Microgravity Sci. Technol. (2014) 26:159–169
DOI 10.1007/s12217-014-9390-0

ORIGINAL ARTICLE

Space Program SJ-10 of Microgravity Research

W. R. Hu · J. F. Zhao · M. Long · X. W. Zhang · Q. S. Liu · M. Y. Hou · Q. Kang · Y. R. Wang · S. H. Xu · W. J. Kong · H. Zhang · S. F. Wang · Y. Q. Sun · H. Y. Hang · Y. P. Huang · W. M. Cai · Y. Zhao · J. W. Dai · H. Q. Zheng · E. K. Duan · J. F. Wang

Received: 27 May 2014 / Accepted: 29 August 2014 / Published online: 19 September 2014

Abstract SJ-10 program provides a mission of space microgravity experiments including both fields of microgravity science and space life science aboard the 24th recoverable satellite of China. Scientific purpose of the program is to promote the scientific research in the space microgravity environment by operating the satellite at lower earth orbit for 2 weeks. There are totally 27 experiments, including 17 ones in the field of microgravity science (microgravity fluid physics 6, microgravity combustion 3, and space materials science 8) and 10 in the field of space life science (radiation biology 3, gravitational biology 3, and space biotechnology 4). These experiments were selected from more than 200 applications. The satellite will be launched in the end of 2015 or a bit later. It is expected that many fruitful scientific results on microgravity science and space life science will be contributed by this program.

Keywords Microgravity science · Microgravity fluid physics · Microgravity combustion · Space materials science · Space life science · Radiation biology · Gravitational biology · Space biotechnology · SJ-10

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 (Hu 2008; Li et al. 2008), and such kind of satellites have been launched successfully 23 times in China (Li et al. 2008). Space

W. R. Hu (✉) · J. F. Zhao · M. Long · Q. S. Liu · Q. Kang · Y. R. Wang · S. H. Xu · S. F. Wang ·
Key Laboratory of Microgravity (National Microgravity Laboratory), Institute of Mechanics, Chinese Academy of Sciences (CAS), Beijing 100190, China
e-mail: wrhu@imech.ac.cn

X. W. Zhang
Institute of Semiconductor, CAS, Beijing 100083, China

H. Zhang
Tsinghua University, Beijing 100084 China

M. Y. Hou
Institute of Physics, CAS, Beijing 100190, China

W. J. Kong
Institute of Engineering Thermophysics, CAS, Beijing 100190, China

Y. Q. Sun
Dalian Maritime University, Dalian 116026, China

Y. Zhao · E. K. Duan
Institute of Zoology, CAS, Beijing 100101, China

H. Y. Hang
Institute of Biophysics, CAS, Beijing 100101, China

Y. P. Huang · W. M. Cai · H. Q. Zheng
Institute of Plant Physiology and Ecology, CAS, Shanghai 200032, China

J. F. Wang
Zhejiang University, Hangzhou 310058, China

J. W. Dai
Institute of Genetics and Developmental Biology, CAS, Beijing 100101, China

microgravity experiments in China have been completed mainly aboard the recoverable satellites since the late 1980's (Zhong and Lin 1997) and the spaceships Shenzhou since the late 1990's. The launch of the satellite SJ-8 was a turn point of transportation the mission purpose from earth observation mainly to microgravity experiments. The main scientific results of SJ-8 missions were published in a special issue of Microgravity Science and Technology (2008, vol. 20, no.2). The space experiments of microgravity fluid physics, including one in cooperation with the Russian scientists aboard the Mir space station, were summarized by Hu et al. (2009).

The program of SJ-10 satellite was organized by the Chinese National Space Administration (CNSA) in the middle of 2000's. 10 experiments of microgravity science 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 cooperation experiments in collaboration with the French Space Agency and one with the Europe Space Agency) was reviewed in the October of 2005. The engineering proposal of satellite platform was reviewed in May of 2006 by the 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 satellite from CNSA to the Chinese Academy of Sciences (CAS) in 2011. The re-started demonstration phase was completed in the end of 2012, and the engineering phase of program SJ-10 is started since the beginning of 2013. According to the schedule, the satellite is purposed to be launched in 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 satellites SJ-8 and SJ-10 have been followed in this approach to be arranged in the seven fields. In the program SJ-10, there are 6 experiments in the field of microgravity fluid physics, 3 in microgravity combustion, 8 in space material science, 3 in radiation biology, 3 in gravitational biology, and 4 in space biotechnology. 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 the high-technology by experiments of coal combustion, materials processing and biotechnology.

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

Microgravity Fluid Physics

A1-1: Space Experiment of Evaporation and Fluid Interfacial Effects (EFILE)

The EFILE experiment will be emphasized to study the thermocapillary effect at the liquid-gas phase changed interface on the evaporation in space environment. By injection of a liquid droplet on the heating subtract, two kinds of sessile drop evaporation processes are planned to investigate during the experimental runs: (i) a free evaporation of an injected drop while the drop shape and its contact angle along the triple line change or the 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.

The scientific objectives are to obtain the novel knowledge on the coupling mechanism of evaporation and convection in a system with phase-changed interface in microgravity environment, and to understand the gravity effects on the heat and mass transfers of evaporation (Brutin et al. 2010). The scientific problems include the coupling mechanism of phase-changed evaporation and thermocapillary convection, and the evaporation and Marangoni effects on the gas-liquid-solid contact dynamics of an evaporating

A1-2: Phase Separation and Dynamic Clustering in Granular Gas

In this experiment clustering conditions in single and connected double cells are studied and tested in microgravity for the first time. 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. In this

Table 1 List of microgravity science experiments

	Fields		Name of experiment	Institution	PI
1	A1. Microgravity Fluid physics	A1-1	Space experiment of evaporation and fluid interfacial effects (EFILE)	Inst. Mech., CAS	Q.S. Liu
2		A1-2	Phase separation and dynamic clustering in granular gas	Inst. Mech., CAS	M.Y. Hou
3		A1-3	Thermal dynamical behavior of vapor bubble during pool boiling (SOBER-SJ10)	Inst. Mech., CAS	J.F. Zhao
4		A1-4	Space experimental on surface wave of thermocapillary convection	Inst. Mech., CAS	Q. Kang
5		A1-5	Study on the colloidal assembling	Inst. Mech., CAS; Inst. Chem., CAS	Y.R. Wang
6	A2. Microgravity Combustion	A2-1	Study on ignition, soot emission and smoke distribution of wire insulations by overload	Inst. Eng. Thermophys., CAS	W.J. Kong
7		A2-2/3	Investigation of the coal combustion and pollutant formation characteristics under microgravity	Tsinghua Uni.; Huazhong Univ. Sci. & Tech.	H. Zhang; M.H. Xu
8		A2-4	Ignition and burning of solid materials in microgravity	Inst. Mech., CAS	S.F. Wang
9	A3. Space Materials Science	A3-1	Solidification and crystal growth in space: materials science	Inst. Semiconductor, CSA; etc	X.W. Zhang; et al
10	ESA Cooperation	A1-6	Soret coefficients of crude oil (SCCO)	ESA; Inst. Mech., CAS	A. Verga; Z.W. Sun

Table 2 List of space life science experiments

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

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 (Hou et al. 2008).

This clustering feature is also tested in a window-connected double cell for possible application of granular transportation in microgravity environment (Li et al. 2012). By using the so called Maxwell's demon effect in granular medium, we are to answer the question on how to transport grains in zero gravity. Transporting grains appears very simple on earth: a vibrating or rolling stripe will have the grains transported due to the friction in normal gravity (1g). But does this also happen in zero gravity? And how can one force the grains to go in the right direction in zero gravity? This is what planned to be answered via this experiment.

A1-3: Thermal Dynamical Behavior of Vapor Bubble During Pool Boiling (SOBER-SJ10)

The experiment SOBER-SJ10 (Single bubble pOol Boiling ExpeRiment aboard SJ10) is proposed to study local convection and heat transfer around an isolated growing vapor bubble during nucleate pool boiling on a flat plate heater, and is a further one of our previous researches of pool boiling on thin wire and flat in microgravity (Zhao et al. 2008; Zhao et al. 2009). An integrated heater has developed to trigger an embryo bubble, to provide an approximate constant input power, and to measure the local temperatures on the surface of heating wall underneath the growing bubble. Local superheating method is used to pinpoint the embryo bubble with both temporal and spatial precisions. The bubble grows on the top surface of a flat plate, which is resistance-heated on the bottom surface with an approximate constant input power. Data will be taken for power input to the heater, averaged temperature on the bottom surface, local temperature distribution on the top surface underneath the growing bubble, bulk liquid temperature and pressure in bulk liquid. Visual observations will provide quantitative data on processes of bubble inception, growth, merger, and departure.

The main objective is to develop a basic understanding of the local convection, vapor removal, and heat transfer processes that take place during nucleate boiling from a well characterized surface in microgravity (Straub 2001). The local processes include three-dimensional transient conduction inside the solid wall, micro-layer evaporation underneath the growing bubble, evolvement of local dry-out 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.

A1-4: Space Experimental on Surface Wave of Thermocapillary Convection

This experiment will present an inner heated cylindrical liquid pool to study the instabilities of thermocapillary flow patterns and transition pathways (Kamotani and Ostrach 2000) taking liquid volume effect into account at first time. A set of facility includes a cylindrical annuli liquid test system, liquid storage and filling liquid system, two sets of temperature controlling system and a set of temperature measurement system, a thermal infrared imager, a high-precision displacement sensor to surface oscillation system, and experiment controlling system.

The scientific purposes of this experiment are to study the effect of liquid volume on the critical conditions of instabilities, the oscillatory flow patterns, and transitions features in the cylindrical liquid pool (Tang and Hu 1994).

A1-5: Study on the Colloidal Assembling

The main research contents of this experiment includes the self-assembly of the colloidal spheres (with or without Ag shell) and the liquid crystal phase transition by using a scientific facility of colloidal material box (CMB). The CMB consists of injection management unit, optical observation unit, sample management unit, and electronic control module.

The scientific purposes of this experiment are to study the self-assembly dynamic of the colloidal sphere under microgravity (Dag et al. 1997) and the assembly mechanism of colloidal spheres with Ag nanoparticles coated, and to test the liquid crystal phase transition model, namely Onsager model, which is considered to be an entropy-driven process but difficult to be confirmed in Earth's gravity condition (Whitesides and Grzybowski 2002). The experimental results may be first time to deposit ordered colloidal crystal for studying the mechanism of the assembly under the Marangoni stress, and to verify firstly the mechanism of the pure entropy driven phase formation.

A1-6: Soret Coefficients of Crude Oil (SCCO)

Due to the fact that the temperature gradient causes convection on the ground (Galliéro and Montel 2008), the SCCO experiment (Géoris et al. 1999) was proposed by ESA to study the thermodiffusion and to measure the Soret coefficient under microgravity condition. Several experiments had been performed aboard the Russia recoverable satellite Foton M3 in 2007.

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. The mixtures proposed are directly relevant to the CO_2 geological storage and to the specific Chinese petroleum reservoirs. Academically, the SCCO experiment aboard 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.

Microgravity Combustion

A2-1: Study on Ignition, Soot Emission and Smoke Distribution of Wire Insulations by Overload

This experiment investigates the pre-ignition characteristics of wire insulation by overload in microgravity, 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 experiment will measure the temperature variations, soot emission, and the smoke distributions of the overloaded wire insulation. The study focuses on the pre-ignition characteristics by overload, the soot emission from the wire insulation during the pre-ignition and ignition stages, the smoke release and distribution characteristics of wire insulation combustion, and the theoretic model to predict the ignition and combustion characteristics of the wire insulation in microgravity.

Wire insulation can be ignited by either an external heat source or internal heating under overload conditions. Extensive researches have been conducted to investigate flame spread along wire surface caused by external ignition sources (Kong et al. 2008). However, 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 on the ground-based facility. Then it is significant to conduct the experiment in space microgravity environment.

A2-2 & A2-3: Investigation of the Coal Combustion and Pollutant Formation Characteristics under Microgravity

The scientific objectives are to discover the fundamental phenomena and control mechanisms in the entire combustion process of single particle and pulverized clouds of a few kinds of typical coals of China, to obtain ideal experimental data that is useful for the validation of theory and model for coal ignition and combustion, to better understand the buoyancy effect in coal combustion on the ground, and to improve the modelling and theory development for coal combustion and emission control on Earth (Zhu et al. 2009, 2011).

The experiment may optically observe the entire combustion process of single particle and pulverized clouds in a furnace, measure the flue gas composition after the burn of single particle or pulverized clouds, and compare the data in microgravity with those in normal gravity. This experiment will be in the first time to study the entire coal combustion process in an ideal buoyancy-free environment where surrounding mass and heat transfer is isotropic.

A2-4: Ignition and Burning of Solid Materials in Microgravity

The experiment will study the flame spread over thick fuels in microgravity. Most previous researches on microgravity flame spread have involved purely opposed or purely concurrent flow, in which ignition occurs at one end of the fuel sample and flame propagates toward another end (T'ien et al. 2001), although the combination of these two modes is practically important (Prasad et al. 2002). The research will focus on finding a limiting oxygen concentration or flow velocity, evaluating effects of flow velocity, oxygen percentage and material shape on flame spread modes, and improving the prediction model of solid material combustion.

The microgravity experiment consists of 8 fuel samples. In most 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 modes, 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.

Space Materials Science

The space microgravity environment provides a unique opportunity to further understand various materials phenomena (Chen et al. 2001; Zhou et al. 2010; Yoshizaki et al. 2014). The materials science experiments aboard SJ-10 mainly focus 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 from 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.

The materials science experiments aboard SJ-10 include the following 8 ones, which will be carried out in a multifunction furnace to reduce the load mass of satellite and save the energy in space.

(1) Space synthesis and characterization of high-performance thermoelectric semiconductors. The thermal/electrical properties of thermoelectric semiconductors have a close correlation with their compositions and microstructures. The ultimate goals of this experiment 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. The world-wide researches of diluted magnetic semiconductors have been stimulated by the urgent demands to control the magnetic order by means of electric field, or vice versa. This experiment aims at achieving a constant doping concentration, disclosing the location of doping Mn atoms, and revealing the link between the magnetic properties and the microstructures for GaMnSb.
(3) Growth and properties of InAsSb under microgravity condition. Ternary semiconductor InAsSb is one of the most possible candidates to replace TeCdHg for fabricating the long-wave infrared detectors. The objectives of this experiment 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. 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 for fabricating high-efficiency photoelectric conversion devices. This experiment 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. 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. We planned this experiment 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. Marangoni convection has strong impacts on the interfacial microstructures of metal alloys during the melting process in microgravity environment. This experiment focuses on discovering the effects of composition on the surface tension gradient in microgravity environment, 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. Self-propagating high-temperature synthesis (SHS) is a materials preparation method started from finely powdered reactants that are intimately mixed. The main goals of this experiment 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. 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.

Radiation Biology

B1-1: Molecular Biology Mechanism of Space Radiation Mutagenesis

In the experiment, plant model materials will be located at 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 we could harvest biological materials irradiated by different kinds of particles that belong to the same satellite orbit.

After satellite recovered, by applying system biology analysis such as genome epigenetic scanning and proteomic approaches, we are going to obtain information of biological changes under different radiation qualities and to find relevancies between biological effects and different radiation parameters. The main goals of this experiment are: (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; and (ii) studying proteomics profiles of model organisms caused by different radiation qualities, mining molecular mechanisms of functional proteins, and establishing biological systems that evaluate radiation qualities (Wang et al. 2008) .

B1-2: Roles of Space Radiation on Genomic DNA and its Genetic Effects

Using the wild type and corresponding radiation sensitive mutant mammalian cells and fruit flies models created by our team, we will study the quantitative effects of space radiation on genomic stability and 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 this experiment, we will study the roles of space radiation on genomic DNA and its genetic effects in the real space environment. The following two topics will be studied. (i) Space radiation and genomic stability. We will investigate the genomic stability of wild type and radiation sensitive mouse cells and fruit flies before and after space flight and at different time points during the spaceflight. Then we will obtain the quantitative parameters of space radiation of genome and its genetic effects in the real space environment. (ii) 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, we will 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 (Wang et al. 2011; Cui et al. 2010).

B1-3: Effects of Space Environment on Silkworm Embryo Development and Mechanism of Mutation

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

The novelty of this research is the systematic approaches of the embryo development design under the space condition and multiple sampling throughout the whole embryo development stage. Secondly, multiple platforms, such as gene expression, proteomics, and functional genomics, are employed to find the development character of silkworm under space environment. It is expected that we could find the possible mutation through molecular approaches (Miao et al. 2004).

Gravitational Biology

B2-1: Biological Effects and the Signal Transduction of Microgravity Stimulation in Plants

We focus on the molecular mechanism of the interaction between plants and microgravity environment, try to understand the effects of microgravity (weightless) 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, and then through the signal transduction cascades and auxin asymmetric transmission to the reaction site of gravitropic response, spurring the asymmetric growth. We will explore whether plants' feel of the weight loss is also mediated by statoliths or by other mechanisms, and whether there are any differences in transduction cascades between weight loss and gravitropic signaling.

Space experiments showed that plant lignin metabolism was influenced by microgravity. We 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. We try to understand whether microgravity affects the rigidity of plant cell wall, which in turn affects the growth of plants. We will prepare the flight experiments to test the postulates about microgravity sensing and alteration of metabolism of plant cell wall by microgravity (Hu et al. 2005; Cui et al. 2005).

B2-2: Biomechanics of Mass Transport of Cell Interactions under Microgravity

How mammal cells sense microgravity is a fundamental issue in space life science. It is still unclear whether a single cell sense gravity change, whether 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. This experiment 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.

This novelty of this experiment 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 (Sun et al. 2008; Long et al. 2011).

B2-3: Photoperiod-Controlling Flowering of Arabidopsis and Rice in Microgravity

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 aboard the Chinese recoverable satellite SJ-8 and 3D clinostat stimulate experiments on the ground, we have shown 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 our pervious data on the molecular level to converge to microgravity regulate 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 *Hd 3a* 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 normal gravity on the ground (Zheng and Staehelin 2011; Wei et al. 2010).

Space Biotechnology

B3-1 & B3-2: Three-Dimensional Cell Culture of Neural and Hematopoietic Stem Cells in Space

Stem cells, which are undifferentiated cells that can differentiate into specialized cells and can divide to 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 experiment will focus on the three-dimensional cell culture of hematopoietic stem cells and neural stem cells in space. We will establish the 3D 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 through the returned samples, which will reveal the characteristics of growth and differentiation of 3D cultured hematopoietic and neural stem cells under microgravity. Currently, there are no reports about 3D 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 3D cell culture system under microgravity in space, which will be a forefront science exploration (Cui et al. 2008; Chen et al. 2007).

B3-3: Development of Mouse Early Embryos in Space

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 experiments of human or animal reproduction, including fertilization and early embryo development, have not yet been studied clearly in a space environment. In this experiment we hope to detect the developmental status of mouse early embryos in space. We will culture 2-cell or 4-cell stage 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 space environment affecting mouse early embryo development.

The aims of the experiment are as follows (i) to determine whether early mammalian embryo can develop in outer space or not; (ii) if yes, to observe the development process during space flight by tele-transferring of the embryo photos from the satellite to the ground; and (iii) to investigate the profiles of the early embryo development in space. 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 (Zhou et al. 2006; Liu et al. 2007).

B3-4: Potential and Molecular Mechanism of Osteogenic Differentiation from Human Bone Mesenchymal Stem Cells

The main objective of this experiment 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: (i) 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; (ii) 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, and to identify the effects of space microgravity on osteogenic differentiation of human bone mesenchymal stem cells; and (iii) 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 how the space microgravity environment affects the osteogenic differentiation of human bone mesenchymal stem cells through the key cell signaling pathways and what are the molecular mechanisms and the roles of key cell signaling molecules such as PI3K in osteogenic differentiation of human bone mesenchymal stem cell in the space microgravity environment.

The new points of this experiment include: (i) a novel automation space experimental device for studying the osteogenic differentiation of human bone mesenchymal stem cells; (ii) a novel technical system including 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; and (iii) the studies of the effect of microgravity on the osteogenic differentiation of human bone mesenchymal stem cells and the molecular mechanism relative to this effect (Pan et al. 2008; Shi et al. 2010).

Conclusion

The recoverable satellite is a very useful tool for space microgravity experiments. The first Chinese 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 space microgravity experiments of microgravity science and space life science, which is determined as the program SJ-10. The satellite will be launched in end of 2015 or a bit later.

The SJ-10 program was started on 2008 by CNSA for the phases of selection space experiments, engineering preparations of space techniques and scientific facilities designs. Unfortunately, the program was paused before the starting of the engineering phase. The SJ-10 program is re-started and re-organized by the Strategic Priority Research Program on Space Science, 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 in the progress. It is expected that the satellite will be launched on schedule, and many fruitful scientific results on microgravity science and space life science will be contributed by this program.

Acknowledgments The program SJ-10 is supported by the Strategic Priority Research Program on Space Science, the Chinese Academy of Sciences under the grant of XDA04020000.

References

Brutin, D., Zhu, Z.Q., Rahli, Q., Xie, J.C., Liu, Q.S., Tadrist, L.: Evaporation of ethanol drops on a heated substrate under microgravity condition. Microgravity Sci. Tech. **22**, 387 (2010)

Chen, B., Lin, H., Wang, J., Zhao, Y., Wang, B., Zhao, W., Sun, W., Dai, J.: Homogeneous osteogenesis and bone regeneration by demineralized bone matrix loading with bone morphogenetic protein-2. Biomaterials **28**(6), 1027 (2007)

Chen, N.F., Zhong, X.R., Lin, L.Y., Zhang, M., Wang, Y.S., Bai, X.W., Zhao, J.: Comparison of field effect transistor characteristics between space-grown and earthgrown gallium arsenide single crystal substrates. Appl. Phys. Lett. **78**, 478 (2001)

Cui, D., Neill, S.J., Tang, Z., Cai, W.: Gibberellin-regulated XET is differentially induced by auxin in rice leaf sheath bases during gravitropic bending. J. Exp. Botany **56**, 1327 (2005)

Cui, M., Huang, Y.L., Zhao, Y., Zheng, J.L.: FoxO3a transcription factor mediates cell death in HIV-1 infected macrophages. J. Immunol. **180**(2), 898 (2008)

Cui, P., Lin, Q., Xin, C., Han, L., An, L., Wang, Y., Hu, Z., Ding, F., Zhang, L., Hu, S., Hang, H., Yu, J.: Hydroxyurea-induced global transcriptional suppression in mouse ES cells. Carcinogenesis **31**(9), 1661 (2010)

Dag, O., Ahari, H., Coombs, N., Jiang, T., Aroca Ouellette, P.P., Petrov, S., Sokolov, I., Verma, A., Vovk, G., Young, D., Ozin, G.A., Reber, C., Pelletier, Y., Bedard, R.L.: Does microgravity influence self-assembly. Adv. Mater. **9**(15), 1133 (1997)

Galliéro, G., Montel, F.: Nonisothermal gravitational segregation by molecular dynamics simulations. Phys. Rev. E **78**, 041203 (2008)

Géoris, Ph., Montel, F., Van Vaerenbergh, S., Decroly, Y., Legros, J.C.: Measurement of the Soret coefficient in crude oil. SPE, 50573 (1999)

Hou, M.Y., Tu, H.G., Liu, R., Li, Y.C., Lu, K.Q., Lai, P.Y., Chan, C.K.: Temperature oscillation in a compartmentalized bidisperse granular gas. Phys. Rev. Lett. **100**, 068001 (2008)

Hu, X.-Y., Neill, S., Tang, Z.-C., Cai, W.-M.: Nitric oxide mediates gravitropic bending in soybean roots. Plant Physiology **137**, 663 (2005)

Hu, W.R.: Microgravity experiments on board the Chinese recoverable satellite. Microgravity Sci. Tech. **20**, 59 (2008)

Hu, W.R., Long, M., Kang, Q., Xie, J.C., Hou, M.Y., Zhao, J.F., Duan, L., Wang, S.F.: Space experimental studies of microgravity fluid science in China. Chin. Sci. Bull. **54**, 4035 (2009)

Kamotani, Y., Ostrach, S.: Microgravity experiments and analysis of oscillatory flows in cylindrical containers. J. Fluid Mech. **410**, 211 (2000)

Kong, W.J., Wang, B.R., Zhang, W.K., Ai, Y.H., Lao, S.Q.: Study on prefire phenomena of wire insulation at microgravity. Microgravity Sci. Tech. **20**, 107 (2008)

Li, C., Zhao, H., Ni, R.: China's recoverable satellite and their on board experiments. Microgravity Sci. Tech. **20**, 61 (2008)

Li, Y.C., Liu, R., Hou, M.Y.: Gluing bifurcation and noise-induced hepping in the oscillatory phenomena of compartmentalized bidisperse granular gases. Phys. Rev. Lett. **109**, 198001 (2012)

Liu, W.M., Cao, Y.J., Li, J., Fan, X.J., Zhao, P., Duan, E.K.: The expression of CD9 in the peri-implantation mouse uterus is up-regulated in an ovarian steroid hormone-dependent manner. Fertility Sterility **87**(3), 664 (2007)

Long, M., Sato, M., Lim, C.T., Wu, J.H., Adachi, A., Inoue, Y.: Advances in experiments and modeling in micro- and nano-biomechanics a mini review. Cell. Mol. Bioengi. **4**(3), 327 (2011)

Miao, X.-X., Xu, S.-J., Li, M.-H., Li, M.-W., Huang, J.-H., Dai, F.-Y., Marino, S.W., Mills, D.R., Zheng, P.-Y., Mita, K., Jia, S.-H., Xu, A.-Y., Zhang, Y., Liu, W.-B., Xiang, H., Guo, Q.-H., Kong, X.-Y., Lin, H.-X., Shi, Y.-Z., Yasukochi, Y., Sugasaki, T., Shimada, T., Nagaraju, J., Xiang, Z.-H., Wang, S.-Y., Goldsmith, M.R., Lu, C., Zhao, G.-P., Huang, Y.-P.: An informative simple sequence repeat-based consensus linkage map of the silkworm genome, vol. 102, p. 16303 (2004)

Pan, Z., Yang, J., Guo, C., Shi, D., Shen, D., Zheng, Q., Chen, R., Xu, Y., Xi, Y., Wang, J.F.: Effects of hindlimb unloading on ex vivo growth and osteogenic/adipogenic potentials of bone marrow-derived mesenchymal stem cells in rats, vol. 17, p. 795 (2008)

Prasad, K., Nakamura, Y., Olson, S.L., Fujita, O., Nishizawa, K., Ito, K., Kashiwagi, T.: Effect of wind velocity on flame spread in microgravity. Proc. Combustion Inst. **29**, 2553 (2002)

Shi, D.Y., Peng, S., Wang, J.F.: Effects of microgravity modeled by large gradient high magnetic field on the osteogenic initiation of human mesenchymal stem cells. Stem Cell Rev. Rep. **6**, 567 (2010)

Straub, J.: Boiling heat transfer and bubble dynamics in microgravity. Adv. Heat Transfer **35**, 57 (2001)

Sun, S.J., Gao, Y.X., Shu, N.J., Tao, Z.L., Long, M.: A novel counter sheet-flow sandwich cell culture system to unravel cellular responses in space. Microgravity Sci. Tech. **20**(2), 115 (2008)

Tang, Z.M., Hu, W.R.: Influence of liquid bridge volume on the onset of oscillation in floating zone convection. II. Numerical simulation. J. Crystal Growth **207**, 239 (1994)

T'ien, J.S., Shih, H.Y., Jiang, C.B., Ross, H.D., Miller, J., Fernandez-Pello, A.C., Torero, J.L., Walther, D. In: Ross, H.D. (ed.): Mechanisms of flame spread and smolder wave propagation. In: Microgravity Combustion: Fire in Free Fall, p. 299. Academic Press, San Diego (2001)

Wang, Y., An, L., Jiang, Y., Hang, H.: Effects of simulated microgravity on embryonic stem cells. PLoS One **6**(12), e29214 (2011)

Wang, W., Gu, D.P., Zheng, Q., Sun, Y.Q.: Leaf proteomic analysis of three rice heritable mutants after seed space flight. Adv. Space Res. **42**, 1066 (2008)

Wei, N., Tan, C., Qi, B., Zhang, Y., Xu, G., Zheng, H.Q.: Changes in gravitational forces induce the modification of Arabidopsis thaliana silique pedicel positioning. J. Exp. Bot. **61**, 3874 (2010)

Yoshizaki, I., Shimaoka, T., Sone, T., Tomobe, T.: Recent crystal growth experiments onboard the ISS KIBO. Trans. JSASS, Aerosp. Tech. Jpn. **12**(ists29), Th_1 (2014)

Zhao, J.F., Liu, G., Wan, S.X., Yan, N.: Bubble dynamics in nucleate pool boiling on thin wire. Microgravity Sci. Tech. **20**, 81 (2008)

Zhao, J.F., Li, J., Yan, N., Wang, S.F.: Bubble behavior and heat transfer in quasi-steady pool boiling in microgravity. Microgravity Sci. Tech. **21**(S1), S175 (2009)

Zheng, H.Q., Staehelin, L.A.: Protein storage vacuoles are transformed into lytic vacuoles in root meristematic cells of germinating seedlings by multiple, cell type-specific mechanisms. Plant Physiol. **155**(4), 2023 (2011)

Whitesides, G.M., Grzybowski, B.: Self-assembly at all scales. Science **295**, 2418 (2002)

Zhong, X.R., Lin, L.Y.: GaAs single crystal growth in space. In: Space Science in China, p. 333. Gordon & Breach, New York (1997)
Zhou, J., Jia, L., Liu, W., Miao, C., Liu, S., Cao, Y., Duan, E.: Role of sonic hedgehog in maintaining a pool of proliferating stem cells in the human fetal epidermis. Human **21**(7), 1698 (2006)
Zhou, Y.F., Li, X.Y., Bai, S.Q., Chen, L.D.: Comparison of space-and ground-grown $Bi_2Se_{0.21}Te_{2.79}$ thermoelectric crystals. J. Crystal Growth **312**, 775 (2010)
Zhu, M., Zhang, H., Tang, G., Liu, Q., Lu, J., Yue, G., Wang, S., Wan, S.: Ignition of single coal particle in a hot furnace under normal- and micro-gravity condition. Proc. Combustion Inst. **32**(2), 2029 (2009)
Zhu, M., Zhang, H., Zhang, Z., Zhang, D.: A numerical modeling study of ignition of single coal particles under microgravity conditions. Combustion Sci. Tech. **183**(11), 1221 (2011)