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Science Research and Utilization Planning of China's Space Station in Operation Period 2022–2032

GU Yidong GAO Ming ZHAO Guangheng

(*Key Laboratory of Space Utilization, Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences, Beijing* 100094)

Abstract The core module of China's Space Station (CSS) is scheduled to be launched around the end of 2020, and the experimental module I and II will be launched in the next two years. After on-orbit constructions, CSS will be transferred into an operation period over 10 years (2022–2032 and beyond) to continuously implement space science missions. At present, based on the project selection and research work in the ground development period of CSS, China is systematically making a utilization mission planning for the operation period, which focuses on the fields of aerospace medicine and human research, space life science and biotechnology, microgravity fluid physics, combustion science, materials science, fundamental physics, space astronomy and astrophysics, Earth science, space physics and space environment, space application technology, *etc.* In combination with the latest development trend of space science and technology, China will continue to update planning for science research and technology development, carry out project cultivation, payload R&D, and upgrade onboard and ground experiment supporting systems to achieve greater comprehensive benefits in science, technology, economy, and society.

Key words China's space station, Utilization, Planning, Experiment

Classified index V 476

1 Progress of CSS Development

The core module of China's Space Station (CSS) will be launched by the launcher Long March 5B after 2020, the experimental module I, II will be launched in the next two years and the assembly of three modules is expected to be completed around 2022, and then the CSS will be transferred into an operation period over 10 years (2022–2032 and beyond)[1]. At present, the scientific experimental racks and related supporting systems are in the pressurized module and some exposed facilities are being developed. By 2019, China has issued two large-scale AO (Announcement of Opportunity) to solicit scientific research and application projects, published a number of project guidelines[2], a total of nearly 1000 proposals have been received, which laid a good foundation for the ground research and preparation for the follow-up consecutive projects of CSS. Based on all these works, China is systematically working out a complete scientific research plan on board for CSS operation which will guide to make full use of the experiment facilities and maximize the utilization efficiency.

2 Main Mission of CSS Operation

CSS aims to become a national space laboratory at an international advanced level in the operation period. The main mission of CSS comprehensively focuses on the research fields of space science, aerospace medicine, and new technology for future applications, continuously implement science and other application projects on orbit. At the same time, firstly, it is necessary to continuously update the planning of CSS utilization, carry out project cultivation (ground research), and payloads R&D,

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E-mail: gxd@nssc.ac.cn

make full use of the facilities that have been planned in CSS ground development period. Secondly, it is necessary to further expand the scale of researches and utilizations by making full use of the resources inside and outside three modules, to promote new scientific experimental platforms and facilities. Thirdly, it is necessary to make rational and efficient use of relevant scientific data and research results, systematically and comprehensively popularize technology and achievements, lead international cooperation and expand space educations, to achieve greater benefits in science, technology, economy, and society ultimately.

3 Planning Ideas

The science planning should be based on the principle of combining science and technology to ensure every project with high scientific significance and cutting-edge technologies. At the same time, it must pay attention to the maturity of the technical solutions of the mission and consider the feasibility of the project, and establish project cultivation mechanism to carry out ground research in depth, strengthen the integration of science and engineering, and improve the Technology Readiness Level (TRL), so that engineering development could effectively under the guidance of planning. Firstly, expert teams composed of chief scientists, senior scientists (including experimental system engineers) and young scientists have been organized to continuously specify a systematic, serialized and step-by-step research plan, to optimize the top-level design of key research directions for CSS. The top-level design will contribute to the foundational framework and main content of the planning. Secondly, the planning process will continue to collect new research proposals and ideas through an extensive AO mechanism effectively supplement the planning contents. In addition, based on the planning priorities, targeted project guidance can be conducted for directional AO, so that the science planning can be closely integrated with the specific research projects, which will help to consolidate major projects with scientific significances and influential results.

Before the launch of CSS until the whole operation period, the planning is expected to provide a clear and definite reference for scientific research and utilization, continuously guide to review and select high-quality projects, and to propose a scientific project planning suitable for the project implementation through ground cultivations (ground research funding), so as to maximize the outputs in fundamental science researches, applied basic researches, and related technological innovations.

4 Science Planning for CSS Operation

China's manned spaceflight program has accumulated utilization experiences and achieved fruitful research results in Shenzhou spaceships and Tiangong laboratories. With the ground development of CSS, planning has been carried out for many years. On those earlier bases, at present, the planning is more oriented to the international scientific frontier[3], to original innovations and China's development needs[4], and all work will comply with a more comprehensive science plan with series research fields and directions.

4.1 Aerospace Medicine

The field of aerospace medicine focuses on human science and major medical problems that restrict human long-term spaceflight[5]. It also takes into account the health needs of the general public on the ground. The planning is mainly to research and solve the problems of long-term weightlessness on astronaut's physiological functions and protection mechanisms, impacts of space radiation on astronaut's health and protection mechanisms, new technologies and methods for aerospace medical research, mechanisms of traditional medical aerospace application technology, aerospace nutrition, and metabolic mechanisms, *etc.* Research achievements are expected to provide basic support for the long-term mission health in the space station, provide technical support for improving the operation ability of astronauts, and accumulate experience for longer-term manned flight and manned deep space exploration.

4.2 Space Life Science and Biotechnology

Researching the existence, response, and activities of life under space radiation, microgravity and weak magnetic could deeply understand the nature of life phenomena and the needs of human long-term space exploration. The objectives of space life science research are to promote the understanding and cognition of the essence of life phenomena and to explore the scientific laws, including the perception and response mechanism of various levels of life to the change of gravity[6]; the mechanism of damage, change and stress under space radiation; the basic issues of the controlled ecological support system, and the exploration of the origin of life. Space biotechnology is focused on obtaining innovative materials, drugs, and medical technologies by using space microgravity and other environments. It is expected to help improve people's health, the development and application of regenerative medicine, biological cell therapy, biological medicine, and environmental biotechnology; carry out research on biomolecular design and its synthetic biology, expand germplasm resources by using space radiation mutagenesis, and promote agriculture and medicine service: develop the controlled ecosystem that can operate stably and adapt to the needs of long-term human space exploration.

4.3 Microgravity Fluid Physics

The planning of microgravity fluid physics focuses on discovering new phenomena and new laws of fluid movement under microgravity conditions, expanding the development of fluid basic theory, realizing new systems that are difficult to construct on the ground, and forming systematic theoretical innovations and technological breakthroughs[7]. The science research focuses on the dynamics of interface and diffusion processes, including multiphase flow and heat transfer problems, and complex fluid behavior. The application research is closely related to fluid management, chemical smelting, biology and medicine, material manufacturing and processing, and is helpful to solve the key technologies of propellant management, optimizing propellant storage and transportation on-orbit. On the ground, it is conductive to the transfer of related technologies, and promoting R&D and manufacturing of new high-efficiency-safe space fluid and thermal equipment.

4.4 Microgravity Combustion Science

The planning of combustion science focuses on combustion characteristics and basic theory research, space fire safety, *etc.* In addition, microgravity combustion science research is closely related to energy saving and emission reduction, improving the characteristics of spacecraft engines, and testing the flammability of related materials. The research achievements are expected to deepen understanding of droplet-phase, gas-phase, and solid combustion phenomena in reduced gravity with longer durations, larger scale. CSS will establish the international leading combustion research platform which can provide advanced diagnostic means, integrate models with experiment and design, and provide other knowledge to terrestrial applications.

4.5 Space Material Science

Space materials science is an integrated field with both science and applications. More discoveries, techniques, and methods of materials research can be obtained under microgravity conditions. The planning focuses on material science and the national strategic needs, will carry out serialized and interdisciplinary researches on the basic theoretical issues of material science and the development of new materials with major national needs. The plan is related to: firstly, revealing the special physical and chemical properties and processing rules of various materials under the conditions of space environment, solving key scientific issues in materials microstructure and defect control, enriching and develop basic theories of materials science, and guiding the research and application of ground materials science; major breakthroughs are expected in the basic principles of material science, materials preparation and processing methods, and development of new materials; secondly, researching and preparing new materials is expected to achieve important results in special structural materials, functional materials, energy materials and biological materials; thirdly, recognizing the special laws and behaviors of materials in the outer space environment, and providing scientific basis for the design and development of advanced materials and components for aerospace engineering and space technology are expected; fourthly, developing new types of space materials science on-orbit experimental facilities, and making important breakthroughs in terms of guarantee conditions, experimental technology and research capabilities.

4.6 Fundamental Physics

An important advantage of using space conditions to research fundamental physics is that high- precision physical measurements can be performed, many of the essential problems of modern physics are likely to be solved only through space research. The planning of fundamental physics in microgravity is going to make use of the Cold Atom Experimental Rack (CAER) for carrying out a series of ultra-cold atomic physics experiments under extreme conditions to achieve breakthroughs in the theories of modern physics[8]. Utilizing the High-precise Time-Frequency Rack (HTFR) to improve the stability and accuracy for precise fundamental physics research, will promote practical applications, such as leading the quantum sensor technology, and promoting the advanced technologies and science for high precision measurement in space. As for the complex plasma physics research, a world-leading microgravity complex plasma experiment platform will be developed into a series of basic science and applications such as the interaction between dust particles and the spacecraft.

4.7 Space Astronomy and Astrophysics

With the prosperity of international big-science project, the observation of space astronomy entered a new age of multi-messenger with all-weather, all-round, high-resolution, high-sensitivity, and wide-field detection. Space Astronomy and Astrophysics is highly valued in CSS, the 2 m-caliber China Space Station Telescope (CSST, or called Multifunctional Optical Facility)[9], the High Energy Cosmic-Radiation Detection (HERD)[10], POLAR-2[11] and other astronomical observation equipment will be launched after 2022, those will acquire a series of major breakthroughs in international frontier hotspots such as dark matter and dark energy, the origin of cosmic rays, the formations and early evolutions of the universe, the large-scale structure of the universe, galaxies and supermassive black holes, and exoplanet search, *etc.*, it is demonstrated the ultraviolet telescope will open up a new research field and fill in the blank of the observation of the ultraviolet diffuse source. These studies will make outstanding contributions to the development of astronomy, physics, and a series of key technologies such as high-sensitivity particle detection, ultra-low temperature refrigeration, and high-precision polarization detection. These technologies will strengthen engineering development, including optics, high-performance electronic devices, and advanced electromechanical and thermal technologies.

4.8 Earth Science

Using the CSS platform to conduct Earth science project could cross-penetrate with other disciplines and supplement science satellites, with a long term, a more refined, in-depth and more quantitative perspective to detect and understand the Earth, and can provide possibilities for many basic scientific problems on Earth science and acquire many application achievements that were difficult to solve on the ground. The planning of Earth science focuses on developing a new generation of high-precision and quantitative remote sensing technology, to acquire multidimensional information of the Earth system, research global climate change and natural disasters, monitor environmental pollution, and explore resources.

4.9 Space Physics and Environment

The orbit of the CSS is located in the middle chain of the Sun-Earth system, which is involved with different physical properties, various physical phenomena in unique high-vacuum, high-radiation, and high-conductivity environments. It is an important channel for material and energy transfer, such as the mechanism and path of the matter outflow, the energy deposition[12]. The science planning focuses on a comprehensive exploration of near-earth space environment, remote sensing of solar physics, and remote sensing of planetary space environment. Making full use of the advantages of long-term stability in orbit, multiple detectors with long-term observation data, explore the role of the plasmasphere in the coupling process of the ionosphere and the magnetosphere, the influence of the plasmasphere on the near-Earth space environment, to establish a dynamic three-dimensional model of the plasmasphere. To understand the origin and burst mechanism of the solar activity such as the transmission mechanism of matter and energy in the solar atmosphere, scientific problems such as coronal heating, triggering and acceleration of solar wind, the origin of solar activity will be analyzed in order to improve the forecasting model accuracy of near-earth space weather.

5 Upgrade Planning of Experiment Support Systems

5.1 Onboard Experiment Support Systems

The onboard science experimental systems are mainly composed of experimental racks in-station and exposed experiment facilities extra-station. At present, the experimental racks include experiment rack Life and Ecology Research Rack (LER), Biotechnology Research Rack (BTR), High Microgravity Level Research Rack (HMLR), Fluid Physics Research Rack (FPR), Cold Atom Physics Research Rack (CAPR), High Precision Time-Frequency System (HPTFS), High-Temperature Materials Research Rack (HTMR), Containerless Materials Processing Rack (CMPR), Two-Phase System Research Rack (TPSR), Combustion Sciences Research Rack (CSR), Glovebox and Cold Storage Rack (GCSR), On-orbit Maintenance and Manipulation Workbench (MMW), Varying Gravity Research Rack (VGR)[13]. The exposed experiment facilities include Biology Research Exposed Facility (BREF), Material Research Exposed Facility (MREF), and Components Test Exposed Facility (CTEF). All the experiment capabilities can provide effective support for most of the projects planned in the early operation period.

To ensure the continuous and efficient development of on-orbit science projects, it is necessary to carry out maintenance and capacity improvement of onboard experimental support systems including scientific experimental racks, CSST, payload adapters, exposed experiment facilities, information systems, application fluid circuits. The scientific experiment racks need to be periodically replaced with components, upgraded in the diagnostic methods and scientific experiment modules, replaced by new SDU and SPU, *etc*. The fluid circuit needs to be upgraded and improved in heat dissipation capacity. The level of microgravity environment needs to be improved by developing the active vibration isolation devices and microgravity measurement network. The on-orbit storage and transportation equipment needs to be developed to meet the storage requirements such as active biological samples and special test samples. The CSST needs to reserve key components, cooperate with astronauts and space station systems to conduct maintenance training, prepare maintenance manuals, and update back-end scientific modules.

5.2 Ground Experiment Support Systems

The ground experimental support system mainly consists of the mission development support system, Payloads Operation Management Center, and ground research infrastructures. During the operational period, Firstly, it is needed to ensure the routine operation and maintenance of the facility building in CSS ground development period. Secondly, it is needed to build a full-lifecycle collaborative design system, demonstration support system, project certification test system, *etc*., for the large-scale and complex characteristics of a science project during the operation period. The upgrading of the ground experiment support system will strengthen the operational support for planning, demonstration, development, and management of space science project, and will improve the capability of integrated test for experimental payloads, and will improve the support capability and intelligence level of the payload operation management system.

The ground experiment base of space laboratory aims to build the world's leading ground experimental base, including experimental research, sample analysis, simulated microgravity experiments, and data processing. In the meantime, the ground mirror platforms of the experiment system are being developed and built, which could solve the problem of the shortage of ground station scientific research facilities and provide support for the continuous research work before launching.

6 International Cooperation, Education and Achievements Transfer

International cooperation in a variety of ways can be carried out during the CSS operation, including scientific experiment, project cooperation, astronaut training, and visits, *etc*. In 2018, China Manned Space Agency and the United Nations Office for Outer Space Affairs jointly issued a cooperation opportunity announcement to the United Nations members, inviting member states to participate in space science and utilizations in the China Space Station. 42 project proposals from 27 countries were received. Through two stages of primary and final selections, 9 projects from 17 countries and 23 entities were successfully selected, which include space astronomy, space life science and biotechnology, space application technology, microgravity fluid physics, combustion science, and Earth science[14]. China will actively use the capabilities of CSS platform to organize international big science project and contribute to the development of space science and technology all over the world.

Manned spaceflight, as a participatory space exploration activity, has a unique advantage as an educational resource and platform. In terms of the science outreach program, an integrated STEM (Science, Technology, Engineering, and Mathematics) education system with unique characteristics of manned spaceflight will be built to carry out various science education activities such as scientific experiment projects, popular science competitions, hardware development, and educational demonstrations. It is expected to strengthen public support for the space industry and stimulate young people's interest in manned spaceflight.

It is an important work to transfer new technologies produced in the CSS operation period into new products, new processes, new materials, and to promote new jobs and industries. Establishing a comprehensive platform for the release of scientific and technological achievements will build an effective bridge between CSS knowledge, technologies, and the market. These scientific and technological achievements could be transferred into biopharmaceuticals, medical health, material manufacturing, advanced energy, disaster relief support, land resource exploration. Improvement in the comprehensive benefits of CSS will drive industrial reform and promote socioeconomic development.

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