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Science Research of Microgravity Satellite SJ-10

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Abstract The program SJ-10, one of the scientific satellite programs in the Strategic Priority Research Program on Space Science, the Chinese Academy of Sciences, was launched on April 6, 2016. There are totally 19 scientific payloads, a multi-function furnace for 8 material researches and three-dimensional cell cultures for the neural stem cell and the hematopoietic stem cell respectively. The recoverable satellite consists mainly of two capsules: a recoverable capsule was recovered on 18 April 2016, with all payloads of life science, the multi-function furnace and the payload for measurement of Soret Coefficients of Crude Oil (SCCO); and an un-recoverable capsule continued to work in additional 3 days with all other physics payloads. The experiments were operated *via* teleoperations, and all experimental data were received by the ground station in real time. The data and recoverable samples are analyzed by the experiment teams of the program.

Key words Microgravity science, Space life science, Scientific payloads, Space experiments, SJ-10

Classified index V 527, V 4

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, and such kind of satellites have been launched successfully 23 times in China[1,2]. Space microgravity experiments in China have been completed mainly aboard the recoverable satellites since the late 1980's[3] and the spaceships Shenzhou since the late 1990's. The launch of the satellite SJ-8 was a turning point of mission purposes 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[1].

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 in the early of 2005. The mission proposal of space experiments 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 named as SJ-10. Unfortunately, the demonstrative phase was stopped after one year due to the reform of CNSA and re-started when the Chinese Academy of Sciences (CAS) began to manage a scientific satellite program in 2011. The re-started demonstration phase was completed in the end of 2012, and the engineering phase of program SJ-10 was started at the beginning of 2013. Then, the satellite was launched on 6 April 2016. In the SJ-10 program, there are 6 experiments in the field of microgravity fluid physics, 3 in microgravity combustion, 8 in space materials science, 3 in radiation biology, 3 in gravitational biology, and 4 in space biotechnology[4−6]. Main scientific purposes of these experiments may be summarized as follows[7].

(1) To promote the basic research of fluid physics and biology experiments.

(2) To support the manned space flight for fire safety research.

(3) To improve the human health though biotechnology studies.

(4) To develop the high-technology by experi-

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ments of coal combustion, materials processing, and biotechnology.

2 Microgravity Scientific Research on Board SJ-10

There are 10 microgravity scientific payloads on board SJ-10. The research progress of space scientific experiments are described as follows.

A1-2: Granular Energy Dissipation in Freely Cooling and in Steadily Driven System

Clustering is a key ingredient for the formation of planetesimals and larger objects in solar systems. Quantitative experiments are very much needed for better understanding of the fundamental features of such ensembles. In SJ-10 satellite, clustering in steadily driven, freely cooling, and in connected-double-cell granular gases are systematically studied. In the microgravity experiment we observed for the first time the Granular Maxwell's Demon in microgravity, we investigated the Haff's energy dissipation law in dilute freely cooling granular systems as well. The phase diagram of clustering in steadily driven granular gases is also quantitatively verified. Figure 1 shows the snapshots at the initial and final stages of a typical segregation process driven by mechanical vibrations. Figure 2 shows Average speeds of vertical direction and horizontal direction decay with time during freely cooling.

A1-3: Thermal Dynamical Behavior of Vapor Bubble during Pool Boiling

SOBER-SJ10 is proposed to study local convection and heat transfer around an isolated growing vapor bubble during nucleate pool boiling on a wellcharacterized flat surface in microgravity, as well as heat transfer performance of normal pool boiling in different gravity conditions. After the launch of the satellite SJ-10 on 6 April 2016, the flight experiments of SOBER-SJ10 were conducted successfully on April 10, 19 and 23, respectively. It is found that single phase heat transfer results in normal and microgravity agree well with the common-used empirical correlations. Nucleate pool boiling curves at different subcooling conditions in normal and microgravity are obtained. It is found that nucleate boiling heat flux and CHF of pool boiling in microgravity is lower than those in normal gravity. The data exhibit, however, an approximate trend in normal and microgravity at the same subcooling condition. At lower superheating, heat transfer efficiency is enhanced with the increasing subcooling, while at high superheating larger than 20 K, the curves at different subcooling conditions tend to merge together as a single one, which means that heat transfer coefficients are not affected by the subcooling at high superheating condition. Film boiling curves at different subcooling in microgravity indicate that the heat transfer efficiency of film pool boiling increases with the increasing sub-

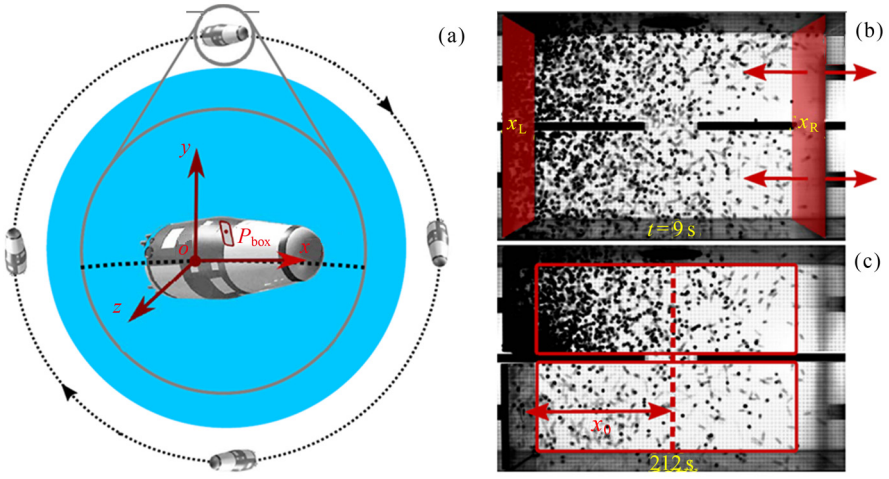

Fig. 1 (a) Sketch of the SJ-10 recoverable satellite in orbit (short-dashed line) with a Cartesian coordinate defined in the satellite system. O corresponds to the center of mass (CM) of the satellite. x and y point to the tangential and normal direction of the orbit. (b) (c) correspond to the snapshots at the initial and final stages of a typical segregation process driven by mechanical vibrations of the right wall located at x_R, respectively. x_0 corresponds to the distance from the left wall to the center of the window

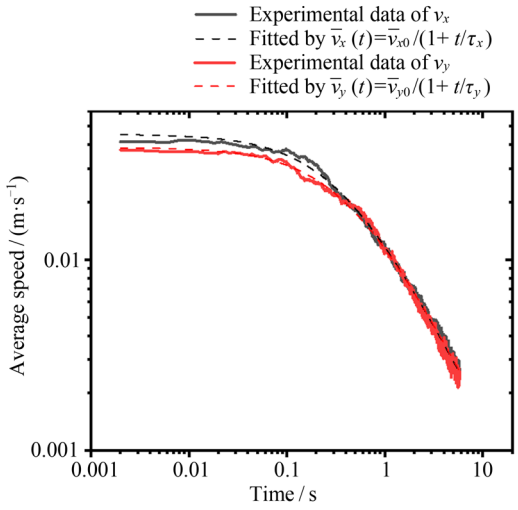

Fig. 2 Average speeds of vertical (x, black curves) direction and horizontal (y, red curves) direction decay with time during freely cooling. The dashed lines are fittings by Haff's law

cooling at lower superheating and/or heat flux. At higher superheating and/or heat flux, the curves tend to merge together, which implies that the influence of subcooling to the film boiling heat transfer efficiency is decreasing. Space experiments of single bubble pool boiling mode with the activation of the bubble trigger were also realized. The spatio-temporal evolutions of transient temperature on the heated surface are reconstructed based on the measurement. The variations of bubble radius are also obtained by image analyses of the recorded video images from the two CCDs. These results provide a good database for further understanding on nucleate pool boiling phenomenon, particularly on partial nucleate pool boiling at low heat flux.

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

Thermocapillary convection has always been one of the most important research topics in microgravity fluid physics. We carried out a microgravity experiment for studying thermocapillary convection in an annular liquid pool on SJ-10 recoverable satellite in space. Thermocapillary convection models of different volume ratios (the ratio of real liquid volume to the one of plat free surface $V_r = V/V_0$) with different curved interfaces are established. Thermocouples with high sensitivity are used to measure the temperature at six points in the fluid, and an infrared thermal imager is used to capture temperature distribution on the fluid surface in real time at a rate of 7.5 frame·s^{-1}. Totally 23 groups of space experiments are completed. The important problems about thermocapillary convection are discussed in depth by analyzing the space experimental data. The critical condition of thermocapillary convection obtained in space experiments are more than ten degrees lower than that in buoyant-thermocapillary convection obtained in ground experiments, the oscillation frequency in space experiments is less than that in ground experiments in one order of magnitude. The thermocapillary convection generally stays in the periodic oscillation state, the transition appears only in the condition when the temperature difference between two sides of the liquid layer is very large. Three types of transition routes have been observed, including quasi-periodic, period-doubling and intermittency. The transition of temperature oscillations corresponds to the transition of w hydrothermal waves, the developing process of thermocapillary convection can be divided into four stages: steady-standing wave-traveling wave-coupling of standing and traveling waves. The present space experiment demonstrates that these physical phenomena are affected by the volume ratio, and the volume effect is an important problem to be studied.

A1-5: Colloidal Ordered Assembly and New Materials Research

The colloidal self-assembly driven by micro-flow is an un-equilibrium process. The thermal motion of the colloidal particles in the colloidal system is suppressed due to the directional micro-flow which often lead to the macroscopic ordered structure. In microgravity, buoyancy convection was severely suppressed, and there is no hydrostatic pressure, no sedimentation, which provided favorable conditions for in-situ observation of the colloidal self-assembly. "Colloidal ordered assembly and new materials research" is one of the 19 science projects which had been carried out on the SJ-10 satellite. It was the first time to deposit ordered colloidal crystal and study the un-equilibrium self-assembly mechanism in space. We performed microgravity experiments of drop manipulation on the SJ-10 satellite and successfully conducted drop manipulation experiments in space. The drop was captured by a patterned substrate, which was composed of a circular super-hydrophilic matrix surrounded by a super-hydrophobic coating. Through the test of injection, separation and oscillation of a colloidal drop, it was shown that this patterned substrate had excellent ability to capturing aqueous dro-

ps in space. The experiments indicate the confined drop could be considered as a spherical and ellipsoidal cap model in microgravity and normal gravity, respectively, and the substrate could confine aqueous drops with larger volume under microgravity than in normal gravity. With advantages of simple operation, a strong capacity to capturing large drops in space, this technique shows promising prospects in fluid management, bio-sensing, and pharmacy in microgravity conditions in the future.

We report a network pattern inside the ring-like stains that form in the final evaporation stage of colloidal droplets. The previous works might have created an impression that the final pattern morphologies are entirely determined by various microflows inside the droplet. However, in the last stage of evaporation, the pinned droplet will evolve into a thin liquid film, which spontaneously undergoes dewetting and promotes particles inside the coffee ring redistribution to form the resulting patterns. Experimental results show that the evolution of a dry patch could be divided into three stages: rupture initiation, dry patch expansion, and drying of the residual liquid. A growing number of dry patches will repeat these stages to form the network patterns inside the ring-like stain.

Our study expanded the cognition of the "coffee-ring effect".

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

The thermodiffusion of multicomponent nalkane mixtures at a pressure above 30 mPa was investigated by experiments in space onboard SJ-10 satellite. Measurements have shown that the lightest and heaviest species had a tendency to migrate to the hot and cold region, respectively. Quantitatively, the experimental thermal diffusion ratios for the quaternary mixture are of the same order of magnitude as those obtained experimentally in binary mixtures and are also consistent with simulation results by molecular dynamics. Therefore, the comparison with experimental and simulation data confirms their overall reliability. Molecular simulations have also shown that the pressure has only a weak influence on thermal diffusion ratios in quaternary and ternary mixtures, which is consistent with existing experimental results in binary mixtures.

Furthermore, the measured data have been used to quantify the influence of thermodiffusion on the initial fluid distribution of an idealized one-dimensional reservoir. It is shown that thermodiffusion tends to counteract the influence of gravitational segregation. A more striking result is the influence of thermal diffusion on density distribution in the reservoir. It is easy to understand that density increases with depth in the gravity-only case. However, when thermodiffusion is included, the density gradient is reversed, which could result in an unstable fluid column. These results confirm that, in oil and gas reservoirs, thermodiffusion data for multicomponent mixtures are crucial for a correct evaluation of the initial state fluid distribution.

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

Under microgravity, the investigation intends to reveal the characteristics on ignition, combustion and pollutant formation for the single particles and particle clouds of typical Chinese coals in an ideal isotopic environment; to obtain the fundamental data and to develop better coal combustion models for normal-gravity coal combustion.

The investigation finished 8 cases of experiments on single coal particle combustion and 10 cases of experiments on coal cloud combustion and measured ignition temperature, ignition delay time, volatile combustion time, char burnt out time and emission *etc.*

For the first time, the investigated accomplished the engineering setup of the coal combustion box for the satellite, and established the methodologies for coal combustion experiments in space; obtained full process images and relevant data of multiple experimental cases on the single coal and pulverized coal cloud combustion. Space experiments revealed that coal ignition often starts from volatile jets ejected from pores of coal particles, instead of the uniform combustible gases around the particles, a phenomenon which is difficult to discover under normal gravity.

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

The space experiments examine the ignition and burning characteristics of thermally-thick solids in varying low-velocity flow and varying ambient oxygen concentration. There are two categories of samples, which are flat and rod respectively. Steady spread, extinction, and dynamic transition behaviors are revealed for flames spreading over a flat PMMA in step changed opposing flows. It is found that, as the flow velocity reduces, an extended flame may break into separate flamelets after a dynamic transition process. This is the first observation of flamelets for thick solids in microgravity. Both flame and flamelet pro-

pagate with a steady spread rate that increases with increasing flow velocity and oxygen concentration. A flammability map for thick PMMA is established, which delineates the uniform flame regime, flamelet regime, and extinguished regime. The flammability boundary is extended to lower oxygen concentrations and lower flow velocities by the flamelet regime. Furthermore, the microgravity results are compared with the counterparts in Narrow Channel Apparatus (NCA) experiments conducted in normal gravity. Although the NCA tests overestimate the flame spread rate and flammable area, microgravity flame and flamelet behaviors for a thick solid are essentially reproduced in these ground-based tests. For a cylindrical PMMA, the flame spread is observed in microgravity at an opposed-flow velocity less than $12\,\mathrm{cm{\cdot}s^{-1}}$, and complementary experiments are performed at higher opposed flow in normal gravity. The effects of flow velocity on flame spread are demonstrated for the entire flow velocity range. Particularly, in low-velocity flow range, the flame spread rate is found to increase when the flow velocity increases, while previous experiments at normal gravity have shown that the spread rate remains practically constant in slowly forced air flows. The present results of flame spread and extinction enable us to improve theoretical models of solid burning, and also provide direction for the fire safety of spacecraft.

A3: Melt Solidifications and Crystal Growths on SJ-10

(1) The wetting behaviors of Sn-based alloys on Cu substrates were studied on the SJ-10 scientific platform and we found that the spreading process has a close correlation with interfacial reactions. Moreover, we modeled and analyzed the contact angle and its evolution by extracting the shape and dimension of the molten drop.

(2) Bi_2Te_3-based thermoelectric alloy was grown under microgravity by the zone melting method. Our studies show that due to the suppression of gravity-driven convections, the space-grown crystal has a more uniform composition distribution than the ground-based sample. Moreover, the crystal quality of the space sample is also better than that of the ground sample.

(3) InAsSb crystal growth was carried out by using the Bridgman method. Detached growth was clearly observed during the $InAs_xSb_{1-x}$ growth under microgravity. By contrast, detached growth is absent for the $InAs_xSb_{1-x}$ crystals prepared at the same experimental condition and facility on the ground. The lack of contact between the crystal and the crucible wall has great implications to reduce the dislocation densities.

(4) The vertical gradient freezing method was used to grow InGaSb crystal on SJ-10. It is found that the space crystal has a uniform composition both along the axial and radial directions. The analyses reveal that composition inhomogeneity is less than 1% within the whole growth region of InGaSb crystal.

3 Life Science Research on Board SJ-10

There are 9 life science payloads on Board SJ-10. The research progress of space scientific experiments is described as follows.

B1-1: Molecular Biology Mechanism of Space Radiation Mutagenesis

The project investigates system biological changes under different radiation qualities and to find relevancies between biological effects and different radiation parameters. The study was designed and implemented by putting the space radiation detectors and model organisms (*O.sativa* seeds, *Arabidopsis* seeds and *C.elegans*) into three bio-radiation boxes inside the SJ-10 satellite.

The space bio-effects experiment was successfully conducted on board the SJ-10 satellite. The space radiation quantities and LET spectra were precisely measured with CR-39 nuclear track detectors and thermoluminescent dosimeters, results presented nuclear tracks and bio-samples-hitting distributions of GCR heavy ions. According to the number of GCR heavy ions hitting on the seeds of *O.sativa*, the total of 576 seeds in the biostacks was divided into nine groups, about 9.9% of rice seeds were not hit by heavy ions. About 18.2% of the seeds were hit once, 23.1% of the seeds were hit twice, and about 48.8% of the seeds were hit no less than three times. There were seven rice seeds, each of which is hit by eight heavy ions. The results were published as "Radiation Measured for Chinese Satellite SJ-10 Space Mission" in *Journal of Geophysical Research*: *Space Physics* in 2018.

So far, the biological results of *O.sativa* plants indicated that radiation hormesis occurred after spaceflight. The influence of the phenotypic traits induced by spaceflight is persistent and related to the growth stage of *O.sativa*: the stimulation effect at the three-leaf stage, the coexistence of the stimulation and inhi-

bition effects from the four-leaf stage to the heading stage and the growth inhibition effects at a mature stage. The results of *C.elegans* showed that spaceflight improved the survival rates and prolonged the lifecycle of the nematodes. By comparing the muscle movement through lifecycle and expression levels of proteins especially participate in regulating muscle contract pathway between wild-type and gravity-sensing defect *C.elegans* (dys-1 mutation), results revealed that dystrophy is an important protein that responds to microgravity stress and probably acts by affecting Ca^{2+} transduction and binding pathways.

The further in-depth studies will focus on the system biology approaches, which will be used to mine the biomarker sensitive to the space radiation and the key factors or main mechanisms of the biological effects induced by space radiation.

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

Because of the development of spacecraft and life-support technologies, people can be sent farther in space and stay in space longer. The characteristics of the space environment include the space radiation, microgravity, temperature extremes, high vacuum, space debris and ionospheric plasma *etc.* Among them, the two major challenges associated closely with astronauts are the biological effects of space radiation and microgravity. DNA, the genetic material, is an important biologic molecule. The maintenance of the stability of genomic DNA safeguards many cellular events, which prevents diverse human diseases. DNA can accumulate numerous lesions which are the underlying hallmark of cancer, aging, and many other diseases. It is well known that many environmental factors can affect the integrity of DNA molecules. Thus, it is important to investigate the effects of space environment on the maintenance of genomic stability.

In this work, we investigated "Roles of space radiation on genomic DNA and its genetic effects" on board the microgravity satellite SJ-10. Using the wild-type and corresponding radiation sensitive mutant mammalian cells and fruit flies models developed by our team, we studied the effects of space radiation on genomic stability and to discover novel sensitive biological molecules as space radiation markers, which might be useful to use as sensitive markers of the biological effects of space radiation in the future.

B1-3 Embryonic Development and Mechanisms of Mutation under Space Environment

The domesticated silkworm, Bombyx mori, is a lepidopteran model insect with economic importance. The silkworm is originated from China and has been cultivated for thousands of years as the major contributor to sericulture. During the long-term domestication, the silkworm has acquired many unique characteristics such as short life cycle, high fecundity, moderate sizes which are suitable for rearing in a limited area such as space environment. We participated in the project of SJ-10 recoverable satellite which carried silkworm embryos as one of 19 scientific experiments in 2016. Silkworm embryos have been recovered from space successfully and preliminary experiments have been done to investigate the influence of space environment on silkworm embryonic and post-embryonic development. Using the embryos carried by SJ-10 satellite, we investigated the difference of embryos between space environment and ground control groups at genomic, transcriptional and translational levels. Furthermore, using the genetic manipulation technologies such as transposon-based transgenesis and the CRISPR/Cas 9 system, we will perform functional analysis on selected key genes to exploit their functions in silkworm embryonic and post-embryonic development. These studies will not only contribute to modern sericulture but also explore how the space environment affects silkworm embryonic development and provides fundamental knowledge and experimental approaches for future space life science.

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

The spaceflight experiment on board the Chinese recoverable satellite SJ-10 demonstrated that plant cell wall and seedling growth of *arabidopsis thaliana* were influenced under microgravity. We also carried out epigenetic studies associated with microgravity conditions and found the variation of DNA modification in Arabidopsis seedlings exposed to microgravity. These results are important to understand the mechanism of plant adaptation to the microgravity environment.

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

Cell growth and differentiation associated with controllable mass transportation under microgravity is an experiment on SJ-10 recoverable satellite.

This study attempts to develop a novel Space Cell Culture System (SCCS), mainly consisting of the precisely controlled flow chamber and gas exchange unit, to investigate the responses of endothelial cells and Mesenchymal Stem Cells (MSCs) as-

sociated with mass transportation under microgravity. The primary goal is to isolate the direct responses of the 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 cytoskeletal remodeling of endothelial cells and mesenchymal stem cells under well-defined mass transportation in space. Comparative analyses of the data between space sample (12-day mission in SJ-10 satellite in April 2016) and ground-based control indicate that flow-induced mass transport patterns could alter cellular metabolism. Under microgravity, the endothelial cells and MSCs respond differentially in initiating cytoskeletal remodeling, dysregulating signaling pathways relevant to cell adhesion, or directing hepatic differentiation. These results provide an insight in understanding the mechanosensing and mechanotransduction of mammalian cells under space microgravity.

B2-3: Spatiotemporal Control of Flowering Gene Expression Using a Heat-shock-activated Gene Switch under Microgravity Onboard SJ-10 Recoverable Satellite

The reproductive success of plants is often dependent on their flowering time being adapted to the territorial environment, in which gravity remains constant. Whether plants can follow the same rule to determine their flowering time under microgravity in space is unknown. Flowering time in *Arabidopsis* is controlled by the day-length specific expression of FLOWERINGLOCUS (FT) gene in leaves. In the present experiment, we developed transgenic Arabidopsis containing the heat shock (HSP 17.4)-inducible gene promoter to the green fluorescent protein (GFP) reporter gene (HSPpro::GFP) and the FT gene (HSPpro::FT), respectively, to assess whether function of FT in regulating flowering time was similar to that on the terrestrial condition. The expression of HSPpro::GFP and HSPpro::FT in Arabidopsis leaves at 37°C under short-day conditions, were monitor by a plant GFP imager. In the same time, time-lapse images also documented the effect of microgravity on the flowering induction of Arabidopsis and rice plants under a long-day (16 h light::8 h dark) and a short-day (8 h light::16 h dark) conditions, respectively. 37°C heating for 30 min induced strong expression of GFP and FT in the leaves of Arabidopsis plants in microgravity but flowering time apparently delayed. For the first time, the importance of gravity in the expression of FT gene and its induction flowering in microgravity was unequivocally demonstrated. The network of transcriptional regulation of flowering gene expression is also analyzed.

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

Hematopoietic stem cells and neural stem cells are important cell sources for treatment of various blood diseases and neural injury, respectively. The present experiments have focused on the three-dimensional (3D) cell culture of hematopoietic stem cells and neural stem cells in space. We have established the 3D cell culture system for these two cell types to detect the effects of microgravity on the self-renewal/differentiation of them by the detection of microscope, image transmission, and gene/protein analysis through the returned samples, which will reveal the characteristics of growth and differentiation of 3D cultured hematopoietic and neural stem cells under microgravity. In this research, stem cells were alive during the whole fight, and the images of proliferating stem cells were transmitted from the satellite to the ground. Through analysis of the returned cell samples, we found that the proliferation of both hematopoietic stem cells and neural stem cells were held on under microgravity. As to differentiation, the differentiation of neural stem cells was promoted, however, differentiation of hematopoietic stem cells into macrophages was inhibited.

Before us, there were no reports about 3D culture of hematopoietic stem cells and neural stem cells in space. These studies of stem cell in space have, for the first time, offered evidence for the characteristics of hematopoietic and neural stem cells based on the 3D cell culture system under microgravity in space.

B3-3: Development of Mammalian Preimplantation Embryo in Microgravity

Does gravity affect the reproductive system and normal embryonic development? In the past three decades, numerous experiments on reproductive in space environment have been performed using birds, fish, amphibian and sea urchin. However, unlike the other taxa studied to date, the potential effects of weightlessness on the mammalian development are still unclear. Thus, investigating the possibility of successful development of mammalian embryos in microgravity is a fascinating program. In 2016, China launched satellite SJ-10, which carried thousands of mouse embryos in a space embryonic culture incubator for culturing in space. Scientists successfully received high-resolution pictures of embryos developing

in space. The results crucial from experiments aboard China's SJ-10 recoverable satellite prove for the first time that 2-cell mouse embryos could develop into an advanced blastocyst in space. Besides, the development rates of blastocyst of returned embryos has been analyzed and compare it with those of ground cultured embryos. Importantly, the returned blastocysts have been analyzed by single-cell DNA genome sequencing and single cell methylation sequencing to evaluate the quality of embryos developed in space and a potential mechanisms that affect the development of mammal preimplantation embryos in space. In brief, this finding 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 and understanding the early embryo development process in space will provide an insight into human reproduction in space in the future.

B3-4: Studies of the Effect and Molecular Mechanism of Space Microgravity on Osteogenic Differentiation of Human Bone Mesenchymal Stem Cells

This research is focused on the effect and molecular mechanism of space microgravity on osteogenic differentiation of human bone mesenchymal stem cells (hMSCs). Wang *et al.* in Zhejiang University are responsible for scientific research, and Jiang *et al.* in National Space Science Center of Chinese Academy of Sciences are responsible for preparation of the automated device for a space experiment. Three innovation points have been achieved in this project. Firstly, the osteogenic differentiation system of hMSCs in the space environment has been developed. Various requirements for space experiment have been achieved through the attached culture and induction experiments in the culture units of the automated space experiment device. Secondly, the device prototype for differentiation experiment in space environment has also been prepared. Finally, we find the effect of space microgravity on trans-differentiation from osteogenesis to adipogenesis of hMSCs. The results from the space experiment show that space microgravity inhibits osteogenic differentiation, and results in adipogenic differentiation, even under osteogenic induction conditions. Under space microgravity, the expression of 10 genes specific for osteogenesis decreases, whereas the expression of 4 genes specific for adipogenesis increases. In the analysis of signaling pathways specific for osteogenesis, we have found that the expression and activity of Runx2 are inhibited, expression of bone morphogenetic protein-2 (BMP2) and activity of Smad 1/5/9 are decreased, and activity of focal adhesion kinase (FAK) and extracellular signal-regulated kinase (ERK)-1/2 declines significantly under space microgravity. In addition, we have found that space microgravity increases p38 mitogen-activated protein kinase (MAPK) and protein kinase B (AKT) activities, which are important for the promotion of adipogenic differentiation of hMSCs. Space microgravity significantly decreases the expression of Tribbles homolog 3 (TRIB3), a repressor of adipogenic differentiation. Y15, a specific inhibitor of FAK activity, is used to inhibit the activity of FAK under normal gravity; Y15 decreases protein expression of TRIB3. Therefore, it appears that space microgravity decreases FAK activity and thereby reduces TRIB3 expression and depresses AKT activity.

4 Conclusion

The recoverable satellite is a useful infrastructure for microgravity science and space life science. The SJ-10 program provides a chance of space microgravity experiments including both fields of microgravity science and space life science. It is designed to promote the scientific research in the space microgravity environment by operating the satellite at lower earth orbit for 2 weeks. Scientific purposes of these experiments are achieved 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; and to develop the high-technology by experiments.

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