China's Space Science Satellite Series–A Review and Future Perspective

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Abstract: The National Space Science Center of the Chinese Academy of Sciences (NSSC, CAS), as the leading institute responsible for the overall management of scientific satellite missions in China, is China's gateway to space science. NSSC is the cradle of China's first artificial satellite "*Dongfanghong*-1" (DFH-1). In the course of more than 60 years' development, NSSC has led the implementation of "Double Star Program", the first science-driven space mission in China, and successively implemented a fleet of scientific missions under the Strategic Priority Program on Space Science (Phase I and II), such as the Dark Matter Particle Explorer (DAMPE, or *Wukong*), the Quantum Experiments at Space Scale (QUESS, or *Micius*), the Hard X-ray Modulation Telescope (HXMT, or Insight), the *Taiji*-1, the Advanced space-based Solar Observatory (ASO-S, or *Kuafu*) and the Einstein Probe (EP). Currently, the space science satellite series has been established, yielding substantial scientific output. For the future, the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE), a China-ESA joint mission, will be launched in 2025. In addition, the newly released *National Mid- and Long-term Program for Space Science Development in China (2024–2050)*, the first of its kind at the national level, has identified five key scientific themes. A fleet of future scientific missions revolving these themes will deepen mankind's scientific understanding of the universe.

Keywords: space science; scientific satellite; Strategic Priority Program on Space Science; ZHAO Jiuzhang; China-ESA SMILE mission

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1. China's artificial satellite endeavor commenced with DFH-1

During the first International Geophysical Year (from July 1, 1957 to December. 31, 1958), the Soviet Union launched Sputnik-1, the world's first artificial satellite, on October 4, 1957, marking the beginning of the space age. On January 31, 1958, the USA launched Explorer-1, the world's first scientific satellite, which discovered the Earth's radiation belts—Van Allen Belts.

Shortly after the founding of the People's Republic of China, Chinese scientists QIAN Xuesen (Hsue-Shen Tsien, 1911–2009) and ZHAO Jiuzhang (Jeoujang Jaw, 1907–1968), both CAS Members, actively proposed to the central government that China should develop and launch artificial satellites. It was ZHAO who originally put forward the general plan for China's artificial satellite. He organized sounding rocket experiments and the preliminary study of satellite pro-

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gram, carried out the technology study of the first Chinese artificial satellite DFH-1, led the satellite design, and formulated a series of satellite development plans. After arduous work, DFH-1 was successfully launched on April 24, 1970, making China the 5th country in the world to independently develop and launch an artificial satellite. DFH-1 officially kicks off China's exploration of space. Since 2016, April 24 is celebrated as "China Space Day" every year.

In 1999, ZHAO Jiuzhang was posthumously awarded the medal for the development of the atomic and hydrogen bombs and man-made satellite. The Chinese Academy of Sciences (CAS) and the Committee on Space Research (COSPAR) jointly established the CAS/COSPAR Jeoujang Jaw Award[1] as one of its eight major awards. The award is given every two years since 2006. Professor Dan Baker from the University of Colorado at Boulder, a Member of the U. S. National Academy of Engineering, won the award at the 45th COSPAR Scientific Assembly in Busan, South Korea, on July 15, 2024 (Fig. 1).

2. The Double Star Program-Cluster Mission realized six-point three-dimensional exploration of geospace

China implemented the Double Star Program (DSP), the first Chinese science-driven mission, with two launches in December 2003 and July 2004 respectively. The two spacecraft were named TC-1 and TC-2 (Fig. 2). Prof. LIU Zhenxing (1929–2016) from NSSC, a Member of CAS, originally proposed the DSP mission concept in 1997, which consists of two satellites: TC-1 operating on the near-Earth equatorial orbit and TC-2 on the polar orbit, covering the near-Earth magnetospheric activity zone that had not yet been explored by international geospace exploration satellites. The scientific objectives of DSP include revealing the triggering mechanism of space storms in the Earth's magnetosphere and discovering important pathways for the transportation of energy particles.

Fig. 1. Prof. WANG Chi, CAS Member and Director General of NSSC, delivered the CAS/COSPAR Jeoujang Jaw Award to Prof. Dan Baker

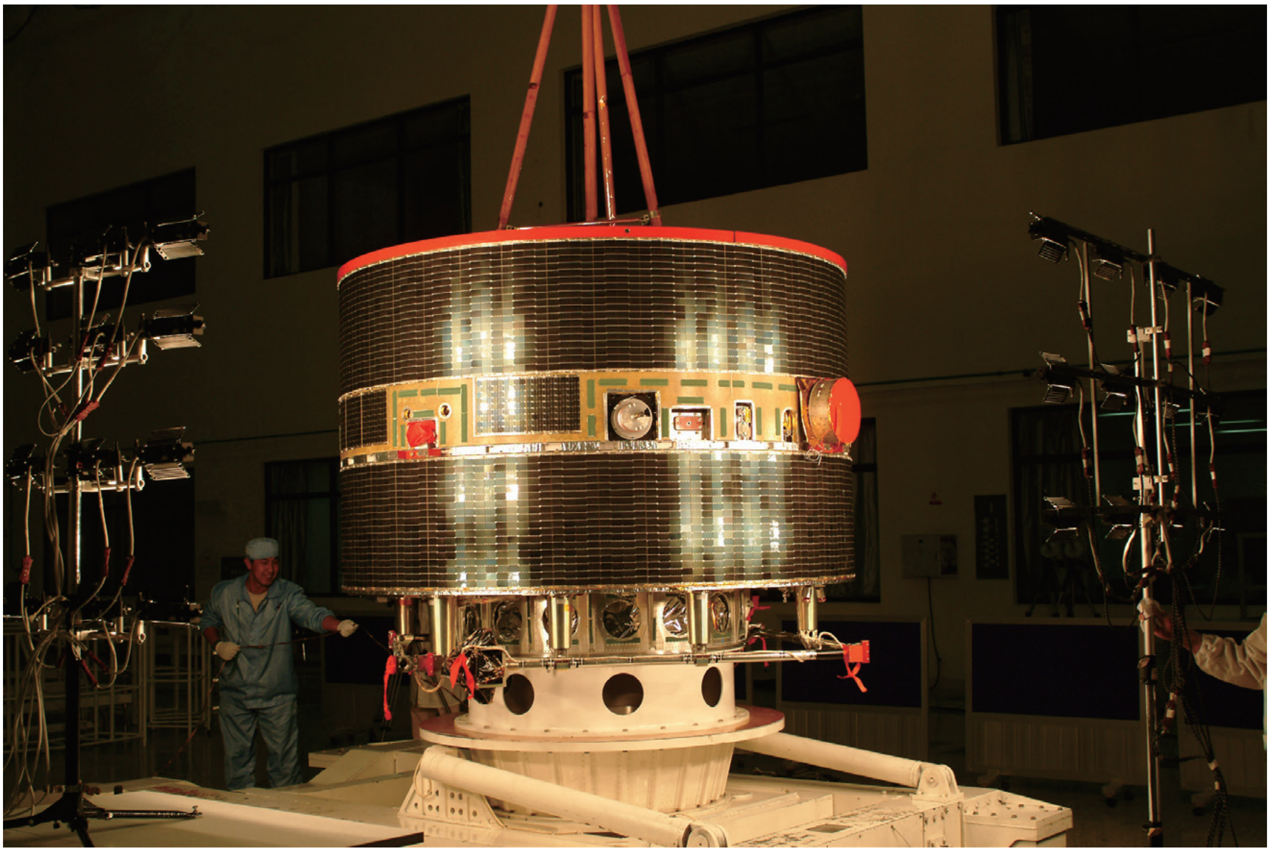
1 Committee on Space Research (COSPAR) » Jeoujang Jaw Award (cnes.fr), https://cosparhq.cnes.fr/awards/jeoujang-jaw-award/

In July and August 2001, the European Space Agency (ESA) launched four satellites of the Cluster mission operating in a higher polar orbit, which formed a tetrahedral structure in space. On July 9, 2001, the China National Space Administration (CNSA) and ESA officially signed the cooperation agreement on the DSP, specifying that ESA supplies seven scientific payloads which are from the Cluster mission, both sides jointly develop the Neutral Atom Imager on TC-2, and that ESA aids China in some key technology issues in mission development (Liu *et al.*, 2005).

From 2004 to 2007, the joint science operations of the DSP-Cluster mission demonstrated an unprecedented detection capability. The joint effort realized the first simultaneous "six-point" exploration of geospace using identical or similar detectors (Fig. 3). This successful international collaboration has produced a number of scientific discoveries, and has attracted considerable attention from the international space science community and the public. The discoveries include large-scale oscillations in magnetotail plasma sheet, ion-density voids in the solar wind, and pulse-modulated magnetic reconnection lasting several hours, and the proposal of the "frontal surface" theory of substorms. Together with NASA's IMAGE satellite, the TC-2 satellite also realized, for the first time, the simultaneous imaging of the inner magnetosphere from the north and south poles.

As a milestone of China's space science satellite, the DSP, starting from scratch, is a crucial space science mission implemented by CNSA with the engagement of ESA. It is the first major scientific cooperation project between China and ESA. In 2010, the DSP was awarded the First Prize of China's National Science and Technology Progress Award, while the joint team of DSP-Cluster mission was awarded the Laurels for Team Achievement by the International Academy of Astronautics (IAA) in 2010. The DSP has attracted the world's attention on space science in China.

Fig. 2. The Double Star TC-2 spacecraft in the Sun simulation test on 29 June 2004.



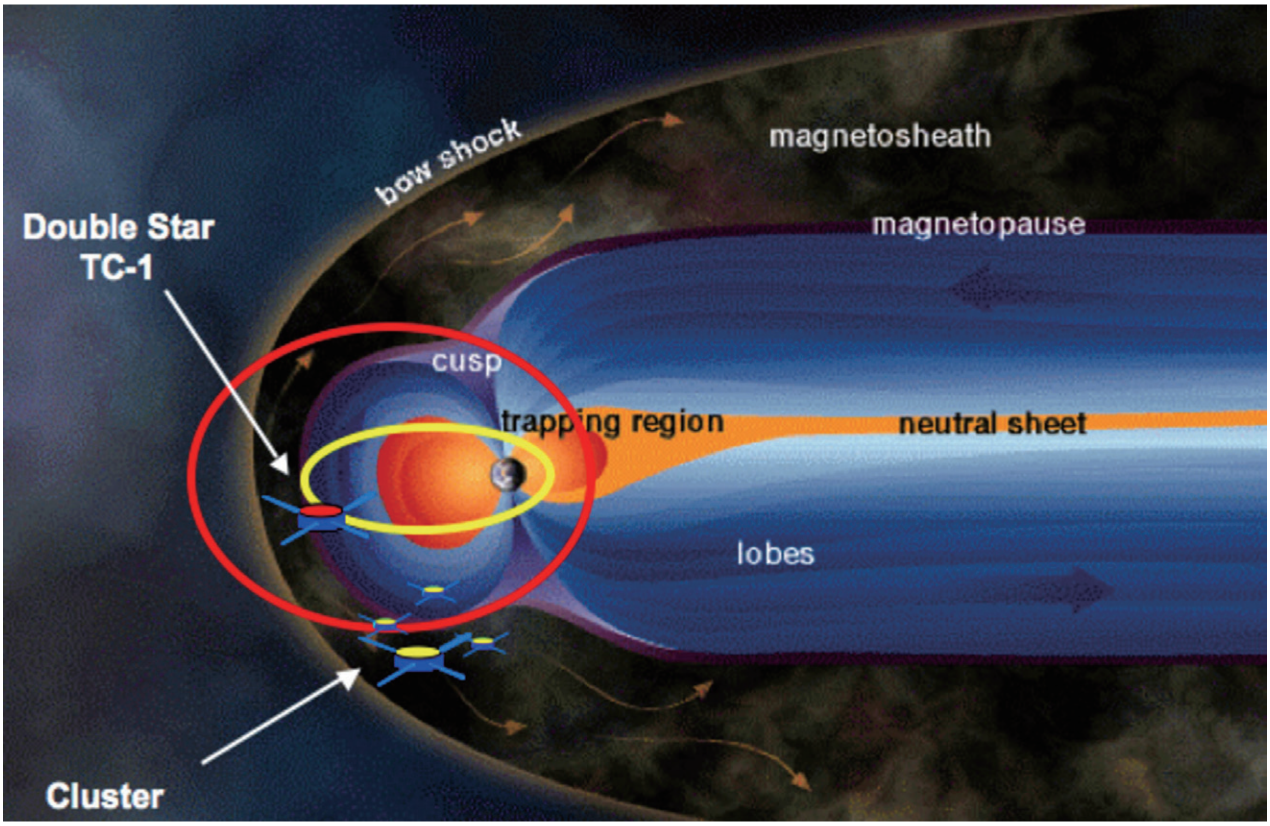
3. Chinese space science satellite series established by Strategic Priority Program on Space Science

In 2011, the Strategic Priority Program on Space Science is approved by the Chinese government with CAS responsible for its implementation. As a forward-looking major scientific program with strategic significance, it has been implemented in two phases by far, and its overall goals include making major scientific breakthroughs through independent scientific missions and international cooperation in scientific satellites, and promoting the leapfrog development of related high technologies, in a bid to demonstrate the strategically important role of space science in the development of the country (Wu *et al.*, 2022). The Strategic Priority Program on Space Science covers the whole life cycle from the proposal of original ideas all the way to the major scientific output. The research projects in the framework of the Strategic Priority Program on Space Science can be divided into two categories, namely, advanced-study projects and scientific satellite engineering projects.

The Strategic Priority Program on Space Science (Phase I) adopted four scientific missions, namely the Dark Matter Particle Explorer (DAMPE, or *Wukong*, launched in December 2015), *Shi-Jian*-10 (SJ-10, launched in April 2016), Quantum Experiment at Space Scale (QUESS, or *Micius*, launched in August 2016), and Hard X-ray Modulation Telescope (HXMT, or Insight, launched in June 2017). Another four missions were adopted by the Strategic Priority Program on Space Science (Phase II), including the Einstein Probe (EP), the Advanced space-based Solar Observatory (ASO-S, or *Kuafu*-1), the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) and the Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM, or *Huairou*-1). The *Taiji*-1, the first technology demonstration mission of *Taiji* Program, was launched for the exploration of gravitational waves. For the time being, the engineering implementations of all the scientific satellite missions in Phase II are progressing smoothly. All the missions are in orbit operation phase, except for SMILE, which is currently in the flight model development phase.

Substantial scientific achieve-

Fig. 3. Sketch of the Earth's magnetosphere with the orbit of the Double Star TC-1 spacecraft (in yellow) and the Cluster satellite quartet (in red) around May 2004.



ments have been materialized by the Strategic Priority Program on Space Science (WANG *et al*., 2024). The DAMPE mission has produced, so far, the world's most accurate spectral features of cosmic ray electrons, protons and helium nuclei (DAMPE Collaboration, 2017; DAMPE Collaboration, 2019; Alemanno *et al*., 2021). In 2020, the HXMT mission directly measured the strongest magnetic field in the universe for the first time in history, and in July 2022, the mission created a new observation record (Kong *et al*., 2022), confirming the existing assumption that fast radio bursts originate from magnetic stars (Li *et al*., 2021). The QUESS mission is the first in the world to realize satellite-to-ground quantum entanglement distribution over the scale of 1000+ kilometers (Yin *et al*., 2017), satellite-to-ground quantum key distribution (Liao *et al*., 2017), and satellite-to-ground invisible state quantum teleportation experiments (Ren *et al*., 2017). In addition, the mission completed the gravitation-induced quantum entanglement decoherence experiment, and constructed an integrated space-ground large scale quantum key communication network, which makes China the leading nation in space quantum science research. The *Shijian*-10 mission is the first to realize the development of cellular embryos to blastocysts under microgravity conditions (Lei *et al*., 2020). The mission also obtained the microscopic structure and dynamics study of glandular segregation mechanism in microgravity environment, which is inspirational to industrial processes requiring mixing or separation (Li *et al*., 2021). *Kuafu*-1 has realized China's first hard X-ray imaging of the Sun, and its observations of white-light flares play an important role in our understanding of the energy deposition and energy transport processes of solar and stellar flares (Gan, 2024). The Einstein Probe mission has, by far, detected 3000+ known sources, 200+ stellar flares, 20+ high-confidence transient sources, and 200+ faint transient sources. In addition, it has successfully detected high-redshift gamma-ray bursts.

The scientific satellite series established by the Strategic Priority Program on Space Science has provided an unprecedented platform for Chinese scientists to carry out well-organized mission-driven basic research in space science. It is a systematic program to support the development of space science in China. In doing so, the Chinese space scientists are no longer bystanders and minor participants, but key players approaching the center of the world's space science community.

4. China-ESA SMILE mission to be launched in 2025

The Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission is a joint effort at the mission level between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS). It is an all-round cooperative space science mission. Both sides created a new pattern of in-depth cooperation starting from mission planning, call for proposals, spacecraft development, launch campaign, mission operation to science output. The SMILE mission (Fig. 4) aims to study the global interactions of solar wind–magnetosphere–ionosphere innovatively by imaging the Earth's magnetosheath and cusps in soft X-rays and the northern auroral region in ultraviolet (UV) while simultaneously measuring plasma and magnetic field parameters in the solar wind and magnetosheath along a highly-elliptical and highly-inclined orbit (Sun *et al*., 2024). The mission engineering development is jointly managed by the National Space Science Center and ESA, while the spacecraft is managed by the Innovation Academy for Microsatellites of CAS (IAMCAS). The satellite will be launched by the Arianespace Vega-C launcher from the Kourou launch site in French Guiana (Branduardi-Raymont *et al*., 2018).

On September 27, 2024, the SMILE mission passed the flight model review in Shanghai, China, and the spacecraft platform was ready for shipment, marking the completion of the mission's flight model development phase that includes spacecraft testing, system interface testing and environmental testing carried out in China since January 2023 (Fig.5). According to the joint implementation plan, the satellite platform and payload module are expected to arrive at the European Space Research and Technology Center (ESTEC) in the Netherlands in October 2024 to carry out the assembly and testing of the whole flight model together with the payload module developed by ESA. It is expected to be shipped to the Kourou launch site in French Guiana in the second half of 2025, with a launch window before the end of 2025[2].

[2] China-Europe SMILE satellite for solar-wind investigation completes dev't-Xinhua (news.cn). https://english.news.cn/20240927/e5ca27fef8484f-8c8665f3b228f2810b/c.html

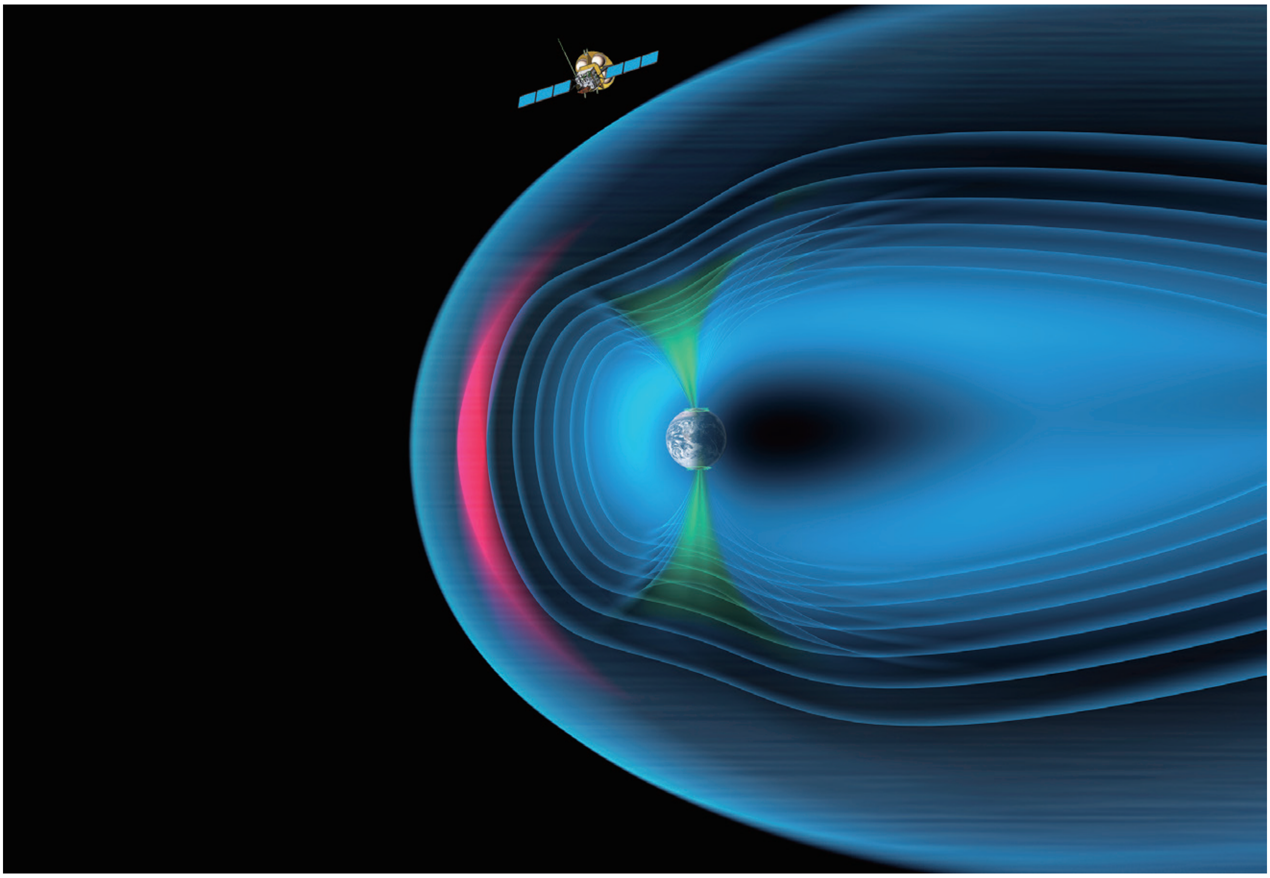


Fig. 4. Mission concept of SMILE

Credit: IAMCAS

Fig. 5. Magnetic testing of the SMILE flight model.

5. Conclusion

Based on the achievements of China's space endeavor over the past 60 years, China has begun to establish a space science satellite series. The past 10 years, in particular, have witnessed that space science in China entered into a new era of development. The priority of major scientific objectives and the orientation of major scientific output have become the most important principles for the space science mission solicitation, selection and implementation in China. Sticking to the principles of equality and mutual benefit, peaceful utilization and win-win cooperation, CAS has been carrying out international cooperation at different levels, from joint scientific research, payload collaboration, all the way to mission level cooperation with ESA and major space countries, such as Italy, Germany, Britain, Austria, Switzerland, France, Spain, etc.

The National Mid- and Long-term Program for Space Science Development in China (2024-2050) released this year is the first program in space science at the national level. Setting sight on the future, China will carry out science frontier exploration and research in 17 priority areas and 5 key scientific themes, including *Extreme Universe, Space-Time Ripples, Panoramic View of Sun-Earth, Habitable Planets, and Biological & Physical Science in Space*. China welcomes its counterparts in the world to actively participate in space science satellite mission and international big science projects, and to carry out in-depth international exchanges following the principles of extensive consultation, joint contribution, and shared benefits.

During the Fifteenth Five-Year Plan period (2026–2030), China will implement a number of major space science satellite missions, with the expectation of making breakthroughs in science frontiers such as the discovery of dark matter signals, the exploration of the dark ages and the dawn of the universe, extraterrestrial habitable planets, and solar activity and its impact on Earth. These missions not only will push back the boundaries of human knowledge and venture into new fields for development, but also contribute to our peaceful use of space.

References

Branduardi-Raymont, G., Wang C., Escoubet C.P., *et al*. (2018). SMILE definition study report, European Space Agency, ESA/SCI, 1. doi:https://doi.org/10.5270/esa.smile.definition_study_report-2018-12.

DAMPE Collaboration. (2017). Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons. *Nature*, 552(7683), 63–66. doi:10.1038/nature24475

DAMPE Collaboration. (2019). Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite. *Science Advances*, 5(9), eaax3793. doi:10.1126/sciadv.aax3793

DAMPE Collaboration. (2021). Measurement of the cosmic ray helium energy spectrum from 70 GeV to 80 TeV with the DAMPE space mission. *Physical Review Letters*, 126 (20): 201102. doi:10.1103/PhysRevLett.126.201102.

Gan, W. Q. (2024) Progress Report on ASO-S: 2022-2024. *Chin. J. Space Sci.*, 44(4): 687–689.

Kong, L.-D., Zhang, S., Zhang, S.-N., *et al*. (2022). Insight-HXMT Discovery of the Highest-energy CRSF from the First Galactic Ultraluminous X-Ray Pulsar Swift J0243.6+6124. *The Astrophysical Journal Letters,* 933(1), L3. doi:10.3847/2041-8213/ac7711

Lei, X., Cao, Y., Ma, B., *et al*. (2020). Development of mouse preimplantation embryos in space. *National Science Review*, 7(9), 1437–1446. doi:10.1093/nsr/nwaa062

Li, Z. F. Li, Zeng Z.K. K Zeng, Xing Y. Xing, et al. (2021). Microscopic structure and dynamics study of granular segregation mechanism by cyclic shear. *Science Advances*, 7 (8): eabe8737 doi:10.1126/sciadv.abe8737.

Li, C.K., Lin, L., Xiong, S.L., *et al*. (2021). HXMT identification of a non-thermal X-ray burst from SGR J1935+2154 and with FRB 200428. *Nature Astronomy*, 5(4), 378–384. doi:10.1038/s41550-021-01302-6

Liao, S.-K., Cai, W.-Q., Liu, W.-Y., *et al*. (2017). Satellite-to-ground quantum key distribution. *Nature*, 549(7670), 43–47. doi:10.1038/nature23655

Liu, Z.X., Escoubet, P., and Cao, J.B. (2005). A Chinese-European Multiscale Mission: The Double Star Program. Editor(s): Lui A.T.Y. Lui, Kamide Y. Kamide, Consolini G. Consolini, *Multiscale Coupling of Sun-Earth Processes*, Elsevier Science B.V., Pages 509–514,

Liu, Z., Pu, Z., Cao, J. *et al*. (2008). New progress of Double Star-Cluster joint exploration and study. *Sci. China Ser. E-Technol. Sci.* 51, 1565–1579. doi: (2008). https://doi.org/10.1007/s11431-008-0267-6

Ren, J.-G., Xu, P., Yong, H.-L., *et al*. (2017). Ground-to-satellite quantum teleportation. *Nature*, 549(7670), 70–73. doi:10.1038/nature23675

Sun, T. R., Connor, H., and Samsonov, A. (2024). Preface to the Special Issue on Modeling and Data Analysis Methods for the SMILE mission. *Earth Planet. Phys*., 8(1), 1–4. doi: 10.26464/epp2023089

Wang, C. (2022). Prospects of Global Space Science Breakthroughs and China's Contributions. *Bulletin of Chinese Academy of Sciences*, 37(8), 1050–1065. doi:10.16418/j.issn.1000-3045.20220513001 (in Chinese)

Wang, C., Song, T.T., & LI, M., & CAO S. (2024) Strategic Study on the Development of Space Science in China and Proposals for Future Missions[J]. *Chinese Journal of Space Science*, 44(04): 699–703.

Wu, J., Wang, C., & Fan, Q. (2022). Review on 11 Years of Implementation of Strategic Priority Program (SPP) on Space Science and Its Prospect. *Bulletin of Chinese Academy of Sciences*, 37(8), 1019–1030. doi:10.16418/j.issn.1000-3045.20220806001 (in Chinese)

Yin, J., Cao, Y., Li, Y.-H., *et al*. (2017). Satellite-based entanglement distribution over 1200 kilometers. *Science*, 356(6343), 1140–1144. doi:10.1126/science.aan3211