Introduction to Physical Sciences Experiments Completed in SJ-10 Recoverable Satellite

Wenrui Hu and Qi Kang

Abstract SJ-10 satellite is the recoverable scientific experiment satellite special for the space experiments of microgravity physics science and space life science. This mission was officially started on December 31, 2012, and the satellite was launched On April 6th 2016. This chapter introduced in briefly the SJ-10 mission, the progress of SJ-10 engineering and the projects constitution of physical sciences experiments onboard SJ-10 satellite.

Keywords SJ-10 mission · Space experiment · Microgravity physical sciences · Microgravity fluid physics · Microgravity combustion sciences · Space material sciences

1 Introduction to SJ-10 Mission

> "Shi-Jian Ten" satellite (SJ-10) is the second mission of the Strategic Priority Research Program (First-Stage) on Space Science, the Chinese Academy of Sciences (CAS). The first mission is Dark Matter Particle Explorer (DAMPE, also known as "Wukong", Launch date: December 18, 2015); the third mission is Quantum Experiments at Space Scale (QUESS, also known as "Mozi", Launch date: August 16, 2016); and the Last mission is Hard X-ray Modulation Telescope (HXMT, also known as "Insight", Launch date: June 15, 2017).

On April 6th 2016, at 01:38:04, Long March 2D rocket was launched at Jiuquan Satellite Launch Center (see Fig. 1). 559 s later, SJ-10 recoverable scientific experiment satellite was successfully sent into the near-circular orbit at the height about 250 km. This is the 24th successful launch of China's recoverable satellite. In the past,

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Fig. 1 SJ-10 satellite was launched successfully at Jiuquan Satellite Launch Center (6 April 2016, Photo courtesy of Q. Kang)

we also carried out many microgravity science experiments with China's recoverable satellites [1–3].

SJ-10 satellite is the recoverable scientific experiment satellite special for the space experiments of microgravity physics science and space life science. This mission was officially started on December 31, 2012 (see Fig. 2). With the long period of time in the microgravity environment and the radiation condition in space provided by SJ-10 satellite, a number of scientific and technological experimental studies on the law of matter movement and the rule of life activity were carried out through remote scientific and technological methods and sample recovery analytic techniques of space experiments. These space experiments focused on some fundamental and hot issues in microgravity physics science and space life science, especially for the verification of the original physical model, the utilization of spacecraft technology and space environment, and the important applications and theoretical breakthrough in space science in the future. The purpose of this mission is to discover the law of matter movement and the rule of life activity that cannot be discovered on the ground due to the existence of gravity, and to know the acting mechanism on organisms by the complex radiation of space that cannot be simulated on the ground.

SJ-10 engineering includes six systems: Satellite, Rocket, Launch, Control and Recovery, Ground Support and Scientific Applications (as shown in Fig. 3). The National Space Science Center of CAS is the general engineering management organization, and Wenrui Hu, the academician of Chinese Academy of Sciences, is the

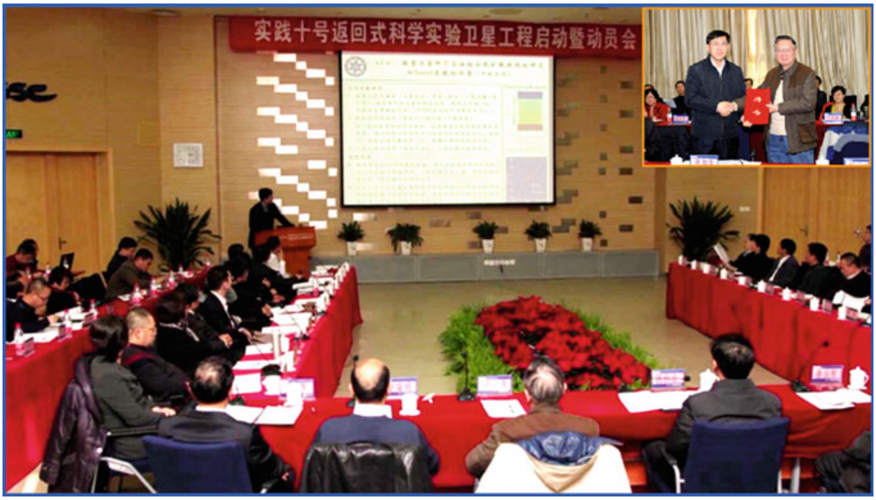


Fig. 2 Launching ceremony of SJ-10 engineering mission (31 December 2012, Photo courtesy of S. Chen)

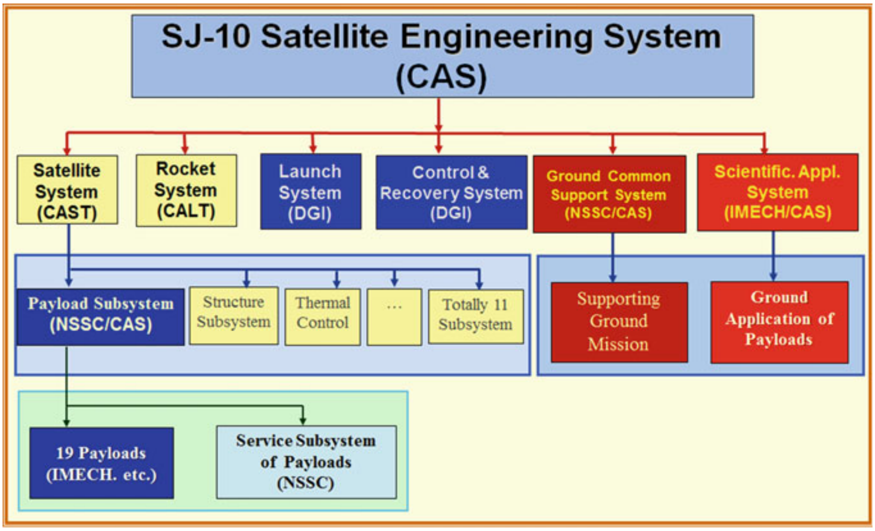


Fig. 3 Organization structure of SJ-10 engineering mission

principal investigator (PI) of SJ-10 mission. The Institute of Mechanics of CAS is in charge of the scientific application system of the mission. Their tasks include overall organization, coordination, operation, and management of the scientific research work, as well as completing the planning and guiding the implementation of scientific experiments, etc.

2 Introduction to SJ-10 Engineering

There are totally 28 research topics on microgravity physics and space life science aboard the SJ-10 satellite, and they are integrated into 19 projects of payloads. Among them, there are 10 payloads about microgravity physics sciences as listing in Table 1, and the research fields include 3 subjects: microgravity fluid physics (A1), microgravity combustion science (A2), and space material science (A3). The satellite fully inherited China's recoverable satellite technology, and it is divided into the orbit capsule and the reentry capsule. All the 8 projects in the orbit capsule are about experiments of microgravity physics sciences, including 5 experimental payloads of fluid physics (A1-1–A1-5) and 3 experimental payloads of combustion (A2), which all do not require sample recovery. In the reentry capsule, there are two experimental payloads about microgravity physics sciences: (1) synthetic furnace of multifunctional material in space (A3-1), (2) SCCO experimental payload of complex fluid (A1-6); and nine other experimental payloads are all for life science research. All experimental samples in the reentry capsule need to be analyzed furtherly in the ground laboratory after the recovery.

The research and development of the payload prototypes of SJ-10 were completed in September 2013. The development of engineering prototypes and flight prototypes was completed in December 2014 and January 2016 respectively. The total weight of the 10 experimental payloads of microgravity physics science is about 350 kg. Figure 4 shows the debugging and testing site of scientific experiment payloads and the satellite of SJ-10.

On April 6th, 2016, four hours after the satellite was launched into the orbit, the orbit capsule firstly started the research experiment of colloidal crystals (A1-5), then the experimental payloads in the orbit capsule carried out cycled rounds of scientific experiments in a serial operating mode (see Table 2). In the reentry capsule, the experiment of SCCO payload lasted for 270 h (A1-6), and the melting experiment on synthetic furnace of multifunctional materials accumulated totally 208 h with 6 working positions switched in turn (A3-1). The scientific experimental data from the satellite were received by the three satellite earth receive stations of CAS at Miyun, Sanya and Kashi, and delivered to the integrated operating and control center of the ground support system at the National Space Science Center of CAS in Beijing in real time for primary processing; Then the first level data packages were distributed to the scientific experiment operating center of scientific application systems at the Institute of Mechanics of CAS. Scientists interpreted and processed the space experimental data on line and adjusted space experimental parameters, operating mode and plans according to the space experimental status. Figure 5 shows the working scenes of Huairou integrated operating and control center of the ground common support system and Beijing scientific experiment operating center of the scientific application system. After 12 days in orbit, the reentry capsule separated from the orbit capsule and returned to Siziwangqi recovery area in Inner Mongolia, China. The payloads and samples were disassembled on site and taken

Table 1 Space experimental projects on board the SJ-10 satellite—the part of microgravity physics

No.	Subject	Project ID	Project	Executor	Location
1	A1 microgravity fluid physics	A1-1	Space experiment of evaporation and fluid interfacial effects	Institute of Mechanics, CAS	Orbit Capsule
2		A1-2	Phase separation and dynamic clustering in granular gas	Institute of Physics, CAS	Orbit Capsule
3		A1-3	Thermal Dynamical behavior of vapor bubble during pool boiling	Institute of Mechanics, CAS; Xi'an Jiaotong University	Orbit Capsule
4		A1-4	Space experimental on surface wave of thermocapillary convection	Institute of Mechanics, CAS	Orbit Capsule
5		A1-5	Study on the colloidal assembling	Institute of Mechanics, CAS; Institute of Chemistry, CAS	Orbit Capsule
6		A1-6	Soret coefficients of crude oil (SCCO)	ESA Institute of Mechanics, CAS	Reentry Capsule
7	A2 microgravity combustion science	A2-1	Study on ignition, soot emission and smoke distribution of wire insulations by overload	Institute of Engineering Thermophysics, CAS	Orbit Capsule
8		A2-2/3	Investigation of the coal combustion and pollutant formation characteristics under microgravity	Tsinghua University; Huazhong University of Science & Technology	Orbit Capsule
9		A2-4	Ignition and burning of solid materials in microgravity	Institute of Mechanics, CAS	Orbit Capsule
10	A3 space materiel science	A3-1	Melt material science experiments	Institute of Semiconductors, CAS; etc.	Reentry Capsule

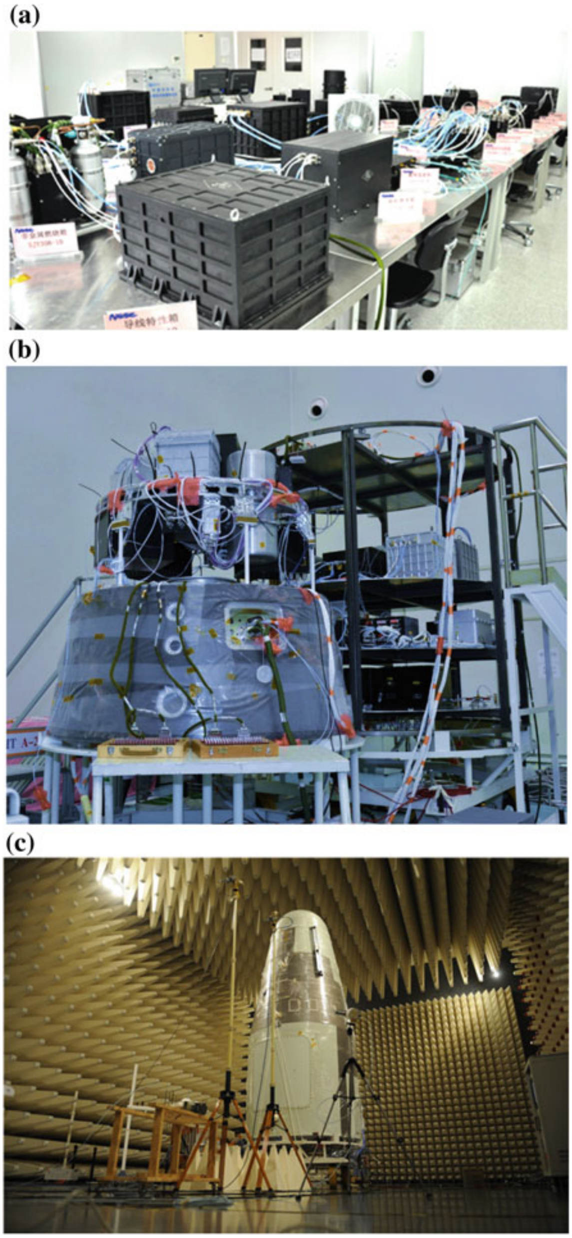


Fig. 4 The test of payloads and satellite (Photo courtesy of SJ-10 mission department). **a** The desktop test of payloads; **b** The satellite test of payloads; **c** SJ-10 satellite test

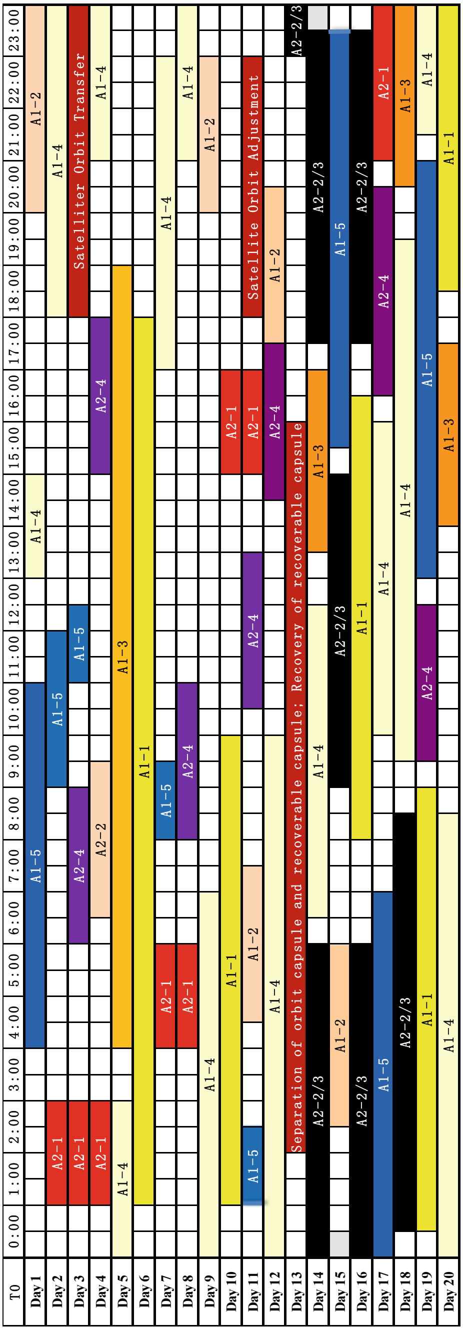
Fig. 5 **a** Huairou integrated operating and control center of payloads; **b** Beijing scientific experiment operating center (Photo courtesy of Q. Kang)

back to laboratories for post-processing. The orbit capsule continued to work 8 days in space to complete all the follow-up and expanded experiments.

3 Introduction to the Objectives of Microgravity Physical Sciences Projects

The research on microgravity physical sciences depends heavily on advanced space technologies. It promotes the development of space science and applications. It fully demonstrates a country's ability in science and technology. It is the important

Table 2 The procedure of space experiments on physics science in the orbit capsule



driven force for the development of science and technology in the world. Therefore, microgravity physical sciences naturally become the hot subject of research in the world (especially in power countries in spaceflight). In recent years, the International Space Station (ISS) has become the main platform for the research on microgravity physical sciences internationally. NASA, ESA, JAXA and Roskosmos/RKA established many special experimental racks for the research on microgravity physical sciences, and greatly improved the experimental platform in the space station to carry out studies on microgravity physical sciences. They are promoting the fast development of microgravity physical sciences at an unprecedented speed.

The study on microgravity physical sciences in China started at late 1980s. Since then, more than ten batches of space experiments on microgravity physical sciences have been carried out mainly on China's recoverable satellites and Shenzhou spaceships. Chinese scientists have obtained some valuable first-hand experiences in space research, which has laid a good foundation for the development of this subject. In recent years, microgravity science, as an important content in space science, has been deeply demonstrated and planned for a medium and long term by the Strategic Priority Research Program on Space Science of CAS and China Space Station Program. Among the pre-research projects of the Strategic Priority Research Program on Space Science and the first batch of science projects of China Space Station Program, dozens of microgravity physical science projects have been supported.

The space experimental research on microgravity physical science in SJ-10 focuses on some frontier subjects in the field of microgravity science in the world—microgravity fluid physics, microgravity combustion science, and space material science [4, 5]. It is based on the fact that, some important physical processes could be understood clearly only in the long period of time in the microgravity environment of space, and the research could increase people's knowledge of the laws of matter movement under the extreme condition of microgravity: the processes of convection, self-organizing and phase change, and the laws of heat and mass transfer; material ignition and combustion behavior, coal combustion mechanism under the microgravity condition; the growth and solidification processes of new material samples in the microgravity environment. It will improve and optimize engineering fluid and thermal power machinery as well as material processing technology on the ground and in space, obtain high-quality materials that are difficult to grow in the gravity field on the ground, and provide scientific basis and fundamental data for the safety of manned spacecraft in China and some major national requirements such as energy and carbon emission reduction, etc. [6–8].

The projects objectives of microgravity physical sciences are as follows:

(1) **Microgravity fluid physics**: to study the internal mechanisms, dynamic processes and instabilities of heat and mass transfer in the convection and phase change (evaporation and boiling), and discover new laws and verify independently developed physical models; to verity the such molecule gas-liquid separation theory of granular gas; using typical colloid system to study the establishment and evolution processes of the ordered phase driven by pure entropy, the establishment of liquid crystalline phase and the self-assembly

mechanism of metal nano-particles; to accurately measure the Soret coefficient of the samples including Chinese petroleum, and study the cross diffusion rule of multi-component medium. In this book, these studies are presented in Chap. 3 through Chap. 8.

(2) **Microgravity combustion science**: to discover the laws of ignition, combustion, flame spread, flue gas precipitation, soot emission and smoke distribution of typical non-metallic materials and wire insulations under microgravity condition; and to reveal the laws of pyrolysis, ignition, combustion and pollutant generation of typical coal of China under microgravity condition. To provide a theoretical basis and technical support for ground combustion and space safety by microgravity research results. In this book, these studies are presented in Chaps. 9 through Chap. 11.

(3) **Space material science**: to discover the selective occupation law of dopant atoms, the morphogenesis and evolution mechanisms of the alloy structure during the crystal growth process, and understand in depth the interface dynamics in the formation of materials from the melt and develop relative theories; to realize the mass transport process dominated by diffusion, and obtain uniform and large scale semiconductor crystals, high-quality metal alloys and composite materials that are difficult to grow in the gravity field on the ground. In this book, only two related studies are presented in Chaps. 13 and 14.

The eleven space experiments on microgravity physical sciences will be introduced in detail in the following chapters. In addition, SJ-10 recoverable satellite platform and the synthetic furnace of multifunctional material will also be introduced in detail in Chap. 2 and Chap. 12 respectively.

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