0254-6124/2024/44(4)-0699-05 *Chin. J. Space Sci.* 空间科学学报

WANG Chi, SONG Tingting, LI Ming, CAO Song. Strategic Study on the Development of Space Science in China and Proposals for Future Missions. *Chinese Journal of Space Science*, 2024, **44**(4): 699–703. DOI:10.11728/cjss2024.04.2024-yg19

Strategic Study on the Development of Space Science in China and Proposals for Future Missions*

WANG Chi SONG Tingting LI Ming CAO Song

(*National Space Science Center*, *Chinese Academy of Sciences*, *Beijing* 100190)

Abstract Since 2011, the Chinese Academy of Sciences (CAS) has implemented the Strategic Priority Program on Space Science (SPP). A series of scientific satellites have been developed and launched, such as Dark Matter Particle Explorer (DAMPE), Quantum Experiments at Space Scale (QUESS), Advanced Space-based Solar Observatory (ASO-S), Einstein Probe (EP), and significant scientific outcomes have been achieved. In order to plan the future space science missions in China, CAS has organized the Chinese space science community to conduct medium and long-term development strategy studies, and summarized the major scientific frontiers of space science as "One Black, Two Dark, Three Origins and Five Characterizations". Five main scientific themes have been identified for China's future breakthroughs, including the Extreme Universe, Space-Time Ripples, the Panoramic View of the Sun and Earth, the Habitable Planets, and Biological & Physical Science in Space. Space science satellite missions to be implemented before 2030 are proposed accordingly.

Key words Space science, Space missions, Space exploration

Classified index V11

1 Introduction

In recent years, China's space science has entered the fast lane of innovation and development. With the implementation of a batch of space science missions, a series of original scientific results have been achieved. Chang'E-4 realized the world's first soft landing and roving on the far side of the moon, Chang'E-5 returned China's first sample from an extraterrestrial body, and Tianwen-1 left the imprint of a Chinese spacecraft on Mars for the first time. China Space Station has completed its in-orbit assembly and entered a new era of application and development, with the deployment of scientific experiment cabinets and extravehicular exposure platforms, as well as the Chinese Survey Space Telescope (CSST).

Since 2011, SPP, led by CAS, has been successfully implemented. The scientific achievements of the missions in the program, such as DAMPE, QUESS, Shijian-10 (SJ-10) and Hard X-ray Modulation Telescope (HXMT), Taiji-1, the Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM), ASO-S, EP, *etc*., have significantly improved our understanding of the Universe. The DAMPE spectral measurement of cosmic ray proton and Helium nuclei hints a hardening structure at about 150 TeV in space[1]. HXMT's observations of a black hole x-ray binary indicate formation of a magnetically captured disk[2]. Observations with ASO-S at 360 nm waveband show that about 25% of flares have enhanced emission in the Balmer continuum, indicating white-light flares are not rare. This greatly benefits our understanding of energy

* Supported by Consultation and Evaluation Program on Academic Divisions of the Chinese Academy of Sciences (2022-DX02-B-007)

Received June 15, 2024

deposit and transfer processes of the solar and stellar flares[3]. During the commissioning phase, EP has detected a number of transient sources, stellar flares, and a high-redshift (z=4.859) gamma-ray burst.

In recent years, China has exhibited breakthroughs in space science, However, the number of space science satellites in China is relatively small, and significant scientific achievements with great impact are few. In general, the development of China's space science is still in its early stage. To foster the high-quality development of space science, the Chinese space science community has conducted strategic research, resulting in a series of outcomes that lay a foundation for planning future missions.

2 China's Space Science Development Strategy

In recent years, the United States has released new versions of "Decadal Survey" in different areas of space science, such as the Pathways to Discovery in Astronomy and Astrophysics for the 2020s (Astro2020), Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032, THRIVING IN SPACE: Ensuring the Future of Biological and Physical Sciences Research: A Decadal Survey for 2023–2032, *etc*. The European Space Agency (ESA) has released VOYAGE 2050: Long-Term Planning of the ESA Science Programme. Since 2022, CAS has organized scientists across the country to conduct a new round of study on the medium and long-term development planning for space science activities in China. It has sorted out the major scientific frontiers in space science and, and identified five major scientific themes for China to make breakthroughs in the future.

2.1 Major Space Science Frontiers

The major scientific frontiers in areas of space astronomy, heliophysics, lunar and planetary science, Earth science, microgravity physics and space life sciences can be summarized as "One Black, Two Dark, Three Origins and Five Characterizations".

2.1.1 One Black

The aim of "One Black" is to explore dense celestial bodies, as represented by black holes, and the physical laws under extreme conditions in the universe.

By means of multi-messenger, such as electromagnetic waves, gravitational waves, neutrinos, cosmic rays, *etc*., the aim is to reveal the internal structure of dense celestial bodies, the laws of matter movement in strong gravitational fields, and the nature of gravity and space & time.

2.1.2 Two Dark

"Two Dark" refers to dark matter and dark energy, the natures of which are poorly understood. The universe is filled with gamma rays and cosmic rays with very high energy, which may originate from dark matter particle annihilation or decay. Direct detection in space has significant advantages for gamma rays in the sub-TeV range and cosmic rays in the PeV range, which might prove the existence of dark matter particles indirectly.

Various hypotheses about dark energy are imperfect and fail to explain observations. There is an urgent need to detect and understand dark energy through photometric and spectroscopic surveys, utilizing a variety of means such as supernovae, baryon acoustic oscillations, gravitational lensing, and redshift spatial distortions of galaxies.

2.1.3 Three Origins

"Three Origins" focus on the origin of the universe, the solar system and life. With approximately 13.8 billion years of evolutionary history since the Big Bang, the universe is still facing unanswered questions, such as how the universe began and how the early universe expanded.

The original matter of the solar system and its distribution on the protoplanetary disk determine the composition and evolutionary history of various types of planets. However, the intense impacts during the Late Heavy Bombardment made it difficult to preserve early information.

Life on Earth is the only confirmed existence of life by far, and the search for the most favorable environment for the emergence of life in Earth's early years and the earliest records of life in the solar system will shed some light on the question of "where did we come from". The pursuit of extraterrestrial life, the unraveling of the origins and evolution of life, and comprehending of biodiversity will address the fundamental question of the origin of life.

2.1.4 Five Characterizations

"Five Characterizations" explores the characteristics and working laws of the near-Earth system, Earth-Moon system, the solar system, and the extra-solar system, as well as the laws governing matter movement and life activity in the space environment.

The radiation and energy balance of the Earth system, the water cycle, the carbon cycle, the coupling of the Earth's layers, and the interaction between human activities and the natural environment are all intricately linked to global climate change, which directly impacts the sustainable development of humankind. There is an urgent need to address the complexities of the Earth system and understand the key processes within it.

The origin and evolution of the Earth-Moon system, the layers and structure of the Moon and terrestrial planets and their modification processes, as well as the surface topographical features, the causes and distribution of resources, and the Sun-Earth-Moon space environment are important frontiers.

Solar eruptions have an important impact on the Earth's space environment and the solar system. The magnetic fields and hydrospheres of solar system planets vary greatly, and there is an urgent need for further understanding of the internal composition, physical properties and structural characteristics of layers of the terrestrial planets, the giant planetary systems, the exoplanets, and the comets in the outer solar system.

Interstellar space beyond the heliopause is a "no man's land" rarely visited by human spacecraft. Space observations confirm the ubiquity of exoplanets, challenging the universality of our solar system. The discovery of potentially habitable worlds is desirable and promises to provide crucial evidence to answer the question "Are we alone in the universe?" Exoplanets also hold great scientific opportunities.

Conditions in space are characterized by variable gravity, strong radiation, weak magnetic fields *etc*., which are fundamentally different from those on the Earth, providing ideal laboratories to reveal the laws of matter and life activities, and to carry out space intelligent manufacturing, innovative energy and the terrestrial application of space medical science.

2.2 China's Main Scientific Themes

Facing the frontiers of space science and addressing the major needs of the country, we must also take China's reality into account, such as the disciplinary advantages, human resources, and the maturity level of the engineering and technology. Accordingly, China's space science will focus on five scientific themes, namely, "Extreme Universe", "Space-Time Ripples", "the Panoramic View of the Sun and the Earth", "Habitable Planets", and "Biological & Physical Science in Space".

The theme "Extreme Universe" explores the origin and evolution of the universe, and reveals the physical laws of the universe under extreme conditions. The main scientific questions to be addressed include the nature of dark matter particles, the sources of high-energy radiation in the universe, the nature of dark energy, the physical mechanisms of dynamic cosmic detections and transient sources, the dark age of the universe, and the history of reionization.

The theme "Space-Time Ripples" detects low and medium-frequency gravitational waves and primordial gravitational waves in order to reveal the nature of gravity and space-time. The scientific questions to be addressed include the formation of supermassive black holes and their co-evolution with host galaxies, as well as the testing of early cosmological models.

The theme "the Panoramic View of the Sun and the Earth" explores the Sun, Earth and the heliosphere, and reveals the physical processes and laws governing the complex system of the Sun-Earth and the Sun-Solar system connections. The main scientific questions to be addressed include the structure and coupling processes of the solid Earth's inner layers, the characteristics of the solar magnetic field and the mechanism of the origin of the solar magnetic cycle, and the processes and mechanisms of solar wind and interstellar medium interaction.

The theme "Habitable planets" explores the habitability of solar system planets and exoplanets, and searches for extraterrestrial life. The main scientific questions to be addressed include the mechanism of interaction between human activities and the natural environment, the composition of the Moon's deep matter and its layer structure, the origin and evolution of asteroids and comets, the evolution of habitable environments and potential life signals on Mars, and the habitability and life signatures of exoplanets.

The theme "Biological & Physical Science in Space" reveals the laws of matter movement and life activities under space conditions, and deepens the knowledge of fundamental physics such as quantum mechanics and general relativity. The scientific questions to be solved mainly include fire safety in manned spaceflight, preparation of high-performance materials and the behavior of materials in extreme space environments, quantum effects in the gravitational field, basic medical problems of medium- and long-term spaceflight and residence, and research on special biotechnology in space.

3 Proposals for China's near Future Space Science Missions

Based on the China's development strategy study for space science, a series of new space science satellite missions have been proposed for the near future, which will focus on major scientific issues in the category of "origins", such as the origins of the universe, the origins of space weather, the origins of life, *etc*. It is proposed that by 2030, in-orbit scientific exploration is expected to yield major discoveries and original results in the following directions, such as the dark age of the universe, the solar magnetic activity cycle and high-speed solar wind, Earth-like exoplanet, the physical laws of the universe under extreme conditions, and the nature of gravity and space-time.

Discovering the Sky at the Longest wavelength (DSL)[4]. With 1 mother satellite and 9 daughter satellites operating in a 300 km circular lunar orbit, DSL takes advantage of the highly clean electromagnetic environment on the far side of the Moon to conduct ultra-long-wave radio astronomy observations, which will provide key observational evidence to open a new-window to image the dark age of the universe with MHz radio waves.

Solar Polar Orbit Observatory (SPO)[5]. With the implementation of the solar polar orbit observation system above the ecliptic plane, SPO aims to achieve the first-ever frontal imaging of the solar polar region, so as to make crucial breakthroughs in research on the origin of solar magnetic activity cycles and the origin of high-speed solar wind.

The Earth 2.0 (ET)[6]. A space observatory at the Earth-Sun L2 point conducts a long-term, large-scale survey of exoplanets, to explore habitable Earth-like planets outside our solar system, and target candidates for extraterrestrial life search.

Enhanced X-ray Timing and Polarimetry (eXTP)[7]. The mission will conduct research on the detection of dense celestial bodies, such as black holes and neutron stars, with high time resolution, high energy resolution and high-precision polarization, so as to explore the physical laws and principles under the extreme conditions in the universe, including extreme gravity, magnetism, and density.

Taiji-2[8]. A three-satellite constellation in a 60-million-kilometer heliocentric orbit, constituting a 3-million-kilometer ultra-long baseline space-based gravitational wave observation system, detects millihertz (0.1 mHz–1.0 Hz) gravitational waves in space.

In addition, with the successful implementation of the Chang'E-6 lunar sample-return mission, the future missions are also being developed, such as the Chang'E-7 Lunar Polar Regions Exploration, Tianwen-2 near-Earth asteroid sample return and main-belt comet exploration mission, the International Lunar Research Station (ILRS), and the China Space Station for Space Science and Applications.

4 International Cooperation

The peaceful use of outer space is a matter of concern for the well-being of all humankind. Since space exploration entails high investment and risk, a country cannot and should not be alone in its own endeavors. In the 21st century, international cooperation in space science has received increasing attention, and almost all flagship space science missions incorporate elements of international cooperation, which not only reduces a country's space investment and risks, but also multiplies scientific outputs, facilitates the country's scientific and technological diplomacy, and has become an important part of international foreign policy.

Missions such as the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) and the Einstein Probe (EP) involve in-depth international cooperation. Missions such as the planned DSL, ET, and eXTP will also involve specific international cooperation in scientific research. Chang'E-4, Chang'E-5, and Chang'E-6 missions of the Lunar and Planetary Exploration Project have carried onboard international payloads from other countries, and have produced influential scientific results. The China Space Station has also invited other countries to participate in international cooperation, and projects from Switzerland, Germany, Italy, and other countries have been selected.

In the future, China will actively initiate, propose and participate in international cooperation projects. Through mutual cooperation across missions, joint observations and scientific experiments, joint payload development, testing and calibration, or flying piggyback payloads on each other's platform, open access of scientific data, and joint scientific teams, China will engage in multi-level international cooperation to fully leverage the platforms such as China Space Station and ILRS, to make significant contributions to answer fundamental scientific questions.

5 Summary

Space science in China is advancing from the initial stage into a new era of accelerated development. The release of the first national medium and long-term plan for space science is imminent, and a series of new space science satellite missions are about to be approved for implementation. China will continue to promote international scientific and technological cooperation to explore the vastness of the universe, and contribute more Chinese wisdom and solutions to the peaceful use of outer space.

References

[1] ALEMANNO F, *et al*. (DAMPE Collaboration). Measurement of the cosmic p + He energy spectrum from 50 GeV to 05 PeV with the DAMPE space mission[J]. *Physical Review D*, 2024, **109**: L121101

[2] YOU B, CAO X W, YAN Z, *et al*. Observations of a black hole X-ray binary indicate formation of a magnetically arrested disk[J]. *Science*, 2023, **381**(6661): 961-964

[3] JING Z C, LI Y, FENG L, *et al*. A statistical study of solar white-light flares observed by the *White-Light Solar Telescope* of the *Lyman-Alpha Solar Telescope* on the *Advanced Space-Based Solar Observatory* (ASO-S/LST/WST) at 360 nm[J]. *Solar Physics*, 2024, **299**(2): 11

[4] CHEN X L, YAN J Y, DENG L, *et al*. Discovering the sky at the longest wavelengths with a lunar orbit array[J]. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 2021, **379**(2188): 20190566

[5] DENG Yuanyong, ZHOU Guiping, DAI Shuwu, *et al*. Solar polar-orbit observatory[J]. *Chinese Science Bulletin*, 2023, **38**(4): 298-308 (邓元勇, 周桂萍, 代树武, 等. 太阳极轨天文台 [J]. 科学通报, 2023, **38**(4): 298-308)

[6] GE J, ZHANG H, DENG H P, *et al*. The ET mission to search for earth 2.0s[J]. *The Innovation*, 2022, **3**(4): 100271

[7] ZHANG S N, SANTANGELO A, FEROCI M, *et al*. The enhanced X-ray timing and polarimetry mission—eXTP[J]. *Science China Physics, Mechanics & Astronomy*, 2019, **62**(2): 29502

[8] LUO Z R, ZHANG M, WU Y L. Recent status of Taiji program in China[J]. *Chinese Journal of Space Science*, 2022, **42**(4): 536-538

Author Biography

WANG Chi Male, born in February 1967 in Shaoyang City, Hunan Province, China, is currently a professor at the National Space Science Center, Chinese Academy of Sciences (CAS), and an academician of the CAS. His research focuses on the large-scale structures of the solar wind, the interaction between the solar wind and Earth's magnetosphere, and related fields. He has published more than 300 articles in a batch of academic journals like Nature.
E-mail: cw@spaceweather.ac.cn