Home

Space Experiments Onboard the Microgravity Satellite SJ-10

AUTHORS

Hu W R[1]
Zhang X W[2]
Zhang H[3]
Zhao Y[4]
Liu Q S[1]
Hou M Y[5]
Zhao J F[1]
Kang Q[1]
Wang Y R[1]
Xu S H[1]
Kong W J[6]
Wang S F[1]
Sun Y Q[7]
Hong H Y[8]
Huang Y P[9]
Cai W M[9]
Long M[1]
Zheng H Q[9]
Duan E K[7]
Wang J F[10]

[1] Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080
[2] Institute of Semiconductor, Chinese Academy of Sciences, Beijing 100083
[3] Tsinghua University, Beijing 100084
[4] Institute of Zoology, Chinese Academy of Sciences, Beijing 100101
[5] Institute of Physics, Chinese Academy of Sciences, Beijing 100190
[6] Institute of Engineering Thermophysics, Beijing 100190
[7] Dalian Maritime University, Dalian 116026
[8] Institute of Biophysics, Chinese Academy of Sciences, Beijing 100101
[9] Institute of Plant Physiology and Ecology, Chinese Academy of Sciences, Shanghai 200032
[10] Zhejiang University, Hangzhou 310058

ABSTRACT

SJ-10 satellite will carry out the missions of space microgravity experiments in both fields of physical science and life science on board the 24th recoverable satellite of China. Scientific purpose of the program is to promote the scientific research in the space microgravity environment by operation of recoverable satellite at low Earth orbit for 2 weeks. There are 6 experiments of fluid physics, 3 of combustion and 8 of materials science in the field of physical science, 3 experiments of radiation biology, 3 of gravitational biology and 4 of biotechnology in the field of life science. The experiments were selected from more than 200 applications. The satellite will be launched at the end of 2015 or later. Fruitful scientific results on microgravity science and space life science are expected to be contributed by this program.

KEY WORDS

Microgravity science, Microgravity fluid physics, Microgravity combustion, Space materials science, Space life science, Radiation biology, Gravitational biology, Space biotechnology

1 Introduction

Microgravity experiments for long period, which could be performed only in the space facilities such as space station, space shuttle and satellite, are essential for the development of microgravity science and space life science. The recoverable satellite is a useful and efficient tool for space experiments in the microgravity environment[1−2], and such kind of satellites have been launched successfully 23 times in China[2]. Space microgravity experiments in China have been completed mainly on board the recoverable satellites since late 1980s[3], and the spaceships Shenzhou since the late 1990s. The launch of satellite SJ-8 was a turn point of the transportation mission goal from Earth observation mainly to microgravity experiments, and the main scientific results of SJ-8 missions were published in a special issue of the journal *Microgravity Science and Technology* in 2008. The space experiments of fluid sciences, including one in cooperation with the Russia scientists on board the Mir space station, were summarized in Ref.[4].

The program of SJ-10 satellite was organized by Chinese National Space Administration (CNSA) in the middle of 2000 s. 10 experiments of microgravity physics and 10 experiments of space life science were selected from more than 200 applications of SJ-10 mission in the late of 2004 and early of 2005. The mission proposal of space experiments (including two in collaboration with French Space Agency and one with Europe Space Agency) was reviewed in October 2005, and the engineering proposal of satellite platform was reviewed in May 2006 by CNSA. Then, the demonstration working group on "recoverable satellite of scientific experiments for space environment utilization" was formally organized, and the mission was determined as SJ-10. Unfortunately, the demonstrative phase was stopped after one year due to the reform of CNSA, and re-started when the government of China determined to move the national management of scientific satellites from CNSA to Chinese Academy of Sciences (CAS) in 2011. The re-started demonstration phase was completed at the end of 2012, and the engineering phase of SJ-10 program was started at the beginning of 2013. According to the schedule, the satellite is scheduled to launch at the end of 2015.

The CNSA organized an expert group for microgravity research, and there are seven sub-terms: microgravity fluid physics, microgravity combustion, space material sciences, space fundamental physics, radiation biology, gravitational biology and space biotechnology. The microgravity research and the selection of space experiments in the programs of recoverable satellite SJ-8 and SJ-10 have been arranged in the seven fields following the approach. There are 6 experiments of fluid physics, 4 of combustion, 8 of material science, 3 of radiation biology, 3 of gravitational biology and 4 of biotechnology in SJ-10 program. Scientific purposes of these experiments may be summarized as follows.

- To promote the basic research of fluid physics and biology experiments.
- To support the manned space flight for fire safety research.
- To improve the human health by biotechnology studies.
- To develop high-technology by experiments of coal combustion, materials processing and biotechnology.

The issues of selected space experiments are listed respectively in Table 1 for physics and Table 2 for life science, and the details will be discussed in the following sections.

2 Fluid Physics

2.1 A1-1

The EFILE experiment will be emphasized to study the thermocapillary effect at the liquid-gas phase-change interface on evaporation in space environment. By injection of a liquid droplet on the heating subtract, two kinds of sessile drop evaporation processes are planned to be investigated during the experimental runs: (i) a

Tab.1 List of physical experiments

	fields		name of experiment	institution	PI
1	A1 fluid physics	A1-1	Space experiment of Evaporation and Fluid Interfacial Effects (EFILE)	Inst. Mech., CAS	Liu Q S
2		A1-2	Phase separation and dynamic clustering in granular gas	Inst. Mech., CAS	Hou M Y
3		A1-3	Thermal dynamical behavior of vapor bubble during pool boiling	Inst. Mech., CAS	Zhao J F
4		A1-4	Space experimental on surface wave of thermocapillary convection	Inst. Mech., CAS	Kang Q
5		A1-5	Study on the colloidal assembling	Inst. Mech., CAS Inst. Chem., CSA	Wang Y R
6	A2 combustion	A2-1	Study on ignition, soot emission and smoke distribution of wire insulations by overload	Inst. Eng. Thermophys., CAS	Kong W J
7		A2-2/3	Investigation of the coal combustion and pollutant formation characteristics under microgravity	Tsinghua Uni., Huazhong Univ. Sci. & Tech.	Zhang H, Xu M H
8		A2-4	Ignition and burning of solid materials in microgravity	Inst. Mech., CAS	Wang S F
9	A3 materials science	A3-1	Solidification and crystal growth in space: materials science	Inst. Semiconductor, CAS, *et al*	Zhang X W, *et al*
10	ESA cooperation	A1-6	Soret coefficients of crude oil (SCCO)	ESA Inst. Mech., CAS	Verga A, Sun Z W

Tab.2 List of life science experiments

	fields		name of experiment	institution	PI
11	B1 radiation biology	B1-1	Molecular biology mechanism of space radiation mutagenesis	Dalian Maritime University	Sun Y Q
12		B1-2	Roles of space radiation on genomic DNA and its genetic effects	Inst. Biophysics, CAS	Hong H Y
13		B1-3	Effects of space environment on silkworm embryo development and mechanism of mutation	Inst. Plant Physiology and Ecology, CAS	Huang Y P
14	B2 gravitational biology	B2-1	Biological effects and the signal transduction of microgravity stimulation in plants	Inst. Plant Physiology and Ecology, CAS	Cai W M
15		B2-2	Biomechanics of mass transport of cell interactions under microgravity	Inst. Mech., CAS	Long M
16		B2-3	Photoperiod-controlling flowering of arabidopsis and rice in microgravity	Inst. Plant Physiology and Ecology, CAS	Zheng H Q
17	B3 biotechnology	B3-1	Three-dimensional cell culture of neural stem cells in space	Inst. Genetics & Developmental Biology, CAS	Dai J W
18		B3-2	Three-dimensional cell culture of hematopoietic stem cells in space	Inst. Zoology, CAS	Zhao Y
19		B3-3	Development of mouse early embryos in space	Inst. Zoology, CAS	Duan E Q
20		B3-4	Potential and molecular mechanism of osteogenic differentiation from human bone mesenchymal stem cells	Zhejiang Univ.	Wang J F

free evaporation of an injected drop while the drop shape and its contact angle along the triple line changes or contact line moves, (ii) an evaporation of a sessile drop with a constant volume controlled by feedback system while the shape and contact angle of the drop do not vary as expected.

Scientific objectives include: (i) development of the phase-change interfacial hydrodynamic theory by using microgravity environment, to obtain the novel knowledge on the coupling mechanism of evaporation and convection; (ii) to understand the gravity effects on the heat and mass transfers of evaporation and improve the development of Space Thermal Engineering and Space Life System.

Scientific key problems include (i) coupling mechanism of phase-change evaporation and thermocapillary convection, (ii) evaporation and Marangoni effects on the gas-liquid-solid contact dynamics of an evaporation drop.

Expected results and outputs are (i) to obtain valuable scientific experimental data, to provide engineering theory for space engineering and space life support system on thermal fluid facility design and development; (ii) to develop new theoretical and experimental research methods of complex fluid thermal coupling interface quality; (iii) to establish a prediction model for control enhanced evaporative heat transfer process; (iv) to obtain theoretical innovation on the pure thermal capillary surface evaporation process, for high level scientific papers, and at the same time, to promote the international cooperation in space and space science experiments.

2.2 A1-2

Different from the molecular gas, clustering is the most commonly observed feature of the granular gas. In this project, clustering conditions in single and connected double cells are studied and tested in microgravity for the first time.

The phase separation instability was originally predicted from hydrodynamic equations and then observed in molecular dynamic simulations in a two-dimensional setting: a monodisperse gas of inelastically colliding hard disks at zero gravity, confined in a 2D rectangular box and driven by a side wall that vibrates with a high frequency and small amplitude. A stripe of a denser and colder gas located at the wall opposite to the driving wall. At sufficiently high energy loss, and within a certain "spinodal" interval of grain area fractions, the stripe state becomes unstable with respect to small density perturbations in the lateral direction, unless the lateral container size is too small. Within a broader binodal, or coexistence interval, the stripe state is metastable. In both cases one observes a granular "drop" coexisting with "vapor" or a granular "bubble" coexisting with "liquid" along the wall opposite to the driving wall. This remarkable far-from-equilibrium phase separation phenomenon is in many ways similar to the gas-liquid transition as described by the classical Van Der Waals equation of state, but the role of temperature is now played by the inelastic energy loss. In this experiment we modify the volume fraction of the granular system by tuning the dimensions of the boundary-shaken cell to quantitatively test our previous three-dimensional theoretical prediction based on phase separation modeling.

This clustering feature is also tested in a window-connected double cell for possible application of granular transportation in microgravity environment. By using the so called Maxwell's demon effect in granular medium, questions on how to transport grains in zero gravity (0 *g*) are to be answered. Transporting grains appear very simple on Earth; a vibrating or rolling stripe will have the grains transported due to the friction when there is gravity (1 *g*). But, does this also happen in 0 *g*? And how can one force the grains to go in the right direction in 0 *g*? This is what planned to be answered *via* this experiment.

2.3 A1-3

Nucleate boiling is one of the most efficient modes of heat transfer, resulting in its wide applications for high heat flux transfer both on the Earth and in space. However, boiling is also a complex and elusive process. There's no common agreement on the mechanism of boiling heat transfer and related bubble thermal dynamics, though a great amount of achievements on boiling obtained by experimental, analytical and numerical investigations flooded in the literatures up to now. Particularly, relatively very little experimental data is available to date regarding the local convection and heat transfer rate under and around the bubbles as they grow and depart from the heating surface, which is necessary for obtaining better understanding of heat transfer mechanisms involved in boiling phenomenon. Such information can also serve as benchmarks to validate many of the analytical and numerical models used to simulate boiling.

The project SOBER-SJ10 (Single bubble pool boiling experiment aboard SJ-10) is proposed to study local convection and heat transfer around an isolated growing vapor bubble during nucleate pool boiling on a flat plate heater in microgravity. An integrated heater has been developed to trigger an embryo bubble, to provide an approximate constant input power and to measure the local temperatures underneath the growing bubble. Local superheating method will be used to pinpoint the embryo bubble with both temporal and spatial precisions. The bubble will grow on the top surface of a flat plate, which is resistance-heated on the bottom surface with an approximate constant input power. Several micro platinum resistance thermometers will be used to measure the local temperature distribution on the top surface of the heater, while the averaged temperature on the bottom will also be determined by using the prior calibration of its resistance-temperature correlation. These data will be used to invert the evolvement of three-dimensional transient conduction inside the solid wall. Liquid subcooling and input heating power will be varied parametrically. The system pressure in the experiments will vary over a narrow range around one atmosphere. Data will be taken for power input to heaters, averaged temperature on the bottom surface, local temperature distribution underneath the growing bubble on the top surface, bulk liquid temperature and pressure in the pool. Visual observations will provide quantitative data on bubble inception, bubble growth, bubble merger and bubble departure processes.

The main objective is to develop a basic understand of the local convection, vapor removal, and heat transfer processes which take place during nucleate boiling from a well characterized surface in microgravity. The local processes include three-dimensional transient conduction inside the solid wall, micro-layer evaporation underneath the growing bubble, evolvement of local dryout underneath the growing vapor bubble, condensation and evaporation around the bubble periphery, and local convection. A parallel numerical simulation/modeling effort will provide insights into the mechanisms that should be carefully assessed during the experiments.

2.4 A1-4

(1) Scientific Objectives

Microgravity environment provides an excellent platform for the study of pure thermocapillary convection easily covered by buoyant convection on the ground. This project will present an inner heated cylindrical liquid pool as the convection system to study the instabilities of thermocapillary flow patterns and transition pathways. It will be the first time for taking volume effect into account in deep understanding of thermocapillary convection and oscillation mechanism.

(2) Experiment Equipment

A set of facility has been established, into which were incorporated a cylindrical annuli liquid test system including liquid storage and filling liquid system, two sets of temperature controlling system, a temperature measurement system, a thermal infrared imager, a high-precision displacement sensor to surface oscillation system and an experiment controlling system.

(3) Scientific Issues

Scientific issues include: (i) critical conditions for the instabilities of thermocapillary convection in the cylindrical liquid pool, (ii) oscillatory flow patterns and transitions of the convection, (iii) volume effect of the convection in the cylindrical pool.

Thermocapillary convection is a widespread natural convection phenomenon and has drawn great attention not only for practical applications but also for the development of scientific theories. It is a great opportunity to expand the field of fluid mechanics through space experiments for further information of flow patterns, oscillations, and transition issues of thermocapillary convection research. All the efforts and achievements will finally embrace great success on crystal growth and materials science. Besides, keeping and reconstructing the fluid system, as the key technology in fluid management will also enhance our experimental abilities and skill levels under microgravity environment.

2.5 A1-5

SJ-10 scientific satellite will be launched at the end of 2015 in China. The project SJY305-10 will be carried out, boarding this satellite. The main space researching contents included: (i) self-assembly of the colloidal spheres with or without Ag shell; (ii) liquid crystal phase transition. In order to complete the tasks, a scientific device Colloidal Material Box (CMB) is being developed. CMB can execute the pre-set instruction and automatically do the experiments when the satellite enters into reservation orbit. Certainly, the scientist can adjust the instruction according to the obtained experimental data afterwards. CMB includes four function units: (i) injection management unit to store the colloidal and liquid crystal suspension and make them well-mixed before experiment, and inject the droplets precisely; (ii) optical observation unit to illuminate the experimental samples and get the images during the liquid crystal phase transition and the evaporation of the colloidal droplets; (iii) sample management unit to switch the samples at observing position; (iv) electronic control module to supply power and save experimental instruction and transmit the experimental data.

There are three scientific purposes to be accomplished in this project. (i) The self-assembly dynamics of the colloidal sphere under microgravity. It is well known that the colloidal particles can be arrayed into colloidal crystal for the capillary flow. However, there are many kinds of defects due to the buoyancy convection in the suspension on ground, especially for fabricating large-area colloidal crystal. In space, the buoyancy convection will disappear, which will help us to get high-quality single colloidal crystal. (ii) Assembly mechanism of colloidal spheres with Ag nanoparticles coated. As an important quantum dot material, it is a fascinating topic to get the highly ordered structure of the colloidal particles with Ag coated. (iii) Test of the liquid crystal phase transition model, Onsager model. Liquid crystal phase transition is considered to be an entropy-driven process. But it is difficult to confirm under the gravity which will cause the density difference which will not happen in space.

When the space scientific experiments accomplished, it will be the first time to deposit ordered colloidal crystal and study the mechanism of the assembly under Marangoni stress. Also, using the inorganic liquid crystal colloid system, we try to verify the mechanism of pure entropy driven phase formation for the first time globally.

2.6 A1-6

Oil reservoirs provide many scientific and technical challenges. One is the reliable prediction of how the components of oil in reservoirs are distributed. This is a difficult multicomponent problem involving diffusion, thermodiffusion and convection in porous media. Thermodiffusion and the Soret effect lead to the partial separation of components, induced by a thermal gradient. Recent analysis showed that the inclusion of thermodiffusion could result in a difference of 100 m in the location of the gas/oil interface in the reservoir. Therefore, the Soret effect should be taken into account for the prediction of distribution of oil components in reservoirs. Due to the fact that the temperature gradient causes convection on the ground, the SCCO project was proposed by ESA to study the thermodiffusion and measure the Soret coefficient under microgravity condition.

For the proposed joint investigations during the flight of 6 experimental cells of the SCCO system in SJ-10, three different types of dense fluid mixtures at high pressure are proposed which aim to meet the interest of all partners, the project team and Chinese partners. The mixtures proposed are directly relevant to the CO_2 geological storage and the specific Chinese petroleum reservoirs. The interest is for the point of view of academicals studies as well as the industrial applications. Academically, the SCCO experiment on SJ-10 will go beyond the usual binary mixtures to find appropriate “lumping-delumping” scheme to model n-components mixture, and it will also improve the molecular simulations and macroscopic modeling. For industrial applications, the experiment will improve the modeling of the initial state of the distribution of compounds in a petroleum reservoir, the estimation the trapping time of CO_2 when sequestrated.

3 Combustion

3.1 A2-1

The wire cable is one of the classical non-metal materials used in the manned spacecraft, which has been the main fire source in the history of fire accidents during manned spacecraft flight. Although the electrical wires and components used in manned space shuttle flights have passed strict tests and various routine experiments, all these tests conducted only in normal gravity while the microgravity effects were not fully taken into account. It is well established that the heat transfer processes in microgravity are different from those in normal gravity due to the significantly suppressed natural convection, leading to more heat accumulation in the vicinity of electrical wires and components and higher wire insulation temperatures. Consequently, it is much more likely to encounter fire threatening scenarios in microgravity due to overheating of electrical wires. Up to now, it is still hard to detect these fire occurrences in microgravity. The fire safety is still one of the key problems during the manned spacecraft flight. This project suggests to investigate the pre-ignition characteristics of wire insulation by overload in microgravity, to investigate soot emission during the ignition stage and the smoke distribution of the wire insulation combustion. The objectives are to study the fire characteristics of wire insulation and to provide scientific data for the development of fire detection and fire alarm technology in manned spacecraft.

The project will carry out space experimental study on the smoke distribution after ignition of the overload wire insulation on board SJ-10 satellite. A thorough study on the pre-ignition characteristics of overload wire insulation during long microgravity duration will also been conducted. The experiments will measure the temperature variations, soot emission and the smoke distributions of the overload wire insulation. The study focuses on: (i) study on the pre-ignition characteristics, such as ignition delay time, ignition temperature and ignition radiation energy of wire insulation by overload under microgravity, (ii) investigation on soot emission from the wire insulation during the pre-ignition and ignition stages in microgravity, (iii) investigation on smoke release and distribution characteristics of wire insulation combustion in microgravity, (iv) establishment of the theoretic model to predict the ignition and combustion characteristics of the wire insulation in microgravity, and the model will be verified by the microgravity experiments. The results could enhance the comprehension of fire mechanism under microgravity.

Up to now, there have been limited studies on the ignition of wire insulation in microgravity. Wire insulation can be ignited by either an external heat source or internal heating under overload conditions. Extensive research has been conducted to investigate flame spread along wire surface caused by external ignition sources. However, ignition of wire insulation by external sources in general does not represent typical fire scenarios on board a spacecraft. Besides, the ignition of wire insulation under overload conditions is a slow process, which could take several minutes, several hours, or even longer. It is impossible to create such long microgravity duration in the ground-based microgravity facility. Thus, it is significant to conduct this project on the real microgravity environment.

3.2 A2-2 and A2-3

(1) Scientific Objectives

- To discover the fundamental phenomena and control mechanisms in the entire combustion process of single particles and pulverized clouds of a few kinds of typical China coals in an ideal buoyancy-free environment where surrounding mass and heat transfer is isotropic.
- To obtain ideal experimental data that is useful for the validation of theories and models for coal ignition and combustion.
- To better understand the buoyancy effect in ground coal combustion, and to improve the modeling and theory development for ground coal combustion and emission control.

(2) Main Research Works

- To optically observe the entire combustion process of single particles and pulverized clouds in a furnace with well controlled temperature and gas atmosphere for a few kinds of typical China coals under microgravity.
- To measure the flue gas composition after single particles or pulverized clouds are burnt in a furnace with well controlled temperature and gas atmosphere for a few kinds of typical China coals under microgravity.
- To retrieve the ignition and combustion parameters, such as ignition time, ignition temperature, flame shape and size, volatile evolution manner, burn-out time for the recorded images, and use the data to validate theories and models for coal ignition and combustion.
- To compare the data between microgravity and normal gravity, and then to better understand the buoyancy effect in ground coal combustion, and to improve the modeling and theory development for ground coal combustion and emission control.

The innovation points are as follows.

- For the first time to study the entire coal combustion process in an ideal buoyancy-free environment where the surrounding mass and heat transfer is isotropic.
- Comparative studies are conducted with large single particles and pulverized coal clouds, in microgravity and normal gravity.
- Microgravity studies are aimed to be applied in model and theory development for ground coal combustion and emission control.

3.3 A2-4

Ignition of solid fuels and subsequent transition to flame spread is of fundamental interest and practical importance for fire safety. Motivated primarily by fire safety of spacecraft, a renewed interest in microgravity flame spread over solid materials has arisen. With few exceptions, however, research on microgravity flame spread has been focused on thermally thin fuels due to the constraint on available test time. Such little is known about the flame spread over thick fuels in microgravity. Moreover, most previous research on microgravity flame spread has involved purely opposed or purely concurrent flow, in which ignition occurs at one end of the fuel sample and flame propagates toward another end, although the combination of these two modes is practically important.

The present investigation examines the ignition and burning characteristics of thermally thick solids with varying low velocity flow and varying ambient oxygen concentration. Other variables to be tested are the effects of fuel type and geometry. The research will focus on:

(i) finding a limiting oxygen concentration or flow velocity where a flame will propagate in space, and comparing the limits with those on Earth;

(ii) evaluating effects of flow velocity, oxygen percentage and material shape on flame spread modes;

(iii) improving the prediction model of solid material combustion.

The microgravity experiment consists of 8 fuel samples, and each sample has an igniter wire. There are two categories of samples, which are flat and rod respectively. Thick materials of Polymethylmethacrylate (PMMA) and Polyethylene (PE) are included. In most of the tests, the ignition is initiated in the middle of the sample, and the subsequent flame propagation would take place as an opposed-flow mode or a combination of opposed and concurrent mode, depending on ambient oxygen concentration and flow velocity. The other samples are ignited at the upstream end to yield concurrent spread rates and extinction limits. The important observations from space experiments include flame behavior and appearance as a function of ambient oxygen concentration and flow velocity, temperature variation in gas and solid phases, and flame spread rate.

Current methods of screening spacecraft materials are based on how the materials burn on Earth. The prediction of fire behavior in microgravity still involves uncertainty. The focus of the work is to provide valuable information on combustion progresses of thick solid materials in microgravity environments and to compare the burning scenario in space with those on Earth. Understanding these differences should improve flammability requirements for spacecraft materials. The simpler combustion process in microgravity will also enable us to validate and improve models of solid burning. These models can be used to more accurately study flames, both in spacecraft and on Earth.

4 Materials Sciences

The microgravity environment is of vital importance for gaining a better understanding of the solidification and crystal growth. The virtual absence of gravity-dependent phenomena in microgravity allows an in-depth study of fundamental events that are normally obscured and therefore are difficult to study quantitatively on Earth. For instance, under microgravity scientists can carefully investigate the influence of Marangoni convection, a phenomenon that is masked by gravity, on crystal growth and heat transfer process. The microgravity environment also provides a unique platform to synthesize semiconductor or metal alloys with homogeneous composition distributions, on both macroscopic and microscopic scales, due to the much reduced buoyancy-driven convection. Moreover, the easy realization of detached solidification in microgravity suppresses the formation of defects such as dislocations and twins, and thereby the crystallographic perfection is greatly increased.

Motivated by these facts, the materials science program in the SJ-10 recoverable scientific experiment satellite mainly focuses on the following issues: (i) synthesizing large-size semiconductor crystals with uniform composition and low defect density, and high quality metal alloys or composites that cannot be obtained on ground; (ii) understanding how the gravity-driven phenomena affect the crystal growth, and elucidating the site occupation of doping atoms, revealing the liquid/solid interfacial structures, as well as clarifying the evolution of the metal alloy (or composite) microstructures during the solidification process. We hope our program not only provides new insights into the crystal growth mechanism but also guides the terrestrial crystal preparation process.

The materials science program in the SJ-10 recoverable satellite includes 8 experimental tasks, which is leaded by Prof. Zhang X W from the Institute of Semiconductors, CAS. These 8 experiments will be carried out successively in the same multifunction equipment, by which one can remarkably reduce the load mass of the satellite.

(1) Space synthesis and characterization of high performance thermoelectric semiconductors (by Prof. Zhou Y F, Shanghai Institute of Ceramics, CAS). The thermal/electrical properties of thermoelectric semiconductors have a close correlation with their compositions and microstructures. The ultimate goals are: (i) disclosing this correlation; (ii) clarifying the role of solute transport in the crystal growth process; and (iii) achieving the Bi_2Te_3-based materials with higher thermoelectric performance.

(2) Space growth of diluted magnetic semiconductors (by Prof. Chai C L and Yin Z G, Institute of Semiconductors, CAS). The world-wide research of diluted magnetic semiconductors has been stimulated by the urgent demands to control the magnetic order by means of electric field, or vice versa. This project aims at achieving a constant doping concentration, disclosing the location of doping atoms and revealing the link between the magnetic properties and the microstructures.

(3) Growth and properties of InAsSb under microgravity condition (by Prof. Zhang X W, Institute of Semiconductors, CAS). Ternary semiconductor InAsSb is one of the most possible candidates to replace TeCdHg for fabricating the long-wave infrared detectors. The objectives of this project are to synthesize InAsSb single crystals with large size and homogeneous composition distribution, and to investigate the relationship between the optical properties and the composition.

(4) Space growth, numerical simulation and characterization of InGaSb ternary photoelectric crystals (co-headed by Prof. Y. Inatomi from JAXA and Prof. Y. Liu from Shanghai Institute of Ceramics, CAS). InGaSb is ternary compound semiconductor in which the bandgap is adjustable in a rather large range by the concentration of Ga, and therefore is useful in various industrial applications. This project aims to prepare high quality, composition-uniform InGaSb alloys, and pave the way for their applications in photoelectric conversion devices.

(5) Space solidification and defect control of the superalloy single crystals (by Prof. Jin T, Institute of Metal Research, CAS). Al-Zn-Cu-Mg alloy is a useful

model system to investigate the effects of gravity on the solidification process and microstructures of superalloy single crystals. Prof. Jin planned this project to analyze the effects of gravity on the dendrite shape, element distribution and defect formation, as well as to reveal the underlying physical mechanisms.

(6) Interfacial phenomena during the melting of the tin-based alloys (by Prof. Yuan Z F, Peking University). Marangoni convection has strong impacts on the interfacial microstructures of metal alloys during the melting process in microgravity environment. This task focuses on revealing the influence of Marangoni flow on the microstructures of tin-based alloys, and developing a new model of tin whisker spontaneous growth.

(7) Synthesis of metal matrix composites by self-propagating reaction under microgravity environment (by Prof. Zhang T, Beihang University). Self-propagating High-temperature Synthesis (SHS) is a material preparation method started from finely powdered reactants that are intimately mixed. The main goals of this project are revealing the detailed SHS process in microgravity situation and analyze the underlying mechanism, and developing a model to describe the microstructure formation of particle-reinforced metal-matrix composites.

(8) Preparation and wettability properties of Al_2O_3/Ti-based composites in space (by Prof. Zhang H F and Li H, Institute of Metal Research, CAS). The major factors that control the properties of Al_2O_3 reinforced Ti matrix composites are the interface structure, Al_2O_3 particle size and distribution. This study focuses on disclosing the interfacial interaction between the melt and Al_2O_3, and establishing a theoretical model to guide the terrestrial preparation process.

5 Radiation Biology

5.1 B1-1

In the project, plant model materials will be located in three distinct radiation environments inside the satellite. By monitoring three tissue equivalent detector devices, the space radiation parameters such as absorbed dose, absorbed dose rate, linear energy transfer value and dose equivalent will be detected, meanwhile biological materials, irradiated by different kinds of particles that belong to the same satellite orbit, could be harvested.

After satellite recovering, by applying system biology analysis such as genome epigenetic scanning and proteomic approaches, it is planned to obtain information of biological changes under different radiation qualities and finding relevancies between biological effects and different radiation parameters through:

(i) analyzing the sequence information of genome methylation and transposons changes caused by space radiation, exploring the molecular mechanisms of space radiation induced genomic instability;

(ii) studying proteomics profiles of model organisms caused by different radiation qualities, mining molecular mechanisms of functional proteins, establishing biological systems that evaluate radiation qualities.

5.2 B1-2

Using the wild type and corresponding radiation sensitive mutant mammalian cells and fruit flies models created by the team, it is expected to study the quantitative effects of space radiation on genomic stability and to discover novel sensitive biological molecules as space radiation markers, which will be useful for developing sensitive detecting methods of the biological effects of space radiation in the future.

In previous work, it was found that simulated microgravity could delay the repair of DNA double strand breaks induced by radiation, and there was no significant difference in DNA damage between the simulated microgravity group and the 1 g group at Day 1 and Day 5 to the wild type mouse cells. In contrast, there were significantly more DNA damage in the radiation sensitive mouse cells under the simulated microgravity than 1g gravity on Day 1 but not on Day 5.

Through the space experiment , the roles of space radiation on genomic DNA and its genetic effects in the real space environment will be studied.

(1) Study on space radiation and genomic stability is to investigate the genomic stability of wild type and radiation sensitive mouse cells and fruit flies before and after spaceflight and at different time points during the spaceflight; then to obtain the quantitative parameters of space radiation of genome and its genetic effects in the real space environment.

(2) Study on gene expression profiles and the sensitive response genes to space radiation using the wild type and radiation sensitive mouse cells and fruit flies models mentioned above, is to obtain gene expression profiles of mouse cells and of fruit flies, and identify novel and sensitive biological molecules as space radiation markers.

This work will provide novel important information for developing evaluation methods for the risk factors and protection tools against space radiation.

5.3 B1-3

Silkworm is an important economic insect. It could produce more than 30 billion dollars income for silkworm breeders, commercial as well as industry. Because of its great importance, the development of new silkworm strains for multiple purposes is the target for all of the researchers.

As silkworm is a domesticated insect, it could be well bred in limited space with artificial diet. Moreover, its duration of the development of each stage, especially, the embryo state is well matched with the satellite flight period of SJ-10. Therefore, it is decided to send the silkworm embryo into space on this platform.

Silkworm has been brought to space environment in previous space programs. The mutations have been found through the land based observations. With the available techniques, such as genome sequence, microchips, it is necessary and possible to pursue the effects of space environment on silkworm development and discover the mechanisms of mutations. Considering the duration of SJ-10 satellite in the space (about two weeks), we select the embryo stage as the research target to purse the following content: (i) gene expression pattern of embryo at the space condition, (ii) proteome of silkworm embryo, (iii) mutation discovery and function analysis, (iv) embryo development and its characterization.

The novelty of this research is the systematic approach design for the embryo development under space condition and multiple sampling throughout the whole embryo development stage. Furthermore is the employment of multiple platforms, such as gene expression, proteomics, and functional genomics to find the development characters of silkworm under space environment. It is expected to find the possible mutation through molecular approaches.

6 Gravitational Biology

6.1 B2-1

The experiment focuses on the molecular mechanism of the interaction between plants and microgravity environment, try to understand the effects of microgravity (weight loss) environment in the space on plant growth, and the molecular mechanisms underlying.

The most important hypothesis of how plants feel the gravity on the ground is that the starch grains (statoliths) in special plant tissues sense the direction of gravity. This physical signal of statolith displacement is converted further into a chemical signal. Then through the signal transduction cascades and auxin asymmetric transmission to the reaction site of gravitropic response, spur the asymmetric growth. The experiment will explore whether plants feel the weight loss is also mediated by statoliths or by other mechanisms. Are there any differences in transduction cascades between weight loss and gravitropic signaling?

Space experiments showed that the bone and muscle in human and animal bodies are affected greatly in conditions of weightlessness. That means the tissue responsible for the support and movement of the body is significantly affected by microgravity. Space experiments also showed that plant lignin metabolism is influenced by microgravity. It is hypothesized that the rigidity of the supporting tissue, which is the cell wall in plant, is also influenced by microgravity. The shape of plant cell is maintained by the balance between the rigidity of the cell wall and the pressure exerted on the cell wall (turgor pressure). Vacuole biogenesis and enlargement requires transport of osmotically active substances across the tonoplast, followed by a rapid influx of water into the vacuole. This influx generates the turgor pressure that drives cell expansion and maintains the cell shape. Rapid cell expansion may require a high hydraulic permeability of the tonoplast to support water entry into the vacuol. To understand whether microgravity affects the rigidity of plant cell wall, which in turn affects the growth of plants, the flight experiments will be prepared to test the postulates about microgravity sensing and alteration of metabolism of plant cell wall by microgravity.

6.2 B2-2

How mammal cells sense microgravity is a fundamental issue in space life science. It is still unclear whether a single cell can sense gravity change, if the cellular sensation is direct or indirect, how the gravity signals are transmitted or transduced into cells, and what are the underlying mechanisms regulating cell-cell or cell-surface interactions under microgravity. Technically, mammal cell growth in space requires well controlled nutrient supply, mass transport and mechanical stimulation, as well as temperature and pH value, since the disappearance of buoyant convection and sedimentation in space remarkably alter the processes of nutrient supply and mass transport as compared to those in conventional laboratories on ground. Thus, space cell biology experiments ask for the specialized hardware to quantify the consistency between the two data sets on the basis of limited space missions.

(1) Issues and Aims

This project attempts to develop a novel space cell culture hardware mainly consisting of precisely controlled flow chamber and gas exchange system, and to investigate the mass transport mechanisms in cell growth and cell-cell interactions under microgravity. The primary goal is to distinguish the direct responses of cells from those indirect responses *via* the varied mass transport conditions induced by gravity changes. The specific aims are to collect the data on the metabolism, proliferation, apoptosis, differentiation and cytoskeleton of osteoblasts and mesenchymal stem cells under well defined mass transportation. These new techniques and data are expected to reveal the effects of gravity on cell-cell interactions, to elucidate the underlying mechanisms of cell growth and differentiation in space and to overcome the methodological bottlenecks of space cell biology research.

(2) Novelty

The novelty of this project lies in at least two aspects. (i) A new hardware of mammal cell culture is built with precisely controlled medium flow at different shear stress, which allows to isolate the effect of microgravity from the accessional impact of medium flow. (ii) Data are first obtained under well defined medium flow for major functions of typical mammal cells, which provides an insight into quantifying the direct cellular responses in space.

6.3 B2-3

Gravity and light represent two of the most important environmental signals that profoundly influence plant growth and development. On Earth, the photoperiod signal has been proved to be perceived in the leaf by induction of the *FT* gene expression and then be transported to the shoot apex, where floral initiation occurs, but how this macromolecular transportation from the leaf to the shoot apex is affected by gravity is not known. Using live imaging technique for studies of growth and development of Chinese cabbage in microgravity in a recoverable satellite (SJ-8) and 3D clinostat stimulate experiments, we have shown that the plant flowering was apparently delayed under microgravity, but we have no idea about the molecular basis of the microgravity response. Using the SJ-10 facility we could nicely extend pervious data on the molecular level to converge on microgravity regulated the transportation of flowering signals from leaf to shoot apex. To study the controlling of flowering in the spaceflight environment is of great interest not only because of fundamental questions regarding the role of gravity in plant development, but also because plants could provide food and atmosphere regeneration in a closed environmental life-support system.

On Earth, *Arabidopsis thaliana* is a long-day plant, while rice is a short-day plant, but the photoperiodic response of controlling mechanism in microgravity is not clear. Regulation of photoperiod controlling flowering in both *Arabidopsis thaliana* and rice by microgravity shall be addressed properly in this experiment. In transgenic Arabidopsis and rice plants (expressing *FT* or *Hd3a* with the reporter gene GFP or GUS), living fluorescence imaging technique will be further developed to determine the induction of *FT* and *Hd3a* gene expression and floral initiation in shoot apex under long-day and short-day photoperiod condition in microgravity or in 1g ground gravitational field.

7 Biotechnology

7.1 B3-1 and B3-2

Stem cells, which are undifferentiated cells that can differentiate into specialized cells and can produce more stem cells, have been considered as a key source of regenerative medicine. Hematopoietic stem cells and neural stem cells are important cell sources for treatment of various blood diseases and neural injury respectively. Today, the researches on hematopoietic stem cells and neural stem cell have made great progress. However, how to maintain the self-renewal state and the efficient differentiation of stem cells into specialized cells have not been fully understood yet. It has been shown that the microgravity environment might be suitable for the self-renewal and differentiation of stem cells. The present project will focus on the three-dimensional cell culture of hematopoietic stem cells and neural stem cells in space by SJ-10 recoverable satellite. We will establish the three-dimensional cell culture system of these two cell types to detect the effects of microgravity on the self-renewal/differentiation of them by the microscope detection, image transmission, and gene/protein molecular analysis on the returned samples, which will reveal the characteristics of growth and differentiation of three-dimensional cultured hematopoietic and neural stem cells experienced microgravity. Currently, there are no report about three-dimensional culture of hematopoietic stem cells and neural stem cells in space. The proposed studies will, for the first time, offer evidence for the characteristics of hematopoietic and neural stem cells based on the three-dimensional cell culture system under microgravity in space, which will be a forefront science exploration.

7.2 B3-3

Outer space represents a kind of special environment absolutely different from the Earth. Despite several biologic experiments such as effect of space travel on the physiology of living organisms have been performed in a space environment, the potential effect of weightlessness on the reproductive system in most species and particularly mammalian are still limited and controversial. So far, the experiment of human or animal reproduction, including fertilization and early embryo development, has not yet been studied clearly in a space environment. A preimplantation embryo is the initial of mammalian life. During the first 4 days of embryo-development in the mouse, a single-cell zygote undergoes a series of cleavage and morphogenetic changes to form blastocyst which will implant in uterus subsequently. Within 96 h, the mouse pre-implantation embryo fulfills the entire early stage development. This program hopes to detect the developmental status of mouse early embryos in space. The SJ-10 satellite mission will culture 2-cell or 4-cell stages of mouse embryos in specialized instrument for 96 h. A part of the samples will be captured by microscope to obtain the morphologies of various stages (4-cell, 8-cell, early morula, compacted morula, blastocyst and hatched blastocyst) of early embryos in space, and the others will be returned after chemical fixation to study the mechanism of how space environment affects mouse early embryo development. The aims of the program are: (i) to determine whether early mammalian embryo can develop in outer space or not; (ii) and if yes, to observe the development process during space flight by tele-transferring of the embryo photos from the satellite to the ground; (iii) to investigate the profiles of the early embryo development in space.

Human long-duration space flight on the International Space Station (ISS), colonization of the Moon, exploration of Mars and other new space missions will depend on the ability of plants, animals and humans to function and reproduce in the space environment. It is important to determine whether or not embryos can develop normally without gravitational cues, and to determine if any stages of early embryogenesis are adversely affected by weightlessness. This investigation will be critical in understanding the beginning of mammalian life, as well as the first step in understanding the entire process of reproduction in space.

7.3 B3-4

The main objective of this project is to examine the potential and molecular mechanism of osteogenic differentiation from human bone mesenchymal stem cells in space microgravity. For this objective, the following three research contents will be performed in SJ-10 mission.

(1) To develop a novel space experimental device for the osteogenic differentiation experiment of human bone mesenchymal stem cells in the space microgravity environment, and to generate a technical system for the osteogenic differentiation experiment of human bone mesenchymal stem cells in the space microgravity environment.

(2) To examine the osteogenic differentiation potential of human bone mesenchymal stem cells in the space microgravity environment, which will be marked by the positive ratio of alkaline phosphatase. It will identify the effects of space microgravity on osteogenic differentiation of human bone mesenchymal stem cells.

(3) To analyze the Ras/ERK/Runx2 cell signaling pathways and the protein expression and activation of PI3K relative to the osteogenic differentiation of human bone mesenchymal stem cells in the space microgravity environment. It will clarify the pivotal scientific problems of how the space microgravity affects the osteogenic differentiation of human bone mesenchymal stem cells through the key cell signaling pathways and the molecular mechanisms and role of key cell signaling molecules as PI3K in osteogenic differentiation of human bone mesenchymal stem cell in the space microgravity environment.

The new points of this experiment are as follows.

(1) A novel space experimental device is designed for the osteogenic differentiation experiment of human bone mesenchymal stem cells, which can be used for the automation experiment of cell differentiation in the space microgravity environment.

(2) A novel technical system for the osteogenic induction of human bone mesenchymal stem cells to osteoblasts in spaceborne environment will be set up in this project. This novel technical system includes the attached culture and the osteogenic induction of human bone mesenchymal stem cells in the space experimental

device, the fixing and lysis of induced cells, and the final preservation of cell samples in the low temperature.

(3) The studies for the effect of space microgravity on the osteogenic differentiation of human bone mesenchymal stem cells and the molecular mechanism relative to this effect will be a characteristic feature for this project.

8 Conclusions

The recoverable satellite is a very useful tool for space microgravity experiments. China's first recoverable satellite was launched in 1975 and 23 recoverable satellites have been launched and recovered successfully since then. The 24th recoverable satellite is designed specially for microgravity experiments of microgravity physics and space life science, and named as SJ-10 program. The satellite will be launched at the end of 2015 or a bit later.

The SJ-10 program was started in 2008 by CNSA for the phases of space experiments selection, engineering preparations of space techniques and scientific facilities designs. Unfortunately, the program was stopped before the starting of the engineering phase. The SJ-10 program has been re-started and re-organized by the Strategic Priority Research Program on Space Science of CAS since 2011, and now is in the engineering phase. The scientific theoretical and experimental researches on the ground related to the space experiments are now in progress. It is expected that the satellite will be launched on schedule, and many scientific results will be obtained.

Acknowledgement

This report is supported by the Strategic Priority Research Program on Space Science, the Chinese Academy of Sciences.

REFERENCES

[1] Hu W R. Microgravity experiments on board the Chinese recoverable satellite [J], *Microgravity Sci. Tech.*, 2008, **20**: 59

[2] Li C, Zhao H, Ni R. China's recoverable satellite and their on bard experiments [J]. *Microgravity Sci. Tech.*, 2008, **20**: 61

[3] Zhong X R, Lin L Y. GaAs single crystal growth in space[R]//Space Science in China. New York: Gordon & Breach, 1997: 333

[4] Hu W R, Long M, Kang Q, *et al*. Space experimental studies of microgravity fluid science in China [J]. *Chin. Sci. Bull.*, 2009, **54**: 4035