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Scientific objectives and payloads of Tianwen-1, China's first Mars exploration mission

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Abstract

This paper describes the scientific objectives and payloads of Tianwen-1, China's first exploration mission to Mars. An orbiter, carrying a lander and a rover, lifted-off in July 2020 for a journey to Mars where it should arrive in February 2021. A suite of 13 scientific payloads, for in-situ and remote sensing, autonomously commanded by integrated payload controllers and mounted on the orbiter and the rover will study the magnetosphere and ionosphere of Mars and the relation with the solar wind, the atmosphere, surface and subsurface of the planet, looking at the topography, composition and structure and in particular for subsurface ice. The mission will also investigate Mars climate history. It is expected that Tianwen-1 will contribute significantly to advance our scientific knowledge of Mars.

Keywords: China's first Mars exploration; Scientific tasks; Scientific payloads

1. Introduction

China's first Mars exploration mission, Tianwen-1, was launched on 23 July 2020 at 12:41 Beijing time from Wenchang Space Launch Center in Hainan province. Tianwen-1 was delivered directly into the Earth-Mars transfer orbit and is expected to arrive at Mars in February 2021. The

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spacecraft will be inserted into a Mars parking orbit following three periareon braking manoeuvers, from where it will perform an initial survey of the landing area. Approximately 2–3 months later, the spacecraft will be briefly placed in a deorbit and entry arc to release the landing capsule, from which the capsule with the rover will descend and land on the Mars surface. The rover will egress onto the Martian surface a few days after touchdown, following an assessment of the terrain surrounding the lander. For at least 92 Martian days, the rover will conduct high resolution in situ surveys in a critical area of Mars.

After releasing the capsule, the orbiter will maneuver to enter into a data relay orbit (265 km × 12,500 km) for the duration of the rover surface mission. Thereafter, the orbiter will be placed on a 265 km × 12,000 km elliptical orbit to conduct a global survey study for one Martian year.

2. The scientific objectives of Tianwen-1

The scientific objectives of Tianwen-1 are as follows (Geng et al., 2018; Li et al., 2018):

(1) To study the characteristics of the Martian topography and geological structure.
(2) To study the characteristic of the soil on the Martian surface and the distribution of water ice.
(3) To investigate the substance composition of the Martian surface.
(4) To study the ionosphere, surface climate and environmental characteristics of Mars.
(5) To study the Martian physical fields (electromagnetic, gravitational) and internal structure.

To achieve the above scientific objectives, there are 13 scientific payloads on Tianwen-1, 7 payloads on the orbiter, 6 payloads on the rover, and 2 payload controllers separately installed on the orbiter and the rover, respectively. They constitute the scientific payload system.

The scientific payloads mounted on the orbiter include: Moderate Resolution Imaging Camera (MoRIC), High-Resolution Imaging Camera (HiRIC), Mars Orbiter Scientific Investigation Radar (MOSIR), Mars Mineralogical Spectrometer (MMS), Mars Orbiter Magnetometer (MOMAG), Mars Ion and Neutral Particle Analyzer (MINPA), Mars Energetic Particles Analyzer (MEPA). The location of the scientific payloads on the orbiter are displayed in Fig. 1.

The scientific payloads on the orbiter conduct a global comprehensive exploration from the orbit. Their scientific exploration tasks include:

(1) To analyse the Mars ionosphere and survey the interplanetary environment.
(2) To detect Martian surface and subsurface water ice.
(3) To survey the characteristics of soil and structures of Mars.
(4) To survey the characteristics of Martian topography and geomorphology.
(5) To analyse the composition of the Mars surface material.

The scientific payloads mounted on the rover include: Navigation and Terrain Camera (NaTeCam), Multispectral Camera (MSCam), Mars Rover Penetrating Radar (RoPeR), Mars Surface Composition Detector (MarSCoDe), Mars Rover Magnetometer (RoMAG) and Mars Climate Station (MCS). The location of the scientific payloads on the rover is shown in Fig. 2.

After the Mars rover moves away from the landing platform to the surface of Mars, its scientific payloads will be powered on following ground command. The scientific exploration tasks of the Mars rover payloads are:

(1) To study topography and geological structure of the Mars roving area.
(2) To survey the soil structure (profile) of the Mars roving area and to search for water ice.
(3) To survey elements, minerals and rock types of the Mars roving area.
(4) To survey the atmosphere physical characteristics and the surface environment of Mars roving area.

The relationship between scientific objectives of Tianwen-1, exploration tasks and scientific payloads is shown in Table 1.

3. Landing area selection

In addition to the safety considerations of the landing, the landing area must meet the requirements of scientific exploration. Initially, two candidate landing locations were considered for the Tianwen-1 rover. As a result of this evaluation, the landing site has been selected to be in Utopia Planitia (Wan et al., 2020). The candidate landing area on Mars of Tianwen-1 is shown in Fig. 3.

Utopia Planitia is the largest recognized impact basin in the northern hemisphere of Mars (McGill, 1989). The geological map (Tanaka et al., 2014) shows that the majority of Utopia Planitia is covered by extensive sedimentary materials from Vastitas Borealis interior unit. Analysis of roughness and slope data show that the Utopia basin is characterized by subdued and smooth morphology (Kreslavsky and Head, 2000). Several features in Utopia Basin have been interpreted as morphological indicators of water/ice. The dielectric constant derived from observations by the SHARAD radar of the Mars Reconnaissance Orbiter (MRO) further confirms the existence of subsurface water/ice in the high latitude (Stuurman et al., 2016). The Amazonian-aged lava flow and lahars emanating from the flank of northwest Elysium Rise superpose on the center of the Utopia basin.

Although currently available spectral data show that there are few water-bearing minerals in the roving area

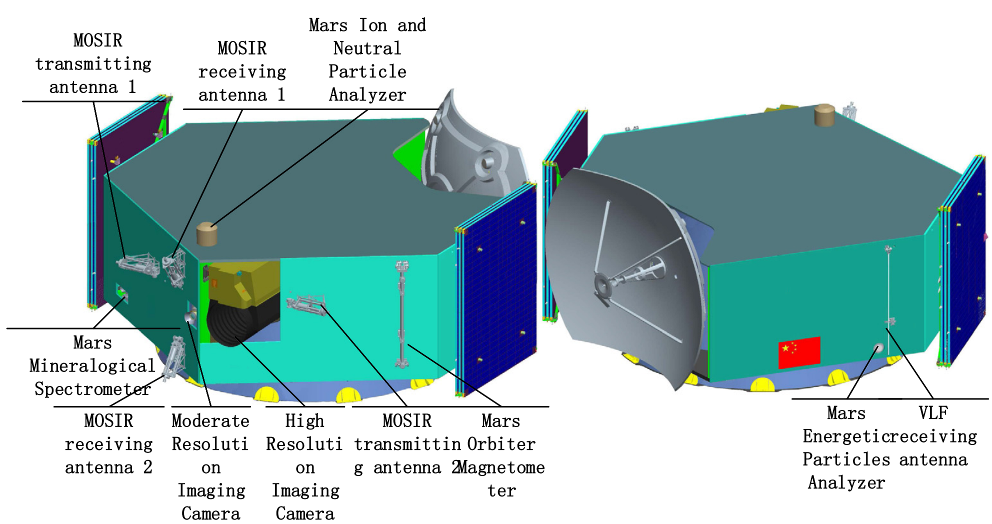


Fig. 1. Location of the scientific payloads on the Orbiter.

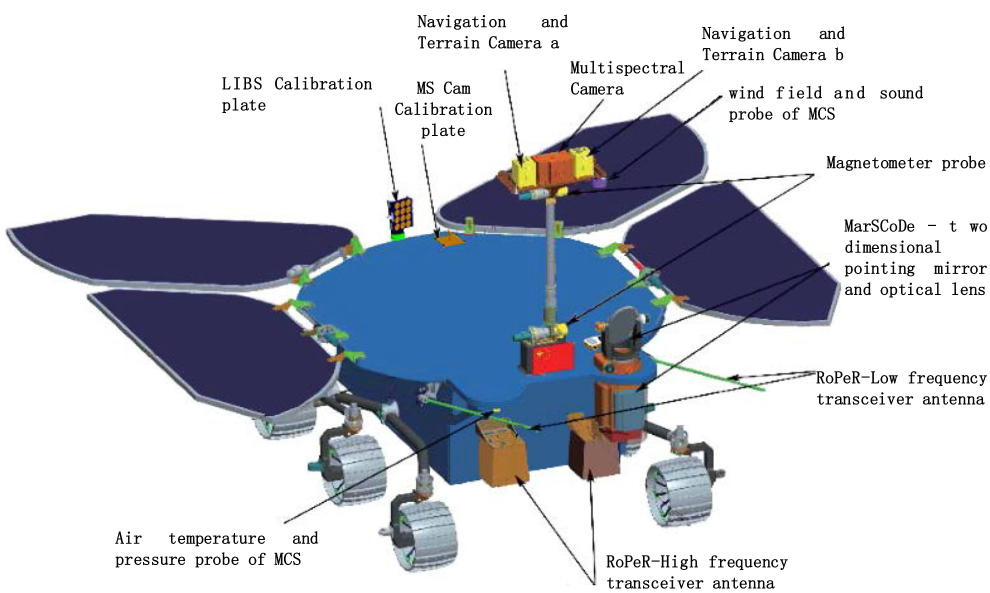


Fig. 2. Installation position of scientific payloads on the rover.

due to the low spatial resolution. This may be due to the low spatial resolution of the observations and the presence of such materials cannot be excluded. The in situ exploration by a suite of instruments on the Mars Rover (i.e., MarSCode) with higher resolution can potentially detect hydrated minerals in the area, and can provide important clues on the regional and global evolution of the Mars climate.

4. Scientific payloads of Tianwen-1

4.1. Scientific payloads on the orbiter

4.1.1. Framework of scientific payloads system on orbiter

The scientific payloads system of the orbiter has the payload controller as the core, and 7 scientific payloads are integrated into the system through an internal bus network. The payload-controller interfaces with the orbiter platform, and provides electric power, thermal control, command, data collection and processing. The scientific payloads perform their scientific tasks under the control of the payload controller. The payload system operates autonomously and can monitor independently the status of the system and fix its problems (Zhu et al., 2017). The framework of scientific payloads system on the orbiter is shown in Fig. 4.

The payload controller can control the scientific payloads, execute the mission commands, reduce the data volumes, overcome communication bottlenecks and thereby execute the scientific mission more efficiently. Furthermore, the payload controller is designed to deal with malfunctions and to control contingencies. It achieves fault detection, isolation and recovery and system reconfiguration for the healthy operation of the payload. The payload

Table 1
The relationship between scientific objectives, exploration tasks and scientific payloads.

Scientific objectives	Exploration tasks		Payloads
To study the characteristics of the Martian topography and geological structure	Orbiter	To survey the characteristics of Martian topography and geomorphology	MoRIC HiRIC MOSIR
	Rover	To study topography and geological structure of the Mars roving area	NaTeCam
To study the characteristic of the soil on the Martian surface and the distribution of water ice	Orbiter	To detect Martian surface and subsurface water ice	MOSIR
		To survey the characteristics and distribution of soil and structures of Mars	MOSIR
	Rover	To survey the soil structure (profile) of the Mars roving area and to search for water ice	RoPeR
To investigate the substance composition of the Martian surface	Orbiter	To analyse the composition of the Mars surface material	MMS
	Rover	To survey elements, minerals and rock types of the Mars roving area	MarSCoDe MSCam
To study the ionosphere, surface climate and environmental characteristics of Mars.	Orbiter	To analyse the Mars ionosphere and survey the interplanetary environment	MOMAG MINPA MEPA MOSIR(VLF)
	Rover	To survey the atmosphere physical characteristics and the surface environment of Mars roving area	MCS
To study the Martian physical fields (electromagnetic, gravitational) and internal structure	Orbiter	To analyse the Mars ionosphere and survey the interplanetary environment	MOMAG MINPA MEPA
	Rover	To survey the atmosphere physical characteristics and the surface environment of Mars roving area	RoMAG

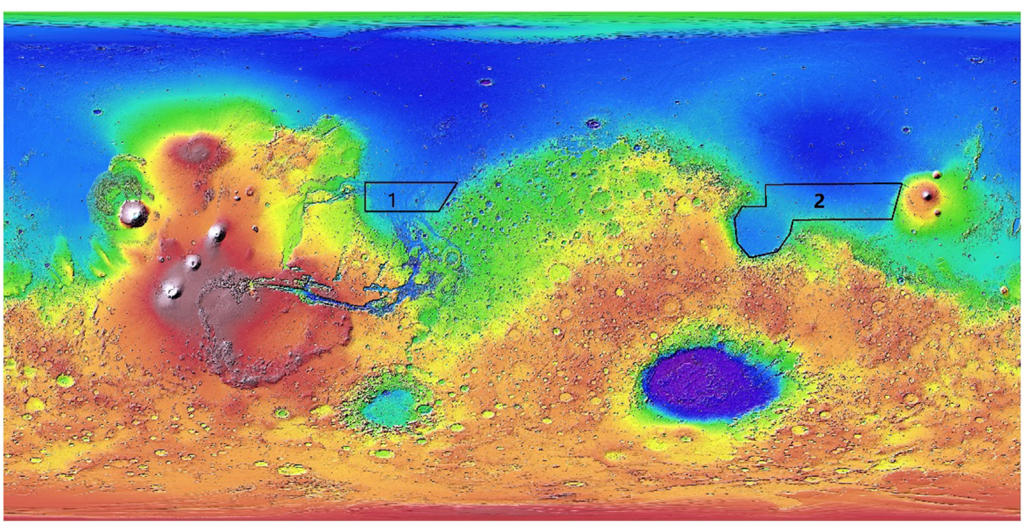


Fig. 3. Candidate landing area on Mars. The pre-selected landing area 1 is located on the Chryse Planitia plain, the pre-selected landing area 2 is located on the Utopia Planitia.

controller implements dual redundancy to increase failure tolerance and reliability.

4.1.2. Design of scientific payload on orbiter work mode

The scientific payloads of the orbiter are designed to work during the Earth-Mars transfer and also in Mars remote sensing orbit. The specific working times and operation modes are shown in Table 2.

On the Earth-Mars transfer orbit, the MINPA, MEPA and VLF radio receiver of MOSIR are powered on to monitor the space environment between Earth and Mars, and the other scientific payloads carry out auto-checks according to work programme. From the remote sensing orbit, when below 800 km altitude, the HiRIC, MoSIR and MMS can intermittently monitor the regions of interest, while the other scientific payloads will operate continuously. Form the remote sensing orbit, when above 800 km altitude, the MOMAG, MINPA and MEPA will work continuously, while the MoRIC and MMS perform on-orbit calibrations, and the HiRIC and MOSIR will be in sleep mode due to the far distance from Mars.

Table 2
Working model of the orbiter scientific payloads.

Payloads	Earth-Mars transfer orbit	Remote sensing orbit	
		Orbit altitude below 800 km	Orbit altitude above 800 km
MoRIC	Self- check every two months	Continuous working	On-orbit calibration once a month
HiRIC	Self- check every two months	Detection of interested area	Shutdown
MMS	Self- check every two months	Monitoring of interested areas	On-orbit calibration once to twice each month
MOSIR	Continuous working on VLF radio spectrum acquisition	Average working time of 26 min each orbit	Shutdown
MOMAG	Self- check every two months	Continuous working	Continuous working
MINPA	Continuous working	Continuous working	Continuous working
MEPA	Continuous working	Continuous working	Continuous working

Because the longest distance between Earth and Mars is over 400 million kilometers, radio communications take a long time and the information transfer rate is low. The payload controller executes a stored working program of the direct and delayed commands.

The payload controller stores a list of the sequences of in-orbit working modes of the multiple scientific payloads and starts these sequences on ground command. Moreover, this pre-stored sequence list can be updated from ground based on the actual on-orbit conditions and the scientific requirements. The ground station uploads the work programme to the orbiter's data management system, which forwards it to the payload controller via a MIL 1553B bus. The payload controller controls the work of the corresponding scientific payload according to the stored commands. (Zhu et al., 2017).

Pictures of the orbiter scientific payloads are shown in Fig. 5.

4.1.3. Design of the orbiter scientific payloads

The Moderate Resolution Imaging Camera (MoRIC) is a wide-field of view camera that can image the Mars surface from an altitude of 800 km to 265 km in orbit, and the collected data are used to study Mars topography, geomorphology and geological structure. MoRIC can provide 2D and 3Dimages.

During the absolute radiometric calibration test of the MoRIC, four levels of saturation (80%, 60%, 40% and 20%) will be utilized to acquire images at 5 homogeneous light intensities (729.65 μw/cm^2, 321.50 μw/cm^2, 1260.23 μw/cm^2, 1937.00 μw/cm^2, 196.93 μw/cm^2) for absolute radiometric calibration. The maximum error after calibration was 2.92%. The main performance parameters of the MoRIC is shown in Table 3.

The detector of the High-Resolution Imaging Camera (HiRIC) is a TDI-CCD. HiRIC operates in a linear sweep mode to obtain high-resolution optical images of Mars to support studies of topography, geomorphology and geological structure. It provides full-color and spectral images. It has an in-orbit focusing capability.

Before the capsule with the rover separates from the orbiter, HiRIC is used to select the landing area to ensure a safe landing. The main performance parameters of the HiRIC is shown in Table 4.

The Mars Orbiter Scientific Investigation Radar (MOSIR) uses linear frequency modulation techniques for pulse compression. The electromagnetic pulses, emitted by the radar, are reflected to the receiver after penetrating the target. The echos provide information on both the Mars surface and subsurface (i.e., the depth and spatial distribution of the underground water ice).

The MOSIR uses two frequency channels and has wideband dipole antennas. The instrument can work in HH (horizontal transmission – horizontal reception) and HV (horizontal transmission – vertical reception) polarization modes.

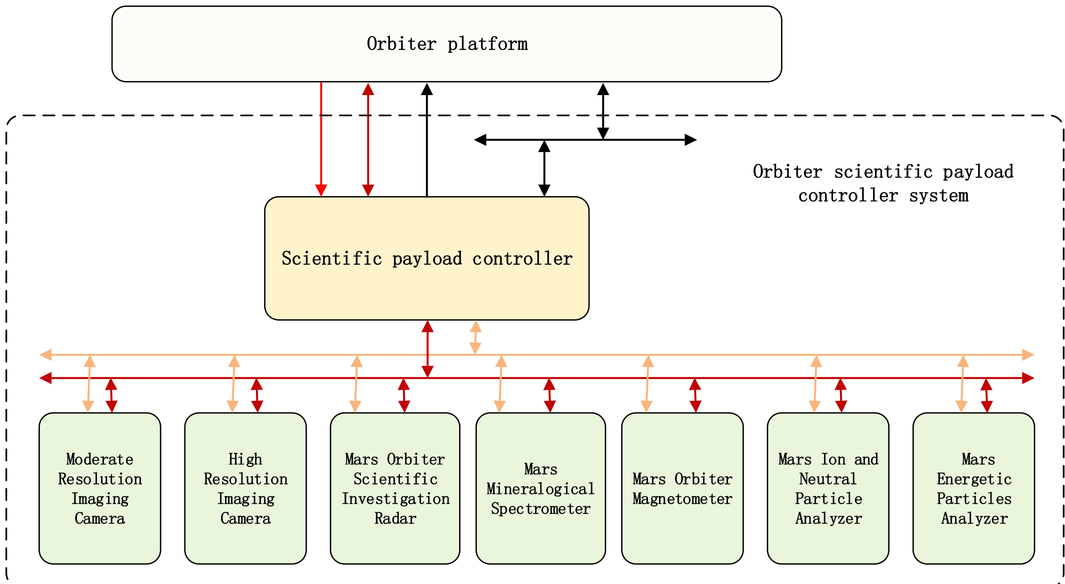


Fig. 4. Framework of scientific payloads system on the orbiter.

Fig. 5. Pictures of the orbiter scientific payloads (from left to right, first row: payload-controller on the orbiter, Moderate-Resolution Imaging Camera, High-Resolution Imaging Camera; second row: Mars Mineralogical Spectrometer, Mars Ion and Neutral Particle Analyzer, Mars Energetic Particles Analyzer; third row: Electronic equipment and probes of Mars Orbiter Magnetometer, Master processor of Mars Orbiter Scientific Investigation Radar).

On the Earth-Mars transfer orbit, the VLF receiver of MOSIR can detect the interplanetary low-frequency electromagnetic waves. The main performance parameters of the MOSIR is shown in Table 5.

The scientific exploration tasks of the Mars Mineralogical Spectrometer (MMS) include 1) to analyze the mineral composition and distribution; 2) to study Mars chemical composition and its evolution; 3) to analyze Mars resources and distribution.

MMS has an off-axis 3 mirror telescope, with free-form elements, flat grating for spectral separation. It works in push-broom mode. As a maximum, it has 512 pixels in

Table 3
Main performance parameters of the MoRIC.

Spectral range	visible spectrum (430–690 nm)
Color	standard R,G,B
Resolution	better than 100 m@400 km;
Imaging width	400 km@400 km orbit altitude;
Effective pixel number	4096 × 3072
Mass	3.5 kg
Power	20 W
Data rate	≤16 Mbps

the spatial dimension and 576 channels in the spectral dimension. The instrument can select suitable combinations of spatial and spectral dimensions as required by the scientific needs. Calibration is achieved by means of the Sun and a lamp.

The radiometric calibration of MMS was measured by reference light sources (integrating sphere and black body) with different energy levels. The error in absolute radiometric calibration for two integration time levels (5.15 ms and 44.6 ms) in the V-NIR channel is below 7.5%, while the error in absolute radiometric calibration for each integration time (1.5–2.3 ms) in the N-MIR region is below 8.5%. The main performance parameters of the MMS is shown in Table 6.

The Mars Orbiter Magnetometer (MOMAG) is a fluxgate magnetometer to measure the magnetic field. By measuring the magnetic field environment of Mars, MOMAG can be used to study the interaction mechanism between the Martian ionosphere, the magneto-sheath and the solar wind.

MOMAG has a dual fluxgate probe sensor mounted on the special stretching pole, and uses a dual probes gradient method to eliminate the influence of the magnetic field of the Tianwen-1 spacecraft on the magnetometer measurements. The main performance parameters of the MOMAG is shown in Table 7.

The Mars Ion and Neutral Particle Analyzer (MINPA) is used to detect low energy ions and neutral particles in the space plasma environment of Mars, and to understand how and why the Martian atmosphere escaped and the acceleration mechanism of neutral particles near the Martian shock wave.

Table 4
Main performance parameters of the HiRIC.

Resolution (at 265 km orbit altitude)	Panchromatic: better than 2.5 m, in key areas better than 0.5 m;
	Color: better than 10 m, in key areas better than 2.0 m;
Spectral bands	Panchromatic: 0.45–0.9 um
	color: blue 0.45–0.52 um, green 0.52–0.60 um, red 0.63–0.69 um, near-infrared 0.76–0.90 um
Coverage width	9 km@265 km
Mass	43 kg
Power	127 W
Data rate	≤2254 Mbps

Table 5
Main performance parameters of the MOSIR.

Frequency	10–20 MHz, 30–50 MHz;
Detecting depth	Mars subsurface structure, ~100 m (soil, $\varepsilon\gamma^* = 3.0 \sim 4.0$), ice, ~1000 m (ice, $\varepsilon\gamma^* = 3.0$)
Thickness resolution	meter level
Mass	28 kg
Power	67 W
Data generation rate	≤1 Mbps

*ε: Dielectric constant, γ: dielectric loss, εγ represents the electromagnetic scattering and radiation characteristics of a substance, used to retrieve the penetration depth of electromagnetic waves in soil or water ice.

Table 6
Main performance parameters of the MMS.

Spectral region	Visible-near infrared, 0.45–1.05 um;
	Near-infrared and mid-wave infrared, 1.00–3.40 um;
Spectral resolution	visible-near infrared, better than 6 nm;
	Near-infrared and mid-wave infrared:
	better than 12 nm@1.0–2.0 um,
	better than 20 nm@2.0–3.4 um
Spatial resolution	2.8 km@265 km, The sampling points in the field of view ≥3, Field of view for each point ≤0.6°
Mass	7.2 kg
Power	48 W
Date rate	≤3.8 Mbps

Table 7
Main performance parameters of the MOMAG.

Measurement range	±2000 nT;
Noise level	≤0.01 nT/$\sqrt{\text{Hz}}$;
Resolution	better than 0.01 nT;
Mass	7.5 kg
Power	3.8 W
Data generation rate	1.95 kbps

The MINPA is equipped with an ionization plate to ionize neutral particles, and the time-sharing detection method of ion and neutral particles is adopted to realize the reuse of sensors and electronics. The main performance parameters of the MINPA is shown in Table 8.

With a single telescope system, combined with anticoincidence detector, the Mars Energetic Particles Analyzer (MEPA) can obtain comprehensive and accurate measure-

Table 8
Main performance parameters of the MINPA.

	Low energy ions	Low energy neutral particles
Energy range	5–25 keV	50–3 keV
Energy resolution (ΔE/E)	15%	100%
Mass	1–70 amu	1–32 amu
Mass	4.7 kg	
Power	11 W	
Data generation rate	18 kbps	

Table 9
Main performance parameters of the MEPA.

Energy range	Electronics: 0.1–12 MeV; Protons: 2–100 MeV; α-particles, heavy ions: 25–300 MeV;
Energy resolution (ΔE/E)	15%
Flux range	0–10^5 cm^{-2} s^{-1}
Elementary composition	H–Fe (1 ≤ Z ≤ 26)
Heavy-ion mass resolution (Δm/m)	≤25% (Z ≤ 9, energy range 25–300 MeV); ≤25% (10 ≤ Z ≤ 26, energy range 100–300 MeV); ≤60% (10 ≤ Z ≤ 26, energy range 25–100 MeV)
Mass	3.1 kg
Power	8.4 W
Data generation rate	1.3 kbps

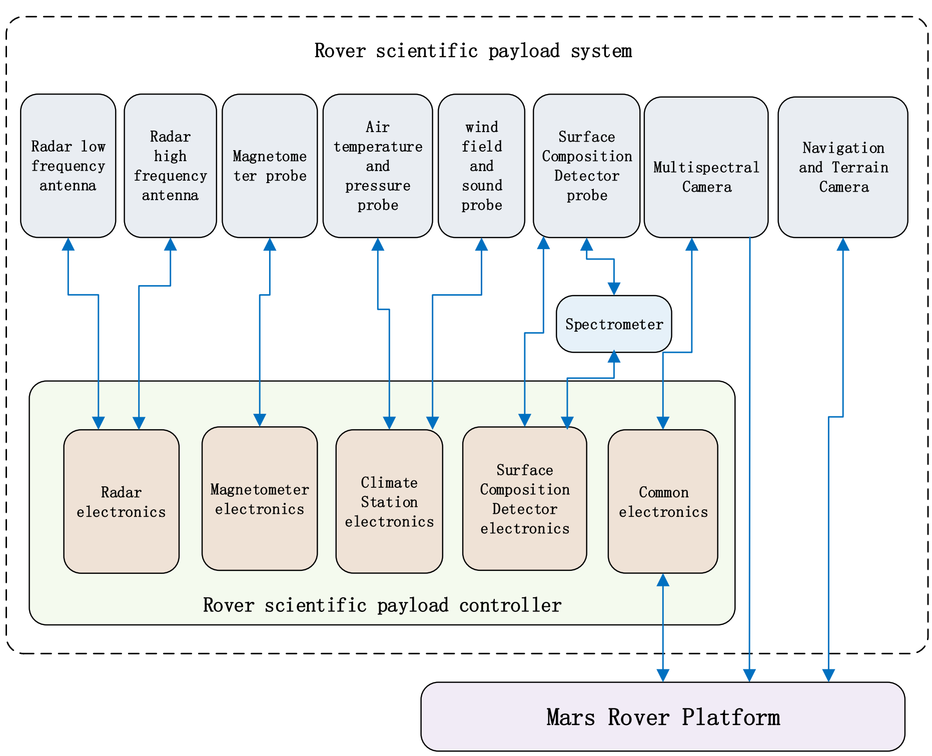


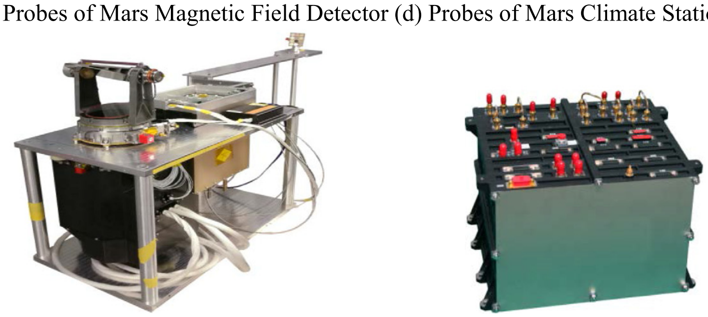
Fig. 6. system architecture of scientific payloads on Mars rover.

Table 10
Working model of the rover scientific payloads.

Payloads	When Mars rover is moving	When Mars rover remains Stationary
NaTeCam	Shutdown	Intermittent working
MSCam	Shutdown	Intermittent working
MarSCoDe	Shutdown	Intermittent working
RoPeR	Continuous working	Shutdown
RoMAG	Intermittent working	Intermittent working
MCS	Intermittent working	Intermittent working

(a) Multispectral Camera (b) Low and high frequency antenna of Mars-rover Subsurface Exploration Radar

(c) Probes of Mars Magnetic Field Detector (d) Probes of Mars Climate Station



(e) Mars Surface Composition Detector (f) Mars rover payloads controller

Fig. 7. Physical pictures of the rover scientific payloads.

ments of electron, proton, alpha-particle and heavy ions, study the characteristics and change rules of the energy spectrum of energetic particles, the elementary composition and flux in the near-Mars space environment and the Earth-Mars transfer orbit, and map the spatial distribution of different types of energy particles radiation.

MEPA has the capability of calibration on orbit. The main performance parameters of the MEPA is shown in Table 9.

4.2. Scientific payloads on the rover

4.2.1. Framework of the scientific payloads of the Mars rover

The payload system of the Mars rover has an integrated design compatible with the rover resources and layout. The payload controller of the Mars rover integrates the master electronic units of the Mars Climate Station, Mars Rover Magnetometer, Mars Surface Composition Detector and Mars Rover Penetrating Radar.

The rover scientific payload system has the payload controller as its core, and the five payloads are integrated into a system through the internal bus network. The payload-controller interfaces with the rover platform and provides interfaces for electric power, data and control. The rover scientific payload controller provides power and instructions to the multispectral camera, and the imaging data collected by the multispectral camera is directly sent to the

Table 11
Main performance parameters of the NaTeCam.

Imaging spectrum	Visible spectrum
Normal imaging distance	0.5 m $\sim \infty$
Effective Pixel Number	2048×2048
Mass	0.7 kg
Power	1.8 W

rover platform. The Navigation and Terrain cameras are directly connected to the rover platform (Zhu et al., 2017). The system architecture of scientific payloads on Mars rover is shown in Fig. 6.

The rover payload controller, like the orbiter payload controller, is capable of autonomous operation, running a stored working programme. The common electronics of the rover payload controller is redundant in design. It also has the autonomous capability of fault detection, isolation and recovery (FDIR) and system configuration.

The payload controller stores a list of the sequences of in-orbit working modes of the scientific payloads and starts these sequences on ground commands. Moreover, this pre-stored sequence list can be updated from the ground based on actual in-situ conditions and the scientific requirements. The ground station uploads the working programme to the rover's data management system, which forwards it to the rover payload controller via a MIL 1553B bus. The rover payload controller controls the work of the corresponding scientific payload according to the stored commands and management software.

4.2.2. Working mode of the scientific payloads on Mars rover

The scientific payloads of the Mars rover will choose the time to work according to the environmental conditions. The NaTeCam, MSCam and MarSCoDe work while the rover is in a stationary mode, and the RoPeR works when the rover is moving, and the RoMAG and MCS can be selected to work during the moving and stationary conditions of the rover. The in situ working modes of the Mars rover payloads are shown in Table 10. (Zhu et al., 2017).

Physical pictures of the rover scientific payloads are shown in Fig. 7.

4.2.3. Design of the scientific payloads of the Mars rover

There are two Navigation and Terrain Cameras (NaTeCam) with identical function, performance and interfaces. They are installed on the mast of the rover to conduct three-dimensional panoramic imaging of the Mars surface, study topography and geological structure of the roving area. They also have a navigation function. The main performance parameters of the NaTeCam is shown in Table 11.

The Multispectral Camera (MSCam) is installed on the mast of the rover. According to the pointing direction of the mast, the MSCam can get multispectral images of the landing and roving areas and study the types of Mars surface materials and their distribution. The MSCam uses a filter wheel and has a compensation mirror for automatic focusing. The MSCam calibration is achieved by imaging the standard calibration board installed on the Mars rover. The main performance parameters of the MSCam is shown in Table 12.

The Mars Rover Penetrating Radar (RoPeR) can obtain full-polarization echo data with ultra-wide band, which can be used to study the soil and ice thickness and structure of the Mars surface and subsurface.

The RoPeR has two channels centered at 55 MHz and 1300 MHz respectively. The low-frequency channel uses linear frequency modulation (LFM) signals and has a pair of monopole antennas to probe the Mars ground down to 100 m depth with a vertical resolution of 1 m. The high-frequency channel uses frequency-modulated interrupted continuous wave (FMICW) signals and Vivaldi antennas to probe the superficial layers of Mars down to 10 m with cm level resolution. The main performance parameters of the RoPeR is shown in Table 13.

The Mars Surface Composition Detector (MarSCoDe) is a spectral detection instrument with a combination of active-passive detection techniques. MarSCode has a laser-induced breakdown spectroscopy (LIBS) spectrometer analyzing the laser-excited plasma from the ultraviolet (UV) to near-infrared ray (NIR). MarSCoDe also has a passive spectrometer operating from the NIR to the short-wave infrared (SWIR), which uses Acousto Optical Tunable Filters (AOTF) for band selection. Combining these techniques MarSCoDe can analyze the composition of the surface materials and identify the different types of rocks.

The calibration of the LIBS instrument and the passive spectrometer is achieved using dedicated calibration targets. The LIBS calibration board has 12 standard samples, including simple minerals as graphite, titanium and mixed minerals as obsidian, norite, picrite, kaolinite and chlorite. The main performance parameters of the MarSCoDe is shown in Table 14.

The Mars Rover Magnetometer (MoMAG) is a fluxgate magnetometer. The probes are mounted on the mast of the rover to detect the magnetic field of the landing and roving area. There are two probes to eliminate by subtraction the

Table 12
Main performance parameters of the MSCam.

Spectral bands and resolution (nm)	There are nine spectral bands: 480(20), 525(20), 650(12), 700(15), 800(25), 900(30), 950 (50), 1000 (50), and panchromatic note: numbers with bracket is FWHM
Normal imaging distance	1.5 m ~ ∞
Effective Pixel Number	2048 × 2048
Mass	1.65 kg
Power	$\leq$8 W
Data rates	25 Mbps

Table 13
Main performance parameters of the RoPeR.

	First channel	Second channel
Center frequency	55 MHz	1300 MHz
Bandwidth	15–95 MHz	450–2150 MHz
Resolution of thickness	meter level(for ice)	centimeter level,
Detection depth	$\geq$100 m(ice, $\varepsilon\gamma^* = 3.0$)	$\geq$10 m(ice, $\varepsilon\gamma^* = 3.0$)
	$\geq$10 m(soil, $\varepsilon\gamma^* = 3.0$–4.0)	$\geq$3 m(soil, $\varepsilon\gamma^* = 3.0$–4.0)
Mass	6.1 kg	
Power	26.5 W	
Data rate	$\leq$1 Mbps	

Table 14
Main performance parameters of the MarSCoDe.

LIBS spectrometer	
Types of element	No less than 10 element (Si, Al, Fe, Mg, Ca, Na, O, C, H, Mn, Ti, S etc.)
Spectral resolution	0.1 nm@240–340 nm
	0.2 nm@340–540 nm
	0.3 nm@540–850 nm
Wavelength of the laser	1064 nm ± 15 nm
Pulse energy density	$\geq$10 MW/mm^2
Passive spectrometer	
Spectral range	850–2400 nm
Spectral resolution	3–12 nm
Number of spectral bands	321 bands@5 nm sampling
Mass	16.4 kg
Power	64 W
Data rate	$\leq$1 Mbps

Table 15
Main performance parameters of the MoMAG.

Measure range	±2000 nT
Resolution	better than 0.01 nT
Noise level	$\leq$0.01 nT/$\sqrt{\text{Hz}}$
Mass	1.05 kg
Power	5.5 W
Data rate	$\leq$1 Mbps

parasitic magnetic effects of the rover. RoMAG works with the orbiter MOMAG to detect the Martian space magnetic field and retrieve the currents of the Martian ionosphere. The main performance parameters of the MoMAG is shown in Table 15.

The Mars Climate Station (MCS) uses micro electro mechanical system (MEMS) capacitive type micro pressure transducer, MEMS hot-film anemometer, a Fabry-Perot interferometer (EFPI) optical fiber acoustic sensor, and a set of thermometric platinum resistors. MCS can obtain key atmospheric state data such as temperature, pressure, wind speed and direction to monitor Martian surface meteorology. The main performance parameters of the MCS is shown in Table 16.

Table 16
Main performance parameters of the MCS.

Temperature		Pressure	
Measure range	−130 °C to +70 °C	Measure range	1–2000 Pa
Resolution	0.1 °C	Resolution	0.1 Pa
Wind speed		Wind direction	
Measure range	0–70 m/s	Measure range	0–360°
Resolution	0–10 m/s: Better than 0.2 m/s	Resolution	5°
	10–20 m/s: Better than 0.3 m/s		
	20–70 m/s: Better than 0.5 m/s		
Sound			
Frequency range	20 Hz–2.5 kHz, 2.5–20 kHz	Sensitivity	Better than 50 mV/Pa
Dynamic range	$\geq$90 dB		
Mass	1.75 kg		
Power	11 W		
Data rate	$\leq$1 Mbps		

5. Conclusions

The article introduces the exploration tasks, physical, functional, performance and operational design of the Tianwen-1 scientific payloads. Through their flexible system and operational design, the payloads can perform their tasks and thus achieve the mission objectives. All the scientific payloads have been tested and calibrated on the ground and their performance results meet the requirements.

"Tianwen-1" is the first mission of China's deep exploration plan. It will carry out a comprehensive study of Mars by orbiting, landing and roving. It will achieve global and locally detailed surveys from the orbiter and the rover, respectively. With the Tianwen-1 scientific data, studies will be conducted on Mars magnetosphere and ionosphere, surface and sub-surface, and the results will make significant contributions to Mars science.

Declaration of Competing Interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

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