Updates on the Capabilities of the MSSF Facility at NASA Kennedy Space Center

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[2] NASA NPP Program
[3] NASA John F. Kennedy Space Center

Microgravity Simulation Support Facility (MSSF)

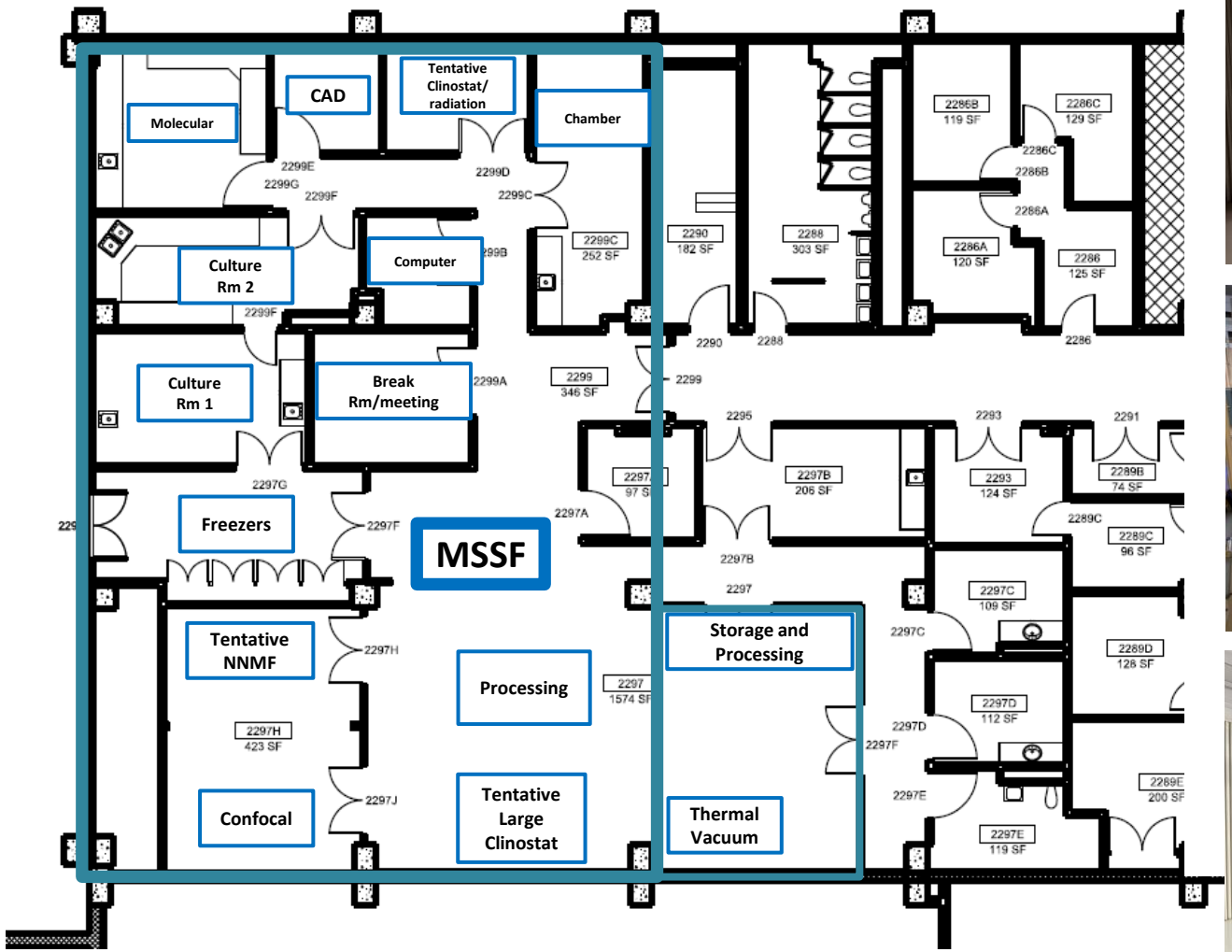
- Funded by BPS, the Microgravity Simulation Support Facility (MSSF) was established in 2017 and opened to the Space Biology community in 2018 to provide the science community an array of two-dimensional (2D) and three-dimensional (3D) clinostats, and Random Positioning Machine (RPM) platforms to conduct ground-based microgravity research.

- The capabilities cover a wide range of research using biological systems from plants, microorganisms, mammalian cells, to small animals. Engineering support and in-house 3D printer capabilities can develop customized science modules for the microgravity simulators based on the unique science requirements of each project.

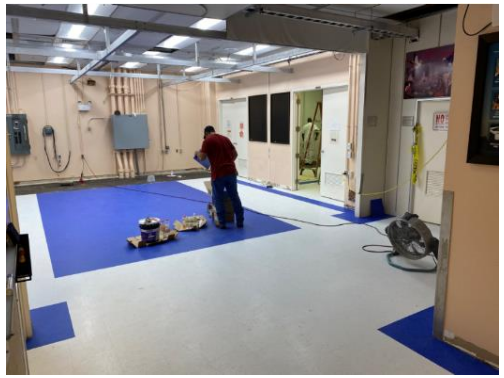
- In this presentation, we will share:
  - Status of facility modifications
  - Current capabilities
  - Projects supported in the MSSF and achievements
  - Development plans, including new hardware additions, and lessons learned from past and current ground-based microgravity simulation research in the MSSF

Microgravity Simulation Support Facility (MSSF)

MSSF Renovation Complete

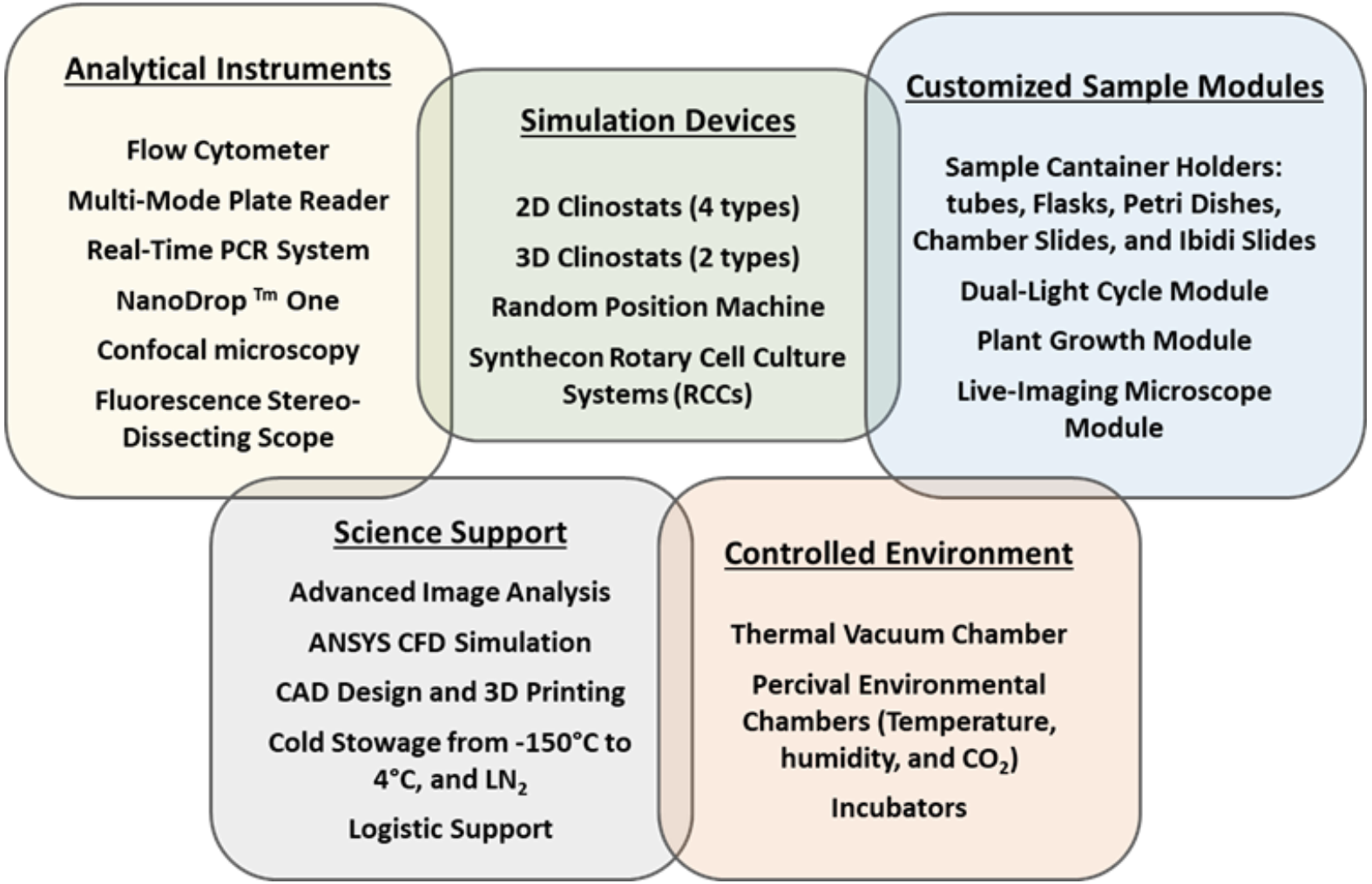






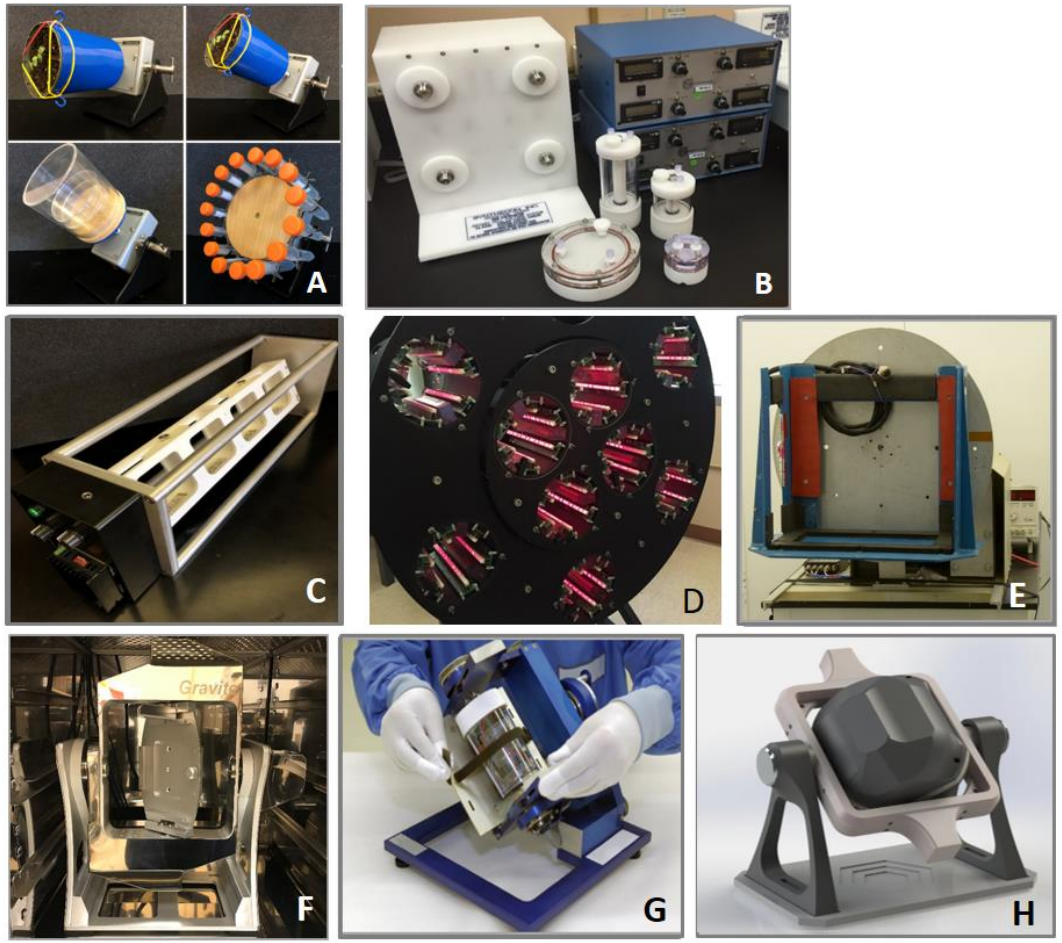


Critical Supporting Capabilities

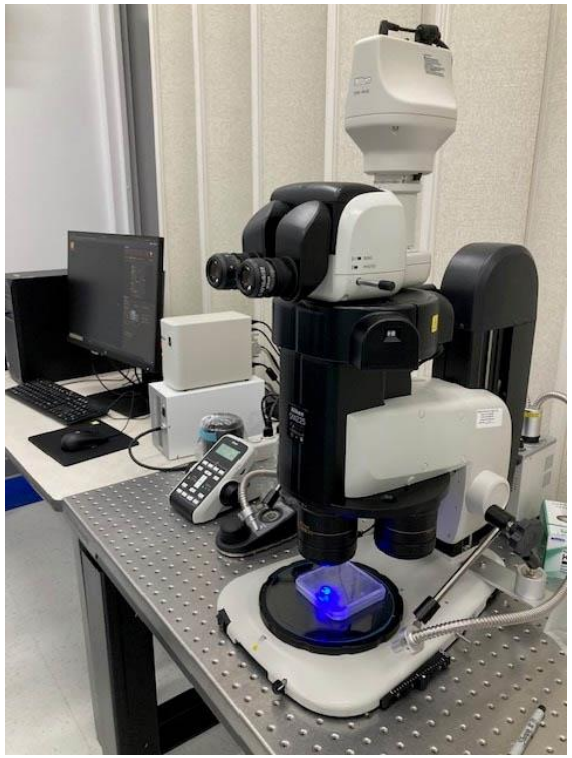


Microgravity Simulation Devices Currently Available

- 2-Dimensional (2D) Clinostats (A, n=6)
- Rotating Wall Vessel Clinostats (Rotating Bioreactors; B, n=4)
- KSC 2D Clinostat with LED (C, n=2)
- Large 4’ Diameter 2D Clinostat with Light Emitting Diodes (LED) (D, n=1)
- KSC Heavy Load 2D Clinostat with middeck locker payload (E, n=1)
- Gravite 3-Dimensional (3D) Clinostat (F, n=2)
- Random Positioning Machine (G, n=4)
- SciSpinner 3D Clinostat (H, n=6)
- Cell SpinPod Roller (I, n=1)



State-of-the-Art Imaging Capabilities



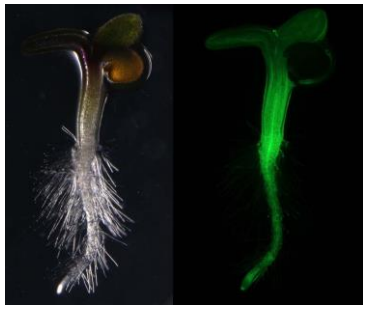
Nikon SMZ25 stereofluorescence microscope



Nikon A1R point scanning confocal microscope



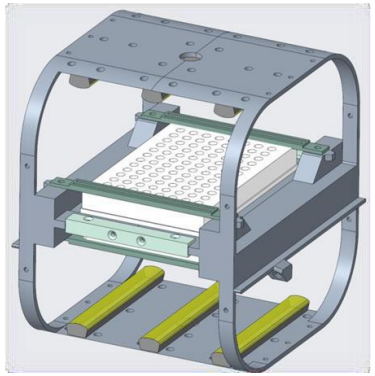
Echo revolution wide-field fluorescence microscope



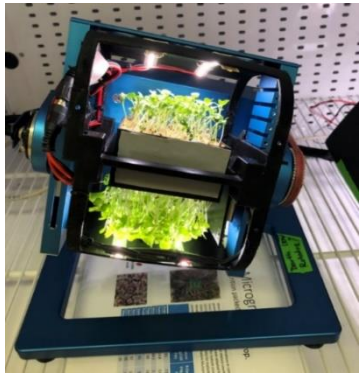
Arabidopsis thaliana **seedlings expressing a green fluorescence protein (GFP)-based biosensor for calcium under the Nikon SMZ25**

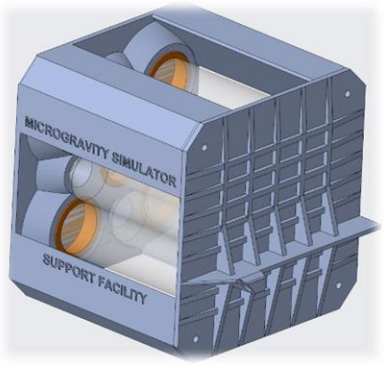
Customized Science Carrier Modules

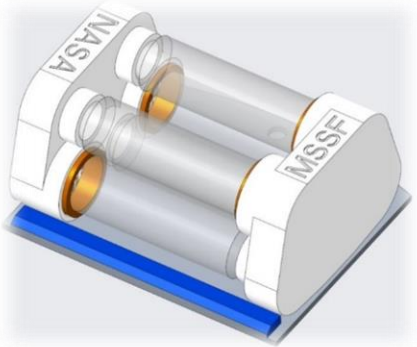
- Plant chambers with horticultural LED lights covering full-spectrum PAR (400 nm to 700 nm) for plant research in 10 cm x 10 cm petri dishes.
- HARV holder accommodating two 50 ml HARV vessels, eight 10 mL HARV vessels, or a combination.
- 35mm petri dish holder with adjustable intensity white LED light supply.
- Plant growth chamber.
- 50 ml test tube holders for RPM, Gravite, and RCC systems.

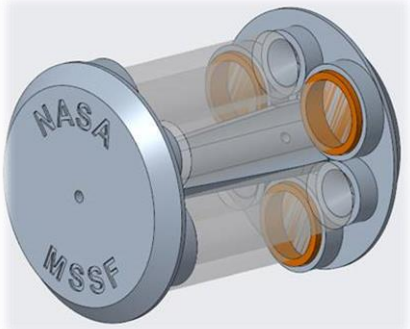


Plant Growth Chamber

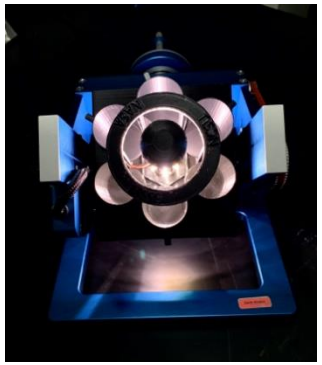








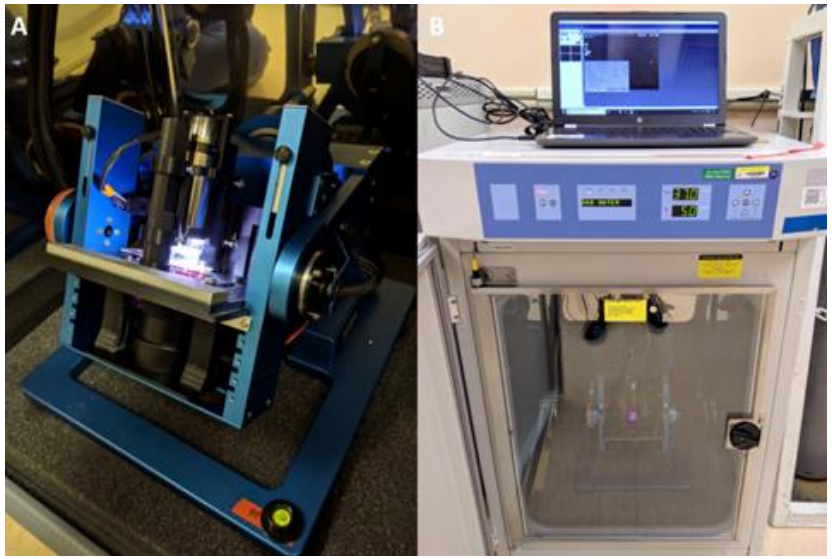
50 ml Tube Holders

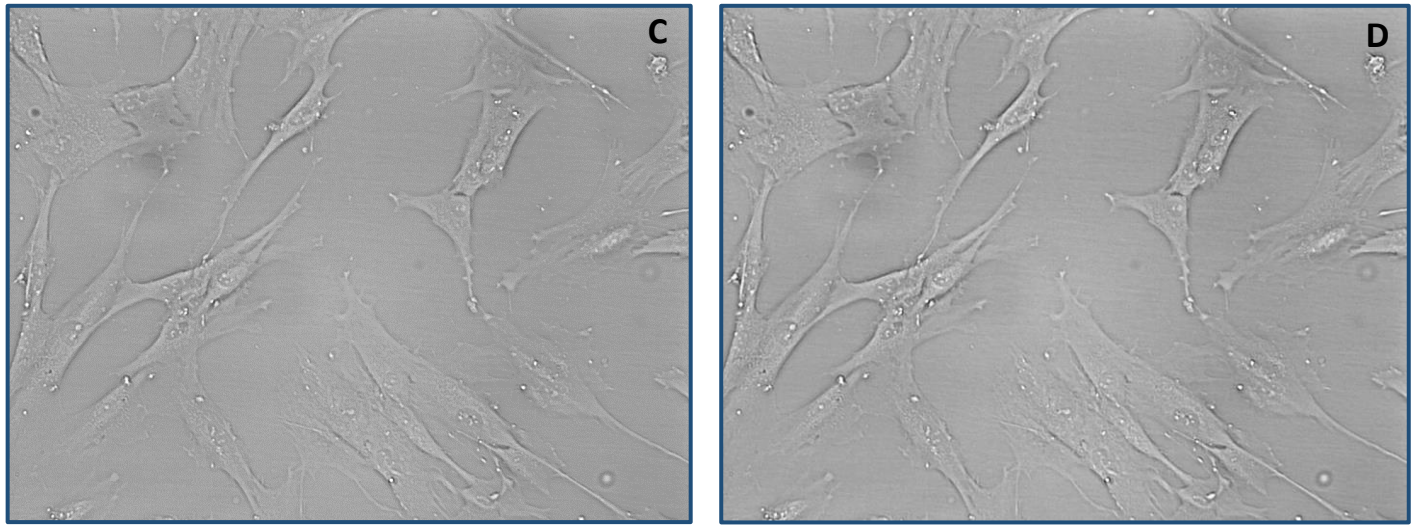


Time-Lapse Sample Removal Module

Customized Science Carrier Modules

RPM – Live cell microscopic imaging module (N=2)



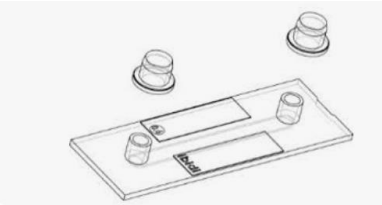


A and B. Live cell imager experimental setting; C. Raw time-lapse video; D. Time-lapse video after correction.

Sample Carrier: Chamber slide, Nunc™ Lab-Tek™ Flask on Slide, or ibidi µ-Slide.
Magnification: 750X – 900X
Imaging Capability: Up to 5.0 MP vivid color resolution (2592x1944), live video (30fps), or time-lapse video.
Single Imaging Mode: Bright-field, dark-field, or fluorescence.
Other Capabilities: Wi-fi adaptor and real-time image transfer.

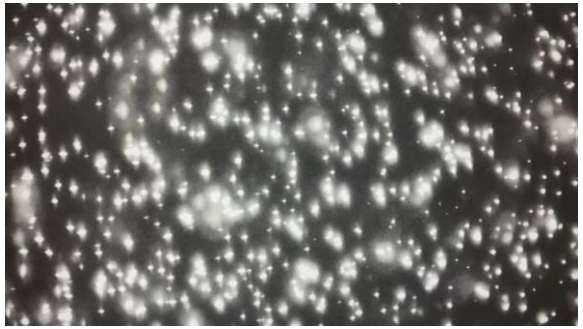
Customized Science Carrier Modules

Particle Tracking: Validation of particle behavior under simulated conditions

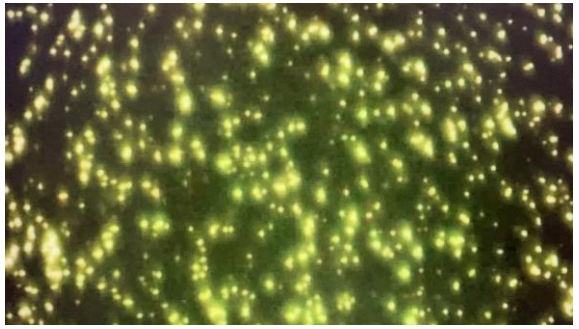


Ibidi Slide (200 µL sample)

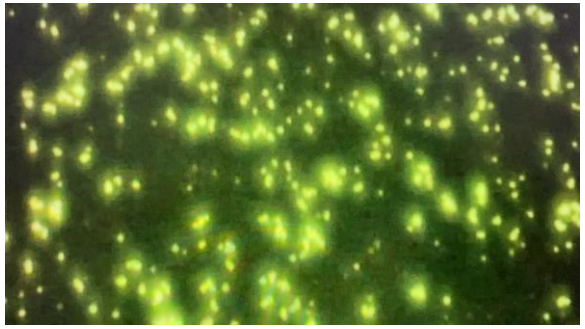
2-5 µm fluorescent beads



Simulated 0 g

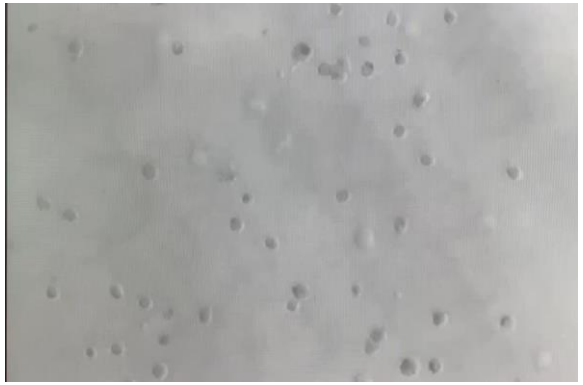


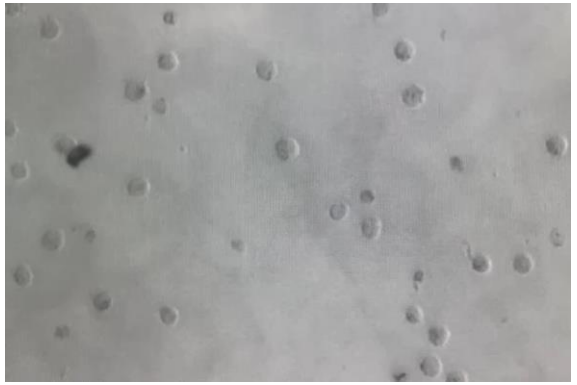
Simulated Moon g

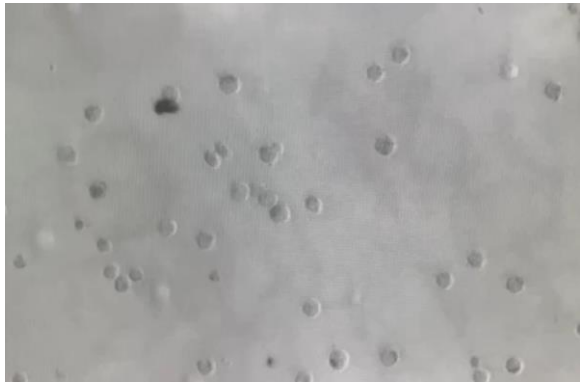


Simulated Mars g

TK6 lymphoblastoid cells





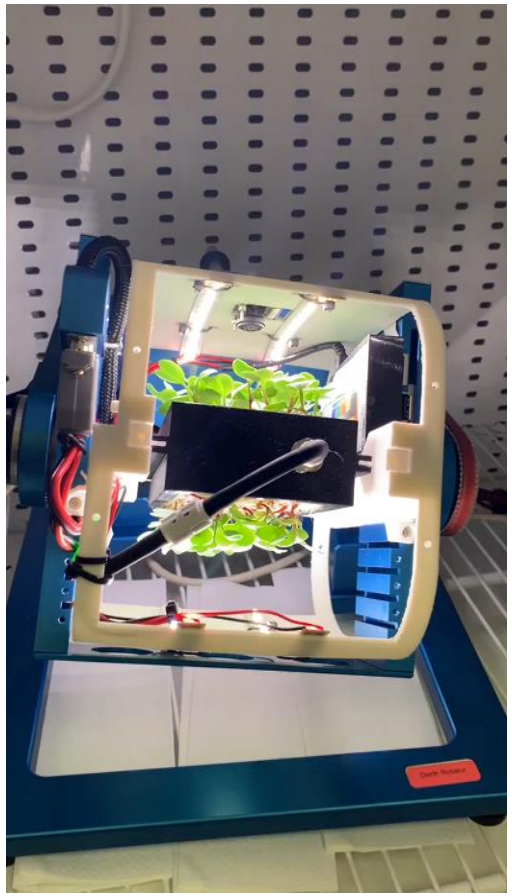


Examples of Plant Experiment and Microbial Experiment

Plant growth chamber designed for microgreen study and other plant research







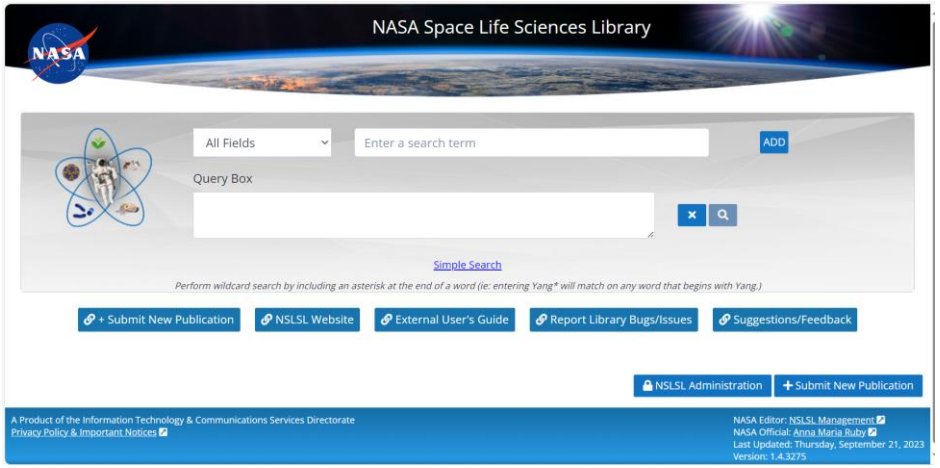
Microbial experiment for cross-device comparison



New Capability Development

NASA Space Life Sciences Library:





- The NASA Space Life Science Library (NSLSL) is developed to provide easy access to references and publications relevant to space life sciences research.
- The public-facing library is accessible to everyone. Users can submit new, relevant publications to be included in the library.
- The database includes NASA and non-NASA funded research, peer-reviewed articles, dissertations, white papers, and technical publications. Currently the NSLSL holds 250K+ entries.
- The Library website provides links to other NASA and space research resources and databases.

Website: https://public.ksc.nasa.gov/nslsl/
Library Site: https://extapps.ksc.nasa.gov/NSLSL/Search

New Capability Development

Thermal Vacuum Chamber dedicated to space life sciences research to support ground testing of stratosphere, LEO and potentially deep space related research projects.



Thermal:

- Maximum Temperature: -60°C to +60°C
- Ramp Rate: -40°C to +60°C to -40°C in 90-minute cycle

Vacuum:

- Maximum vacuum pressure of <1.0 X 10^{-6} Torr
- Capability to monitor and control vacuum to set points
- Enhanced water vapor removal capability

Operations:

- Capable of operating reliably for 6-month durations with minimum operator oversight
- Usable volume above the platen maximum of 20”L X 20”W X 20”H
- Support a maximum 75 lb static load

Activities (2018-2023) and Publications

Space Biology Funded Ground-based and Flight Studies:

Ground-based Studies:

1. Universal Time and Space, Determining the Interactions between the Circadian Clock and Microgravity (PI: Dr. Colleen Doherty)
2. Probing the Effect of Simulated Microgravity on the Pathogenic Potential of Cariogenic Streptococcus mutants (PI: Dr. Kelly Rice)
3. The Use of Microgravity Simulators for a Mechanistic Understanding of Cytoskeletal-mediated Regulation of Root Growth Directionality (PIs: Drs. Elison Blancaflor/Simon Gilroy)
4. Effects of Modeled Microgravity on the Induction of Bacteria-induced Apoptosis during Animal Development (PI: Dr. Jamie Foster)
5. Extending the Reach of the GeneLab Data System Across Kingdoms (PI: Dr. Simon Gilroy)
6. Quorum Sensing and S. aureus Virulence Potential during Simulated Microgravity Growth (PI: Dr. Kelly Rice)
7. Characterization of ISS microorganisms that assist in the decomposition of complex organic matter during spaceflight (PI: Dr. Clay Wang)
8. Are Rel and SigH Required for Survival and Biofilm Formation of LSMMG Grown *Mycobacterium marinum*? (PI: Dr. Lynn Harrison)
9. LINC dependent effect of microgravity on nuclear shaping and gene expression in breast epithelial cells (PI: Dr. Srujana Neelam, NPP)
10. Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity (PI: Dr. Christina M. Johnson, NPP)
11. Modeling Plant Growth and Gas Exchanges in Various Ventilation and Gravity Levels (PI: Dr. Lucie Poulet, NPP)
12. GRAVRAD: Ground-based RNA Analysis under Variable Radiation and Differential Gravity (PI: Dr. Alexander Meyers, NPP)

ISS and Other Flight Projects:

1. Impact of spaceflight on beneficial animal-microbe interactions (ISS, PI: Dr. Jamie Foster)
2. Assessing the impact of Agr quorum sensing on Staphylococcus aureus physiology in the space flight environment (ISS, PI: Dr. Kelly Rice)
3. Microgravity Can Down-Regulate Host Resistance and thus May Up-Regulate Plant Disease Development in Space (ISS, PI: Dr. Andrew Schuerger)
4. Role of Mesenchymal Stem Cells in Microgravity Induced Bone Loss (ISS, PI: Dr. Abba Zubair)
5. Spaceflight Alters Post-Transcriptional Regulation (ISS, PI: Dr. Sarah Wyatt)
6. Effect of altered gravity on the nucleus (Parabolic Flight, PI: Dr. Srujana Neelam)
7. Harnessing Extremophilic Black Yeasts to Understand the Adaptive Strategies of Eukaryotes to Mars-like Conditions (Antarctic Balloon, PI: Dr. Zheng Wang)
8. MISSE-SEED (ISS)
9. PONDS Demonstrations (ISS)
10. RAD-SEED (X-37B)

Space Act Agreements: 4 Agreements with the University of Zurich, University of Florida, Florida Institute of Technology, and Mayo Clinic. Two more Agreements are in development

Publications: 14 peer-reviewed publications, 1 book chapter, and 1 technical publication

Future Strategic Development Plan

- For missions beyond Low Earth Orbit (LEO), life will experience the absence of Earth's protective magnetic field, increased space radiation, micro to reduced gravity, and enclosed environments with significant space and resource constraints.

- Because opportunities for conducting deep space biological science are rare, ground studies using microgravity simulation devices at micro g and partial g levels in combination with ionizing radiation exposures relevant to deep space radiation, as well as other risk factors, are promising analog approaches for continuing research beyond LEO.

- Future development will focus on:
  - Enhance microgravity simulation, validation, and data interpretation.
  - Expand current capabilities to support alternative flight platforms, such as parabolic flight, suborbital flight, Antarctica balloon flight, and commercial LEO platforms.
  - Develop strategies to simulate the deep space multi-stressor environment to enable beyond LEO science.

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