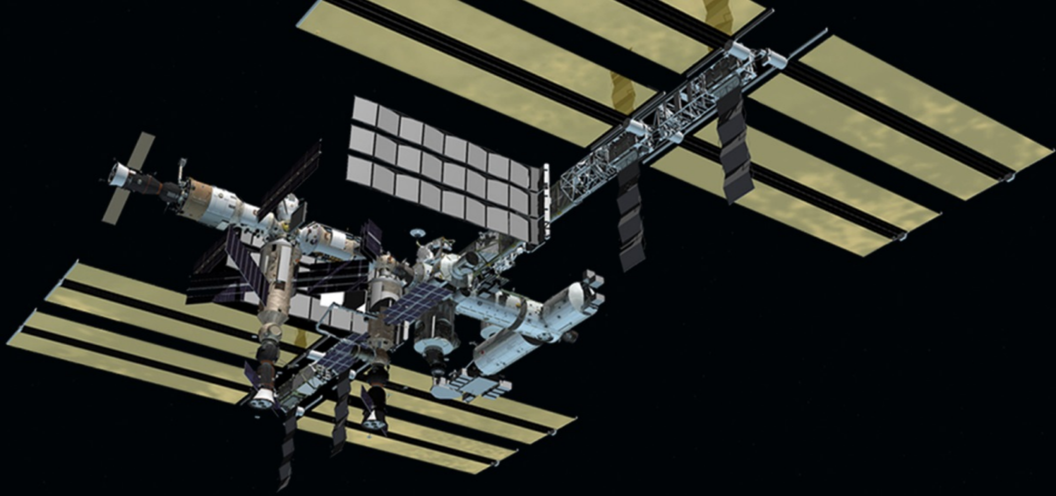
Space Biology

Space Life and Physical Sciences Division
Human Exploration and Operations Mission Directorate
David Tomko, Ph.D., Program Scientist

National Academy of Science Committee on Biological and Physical Sciences in Space
October 31, 2017
3:15 – 4:00 PM

Research for Human Exploration



National Aeronautics and Space Administration

Space Biology

RESEARCH FOR HUMAN EXPLORATION

Nicki Rayl, Space Biology Program Manager
David Tomko, PhD, Space Biology Program Scientist
Rob Ferl, PhD, Professor and Director of ICBR at University of Florida
Kevin Sato, PhD, ARC Senior Project Scientist
Howard Levine, PhD, KSC ISS Research Office Chief Scientist

Nicki Rayl, Space Biology Program Manager

PROGRAM OVERVIEW

Space Biology Organization

Space Biology NASA Headquarters

- **Nicole Rayl -** *Program Manager – nicole.a.rayl@nasa.gov*
- **David Tomko-** *Program Scientist – dtomko@nasa.gov*
- ***Programmatic Support:***
  - *Anthony Hickey*
  - *Linda Timucin*

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- Project Manager:

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- Senior Project Scientist:

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NASA Kennedy Space Center

- Life Science Utilization Manager:

Debbie Hahn – deborah.j.hahn@nasa.gov

- ISS Research Office Chief Scientist:

Howard Levine – howard.g.levine@nasa.gov

Space Biology Ethos

Priorities:

- **Enabling exploration** and **pioneering discovery**
- Implement push and pull approach across portfolio
- Continue to maximize utilization of ISS
  - Fully utilize additional crew time available
- Leverage on partnerships and shared funding to increase reach of science
- Execute the highest quality science possible to enable agency goals and objectives

Executing Science

- Implement balance of ground vs. flight within portfolio
- Return to annual NRA cadence
- Develop alternative platform science pipeline while emphasizing ISS research
  - Orion/EM-1
  - High Altitude Balloons
  - Suborbital Flight
  - Antarctic

How we have addressed programmatic challenges

Crew Time:
- Crew time for science is at an all time high
- Working closely within NASA to accelerate flights where possible to take advantage of crew time
- Collaborate with CASIS or other programs with joint interest to leverage on flight slots
- Expand data in the GeneLab Data Systems for open access science

Rodent Research:
- Completed development of Rodent Research Fly off plan – targets for flight identified between now and 2022
- Collaborate with Russia and Japan for joint rodent research and hardware sharing
- Enable access to JAXA Rodent Centrifuge
- Enable flight rodent tissue sharing from commercial and international partners

Funding:
- SB portfolio prioritizes NRA grant funding over all elements
- To overcome funding challenges with delays in flight we have released funds incrementally to PIs
- Delayed funding start for flight grant based on target launch date
- Paused funding between science definition and flight implementation

Beyond LEO:
- Target alternate vehicles to increase flight opportunities and go beyond LEO

Grant Funding

Flight delays and pauses between science definition work and flight have serious impacts:

- PI staff and ability to maintain key personnel
- Impacts to graduate student projects and thesis/dissertation timelines
- Significant requests for grant augmentations flowing in – trying to balance augmentation requests with our ability to fund and implement new awards
- Fly off plan for existing portfolio developed – forward plan for new awards solidified
- Joint Research Solicitations with the NASA Human Research Program to leverage funds for key exploration research areas

Pioneering Scientific Discovery
Space Biology: Partnerships and Collaborations

International Space Life Sciences Working Group:
- Forum for developing life science collaborations between NASA, ESA (CSA, CNES, DLR, ASI) and JAXA: ISS experiments, Research Announcements, and GeneLab

JAXA: OP3 Framework:
- Rodent Experiments, Rodent Centrifuge and Aquatic Habitat

U.S./Russian Joint Working Group:
- Forum for developing life science collaborations with Russia: ISS experiments, Bion, Foton, and GeneLab

CASIS:
- Collaboration on ISS based experiments with translational relevance

Rodent Biospecimen Sharing: JAXA and Russia

GeneLab Status Update

(genelab.nasa.gov)

Maximize use of Space Biology flight and ground research resources

- Collect genomic, transcriptomic, proteomic, and metabolomics data
- Enable exploration of the molecular network responses of terrestrial biology to the space environment (Translational Research)
- Make data easily available to a worldwide network of researchers in an open-access database

Updates to Project Approach:

- Annual solicitation as part of the overarching Space Biology NRA
- Future data will be generated from NRA funded investigations
- Most samples will be processed by NRA PI investigators

Dissecting Low Atmospheric Pressure Stress: Transcriptome Responses to the Components of Hypobaria in Arabidopsis [Experiment 1]

GLDS-134

Organisms	Factors	Assay Types	Release Date	Description
Arabidopsis thaliana	organism part Atmospheric Pressure	transcription profiling	11-May-2017	Controlled hypobaria presents biology with an environment that is never encountered in terrestrial ecology, yet the apparent components of hypobaria are stresses typical of terrestrial ecosystems. High altitude, for example, presents terres...

Global gene expression analysis highlights microgravity sensitive key genes in longissimus dorsi and tongue of 30 days space-flown mice

GLDS-135

Organisms	Factors	Assay Types	Release Date	Description
Mus musculus	Microgravity	transcription profiling	23-May-2017	Microgravity as well as chronic muscle disuse are two causes of low back pain originated at least in part from paraspinal muscle deconditioning. At present no study investigated the complexity of the molecular changes in human or mouse para...

Dr. David Tomko, Space Biology Program Scientist

PROGRAM SCIENCE UPDATE

Space Life Sciences Recommendations for 2010-2020: NRC Decadal Study 2011

Plant and Microbial Biology

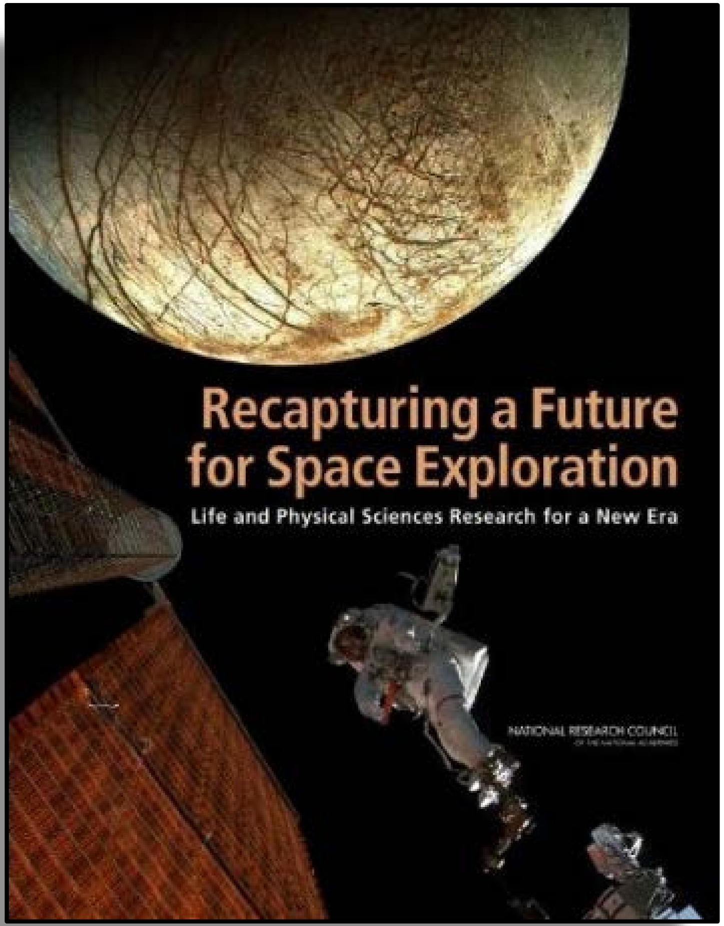
- Multigenerational studies
- Responses to spaceflight
- Plants and microbes in closed-loop life support

Animal and Human Physiology

- Bone and muscle studies
- Drug/countermeasure evaluations
- Vascular and interstitial pressure changes during spaceflight
- Orthostatic intolerance
- Deposition of aerosols in lung
- T-cell and immune system studies
- Multi-generation and early development

Cross-Cutting Issues for Humans in Space

- Artificial-G as a countermeasure
- Animal studies to assess radiation risks
- Cellular studies to define biomarkers for radiation toxicity
- Understanding gender differences in adaption to spaceflight



http://www.nap.edu/catalog.php?record_id=12944

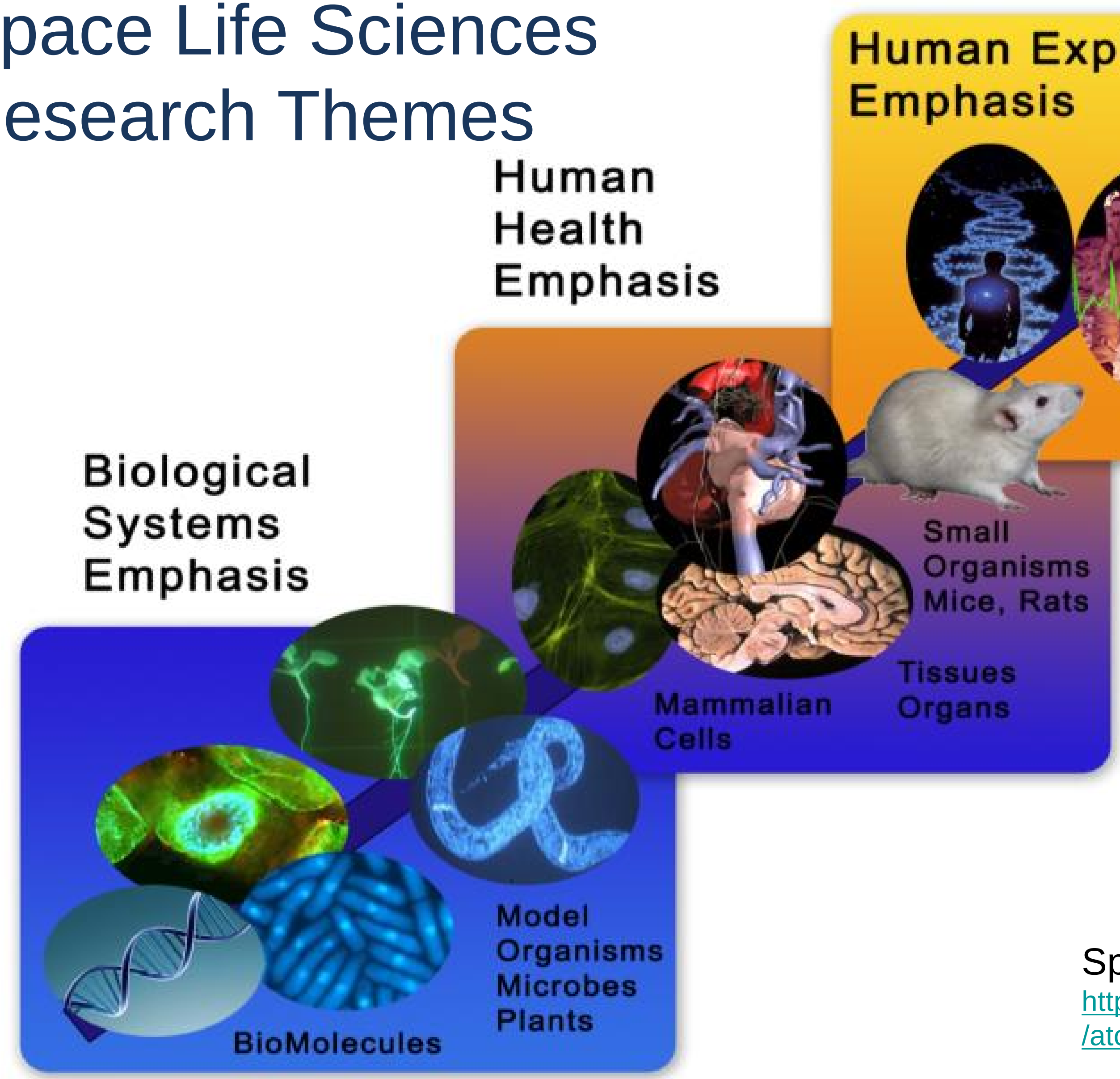
Space Biology Elements and Strategic Plans

Vision and Goals

- Create new knowledge of how different gravity levels affect biological systems important to the human exploration of space
- Build Links between Space Biology and Human Research
- Perform translational research by design - from DNA and RNA to clinical medicine
- Leverage and amplify Space Biology research findings using state-of-the art omics, molecular/ systems biology tools, and the open access GeneLab data base
- Train and inspire a new generation of Space Biologists

https://www.nasa.gov/sites/default/files/atoms/files/16-05-11_sb_plan.pdf

Space Life Sciences Research Themes



Space Biology Science Plan
https://www.nasa.gov/sites/default/files/atoms/files/16-05-11_sb_plan.pdf

Translational Research by Design:Space Life Sciences at NASA

Space Biology | Basic | Translational Research | Applied | **Human Research**

Fundamental Science

Study how life responds, adapts, develops, interacts and evolves in the space environment and across the gravitational continuum:

- Cell and Molecular Biology
- Microbiology
- Animal Biology
- Plant Biology
- Developmental & Reproductive Biology

Science Exploring the Unknown

Space Biology provides knowledge and collaborates with HRP reduce risks and develop countermeasures:

- Animal Research
- Cells & Tissues
- Immunology
- Wound healing & fracture repair
- Bone & muscle
- Radiation/micro-g interactions
- Microbiome of the built environment

← *Critical Link!* →

Identify, characterize and mitigate the risks to human health and performance in space:

- Exercise Countermeasures
- Physiological Countermeasures
- Space Radiation Biology
- Behavioral Health and Performance
- Space Human Factors and Habitability
- Exploration Medical Capability
- Environmental Monitoring

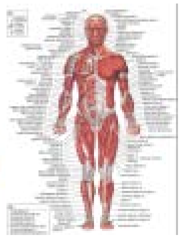
Science Addressing The Known Risks

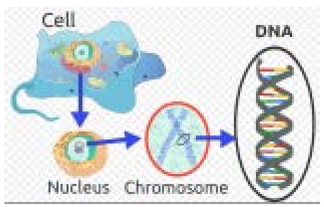
Medical Operations

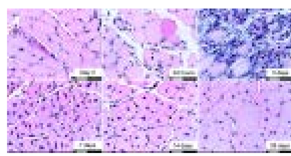
Gravity as A Continuum

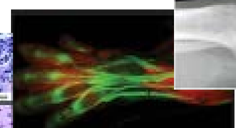
The Gravity Dose Response Curve: Threshold or Continuum?

- Gravity induces biological responses at the gene expression, cellular, systems and whole organism level
- The dose response curve of any of these responses is not fully characterized









- It is not known if responses are a continuum or are based on reaching thresholds
- It is not known if responses require continuous or intermittent exposures
- It is not known if the sensitivity/dose response changes during development

Gravity as a Continuum ToolBox - ground & flight research on a variety of organisms to define dose response curve & adaptation mechanisms from 0 to >2+g

Ground-based Centrifuges

In-flight Centrifuges (KUBIK, JAXA mouse centrifuge, Free-flyers)

Parabolic Flight

Ground-Based Fractional G Simulators (Clinostats, RPMs, HARVs, etc)

Partial Unloading in Animals and Humans

Recent Solicitations

NRA NNH16ZTT001N Research Opportunities in Space Biology (ROSBio) - 2016
Released: Mar 24, 2016; Open until Dec 31, 2017 (Will be updated and re-issued to cover January 1, 2017 through December 31, 2019)

- Omnibus Research Announcement (NRA) that covers all aspects of basic and applied research and technology supporting Space Biology.
- Specific research/funding opportunities announced through Appendices soliciting research proposals that address one or more of Space Biology's primary objectives.

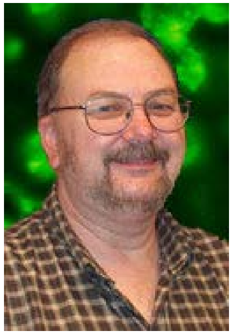
NRA NNH16ZTT001N-GL Appendix A: "GeneLab Innovation Awards for Translational Systems Biology and Informatics Research Using the GeneLab Data System"
Released: Mar 24, 2016; Closed: June 28, 2016

- Solicited research projects to: 1) perform ground-based experiments to test novel hypotheses derived from analysis of data in the GeneLab DataBase, or 2) develop novel computational tools that enhanced the usability and value of GeneLab. Total value ~$1.4M Selected 6/32 proposals.

NRA NNH16ZTT001N-MOBE Appendix B: "Research Opportunities for Post-Doctoral Fellowships in Space Biology to Study ISS Microbiome as a Built Environment: Using ISS as a Microbiological Observatory" Released: Sept 15, 2016; Closed: Nov 30, 2016

- Post-doctoral research proposals to conduct studies to characterize ISS microbial isolates.
- NASA and the Sloan Foundation released parallel solicitations on Sept 15, 2016. - 5 proposals selected, **3** funded by NASA and 2 funded by the Sloan Foundation.

NRA NNH16ZTT001N-GL Appendix A: "GeneLab Innovation Awards for Translational Systems Biology and Informatics Research Using the GeneLab Data System" Awardees



Comparative Evaluation of Microbial Transcriptomic Responses to Spaceflight Stress: Elucidating Underlying Molecular Mechanisms PI: Wayne Nicholson U Florida, Gainsville

Use data in Genelab Data System to explore commonalities and differences in responses to spaceflight of various microbes to uncover common fundamental mechanisms of acclimation. The work will test the hypothesis that exposure to spaceflight environment alters the physicochemical environment immediately surrounding bacterial cells and within the cells themselves (mainly due to microgravity effects and ionizing radiation).

GeneLab: Revealing Spaceflight- and Gravity-Response Networks in Plants. PI: Simon Gilroy; Co-I: Richard Barker, University of Wisconsin, Madison

Use bioinformatic approaches to determine how spaceflight alters the plant transcriptome and proteome using GeneLab data. They will test the functions of the genes identified through these analyses by performing phenotypic assays with mutants. During this work the will create bioinformatics tools that eventually can be applied to datasets outside of Arabidopsis, which will also be made available for public use.

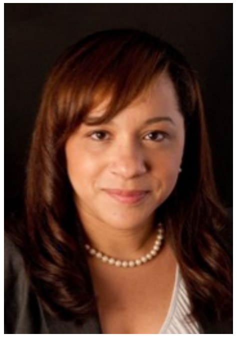
Using GeneLab Data to Identify Novel Gravity Sensory Components in Arabidopsis.

PI: Elliot Meyerowitz, Cal Tech; ; Co-Is: Alphan Altinok, Daniel Crichton, Jet Propulsion Lab

The investigator will screen NASA GeneLab data for novel genes that function in plant gravity sensing and mechanoperception. He will then perform functional analysis of the genes identified through this screen using specific gene mutants to assess the effects of the mutations on rapid mechanical responses.

NASA Space Biology Investigations in Progress

NRA NNH16ZTT001N-GL Appendix A: "GeneLab Innovation Awards for Translational Systems Biology and Informatics Research Using the GeneLab Data System" Awardees



Microgravity Effects on Co-cultured Vascular Cells Types
PI: Josephine Allen, University of Florida, Gainesville

- Optimization of experiment parameters and specimen culturing was completed for cell survival, proliferation, and downstream biological response following long term microgravity culture (modeled microgravity)
- Current work on Aim 1 is in progress: *Evaluate the functional changes in microgravity exposed endothelial cells*. Currently long term microgravity cultures are running as described to characterize the functional changes in endothelial cells and smooth muscle cells at various time points

"Omics" Data Mining of the ISS Aspergillus fumigatus Strains in Elucidating Virulence Characteristics. PI: Nancy Keller, University of Wisconsin, Madison; Co-I: Kasthuri Venkateswaran, JPL

- Aims 1 and 2 completed – Published: Knox BP, Blachowicz A, Palmer JM, Romsdahl J, Huttenlocher A, Wang CCC, Keller NP, Venkateswaran K (2016) Characterization of *Aspergillus fumigatus* isolated from air and surfaces of the International Space Station. MSphere 1(5). pii: e00227-16.
- Aim 3 – Specimens production in progress

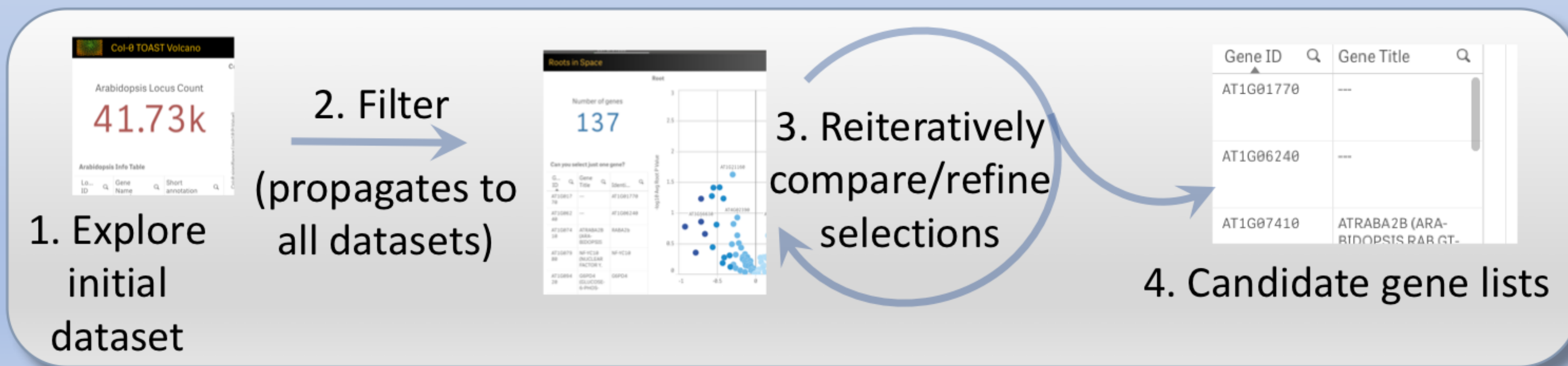
<u>Effects of Microgravity on the Risks of Space Radiation-Induced Leukemogenesis</u>
PI: Christopher Porada, Wake Forest University. Co-Is: Maria Graca Almeida-Porada, Steve Walker, Wake Forest; Paul Wilson, UC, Davis

- Completed studies with radiomimetic drug Bleomycin (double stranded break [DSB] induced) treatment of human stem cell-like KG1a in combination with simulated microgravity; discovered untreated+ug treated cells repaired DNA but treated cells continued to increase DSB.
- Completed study demonstrating that simulated ug delays/inhibits dendritic cell differentiation from human stem cells (HSC). Repeating studies with KG1a and primary HSC followed by preparation of a manuscript
- Currently, initited HSC differentiation to Natural Killer cells (NK) in simulated microgravity

Spaceflight- and Gravity-Response Networks in Plants

GeneLab Innovation Grant: NNX17AD52G
PI: Simon Gilroy; CoI: Richard Barker
University of Wisconsin, Department of Botany

- **Goal:** Develop data exploration environment allowing for seamless analysis and comparisons across all GeneLab transcriptomic and proteomic data
- **Architecture:** Built around Qlik data visualization environment
- **Content:** Imported all GeneLab plant data; supplemented with published and unpublished datasets from other space agencies and researchers
- **Uniformity:** Reanalyzed all data using standardized analytical pipeline for robust comparisons
- **Status:** public beta testing: http://astrobotany.com/toast-database/



Microbiome of the Built Environment Post-doctoral Fellows NASA Research Announcement NNH16ZTT001N-Mobe

Microbial evolution and transmission aboard the ISS: inferring mutation rates, assessing pangenomes, and tracking microbiome transmission between astronauts and the space-based built environment - NASA Fellow: Michael Lee, USC - Advisor: Craig Everroad, NASA Ames Research Center

Virulence and drug resistance of Burkholderia species isolated from ISS potable water systems - NASA Fellow: Aubrie O'Rourke, King Abdullah University of Science and Technology - Advisor: William Nierman, J. Craig Venter Inst

Genomic and functional analysis of biofilm morphotypes of International Space Station isolated Staphylococcus epidermidis and their pathogenicity in Caenorhabditis elegans - NASA Fellow: Noelle Bryan, Louisiana State University - Advisor: Maria Zuber, Massachusetts Institute of Technology

Biodeterioration and Biocorrosion in Spaceflight Ecosystems: Implications for Material/ Microbiome Interactions on the International Space Station - Sloan Fellow: Blake Stamps, University of Oklahoma - Advisor: John Spear, Colorado School of Mines

Developing predictive model systems of polymicrobial biofilm formation and susceptibility to chemical disinfectant: A longitudinal study with implications for spaceflight systems integrity and health risks - Sloan Fellow: Jiseon Yang, Arizona State University - Advisor: Cheryl Nickerson, Arizona State University

Microbiomes of the Built Environment

What are the impacts of the MoBE on human health?
- Negative
- Positive

What are the impacts of the MoBE on plant health?

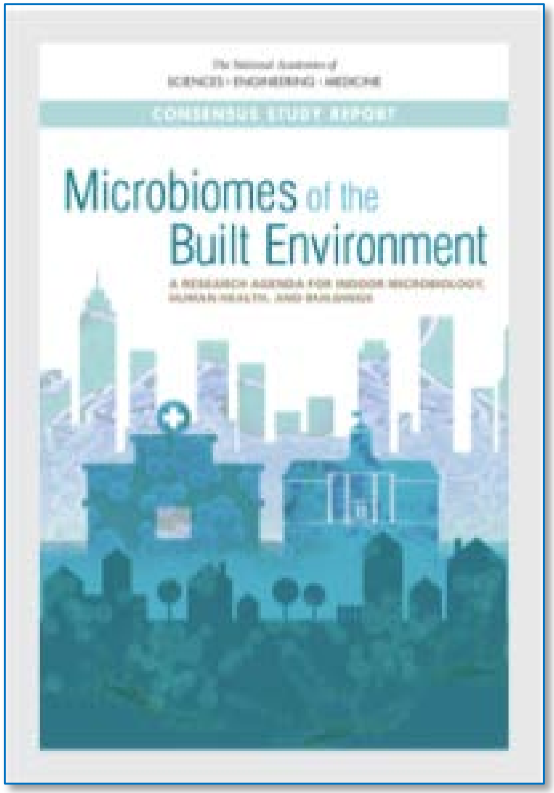
How do the microbiomes of the human, plant, and built environment interact with one another?

What properties are desirable for the MoBE of
- Capsule
- Habitat
- Lander
- Rover
- Space Suit?

How we monitor the MoBE?

How do we control the MoBE?

How do we recover from an undesirable MoBE?



http://nap.edu/23647

Recent Solicitations

- **NRA NNH16ZTT001N-BION Appendix C: "Solicitation of Proposals for Possible Inclusion in the Russian Bion-M2 Mission" -** Released: July 14, 2017
  - NASA invited to propose candidate studies for Russian Bion-M2 mission. NRA solicits pre-proposals compatible with those to be flown by Russian investigators in 2020-21.
  - NASA will use a two-phase submission and review process for investigators wishing to submit proposals to this Appendix:
  - **34** pre-proposals submitted by Sept 21, 2017 deadline. Pre-proposals are being evaluated by NASA for suitability for inclusion in mission planning. Investigators with pre-proposals that satisfy evaluation criteria will be invited to submit complete full proposals at the beginning of phase 2, which will occur at a to be determined date.
  - During Phase 2 , full proposals will undergo scientific merit and technical feasibility review by the NASA Space Biology Program and IPs and final selection of research projects will be made.
- **NRA NNH16ZTT001N-MS Appendix D: "Solicitation of Proposals to Conduct Research Using Microgravity Simulation Devices"** Released: 08/16/17; Closed: 10/16/17: <u>43 Proposals Submitted</u>
- **NRA NNH16ZTT001N-PS Appendix E: "Solicitation of Proposals to Conduct Research In Parabolic and Suborbital Flights"** Released: 08/16/17; Closed: 10/16/17: <u>11 Proposals Submitted</u>
- **NRA NNH16ZTT001N-AB Appendix F: "Solicitation of Proposals to Conduct Research on Antarctic Balloon Flights"** Released: 08/16/17; Closed: 10/16/17: <u>9 Proposals Submitted</u>

Space Biology Solicitation Status

- **NRA NNH16ZTT001N-FG Appendix: "Appendix G: Solicitation of Proposals for Flight and Ground Space Biology Research" NNH16ZTT001N-FG"** Solicits flight & ground research to answer Space Biology questions: To be released Nov 3, 2017
- **NRA NNH16ZTT001N Appendix: "Space Biology Ames Life Science Data Archive Biospecimen Sharing"** (PLACEHOLDER)
- **NRA NNH16ZTT001N Appendix: "Space Biology Beyond Low Earth Orbit (Orion EM-1)"** (PLACEHOLDER)

<u>Collaborative between HRP and SB</u>

- **NNJ15ZSA001N-AG "Appendix D: NASA Human Research Program Artificial Gravity Opportunity"** Released July 31, 2015; Closed Sept, 16, 2015: <u>SB and HRP currently jointly-funding 2 selected projects</u>
- **NNJ16ZSA001N-SRHHC "Space Radiation and Human Health Countermeasures Topics" Topic 6 – "Effects of hindlimb unloading and space radiation in rats"** Released March 22, 2017, Five Step 2 proposal submitted 07/31/17
- **Request for Information on Biological, Physiological, and Behavioral Adaptations to Spaceflight; Topic 1: Biological, Physiological, and Behavioral Functions of Mice during Partial (0 – 1) G-Exposures Provided by Centrifugation on the International Space Station.** Released 10/20/17, Final Release: ?

Upcoming Solicitations

NRA NNH16ZTT001N Appendix G: "Solicitation of Proposals for Flight and Ground Space Biology Research" – Release date: November 3, 2017, proposals due February, 2017

- Solicits individual and/or team proposals that respond to SB research elements:

1) Microbiomes of the Built Environment (MoBE) in Space
2) Plant Biology in support of Human Space Exploration
3) Animal Biology in support of Human Space Exploration
   (ISS experiments on non-rodents only)
4) Molecular and Cellular Biology

Proposals submitted in response to this Appendix may include the following types:

1) ISS or non-ISS Spaceflight experiments (suborbital, parabolic flight, stratospheric balloons, etc.) to test, develop, or refine flight hypotheses;
2) Ground-based experiments in non-NASA or NASA laboratories, including drop towers facilities, and/or specialized centrifuge facilities to study gravity as a continuum;
3) New Space Biology investigations;
4) Postdoctoral fellows who wish to develop a career in Space Biology research;
5) Investigators who wish to develop new experimental hypotheses based on data in the open science GeneLab database for space life science research

- Awards will range from $ 70 K per year, for 2 years, for postdoctoral fellowship awards to up to $750 K total for ground and/or flight- based projects awarded to PI teams.

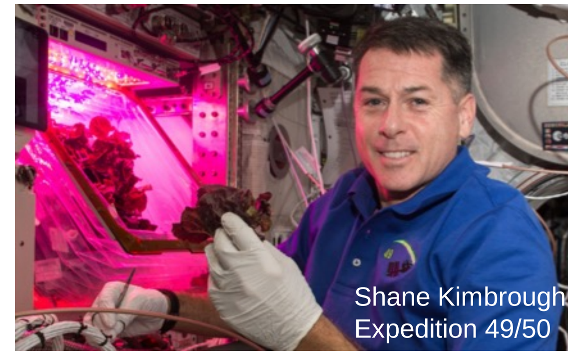
Planned Solicitations

- **2018: “Space Biology Research Pathfinder for Beyond Low Earth Orbit Space Biology Investigations”.**
  - Will solicit proposals for experiments to be flown on the upcoming Orion EM-1 mission.

- **2018: “NASA Life Science Data Archive Biospecimen Sharing”**
  - Will solicit proposals for studies that will use existing specimens in the LSDA for research purposes that align with the goals of the Space Biology Program.

Status of Nutrient and Microbial Results from Vegetable Growth Testing in Veggie

Gioia Massa, Matt Romeyn, Mary Hummerick, Christina Khodadad, LaShelle Spencer
Exploration Research and Technology Programs, NASA, Kennedy Space Center



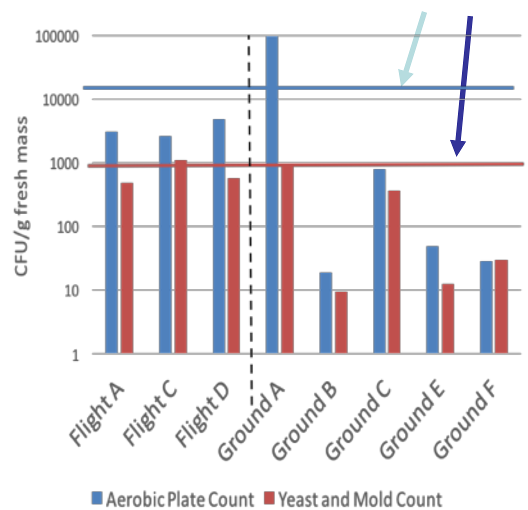
VEG-01 (2014-2016)
'Outredgeous' lettuce & 'Profusion' Zinnia
Crew consumption approval

VEG-03 (2016-Present)
'Outredgeous' lettuce, 'Tokyo Bekana' Chinese cabbage, Mizuna, 'Waldmann's Green' lettuce

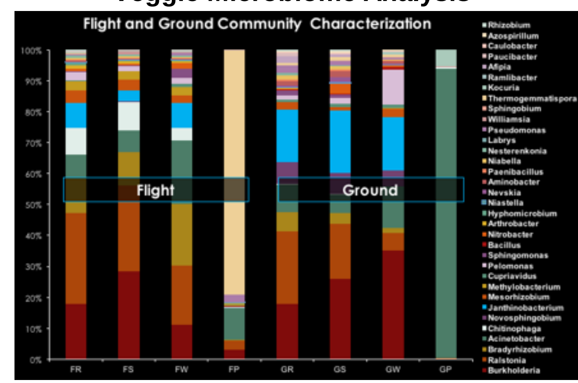
Nutrient Levels – Veg-01 Lettuce

- Fe, Ca, Mo & P & Anthocynains same between flight & ground.
- B, Cu, Mg, Mn, Na & S slightly ^ in flight.
- K slightly > in ground plants.
- Ni & Zn considerably ^ in flight plants.

Veggie Microbiology Food Safety

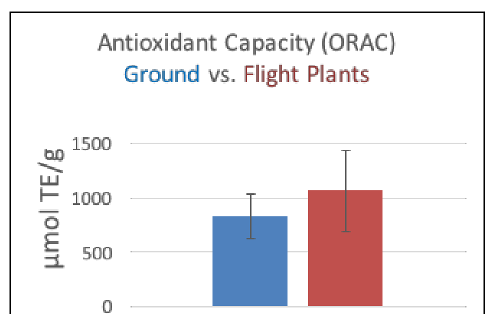


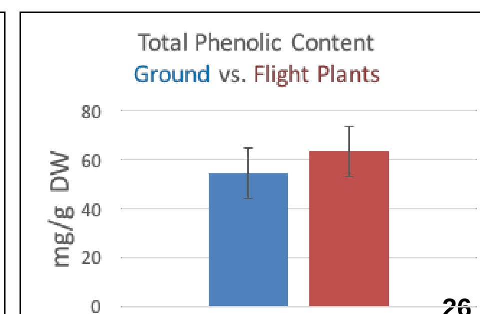
Veggie Microbiome Analysis



Publications

- Massa, *et al*. Growth chambers on ISS for large plants. Acta Hortic. 2016:1134:215-22.
- Massa, *et al.* VEG-01: Veggie hardware validation testing on ISS. Open Agriculture. 2017:2(1):33-41
- Massa *et al*. Plant pillow preparation for Veggie plant growth system on ISS. Grav Space Res. 2017:5(1):24-34.





NASA Space Biology Investigations in Progress

RR-9 – First NASA Space Biology Rodent Research Mission

- All mice returned alive; healthy in appearance and behavior
- All PI tissues were harvested and preserved and stored as required
- Surrogate controls processed with cohort mice from Jackson Lab
- Awaiting completion of planning to repeat ground control at KSC

Delp - Effects of microgravity on Cerebral Arterial, Venous and Lymphatic Function: Implication for Elevated Intracranial Pressure

- Successfully completed immediate post-dissection vasculature elasticity tests

Mao - Space flight environment induces remodeling of vascular network and glia-vascular communication in mouse retina

- Successfully completed eye pressure measurements

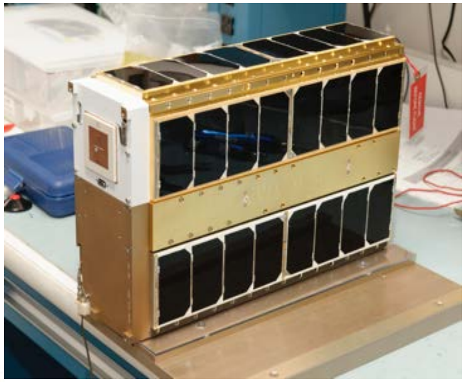
Willey - Exercise Countermeasures for Knee and Hip Joint Degradation during Spaceflight

- Completed immediate post-flight gait measurements
- Flown and unflown mice (pre-flight and cohort) moved very well
- Forelimb gait pattern similar between groups;
- Hind limb gait pattern differed between control and flown mice; flown mice gait pattern resembled some neuropathies

Research Highlight- EcAMSat: Spaceflight Effects on Bacterial Antibiotic Resistance and its Genetic Basis "AntimicrobialSat"

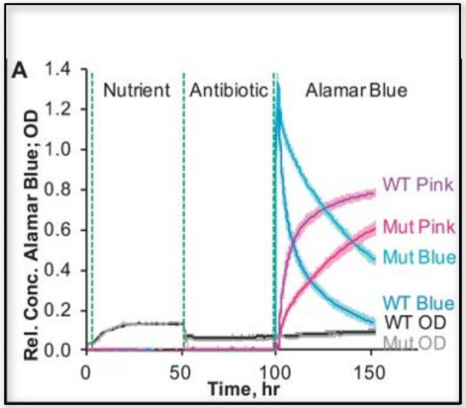
A.C. Matin, Stanford University

E. coli Anti Microbial Satellite (EcAMSat) mission - designed to investigate effects of spaceflight on antibiotic resistance of E. coli responsible for urinary tract infection in humans and animals
Launching on OA-8 **November 11, 2017**



- Spaceflight causes some microorganisms to become more virulent, creating a potential risk to crew health.
- Are changes in virulence accompanied by changes in microbial antibiotic resistance
- Understand potential impacts to astronauts in microgravity, where the immune response is blunted
- Use colorimetric assay (Alarmar Blue which changes color from blue to pink in the presence of metabolically active, bacteria) to determine viability of bacteria after exposure to differing concentrations of antibiotic.
- Color changes monitored by an optical system in real time allow EcAMSat to acquire and record viability data.
- Will determine the lowest concentration of antibiotic that inhibits bacterial growth in space.

Alamar Blue Reduction



Matin et al., 2017, *Life Sci Res*, 15, 1-10

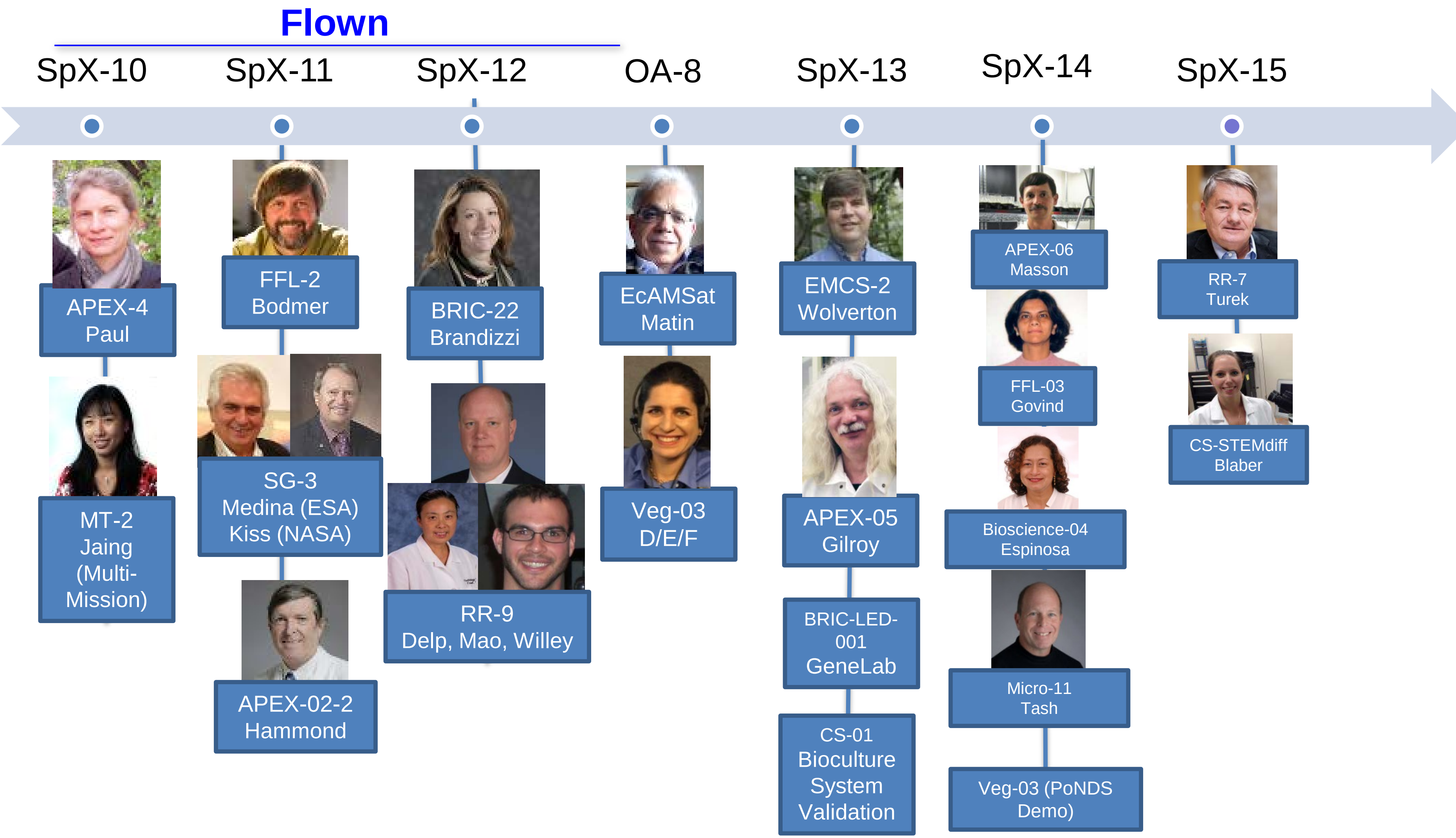
- Explores the genetic bases of spaceflight-induced changes in antibiotic resistance, using a mutant (*DrpoS*) strain of E.coli to help determine the role that bacterial stress response plays in resistance changes.
- Knowledge gained will be useful for prescribing antibiotic doses for future space travelers to protect their health during long-duration human space missions

JOURNAL PUBLICATION REFERENCES FOR HIGHLIGHTED RESEARCH PROJECTS

- Massa, *et al*. Growth chambers on ISS for large plants. Acta Hortic. 2016:1134:215-22. http://dx.doi.org/10.17660/ActaHortic.2016.1134.29
- Massa, *et al.* VEG-01: Veggie hardware validation testing on ISS. Open Agriculture. 2017:2(1):33-41. https://doi.org/10.1515/opag-2017-0003
- Massa *et al*. Plant pillow preparation for Veggie plant growth system on ISS. Grav Space Res. 2017:5(1):24-34. http://gravitationalandspacebiology.org/index.php/journal/article/view/749
- Wang, Matin *et al*. "Sigma S-dependent antioxidant defense protects stationary-phase Escherichia coli against bactericidal antibiotic gentamicin." Antimicrob Agents Chemother. 2014 Oct;58(10):5964-75. http://dx.doi.org/10.1128/AAC.03683-14 ; Epub 2014 Jul 28. PubMed PMID: 25070093; PubMed Central PMCID: PMC4187989
- Matin *et al*. Payload hardware & experimental protocol development to enable future testing of effect of space microgravity on resistance to gentamicin of uropathogenic Escherichia coli & its (sigma)s-deficient mutant." Life Sciences in Space Research. 2017 Nov;15:1-10. https://doi.org/10.1016/j.lssr.2017.05.001
- Singh & Matin. Cellular response of Escherichia coli to microgravity & microgravity analogue culture in "Effect of spaceflight and spaceflight analogue culture on human & microbial cells: Novel insights into disease mechanisms." Ed. C.A. Nickerson, N.R. Pellis, C.M. Ott. New York : Springer, 2016. p. 259-282. http://dx.doi.org/10.1007/978-1-4939-3277-1_13

Dr. Kevin Sato, ARC Senior Project Scientist

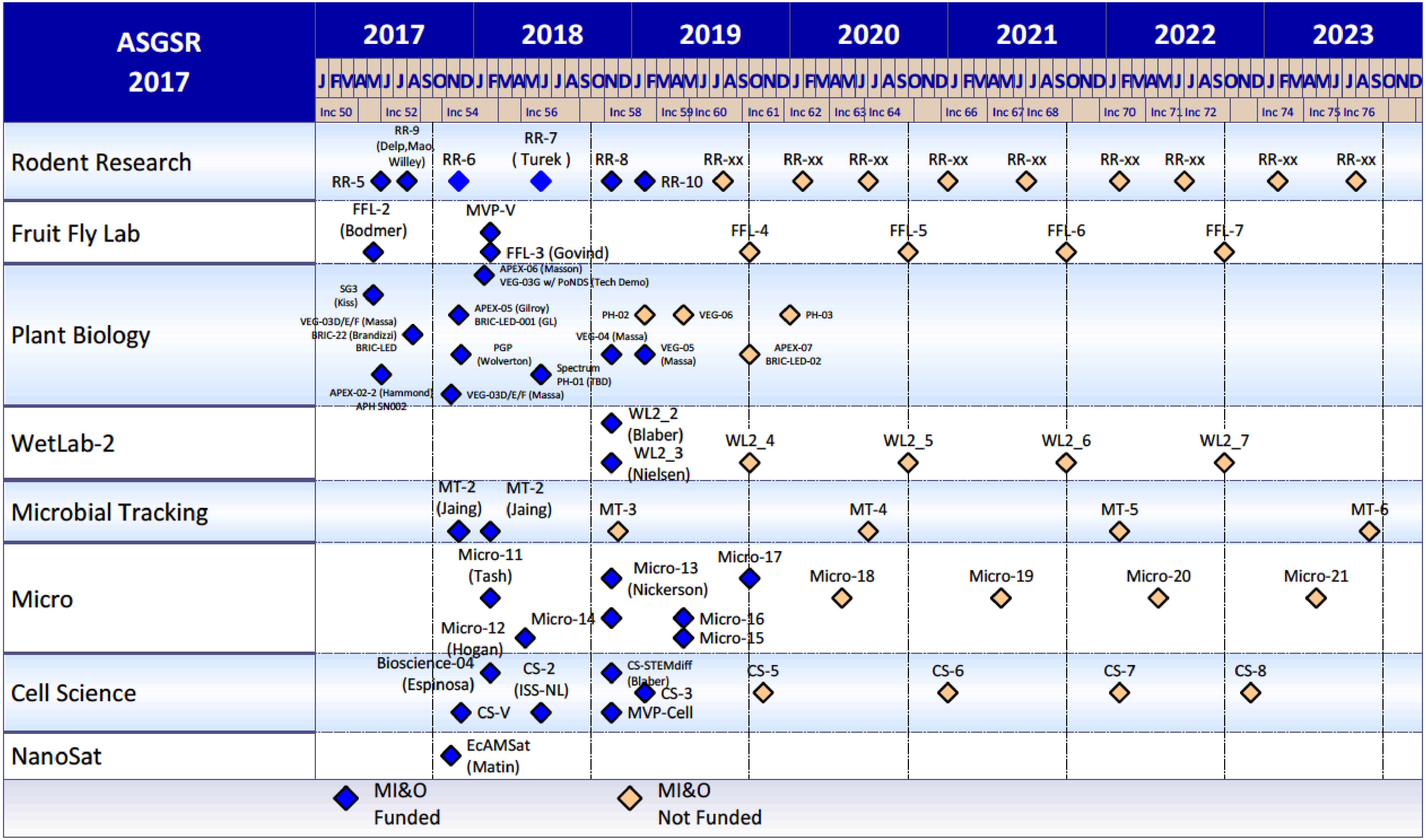
EXECUTING SCIENCE AND STUDENT OPPORTUNITIES


Flown
SpX-10
SpX-11
SpX-12
OA-8
SpX-13
SpX-14
SpX-15
APEX-4 Paul
MT-2 Jaing (Multi-Mission)
FFL-2 Bodmer
SG-3 Medina (ESA) Kiss (NASA)
APEX-02-2 Hammond
BRIC-22 Brandizzi
RR-9 Delp, Mao, Willey
EcAMSat Matin
Veg-03 D/E/F
EMCS-2 Wolverton
APEX-05 Gilroy
BRIC-LED-001 GeneLab
CS-01 Bioculture System Validation
APEX-06 Masson
FFL-03 Govind
Bioscience-04 Espinosa
Micro-11 Tash
Veg-03 (PoNDS Demo)
RR-7 Turek
CS-STEMdiff Blaber

Space Biology RESEARCH FOR HUMAN EXPLORATION

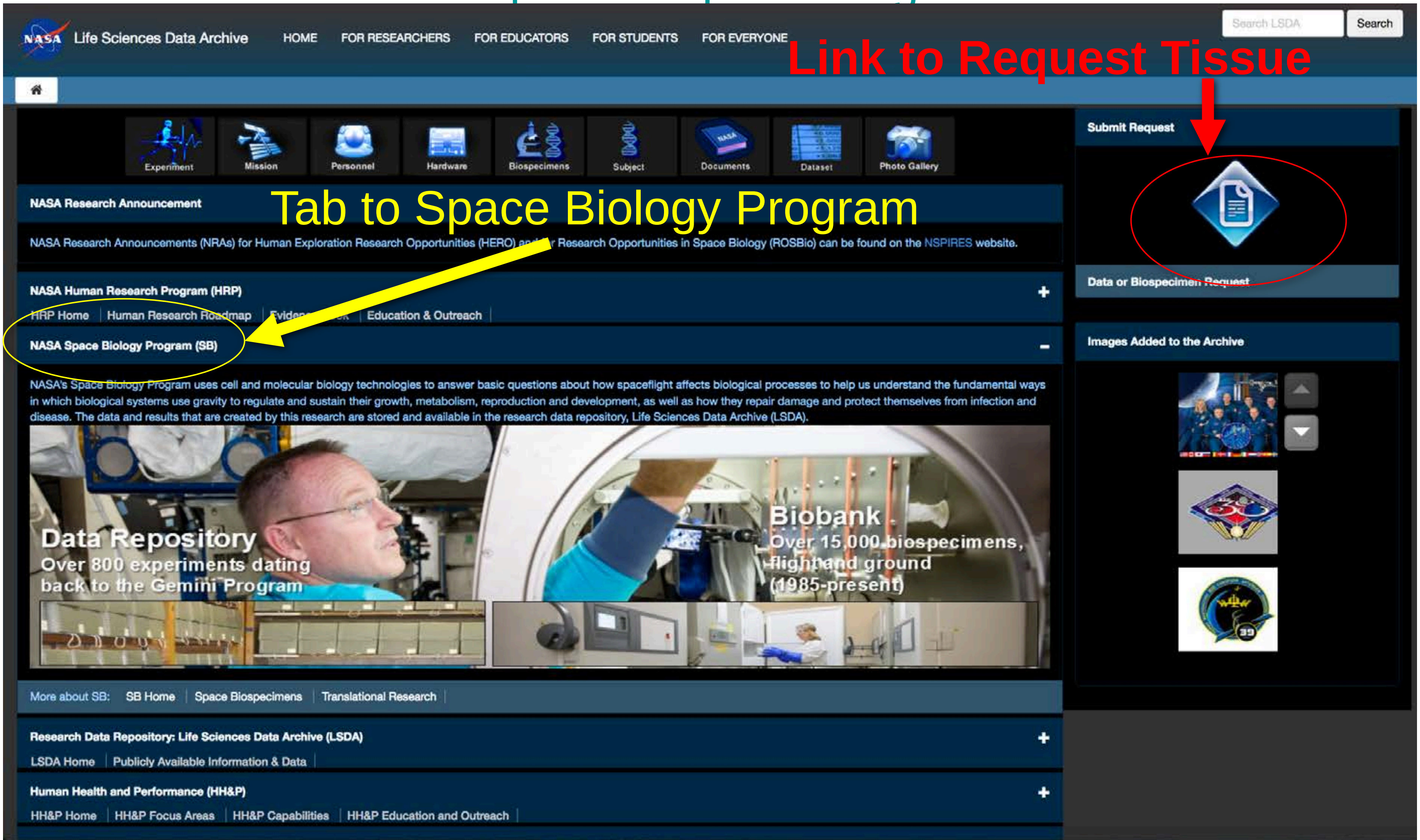
National Aeronautics and Space Administration

Fly Off Schedule



Life Sciences Data Archive

https://lsda.jsc.nasa.gov/



Orion Space Biology Pathfinder: Mission Summary

Objective: Establish a life sciences payload on the Orion EM-1 mission to serve as a pathfinder for biological research beyond LEO

Biology Challenges on the Journey to Mars

It has been over 40 years (Apollo 17) since any life from Earth has traveled beyond LEO and returned home safely.

For a mission to Mars, life must survive safely in deep space ***20-80 times longer*** and travel at least ***150 times farther*** than ever before

Value to SLPS and Orion

1) Pave the way for biology research beyond LEO with critical sample return-to-Earth capability.

2) Provide critical and unique data about life beyond LEO for the first time in over 40 years

3) Answer questions about sustaining life beyond LEO for long periods

Implementation Approach

Leverage existing small payload hardware systems with low power required and fully autonomous operations.

- Modifications will be required due to EM-1 constraints

Collaborate with Orion to support the payload without interfering with other Orion EM-1 mission objectives.

What is a Gateway Garden ?

- The “Gateway Garden” is a concept for the development of a reliable and sustainable operational food production system that would provide visiting crews with access to both fresh fruits and vegetables as well as the psychosocial benefits associated with having access to plants during their stay on the Deep Space Gateway Habitat.
- The Garden can be scaled to meet the specific constraints and would be compatible with the conops of the Gateway Habitat architecture.
- The Garden is planned to be just one aspect of the food system and is not meant to provide a significant contribution to daily caloric intake for the crew or to reduce the contribution of pre-packaged food

Why do we need one?

- A Gateway Garden would provide the following benefits:
  - Supplementation of key nutrients for visiting crews by access to fresh fruits and vegetables
  - A range of psychosocial benefits attributed to both variety of diet and living with plants in a confined space environment
  - Research into the microbiomes of the Garden and the Gateway Habitat
  - A platform for understanding the impacts of the deep space environment on plants and fresh food systems
  - Demonstrate initial capability for Earth-independent operations will be requir as mission duration and distance from Earth drive greater resource autonon
  - Provide valuable data on the incorporation of plant growth systems for future vehicle designs

Training and Internship Opportunities

NASA Interns, Fellows, and Scholars One Stop Shopping Initiative (https://intern.nasa.gov/ossi/web/public/main/).

NASA Post-Doctoral Program (NPP) https://npp.usra.edu

Provides early-career and more senior scientists the opportunity to share in NASA's mission

Fellows work on 1 to 3 year assignments at NASA centers and institutes

Fellows contribute to our national scientific exploration, confirm NASA's leadership in fundamental research, and complement the efforts of NASA's partners in the national science community.

Space Life Sciences Training Program (SLSTP)
https://www.nasa.gov/ames/research/space-life-sciences-training-program

- Trains our next generation of scientists and engineers and enable NASA to meet future research and engineering challenges in the space life sciences
- Students conduct hands-on research, as well as attend technical lectures, develop professional & project management skills, perform a team project and submit an abstract to a professional scientific or engineering organization for presentation

Training and Internship Opportunities

GeneLab for High Schools (GL4HS)

https://www.nasa.gov/ames/genelab-for-high-schools

Provides education and training of high school students:

- Learn about NASA Space Biology research
- Learn and obtain training in omics-based research
- Learn and obtain hands-on training in bioinformatics and computational biology methods and techniques to analyze omics data
- Learn about applications of the bioinformatics analyses to NASA Space Biology science
- Network and form connections with guest lecturers including university professors and industry experts
- Learn how to and develop a competitive research proposal based on data analyzed from the GeneLab Data Repository and apply to the Space Biology Research Training Competition

Pilot course conducted this summer was very successful. 16 students from local Bay Area high schools participated. Students who won the research proposal competition are participants at the ASGSR meeting

"Before I came to this program I thought I was decided on studying computer science and becoming a programmer. Now I realize that there are so many rewarding and exciting things to do in this world"

" …it was all so interesting because we learned the real-life applications to biology, which made it infinitely cooler than learning the biology from a textbook or in a classroom."

"What this course taught me most is that, while knowledge is transient, the approaches and ways of thinking that one uses to approach a problem are what is truly important."

Training and Internship Opportunities

NASA/Fairchild Tropical Botanical Garden Challenge Collaboration – Growing Beyond Earth

With the Fairchild challenge collaboration, KSC touching a few thousand middle and high school students who are collecting data on crop production for NASA's Veggie project. Students are testing new crops and different growing techniques including harvest methods, fertilizer levels and photoperiod. NASA scientists get the students data and are mining it for new plants to grow and the best ways to grow them.

http://www.fairchildgarden.org/Education/The-Fairchild-Challenge

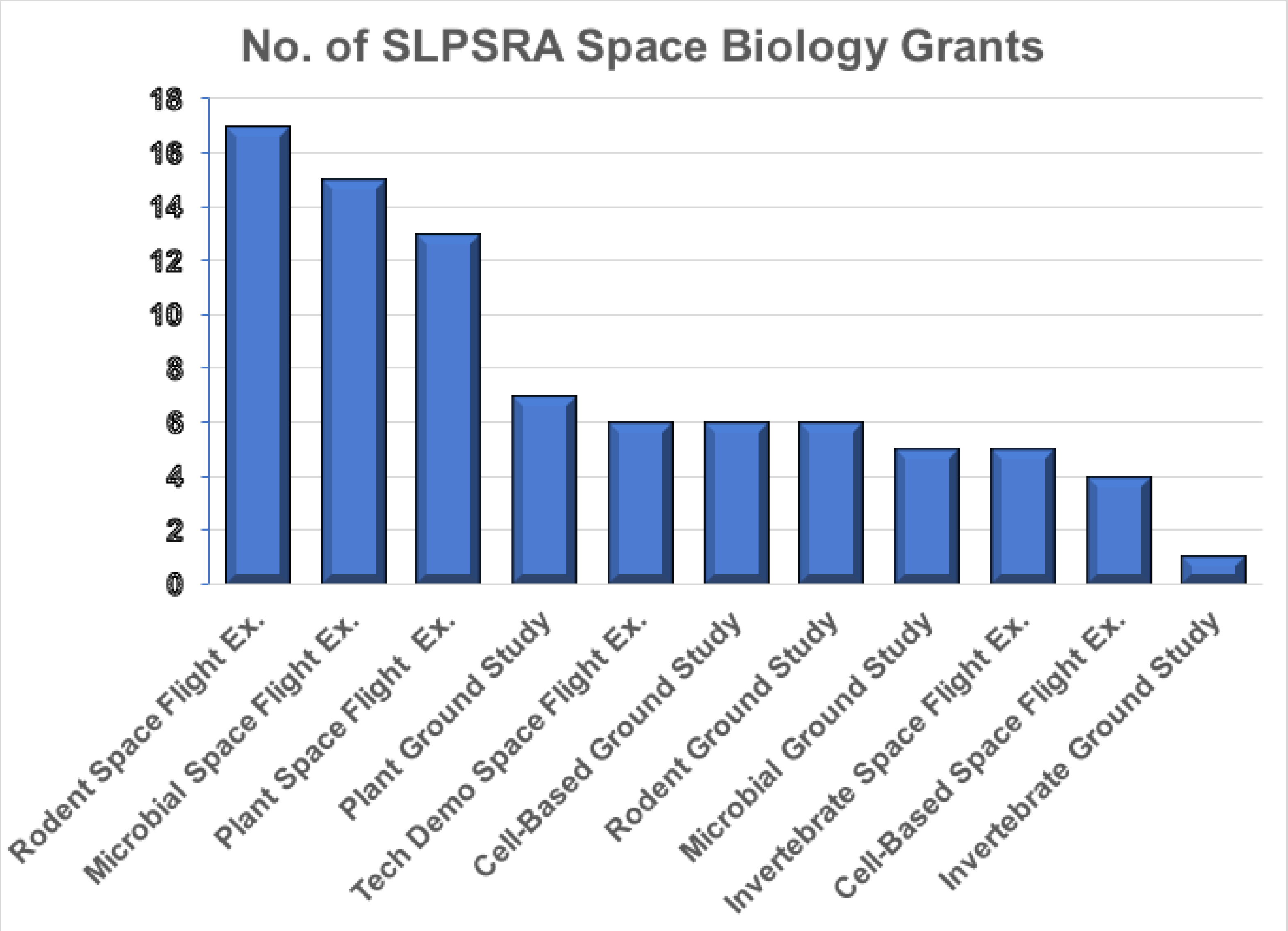
X-HAB – eXploration HABitation

Charles Quincy- charles.d.quincy@nasa.gov

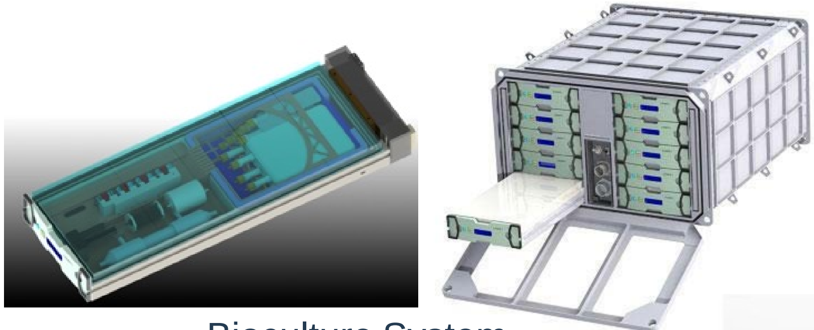
With the X-HAB program NASA is working with undergraduate and graduate students in engineering design courses to develop new concepts, hardware and methodology for future space crop production. This school year we are advising four teams looking at novel methods of watering plants, recycling inedible plant materials for new purposes, and sanitizing produce.

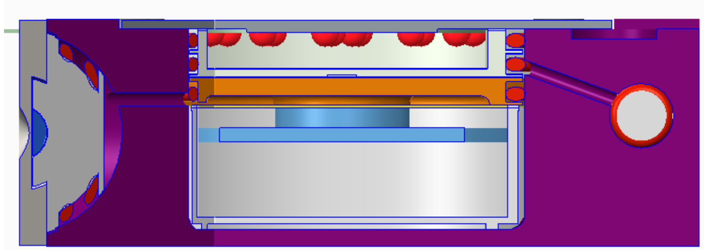
Dr. Howard Levine,
KSC ISS Research Integration Office Chief Scientist

CURRENT GRANTS, NEW CAPABILITIES, OPPORTUNITIES AND UPCOMING SOLICITATIONS


No. of SLPSRA Space Biology Grants
18
16
14
12
10
8
6
4
2
0
Rodent Space Flight Ex.
Microbial Space Flight Ex.
Plant Space Flight Ex.
Plant Ground Study
Tech Demo Space Flight Ex.
Cell-Based Ground Study
Rodent Ground Study
Microbial Ground Study
Invertebrate Space Flight Ex.
Cell-Based Space Flight Ex.
Invertebrate Ground Study

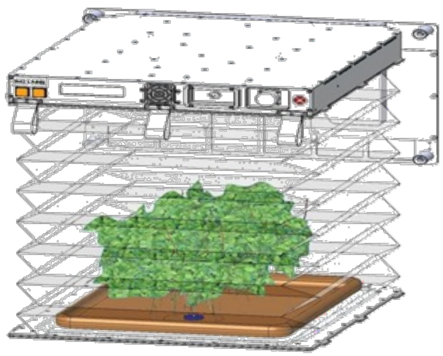
New Capabilities to Enable Research





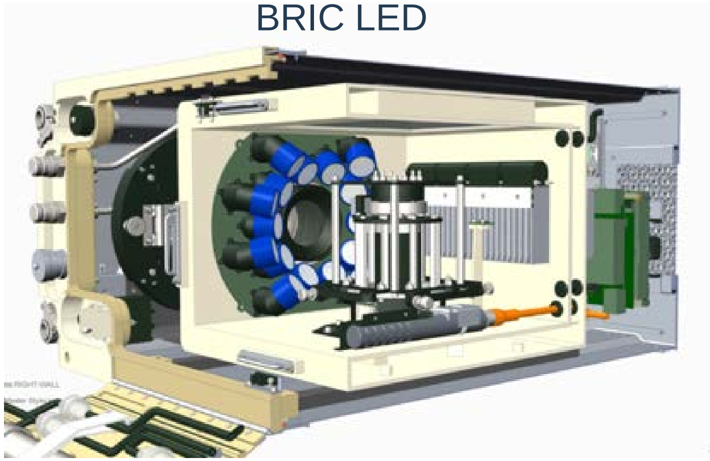
BRIC LED

Bioculture System

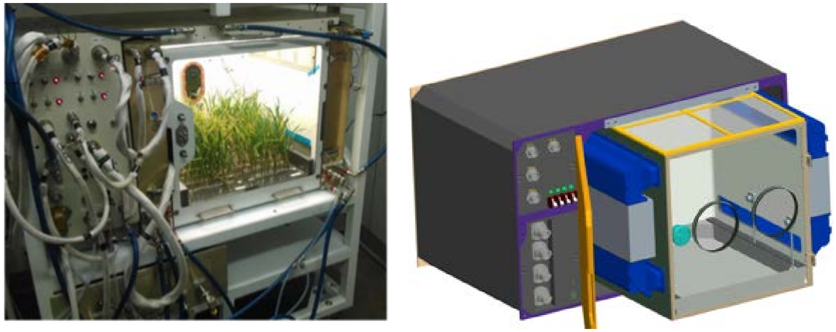


Veggie Units #1 & #2 on ISS,

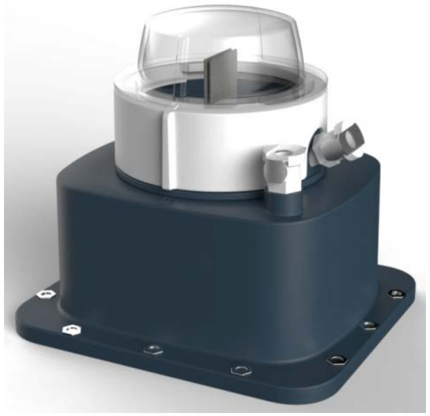
WetLab 2 on ISS)



Spectrum Imager



Advanced Plant Habitat on ISS



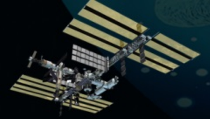
PONDS:
Passive Orbital
Nutrient Delivery System

Alternative Platforms for Life Science Experiments

Objective:

Provide capabilities and opportunities to support NASA-selected life science investigations (and technical demonstrations) to meet recommendations of the NRC Decadal Report and Space Biology Plan with appropriate platforms.

- **Microgravity Simulators (Appendix D)**
- **Parabolic Flight Campaigns (Appendix E)**
- **Suborbital Flight Campaigns (Appendix E)**
- **Antarctic Balloon Campaigns (Appendix F)**
- **Bion M2 (Appendix C)**
- **Exploration Mission-1 (EM-1)**



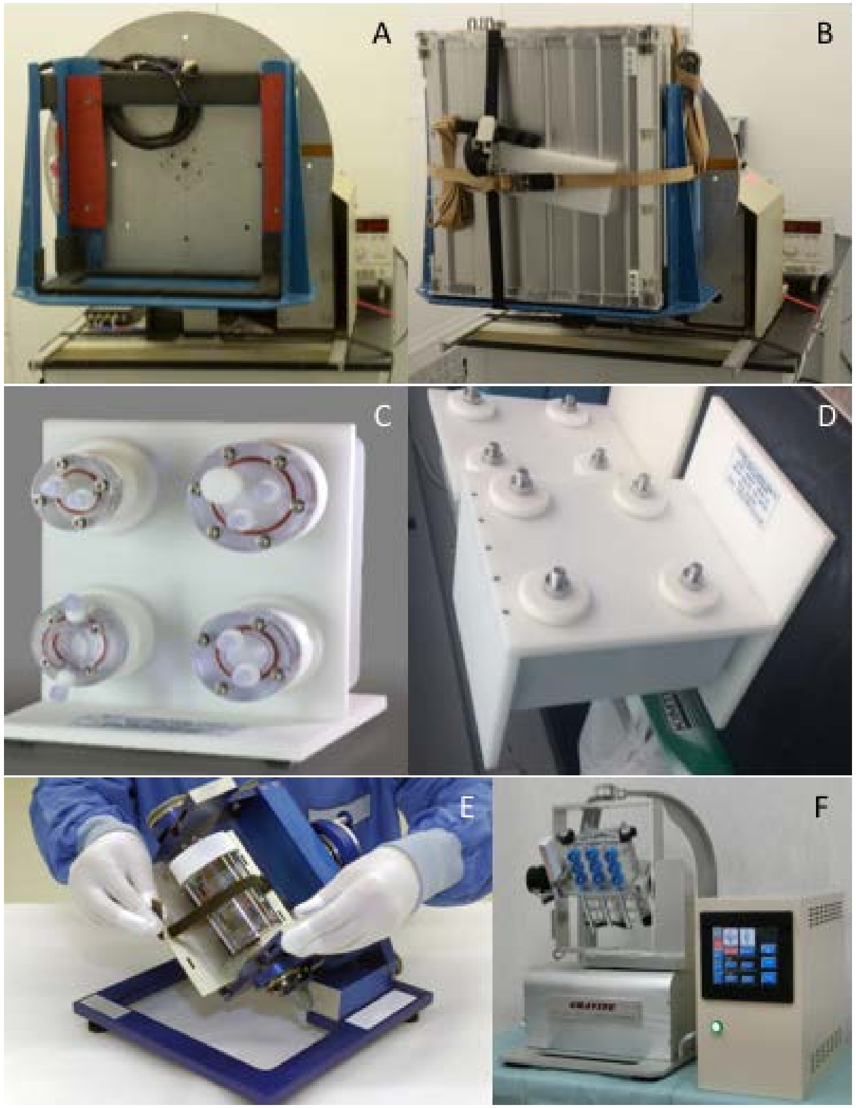
Microgravity Simulators for Ground-Based Gravitational Research (Appendix D)

Objective:

Provide the U.S. Space Biology research community a **ground-based micro-g & partial-g simulation capability** composed of devices that negate the directional influence of the “g” vector (e.g. 2D & 3D Clinostats, Random Motion Machines, Rotating Wall Vessels).

Clinostats currently available for use.

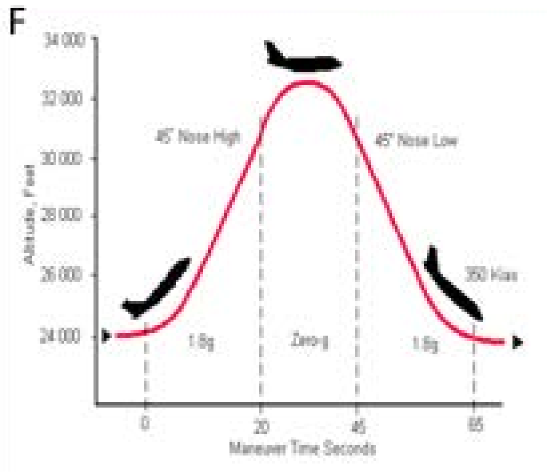
A. KSC Slow Rotating Clinostat for large containers (up to 32 kg).
B. KSC Slow Rotating Clinostat in ISS stowage locker configuration.
C. Rotating Wall Vessel (Micro-*g* configured with HARV’s attached).
D. Rotating Wall Vessel holder in 1*g* “control” configuration.
E. Airbus RPM 2.0 configured with experimental vessel.
F. Space Bio-Laboratories, Inc. GRAVITE RPM.



Parabolic Flight Campaigns for Microgravity and Partial Gravity Life Science Experiments (Appendix E)

Objective:

Establish a **yearly Parabolic Flight Campaign** for Life Scientists that will provide opportunities for short duration **micro-g and partial-g** investigations.

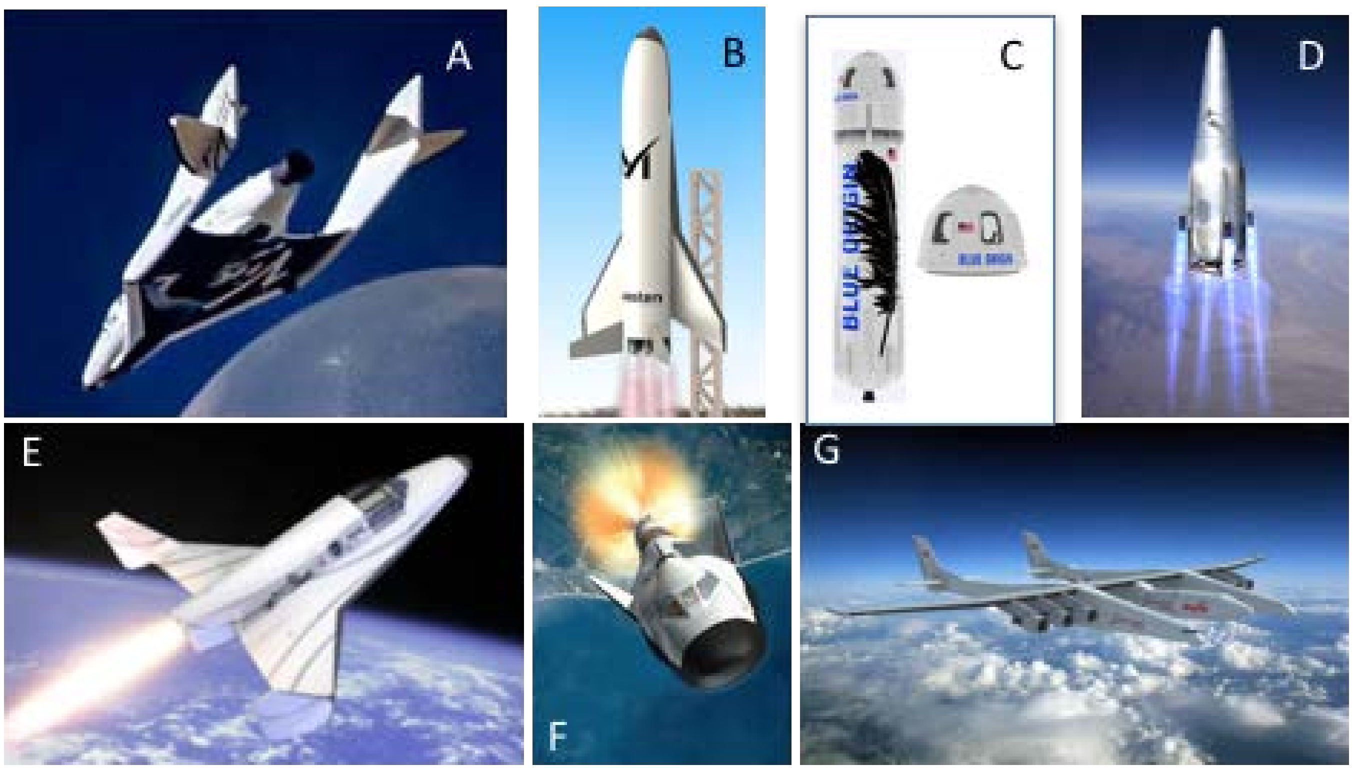


Some Commercial Parabolic Flight Providers.

A. Starfighters Aerospace F104.
B. Starfighters Aerospace Falcon 20.
C. Swiss Space Systems Airbus A310.
D. T-6 Texan WWII Warbird.
E. Zero Gravity Corp Boeing 727.
F. Parabolic Flight Profile.

Suborbital Flight Campaigns for Microgravity Life Science Experiments (Appendix E)

Objective: Establish yearly Suborbital Flight Campaigns that will provide 200-300 sec micro-g and partial-g exposures for life science investigations.



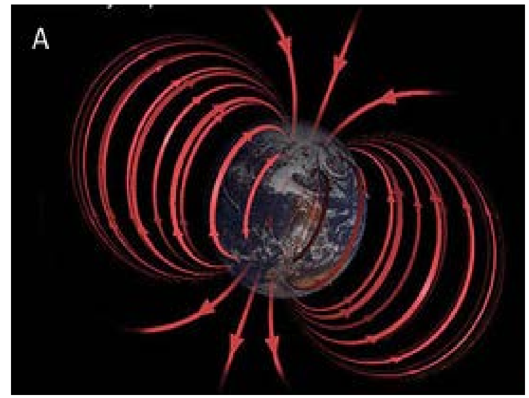
Some Commercial Suborbital Launch Vehicles: A. Virgin Galactic SpaceShip Two. B. Masten Space Systems Experimental Spaceplane XS-1. C. Blue Origin New Shepard. D. Armadillo Aerospace Next Generation Rocket. E. XCOR Aerospace Lynx. F. Sierra Nevada Dream Chaser. G. Stratolaunch Systems Carrier Aircraft.

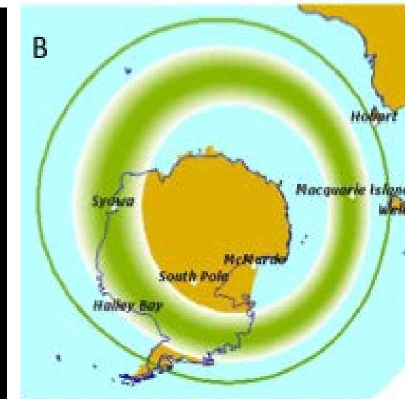
Antarctic Balloons for "Deep Space" Life Science Radiation Studies (Appendix F)

Objective: Facilitate Deep Space Radiation High Altitude 1-16 week life science investigations.

Earth's Magnetic Field Protects us from Space Radiation:

- Most dangerous particles don't hit the Earth's surface because they are forced by **the Earth's magnetic field** to move around the Earth.
- Particles do enter at the magnetic north and south poles where the magnetic field points directly into the ground, so in those areas **particles from deep space** are free to rain in.
- The result is a **Space Radiation** environment **comparable to what the crew will experience on the way to Mars**.





A. Depiction of the magnetic field lines of the Earth showing polar region areas of deep space radiation penetration. B. View of Auroral Zone's ring shaped region representing the area of deep space radiation penetration with a 2500 km radius around the Earth's magnetic pole (about 2000 km away from the geographic pole). C. Investigators will develop hardware (either Cube-based or TBD) that piggyback on the primary science payload's gondola.

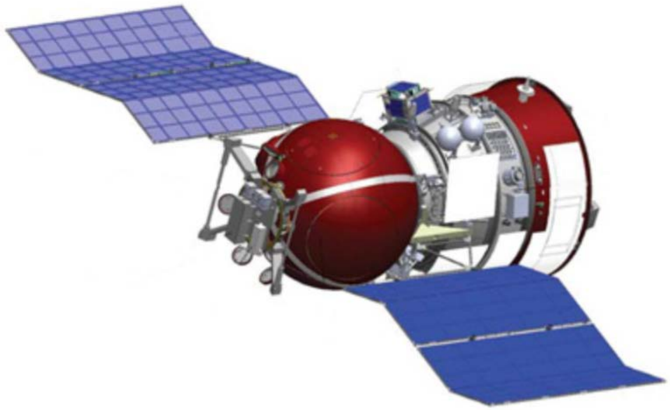
Bion-M2 Free Flyer Mission: Russian/US Collaboration (Appendix C)

Goal: To investigate systemic, cellular and molecular mechanisms underlying adaptation of mice and other model organisms to the combined effects of microgravity, cosmic radiation and other spaceflight factors as well as their readaptation to the terrestrial environment upon return to Earth.

- Bion-M2 experiments will be performed on space-flown C57BL/6 mice as well as ground controls housed in flight habitats and exposed to a simulated flight environment (and vivarium controls).
- Biosamples will be collected to detect acute spaceflight effects 1) approximately 2-3 hours after landing; 2) 14-17 hours after landing; 3) 3 days and 4) 7 days after landing.
- Other model organisms will also be flown.

Bion Characteristics

- 2.5 m Sphere used for spaceflight experiments
- 700 kg of payload mass (4 cubic meters) within recoverable module
- 800-1000 km circular orbit for 30 days
- Internal Pressure: 660-960 mm Hg (typically 720-760 mm Hg)
- pO_2: 140-180 mm Hg
- pCO_2: <7 mm Hg (typically <1 mm Hg)
- Relative Humidity: 30-80%
- Capsule Temperature: 18-28C (targets 25 +/- 0.3C
- Average Power: 350+ Watts
- Inclination Angle: 62.8° or 82.3 °
- Period: Approximately 90 minutes
- Flight Duration: 21-60 days



Exploration Mission-1 (EM-1): Payload Concept

SLPSRA Path Forward Plan

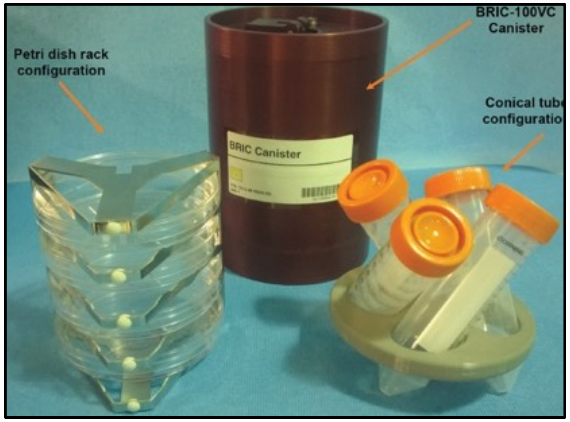
- Release Appendix listing Payload Constraints and requesting science community to propose to use a diverse group of model organisms (cells, plants, microorganisms, invertebrates) within the provided capabilities (BRIC 100VCs, others).
- Peer Review Submitted Proposals and select scientifically meritorious proposals (Score ≥ 70) for Technical Feasibility and Programmatic Relevance.
- Implement EM-1 Payload Experiments.

Mission Flight Plan

- 21-42 day mission duration.
- Payload turn over at L-7 to 30 days (up to 65 days due to launch delays).
- Vehicle return, recovery, and transport to KSC 2-5 days
- Payload Retrieval and Science De-integration 3-5 days
- Internal crew compartment temp predictions: 60-95°F
- Payload shall meet all requirements during and after exposure to thermal range of 49-143°F (MPCV.SBP.007)

Passive Payload (replaces Mass Simulator in Orion Crew Compartment)

- Housing can contain space for several experiments.
- Containment container will be mounted to an interface plate for attachment.
- Interface and payload must meet Orion requirements.
- Multiple proposals may be awarded 3 year grants (TBD).
- Allowable payload dimensions and CG location are baselined.



Concept of Operations Under Consideration

- Fly 6-8 BRIC-100VC canisters with dosimeters and data loggers.
- Petri dishes or other biology containment options (conical tubes, etc.) loaded into autoclaved canisters.
- Canisters flushed with PI-specified gas mixtures (e.g. 5% CO_2).
- Canisters installed into Orion, launch, recovery, post-flight analysis.

SLPSRA Space Biology Solicitation Plan

Appendix C: Bion-M2

Appendix D: Microgravity Simulator

Appendix E: Parabolic/Suborbital Flight Campaign

Appendix F: Antarctic Balloon Campaign

Appendix G:

- Individual Flight Grants
- Individual Ground Grants
- Team Flight Grants
- Team Ground Grants
- New Investigator Grants
- Post-Doc Grants

Appendix TBD: EM-1

Space Biology Summary

Enabling exploration and pioneering scientific discovery:

- Aligning to NASA's needs and performing fundamental research

Developing alternative platform science pipeline while emphasizing ISS research

- ISS crew time is at an all time high
- Pursuing partnerships and collaborations

Returning to annual NRA cadence

- Balancing flight and ground portfolio

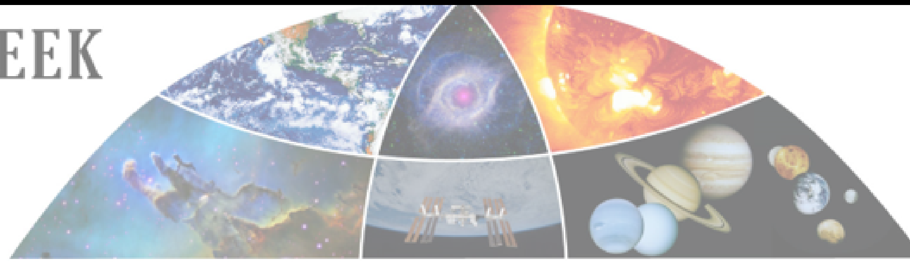
Student opportunities

- High school, undergraduate, and graduate student opportunities available

CBPSS

SPACE SCIENCE WEEK

The National Academies of SCIENCES ENGINEERING MEDICINE



SPACE SCIENCE WEEK
SPRING 2017 MEETING OF THE COMMITTEE ON BIOLOGICAL AND PHYSICAL SCIENCES IN SPACE
March 29, 2017
NAS Building – 2101 Constitution Ave NW – Washington D.C
SYMPOSIUM AGENDA

Wednesday March 29, 2017

COMMITTEE ON BIOLOGICAL AND PHYSICAL SCIENCES IN SPACE (CBPSS) – Room125

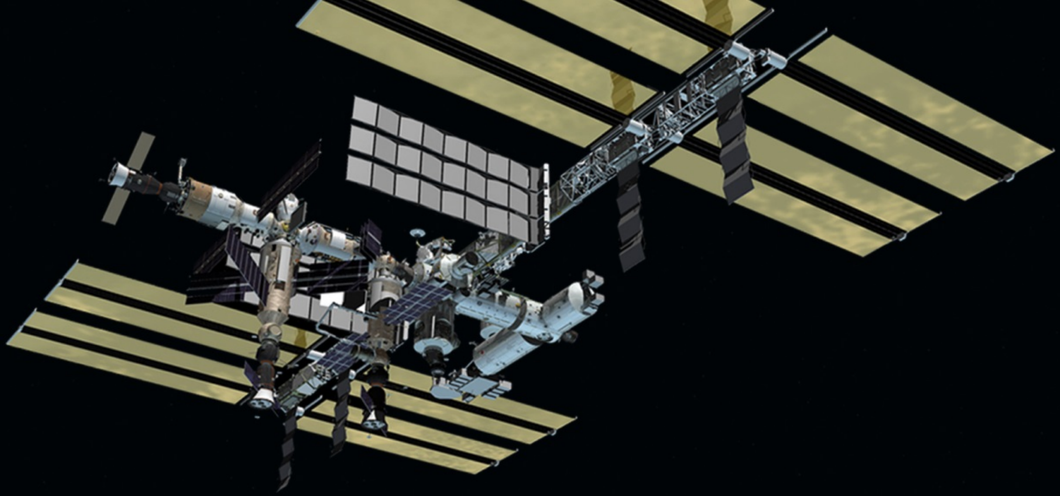
7:30 AM	*Registration opens and breakfast is available in the Great Hall*	

OPEN SESSION

Symposium: Exploration Systems Interface with Biological and Physical Behaviors

8:50 AM	**Welcome and Introductions**	**Robert Ferl and Elizabeth Cantwell, Co-Chairs**
9:00 AM	**Framing the Discussion: Space Research in the Age of Translational Science**	**James Pawelczyk** **Pennsylvania State University**
9:45 AM	*Break available outside room*	
10:00 AM	**Spacecraft and Surface Habitation Technology Interface with Physical Phenomena**	

Thank you!



National Aeronautics and Space Administration

Space Biology

RESEARCH FOR HUMAN EXPLORATION

QUESTIONS?

Space Biology

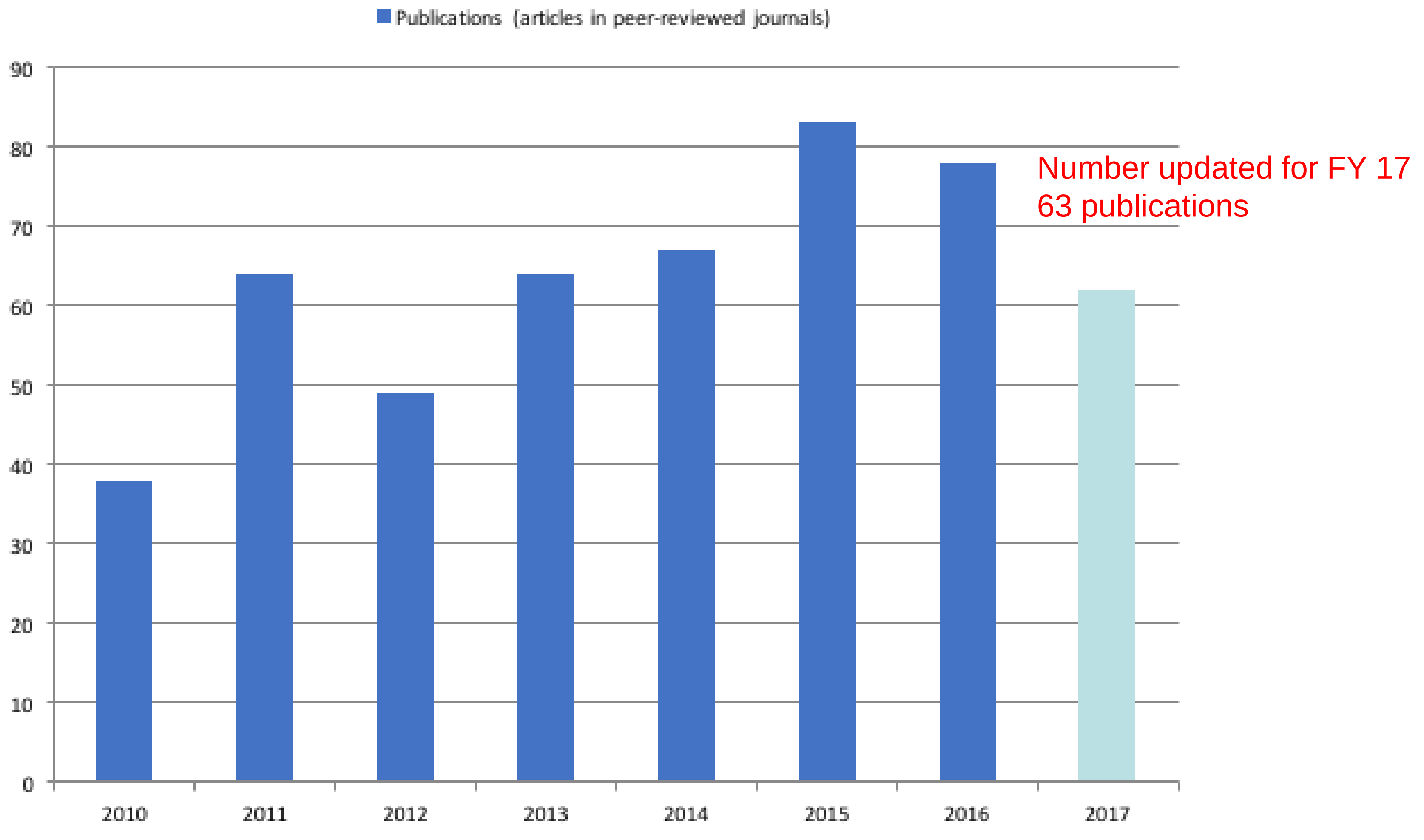
Space Life and Physical Sciences Division
Human Exploration and Operations Mission Directorate
David Tomko, Ph.D., Program Scientist

National Academy of Science Committee on
Biological and Physical Sciences in Space
October 31, 2017
3:15 – 4:00 PM

SUPPLEMENTARY MATERIAL FOR THE COMMITTEE

Research for Human Exploration

Publications (articles in peer-reviewed journals)



SLPSRA NRA Plant Space Flight Study Grants

"Utilizing ISS to Uncover Microgravity's Impact on Root Development & Cell Walls"	
PI: Elison Blancaflor	**Noble Foundation**
"Proteomics Analysis of *Arabidopsis* Seedlings in Microgravity"	
PI: Sarah Wyatt	**Ohio University**
"Characterizing Plant Gravity Perception Systems"	
PI: Chris Wolverton	**Ohio Wesleyan University**
"An Integrated Omics Guided Approach to Lignification and Gravitational Responses in Plants"	
PI: Norman Lewis	**Washington State Univ Pullman**
"Novel Explorations into the Interactions Between Light and Gravity Sensing in Plants."	
PI: John Kiss	**Miami University**
"Epigenetic Change in *Arabidopsis* in Response to Spaceflight Differential Cytosine DNA Methylation of Plants on ISS"	
PI: Anna-Lisa Paul	**Univ of Florida, Gainsville**
"Spaceflight-Induced Hypoxic/ROS Signaling"	
PI: Simon Gilroy	**Univ of Wisconsin, Madison**
"Using *Brachypodium distachyon* to Investigate Monocot Plant Adaptation to Spaceflight"	
PI: Patrick Masson	**Univ of Wisconsin, Madison**
"Transcriptional and Post Transcriptional Regulation of Seedling Development in Microgravity."	
PI: Imara Perera	**North Carolina State University**
"Mechanisms for Plant Adaptation to the Space Environment"	
PI: Federica Brandizzi	**Michigan State University**
"Assessment of Nutritional Value and Growth Parameters of Space-Grown Plants."	
PI: Karl Hasenstein	**Univ of Louisiana Lafayette**
"Elucidating the Nitrogen Cycle of Eu:CROPIS (Euglena: Combined Regenerative Organic-food Production in Space)."	
PI: Rocco Mancinelli	**Bay Area Environmental Research Institute**

HRP/SLPSRA ILSRA Food Production Space Flight Grant

"Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System: Veg-04, Veg-05
PI: Gioia D. Massa — **NASA Kennedy Space Center**

SLPS Supported Life Science Tech Demo Space Flights

"GeneLab Process Verification Test: BRIC-23"
Sci Collaborators: Wayne Nicholson & Patricia Fajardo-Cevazos — **Univ of Florida, Gainsville**

"Biological Research In Canisters-Light Emitting Diodes Validation Flight Experiment (BRIC-LED-01) "
Sci Collaborators: Anna-Lisa Paul & Rob Ferl — **Univ of Florida, Gainsville**

"Veggie Series Proof of Concept Flights: Veg-01a,b,c"
Science Team Lead: Gioia D. Massa — **NASA Kennedy Space Center**

"Veggie Series Proof of Concept Flights: Veg-03a,b,c"
Science Team Lead: Gioia D. Massa — **NASA Kennedy Space Center**

"Veggie Series Proof of Concept Flights: Veg-03d,e,f"
Science Team Lead: Gioia D. Massa — **NASA Kennedy Space Center**

"Veggie Series Proof of Concept Flights: Veg-03g,h,i"
Science Team Lead: Gioia D. Massa — **NASA Kennedy Space Center**

SLPSRA NRA Plant Ground Study Grants

"Mechanosensitive Ion Channels in Plants: Genetic, Computational and Systems-Level Approaches to Understanding their Proposed Role in Gravity Perception."
PI: Elizabeth Haswell — **Washington Univ. St. Louis MO**

"The Role of Vacuole Membrane Fusion in Plant Gravity Perception."
PI: Marcia Rojas-Pierce — **North Carolina State Univ.**

"Defining the Role of the Receptor like Kinase FERONIA in Plant Architecture Development under Mechanical Load."
PI: Gabriele Monshausen — **Pennsylvania State Univ.**

"Early Stage Plant Adaptation to Spaceflight – Molecular Responses of Arabidopsis to the Transition from Terrestrial Environment to Space."
PI: Rob Ferl — **University of Florida, Gainsville**

"GeneLab: Revealing Spaceflight- and Gravity-Response Networks in Plants."
PI: Simon Gilroy — **University of Wisconsin, Madison**

"Using GeneLab Data to Identify Novel Gravity Sensory Components in Arabidopsis."
PI: Elliot Meyerowitz — **Cal Tech.**

"The Use of Light Quality, Intensity, and Spectrum to Drive Metabolite Production in Plants."
***Postdoc Fellowship (NPP)*: Matthew Mickens** — **NASA Kennedy Space Center**

SLPSRA NRA Rodent Space Flight Grants

"The Role of P21/CDKN1a Pathway in Microgravity-Induced Bone Tissue Regenerative Arrest - A Spaceflight Study of Transgenic P21/CDKN1a Null Mice in Microgravity."
PI: Eduardo Almeida — **NASA Ames Research Center**

"Collection of Immune/Stress-related Tissues from Mice Flown on ISS."
PI: Stephen K. Chapes — **Kansas State University**

"Effects of Microgravity on Cerebral Arterial, Venous, and Lymphatic Function: Implications for Elevated Intracranial Pressure."
PI: Michael Delp — **Florida State University**

"Effects of Spaceflight on Ocular Oxidative Stress and the Blood-Retinal Barrier."
PI: Delp, Michael — **Florida State University**

"Free Radical Theory of Aging in Space."
PI: Ruth Globus — **NASA Ames Research Center**

"Space flight environment induces remodeling of vascular network and glia-vascular communication in mouse retina."
PI: Xiao Wen Mao — **Loma Linda University**

"Role of Oxidative Stress in Mediating the Effects of Combined Exposure to Simulated Microgravity and Radiation on Neurovascular Remodeling in Mouse."
PI: Xiao Wen Mao — **Loma Linda University**

"Impact of Spaceflight on Primary and Secondary Antibody Responses."
PI: Michael Pecaut — **Loma Linda University**

"Space Adaptation Effects on Immune System Impacts Reproductive Function and Mammary Gland Development Across Generations"
PI: Janice Pluth — **Lawrence Berkeley National Laboratory**

SLPSRA NRA Rodent Space Flight Grants (continued)

"Foundational In Vivo Experiments on Osteocyte Biology in Space."
PI: Alexander Robling — **Indiana University**

"Female Reproductive Health: Space Flight Induced Ovarian and Estrogen Signaling Dysfunction, Adaptation, and Recovery."
PI: Joseph S. Tash — **University of Kansas Medical Center**

"Spaceflight-Induced Changes in Non-Shivering Thermogenesis and Effects on Bone in Mice."
PI: Russell T. Turner — **Oregon State University**

"Effects of Spaceflight on Gastrointestinal Microbiota in Mice: Mechanisms and Impact on Multi-System Physiology ."
PI: Fred W. Turek — **Northwestern University**

"Exercise Countermeasures for Knee and Hip Joint Degradation during Spaceflight."
PI: Jeffrey S. Willey — **Wake Forest University**

"Effects of Microgravity Adaptations on Cephalic Lymphatic Function and Associated Edema Development and Immune Dysfunction."
PI: David Zawieja — **Texas A&M University**

"Effects of Microgravity on Lymphatic Proliferation and Transport Efficiency in the Gastrointestinal System of C57BL6 Mice."
PI: David Zawieja — **Texas A&M University**

"Vascular Health in Space: MicroRNAs in Microgravity."
PI: Robert Robbins — **Texas Heart Institute/Texas Medical Center**

SLPSRA NRA Rodent Ground Grants

"Bone Loss During Simulated Weightlessness: The Role of Osteoclasts."
PI: Joshua Alwood — NASA Ames Research Center

"Genes that Predict the Loss of Bone during Weightlessness."
PI: Stefan Judex — State University of New York, Stony Brook

"Redox Regulation of nNOS Translocation and Muscle Atrophy During Mechanical Unloading."
PI: John Lawler — Texas A&M, College Station

"Role of Oxidative Stress in Mediating the Effects of Combined Exposure to Simulated Microgravity and Radiation on Neurovascular Remodeling in Mouse."
PI: Xiao Wen Mao — Loma Linda University

"Musculoskeletal response to a partial-gravity analog in rats: structural, functional and molecular alterations."
PI: Seward Rutkove — Beth Israel Deaconess Medical Center, Inc.

HRP/SLPSRA Rodent Ground Grant

"Partial-Gravity Dose Response: Roles of vestibular input and sex in response to AG."
PI: Charles Fuller — University of California, Davis

SLPSRA NRA Microbial Space Flight Study Grants

"Evolution of Genotypic and Phenotypic Changes in Yeast Related to Selective Growth Pressures Unique to Microgravity"
PI: Tim Hammond — **Dept of Veterans Affairs**

"Yeast Colony Survival in Microgravity Depends on Ammonia Mediated Metabolic Adaptation and Cell Differentiation - Flight."
PI: Timothy Hammond — **Institute for Medical Research, Inc.**

"Global Transcriptome Profiling to Identify Cellular Stress Mechanisms Responsible for Spaceflight- Induced Antibiotic Resistance"
PI: Wayne Nicholson — **Univ of Florida, Gainsville**

"Experimental Evolution of *Bacillus subtilis* Populations in Space; Mutation, Selection and Population Dynamics."
PI: Craig Everroad — **NASA Ames Research Center**

"Investigating the Physiology and Fitness of an Exoelectrogenic Microorganism Under Microgravity Conditions."
PI: John Hogan — **NASA Ames Research Center**

"ISS– Microbial Observatory of Pathogenic Virus, Bacteria, and Fungi (ISS-MOP) Project."
PI: Crystal Jaing — **Lawrence Livermore National Security, LLC**

"Spaceflight Effects on Bacterial Antibiotic Resistance and its Genetic Basis "AntimicrobialSat"."
PI: A.C. Matin — **Stanford University**

"High Dimensional Biology to Understand the Functional Response of *Salmonella* to Long-Term Multigenerational Growth in the Chronic Stress of Microgravity."
PI: Cheryl Nickerson — **Arizona State University**

"Genotypic and Phenotypic Responses of *Candida albicans* to Spaceflight."
PI: Sheila Nielsen-Preiss — **Montana State University**

SLPSRA NRA Microbial Space Flight Study Grants (continued)

“Characterizing the Effects of Spaceflight on the *Candida albicans* Adaptation Response .”
PI: Sheila Nielsen-Preiss — **Montana State University**

“Bacterial, Archaeal, and Fungal Diversity of ISS-HEPA Filter System.”
PI: Kasthuri Venkateswaran — **NASA Jet Propulsion Laboratory**

“ISS Microbial Observatory – A Genetic Approach.”
PI: Kasthuri Venkateswaran — **NASA Jet Propulsion Laboratory**

“Influence of Microgravity on the Production of Aspergillus Secondary Metabolites (IMPAS) - a Novel Drug Discovery Approach with Potential Benefits to Astronauts' Health.”
PI: Clay Wang — **University of Southern California**

“The Integrated Impact of Diet on Human Immune Response, the Gut Microbiota, and Nutritional Status During Adaptation to Spaceflight.”
PI: Grace Douglas — **NASA Johnson Space Center**

“Experimental Evolution of *Bacillus subtilis* Populations in Space; Mutation, Selection and Population Dynamics.”
PI: Craig Everroad — **NASA Ames Research Center**

SLPSRA NRA Microbial Ground Study Grants

"RNA Deep Sequencing and Metabolomic Profiling of Microgravity-Induced Regulation of the Host-Pathogen Interaction: An Integrated Systems Approach."
PI: Cheryl Nickerson — Arizona State University

"Effects of Microgravity on the Risks of Space Radiation-Induced *Leukemogenesis*."
PI: Christopher Porada — Wake Forest University

"Comparative Evaluation of Microbial Transcriptomic Responses to Spaceflight Stress: Elucidating Underlying Molecular Mechanisms."
PI: Wayne Nicholson — University of Florida, Gainsville

"Omics Data Mining of the ISS *Aspergillus fumigatus* Strains in Elucidating Virulence Characteristics."
PI: Nancy Keller — University of Wisconsin, Madison

"Virulence and Drug Resistance of *Burkholderia* species Isolated from ISS Potable Water Systems."
Postdoc Fellowship (Sloan ISS MoBE): Aubrie O'Rourke — J. Craig Venter Institute

SLPSRA NRA Cell-Based Space Flight Grants

"Osteogenic Differentiation of Somatic Stem Cells in Space: A Study Investigating the Role of CDKN1a/p21 on Mesenchymal Stem Cell Proliferation, Differentiation, and Regeneration in Microgravity."
PI: Elizabeth Blaber — NASA Ames Research Center

"The Impact of Real Micrograivty on the Proliferation of Human Neural Stem Cells and derived-Oligodendrocytes."
PI: Araceli Espinosa — University of California, Los Angeles

"Study of Mammalian Pluripotent Stem Cells in Microgravity."
PI: Bruce Hammer — University of Minnesota

"Spaceflight-Altered Motility Activation and Fertility-Dependent Responses in Sperm from Sea Urchin and Rodents."
PI: Joseph Tash — University of Kansas Medical Center Research Institute, Inc.

SLPSRA NRA Cell-Based Ground Study Grants

"Microgravity Effects on Co-cultured Vascular Cells Types."
PI: Josephine Allen — University of Florida, Gainesville

"Gravity-induced Plasticity in Mammalian Utricular Hair Cells: Intrinsic or Multisensory?"
PI: Larry Hoffman — University of California, Los Angeles

"Determination of Roles of Microgravity and Ionizing Radiation on the Reactivation of Epstein-Barr Virus."
PI: Satish Mehta — Enterprise Advisory Services, Inc.

"Integration of Mechanotransduction and T-cell Activation Thresholds: Understanding of the Effects of Mechanical Forces on Assembly and Integration of Signal Transduction Machinery During T-cell Activation."
PI: Clarence Sams — NASA Johnson Space Center

"Investigating the Effect of Microgravity on Extracellular Matrix, Nucleus Morphology, and Nucleus Functions."
Postdoc Fellowship (NPP): Srujana Neelam — NASA Kennedy Space Center

"Iron Overload and Oxidative Damage: Regulators of Bone Homeostasis in the Space Environment."
PI: Susan Bloomfield — Texas A&M University

SLPSRA NRA Invertebrate Space Flight Grants

"The Effects of Microgravity on Cardiac Function, Structure, and Gene Expression using the Drosophila Model."
PI: Rolf Bodmer — **Burnham Institute for Medical Research**

"Using Water Bears to Identify Biological Countermeasures to Stress During Multigenerational Spaceflight."
PI: Thomas Boothby — **University of North Carolina, Chapel Hill**

"Does Spaceflight Alter the Virulence of a Natural Parasite of *Drosophila*?"
PI: Shubha Govind — **City College of New York**

"Investigation of Host-Pathogen Interactions, Conserved Cellular Responses, and Countermeasure Efficacy During Spaceflight using the Human Surrogate Model *Caenorhabditis elegans*."
PI: Cheryl Nickerson — **Arizona State University**

"Determining muscle strength in space-flown *Caenorhabditis elegans*."
PI: Siva Vanapalli — **Texas Tech University**

SLPSRA NRA Invertebrate Ground Study Grants

"Epigenetic and Protein Expression Pattern Profiling of *Caenorhabditis elegans* Exposed to Time-Varying Gravitational Fields: a Multi-Generational Study."
PI: Chandran Sabanayagam — **University of Delaware**

Space Biology Research Accomplishments: New Findings

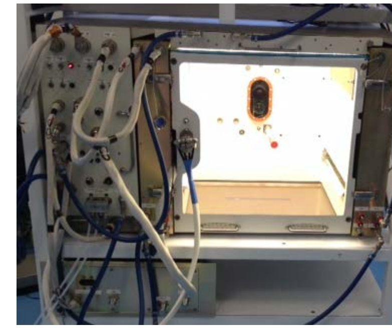
Publication Title	Space Biology Objectives	HRP Risks	Exploration Objectives	Pioneering Discovery
Differential responses of mechanosensitive osteocyte proteins in forelimbs and hindlimbs in hindlimb unloaded rats. (Bloomfield, NNX13AM43G) Ground Study Bone cells that sense mechanical force, known as osteocytes, send signals to bone-building cells (osteoblasts), both from unloaded hind legs and loaded front legs. This is the first study to report on site-specific changes of mechanosensitive osteocyte proteins in response to weight-bearing and disuse.	CMB-1 CMB-7 AN-1	Osteo-1 Osteo-3	P0-12	Yes
Validation of methods to assess the immunoglobulin gene repertoire in tissues obtained from mice on the International Space Station. (Chapes, NNX15AB45G) Ground Study – GeneLab Data System use A novel workflow was developed in this study using data from the GeneLab data system, which can be used for future studies on the antibody repertoire to understand immune dysregulation.	CMB-1 CMB-2 CMB-5	IM-2 IM-3	P0-12	Yes

Space Biology Research Accomplishments: New Findings

Publication Title	Space Biology Objectives	HRP Risks	Exploration Objectives	Enabling Pioneering Discovery
Whole metagenome profiles of particulates collected from the International Space Station. (Venkat, MO NNH12ZTT001N) Flight Study Species-level analyses demonstrated distinct differences between the ISS and cleanroom samples, indicating that the cleanroom population is not reflective of space habitation environments and overall microbial diversity was lower in the ISS, relative to the cleanroom samples.	MB-3 MB-5	Micro-2 Micro-3		Yes
Effects of low-dose rate gamma-irradiation combined with simulated microgravity on markers of oxidative stress, DNA methylation potential, and remodeling in the mouse heart. (Mao, NNX13AL97G) Ground Study This study has provided the first and relatively broad analysis of biomarkers of oxidative stress and cardiac remodeling in response to simulated microgravity + radiation. Further research is needed to fully characterize the early and late effects on the heart.	CMB-3 CMB-7 AN-2 AN-3	CV-1 CV-8 Acute-2 Degen-1 Degen-2 Degen-5 Degen-7	P0-12	Yes
Effects of spaceflight on the muscles of the murine shoulder. Shen H, Lim C, Schwartz AG, Andreev-Andrievskiy A, Deymier AC, Thomopoulos S. FASEB J. 2017 Aug 17. [Epub ahead of print] (Thomopoulos, NNX09AP05G) Flight Study Muscle responses to microgravity were muscle-type specific, short-duration spaceflight caused dramatic molecular changes to shoulder muscles and responses to reloading upon landing were rapid.	CMB-1 CMB-3 CMB-5 AN-3	M-23	P0-12	Yes

Advanced Plant Habitat (APH; *Now on ISS)*

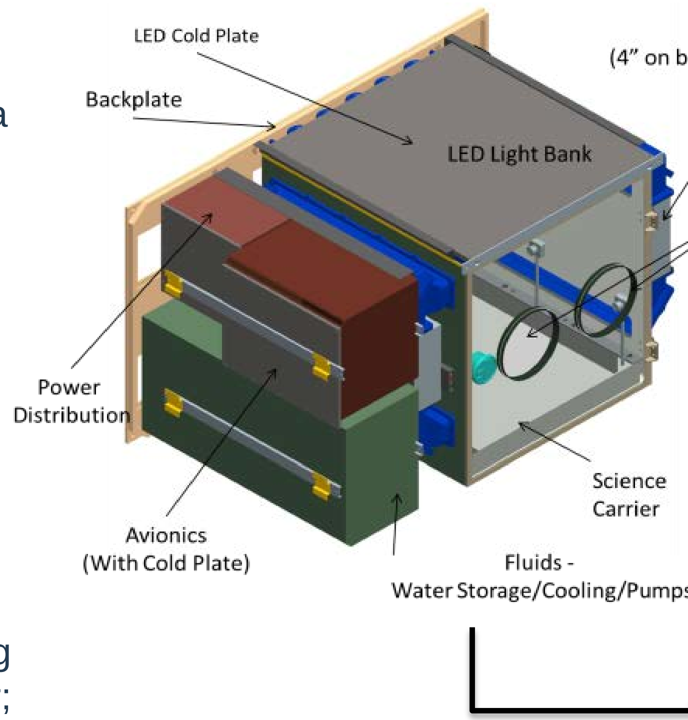
Advanced Plant Habitat (APH) = a large growth volume plant habitat capable of hosting multi-generational studies with environmental variables tracked and controlled in support of whole plant physiological testing (up to 135 days) and Bioregenerative Life Support System investigations.

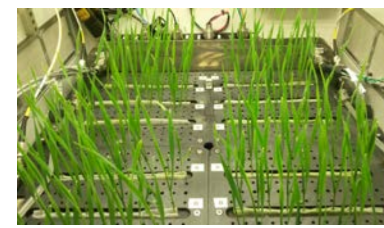


APH Engineering Design Unit (EDU).

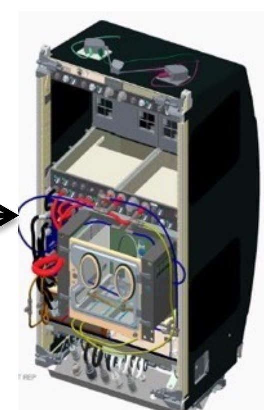
Specifications:

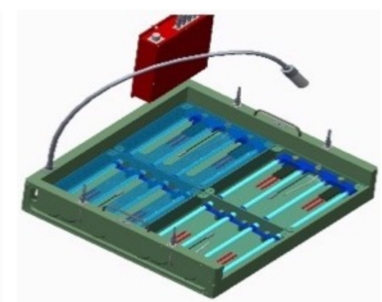
Max. Shoot Height 45 cm; Root Zone Height 5 cm, Growth Area 1,700 cm^2; Growth Volume 112,500 cm^3; Light Intensity <1000 mmoles [Red 630-660 nm, Blue 450±10 nm, Green 525±10 nm, Far Red 730 nm, White]; Temperature 18-30 C; Relative Humidity 50-90%; Condensate Recycled; CO_2 Controlled (400-5000 ppm); Air Flow @ 0.3-1.5 m/s; Ethylene Scrubbed to ≤ 25 ppb; Air Sampling Ports; Water Sampling Ports; Leaf Temperature Sensor; Root Zone Moisture Level Monitored; O_2 Sensors in both Shoot & Root Zone.





Dwarf Wheat Dwarf Wheat Grown within the APH EDU.





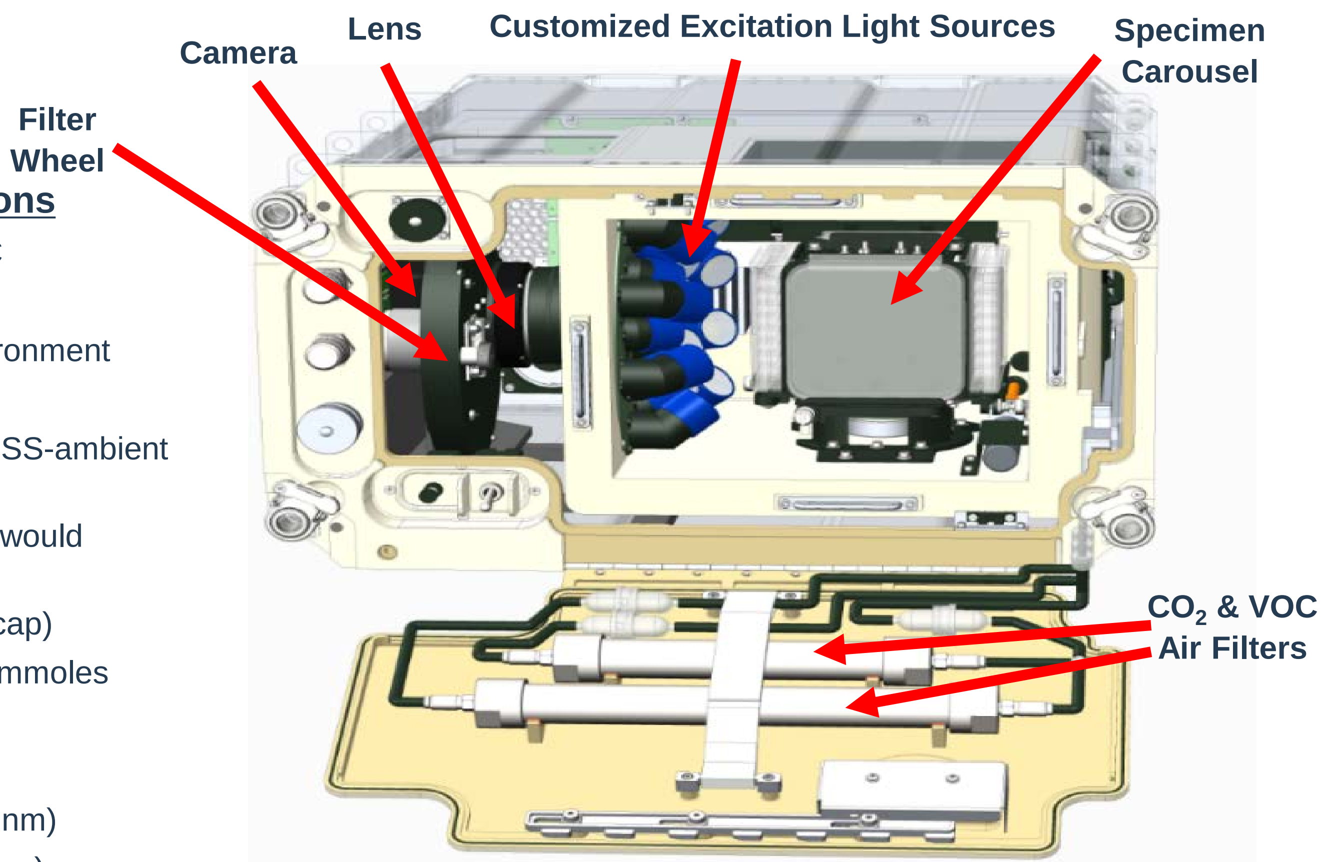
Science Carrier.

Spectrum: Multispectral Fluorescent Imager (SpaceX-15: June 2018)

- Images *in vivo* reporter genes using fluorescent proteins incorporated into model organisms.
- Accommodates 10 cm x 10 cm Petri plates, multi-well culture plates, & other custom containers.
- Capable of capturing high-resolution images with dissection scope level magnification.
- Data collection, storage & downlink retrieval for near-real time evaluation by the investigator team.

Internal Environmental Conditions

- Programmable Temperature: 18-37C
- Programmable Light Cycles
- Relative Humidity: Ambient ISS environment
- Ethylene scrubbing (< 25 ppb)
- CO_2 control (between 400 ppm and ISS-ambient levels in units of 100 ppm)
- Airflow to prevent condensation that would interfere with imaging.
- Lighting (at 10 cm beneath the light cap)
  - Broad-spectrum white light 0-100 mmoles (400-750 nm)
  - Darkness: <1 µmoles
  - Red light: 0-100 µmoles (630-660 nm)
  - Blue light: 0-50 µmoles (400-500 nm)
  - Green light 0-30 µmoles (520-530 nm)



Schematic displaying front view of Spectrum.

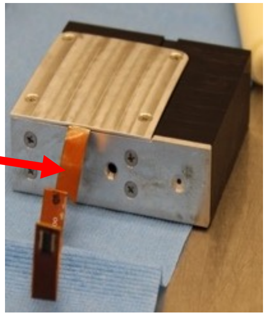
Biological Research In Canisters Light Emitting Diodes (BRIC-LED; 11/17)

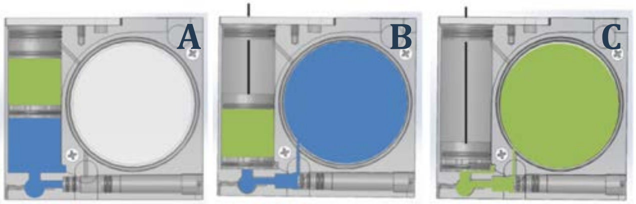
BRIC-LED Hardware Objective: Provide discrete illumination to biological specimens contained in 60mm Petri dishes that are subjected to a microgravity environment.

Petri Dish Fixation Units

Single or Dual Fluid Injections: 17mL total fluid volume for injection of Growth media and/or liquid treatments/preservatives/fixatives.

- N=36 60mm Petri dishes available per mission
- Capable of >150 µmoles of light
- >10% intensity resolution control for each wavelength
- 4 discrete LEDs types currently ranging from 430-750nm (blue, red, white and far-red)
- Customizable wavelengths
- Programmable lighting schedule with 1 sec resolution
- >70% light uniformity when using 4 discrete wavelengths
- Light tight from external sources



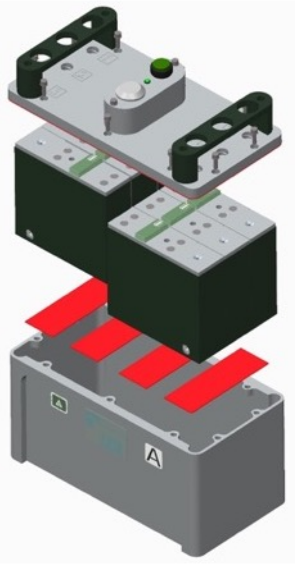


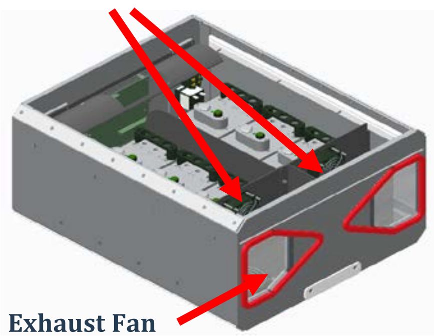
A. Pre-Actuation: Filled with 2 Fluids. B. 1st Actuation: Fluid 1 Dispensed. C. 2nd Actuation: Fluid 2 Dispensed.

BRIC-LED PDFU Lid showing LEDs.

Locker & Tray

- Resides in US Lab on ISS
- Holds 6 BRIC Canisters
- Canisters Travel up/down
- KSC Ground Station controlled
- Commanding start/stop of expt.
- Real time telemetry of Tray and Canister temperatures & LED status
- Forced air cooling to reject heat
  - 1.5C between Canisters
  - 3C from EXPRESS AAA air
- Internal Canister Pressure Logged
- Temperature Sensors on Canister Lid Boards
- One 3-Axis Accelerometer





Passive Orbital Nutrient Delivery System (PONDS; Jan. 2018)

PONDS is a new plant growth approach that contains both an area for a contained plant growth substrate and a reservoir for water and/or plant nutrient solutions. It was developed to fit under the Veggie light cap and replace the current Reservoir/Pillow Nutrient Delivery System used within Veggie on ISS. The system provides more reliable water delivery to seeds for germination (while avoiding overwatering), and fulfills the requirement to transport water from the reservoir for improved plant growth while providing adequate nutrients and aeration to the root zone under both 1g and microgravity conditions.

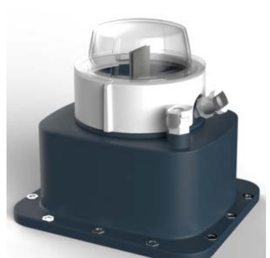
KSC Prototype

Ground Studies

Flight Unit Development Team: Techshot and Tupperware

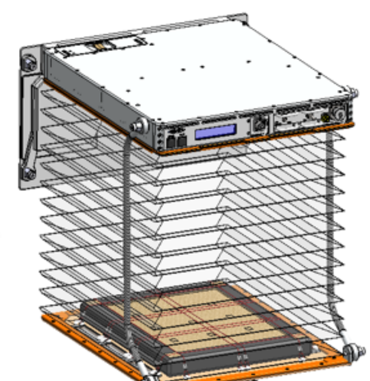
Current Status:

- CDR complete August 10th, and engineering unit delivery in November 2017.
- Progressing toward tech demo risk-reduction test on ISS with FHA of December 2017.
- Targeting Veg-04 & Veg-05.



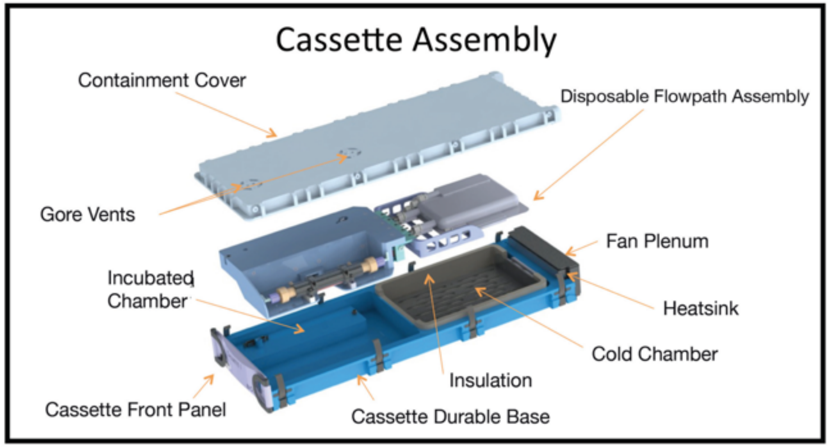
Tupperware Flight Design

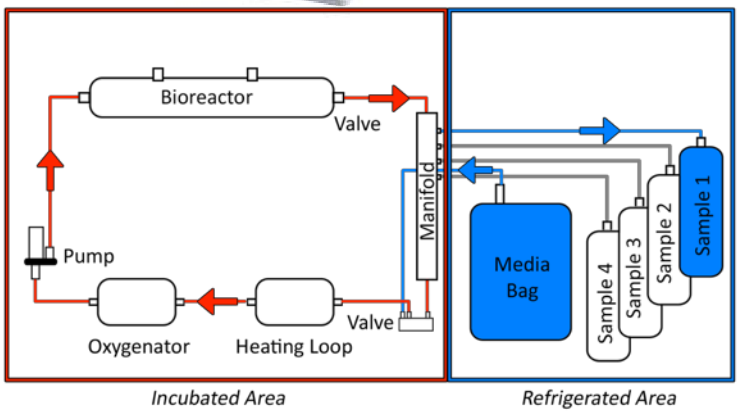
Conceptual image of six PONDS units as to be installed in Veggie.

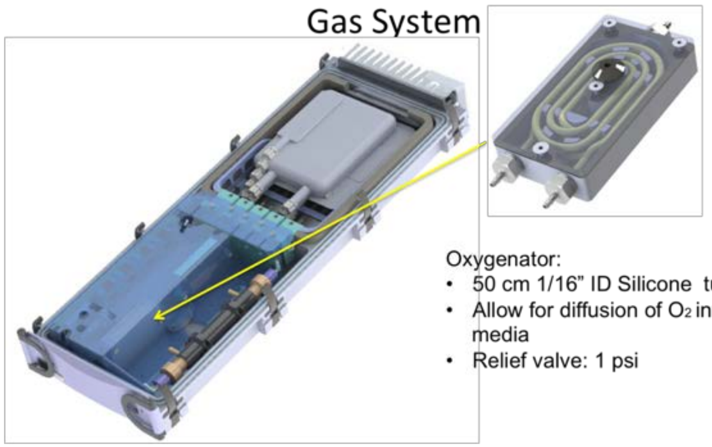


Bioculture System (SpaceX-13 Validation Flight: 11/28/17)

The Bioculture System is a perfusion culture system. The primary component is the hollow fiber bioreactor, designed to efficiently deliver nutrients and remove waste via multiple, tightly packed perfusion fibers. The hollow fiber system is particularly suited for microgravity cell culture where nutrient transfer is limited to diffusion. The increased surface area and low shear perfusion ensures that cells are receiving sufficient nutrients and gas to grow unabated.





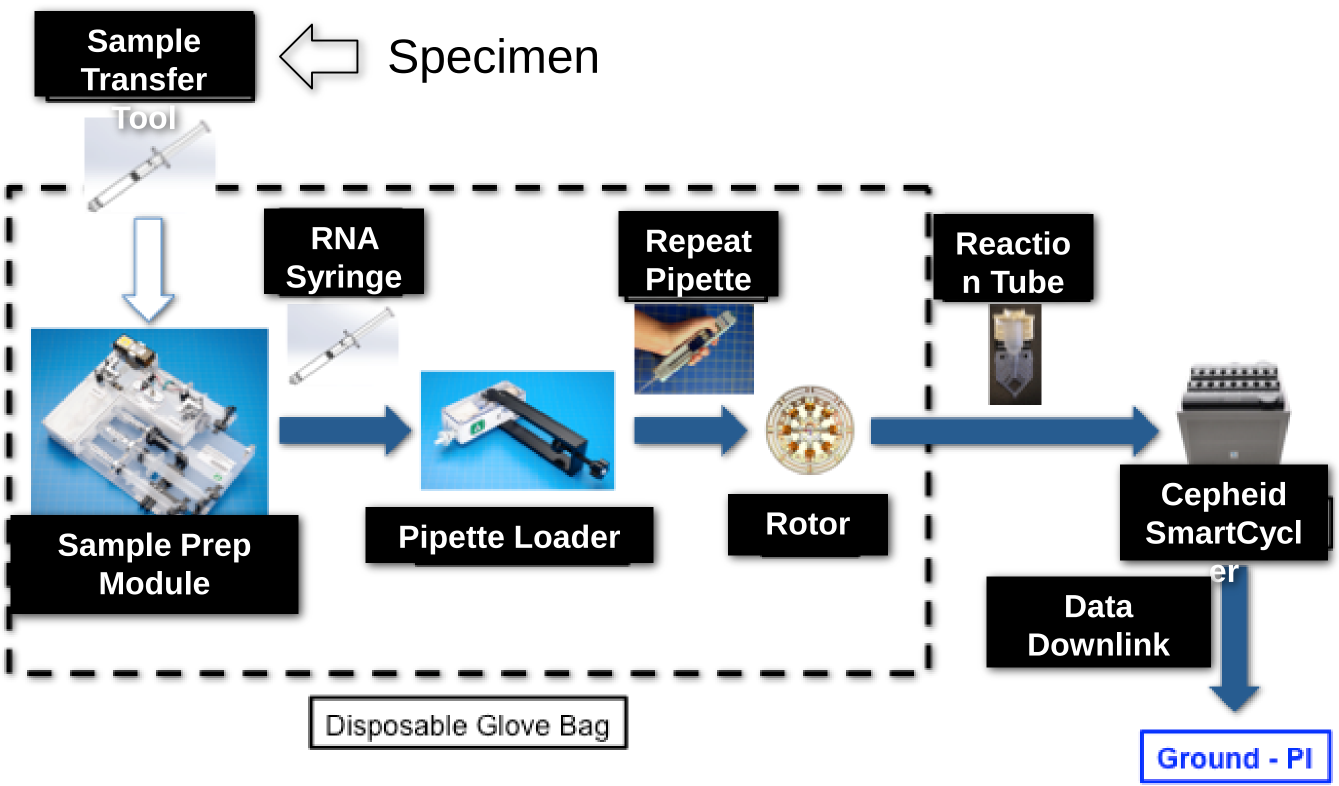


Oxygenator:
- 50 cm 1/16” ID Silicone tube
- Allow for diffusion of O_2 into media
- Relief valve: 1 psi

Wetlab-2 (Validated on ISS during SpX-8)

WetLab-2 System was developed to provide an on-orbit nucleic acid analytical capability. WetLab-2 is a research platform for conducting real-time quantitative gene expression and DNA genetic analyses. The COTS Cepheid SmartCycler and its PCR Reaction Tube were adapted for use on ISS in microgravity. The full system provides the ability to process samples on-orbit, isolate DNA and RNA, reverse transcribe RNA, and perform qPCR. The isolate nucleic acid is amplified and analyzed using the Cepheid SmartCycler. The data is downlinked for analysis within 2 hours of run completion. Purified RNA and DNA may be returned to the PI.

WetLab-2 Suite of Equipment and Workflow



Specifications:

Cepheid SmartCycler
- 16 qPCR in parallel
- 4 optical channels to measure fluorescence

- Reaction Tube
  - Carries reaction solutions and PCR primers
  - Up to quadplex reactions (currently validated for triplex reactions on-orbit)
- Sample Prep Module:
  - Capable of processing microbes, cells, and tissues
  - Sample lysis and extraction and purification of RNA & DNA
- Pipette Loader
  - Provides sample de-bubbler
- Rotor
  - Used with ISS Drill
  - Draws sample down to reaction solutions and primers in the Reaction Tube
- Protocols uplinked from ground

Veggie Unit #2 (on ISS now)

Veggie Configured for Growth of Vegetables


Veggie Light Bank

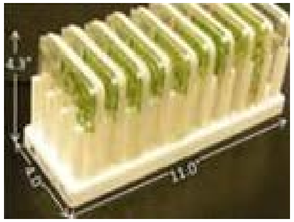

Veggie Plant Pillow


Veggie + 6 Plant Pillows


Veggie on ISS


Astronaut Steve Swanson harvesting Lettuce.

Veggie Configured for Petri Plate Science Experiments


Petri plate holder with *Arabidopsis* petri plates inserted.


Petri plate holder containing up to 30 *Arabidopsis* plates in Veggie with bellows closed.

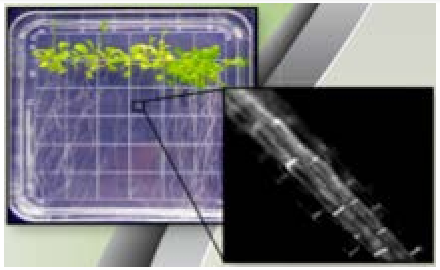


Image of *Arabidopsis* root taken in the Light Microscopy Module (LMM).


Astronaut Butch Wilmore fixing plants on the ISS using a Kennedy Space Center Fixation Tube (KFT).

Veggie is an easily stowed, high growth volume, low resource facility capable of producing fresh vegetables and supporting science experiments on ISS. It also provides real-time psychological benefits for the crew, and facilitates outreach activities.

Specifications:

Light:
- 100-500 μmol m^{-2} s^{-1} PPF of Red (630 nm), Blue (455nm) and Green (530 nm)

Cabin Air Fan Settings:
- Low / High / Off

Baseplate Footprint:
- 29.2 cm x 36.8 cm

Max. Height:
- 47.0 cm empty
- 41.9 cm with root mat

Brainstorming Event: Updates

Brainstorming Innovative Open Source Approaches to Food Production

- Information exchange event held at KSC July 12-13, 2017 to discuss novel solutions for food production in space
- Purpose: Bring people together to share new and creative ideas in food production and discuss how their solutions could help NASA solve some of its largest challenges in food production system development

Activities since workshop:

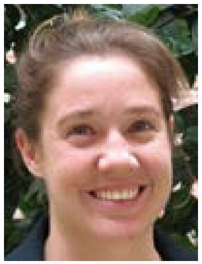
- Conducted follow-on conversations with MIT to plan collaborative next steps.
- Continued collaborations with Fairchild while adding lens of open source collaboration.
- Developed a shared folder on Google Drive and invited all

Additional Elements I Would Have Liked to See

- small group rotating discussion organized by prior online chat communication interest-grouping
- Smaller breakout sessions (combined sessions resulted in 20+ participants with talking dominated by 4-5)- ideal group size for discussion is 8-10
- Some breakout sessions had vague purposes. I think breakout sessions needed to be slightly longer. We don't have a shared vocabulary all the time and we need extra time in discussion. (2)
- more individual stakeholders
- I think next time we could see if there is enough interest to have a poster session? (4)
- I can't quibble, overall, the ratios of items was v good.
- Harvesting of crops and data collection procedures. (8)
- Action items from breakout sessions.

https://www.youtube.com/watch?v=QKdujWpIjSk

Sloan Foundation/NASA Space Biology MoBE Post-Doctoral Fellows



Michael Lee (Advisor – C. Everroad, NASA ARC); Expected start May 2018; Delay in start due to new results in his dissertation

Noelle Bryan (Advisor – M. Zuber, MIT); Funding initiated 9/13/17 Period of performance 9/13/17-9/12/19

Aubrie O'Rourke (Advisor – William Nierman, J. Craig Benter Institute)

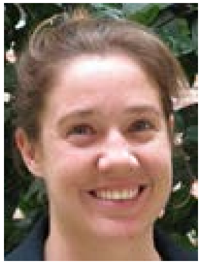
Amber Paul, Ph.D. (Bhattacharya Lab, Started July 2017)
Altered Gravity during Space Flight contributes to Immune Dysfunction through Stress-induced Heat Shock Proteins

Linda Rubenstein, Ph.D. (Globus Lab, Start Dec 2017)
Are the aging-like effects of microgravity in the immune system and vasculature preventable by quenching the mitochondrial ROS?

Cassandra Juran, Ph.D. (Almeida Lab; in Yr 2)
The regulatory effect of gravity loading on p21 expression in mouse stem cells: Proliferation, Osteoblast Differentiation, and Osteoclastogenesis control. **Study findings so far:** Cdkn1a/p21 knock-out mice under different mechanical loading regimens is showing that the absence of p21 encourages stem cell differentiation and function based on measurement in the bone of greater mineralization and physiologically relevant cell network morphology.

NASA Post-Doctoral Fellows

Masahiro Terada, Ph.D. (Globus Lab) – NPP Fellowship ended 9/30/17



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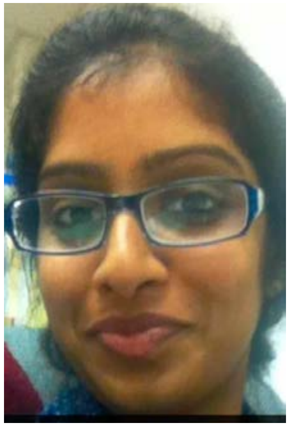
Are the aging-like effects of microgravity in the immune system and vasculature preventable by quenching the mitochondrial ROS?

Sloan Foundation/NASA Space Biology MoBE Post-Doctoral Fellows

Michael Lee (Advisor – C. Everroad, NASA ARC); Expected start May 2018; Delay in start due to new results in his dissertation
Noelle Bryan (Advisor – M. Zuber, MIT); Funding initiated 9/13/17 Period of performance 9/13/17-9/12/19
Aubrie O'Rourke (Advisor – William Nierman, J. Craig Benter Institute)



Post-Doc: **Srujana Neelam**

Advisor(s): Ye Zhang and Howard G. Levine, Kennedy Space Center

Cells reorganize their cytoskeleton when exposed to conditions of microgravity. Cell morphology and gene expression profiles are also altered. What causes these affects is not entirely understood. In normal gravity, cell morphology is linked to both nuclear morphology and gene expression. Cells sense the external cues and these cues alter the cytoskeletal forces and induce cytoskeletal reorganization, which in turn are sensed by the nucleus due to the mechanical coupling between the nucleus and the cytoskeleton. LINC complex proteins are found to be involved in mechanosensing and maintaining normal nuclear shape and gene expression. The hypotheses of this project are: 1. LINC complex plays a role in gravisensing; and 2. LINC complex associated nuclear reshaping regulates the responses of genome-wide transcriptome to altered gravity. Taking together, this study aims to understand how nuclear shape changes in microgravity in mammalian cells, what is its mechanism, and how it is related to microgravity induced genome-wide transcriptomic changes.

Relevance/Impact:

This study will contribute to establishing guidelines for future simulated microgravity research.

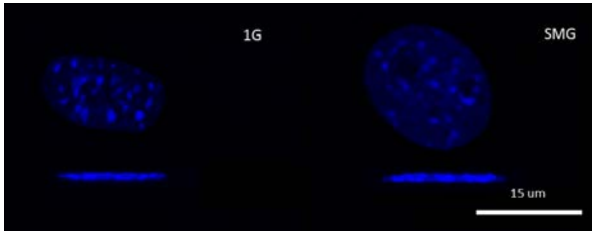
Pull (based on HEOMD Exploration Objectives): (1) P0-10: Evaluate Technologies that may Enable Operations with Reduced Logistics Capabilities: Plants produce food, oxygen, scrub CO_2, and clean water via transpiration thereby reducing resupply requirements. Plant spaceflight experiments contribute to our efforts to develop reliable autonomous culture of plants in an ECLSS/BLSS role for long duration missions. (2) P0-12: Enable Science Community Objectives in Low Earth Orbit. This objective encompasses all basic/fundamental research supported by SLPSRA NRA.

Pull (based upon direction within the NRC Decadal report): (1) Use "omics" analyses for space research. (2) Study how space environments affect model organisms. (3) Undertake Outreach & Training Activities. (4) Undertake Ground Studies investigating gravity sensing & response systems. (5) Study will contribute to establishing guidelines for future simulated micro-gravity research

Partnerships: (1) Dr. Neelam was invited to participate in Dr. Oliver Ullrich's sonic rocket and parabolic flight experiment in mid 2018. (2) Dr. Neelam is also involved as a Co-I in a collaborative effort between KSC and Dr. Kunal Mitra at Florida Institute of Technology to develop a 3D bioprinter and evaluate 3D tissue models using simulated microgravity. The title of the three year agreement with FIT is "Novel Biomanufacturing Platforms for 3D Culture Models For Spaceflight Applications."

Progress/Experiment Status: Grant Initiated 8/26/16.

- Dr. Neelam has completed several experiments and collected data using confocal microscopy to analyze nuclear shape change under simulated microgravity.
- Initial results showed simulated microgravity changed the nuclear shape (dimensions) in fibroblast cells.
- She will give an oral presentation titled "Effect of microgravity on the morphology of the nucleus in human fibroblast cells" in the ASGSR.



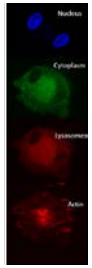


Figure. Example images of her recent experiments using confocal microscopy, (left) fibroblast cell nucleus with xyz views; and (right) cells labeled with multiple cellular markers.

Publications:

- Ye Zhang, Maria Moreno-Villanueva, Stephanie Krieger, Govindarajan T. Ramesh, Srujana Neelam, and Honglu Wu. "Transcriptomics, NF-κB pathways, and their potential spaceflight-related health consequences", ***IJMS***, 2017 May 31; 18(6): 1166. DOI: 10.3390/ijms18061166.
- A review manuscript "Biological pathways in response to the microgravity environment in mammalian cells" is in preparation.

The Use of Light Quality, Intensity, and Spectrum to Drive Metabolite Production in Plants
NPP Postdoctoral Fellowship

Post-Doc: **Matthew Mickens.** Ph.D. in Energy and Environmental Systems from North Carolina Agricultural and Technical State University

Advisor: Gioia Massa, Kennedy Space Center

To drive photosynthesis, light-emitting diodes (LEDs) are becoming the lighting technology of choice because of their efficiency, longevity, small size, safety, and wavelength versatility. Investigations are currently underway to test novel light combinations that can be used to optimize salad crop production within both Veggie and the Advanced Plant Habitat on ISS. Comparisons of plant growth responses to red and blue LEDs, various white LEDs, white LEDs combined with supplemental colors, and an artificial sunlight LED module are revealing optimal lighting environments for food production in space and indoor agriculture.

Progress/Experiment Status: Post-Doc Initiated 9/2/15. Currently in 3rd year of post-doctoral tenure. Preliminary findings have identified a spectrum with ratios of light similar to the solar spectrum that significantly improves biomass, texture, and overall appearance of 'Outredgeous' romaine lettuce in comparison to conventional LED combinations. The final crop planned for light quality testing during Mickens' tunure is 'Rubi F1' Pak Choi cabbage in Fall of 2017. Mickens has been instrumental in obtaining cutting-edge LED technology for NASA food production which includes 2 artificial sunlight LED fixtures and 3 prototype multispectral LED fixtures that closely simulate the Advanced Plant Habitat light cap.

Relevance/Impact:

- This project seeks to advance lighting options in controlled environments here on Earth, in space, Mars, and beyond.
- The discovery of optimal light spectra for specific crops ensures astronauts can grow plants to their full potential, and enables indoor farmers on Earth to equally optimize their crop production.

Pull (based on HEOMD Exploration Objectives): (1) P0-10: Evaluate Technologies that may Enable Operations with Reduced Logistics Capabilities: Plants produce food, oxygen, scrub CO_2, and clean water via transpiration thereby reducing resupply requirements. Plant spaceflight experiments contribute to our efforts to develop reliable autonomous culture of plants in an ECLSS/BLSS role for long duration missions. (2) P0-12: Enable Science Community Objectives in Low Earth Orbit. This objective encompasses all basic/fundamental research supported by SLPSRA NRA.

Pull (based upon direction within the NRC Decadal report): (1) Study Plant & Microbe Responses to Spaceflight (P2). (4) Investigate Plant Roles in Bioregenerative Life Support Systems (P3). (5) Undertake Outreach & Training Activities.

Partnerships: Partnership efforts are being developed between NASA and several LED manufacturers such as Hort Americas and OSRAM.

Publications: Two manuscripts are currently being drafted.

Fall Intern Profiles

Intern: **Christina Johnson, Ph.D.**
Mentors: Gioia Massa, Matt Romeyn, Matthew Mickens, KSC
Project Description: Currently evaluating seed sterilization techniques, seed viability, stress response, germination rates, microbiological effects, potential utilization of seed films, and managing tomato crop testing for ILSRA 'Pick and Eat'
Institution: Miami University, Oxford, OH
Major: Botany

Intern: **Brennan Cordova**
Mentors: Matt Romeyn, Ralph Fritsche, Matthew Mickens, KSC
Project Description: Currently developing and testing several microgravity water delivery methods for food production.
Institution: Ohio State University, Columbus, OH
Major: Biological Engineering

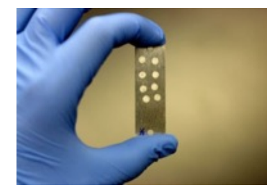
Intern: **Monica Torralba**
Mentors: Matthew Mickens, Gioia Massa, Matt Romeyn KSC
Project Description: Investigating plant response to light quality, intensity, and spectrum to drive biomass and metabolite production in plants.
Institution: New Jersey Institute of Technology, Newark, NJ
Major: Chemical Engineering

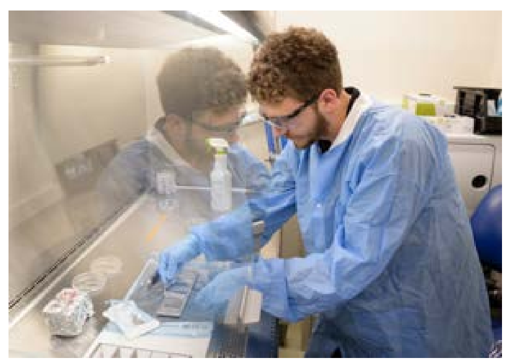
Intern: **Ceasar Udave**
Mentors: Ye Zhang, Srujana Neelam, KSC
Project Description: Investigating microgravity effects on nuclear structure in mammalian cells using confocal microscopy.
Institution: Arizona State University
Major: Biomedical Engineering (MS)

SLSTP 2017

Highlights:

- Participated in the 2017 ASGSR Meeting
- 5 Lightning Talks
- 12 Posters Presented
- Lily Neff recipient of 2nd place poster award
- Successfully flew and returned MicroStrat – microbiology (*P. xerothermoduran*) payloads as piggyback on balloons launched by NASA to monitor the August 2017 Great Eclipse. Students have volunteered to support analysis during the school year





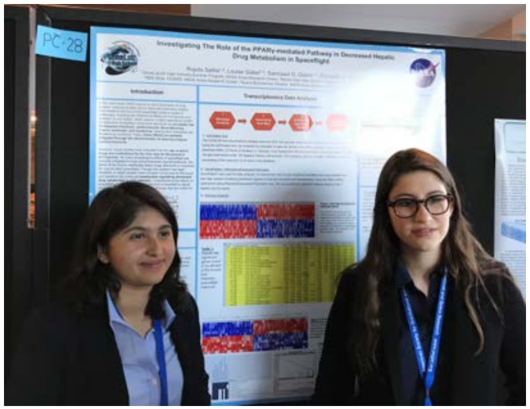
SLSTP Program Coordinator: Jon Rask

ARC Space Biology Project SLSTP Status Report

Project	Mentor	Student	Accomplishments/Findings
Hypergravity exacerbates endoplasmic reticulum (ER) stress in Drosophila melanogaster: an evaluation of countermeasures	Sharmila Bhattacharya	Andrew Pelos	• Created fly line that selective expresses GFP in dopaminergic (DA) neurons of the brain • Confocal analysis revealed decrease in DA neurons quantity in hypergravity treated flies throughout development consistent with ROS stress
Studies in Bone Biology and Biomechanics	Josh Alwood	Aimee Johnson	• Chronic 90 day 2G centrifugation of rats (Fuller collaboration) showed no difference in BV/TV, trabecular number, cancellous changes, or osteoclastogenic activity in femurs compared to 1xg controls
Exposing Microorganisms in the Stratosphere (E-MIST)	David Smith	Tristan Caro	• Validated method for dessicating the yeast (requires 10% trehalose) and duration of vaibility in dessication at different temperatures down to -80C. E-MIST flight in Dec. 2017
Development & testing of radiation biosensors for NASA's BioSentinel mission	Sergio Santa Maria (Sharmila Bhattacharya)	Sawan Dalal	• Evaluated different rad51 mutant strains and identified several with increased dessication tolerance
Skeletal responses to long-duration simulated weightlessness	Ruth Globus	Julia Adams	• 90 HU data demonstrated changes in proximal femur bone connectivity density, trabecular thickness, and number.
Candidate nutritional countermeasure to mitigate adverse effects of spaceflight	Ann-Sofie Schreurs (Ruth Globus)	Ons M'Saad	• Feeding HU+IR mice dried prune diet preserved vertebra L4 compressive strength property, prevented bone architecture loss and in the tibia. Initial ex-vivo analysis indicates partial rescue of osteoblast growth and mineralization capacities.
The Influence of Mechanical Unloading on Stem Cell-Based Tissue Regeneration	Elizabeth Blaber (Eduardo Almeida)	Esther Putman	• The absence of p21 reduces bone marrow stem cell senescence, maintenance of cell proliferation, rate of cell senescence appears to decrease for older mice (7 mo),
GeneLab Data Curation and Analysis	Homer Fogle (Sylvain Costes)	Maya Ramachandran	• Bioinformatics and computational analysis techniques identified candidate networks using RR-1tissues and the GeneLab Data System
Synthetic biology for solar system exploration: How do microbes respond to spaceflight and how can we utilize them for in situ manufacturing?	Jonathan Galazka	Lily Neff	• Conducted a multi-faceted screening process to that allowed identification of yeast strains that could be used in HARV studies. Identified 100 strains of yeast for the study.
Epigenetic Mechanisms and Sex Differences in Prenatal Programming of Adult Brain, Physiology and Behavior	April Ronca	Sophie Benson	2xg hypergravity induced stress in treated mice-placenta analysis: • Females – data shows a potential trend for decrease in factors that regulate corticosteroid levels in the placenta with increase in DNA methylase 3a

GeneLab for High Schools

- Students formed teams and submitted proposals as part of a GL4HS competition
- Winner attended ASGSR and will conduct their proposed investigation with a PI at NASA ARC



1st Place in GL4HS Proposal Competition and 2017 ASGSR High School Poster

Rujuta Sathe, Monte Vista High School, Cupertino

Louise Siskel, Sequoia High School, Pasadena

Investigating the Potential Roles of CIDEC, Acot2, Agpat9 via PPARG and C/EBPA expression in Decreased Hepatic Metabolism of Drugs in Space

Hypothesis: PPARγ and C/EBPα are mechanisms that cause decreased hepatic metabolism of drugs through the upregulation CIDEC , Acot2 , and Agpat9 in microgravity

The Effect of Gamma Radiation on the Cell Cycle

Hypothesis: If gamma irradiation causes cell cycle arrest at the G2/Mcheckpoint in rat keratinocytes due to down regulation of Uracil DNA Glycosylase then overexpression of Ung will push the cell cycle past the G2/M checkpoint into completion

Transdifferentiation of Skeletal Muscle in Spaceflight due to Mitochondrial Dysfunction

Hypothesis: Microgravity leads to the downregulation of enzymes critical for oxidative phosphorylation in the mitochondria of skeletal muscle. This mitochondrial dysfunction causes the transdifferentiation from slow, oxidative Type I muscle fibers to fast, glycolytic Type IIb muscle fibers observed in spaceflight.

Effect of Light Stimulation on Root Growth of Arabidopsis Thaliana Plants in the Absence of Gravity

Hypothesis: RHL41 causes upregulation of cell wall genes causing increased root growth in response to light stimulation.

GL4HS Project Manager: Elizabeth Blaber, Ph.D.

NASA supports the Middle and High School student participation through providing travel funds through a yearly grant to the ASGSR

Travel funding to help with air fares: $20,000

- $10K for drop tower projects; $10K for all other projects

2017 ASGSR:

- 65 middle and high school students participated
- 19 middle and high schools from across the country
- 28 student posters
  - Science topics represented both physical sciences, space biology, and research applications

Highlights

- Students established solid mentorship/advisory offers for their studies
- Received advice on project design an analysis, including offers to provide specimens and test samples from PIs
- One student came with hopes of talking to scientists to learn more about a material that she was trying to make that is capable of using light for propulsion
  - Met 2 investigators who told her to contract them for mentorship and techical support
- One student received an unsolicited offer for a summer internship by Dr. Venkateswaran
- One student was offered an internship at a commercial company when he went to college
- Students expressed how much a learning experience they had and that the experience had made a significant difference in their inspiration to purse studies and careers in science and engineering

RR-5 BSP Overview

RR-5 TISSUE LIST
Diaphragm
Skin (dorsal)
Skin (femoral lateral)
Tail

BSP tissues were collected by the PI team at UCLA. All materials for the tissue collections (pre-labeled/pre-filled tubes and shipping supplies) were shipped to UCLA from ARC. Dissections will be completed in October 2017, at which point ARC will receive BSP tissues from 60 mice (30 Live, 30 frozen carcasses).

PI: Dr. Chia Soo (UCLA), **Co-Is** (UCLA): Dr. Kang Ting, Dr. Benjamin Wu, and Dr. Jin Kwak

Picture: members of ARC BSP Team preparing RR-5 BSP tissue collection materials (L-R): Tiffany Truong, America Reyes, Yi-Chun Chen.

SCHEDULE	ACTIVITY
7/31- 8/1	✓ Completed Live Animal Return BSP dissections at UCLA
September-October	✓ Frozen carcass BSP dissections
Mid-October	✓ Sample shipment to ARC

RR-9 BSP Team

Picture: members of PI teams, Rodent Ops/Science team, KSC Animal Facility, and ARC BSP Team at the RR-9 Team Dinner- Dixie's Crossroads in Titusville, Florida.

ARC/KSC: Kara Martin, Rebecca Smith, Ramona Bober, Autumn Cdebaca, Satro Satyanand, Tiffany Truong, Karin Perkins, Yi-Chun Chen, America Reyes, Sungshin Choi, Tiffany Chen, Rebecca Klotz
Michael Delp (PI- Florida State University), Payal Ghosh, Bradley Behnke, Olga Tarasova, David Zawieja, Pooneh Bagher, Walter Cromer, Sunny Narayanan
Xiao Wen Mao (Co-I- Loma Linda University), Nina C. Nishiyama, Michael J. Pecaut, Penelope Duerksen-Hughes, Tamako Jones
Jeffrey S. Willey (Co-I- Wake Forest University), Eric W. Livingston, Joseph Moore, Andy Kwok, Thomas Hampton, Ted Bateman

RR-9 BSP Overview

SCHEDULE	ACTIVITY
8/9-8/10	✓ Completed Practice Dissections at KSC
8/15	✓ Completed Basal Dissections at KSC
September 18th week	✓ Completed Live Animal Return Flight Dissections at Loma Linda University
9/30-10/1	✓Completed Surrogate Cohort Control Dissections at KSC
10/3-10/4	✓Completed Vivarium Dissections at KSC
October 2017	✓Completed Sample shipment to ARC
Late Winter/Spring 2018	Repeat Ground Control with Rodent Habitats at KSC

RR-9 BSP Summary

RR-9 BSP TISSUE LIST

1. Abdominal lymphatic nodes
2. Adrenal glands
3. Aorta (abdominal and thoracic)
4. Axillary lymph nodes/ lymphatics
5. Blood serum
6. Calvaria
7. Cecum
8. Cephalic lymphatics
9. Colon
10. Cribriform plate of head
11. Diaphragm
12. Duodenum
13. Esophagus
14. Fat (abdominal/brown adipose)
15. Feces
16. Femur
17. Heart
18. Humerus
19. Ileum
20. Inguinal lymph nodes/lymphatics

16. Jejunum
17. Kidneys
18. Liver
19. Lungs
20. Mandible
21. Mesentery
22. M. gastrocnemius
23. M. Extensor digitorum (EDL)
26. M. longissimus dorsi
27. M. quadriceps vastus lateralis
28. M. soleus
29. M. splenius
30. M. tibialis anterior
31. Pancreas
32. Paw
33. Rectum
34. Skin dorsal
35. Skin femoral lateral
36. Spine/pelvis
37. Spleen
38. Stomach
39. Tail
40. Testis
41. Tibia
42. Thymus
43. Whiskers with skin

RR-9 PI TISSUE LIST

DELP

1. Brain
2. Basilar arteries
3. Cerebral arteries
4. Choroid plexus
5. Parietal cortex
6. Coronary arteries
7. Basal veins
8. Jugular Veins
9. Cervical lymphatics
10. Carotid artery

WILLEY

1. Hind limbs

MAO

1. Blood serum
2. Eyes

Over 40 types of tissues were collected from 80 mice by the end of RR-9 BSP dissections in October.

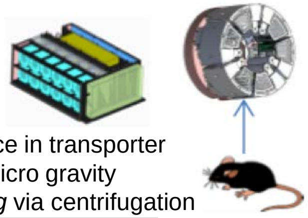
MHU-2 BSP Overview

BSP tissues were collected by the ARC team at Explora Labs, San Diego CA at the invitation of JAXA. All materials for the tissue collections were shipped to Explora Labs from ARC by BSP team. All samples were shipped to ARC for distribution or storage in the ASLDA. Dissections will be completed in March 2018 with the ground control dissection at JAXA. **PI: HiroshiOhno (RIKEN) JAXA MHU-2** POC: Dai Shiba, Ph.D. Project Scientist, DissectionTeam lead:Osamu Funatsu, Ph.D. Lead Disectionist:Fumika Yamaguchi

This work was performed under the JAXA/NASA OP3 umbrella agreement. One continuing collaboration examining changes to the Eye structure and vasculature is planned between Dr. Mao, Loma Linda U. and JAXA.

MHU-2 BSP TISSUE LIST

1. Calvaria
2. Eye, whole,
3. Eye posterior half
4. Pancreas
5. Skin dorsal
6. Skin femoral lateral
7. Testis - one
8. Whiskers with skin
9. Tail



12 mice in transporter
6 at micro gravity
6 at 1*g* via centrifugation

SCHEDULE	ACTIVITY
7/17	✓Dissection training and identification of preservation methods
9/17	✓Supplies ordered and shipped to Exploralab
9/17	✓Practice dissection at Exploralab
9/18/17 - 9/20/17	✓Completed BSP dissections at Explora Lab
9/20/17 -9/23/17	✓Tissues shipped to ARC ALSDA, Eyes shipped to Dr. Mao
March 2018 (tbd)	Ground control dissection at JAXA

MHU-2 (SpX-12) Multi Omics Mouse JAXA

Picture: members of PI teams, JAXA MHU team, and ARC BSP Team at the Explora Lab, San Diego

PI: **HiroshiOhno (RIKEN) (**in front near center) and members of his lab
JAXA MHU/MARS team: Dai Shiba, Ph.D.,Project Scientist, Hiroyasu Mizuno, Project Engineer, Osamu Funatsu Ph.D., dissection team lead, Fumika Yamaguchi, operator, Yuuko Nozawa, Fumiko Yamaguchi, Chie Matsuda, and additional team members
ARC BSP: Karin Perkins, Candice Tahimic, Frances Donovan. Not attending dissection but supporting with materials purchased, labels and shipping of supplies: Rebecca Klotz and Tiffany Truong.
Explora Lab: Grishma Acharya, Ph. D.

ARC Space Biology Project Communications and Outreach
October 2017

Completed

- Rodent Research-9/SpaceX-12 Webpage (https://www.nasa.gov/ames/research/space-biosciences/rodent-research-9)
- SLSTP Snap Chat Story – 1.3M views in 24 hours (in partnership with Ames PAO)
- GL4HS Webpage (https://www.nasa.gov/ames/genelab-for-high-schools)
- Eclipse Balloons to Study Effect of Mars-like Environment on Life Article (in partnership with Ames PAO) (https://www.nasa.gov/ames/feature/eclipse-balloons-to-study-effect-of-mars-like-environment-on-life)
- WetLab-2 Press Release: Microgravity validation of a novel system for RNA isolation and multiplex quantitative real time PCR analysis of gene expression on the International Space Station in scientific journal PLOS ONE (in partnership with Ames PAO) (https://www.nasa.gov/feature/ames/diagnosis-in-space-wetlab-2-sends-molecular-biology-into-orbit)
- Updated NASA Fact Sheets for Bioculture System, WetLab-2, and Fruit Fly Lab
- Space Biosciences Division participation in NASA in Silicon Valley Solar System Showcase-9/22

In-Work

- SpaceX-13 Webpages: Cell-Science Validation, Plant Gravity Perception, Rodent Research-6, Microbial Tracking-2
- Micro-12 (TBD?) package: (webpage, feature article)
- GL4HS Space Biology Research Competition Article
- EcAMSat: talking points, updated webpage, feature, social media, and Wall Street Journal article (collaborative effort involving ARC PAO, Engineering, Space Biology)
- Final post on FFL-02 – A Scientist's Blog (https://www.nasa.gov/feature/ames/fruitflylab02blog)

Upcoming Events

- Bay Area Science Festival: Discovery Day 11/11
- SpaceX-13 Launch-12/4

Upcoming Communications Products

- Micro-12: animation, social media
- SpaceX-14 Webpages