0254-6124/2022/42(4)-0514-05 *Chin. J. Space Sci.* 空间科学学报

WANG Chi, SONG Tingting, SHI Peng, LI Ming, FAN Quanlin. China's Space Science Program (2025–2030): Strategic Priority Program on Space Science (III). *Chinese Journal of Space Science*, 2022, **42**(4): 514–518. DOI:10.11728/cjss2022.04.yg01

China's Space Science Program (2025–2030): Strategic Priority Program on Space Science (III)*

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Abstract The Strategic Priority Program (SPP) on Space Science, which is under the leadership of the Chinese Academy of Sciences (CAS), has established China's space science satellite series from scratch. A number of major scientific achievements have been made by the first phase of the Program (SPP I), while SPP II has been currently being implemented. The future development of space science needs urgent top-level planning and advanced layout to clarify the overall goal and investment portfolio from 2025 to 2030. We will briefly introduce the initiative and possible space science missions of SPP III, including the preparatory work which already started in July 2021. Following the effective administrative tradition since SPP I, National Space Science Center (NSSC, CAS) is responsible for the whole procedure, including soliciting, assessment, and implementation of SPP III. Brief information on the 13 candidate missions will be described, including missions in the fields of astronomy & astrophysics, exoplanets, heliophysics and planetary & Earth science, respectively.

Key words Space science, Strategic Priority Program (SPP), Space science missions, Space exploration

Classified index V11

1 Introduction

One ultimate goal of China's space activities is to explore the geospace, solar system, and vast universe, revealing the secrets of the nature. Space science, space technology and space application are three main themes of China's space activities. Since 2011, The Strategic Priority Program (SPP) on space science, which is under the leadership of the Chinese Academy of Sciences (CAS), has been successfully implemented, the scientific achievements of Dark Matter Particle Explorer (DAMPE), Quantum Experiment at Space Scale (QUESS), ShiJian-10 (SJ-10) and Hard X-ray Modulation Telescope (HXMT), *etc*. are significantly important and have attracted much attention around the globe.

In order to promote space science in China, CAS launches the selection and deployment of the New Horizon Program (*i.e*. SPP III) in July 2021, a space science program for the 15th Five-year Plan period. SPP III will carry out cutting-edge explorations and researches on four major themes: the extreme universe, ripples in time and space, the panoramic view of the Sun and Earth, and the search for habitable planets, with a vision of achieving major discovery and acquiring new knowledge through original scientific achievements.

The selection of SPP III candidate missions follows "Three Principles" and "Five Persistences". The former means we must adhere to the principles of giving priority to scientific goals, balanced development of disciplines, and technological and economic feasibility. While the latter emphasizes that we should bind to scientific objectives, selection on a competitive and compre-

* Supported by Strategic Priority Research Program of the Chinese Academy of Sciences (XDA15060102)

Received May 27, 2022

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hensive basis, scientific output, principle investigator leadership, and openness at home and abroad.

SPP III solicits new mission concepts from research institutes, universities and industries across the country. There are totally 17 proposals submitted before 31 December 2021.

NSSC has conducted the first round evaluation of SPP III mission candidates during 11–13 February 2022. The science mission advising panel was setup and members of the National Space Science Committee and other domestic experts in various fields were invited for the assessment. 13 projects have passed this round of selection. NSSC will carry out a series of specific assessments within the first half of 2022, including overseas assessment of scientific significances, as well as mission profiles on Concurrent Design Facility (CDF), and engineering technology readiness assessment and budget request rationality evaluation. After the above comprehensive procedures, a ranking recommendation of these candidate missions will be given, which will provide solid inputs for the approval of SPP III program by CAS administrations.

2 Brief Description on Candidate Mission Proposals of SPP III

The 13 space science candidate flight missions are categorized into four fields, *i.e.* space astronomy & astrophysics, exoplanets, heliophysics and planetary & Earth science, where the exoplanets are actually a newly cut-crossing discipline emerging from traditional science disciplines. Among them, two candidates are large missions, while others belong to medium and small sized missions. The main ideas of the candidates in each field are introduced briefly as followings.

2.1 Space Astronomy and Astrophysics

Space astronomy and astrophysics aim to discover the origin and evolution of the universe and of life itself. SPP III will address the scientific issues in some specific astrophysics science themes, for example, the matter inside Neutron Stars (NSs), the space-time in the vicinity of the Black Hole horizon, and the extremely magnetized vacuum close to magnetars and accreting pulsars. Besides, possible characteristic features of gamma rays and electrons/positrons from dark matter annihilation or decay, the early history of the Universe, *etc*. are of high interests.

There are 3 space science missions proposed in this field, aiming to address some above mentioned fundamental scientific questions.

(1) Enhanced X-ray Timing and Polarimetry (eXTP) mission. eXTP will address key unsolved problems of fundamental science: the equation of state of cold ultra-dense matter, the effects of strong-field gravity, and the physics of the strongest magnetic fields in nature. eXTP, which is a powerful X-ray observatory orbiting the Earth at 550 km, can continuously monitor the X-ray sky and enable multi-messenger studies for gravitational waves and neutrino sources. This large mission is led by China with major contributions from some European countries, aiming for liftoff not early than 2027[1].

(2) DArk Matter Particle Explorer-2 (DAMPE-2). While DAMPE has impressed the scientific community with its precise measurements of the energy spectrums of cosmic ray electrons, protons and the Galactic Cosmic-Ray (GCR) helium. Its successor DAMPE-2 will hold significant improvements, dedicating to detecting possible characteristic features of gamma rays and electrons/positrons from dark matter annihilation or decay, new spectral structures of GCR beyond 100 TeV, as well as transients associated with events of gravitational waves, tidal disruptions, and high energy neutrinos.

(3) Discovering the Sky at the Longest wavelength (DSL) mission. This mission consists of a linear array of micro-satellites placed on a lunar orbit, which will open up a new window of astronomical radio observation at frequencies below 30 MHz, with great potentials for new and unexpected discoveries, and provide new insights into the various astrophysical processes in the planets and stars, the Milky Way, galaxies and supermassive black holes. It will also make high precision measurements of the global spectrum with minimum systematic error, to probe the history of the early Universe, by observing the redshifted radio signal of neutral hydrogen from the cosmic dark ages after the Big Bang, and the cosmic dawn when the first stars and galaxies formed[2].

2.2 Exoplanets

Exoplanet exploration might be one of the hottest mission types since it encourages us to dwell on the fundamental question "Are we alone?" with some confidence. SPP III will address some scientific issues in this field, including but not limited to: the formation of diverse nearby planetary systems and the emergence of other worlds for solar-type stars. How common are habitable Earth-like planets orbiting around solar-type stars? How do Earth-like planets form and evolve?

In order to answer these scientific questions, there are currently 2 missions proposed for application, both are destined for a halo orbit around the L2 point of the Earth-Sun system.

(1) Closeby Habitable Exoplanet Survey (CHES) mission. CHES is devoted to discover Earth-like planets of the nearby solar-type stars via ultra-high-precision relative astrometry with 1 μas precision at 500–900 nm. The major scientific goals are two-folds: to search for the terrestrial planets in habitable zones orbiting 100 FGK stars within 10 pc; further to conduct a comprehensive survey and census on the nearby planetary systems[3].

(2) Earth 2.0 (ET) mission. ET is a wide-field and ultra-high-precision photometric survey mission, mainly composed of six transit telescopes and one microlensing telescope. ET is designed to measure, for the first time, the occurrence rate and the orbital distributions of Earth-sized planets, including the elusive habitable Earth-like planets orbiting stars just like a sun.

2.3 Heliophysics

Heliophysics paves the way to understand the Sun and its interactions with the Earth, the solar system and the interstellar medium, including space weather. SPP III will answer some aspirational questions persisted in the field of heliophysics, such as the origin of the solar cycles and solar dynamo. What are the characteristics and dynamics of the solar interior? The outward propagation of the solar eruptions and their impacts on the Earth space environment. How does the global magnetic field distribute and evolve? What is the composition of interstellar gas in our galactic neighborhood and how does it influence the heliosphere and its evolution?

There are currently 4 missions proposed for flight, aiming to advance our understanding the solar activities and their influence on Earth and the solar system.

(1) Solar Ring (SOR) mission. SOR is proposed to monitor and investigate the Sun and inner heliosphere from a full 360° perspective in the ecliptic plane. This large mission will deploy three 120°-separated spacecraft on the 1 AU orbit. Solar Ring mission aims to address the origin of solar cycle, the origin of solar eruptions and the origin of severe space weather with necessary in-situ instruments and imagers[4].

(2) Solar Polar-orbit Observatory (SPO). SPO will directly image the solar poles in an unprecedented way with a spacecraft traveling in a large inclination (⩾80°) off the ecliptic plane and a small ellipticity. SPO will unveil the origin of the solar magnetic activity cycle that shapes the living environment of human beings, to determine the generation mechanism of the high-speed solar wind that connects the Sun and celestial bodies in the solar system, and to construct data-driven global heliospheric numerical models which serves as the foundation for space weather prediction.

(3) Earth-occulted Solar Eclipse Observatory (ESEO). It is proposed to place a solar telescope near the second Lagrange point (L2) of the Earth-Sun system exploiting the Earth's occultation to explore the inner corona. As a small mission, ESEO might be very beneficial to reveal the early stage of the solar eruptions in the inner corona and subsequently how the Earth's far magnetotail will respond if being "plowed".

(4) Chinese Heliospheric Interstellar Medium Explorer (CHIME). This candidate spacecraft, being placed at distances up to 3 AU away from the Sun, might provide the first *in-situ* measurements of pristine interstellar gas and dust in their high-density regions at 2–3 AU from the Sun, as well as global energetic neutral atom images of heliospheric outer boundaries. CHIME will be launched into an elliptical, heliocentric orbit with perihelion at about 1 AU and aphelion at about 3 AU.

2.4 Planetary and Earth Science

The mysteries of our planet Earth and other celestial bodies across the solar system are awaiting unlocking. This understanding serves the fundamental need to improve our lives on Earth, advancing the frontier for all humanity stepping out of Earth. SPP III will address some key issues in the field of planetary and Earth science as follows: how do Greenhouse Gases (GHGs) impact and respond to climate change? what are the spatial and temporal variations of multiscale ocean dynamics? how can we trace the 1st 10 Million Years Evolution of the Dichotomic Solar System? What are the geological and thermal history of Venus, the mechanisms of super-greenhouse effect, past and current habitable environments, and the possible existence of life on Venus.

There are currently 4 candidate missions dedicated to address the above questions.

(1) E-type Asteroid Sample Return (ASR) mission. ASR is aimed to explore the E-type 1989 ML asteroid and return samples collected from up to three sites. Careful investigation of the returned samples will reveal the 1st 10 Ma evolution of the nebula under extremely reducing conditions in the inner solar system. It is highly hoped to shed light on the formation of the dichotomy of the solar system through comparison with those acquired from the C-type asteroids Ryugu and Bennu, both formed in the outer solar system. The entire mission will take approximately 4 years to accomplish.

(2) Venus Volcano Imaging and Climate Explorer (VOICE) mission. VOICE is an orbiting mission of a polar-circular orbit of about 350 km to investigate Venusian geological evolution, atmospheric thermal-chemical processes, surface-atmosphere interactions, and habitable environment and life in the clouds.

(3) Climate and Atmospheric Components Exploring Satellites (CACES). This small mission consists of two Low-Earth-Orbit (LEO-LEO) satellites in sun-synchronous orbits. It focuses on benchmark climate variables and atmospheric composition observations. CACES promises to provide a deeper understanding of the major challenge in the Earth system science that how GHGs impact and respond to climate change and weather disasters and support the carbon emission calculation in 2028, as well as China's targets of achieving a carbon peak by 2030 and carbon neutrality by 2060[5].

(4) Ocean Surface Current multiscale Observation Mission (OSCOM). OSCOM is dedicated to the frontier of ocean multiscale dynamics and energetics based on satellite Doppler oceanography. It will contribute to the study of ocean sub-mesoscale non-equilibrium dynamics, multiscale processes, mass/energy exchanges between ocean and atmosphere, biogeochemical cycles, and climate change, all of which are implemented through simultaneous observation of Ocean Surface Currents (OSC), Ocean Surface Vector Winds (OSVW), and Ocean Surface Wave Spectrum (OSWS) by a Doppler Scatterometer (DOPS)[6].

3 Pre-Phase A Studies of Future Science Missions under SPP III

SPP III will continue to adopt the program management model of SPP I and II. Besides the flight missions, SPP III will also carry out preliminary and advanced research projects on the science mission concepts to be deployed in the next five years or beyond, that is, through the concept study as well as concept and technology development of the future space science missions, thus to form a complete research and exploration portfolio.

At present, the first Call of SPP III concept and technology development of the future science mission candidates has been completed, and more than 20 proposals have been submitted, including Very Large Area Gamma-ray Space Telescope (VLAST), Space Weather exploration program, Ceres Exploration program, Gravity Experimental Satellite, *etc*.

These proposals cover all fields of space science, *i.e.* space astronomy & astrophysics, exoplanets, heliophysics, planetary science, Earth science, space biology and fundamental physics, establishing a sound basis for space science and exploration missions in the next decade. They present the researchers' aspirational attempts to achieve scientific objectives, such as "indirect detection of dark matter space", "physical properties and eruption laws of corona and stellar corona", "origin of Ceres and its underground ocean and volcanic geological activities", and "the origin and nature of material inertia", *etc*.

In the second half of 2022, NSSC will organize a panel of experts to review these pre-phase A candidates and make project priority recommendations, which will serve as the effective inputs for SPP III final portfolio.

4 Management of SPP III

The comprehensive evaluation of SPP III science mission candidates will be completed in 2022, and a list of recommended missions will be provided as a decision-making reference for CAS headquarters. By the middle of 2023, the necessary preparatory work of SPP III such as the demonstration of its implementation roadmap and the evaluation of the total budget will be completed, striving to get the program adopted during the late "14th

Five-Year Plan" period, *i.e*. around 2024.

Thanks to the advanced experiences learned from SPP I & II, a complete mission planning and management chain has been established, covering the strategic planning, mission proposal, mission concept study, concept and technology development, design & fabrication, launch and in-orbit operation of flight missions, data analysis and research, as well as scientific outcome evaluation. The "Principal Investigator + Mission Commander + Chief Engineer" system has been set up for the mission management. Nevertheless, SPPs have attracted the major space science communities and related institutions across China and abroad to participate in the research and mission implementation[7].

5 Summary

SPP III is an effective approach to promote China's space activities, and make great contributions to international space science and exploration.

In order to produce original achievements with science excellence continuously, SPP III will be targeted at the frontiers of space science, taking scientific significance and originality of scientific achievements as the most important factor. It is expected that SPP III will select 5–7 space science missions depending on the available budget, technique readiness, and reasonable manufacture schedule.

During the implementation of the mission, NSSC/CAS will continue to uphold the open policy, welcoming international cooperation at every level such as mission level, payload level, or just data sharing. China's space science program will continuously produce new knowledge, new theories, and new ideas through scientific exploration. It will eventually benefit life on the Earth and make great contributions to humanity.

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