0254-6124/2020/40(5)-693–005 *Chin. J. Space Sci.* 空间科学学报

JIA Yingzhuo, ZOU Yongliao, ZHU Yan, DU Qingguo, FAN Yu, CHEN Yuesong, WANG Chi. Development Progress of China's First Mars Exploration Mission: Its Scientific Objectives and Payloads. *Chin. J. Space Sci.*, 2020, **40**(5): 693-697. DOI:10.11728/cjss2020.05.693

Development Progress of China's First Mars Exploration Mission: Its Scientific Objectives and Payloads*

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Abstract China's first Mars exploration mission is scheduled to be launched in 2020. It aims not only to conduct global and comprehensive exploration of Mars by use of an orbiter but also to carry out in situ observation of key sites on Mars with a rover. This mission focuses on the following studies: topography, geomorphology, geological structure, soil characteristics, water-ice distribution, material composition, atmosphere and ionosphere, surface climate, environmental characteristics, Mars internal structure, and Martian magnetic field. It is comprised of an orbiter, a lander, and a rover equipped with 13 scientific payloads. This article will give an introduction to the mission including mission plan, scientific objectives, scientific payloads, and its recent development progress.

Key words China's first Mars exploration mission, Scientific objectives, Scientific payloads

Classified index V 524, P 35

1 Overview of China's First Mars Exploration Mission

China's first Mars exploration mission got approval in 2016. It is comprised of five systems, which are the probe system, the launch vehicle system, the launching site system, the TT&C (Tracking, Telemetry and Command) system, and ground research and application system.

The probe system consists of an orbiter, a lander platform, and a rover. The mission is scheduled to make a soft landing after the lander carrying the rover separates from the orbiter. The orbiter provides the service of communication relay links for the rover on the relay communication orbit as well as to conduct its own exploration mission[1]. The launch vehicle system will use Long March 5 launch vehicle, which will send the probe to the Earth-Mars transfer orbit directly in July 2020. The launch site system is expected to work at Wenchang satellite launch center, located in Hainan province.

Based on the existing spaceflight TT&C network and deep-space TT&C network, the TT&C system has additionally constructed three 35 m aperture antenna in Kashgar deep-space station to implement the TT&C task with assistance of the VLBI network. Ground research and application system will receive the scientific data while completing the observation tasks, and subsequently, carry out the work of data analysis.

The mission is designed to implement a sequence of spacecraft orbiting, landing, and roving on Mars with only a single launch. This mission is scheduled to be launched in July 2020 and expected to reach Mars in 2021. The project objectives of the mission include the following key technology tasks: Mars orbit braking and capture, entering/descending/landing, long-term independent management, long-distance

* Supported by the Major Program of the National Science Foundation of China (41590851) and the Beijing Municipal Science and Technology Commission (Z181100002918003)

Received March 10, 2020

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Tracking, Telemetry, and Command (TT&C) and communication, roving on the Martian surface.

2 Scientific Objectives and Payloads

The orbiter of the mission is scheduled to conduct Mars global survey. The rover is to carry out a detailed comprehensive investigation in some critical areas. The scientific objectives of China's first Mars mission are as follows[2].

(1) To study the characteristics of Martian topography and geomorphology, acquire the data with high-precision to characterize global terrain of Mars and conduct the study on the processes that formed and modified the geologic record within a field exploration area on Mars.

(2) To study the characteristic of soil on the Martian surface and the distribution of water ice, characterize a variety of soils, rocks, and global distribution, search for the clue to past water activity to conduct the study on the surface layer of the Martian soil.

(3) To investigate the composition of the Martian surface, identify the types of rocks and search for the secondary mineral to analyze the mineral composition on the Martian surface.

(4) To study atmosphere and ionosphere, surface climate, and environmental characteristics of Mars; monitor space environmental conditions, temperature, air pressure, and wind field to study the Martian ionosphere structure and the seasonal variation of surface weather.

(5) To study the Martian internal structure and magnetic field, investigate the Mars magnetic field to carry out the study on the history of early geological evolution, internal mass distribution, and gravity field.

There are 13 scientific payloads equipped for the mission, 7 scientific payloads installed on the orbiter including Moderate Resolution Imaging Camera, High Resolution Imaging Camera, Mars Orbiter Scientific Investigation Radar, Mars Mineralogical Spectrometer, Mars Orbiter Magnetometer, Mars Ions and Neutral Particle Analyzer, Mars Energetic Particles Analyzer; 6 scientific payloads installed on the rover including Multispectral Camera, Navigation and Terrain Camera, Mars Rover Penetrating Radar, Mars Surface Composition Detector, Mars Rover Magnetometer, and Mars Mineralogical Spectrometer. There are two payload controllers separately installed on the orbiter and the rover, combined to command the payloads power supply, instruction control, data acquisition, and data processing[3]. The main technical parameters of scientific payloads and their scientific tasks are shown in Table 1.

Table 1 Main technical parameters of scientific payloads

Scientific payloads	Scientific observation tasks	Main technical parameters
Moderate resolution imaging camera	Imaging Mars surface and acquire the remote sensing images from a global view Characterize Mars topographic mapping and geomorphological structure	Spectral range: visible spectrum Resolution: better than 100 m at 400 km Effective pixel number: 4096×3072
High resolution imaging camera	Imaging the critical region of Mars surface Imaging topography and geomorphology of Mars surface in a detailed way	Mars surface Pixel resolution (below 265 km orbit altitude). Panchromatic: better than 2.5 m, local key area better than 0.5 m. Color: better than 10 m, local key area better than 2.0 m
Mars orbiter scientific investigation radar	Investigate Mars subsurface structure and underground water-ice distribution. Acquire the radar echo data with dual-frequency and dual-polarization to study Mars surface topography On Earth-Mars transfer orbit, it is used to observe spectrograms of very low frequency interplanetary radio emissions	Frequency: 10~20 MHz; 30~50 MHz Detecting depth: Mars subsurface structure, 100 m; Mars polar ice layer, 1000 m Thickness resolution: meter level

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Scientific payloads	Scientific observation tasks	Main technical parameters
Mars mineralogical spectrometer	Analyze mineral composition and distribution. Investigate integral chemical composition and evolution history of Mars Analyze resources and distribution on Mars	Spectrum: Visible near-infrared, 0.45~1.05 μm; intermediate infrared and near-infrared, 1.00~3.40 μm Spectral resolution: Visible near-infrared, better than 10 nm; intermediate infrared and near-infrared, better than 12 nm at 1.0~ 2.0 μm, better than 25 nm at 2.0~3.4 μm
Mars orbiter magnetometer	Observe the space magnetic field of Mars, and study the interaction mechanism between Mars ionosphere, magnetic field, and solar wind Revert generator current of Mars ionosphere and research conductivity character of Martian ionosphere cooperating with Mars Magnetic Field Observation Station	Measurement range: ± 2000 nT Resolution: better than 0.01 nT
Mars ions and neutral particle analyzer	Study the particle characteristics of Mars plasma and understand the escape of the Mars atmosphere Study the interaction mechanism between the solar wind and the Martian atmosphere, and the acceleration mechanism of neutral particles near the Mas shock wave	Low energy ions Energy range: 0.005~25 keV Energy resolution $(\Delta E\ /\ E)$: 15% Mass: 1~70 amu Low energy neutral particles Energy range: 0.05~3 keV Energy resolution $(\Delta E\ /\ E)$: 100% Mass: 1~32 amu
Mars energetic particles analyzer	Observe the changes of the energy spectrum of energy particles, elementary composition and flux in the near-Mars space environment and Earth-Mars transfer orbit Survey the spatial distribution of different types of energetic particle radiation on Mars and Earth-Mars transfer orbit	Energy range: Electronic 0.1~12 MeV; Proton 2~100 MeV; α-particle, heavy ion 25~300 MeV Energy resolution $(\Delta E\ /\ E)$: 15% Elementary composition: H~Fe $(1\leqslant Z\leqslant 26)$ Heavy ion mass resolution $(\Delta E\ /\ E)$: ≤25% $(Z\leqslant 9$, energy range 25~300 MeV); ≤25% $(10\leqslant Z\leqslant 26$, energy range 100~300 MeV); ≤60% $(10\leqslant Z\leqslant 26$, energy range 25~100 MeV)
Multispectral camera	Acquire the multispectral images of landing and roving site, and study material type distribution on the Mars surface	Spectral range (nm): there are 9 spectra, which are 480 (20), 525 (20), 650 (12), 700 (15), 800 (25), 900 (30), 950 (50), 1000 (50) Viewing Sun Panchromatic spectrum, note: contents in brackets are full width at half height Normal imaging distance: 1.5 m to ∞
Navigation and terrain camera	Imaging terrain and geological structure of the roving area	Spectral range: Visible spectrum Color: Multicolor (RBG) Normal imaging distance: 0.5 m to ∞ Effective pixel number: 2048×2048
Mars rover penetrating radar	Investigate soil thickness and ice layer structure of the roving area and acquire ultra-wideband full polarized echo data on both of the Mars surface and subsurface Survey subsurface structure of the roving site, acquire geologic structure data on the Mars subsurface	First channel Center frequency: 55 MHz Bandwidth: 40 MHz Resolution of ice thickness: meter level Detection depth: ≥100 m (ice, ε_γ=3.0), ≥10 m (soil, ε_γ=3.0~4.0) Second channel

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Scientific payloads	Scientific observation tasks	Main technical parameters
		Center frequency: 1300 MHz Bandwidth: 1000 MHz Resolution of thickness: cm level Detection depth: ≥ 10m (ice, ε_γ=3.0), ≥ 3 m (soil, ε_γ=3.0~4.0)
Mars surface composition detector	Analyze chemical component of material on Mars surface Analyze mineral and identify rocks on Mars surface	LIBS detection. Types of element: no less than 10 element (Si, Al, Fe, Mg, Ca, Na, O, C, H, Mn, Ti, S, *etc.*) Detection distance: 2~5 m (best detection distance), as far as to 10 m Short-wave infrared spectroscopy. Spectral range: 850~2400 nm. Spectral resolution: ≤12 nm. Spectrum band: no less than 130 band
Mars rover magnetometer	Investigate the magnetic field of the landing area, and detect Mars' interior Investigate Mars space magnetic field and character of Mars ionosphere, invert Mars ionosphere generator current cooperating with orbiting investigation	Measure range: ± 2000 nT Resolution: better than 0.01 nT
Mars mineralogical spectrometer	Conduct in-situ investigation on wind field parameters of Mars surface Monitor the sound on Mars surface Measure environment temperature and air pressure on Mars	Temperature Measure range: –120~ +50°C Resolution: 0.1°C Pressure Measure range: 1~1500 Pa. Resolution: 0.1 Pa Wind speed Measure range: 0~70 m·s^{-1} Resolution: 0.1 m·s^{-1} Sound Frequency range: 0.02~2.5 kHz, 2.5~20 kHz Sensitivity: better than 50 mV·Pa^{-1}

3 Key Technologies of Scientific Payloads

After over four years' development, breakthroughs in the following key technologies have been achieved in scientific payloads.

(1) High resolution imaging camera: aiming at high elliptic orbit, it breaks through the real-time image motion compensation calculation of push-broom imaging and attitude control technology, so as to realize sub-meter level fine imaging observation.

(2) Mars orbiter scientific investigation radar: the technology of dual-frequency and dual-polarization Linear Frequency Modulation (LFM) pulse is used to realize the layered structure detection of different geological targets.

(3) Mars mineralogical spectrometer: it uses Off-axis three reflective mirrors telescope, free-formed surface plane reflection grating technology to realize a wide band, compact and efficient spectrometer, and makes breakthroughs in the key technologies in infrared wide band light detector components.

(4) Mars rover penetrating radar: it uses ultra-wideband frequency Modulated Interrupting Continuous Wave (FMICW) to realize time-shared receiving/transmitting and solve receiving and transmitting channel segregation.

(5) Mars surface composition detector: it breaks

Laser-Induced Breakdown Spectros (LIBS) quantitative inversion technology.

4 Summary

At present, the scientific payloads have been completely manufactured and will be transported to the launching site for installation and test as planned in April 2020. The five systems of the Mars mission schedule to be completed all the research and manufacture works before July 2020. The scientific data processing methods and application research will continue to proceed. The scientific payloads aim at a global investigation of Mars such as terrain, geomorphology, atmosphere, and magnetic fields. Chinese scientists are making efforts to deepen the study on methods and applications of scientific data, and eager to obtain a new understanding of Mars, such as Mars atmosphere, ionosphere, and Mars surface composition.

With the development of the Mars mission, China makes efforts to promote more missions in deep-space exploration such as the asteroid exploration, sample-return from Mars, Jupiter system and beyond exploration. CNSA (China National Space Administration) attaches great importance to international cooperation and has openly announced "Announcement of Opportunities for Scientific Payloads and Projects onboard Asteroid Exploration Mission" in April 2019. Currently, CNSA has received the relevant proposals from some countries, for instance, Russia, Italy, Sweden, Germany, Belgium, and so forth. In the near future, the selection process organized by CNSA will be underway.

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