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Space Research Plan of China's Space Station

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Abstract

China's manned spaceflight missions are introduced briefly, and the research planning of space sciences for China's Space Station (CSS) is presented with the topics in the research areas, including: life science and biotechnology, microgravity fluid physics and combustion science, space material science, fundamental physics, space astronomy and astrophysics, earth sciences and application, space physics and space environment, experiments of new space technology. The research facilities, experiment racks, and supporting system planned in CSS are described, and a dozen of research racks for space sciences in pressurized module, *etc*. ground support platform will be built, including space station mirror platform and space laboratory ground experiment base to provide technical support and environmental conditions for ground-based simulation verification, pre-flight matching experiments, in-flight world comparison experiments, and post-flight sample processing and analysis processes for space-based science experiment projects, obtaining full-chain support capabilities for scientific experiment project demonstration, scientific project development, international application of joint research on space applications, as well as data analysis.

Key words

China's Space Station, Space Science, Research planning, Research Facilities and racks, Ground Support planning

1. Brief Introduction to China's Manned Spaceflight Missions

China Manned Space Program (CMSP) was started in 1992. Space laboratory Tiangong-2 was launched in September 2016, and then docked with Shenzhou-11 manned spaceship and Tianzhou-1 cargo ship in 2017. A permanent space station[1, 2], China's Space Station (CSS), will be started to build in 2018, and completed in 2022 or later. Tiangong-2 is the first space laboratory of CMSP that weighs about 8 tons with 2 to 4 years of lifetime. The Tianzhou-1 weighs 13 tons with cargo transportation capacity of 6 tons. According to the preliminary design, the main part of CSS is a combination of 3 modules including a core module and two experiment-carrying modules and will be assembled in orbit. In addition, there is an independent flight module for optical astronomy in the same orbit near enough to the space station to dock for upgrades and service. The total weight of CSS is more than 66 tons. The orbit parameters of CSS are the same as Tiangong-2, attitude accuracy of 0.1° and attitude stabilization of 10^{-3} °/s, predicted microgravity level of 10^{-3}, payload weight of 15 tons with 12 kW power supply, crew number of 3, communication of downlink though relay satellite of 1.1 Gbps with 90% global coverage. The lifetime of CSS will be more than 10 years. A series of science projects will be carried out onboard CSS.

2. Space Sciences Research Planning for CSS

Space sciences research planning for CSS has been carried out, aiming to promote the development of space sciences in China and get to the frontier in some important research areas[3], to achieve significant breakthroughs in technologies of space utilization, and make contributions to satisfy the need of the social development and people's daily life.

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2.1 Research Planning of Space Sciences for CSS

The research areas of space sciences for CSS include life science and biotechnology, microgravity fluid physics and combustion science, material science, fundamental physics, space astronomy and astrophysics, space physics and space environment, Earth science and application, and experiment of new space technology. The research topics planned in every area are presented as follows.

(1) Life Science and Biotechnology

It focuses on fundamental biology by investigating the response and mechanism of some kinds of ground-living organism in space, to gain a better understanding of the nature of life. It also conducts biotechnology experiments to improve the long time surviving capability of humans in space, and to benefit the human health, drugs industry, agriculture and so on[4]. The research topics include fundamental biology, radiation biology, space biotechnology, fundamental research of Closed Ecology and Life Supporting System (CELSS), and the frontier exploration (space biomechanics, sub-magnet biology, molecular biology related to life origin, and so on).

(2) Microgravity Fluid Physics and Combustion Science

Microgravity fluid physics is aimed at finding the special law of fluids in space (driven by surface tension, heat and solute gradient) which is masked by convection, sedimentation or hydrostatic pressure on the ground. Chemical kinetics is studied to understand the microgravity combustion process[5]. Research in this area also helps to improve the process of producing and processing on the ground, fluid management, energy utilization, propulsion, and fire protection and extinguishing. The topics in this area include hydrodynamics, complex fluid (colloid, foam and particle plasma), two-phase system and combustion dynamics, and related technologies demonstration which can be transferred to the industry.

(3) Space Material Science

Space material science focuses on the mechanism of material formation, crystallization, as well as new method of producing material in space which could deliver new knowledge and benefits for material science and industry in China. The topics in this area include kinetics of material growth under microgravity, preparation of high-value materials, measurement of thermal physical property, a performance study of space function materials and intelligence materials.

(4) Fundamental Physics

Fundamental physics is an emerging area in microgravity science, with the purpose of verifying current physics theory, finding new physics phenomena, and promoting new fundamental physics theory study such as gravitational gauge field theory, grand unified theory and Standard Model of new particle physics. The topics in this area include ultra-cold atom physics, high accuracy time-frequency system in space and related physics experiment, gravitational physics, a test of the equivalence principle, condensed matter physics.

(5) Space Astronomy and Astrophysics

This area focuses on the significant issues[6,7] related to the nature of the universe such as black hole, dark matter and dark energy, and the origin of the universe, galaxy formation and evolution, and extraterrestrial life. The topics in this area include precise multi-band photometry and all sky spectrum survey, detection of high-energy cosmic ray and dark matter, probing of the change of celestial body and burst phenomena (the Sun is included), and the study of new technologies of space astronomy.

(6) Earth Sciences and Application

It utilizes the Earth observation sensors on the space station to obtain dynamic, real and overall information of land, ocean and atmosphere to get a better understanding the key issues related with global changes, alterations of the environment and natural resources due to human activities. The topics in this area include the development and application of new remote sensor, the research of earth sciences related to global change, the monitoring of natural resources and environment, and the detection of natural disasters.

(7) Space Physics and Space Environment

The orbit of the space station at medium and low latitude is suitable for relationship study of the sun, magneto- sphere, and ionosphere. The sun is the primary source that influences the sun-earth space environment, especially the energy release process of the solar flare and Coronal Mass Ejections (CME). The emphasis of the study in this area is striving to guarantee the safe existence for the space station and astronauts by predicting space environment and monitoring burst of the sun and to investigate the structure of ionosphere at medium and low latitude as well as an exploration of thermosphere physics.

(8) Experiments of New Space Technology

The space station is a perfect space technology demonstration platform especially after the participation of astronauts. The focus in this area is on space communication and new generation information technology, laser energy transmission, microsatellite, 3D printing in space, novel space robots, and trials of components in space application.

2.2 Research Facilities, Experiment Racks, and Supporting System in CSS

Researches on board the CSS will be conducted for more than 10 years. The research facilities, experiment racks and related supporting systems are planned in CSS to facilitate the space science experiments. Most of the facilities are being developed.

2.2.1 Major Research Facilities

(1) Multifunctional Optical Facility

The multifunctional optical facility is to implement multi-band photometry and all sky spectrum survey [8], with a primary mirror of 2 meters in diameter. The facility is to study the mechanism of accelerating the expansion of the universe and the nature of dark energy, validate the universe model, and explore the properties of dark matter. The three-dimensional structure of the galaxy and the origin and evolution of stars, black holes, galaxies, and quasars are also included.

The facility will also be utilized to conduct sub-millimeter observation to study the trace components of interstellar matter in the early universe and those of the earth atmosphere. Multi-wavelength and multi-mode laser sensors are adopted to measure the profile wind field of atmosphere, distribution of cloud and aerosol, the biomass of sub-surface of the ocean and the earth vegetation which are for earth science and application.

(2) Research Facility for Cosmic Ray and Dark Matter (TBD)

It is utilized to implement accurate measurement of high-energy cosmic ray with wide energy region[9], to study on the components, origin, transmission and accelerating mechanism of cosmic ray in the galaxy. Possible annihilation spectrum of dark matter is also to be investigated. The facility is with the energy range 5GeV–50TeV, acceptance of 5 $m^2 \cdot sr$, and γ/p resolution better than 10^{-7}, and the detection capability is hoped to be competitive in the world.

In the area of space astronomy, an all sky X-ray monitor, a highly sensitive detector of solar high-energy emission, and a research facility for extreme physics of neutron star are also planned in CSS.

2.2.2 Research Racks for Space Sciences

A dozen of research racks are planned in the pressurized module to accommodate series of scientific experiments by changing experiment units or samples. The research racks for different research areas are described as follows.

(1) Life Science and Biotechnology

Two research racks are arranged in CSS. One is Life and Ecology research Rack (LER), which is utilized to conduct experiments for biological individuals (plants, microorganism, and small animals) and CELSS. One small centrifuge is assembled in it to compare the results at different gravity level. The other rack is Bio-Technology research Rack (BTR), which is utilized to conduct experiments for biological macromolecules, cells, tissues and small mammals. The two racks have the capability of life support, dynamic monitoring and fine observation by microscope, fluorescence detector, spectrum analyzer, CCD camera, and so on.

(2) Microgravity Fluid Physics and Combustion Science

Three racks are arranged. The first one is Fluid Physics research Rack (FPR), which is utilized for experiments of complex fluids and all kinds of transparent system. The second one is Two-Phase System research Rack (TPSR), which is utilized for experiments of two-phase fluids, phase transition, and heat transfer. The third one is Combustion Sciences research Rack (CSR), which is utilized for combustion experiment of gas, liquid (droplet) and solid. These experiment racks are assembled with advanced observation devices such as digital holography, shadow, high-speed CCD, infrared thermal image, PIV, thermochromic liquid crystal, dynamic light scattering, rheology, optical spectrum, mass spectrum and so on.

(3) Space Material Science

There are two racks for material science in CSS. One is High-Temperature Materials research Rack (HTMR), which is utilized for experiments for melt growth and solidification of different kind of samples sealed in ampoules. It can achieve the temperature of 1600°C, provide different temperature fields like gradient, isothermal, zone melting, and is equipped with X-ray and optical diagnostic devices. The other one is Container-less Materials Processing Rack (CMPR), which adopts electrostatic levitation to realize container-less processing. The highest temperature is over 3000°C and it can support the study of material under-cooling and thermal properties measurement.

(4) Fundamental Physics

Three experiment racks are developed in CSS. One is Cold Atom Physics research Rack (CAPR), which is utilized to implement quantum degenerate gas of 10–12 K, which cannot be achieved on the Earth, by means of the magneto-optical trap and optical lattice under microgravity. New quantum phenomena could be studied by using it. The second one is High Precision Time-Frequency System (HPTFS), which aims to build a time-frequency system composed of hydrogen clock, cold atomic clock, and optical clock as well as laser and microwave link chain. The daily stability and uncertainty of the system predicted the order of 10^{-17}–10^{-18}, which enables to conduct the fundamental physics research such as the change of fine structure constant and gravitational redshift. The third rack is High Microgravity Level research Rack (HMLR), which achieves a microgravity level of 2 to 3 times better than in the pressurized module by means of isolating micro-vibration through suspension. In this rack, the test of equivalence principle by means of gyro-accelerometer and cold atom interferometer can be carried out.

(5) Universal Experiment Racks

The Glovebox & Cold Storage Rack (GCSR) facilitates the astronauts to operate experiments in isolated and sealed space. It can also provide three storage temperatures of 4°C, –20°C and –80°C (for biology samples). The second one is Variable Gravity Research Rack (VGR). It can provide variable gravity environment to differentiate the effects of microgravity and other space environmental factors by simulating gravity varying from 0.01 g to 2 g by centrifuge. The third one is On-orbit Maintenance and Manipulation Workbench (MMW), which can serve the assembly, operation and test of fine mechanical structure and electronics devices, to improve the maintenance supporting capability in orbit.

(6) Exposed Experiment Facilities

Three exposed experiment facilities are arranged. A biology research exposed facility is utilized for radiation biology research and life science experiments in extreme environment. A material research exposed facility is utilized for the study of the material service performance in space. The components test exposed facility is to verify the performance of new space components in space.

2.2.3 Onboard and Ground Support Segment for Space Sciences and Application

An integrated information system based on FC-AE-1553 bus fiber optic network has been designed to support the control and information management of hundreds of payloads on CSS. Its bit-rate achieves 4Gbps in each pathway, the storage capability is up to 1000 Tb, and the capability of in-orbit information processing is over 10TFlops. The system can satisfy various needs of the change of task, expansion and in-orbit maintenance.

In order to support complex inter-disciplinary mission design, parallel development, testing, space operation, scientific research and application in space station, an advanced support segment on the ground is presented, which includes capabilities of mission planning, parallel design, integrated simulation and validation, flexible integration testing, operation and control of payloads, scientific data processing and service, etc. It adopts Model Driven System Engineering (MDSE) and the approach of parallel engineering to implement the collaborative design of multiple disciplinary payloads. The testing of payloads is conducted with flexible intelligent test technology. The operation of the complex mission is based on the space-Earth collaborative approach. Besides, high performance computation system is developed to provide the powerful capability of data processing for space sciences and application missions.

3. Ground Support Platform Planning

3.1 Ground mirror platform

Aiming at the long-term people-involving and scroll implement characteristics of space station scientific experimental platform, and for the large-scale continuous application of scientific research needs, Building the space station mirror platform as the national space laboratory ground experimental synchronization support facilities could provide technical support and environmental conditions for ground-based simulation verification, pre-flight matching experiments, in-flight world comparison experiments, and post-flight sample processing and analysis processes for space-based science experiment projects. It provides a one-stop collaborative working environment and a service window for scientists, payload specialists, and astronauts in the field of space science and applied research. It also provides open ground support facilities for scientific experimentation in scientific research institutes, universities, and enterprises at home and abroad, providing young people and the public with intuitive, novel and interactive services.

Build a space station scientific experiment mirror platform, and comprehensively use synchronous mirroring, parallel real-time simulation, and multidisciplinary optimization technologies to provide optimization design, verification simulation, experiments simulation, space and earth contrast experiments, and experiment results analysis. The space station scientific experiment mirror platform will support and promote the space science experimental technology research and project development. Based on the simulation and optimization measures to ensure the effectiveness of the experimental design, the simulation experiment will simulate the physical conditions for the space science experiment and ensure the experimental operation through the simulation exercise. The mirror platform will significantly increase the scale of on-orbit scientific experiments, effectively improve the utilization efficiency of space laboratory resources, and provide services and guarantees for the continuous output of major scientific research results. On the other hand, the platform as a large-scale ground facility of the space station will attract a large number of public participation to serve the science education activities of primary and middle school students.

3.2 Space Laboratory Ground Experiment Base

After the completion of the space laboratory ground experiment base, it will have full-chain support capabilities for scientific experiment project demonstration, scientific project development, international application of joint research on space applications, as well as data analysis. Demonstration of space science and application projects, ground research before and after flight in various disciplines, sample analysis, data storage and sharing, data mining analysis, and support for international cooperation research, etc., to provide space science and application tasks for manned spaceflight support, produce major scientific and technological achievements, maximize the comprehensive application efficiency of manned space flight; laying the foundation for the establishment of a national-level space application laboratory and promoting the healthy and sustained development of China's manned space industry.

The completion of the space laboratory ground experiment base will promote the coordinated development of space science, space technology and space applications in China's manned spaceflight, form a benign interaction of science, application, and technology development, and promote the health of China's manned space industry from a higher level. Sustained development leads to the production of major scientific and technological achievements. Conducting sufficient advance research on the ground before carrying out space experiments not only can verify the relevant principles and techniques of space experiments but also can help improve the level of experimental design and optimize the experimental operation flow, so that the success rate of space experiments can be improved. The efficient use of application resources to achieve maximum scientific output is the best embodiment of the benefits of space station applications. Through the construction and operation of this project, researchers who are interested in space science research will be attracted to carry out space exploration experiments on space science experiments at this base. The basic laws of experimentation will help to constantly propose new space science project proposals, develop space science projects that adapt to space experimental conditions, and at the same time, train and develop talents who are familiar with space experimental conditions and have space experimental research capabilities.

3.3 Microgravity Experiment Facility by Electromagnetic Launch (MEFEL)

The scientific research experiment in the microgravity environment is helpful to reveal the law of physics and explore the essence of life, as well as to promote the result output and application benefit of space utilization and space technology. Traditional microgravity facility on the ground includes drop tower, parabolic flight and so on. For the drop tower, the duration for weightless time is too short, while for parabolic flight, the cost is relatively too much. Recently, the technique of high-power linear motor actuator is maturing following with the applications of electromagnetic launch EML on an aircraft carrier and magnetic levitation high-speed rail. This new technique cut a new path for microgravity facility on the ground. By using this technique, the experiment payload is launched upward and retrieved again by electromagnetic force, so it is able to achieve double times of weightless duration than traditional drop-tower, or we can deem that the drop tower is shortened to a quarter of length if we want to acquire the same duration. Moreover, the electromagnetic force is controllable, so it is not only able to provide the microgravity acceleration, but also to simulate the variable gravity such as on Lunar or Mars.

A Microgravity Experiment Facility by Electromagnetic Launch (MEFEL) is planned to be constructed in Huairou Science City, Beijing. The parameters of this facility are 30 seconds of duration, 500 kg of payload weight, 4 persons of carrying capability, 10^{-5}-10^{-6} microgravity level, 0-2g variable gravity and 5 minutes of preparation time for each operation. The performance of MEFEL facility has exceeded all state-of -the-art ground microgravity facilities in the world and it also has advantages of easy experiment preparation, low operation cost and human carrying ability. It is expected to provide the service for all kinds of microgravity experiment projects on the ground or planned to do in space. It also provides the condition for a national program of manned spaceflight and lunar exploration or astronaut training.

MEFEL is composed with the electromagnetic launcher, experiment cabin, vertical tunnel and assistant facilities. The key techniques of the high-power linear motor actuator, the construction of the big-diameter vertical tunnel, and microgravity or variable gravity control have been taken and the preliminary scheme has been carried out. It is expected to build up and come into use after 3 or 5 years. Till then, MEFEL will become one of the most important infrastructures of China and become a world famous microgravity facility and gathers world-level microgravity scientists and working teams. In addition, this facility has the ability of continuous operation and person carrying, so it is also a good platform for science popularization and youth scientific activities in its off period, for the purpose of arouse the interest of people and get their support to space science and technology and inspire more youth to devote themselves to the space career.

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