 1 kbit/s. Since the data telemetry rate from the Mars orbit to Earth is limited, besides the nominal data mode, the spacecraft payload data management unit will also adopt log compression or data rebinning in various dimensions (energy, angle and time) on board, to fit the available telemetry rate, so that optimizing data acquisition from the YH-1 scientific experiments.

4.2 Sat-Sat Occultation Receiver

A coordinated radio occultation experiment would be carried out between YH-1 and Phobos-Grunt. A radio wave transmitter is mounted on Phobos-Grunt to beam out radio wave at 400/800 MHz in 6 W output to YH-1, and a radio receiver is installed on YH-1 to measure the phase shift during the occultation opportunities. The Total Electron Content (TEC) can be obtained from the occultation experiment, and the Martian electron density profiles would be driven out. After inserting into Mars orbit, YH-1 would be separated from Phobos-Grunt with a relative speed of 2 m/s, and the orbits of YH-1 and Phobos-Grunt are placed in the same plan near the Mars equator, and the Radio Occultation Experiment (ROE) would have opportunities to measure the Mars ionospheric electron density profiles in the altitude range 50∼300 km with Solar Zenith Angle (SZA) smaller than 43° and larger than 138°, which schematically shown in Fig.8.

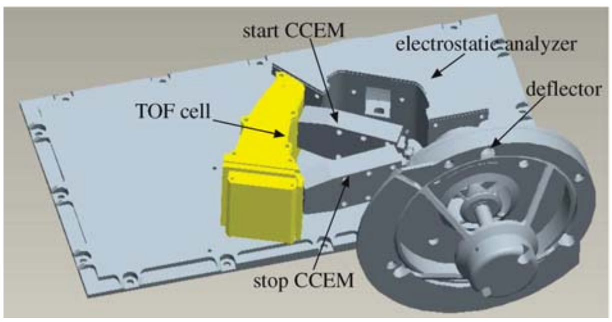

Fig.5 Schematic view of the ion sensor

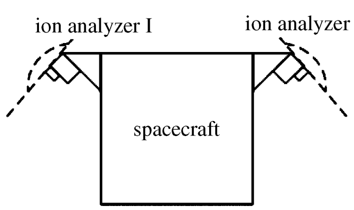

Fig.6 Mounting of the 2 ion analyzers on the spacecraft

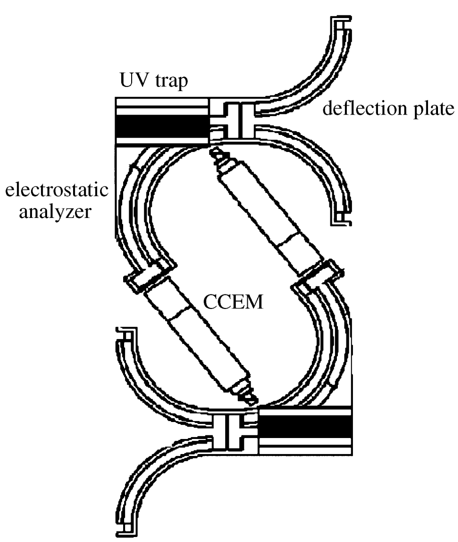

Fig.7 Cross section of the electron sensor

A micro-strip antenna is mounted on the surface of YH-1 to receive the 800/400 MHz wave radiated from Phobos-Grunt, and the signal is amplified and processed by the DPU of the receiver to get the information of bending of the wave. The sensitivity of the receiver is about −145 dBm. The mass of the receiver is about 3.0 kg, and power of 6 W.

4.3 Flux-gate Magnetometer

A fluxgate magnetometer is selected as one of the primary scientific payload to investigate the magnetic field structure and variation near Mars space. The main scientific objectives of Magnetic Field Investigation are planned as: exploring regions of Martian space environment, such as bow shock, magnetosheath, magnetic pile-up region, ionosphere, magnetotail, etc; to understand the interaction with solar wind, coordinated with the observations on Pbobos-Grunt; providing the background magnetic field observational data for Plasma Package measurement to investigate the plasma and planetary ion transport and escaping in Martian space environment.

A flux-gate type magnetometer, with two tri-axial

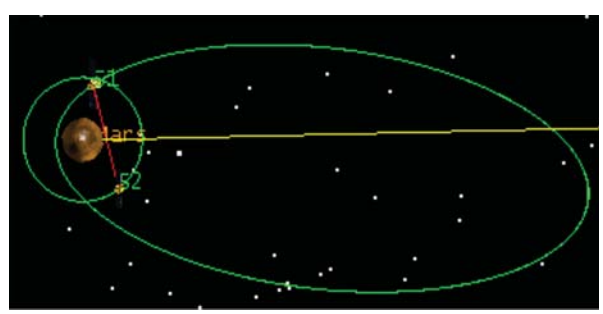

Fig.8 Sat-sat occultation concept

sensors, is developed for YH-1 spacecraft. Two sensors are mounted on one-side of the deployable solar panel with a radial separation about 45 cm to function as a gradiometer to minimize the affects of platform remanence. The dynamic range of the magnetometer is ±256 nT for flight measurement operation mode, and ±65 000 nT for ground test mode. The analog signal from the magnetometer sensors are digitized by a 16 bit ADC converter, and the resulting digital information is fed to the Payload Data Management System through the interface for transmission to Earth. The noise level of the magnetometer is better than 0.01 nT·Hz$^{-1/2}$, to measure three-component magnetic field from DC to 10 Hz.

The specifications of the magnetometer are:

- Dynamic range: ±256 nT (in flight operation mode), ±65 000 nT (in ground test mode).
- Noise: 0.01 nT·Hz$^{-1/2}$ at 1 Hz.
- Resolution: 0.1 nT (RMS in 10 Hz bandwidth).
- Mass (excludes boom and boom cable).
  Outer sensor: 265 g (including of cable-tail and connector).
  Inner sensor: 235 g (including of cable-tail and connector).
  Electronic Assembly: 2300 g.
  Total Weight: 2800 g.
- Size.
  Sensor: 102.2 × 58 × 50 (mm).
  Electronic Assembly: 270 × 210 × 58 (mm).
- Power 6.0 W.
  Telemetry rate (highest data rate): 1024 bit/s.

The sensor mechanical configuration and engineering mode of the magnetometer on YH-1 is show in Fig.9.

There are two independent electronic boards, which connecting to each sensor, in the electronic assembly. Each electronic board and corresponding sensor can operate as a magnetometer, and together as a gradiometer. The operation mode of the magnetometer can be changed by uplink command.

The noise level for each sensor has been tested in the shielding vessel, and some very lower noise sensors are selected to use for the magnetometers.

The noise level of each component of the tri-axial sensor has been test in the zero-geomagnetic field environment, which is provided by 5-layer shielding vessel. All component has a very lower noise level, which is 0.0050, 0.0055, 0.0034 nT·Hz$^{-1/2}$ at 1 Hz for X, Y, Z, respectively, and the results are presented in Fig.10.

The noise level variation *vs.* temperature is also measured, and is given in Fig.11. The sensor was put into a thermal control vessel, which is magnetically shielding. The test result presents that the sensor is working well in very low noise level in 30°C temperature variation range, from 20°C~50°C.

The magnetometer is satisfied with the requirements of YH-1 Mars exploration mission to carry on the magnetic field measurement in Martian space environment. The test results show that the design and development are quite perfect, the final noise level is much less 0.01 nT·Hz$^{-1/2}$ at 1 Hz, and the sensitivity has a width about 30°C *vs.* temperature variation. The engineering mode of the instrument has been manufactured and tested completely, and the flight mode would be ready for deliver to spacecraft in the end of August, 2008.

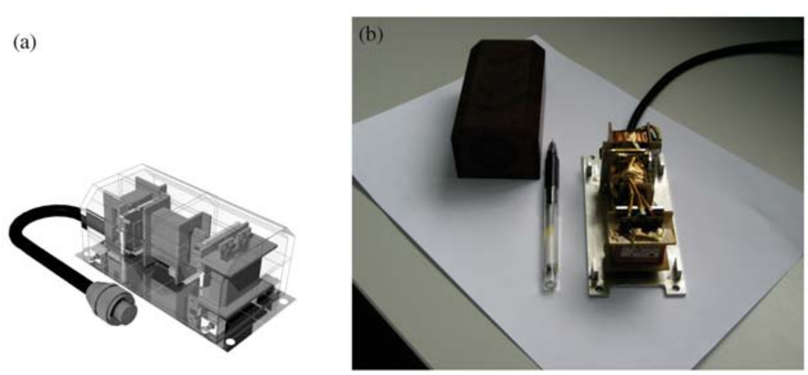

Fig.9 (a) Mechanical structure of the tri-axial fluxgate sensor, and (b) engineering mode of the fluxgate sensor

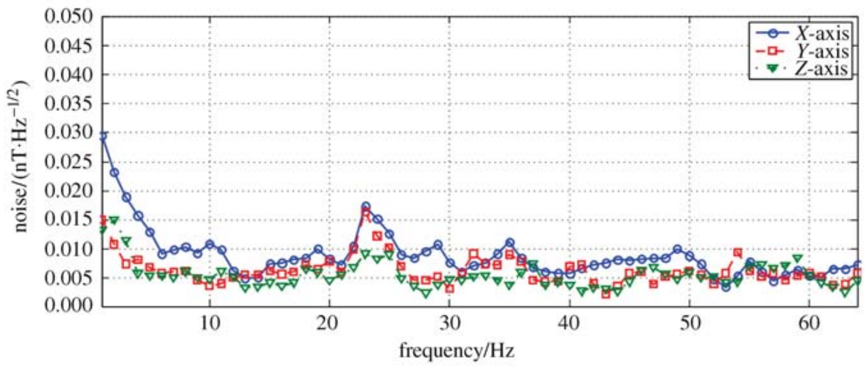

Fig.10 Noise level testing results for each component of the tri-axial sensor

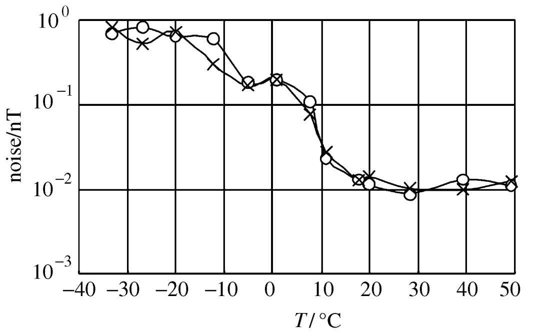

Fig.11 Sensor's noise variation *vs.* temperature change

4.4 Optical Monitor

To monitor the sandstorm on Mars and for the public out-reach, an optical monitor is planned on YH-1 to take photos of Mars surface. The field of view of the monitor is 30°, with 400×10^6 pixel per image. The weight of the monitor is about 1.3 kg, and power consumption, 3 W.

5 Summary

YH-1, a micro-satellite, is developing by Chinese Aerospace industry, and equipped with four scientific instruments, Plasma package, Sat-sat Occultation Receiver, Flux-gate Magnetometer, and Optical monitor, onboard to explore Martian space environment. HY-1 is planned to be launched with Phobos-Grunt in September, 2009, and inserted into Mars orbit in August, 2010. The development of YH-1 is going well. The engineering mode of the spacecraft is ready and carrying on the integration test. The flight mode would be ready for deliver to Russia in March, 2009.

References

[1] Carlson C W *et al.* An instrument for rapidly measuring plasma distribution with high resolutions. *Adv. Space Res.*, 1983, **2**:67∼78