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Science Researches of Chinese Manned Space Flight

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ABSTRACT

With the complete success of the 2nd stage of Chinese Manned Space Program (CMSP), several science researches have been performed on Tiangong-1 experimental spacelab, which was docked with three Shenzhou spaceships one after another. The China's real spacelab, Tiangong-2 will be launched in 2015, docked with a Shenzhou spaceship soon. After six months, it will be docked with the first Chinese cargo ship (Tianzhou-1). More space science researches, involving with space biology, fluid physics, fundamental physics, materials science, Earth science, astronomy and space environmental science, will be operated on Tiangong-2 spacelab, and crewed and cargo spaceships. Furthermore, the considerable large-scale space utilization of Chinese Space Station is planned. The research fields include yet not limited to space medicine and physiology, space life science and biotechnology, fluid physics and combustion in microgravity, space material science, and fundamental physics in microgravity, space astronomy, Earth science, space physics and space environment utilization, technology demonstration.

KEY WORDS

Science research, Chinese Manned Space Program (CMSP), Space station

1 Progress and Future Plans of China's Manned Space Program

Tiangong-1, serving as a target spacecraft as well as an experimental space laboratory, was visited by the other two Shenzhou spaceships after Shenzhou-8 in the latest two years. Shenzhou-9 spaceship docked with Tiangong-1 in June, 2012, which was China's first manned spacecraft rendezvous and docking. Liu Yang, the first Chinese female astronaut, was among the crew. One year later, Shenzhou-10 spaceship docked with Tiangong-1 in June 2013 with another female astronaut. Now Tiangong-1 has exceeded its planned two-year operational life time and entered the extension application phase. It will continue to work in orbit till the fuel runs out.

With the complete success of these spaceflight missions as a milestone, China's Manned Space Program (CMSP) will enter a new phase of manned space station construction. Tiangong-2, serving as a real space laboratory, will be launched in 2015. Half a year later, the first cargo ship (named Tianzhou-1) will be launched and dock with Tiangong-2 in 2016. In 2018, the first module as the core module of the multi-module space station of China will be launched. And two experimental modules will be launched into space in 2020 and 2022 respectively. The China's manned space station is planned to be a state-level space laboratory, for carrying out successive space science researches, technology demonstrations and some space applications.

Between 2015 and 2022, there will be a series of cargo ships and manned spaceships transporting crews and supplies to the space laboratory and space station.

2 Science Researches on Tiangong-1 and Shenzhou Spaceships

Ever since having been launched on September 29, 2011, Tiangong-1 is in flight operation phase, including three rendezvous and docking missions. All the payloads on Tiangong-1 have performed well, *e.g.* the Earth observation and space environment detectors onboard. Tiangong-1 has obtained a great deal of scientific data, which are valuable in mineral resources investigation, ocean and forest application, hydrologic and ecological environment monitoring, land utilization planning, urban thermal environment monitoring and emergency disaster control. Remarkable application benefits have been achieved. For example, Tiangong-1 provided the timely hyper-spectral observation data during the Yuyao (a county in Zhejiang Province of China) flood disaster as well as the image data during the Australia forest fire.

(1) Space Earth Science: Hyperspectral Imager

The key specifications of Hyperspectral Imager (HSI) installed on Tiangong-1 are shown in Table 1. And images from three spectrums are shown in Figure 1–3.

Recently, China Manned Space Agency (CMSA) officially published the data policies and there are two accesses to Tiangong-1 application data to facilitate the data utilization in the nation's economic, social development and scientific research. Under the authorization

Tab.1 Key specifications of HSI

spectral name	spectral range	number of bands	spectral resolution	spatial resolution	width
full chromatographic	0.5–0.8 μm	1	-	5 m	20 km
visible and near infrared	0.4–1 μm	64	10 nm	10 m	10 km
shortwave infrared	1–2.5 μm	64	23 nm	20 m	10 km
thermal infrared	-	1	-	10 m	15 km

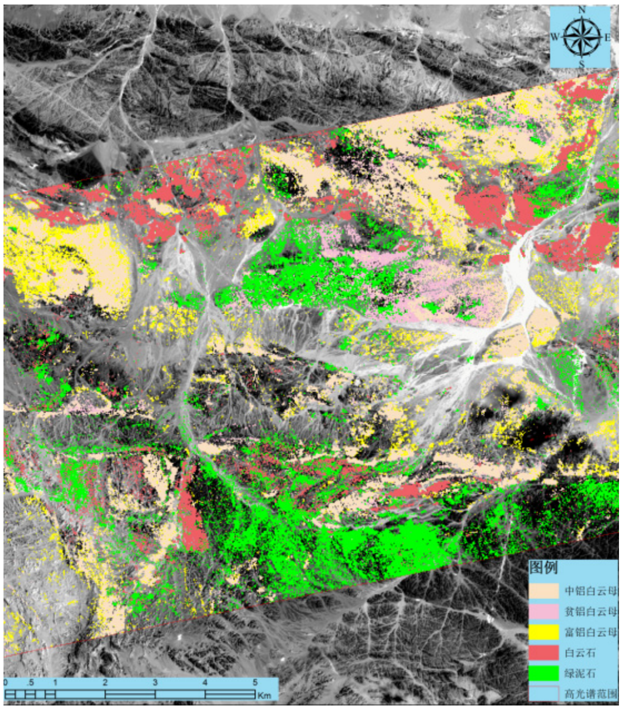

Fig.1 Hyperspectral short-wave infrared spectral data applied to mineral identification

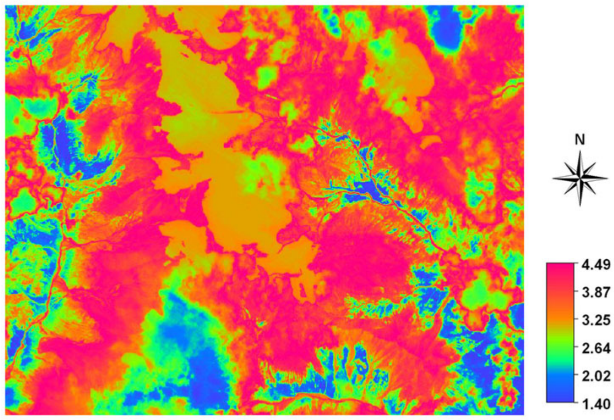

Fig.2 Thermal infrared spectral data and other remote sensing ancillary data applied to Earth surface observation

Fig.3 Hyperspectral visible-near infrared data applied to monitoring of land utilization

of CMSA, Technology and Engineering Center for Space Utilization (CSU) of Chinese Academy of Sciences (CAS) is in charge of processing and distributing the Earth observation data obtained from Tiangong-1. The nonprofit users can fill a form online to obtain the data of Grade 1 and Grade 2. The domestic and international commercial users can purchase the data service *via* several Chinese agents. Tiangong-1 data Service Platform for Expanding Space Utilization has been online. Users may visit *http://www.msadc.cn* to learn the details about the related policies, data acquisition procedure and application cases.

(2) Space Material Science: Composite Colloidal Crystal Growth

A diffract visible light imager was operated in Tiangong-1 to observe the composite colloidal crystals or crystalline phase transition in microgravity environment. The series of comparison crystallization experiments on the ground have been done, to find the effect of gravity in the colloidal crystal growth process and understand more about the mechanism of colloidal crystal growth.

The natural crystallization process of one material sample is showed in Figure 4. The initial state of amorphous material sample in the crystallization

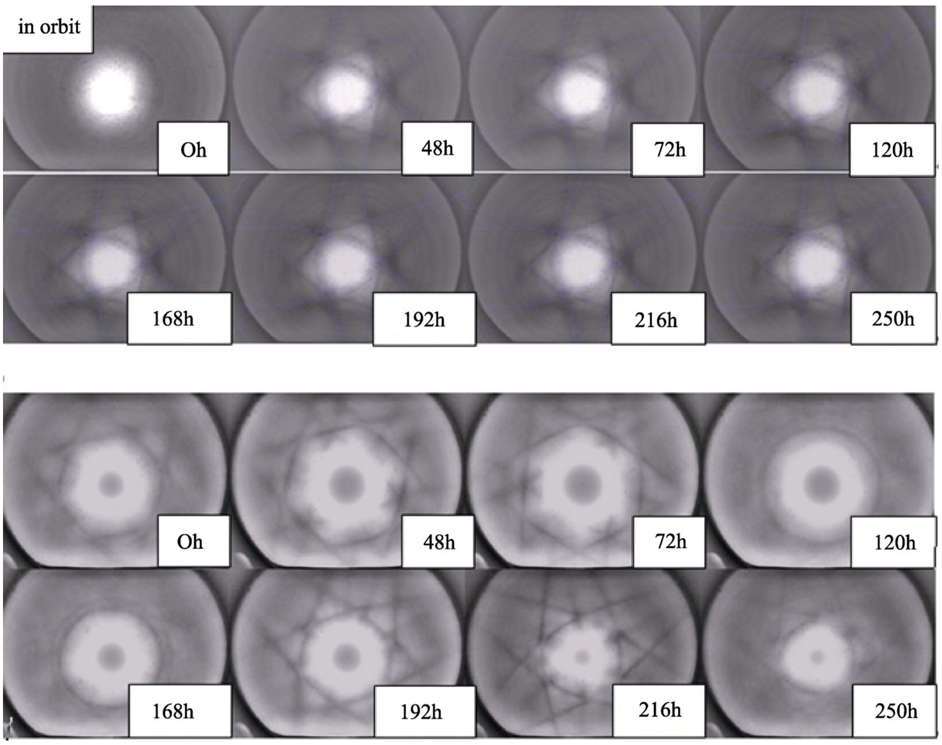

Fig.4 Images of natural crystalline Kossel diffraction for typical sample. The upper are the results of space experiments and the lower are the results of ground experiments

experiments was observed under a zero external electric field (or voltage) and 25 ℃ temperature. The Kossel diffraction lines of the sample process from scratch were observed on board. A number of natural crystalline diffraction experiments were conducted, in order to confirm the experimental result. The typical natural crystalline diffraction figures of in-orbit experiments and of the corresponding comparison ground experiment are shown in Figure 4. The data analyses are illustrated in Figure 5.

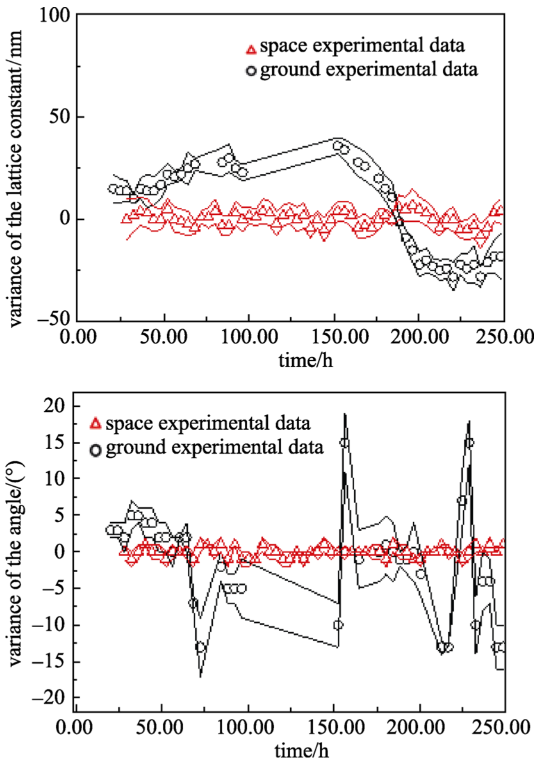

Fig.5 Natural crystalline analyses for typical sample. The left is the change of lattice size during the natural crystalline process, the right is the change of the crystal lattice orientation during the natural crystallization process; the red triangles mark the space experimental data and the black rings mark the ground experimental data

(3) Astrobiology

Aboard the Tiangong-1, the Shenzhou-9 and Shenzhou-10 crew members tested space medicine and conducted a series of technology demonstrations.

Shenzhou-9 astronauts onboard have successfully carried out three major aspects of aerospace medical experimental research: (a) health monitoring of astronaut's nutrition and metabolism, moods and biorhythm changes; (b) physiological effects mechanism of weightlessness and the countermeasures, which include the impact study on the functions of astronaut's cardiovascular, vestibule and brain, bone loss; (c) environmental medicine and the astronaut's operational capability in space.

Aided by her Shenzhou-10 crew member, Wang Yaping, the second Chinese female astronaut, conducted the scientific experiments and gave a physics lesson to Chinese students on live television. Wang demonstrated pendulum movement and gyroscopic motion, and created a water bubble to illustrate the surface tension of water in microgravity. More than 60 million students and teachers from 80 thousand high schools all over China have participated in the interaction.

3 Science Researches on Tiangong-2 Spacelab and Tianzhou-1 Cargo Ship

Tiangong-2, as the first real space laboratory of CMSP, will be launched in 2015. There will be a relatively larger scale space science projects on board. The fields of researches are related with the space biology, fluid physics in microgravity, fundamental physics, Earth science, space astronomy, and space environment detector. All flight models of scientific payloads have been completed development, which are undergoing integrated tests and ground verification now. An experimental cargo ship, Tianzhou-1, is going to be lunched around 2016. A cell bioreactor, a two-phase fluid instrument and an accelerometer for flight demonstration will be launched with it.

(1) Space Biology and Microgravity Physics

A higher plants cultivation experiment on Tiangong-2 would study the growth and development law from seed to seed, to explore how the long-day and short-day photoperiodic induce and control the flowering law and regulation mechanism under microgravity conditions.

An integrated material furnace on Tiangong-2 would focus on the material physical and chemical processes of space material production, the samples including semiconductor optoelectronic materials, metal alloys and metastable materials, new feature single crystal, micro-nano and composite materials, *etc*.

A liquid bridge thermo-capillary on Tiangong-2 convection experiment would observe the large Prandtl number liquid bridge, study the effect of the ratio of height to diameter and the ratio of height to volume on the critical process, search for the secondary transition rules, and get the knowledge of the instability mechanism of space heat convection in the microgravity environment.

A bioreactor on Tianzhou-1 would observe the cellular culture processes onboard, revealing the mechanism of proliferation and differentiation for stem cell in the microgravity environment.

A two-phase fluid experiment on Tianzhou-1 would study the process of evaporation and condensation phase transition.

(2) Fundamental Physics

The space-ground Quantum Key Distribution (QKD) experiment on Tiangong-1 would use Decoy methods of photon polarization state and dynamic space-ground two-way high-precision tracking and pointing techniques. This experiment would test and demonstrate a serial of techniques including the quantum key generation, distribution and extraction, optical link chain keeping, and so on.

A cold atomic clock using laser-cooled rubidium atoms will be tested on Tiangong-2, and the aim is to check and verify the key technology and realize the daily frequency stability of 10^{-15}–10^{-16} level under microgravity condition.

The performance of a high-precision electrostatic suspended accelerometer on Tianzhou-1 would be verified in orbit, cooperated with one active vibration isolation equipment that has the six-degree freedom control capability.

(3) Space Earth Science

There are three payloads on Tiangong-2 for the Earth space science, including a Multi-angle Spectral Imager (MSI), a Three-Dimension Microwave Altimeter (3DMA) and a UV Limb sounder (UVL).

MSI will undertake observations of the ocean, atmosphere, land and other environmental resources related landmark information, to demonstrate the key technology of Chinese next generation of Moderate Resolution Imaging Spectrometer.

3DMA would use Ku band dual-antenna, wide swath interference imaging to observe and obtain high precision marine 3D shape and 3D terrain, which would break through and master new type elevation tracking, aperture synthesis and high-precision interferometry phase acquisition and processing, and other advanced key technology of microwave imaging remote sensing.

UVL would perform ultraviolet spectrum limb detection of the Earth's limb atmosphere, and obtain high spatial and temporal coverage, high vertical resolution images and data, to study the vertical structure and three dimensional distribution of global atmosphere density, ozone distribution, aerosol and other minor-components.

(4) Space Astronomy

Gamma-ray Burst Polarization Detector (POLAR) is a Sino-Swiss cooperated detector for cosmic gamma-ray bursts on Tiangong-2. As the first polarization detector, it would explore the high-sensitivity polarization by GRB mechanism, revealing the structure, the origin and evolution of the universe.

(5) Space Environment Monitoring

The intensity and spectrum of electrons, protons and other particles in all directions, the atmospheric density, composition and spatial and temporal changes, and the capabilities of atomic oxygen erosion and air pollution effects would be monitored.

4 Science Research Plans for China's Space Station

China Space Station (CSS) plans to operate in orbit from 2022 to 2032. The station's core module and two modules for science experiments will be launched into the LEO obit in 2018, 2020 and 2022 respectively. The experiment racks and research facilities on CSS would be provided to scientists worldwide. CSS could support more than a decade racks for life and physical science in pressurized capsule, and individual instruments for sky survey, Earth observations and other utilization on the external platform.

The main purpose of CSS space utilization is to promote the understanding of the nature of life and the universe. The relative large-scale utilization will covers more fields: space medicine and physiology, space life science and biotechnology, fluid physics and combustion in microgravity, space material science, fundamental physics in microgravity, space astronomy, space Earth science, space physics, space environment detector, and technology demonstration, *etc*.

Space life science efforts on CSS will be divided into five areas: fundamental biology, biotechnology, space radiation biology and interdisciplinary studies. The latter includes biological mechanics research and hypo-magnetic biology, the synthesizing biological molecules in space and the biomechanics.

The microgravity science research intends to address fluid physics and combustion, with emphasis on both basic science and technology development for ground applications. One type of science researches is on the surface-tension driven convection and diffusion, capillary phenomena and interfacial processes, and complex fluids, the other is on the two-phase flow, phase change heat transfer and its application. The combustion science research will support the development basic combustion theories, fire prevention, detection and suppression.

Materials science in CSS will strengthen fundamental materials science research to gain a deeper understanding of materials phenomena which could then be used to improve and develop the theory of materials science, explore processes which govern materials synthesis and processing on the ground and produce new materials combined with the important application requirements, and service behavior of the materials related to space exploration.

For fundamental physics, how the ultra-cold rubidium and potassium atoms behave in microgravity will be tested to research exotic quantum state and new phenomena. Also a high-precision time frequency experiment is proposed, which would include a hydrogen atomic clock, a cooled atom microwave clock, a cooled atom optical clock and other equipments, as well as companion ground components. There are also some proposed experiments for relativity and equivalence principle test.

A large optical astronomical facility is proposed to sky survey for carrying out dark energy, accelerating expansion of the universe, cosmic evolution, dark matter, galaxy formation and stellar researches.

Earth science research of CSS focused on global change, the environmental resources and natural disaster research and applications.

Now, about 150 candidate science projects for CSS have been selected in the first round, while the processes of rack development are in Phase B. The international cooperation and academic communications are very important to promote utilization level and scientific output. CSS would provide the ever best opportunities to scientists from all over the world.