Facilities and Techniques of Space Life Science

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Abstract The life science research facility is an important technical means and basic condition guarantee for the development of space life science and biotechnology. Silkworm Culture Apparatus (SCA), Stem Cell Culture Apparatus (SCCA), Embryo Culture Apparatus (ECA), Plant Culture Apparatus (PCA) and Higher Plant Culture Apparatus (HPCA) are customized space life science experiment facilities, developed to carry out several different life science experiments in space microgravity condition, which are on board SJ-10 recoverable science experimental satellite (SJ-10 satellite). In this chapter, the composition, structure, function and space experiment process of ECA, SCCA, SCA, APCA, and PCA are introduced. The common key technologies of each apparatus are summarized and the feasibility of each apparatus in preflight and space flight stage are analyzed.

Abbreviation

ABRS	Advanced Biological Research System
ADSEP	Advanced Separations Processing Facility
BS	Bioculture System
ECA	Embryo Culture Apparatus
HPCA	Higher Plant Culture Apparatus
ISPR	International Standard Payload Rack
ISS	International Space Station
PCA	Plant Culture Apparatus
SCA	Silkworm Culture Apparatus
SCCA	Stem Cell Culture Apparatus
SJ-10 satellite	SJ-10 recoverable microgravity experimental satellite

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1 Introduction

Silkworm Culture Apparatus (SCA), Stem Cell Culture Apparatus (SCCA), Embryo Culture Apparatus (ECA), Plant Culture Apparatus (PCA) and Higher Plant Culture Apparatus (HPCA) are customized space life science experiment facilities, developed to carry out several different life science experiments in space microgravity, which are loaded on China recoverable science experiment satellite (Table 1). SCA is used for space radiation biology research with silkworm embryos. SCCA is used for 3D cell culture and biotechnology experiment in microgravity with two kinds of different stem cells. ECA is used for embryonic development research in space with mice embryos. PCA is used for signal transduction mechanism research in Arabidopsis seedlings. HPCA is used for researching effect of illumination cycles on higher plant.

2 International Progress of Space Life Science Experiment Facilities

With development of space science and technology, the space life science experiment and research has gradually formed a new subject, and the research content has involved widely, which covers the biological effects of space environment factors, effects of gravity on the evolution of life and physiological activities, space biotechnology of producing significant biological products, space controlled ecological protection technology such as energy/material cycle model on long-term orbit, space medicine of human being's physiological and psychological state and astrobiology for origin of life and detection of extraterrestrial life traces and so on. All of these research work get further at both micro cell molecular level and macro comprehensive level. As a result, there are higher demands for the complexity, advancement and completeness of the experimental equipment.

Table 1 Five space life science experiment facilities developed by Shanghai Institute of Technical Physics

Facility	Space experiment
Silkworm Culture Apparatus (SCA)	Effects of space environment on silkworm embryo development and mechanism of mutation
Plant Culture Apparatus (PCA)	Biological effects and the signal transduction of microgravity stimulation in plants
Higher Plant Culture Apparatus (HPCA)	Photoperiod-controlling flowering of Arabidopsis and rice in microgravity
Stem Cell Culture Apparatus (SCCA)	Three-dimensional cell culture of neural stem cells in space
Embryo Culture Apparatus (ECA)	Development of mouse early embryos in space

It is possible to establish and use various kinds of advanced space experiment system on large spacecraft platform and reciprocating spacecraft. Advanced space biology experiment system provides superior environmental conditions and support capabilities for space life science experiments and research: more adequate volume, weight and power consumption in terms of resources; more appropriate temperature, humidity and air pressure in terms of environmental conditions; more refined imaging, spectroscopy and interference technology in terms of detection means; many types of work mode including automatic, manual, remote science and others in terms of the experimental operation method.

The establishment and application of the International Space Station (ISS) marks a great breakthrough in the space science experiments. ISS provides a special laboratory for exploring the basic problems of many disciplines. It is an effective test platform to verify the research results which cannot be verified on the ground, making ISS a new starting point of deep space exploration. A variety of experimental facilities developed for ISS research such as biomedicine, basic biology, biotechnology and other fields of life science development reflect the level of the current international space life science experiment facilities and technology.

The features of design, function and operation of ISS science experiment equipment are mainly in the following aspects.

(1) "Top-to-Down" design

The top layer of ISS major research facilities is device-level payloads—international standard payload rack (ISPR), which is a key part for development of next level basic laboratory instrument ISS experiment system; the second layer is a standard special drawer-style laboratory cabinet installed in ISPR; the third layer is experiment instrument in the special laboratory cabinet and the bottom layer is all kinds of standard components for specific function within the instrument for the experiment. Using this top-down design method to develop the entire equipment and instrumentation system can make the best use of the space experiment resources that the ISS environment can provide.

(2) Unified standard design

From the ISPR design of hardware modules to achieve special function, the same specifications and standards are widely used. ISPR has standardized ISIS (International Subrack Interface Standard) interfaces, including mechanical interfaces with standard guide rails and slide guide mechanisms, and blind with the power supply and data transmission electrical interface, the next level of experimental equipment can be easily installed in the ISPR. Different hardware modules with different functions are also standardized, so that each module has standardized external dimensions, standard mechanical interfaces, and electrical interfaces. The replacement between modules is simple and easy to operate. For example, the Advanced Separations Processing Facility (ADSEP) device developed by Space Hardware Optimization Technology, Inc. in the United States contains six modules with standardized design for cell dynamics, space pharmacy development, and space bimolecular separation techniques. The standardized design provides technical basis for the exchange of

research equipment and resource sharing between different countries or research institutions in the ISS.

(3) System design maintains good compatibility and continuous advancement

The ISPR design aims at multi-users. Under the premise of adopting the standard modular design, the secondary drawer standard special experiment cabinet provides flexible design and installation conditions, allowing researchers to design unique and dedicated research components to meet the needs of special experiments. The experimental device can be designed as an independent and complete instrument, installed on a platform with a locking function cabinet, or the experimental device can be designed as several components or components, and assembled into experimental instruments in a standard dedicated experimental cabinet, with good compatibility. At the same time, the development of system hardware adopts continuous supplementing, perfecting, and improving design methods, so that it is always on the basis of inheriting the original technology and has the rising space for continuous development, ensuring that the experimental system has continuous advancement. The life science experiment facilities on ISS are shown in Table 2.

Table 2 Life science experiment facilities on ISS

Facility	Space experiment
The Advanced Biological Research System (ABRS)	Space biology of plant growth or other small biological samples
Advanced Plant Experiment (APEX)	Plant growth genetics research
The Transgenic Arabidopsis Gene Expression System (TAGES)	The transgenic arabidopsis gene expression
Biological Laboratory (BioLab)	Support biological experiments on micro-organisms, cells, tissue cultures, small plants and small invertebrates
The Bioculture System (BS)	Workbench and storage cabinet
The Vegetable Production System (VEGGIE)	Plant growth and development
Autonomous Biological System (ABS)	Highly self-regulating environment allows controlled proliferation of aquatic samples
Aquatic Habitat (AQH)	Aquatic habitat
NanoRacks Astrium Centrifuge (NRAC)	Biological and microbiological experiments
European Modular Cultivation System (EMCS)	Life science and biotechnology
Astro Garden (Astro Garden)	Plant growth
Portable Astroculture Chamber (PASC)	Life science and biotechnology
X-ray Crystallography Facility (XCF)	Dedicated experimental system for analyzing crystal growth process of macromolecular proteins
Fluorescence Based Biosensor (FBB)	Space microbiological monitoring

(4) Advanced observation, measurement and analysis technologies

The ISS experiment system is equipped with many advanced observation, measurement and analysis equipment, making it easy for researchers to operate the ISS space science experiments as it is at the ground laboratory. ISPR's standard video signal interface stores image information formed in various locations of experimental instruments in real-time through optical fibers and transmitted to ground laboratories. Optical detection technologies (such as laser light scattering, optical interference, X-ray diffraction, etc.) are increasingly used. On the one hand, on-site measurement and real-time analysis of important and unstable biological product components has been realized, changing only the results at an early stage without knowing the status of the process; on the other hand, the quantitative analysis of the change process of space experiment is realized, and create conditions for obtaining scientific significance research results.

(5) Flexible and diverse space experimental operation method

On the one hand, the existence of astronauts makes the operation of space experiments more flexible, and the space operation methods can be divided into several categories, such as astronaut operation, non-astronaut operation, automatic and remote operation. On the other hand, the operation of space experiment contains a multidisciplinary research content, and the professional level is high. Therefore, ISS has established extensive communication, such as voice, image, telemetry and transmit the real-time/delay data, so that the ground professional researchers can fully evaluate the status of the orbit test, and adjust the experimental process. Within the resource constraints, ISS designed a flexible way to enhance the scientists to control the experimental process. First, the ground scientists carefully analyze the previous experimental data and experimental methods, then submit a detailed operation plan in a week before the operation of space experiments, so the effect and quality of the whole space experiment is improved.

(6) Networked control and management

Networked control management Distributed management of payload through automatic data switching. Three data communication network modes are used in this management mode: MIL-STD-1553B payload bus; 802.3 Ethernet; high speed optical data transmission network. All payloads are associated with these three networks. The main control module manages each functional module through addressing and communication. Due to the uniqueness of the instrument control identification, no matter which cabin it is installed in, it can be accurately operated and controlled by a unique equipment identification, including power supply, switch and other operations, acquisition, storage and transmission of the telemetry parameters in various functional modules (such as: temperature, device status, etc.), the functional modules share the data bus, forming a complete network management system.

3 Progress of Space Life Science Experiment Facilities in China

In the past, Chinese space industry has achieved rapid development. Under the support of the national "863" program and the "921" project, China's space science has been greatly developed. A large number of space flight and ground simulations have been carried out, and a series of research results have been obtained. "Shenzhou" series of spacecraft have been equipped with a general biological incubator, protein crystallization device, animal and plant cell fusion device and other space life science experimental equipment, conducting a large number of space biology experimental research.

The crystal growth observation device uses transparent oxide crystals of lithium tetraborate and potassium niobate as experimental materials on the Shenzhou-2 spacecraft. The correlation between the fluid effect and the material preparation has been successfully studied. Figure 1 shows observations of crystal growth observed on satellites and spacecrafts in China in 1996 and 2000. The magnification is 1.5 times and the focusing accuracy is 0.1 mm. It can be saved by tape recording and image transmission.

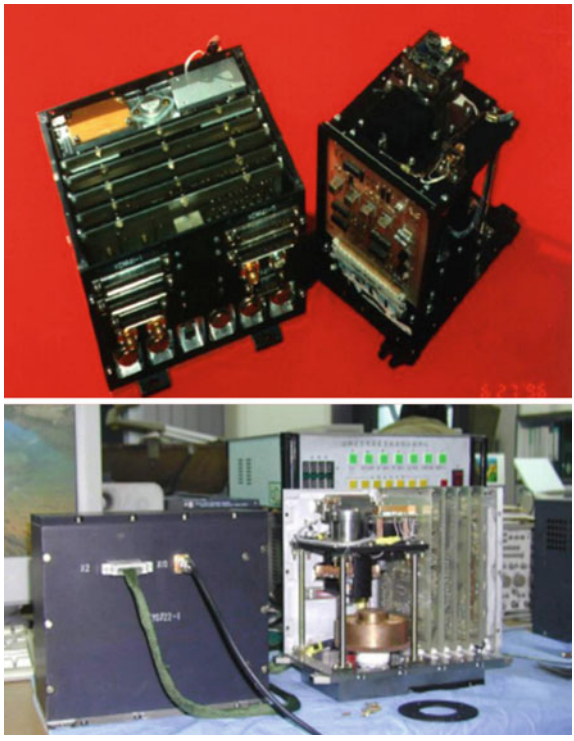


Fig. 1 Crystal growth observation device

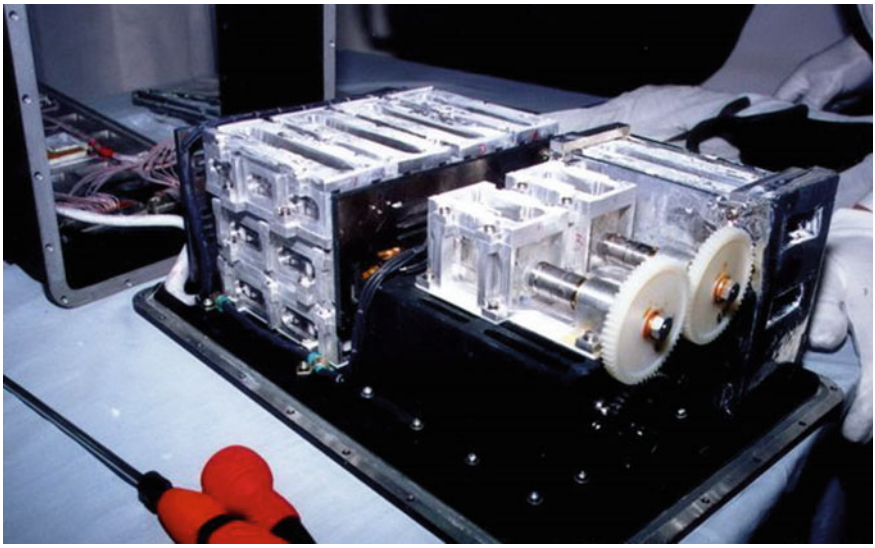


Fig. 2 Space protein crystallization device on Shenzhou-2 and 3 spacecraft

Experimental facilities for life science research in manned space missions mainly include space protein crystallization devices, cell bioreactors, space cell electrofusion devices, space continuous free flow electrophoresis devices, and space biological incubators.

The space protein crystallization device is shown in Fig. 2. The active temperature control is used to control the crystallization temperature to 20 ± 1 °C and 4 ± 1 °C, respectively; the crystallization method is vapor phase diffusion and liquid-liquid diffusion; the crystallization chamber is in the form of a skateboard and cock-style two. The experimental device can perform 60 component sample experiments in one flight, and the sample is recovered with the device. A total of 120 samples of 30 proteins were subjected to crystallization experiments. The crystallization rate reached 70%, and several high-quality crystals that could be used for crystal structure analysis were obtained. The human dehydroisandone sulfotransferase protein crystals obtained in the Shenzhou-3 spacecraft experiment are one of the best growing protein crystals in the space experiments to date.

Cell reactors are used to culture human tissue lymphoma cells, human granulocyte lymphocytes, anti-Chlamydia protein mouse lymphocyte hybridoma cells, and anti-anthrax protein mouse lymphocyte hybridoma cells, which focus on current major human diseases, and on the research of special biological effects in space. The drug cell culture experiment was a complete success, as shown in Figs. 3 and 4. With active temperature control, a device containing two independent experimental groups is suitable for spatial electrofusion experiments of animals and plants. Samples are recovered with the device. Space cell electrofusion devices are used to study the method of space cell fusion and to open up new methods for cell engineering. Cell fusion

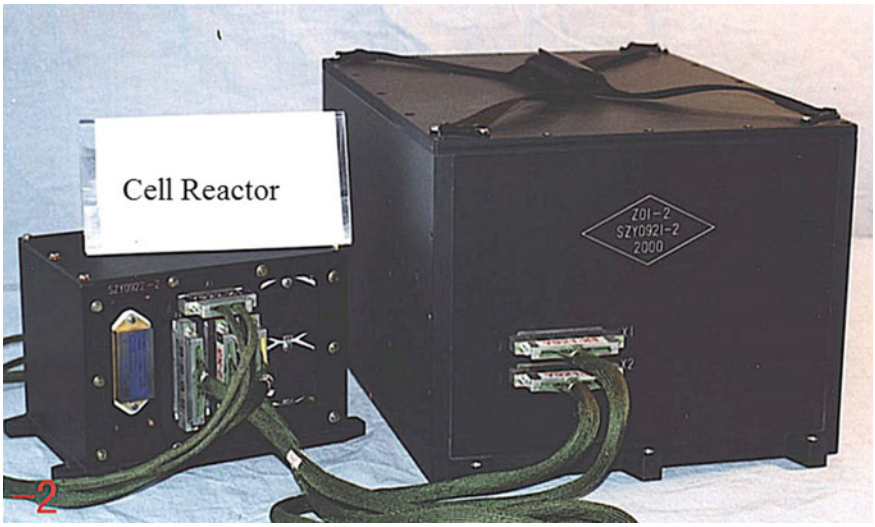


Fig. 3 Cell reactor on Shenzhou 3 spacecraft

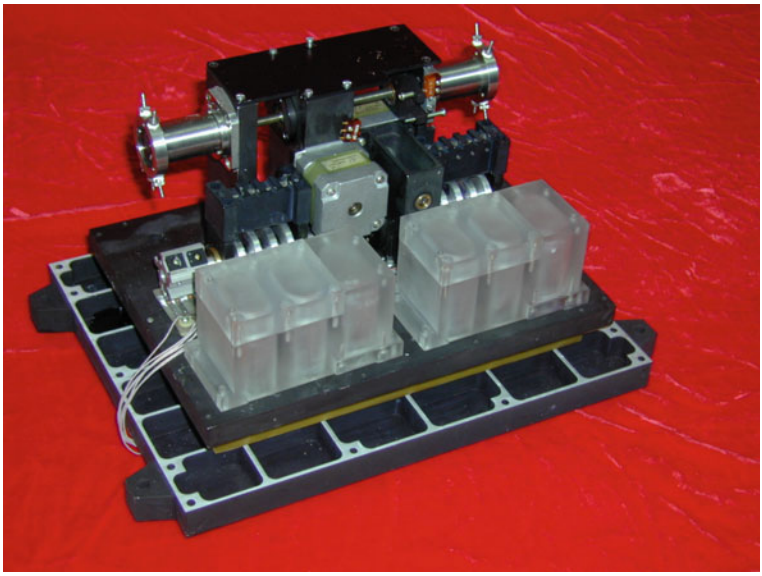


Fig. 4 Space cell fusion apparatus

Fig. 5 Embryonic culture observation system

is a new approach to biopharmaceuticals based on the principle of "complementary advantages", selecting biological cells with different advantages, conducting asexual hybridization, and acquiring and nurturing bioengineering of new species. Taking advantage of space microgravity conditions can increase the yield of hybrid cells.

In 2006, observation experiments on the cultivation of mouse embryos and observation experiments on vegetative growth and reproductive growth of higher plants were carried out on SJ-8 satellite (Lu et al. 2008). The embryo culture observation system realized automatic searching, capturing and microscopic imaging of mouse embryos with a spatial distribution of 60–100 μm in three dimensions in the culture unit (Fig. 5). The supported microscope objective magnification was from 4× to 40×, and the automatic search and capture range was 10.3 mm and the micro displacement control accuracy is 2.5 μm. The space higher plant culture observation system realized real-time image monitoring of the whole process of seedling germination, seedling growth, and flowering of the experimental plants in a space-tight environment, as well as the whole process real-time microscopic image monitoring of flower buds, blooming, and fading of the sample plant flowers (Fig. 6).

Fig. 6 Higher plant culture observation system

The Chinese Academy of Sciences and the German Space Agency collaborated to carry out a common biological incubator experimental study (Peter and Markus 2014). The BIOBOX general biological incubator experiment (Jin et al. 2014; Zhang et al. 2015) was completed on the Shenzhou-8 spacecraft from November 1st to 17th, 2011.

4 Goals and Primary Results of Space Life Science Experiment Facilities on SJ-10 Satellite

4.1 Silkworm Culture Apparatus (SCA)

4.1.1 Preface

SCA (Fig. 7) is used for radiation biology research in space with silkworm embryos on China recoverable science satellite.

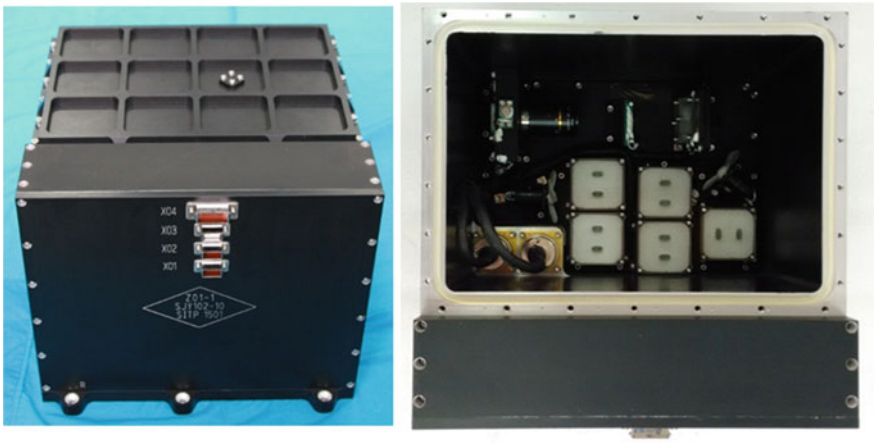


Fig. 7 Silkworm culture apparatus (SCA)

The main functions of SCA are as follows: (1) Suitable for the resource and constraint conditions of recoverable satellite platform such as volume, mass, power; Meeting the needs of the biological research under the condition of existing resources on satellite; (2) Providing the required environment for continuous culture silkworm for more than 12 days in space flight; (3) Providing monitoring and control of temperature and other life support conditions; (4) Fixing biological samples in stages according to the growth cycle of biological samples.

The batch fixing technology of biological samples and the silkworm culture technology in a space enclosed environment are the main technical difficulties and key points of SCA. SCA successfully completed the space flight experiment, and achieved low-temperature fixation of silkworm. The first successful acquisition of images of the silkworm embryo development process provided good support for scientific research.

4.1.2 System Components

There are 6 experiment units (Fig. 8) in SCA, each experiment unit has two experiment containers. Experiment unit 1 to experiment unit 5 can be fixed below 6 °C. Experiment Unit 6 is not fixed at a low temperature, the temperature is kept at a temperature of 23 ± 4 °C, and imaging observation is available. Life support unit provides the required environment for the silkworm experiment including a controlled thermal environment, atmospheric environment and enough oxygen. Fixation unit fixes silkworm eggs in stages according to the growth cycle of biological samples. Camera associate with a LED light is used to observe the silkworm hatch and record the experimental images; Electrical control unit is core control module of the facility, including secondary power conversion, temperature comparison and control,

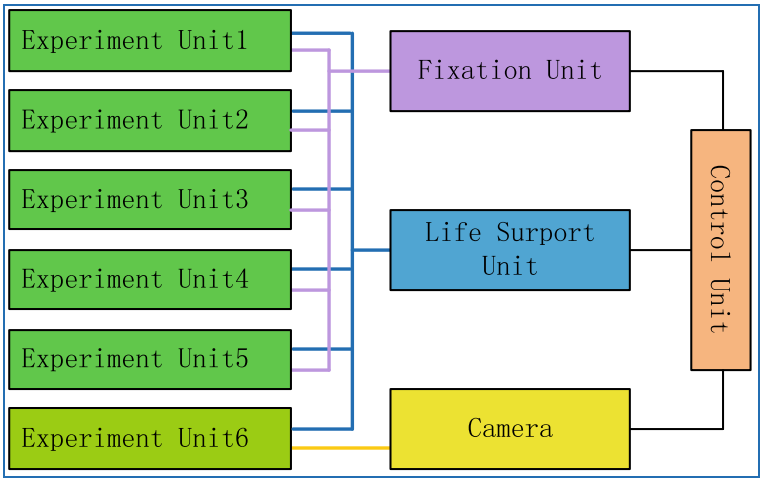


Fig. 8 SCA function composition

control of the experimental process, and reception remote control/program control commands and data exchange with satellite measurement and control systems.

4.2 Main Technical Indicators

The main technical indicators of SCA are shown in Table 3.

Table 3 Main technical indicators of SCA

Parameter	Numerical value
Weight	13.5 ± 0.2 kg
Size	300 mm × 300 mm × 250 mm
Power dissipation	≤15 W
Period	12d
Specimen quantity	6 groups
Culture temperature	23 ± 4 °C
Fixation	Low temperature fixation, 5 groups
Storage temperature	≤6 °C
Imaging	Image, 1 group

4.3 Key Technologies

(1) Closed culture of silkworm eggs in space

The key technology for silkworm culture is to provide appropriate life support conditions, including temperature, air pressure, and oxygen supply. The development of this project fully utilized the experimental basis of the ground-based silkworm culture, combined with the existing space biological culture technology and the development experience of the culture device, and multiple matching experiments (Fig. 9) to solve the space closed culture technology of silkworm. The oxygen supply of the culture unit is a passive method, which is mainly achieved through the exchange of gas between the culture unit and the SCA. In order to ensure the oxygen supply required by the biological sample during the cultivation process, the SCA must maintain enough space inside the incubator for storage the required air.

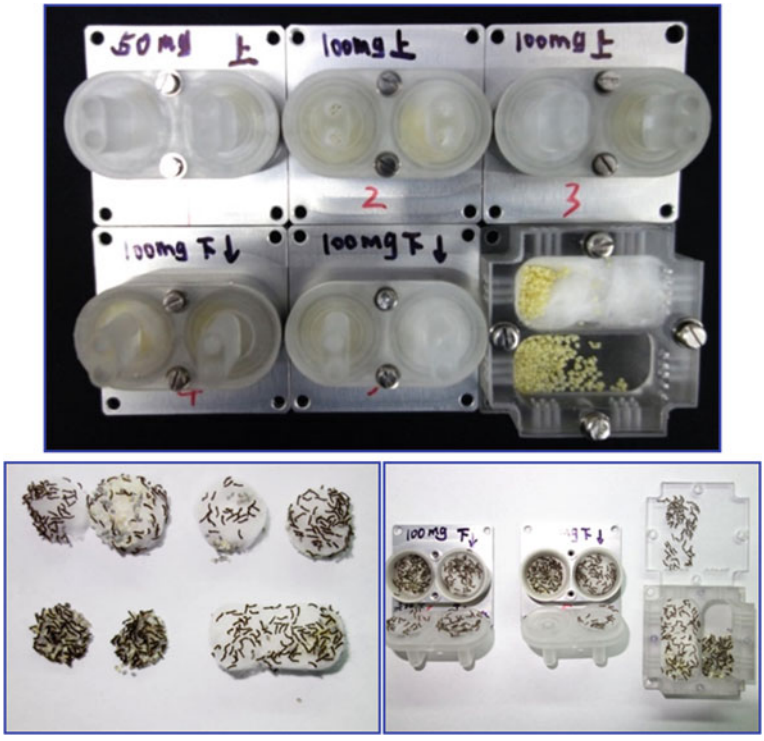


Fig. 9 Closed culture experiment (12d on ground)

(2) Multi-zone low temperature fixation

The method of independent temperature zone design combined with semiconductor rapid cooling technology is used to achieve the cryogenic fixation and preservation of biological samples. According to the demands of biological research, the biological samples are fixed in batches during the experimental process; using a low-temperature fixing method, a semiconductor chiller integrated with the silkworm culturing unit is started for cooling, and the temperature of the biological sample is reduced to fixed requirements (fixed, unit temperature is below 6 °C).

4.4 Space Flight Experiment

SCA conducted space flight experiments for 12 days and 14.5 h according to the on-orbit experimental procedure. The closed culture of silkworm eggs in space and multi-zone low temperature fixation technology was verified.

All the components and parts of SCA functioned properly. Through the analysis of the downlink data, the culture temperature was 20–22 °C, and the fixed temperature was 2–4 °C. For the first time, the image of the space development process of the silkworm embryo was successfully obtained. The obtained images of silkworm embryo development are shown in Fig. 10.

4.5 Facility and Specimen Recovery

On April 18, 2016, SCA was recovered successfully in Siziwangqi along with the returned SJ-10 satellite. After returning, the equipment was working properly. The facility and sample status of the recycling equipment are shown in Fig. 11. The recovered silkworm samples were in good condition and met the needs of scientific applications for further study.

5 Plant Culture Apparatus (PCA)

5.1 Preface

PCA (Fig. 12) is designed for the comparative analysis about different research material, which are plant hormone metabolism and signaling pathways interference genetically modified rice and their wild type, in microgravity environment.

Plant chemical fixing method and low temperature storage are the main technical difficulties and key points of PCA. The PCA successfully completed the space flight experiment, and achieved the first application of technologies and methods such as

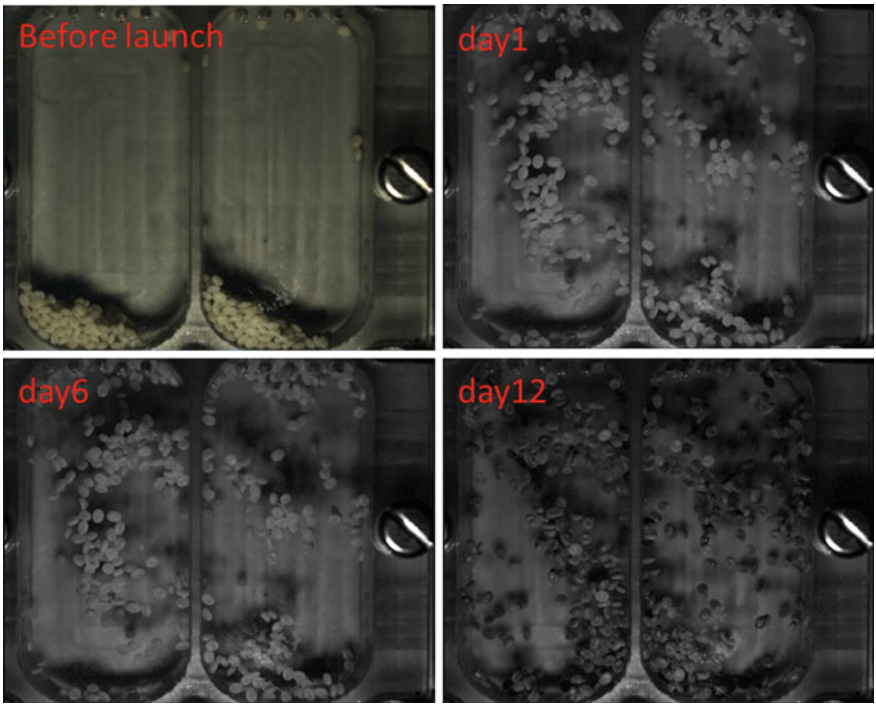
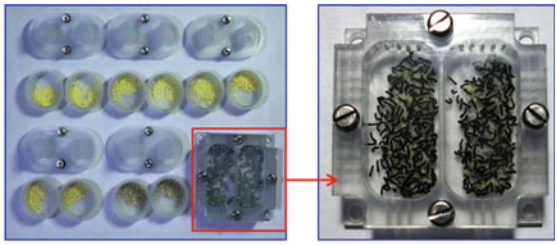


Fig. 10 Silkworm image in space flight

Fig. 11 SCA recovery



seedling chemical fixed storage and 3D printing special functional components in space life science experiments, which provided good support for scientific research.

On April 6, 2016, the PCA carrying the *Arabidopsis thaliana* seedlings was launched with the SJ-10 satellite and began a space flight test for approximately 12 days and 14.5 h. During the orbital operation, PCA successfully achieved chemical fixation and low-temperature storage of Arabidopsis seedlings. A total of 101 visible light images of the plant growth process in real time were obtained, as well as all in-orbit engineering parameters and scientific parameters. On April 18, 2016,

Fig. 12 Plant Culture Apparatus (PCA)

equipment and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained.

5.2 System Components

Six independent experiment units are designed to cultivate plants for this space experiment, each experiment unit contains four to six plants (Fig. 13). After 12 days culture, plants in five experiment units are fixed with reagent. All fixed plants are kept in low temperature until they return to the lab for detailed analysis.

The experiment unit in PCA is designed as airtight box. All conditions that plants need to grow up will be supplied in PCA, such as water, air and nutrient, etc. Five of the six experiment units are temperature adjustable, each experiment unit connect with liquid management system. A camera is used to monitor the status of the plants while it growing up; the sixth experiment units are set in a normal temperature area with a spectrum camera to analysis spectrum character of the plants.

5.3 Main Technical Indicators

The main technical indicators of PCA are shown in Table 4.

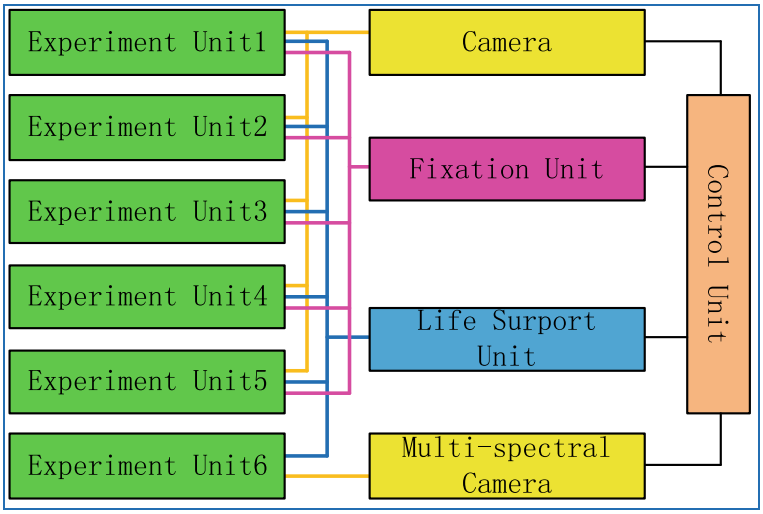


Fig. 13 PCA function composition

Table 4 Main technical indicators of PCA

Parameter	Numerical value
Weight	17.5 ± 0.2 kg
Size	350 mm × 350 mm × 250 mm
Power dissipation	≤25 W
Period	12d
Specimen quantity	6 groups
Culture temperature	22 ± 2 °C
Fixation	Chemical fixation, 5 groups
Storage temperature	≤10 °C
Imaging	1 group

5.4 Key Technologies

(1) Plant chemical fixing method and low temperature storage technology

The implementation of plant fixation under microgravity requires two steps: injecting the fixative solution into the plant cultivating unit and lowering the temperature of the culturing unit. Fixed-solution injection technology is realized by special design methods of transport pump injection of fixed fluid combined with culture unit structure. Ground injection test is used to verify the effective injection of fixed fluid; cooling preservation technology is implemented using a semiconductor refrigerator combined with an independent temperature zone design method; ensuring plant samples fixed effect. The fixed unit (Fig. 14) consists of a liquid reservoir, a check valve, an infusion pump and pipeline. According to the needs of biological experimental,

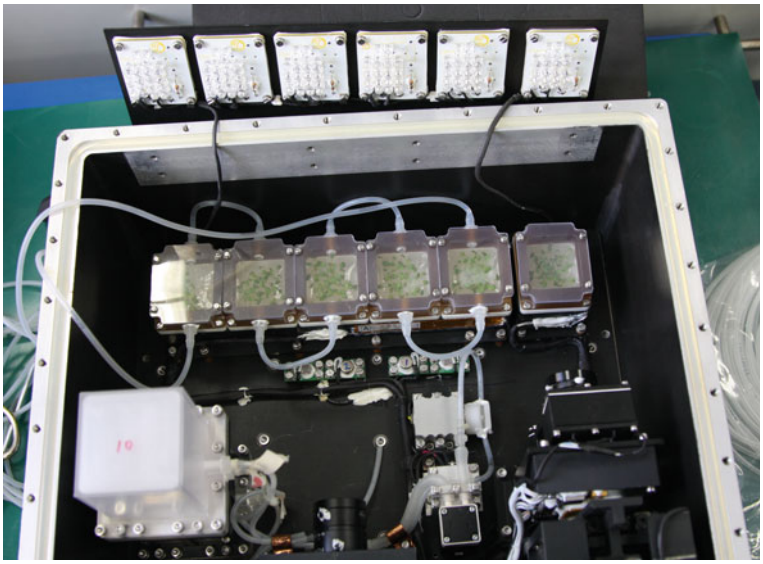


Fig. 14 Fixed unit

program-controlled instructions can be used for low-temperature fixation of plant biological samples during the experiment.

(2) Micro-spectral imaging analysis

The micro-multi-spectral fluorescence camera adopts the new technology of integrated optical splitter spectroscopy proposed by the Shanghai Institute of Technical Physics of the Chinese Academy of Sciences which is significantly reducing the volume and weight of the multi-spectral fluorescence camera. The technology was verified in space.

(3) The culture unit uses 3D printing (Fig. 15) to achieve special design

The culture unit adopts 3D printing to achieve special design and realizes the first application of technologies and methods such as 3D printing special function components in space life science experiments.

PCA successfully completed the space flight experiment, and achieved the first application of technologies and methods such as seedling chemical fixed storage and 3D printing special functional components in space life science experiments, which provided good support for scientific research.

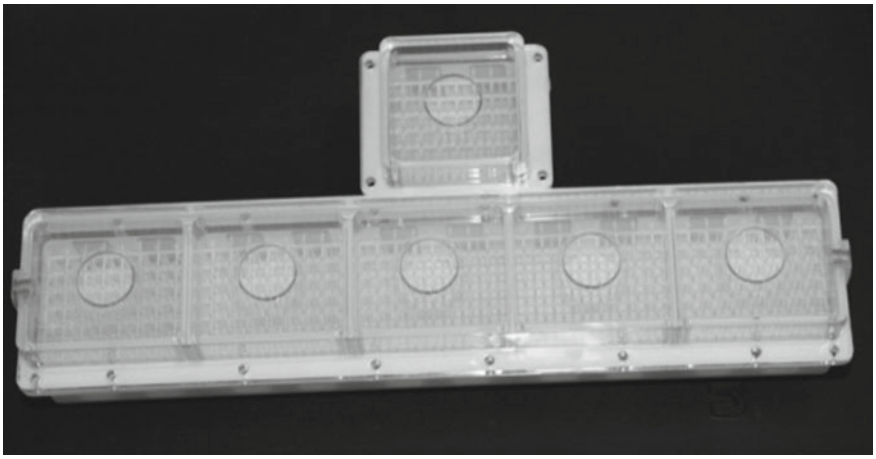


Fig. 15 The culture unit uses 3D printing

5.5 Space Flight Experiment

On April 6, 2016, the PCA carrying the *Arabidopsis thaliana* seedlings was launched with the SJ-10 satellite and began a space flight test for approximately 12 days and 14.5 h. During the orbital operation, PCA successfully achieved chemical fixation and low-temperature storage of Arabidopsis seedlings. A total of 101 visible light images of the plant growth process in real time were obtained, as well as all in-orbit engineering parameters and scientific parameters.

PCA worked properly in space. Culture temperature was 20–24 °C. Fixation storage temperature was 5–9 °C. Illumination was 6000–7000 lx. Arabidopsis was developed normally in space. Arabidopsis was fixed with chemical fixative in space (Figs. 16 and 17).

5.6 Facility and Specimen Recovery

On April 18, 2016, equipment and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained (Fig. 18).

Fig. 16 Culture circumstance

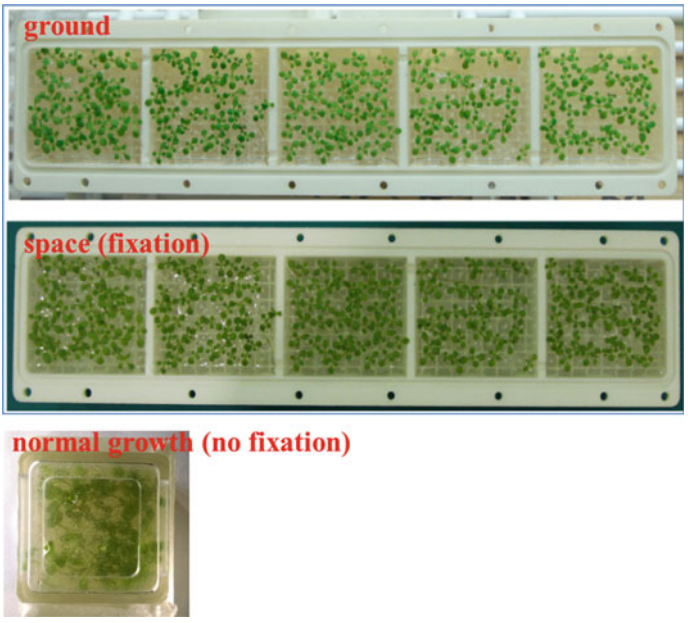


Fig. 17 Arabidopsis in space

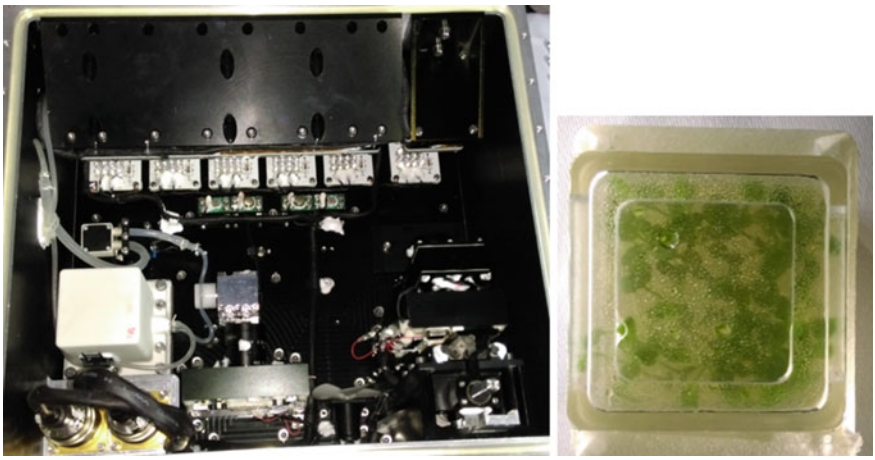


Fig. 18 PCA recovery

6 Higher Plant Culture Apparatus (HPCA)

6.1 Preface

HPCA (Fig. 19) is designed to research the effects of the microgravity on long day and short day photoperiod inducing flowering of plants and its molecular mechanism research of the influence of space experiments, using *Arabidopsis thaliana* and rice as the research materials.

The functions of the equipment include: adapting to the constraints of SJ-10 satellite platform, detection and controlling cultivating environmental temperature, providing lighting and on-line detection, acquisition of real-time color image information and fluorescence of the target sample during the space experiment process, image information, removal of harmful gases, etc.

The key point technologies of HPCA include activation of flowering gene expression in transgenic plant in space by heating and observed GFP gene expression in real-time through fluorescence imaging technology. HPCA successfully completed the space flight experiment. The first time the on-orbit track was successfully used to activate gene expression by thermal control and GFP fluorescence imaging technology of transgenic plants, which provided good support for scientific research.

On April 6, 2016, HPCA containing *Arabidopsis thaliana* and rice was launched with the SJ-10 satellite, and began a space flight experiment for about 12 days and 14.5 h. HPCA successfully achieved heat shock induced gene expression and GFP fluorescence imaging technology for transgenic plants for the first time on track. The long-day visible light image 101, short-day visible light image 48 and fluorescence were obtained. On April 18, 2016, equipment and sample recovery operations were

Fig. 19 Higher plant culture apparatus (HPCA)

successfully performed at the recycling site, and satisfactory data and sample results were obtained.

6.2 System Components

The units of HPCA (Fig. 20) main contains: cultivate unit, camera and electronic control unit. Training unit is mainly composed of rice cultivation box and Arabidopsis box. The cultivate unit mainly includes: Arabidopsis, paddy box of long-day; Arabidopsis, paddy box of short-day. Control unit mainly includes: Fluorescent camera, light unit, life support unit and camera.

Higher plant culture modules are divided into long-day light culture units and short-day light culture units. Shading partitions are used between long and short daylight culture units. Each culture unit contains two culture areas (*Arabidopsis thaliana* and rice). Each culture area is relatively Separation, air, moisture and light are shared. A short-day heat-activated start-up control unit (temperature controlled at 37° C for about 1 h) was set up in the *Arabidopsis thaliana* culture area for experimental studies of heat shock initiation gene expression.

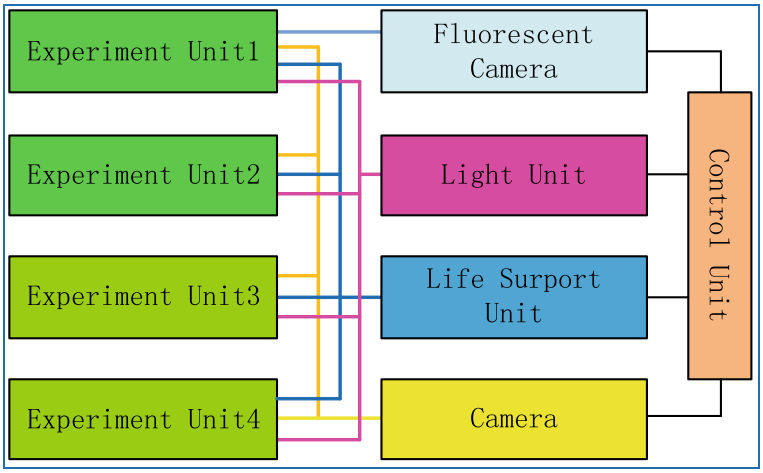


Fig. 20 HPCA function composition

Table 5 Main technical indicators of HPCA

Parameter	Numerical value
Weight	17.5 ± 0.2 kg
Size	370 mm × 270 mm × 270 mm
Power dissipation	≤45 W
Period	12d
Specimen quantity	4 groups
Culture temperature	18–28 °C
Light cycle	Long day (16 h light/8 h dark)/Short day (8 h light/16 h dark)
Light intensity	200 μmol/m^2 s
imaging	Fluorescent image

6.3 Main Technical Indicators

The main technical indicators of HPCA are shown in Table 5.

6.4 Key Technologies

(1) Gene expression thermal activation control of transgenic plant

The heat shock induction technology for gene expression of transgenic plants was successfully achieved for the first time in orbit; the heat shock temperature required for scientific samples was 37 °C. Heater and specially-designed fan structure were

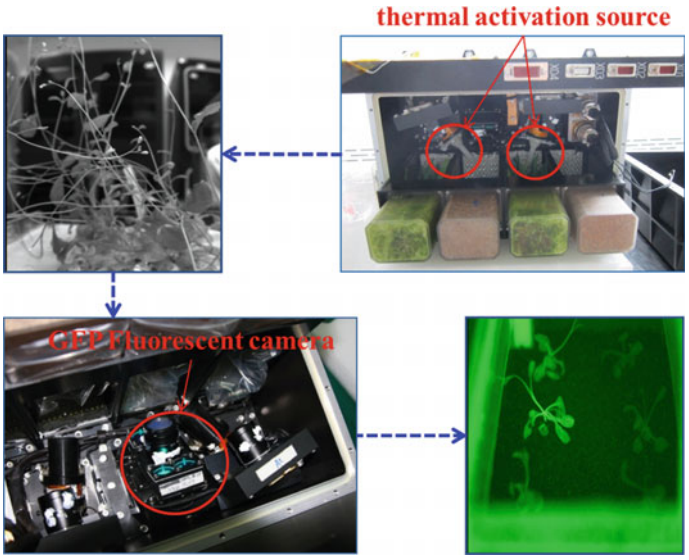


Fig. 21 Fluorescent image with GFP labeling technique

used to perform heat shock on transgenic Arabidopsis and rice plant samples. So, it is required to control the temperature accurately to 37 °C and to ensure the process of heat shock in the transgenic Arabidopsis and rice plants can completed effectively.

(2) GFP Fluorescent Image

HPCA successfully achieved heat shock induced gene expression and GFP fluorescence imaging (Fig. 21) technology for transgenic plants for the first time on track. The long-day visible light image 101, short-day visible light image 48 and fluorescence were obtained in real time for the growth and development of the downstream plants. With 48 images and all on-orbit engineering parameters and scientific parameters, the work is stable and reliable.

6.5 Space Flight Experiment

On April 6, 2016, HPCA containing *Arabidopsis thaliana* and rice was launched with the SJ-10 satellite, and began a space flight test for about 12 days and 14.5 h. HPCA successfully achieved heat shock induced gene expression and GFP fluorescence imaging technology for transgenic plants for the first time on track. The long-day visible light image 101, short-day visible light image 48 and fluorescence were obtained. On April 18, 2016, equipment and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained.

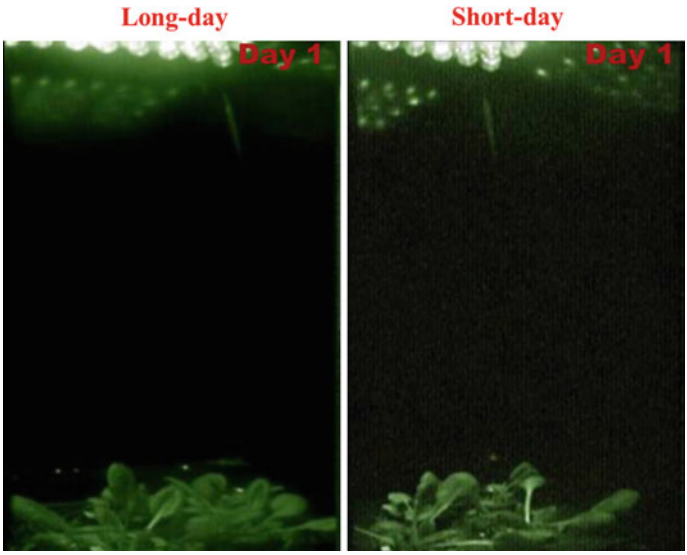


Fig. 22 HPCA images

All the components and parts of HPCA functioned properly. Through the analysis of the downlink data, the culture temperature was 20–23 °C, Rice illumination was 11,000–12,000 lx, Arabidopsis illumination was 6000–7000 lx. Observed specimen every 2 h and fluorescent imaged 48 times (Figs. 22 and 23).

6.6 Facility and Specimen Recovery

On April 18, 2016, equipment and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained (Fig. 24).

7 Stem Cell Culture Apparatus (SCCA)

7.1 Preface

SCCA (Fig. 25) was used for 3D cell culture and biotechnology experiment in microgravity with 2 kinds of different stem cells. SCCA successfully completed the space flight experiment and the recovery of equipment and samples. Microscopic images

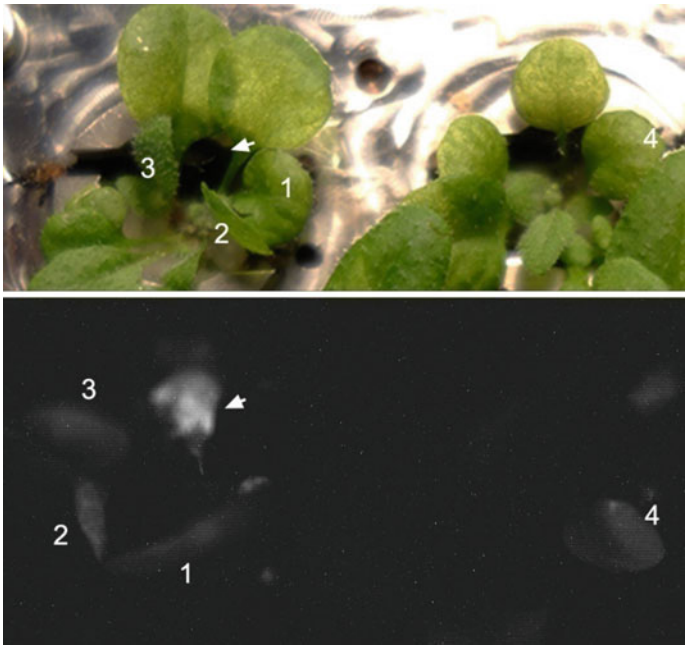


Fig. 23 Fluorescent image after thermal activation

of the proliferation and differentiation process of neural stem cells and hematopoietic stem cells were obtained, laying a very important foundation for further research.

The complicated liquid transportation, auto-focus microscope, multi-zone temperature control and two different chemical fixation methods are key technologies of SCCA.

7.2 System Components

SCCA (Fig. 26) consists of experiment units, auto-focus microscope, control unit, fixation units and life support unit. Sixteen experiment units in SCCA are divided into 4 groups, each group contains 4 experiment units. The group 1 is used for long term culturing, the group 2 and 3 are used for fixation with different chemical fixation liquid after culturing, the group 4 is used for imaging with auto-focus microscope during culturing.

SCCA consists of 3 layer structure within 16 cells, 16 sets of liquid line, 2 sets of 8-channel peristaltic pumps, 8 one-way valves, 4 liquid storage chambers, 4 liquid waste storage chambers, 8 membrane pumps, 4 culture solution and 2 stationary liquid.

Fig. 24 HPCA recovery

Fig. 25 Stem Cell Culture Apparatus (SCCA)

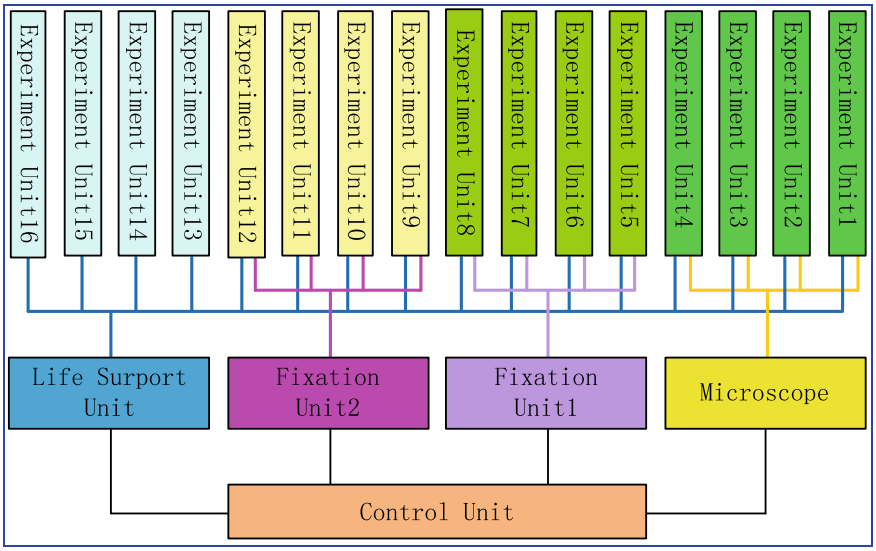


Fig. 26 SCCA function composition

7.3 Main Technical Indicators

The main technical indicators of SCCA are shown in Table 6.

Table 6 Main technical indicators of SCCA

Parameter	Numerical value
Weight	36 ± 0.33 kg
Size	400 mm × 300 mm × 400 mm
Power dissipation	≤28 W
Period	12d
Specimen quantity	4 groups
Culture temperature	36.5 ± 1 °C
Liquid transportation	16 channel, flow 0.5 ml/h ch
Fixation	Chemical fixation, 2 groups
Storage temperature	≤10 °C
imaging	Microscope, 1 group

7.4 Key Technologies

(1) Complicated 16-channel liquid transfer and control system, chemical fixation of stem cells and low temperature storage

The method of chemical fixation and cryopreservation is used for the fixed preservation of space stem cells. Through a combination of a fixed pump and a valve, the fixed solution is injected into the culture chamber, and the temperature control point of the temperature area is switched to achieve chemical fixation of the cell sample.

Under space microgravity conditions, through the use of a fully automatic perfusion culture method and the application of complex fluid pathway management techniques, the culture of stem cells for up to 12 days and the chemical fixation and cryogenic storage of on-orbit stem cells have been successfully achieved.

(2) In situ auto-searching and capturing microscopic image of stem cells

There are two kinds of hematopoietic stem cells and neural stem cells in SCCA. The target characteristics and scales of the two stem cells are different. The neural stem cells will aggregate and the hematopoietic stem cells do not aggregate. The microscope imaging design is compatible with stem cells at different scales. The microscopic imaging system (Fig. 27) consists of microscopic optics, illumination and autofocus components, image sensing components, and information processing. It is mainly used to obtain cell morphology and growth process.

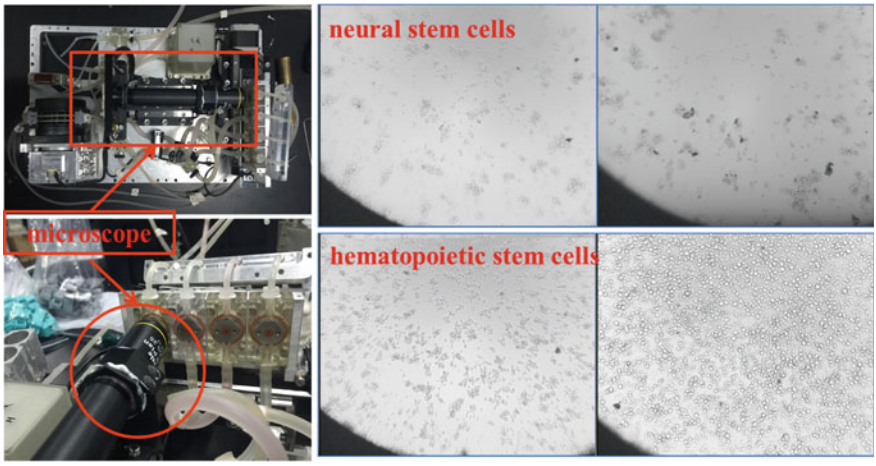


Fig. 27 Microscope of SCCA

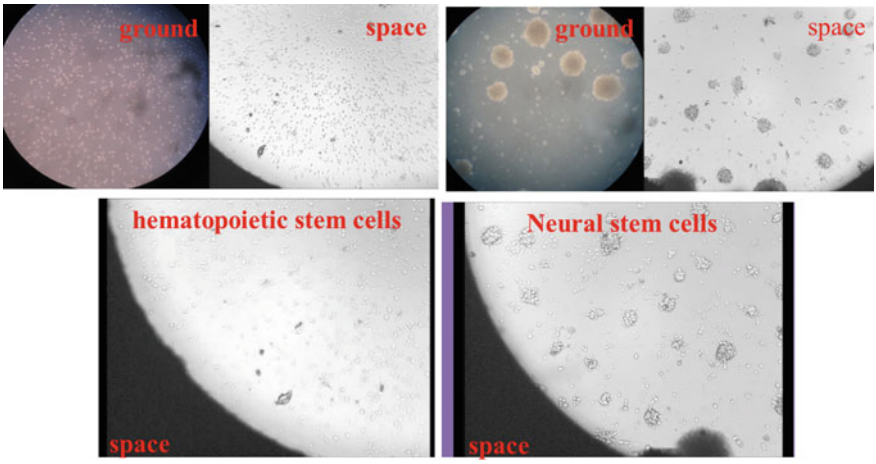


Fig. 28 Microscopic image of stem cells

7.5 Space Flight Experiment

On April 6, 2016, SCCA carrying hematopoietic stem cells and neural stem cells was launched with the SJ-10 satellite and began a space flight test for approximately 12 days and 14.5 h. SCCA successfully achieved perfusion culture and chemical immobilization of the sample. Real-time acquisition of 1184 microscopic images (Fig. 28) of the proliferation and differentiation process of the downstream neural stem cells and hematopoietic stem cells.

All the components and parts of SCCA functioned properly. Culture temperature was 36.5 ± 1 °C. Fixation liquid temperature was 5–6 °C. Fixation storage temperature was 5–6 °C. Microscope imaged 37 times.

7.6 Facility and Specimen Recovery

On April 18, 2016, equipment and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained (Fig. 29).

Fig. 29 SCCA recovery

8 Embryo Culture Apparatus (ECA)

8.1 Preface

ECA (Fig. 30) is a space life science experiment instrument developed by the Shanghai Institute of Technical Physics of the Chinese Academy of Sciences and suitable for SJ-10 satellite in China. ECA is used to develop early embryonic development of mammals under microgravity conditions. The research meets the culture conditions for the growth and development of mouse embryos in a spaceflight environment. It has automatic searching, capturing, and microscopic imaging capabilities for mouse embryos with three-dimensional distribution in the culture unit and transmits the image data.

On April 6, 2016, ECA carrying the mouse embryo was ejected with the launch of SJ-10 satellite. SCA successfully achieved two chemical fixations of the embryonic sample, real-time acquisition of 2368 images of the entire process of early embryonic development in the down-scale space, as well as all on-orbit engineering parameters and scientific parameters, and the work is stable and reliable.

On April 18, 2016, equipment and sample recovery work was successfully performed at the recycling site. The recovered samples were in good condition and satisfactory data and sample results were obtained.

The embryo culture device successfully completed the space flight experiment and equipment and sample recovery work. SCA functioned properly on the track, the data was completely downloaded, and the recovered samples were in good condition. This project achieved embryo culture for the first time in a spaceflight environment

Fig. 30 Embryo culture apparatus (ECA)

and acquired microscopic images of the entire process of early mouse embryonic development in space.

8.2 System Components

ECA (Fig. 31) is used for embryonic development research in space with mice embryos. ECA consists of experiment units, auto-focus microscope, fixation units, life support unit and control box. In the ECA, ten experiment units are divided in 3 groups. The group 1 contains 4 experiment units, used for imaging with auto-focus microscope, the group 2 and 3, each contains 3 experiment units, used for fixation with different chemical fixation liquid after culturing. The fixative fluid is stored in the fixation units. After the fixed instruction is received, the fix fluid is injected into the incubator through the transport pump and 6 samples are fixed at a time.

8.3 Main Technical Indicators

The main technical indicators of ECA are shown in Table 7.

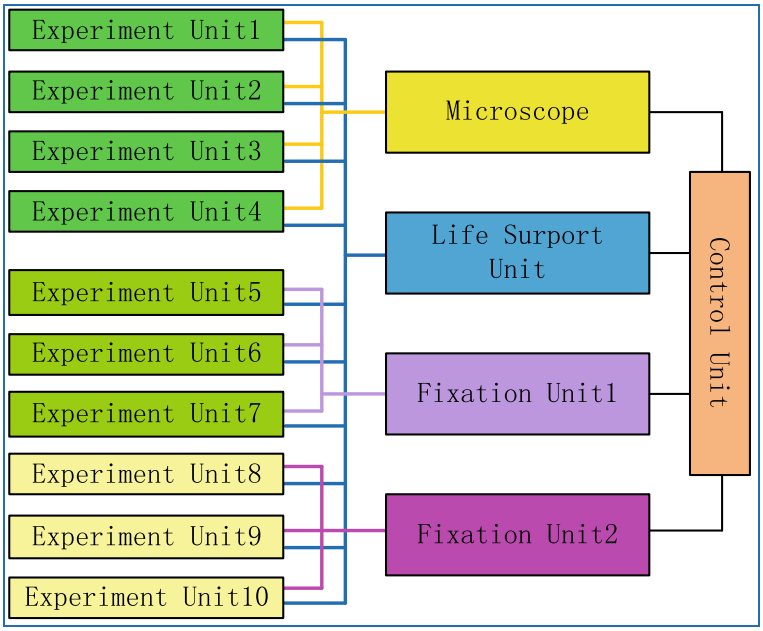


Fig. 31 ECA function composition

Table 7 Main technical indicators of ECA

Parameter	Numerical value
Weight	≤20 kg
Size	270 mm × 250 mm × 200 mm
Power dissipation	≤30 W
Period	4d
Specimen quantity	3 groups
Culture temperature	36.5–37.2 °C
Fixation	Chemical fixation, 2 groups
Storage temperature	≤10 °C
imaging	Microscope, 1 group

8.4 Key Technologies

(1) Embryo culture techniques in space-tight environment

The key technology for mouse embryo culture in space-enclosed environment is to provide appropriate life support conditions, including precise culture temperature control (accurate culture temperature control at 36.5–37.2 °C), nutrient solution supply and CO_2 environment and aseptic environment protection, etc.

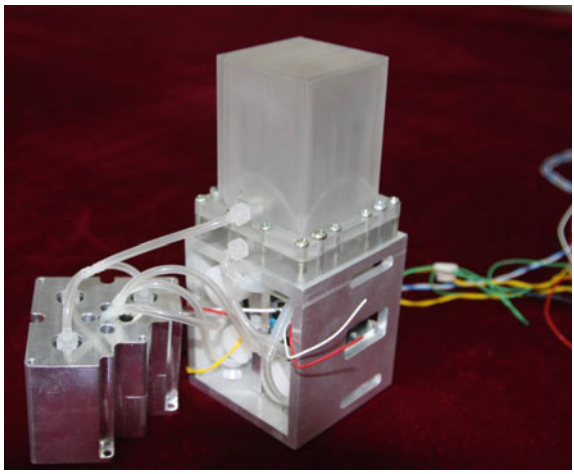


Fig. 32 Chemical fixation and low temperature storage cells

The project is based on the experimental basis of mouse culture and combined with the existing space embryo culture technology and culture device development experience to solve the embryo culture technology in the space closed environment.

SCA successfully completed the space flight experiment and realized embryo culture for the first time in a space flight environment. For the first time, microscopic images of the early development of the space mouse embryo were obtained.

(2) Chemical fixation of embryos and low temperature storage

Chemical fixation and cryopreservation methods were used for the fixed storage of mouse embryos. Through a combination of a fixed pump and a valve, the fixed solution was injected into the culturing chamber, and the temperature control point in the temperature zone was switched to achieve chemical fixation of the cell sample.

Chemical samples are used to fix biological samples, and chemical fixatives are injected into each culture unit through a transport pump to fix the sample. The sample fixing unit is shown in Fig. 32 and consists of the fixed fluid chamber, the transport pump, the culturing chamber, and the valve. This project is to achieve the chemical fixation of six kinds of samples. Six kinds of biological samples are respectively installed in two groups of culture modules for cultivation, in which one group of samples of the culture module is cultured and fixed, and the temperature of the fixed compartment is preserved; the other group of samples of the culture modules is cultured, fixed, and cryopreserved after fixation.

(3) In situ auto-searching and capturing microscopic image of embryos with low density unpredictable distribution

The size of mouse embryos is small and have to be observed with a microscope. However, the depth of field of the microscope is small, and the focusing mechanism have to be used for searching and capturing the target for imaging. The four embryo culture chambers are arranged on the linear displacement platform along the direction

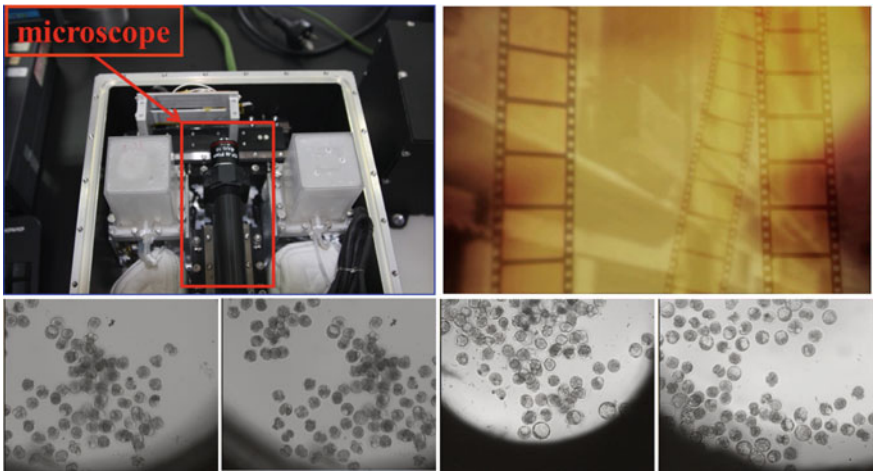


Fig. 33 Microscopic imaging of embryos on ground test

of movement of the platform, and the arrangement of the microscope considers the direction in which the optical axis is perpendicular to the linear motion. The support platform of the microscope also requires a linear motion, and the movement of the microscope is controlled by the translation stage to control its movement to obtain a clear image (Fig. 33).

8.5 Space Flight Experiment

SCA successfully completed the space flight experiment and successfully achieved two chemical fixations of the embryonic sample. The real-time acquisition of 2368 images of the entire process of early embryonic development in the down-scale space was achieved undersealed environment in space and embryo culture was obtained for the first time. The microscopic images of the whole process of early mice embryonic development in space provide good support for scientific research and have been highly recognized by international counterparts.

ECA worked properly in space. Culture temperature was 36.0–37.5 °C. Low temperature storage was 2–4 °C. Normal temperature storage was 21–23 °C. Several embryos were fixed in space and in good condition.

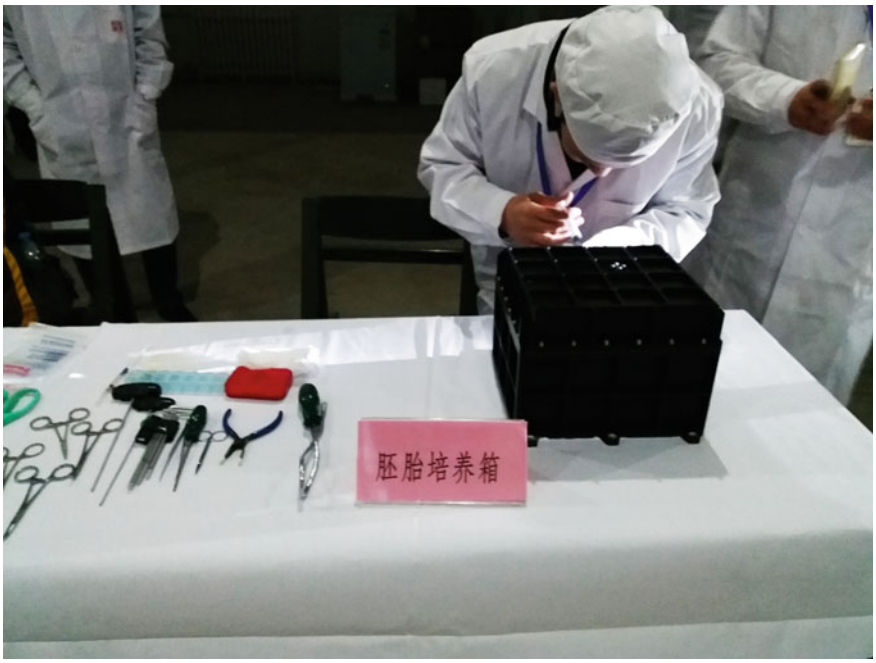


Fig. 34 ECA recovery (picture provided by Xiaohua Lei)

8.6 Facility and Specimen Recovery

On April 18, 2016, ECA and sample recovery operations were successfully performed at the recycling site, and satisfactory data and sample results were obtained (Fig. 34).

9 Conclusion

Five space-based life science experimental devices developed by Shanghai Institute of Technical Physics were successfully launched into orbit with SJ-10 satellite, and the space flight mission was successfully completed according to the experimental procedure. SCA realized the high-density cultivation of silkworm embryos in a space-contained manner and the multi-temperature discrimination batches of silkworm embryos in five culture units. At the same time, for the first time, the images of the embryonic development process of the silkworm were successfully obtained. PCA achieved the first application of technologies and methods such as chemical fixing of Arabidopsis seedlings for low temperature storage and 3D printing of special functional components in space life science experiments; HPCA successfully achieved heat shock induced gene expression and GFP fluorescence imaging

technology for transgenic plants for artificially controlling plant flowering in space; SCCA successfully realized perfusion culture and chemical immobilization of samples, and real-time acquisition of downstream data 1184 microscopic images of the proliferation and differentiation processes of space-derived neural stem cells and hematopoietic stem cells, as well as all on-orbit engineering parameters and scientific parameters, were the first to achieve spatially confined environmental stem cell culture in the country, and the first time in the world was the proliferation and differentiation of neural stem cells and hematopoietic stem cells. SCA successfully achieved two chemical fixations of the embryonic sample, real-time acquisition of 2368 images of the entire process of early embryonic development in the downscale space, and the first realization of embryo culture in a space-tight environment, obtained the microscopic images of early mouse embryonic during spaceflight.

All of these apparatuses worked properly in space. Some new techniques have been applied in space experiments:

(1) Thermal activation and fluorescent imaging;
(2) In situ auto-searching and capturing microscopic image;
(3) Complicated multi-channel liquid transfer and control.

Some important life science research results have been found:

(1) GFP fluorescent images reveal gene expression in space;
(2) Microscopic images reveal mouse embryos and stem cells development process in space.

10 Perspectives of Space Life Science Experiment Facilities in the Future

After decades of hard work and development, Chinese space life science and technology research has achieved a certain technological foundation and a place in the world today. The hardware development work in this phase was based on the exploration of basic experimental technical problems, mainly solving the basic experimental methods and technical support conditions for conducting space life science research, and testing the reliability and practicality of space experimental hardware for future science and the innovative research of technology laid a solid foundation.

However, there is still a big gap between Chinese space life science experimental devices and technology from the international advanced level. The main reason is that most life science payload devices are single devices, and the type of scientific research supported is limited. In-orbit detection methods have a relatively simple ability to cultivate environmental support, and collaborative experiments between various payloads have not yet been conducted. The development of space-based large-scale life science research and technology devices still lacks sufficient experience and there is still a long way to go compared to the level of the International Space Station.

This is also a major factor restricting Chinese ability to carry out multi-type and multi-domain life science research and collaborative experiments. It is urgent to develop the large-scale load of experimental cabinets with the help of Chinese Space Station construction. Therefore, the development of a life science experiment platform such as an experimental cabinet that is highly integrated, modular, and complex in terms of system relationships places high demands on the capabilities of the participating research units. It must be widely developed within the United Nations to carry out common research and increase research efforts. The simultaneous innovation of knowledge and technology was carried out, and efforts were made to narrow the gap with the international advanced level.

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