ISS RESEARCH:
PAST, PRESENT AND FUTURE

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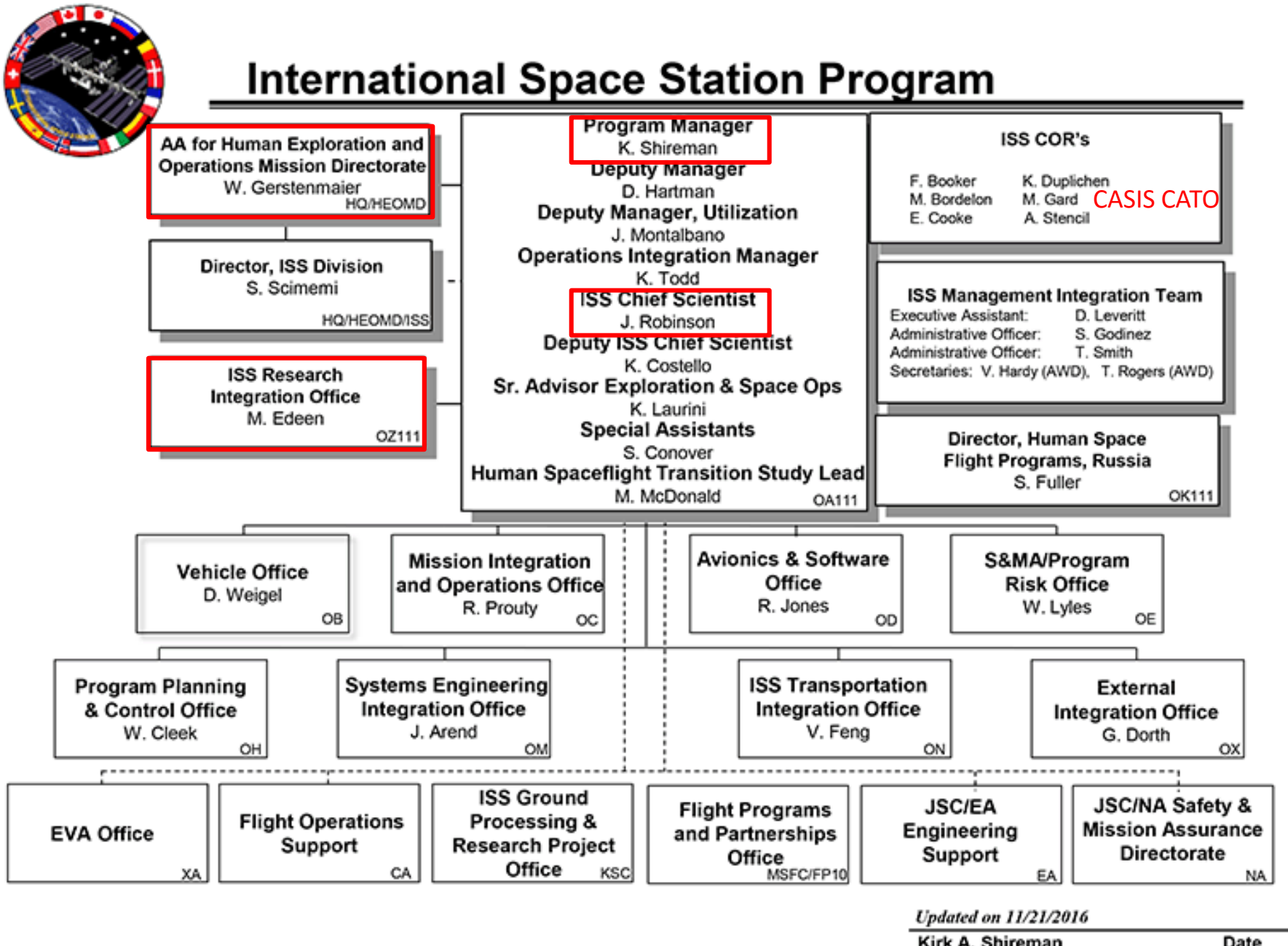
8 February 2017

ISS Program in Human Exploration and Operations Mission Directorate



Overview

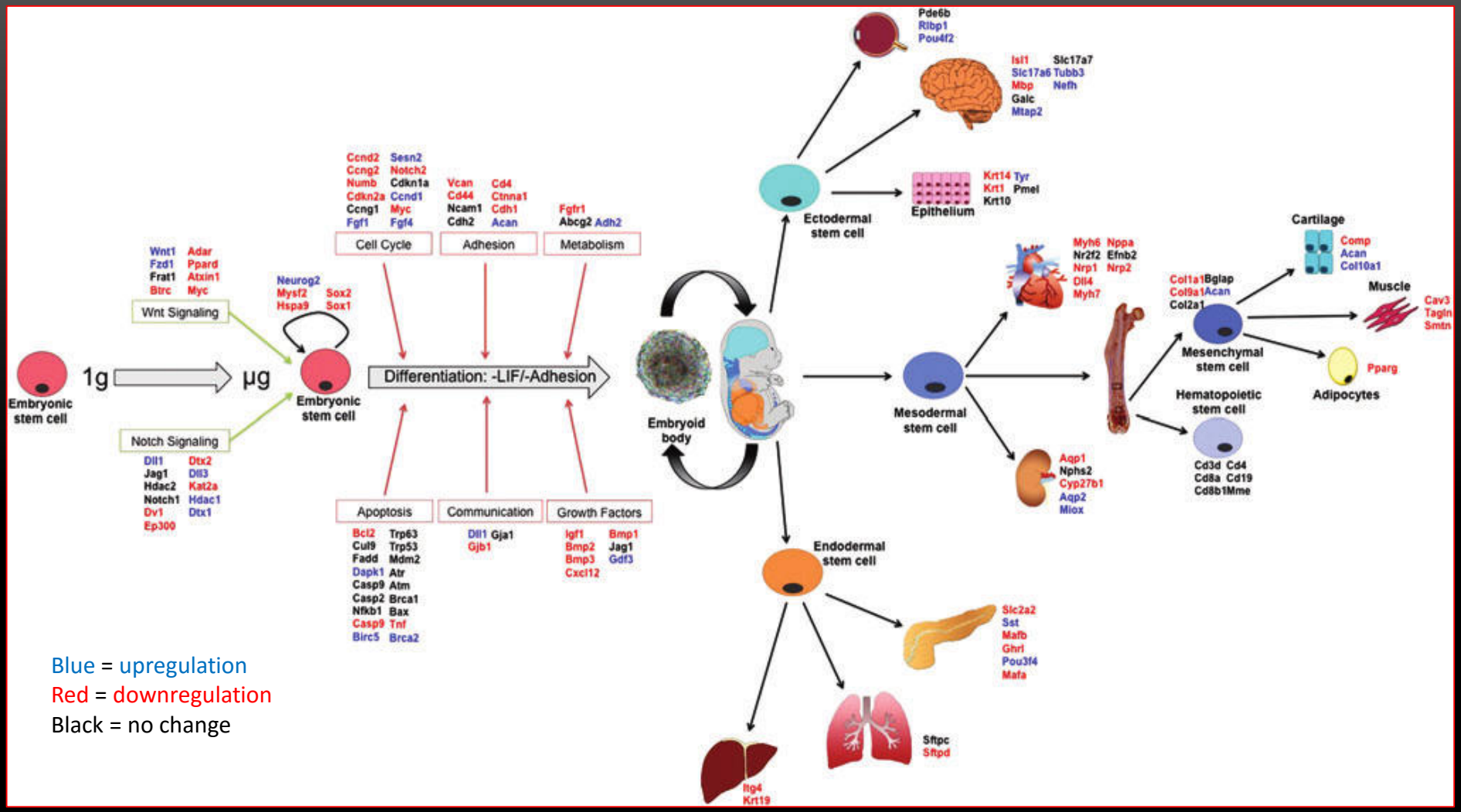
- Research Highlights
- Metrics for ISS Science
- Current and future capabilities (quick reference)

Research Highlights

- Cell Biology
- Model Organisms
- Human Research
- Fluids & Combustion
- Fundamental Physics

An incomplete, and biased list…

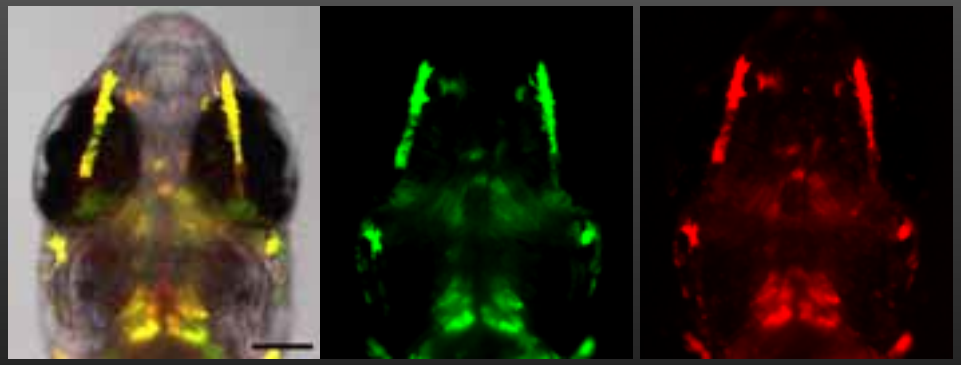
Mechanical Unloading of Stem Cells inhibits differentiation, possibly inhibiting tissue regeneration in space and in disuse conditions on Earth.

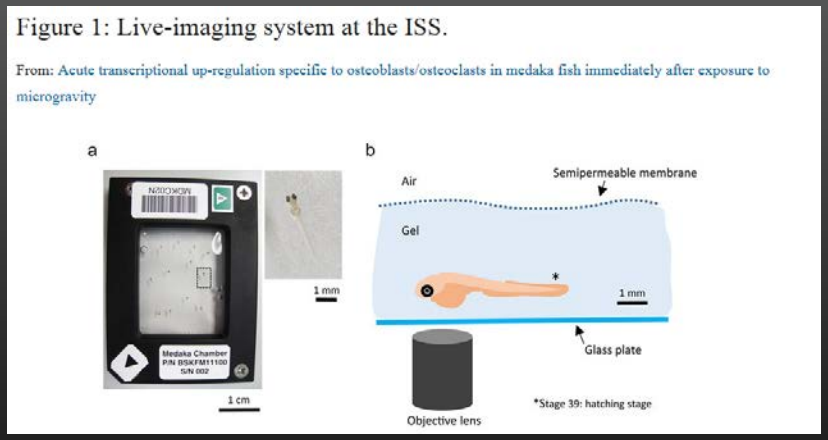


Blue = upregulation
Red = downregulation
Black = no change

Blaber, et. al, Microgravity Reduces the Differentiation and Regenerative Potential of Embryonic Stem Cells. *Stem Cells and Development* (24): 22, 2015.

Upregulation of osteoblasts/osteoclasts immediately after exposure to microgravity (*Medaka* fish)





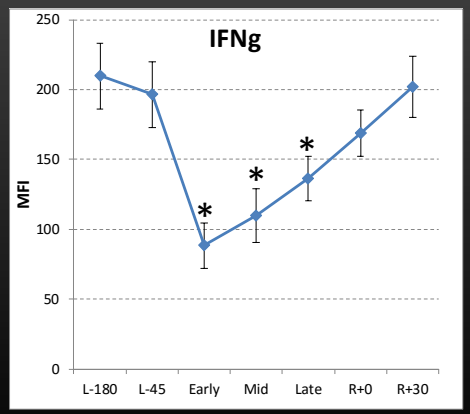
- **Live-imaging of animals during a space mission followed by transcriptome analysis using medaka transgenic lines expressing osteoblast and osteoclastspecific promoter-driven GFP and DsRed.**
- **Osteoblasts: intensity of *osterix*- or *osteocalcin*-DsRed fluorescence in pharyngeal bones was significantly enhanced 1 day after launch; and continued for 5-8 .**
- **Osteoclasts, the signals of *TRAP*-GFP and *MMP9*-DsRed were highly increased at days 4 and 6 after launch in flight.**
- **Several target genes were identified that may share a general mechanism for gravitational activation: *c-fos*, *jun-B-like*, *pai-1*, *ddit4* and *tsc22d3***

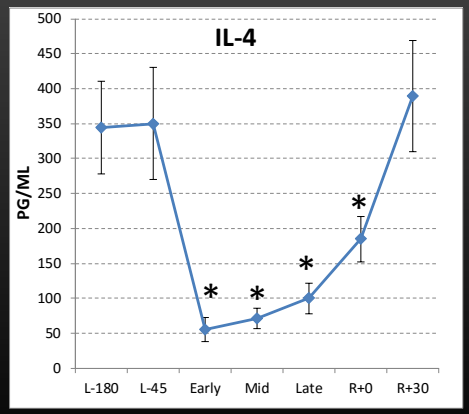
Masahiro Chatani, et. al. Acute transcriptional up-regulation specific to osteoblasts/osteoclasts in medaka fish immediately after exposure to microgravity, *Scientific Reports* 6, Article number: 39545 (2016) doi:10.1038/srep39545

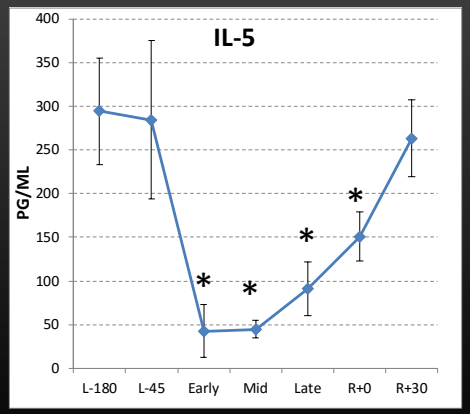
Evidence of functional insufficiency of the human immune system in producing cytokines in space—even though leukocyte, lymphocyte and T-cell counts are unchanged. (And crewmembers don't get sick.)

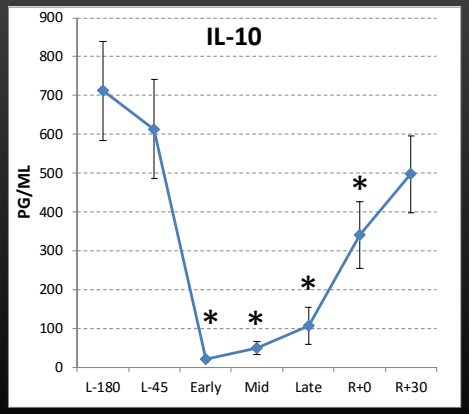
Secreted Cytokine Profiles: Mean ISS Data (n=23)

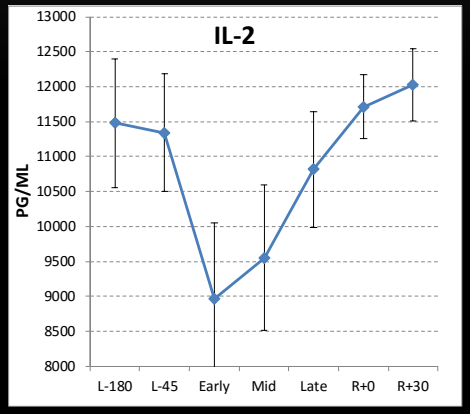
48hr Culture – PMA/I Stimulation

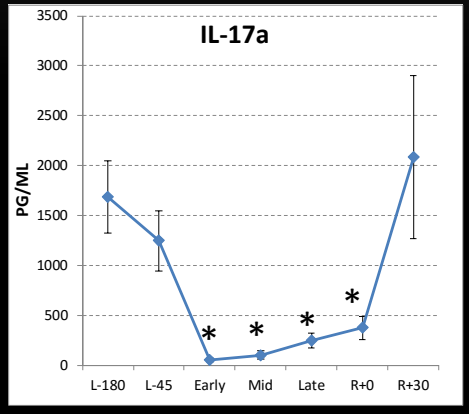


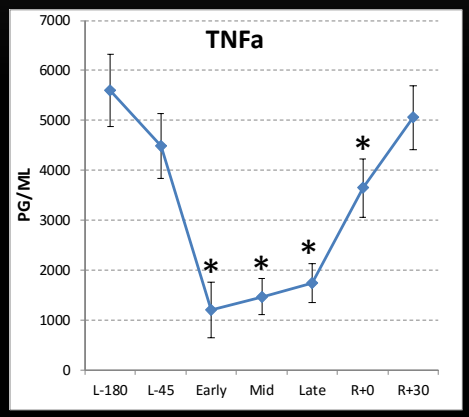


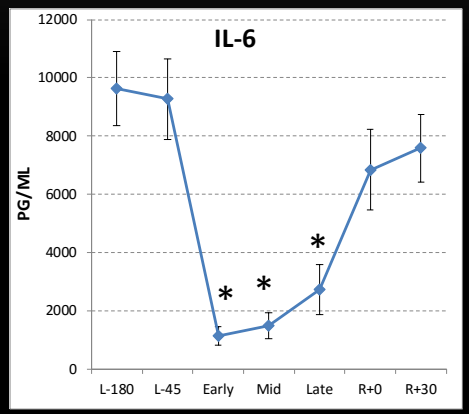






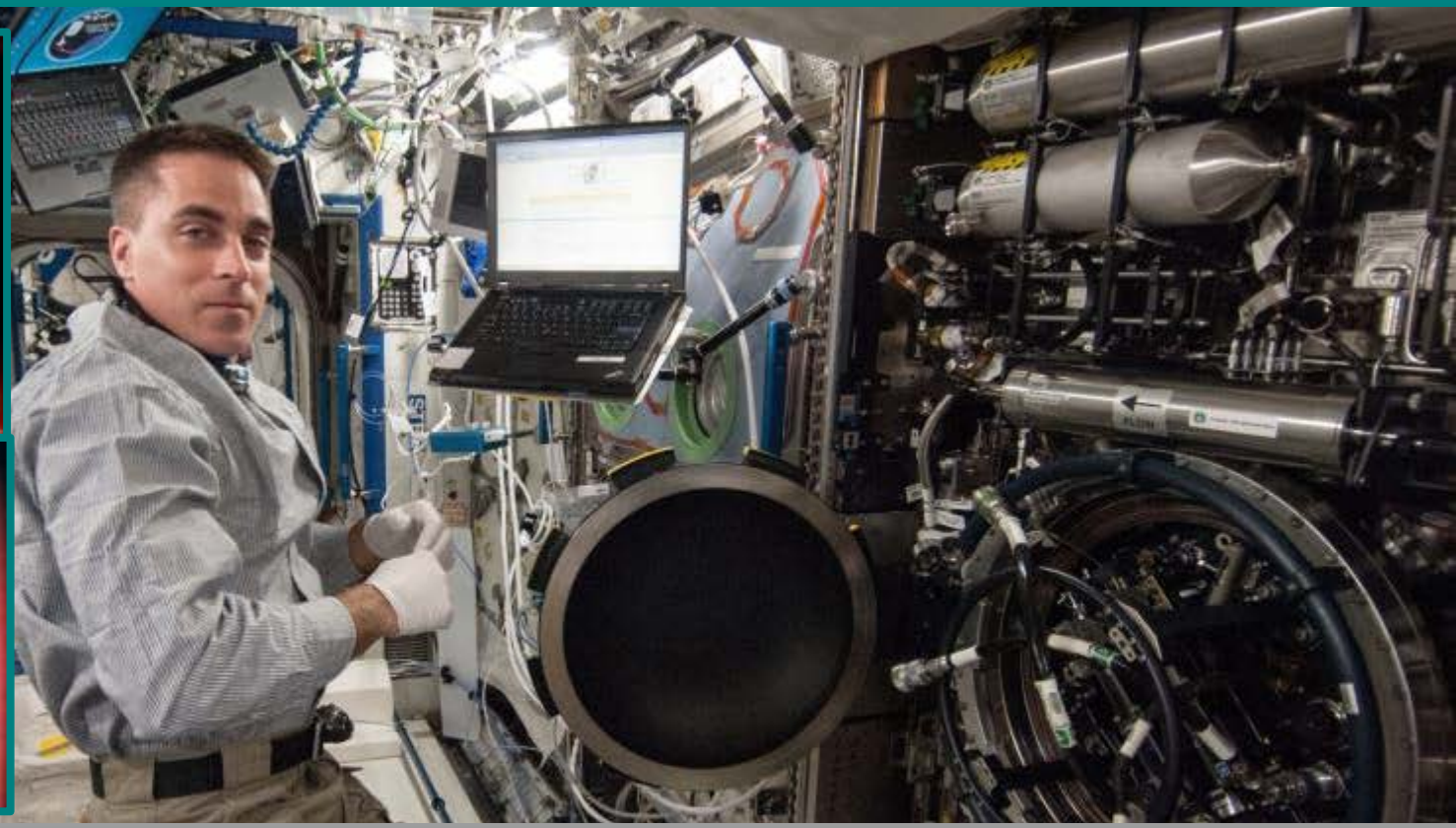






Crucian BE, Stowe RP, Mehta SK, Quiriarte HD, Pierson DL, Sams CF. Alterations in adaptive immunity persist during long-duration spaceflight. npj Microgravity. 2015 September 3; 1: 15013. DOI: 10.1038/npjmgrav.2015.13.

Combustion – “Cool Flames” Phenomenon

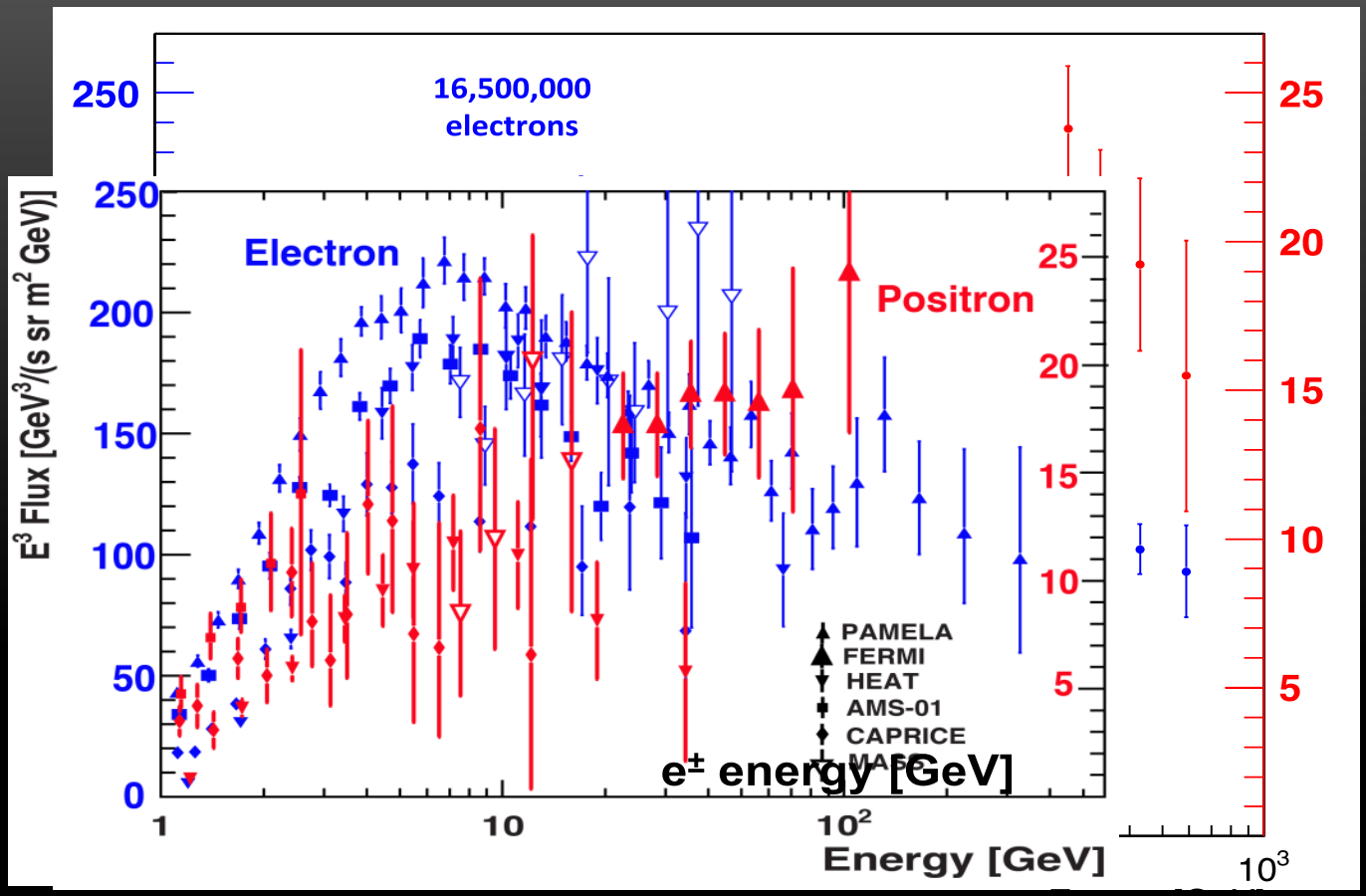


A visible heptane flame ball burned at a high temperature ~1400°F, producing soot, CO_2 and water. As the heptane flame ball cooled and began to go out, “cool flame” combustion took over and continued to burn at ~600°F; with completely different chemistry producing CO and formaldehyde.

This and other studies on flame behavior and fuel mixtures on the space station may lead to improved fuel efficiency and reduced pollution on Earth.

Nayagam V, Dietrich DL, Hicks MC, Williams FA. Combustion and Flame. 2015 May; 162(5): 2140-2147. DOI: 10.1016/j.combustflame.2015.01.012.
And subsequent publications.

Alpha Magnetic Spectrometer at 5 years: Electrons and Positrons, Protons and Antiprotons, Helium, Boron, Carbon, Lithium And 5 possible Antihelium events!



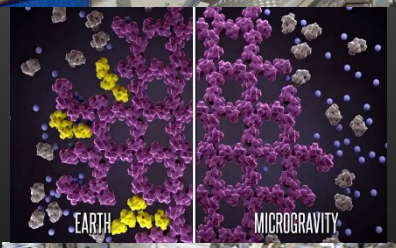
- Before AMS, the theory was that electrons and positrons followed a spectral curve with the same constant—they don't!
- Different magnitude and energy dependences
- Means that there is some undetermined source of positrons (could it be dark matter?)

8 Major publications in *Physical Review Letters*
Review Press Release at: http://www.ams02.org/2016/12/the-first-five-years-of-the-alpha-magnetic-spectrometer-on-the-international-space-station/

Recent ISS Benefits: Highlights

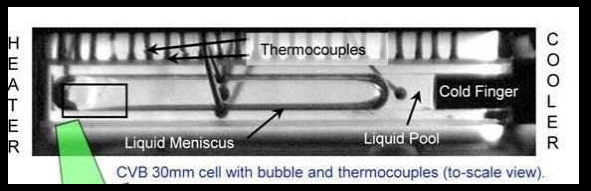
Development of a two-dimensional nanofiber layer that can be traced like a blueprint to mark the processing surface of a semiconductor—useful in developing new motherboards and computers and in creating chemical catalysts for industrial processes.

Clinical trials of a new drug for treating Duchenne Muscular Dystrophy (DMD) are underway in Japan. This drug was developed using improved structures of key proteins that were crystallized on the ISS.



First genetic results investigate a link between folate and eye health in space.

The Constrained Vapor Bubble experiment showed that the flows that result from Marangoni Convection forces can work against the transport of heat in a heat pipe design, limiting the use of this type of cooling in space.



Measurement of capillary flows in space applied to design of technology called Human Emulation System. This “organ on chip” can be used for predicting human response to diseases, medicines, chemicals and foods.

Metrics for ISS Science

- Capacity (how much capability)
- Occupancy (how full)
- Scientific results tracking
- Economic Valuation

Research Sponsors and Allocations* on ISS

*Allocations of flight resources: upmass, downmass, crewtime, as specified in intergovernmental agreements and U.S. Legislation

What are we doing on ISS today?

National Lab (Earth Application)

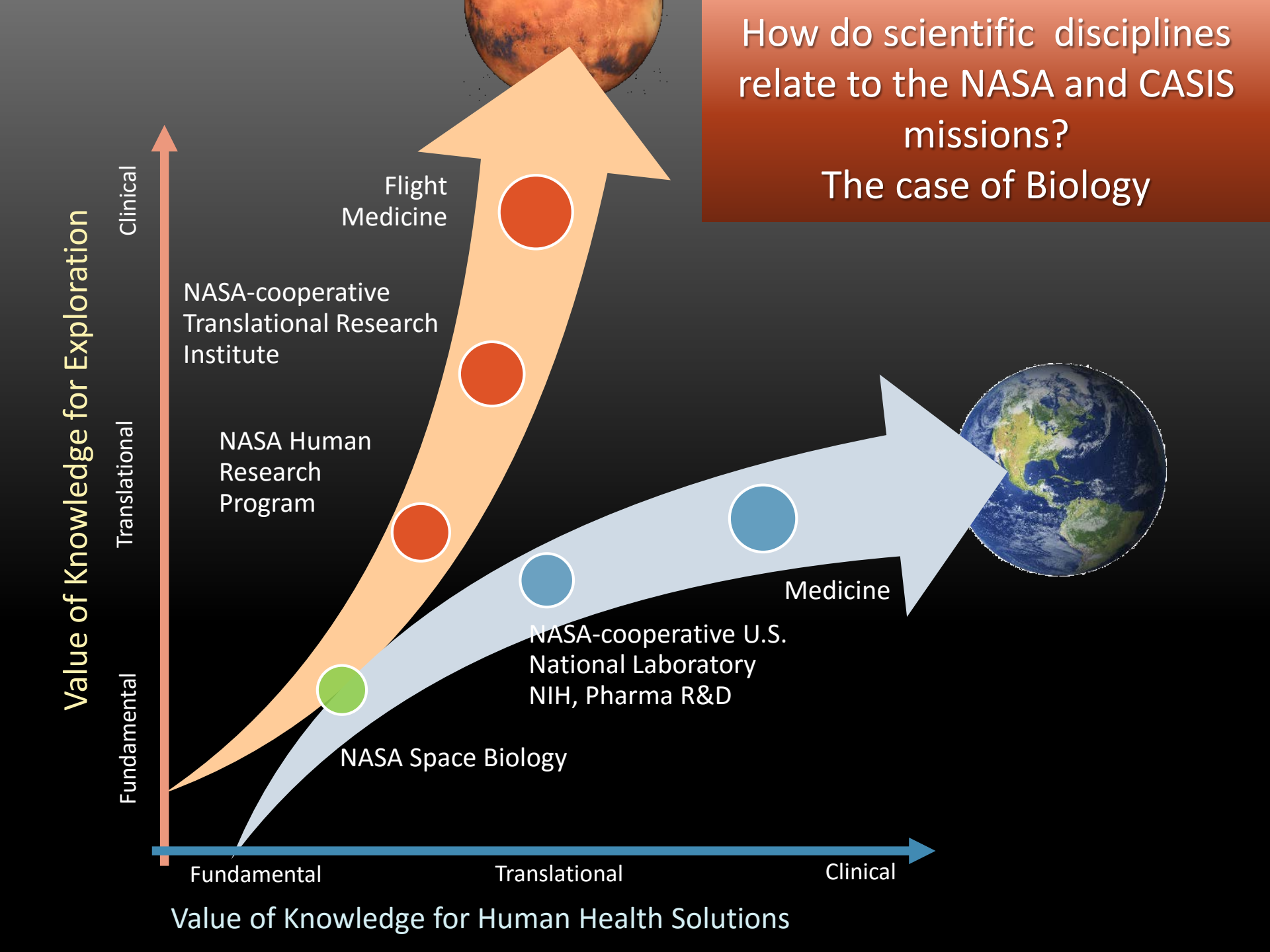
NASA (Exploration Application)

- Biology and Biotechnology
- Human Research
- Physical Sciences
- Tech Demos
- Astrophysics
- Earth Science
- Education

Expedition 47/48 data revised 2016-05

Source: ISS Program Scientist

How do scientific disciplines relate to the NASA and CASIS missions? The case of Biology



Major factors influencing research use of ISS

Resource limitations (e.g., upmass, downmass, crewtime)
- Flight delays to resupply and return plan
- Operations scenarios that reduce crew time for research

Cost to use the platform
- Transportation costs, cost of schedule delays
- Costs and complexity of payload or facility development
- Costs of implementation

Strategies to tip the balance:
diverse transportation providers, simplify integration, implementation partner competition, communicate successes

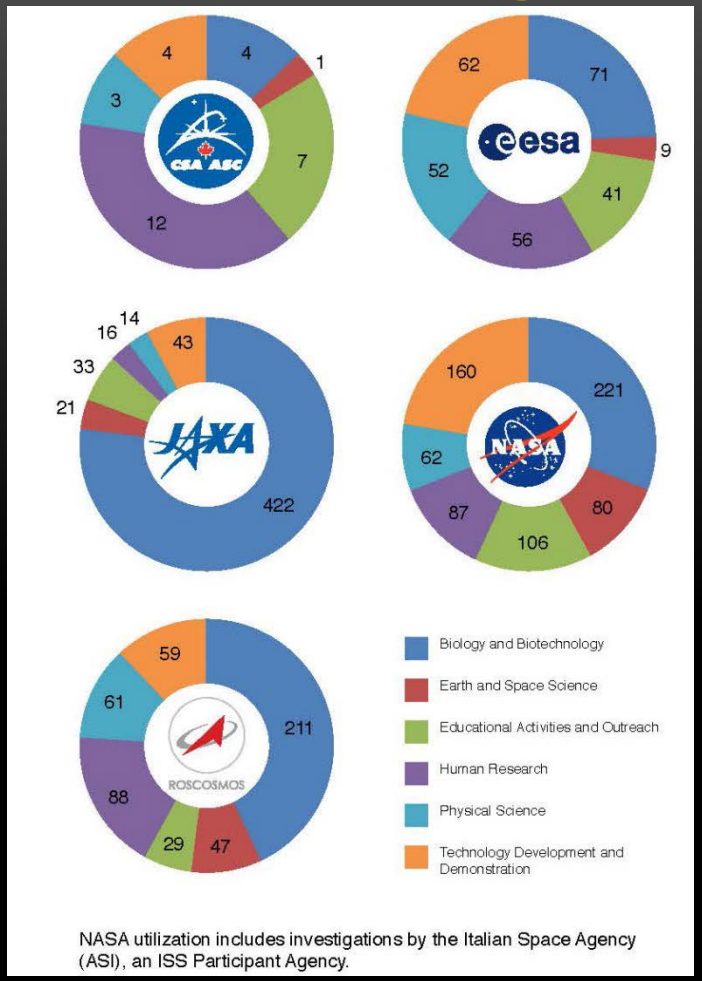
Research Demand
- NASA Funding
- Non-NASA funding
- Research breakthroughs drive funding (Earth applications)

Source: ISS Program Scientist

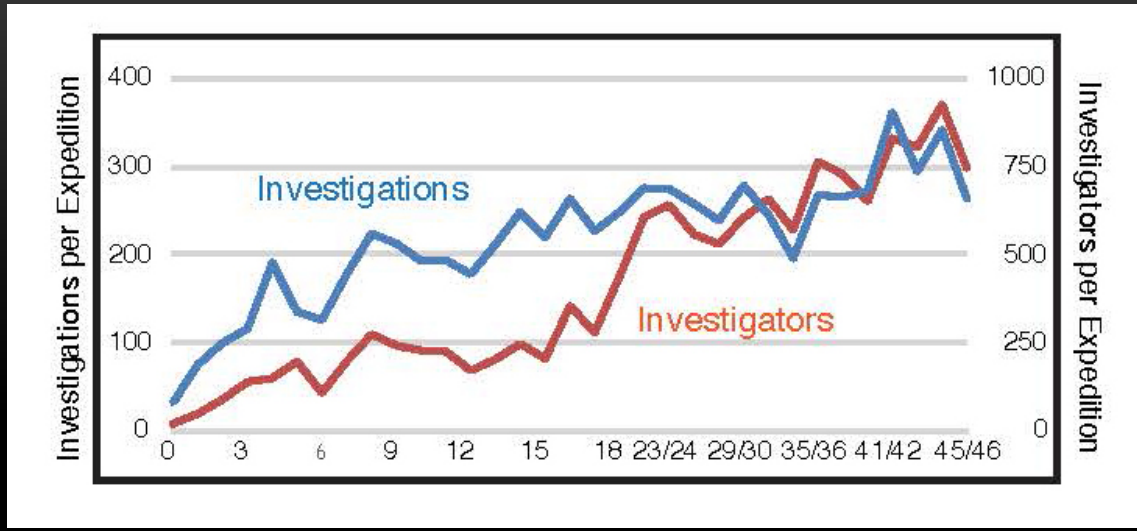
Investigations & Investigators as of March 2016

Expeditions 0-46
December 1998 – March 2016

Number of Investigations



Investigations & Senior Investigtors



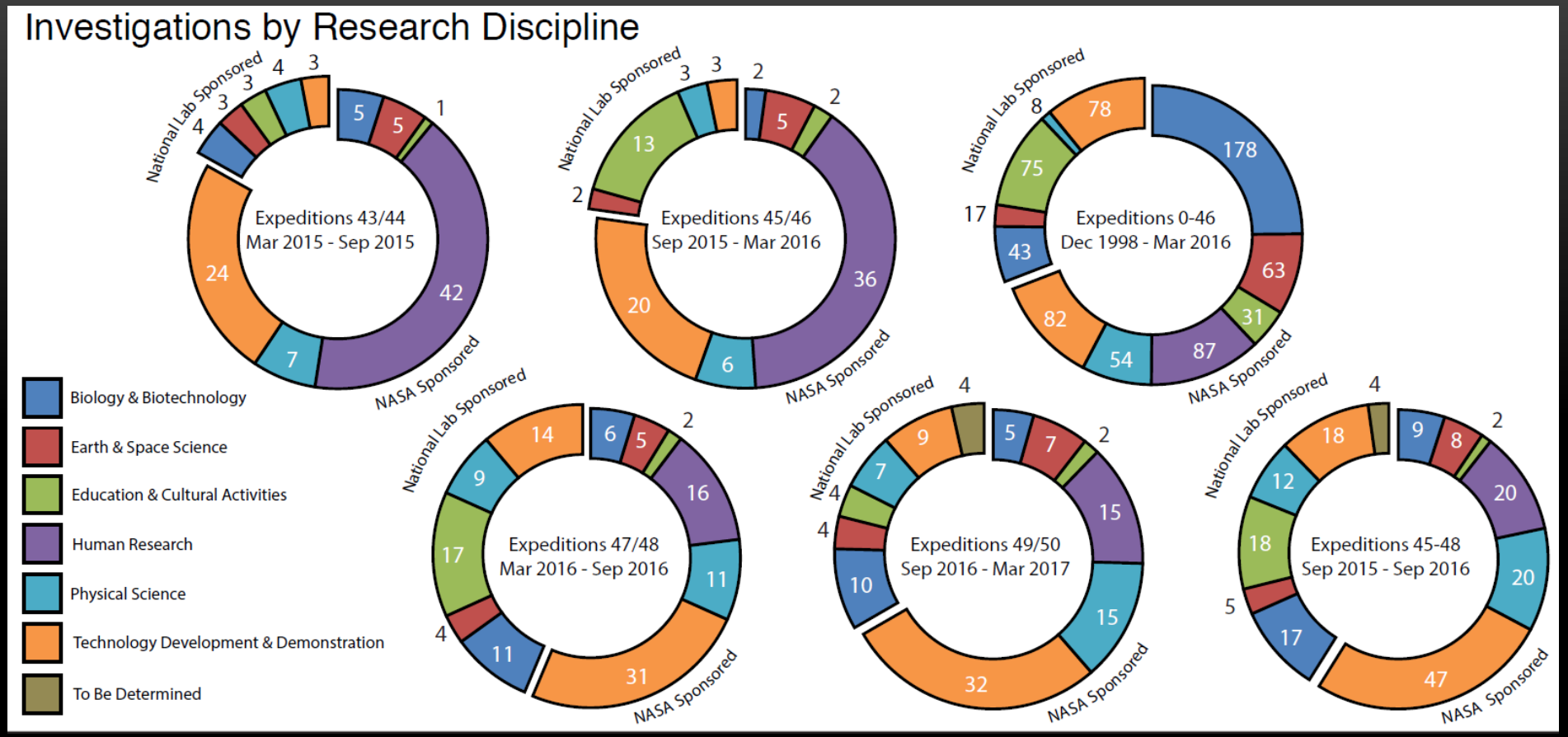
Draft Subject to Change. PSF Approved Nov 2016. SSCB Approved 20 Jan 2017. Pending MCB Approval

Source: ISS Chief Scientist

NASA-National Lab Breakdown in numbers of Investigations, as of September 2016

Number of Investigations

Expeditions 0-48
December 1998 – September 2016



Source: ISS Chief Scientist

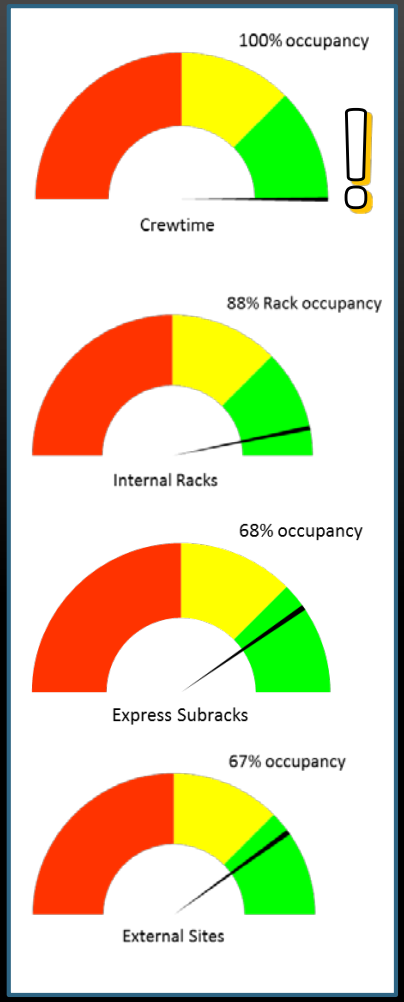
ISS Occupancy as of January 2017

One of the ways that Congress and OMB measure our effectiveness as a research platform

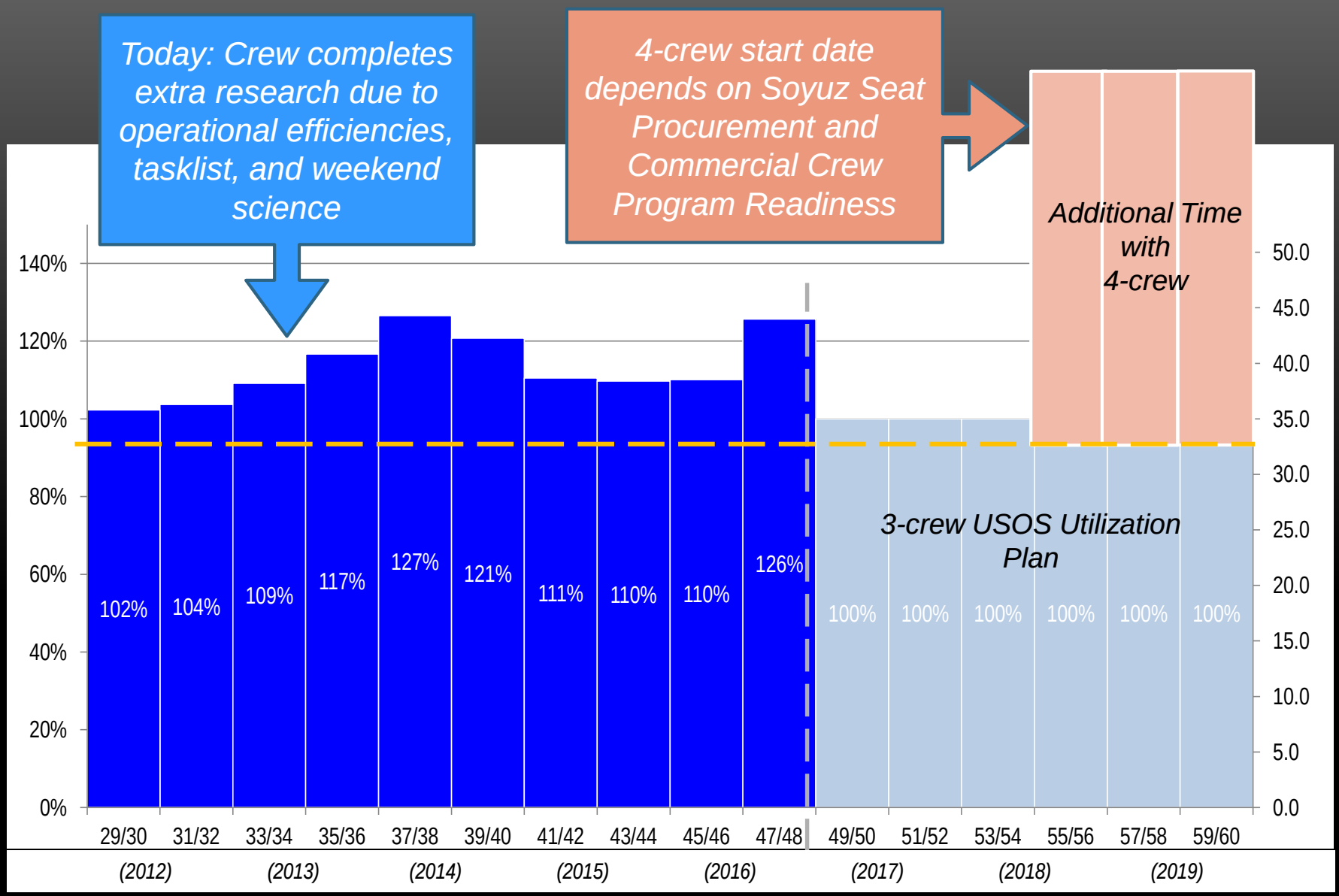
- Crew time heavily oversubscribed (limiting resource for many types of research)
  - Human research and rodent research demand is high, and is crewtime intensive
  - National Laboratory/CASIS demand has grown to fully use the 50% allocation granted in the NASA Authorization of 2010 for crewtime beginning in late 2015, requiring a replanning of NASA-funded research
  - **More in "Crew Time Strategies"**

- Internal Occupancy 88%
  - Express racks: will launch additional Express in 2018 to support small payloads
  - Microgravity Sciences Glovebox: oversubscribed, will launch a 2nd Life Sciences Glovebox to deconflict life and physical sciences
  - Expected Occupancy at the end of the year is 95%
  - Express racks expected to be full by mid-2018
  - **More in "New Capabilities"**

- External Occupancy (rotates but will soon be nearly full)
  - Later in 2017: 5 sites available (launch of SAGE-III, STP-H5, MUSES, NICER, ROSA, CREAM, plus disposals)
  - 2018: Only 1 site available (launch of MISSE-FF, TSIS, ECO-STRESS, SDS, RRM-3, plus disposals)



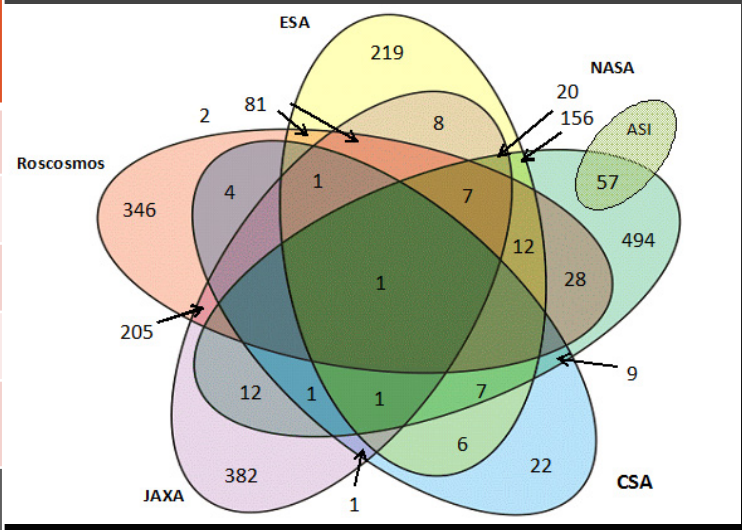
3 → 4 USOS Crew on ISS Doubles Research Throughput



Crew Time Strategies: Collaboration for Efficiency in Facilities and Time

ISS Access Increased Through International Collaboration
Expeditions 0-46, December 1998 – March 2016

	Agency Only	Collaboration (Hosting)	Investigations Implemented	Collaboration (Participating)	Total Agency Impact
CSA	22	9	31	24	55
ESA	219	72	291	230	521
JAXA	382	167	549	90	639
NASA*	551	165	716	89	805
Roscosmos	346	149	495	192	687
			2082		



International collaboration investigations are sponsored by one of the ISS Partners and include scientists from other countries.

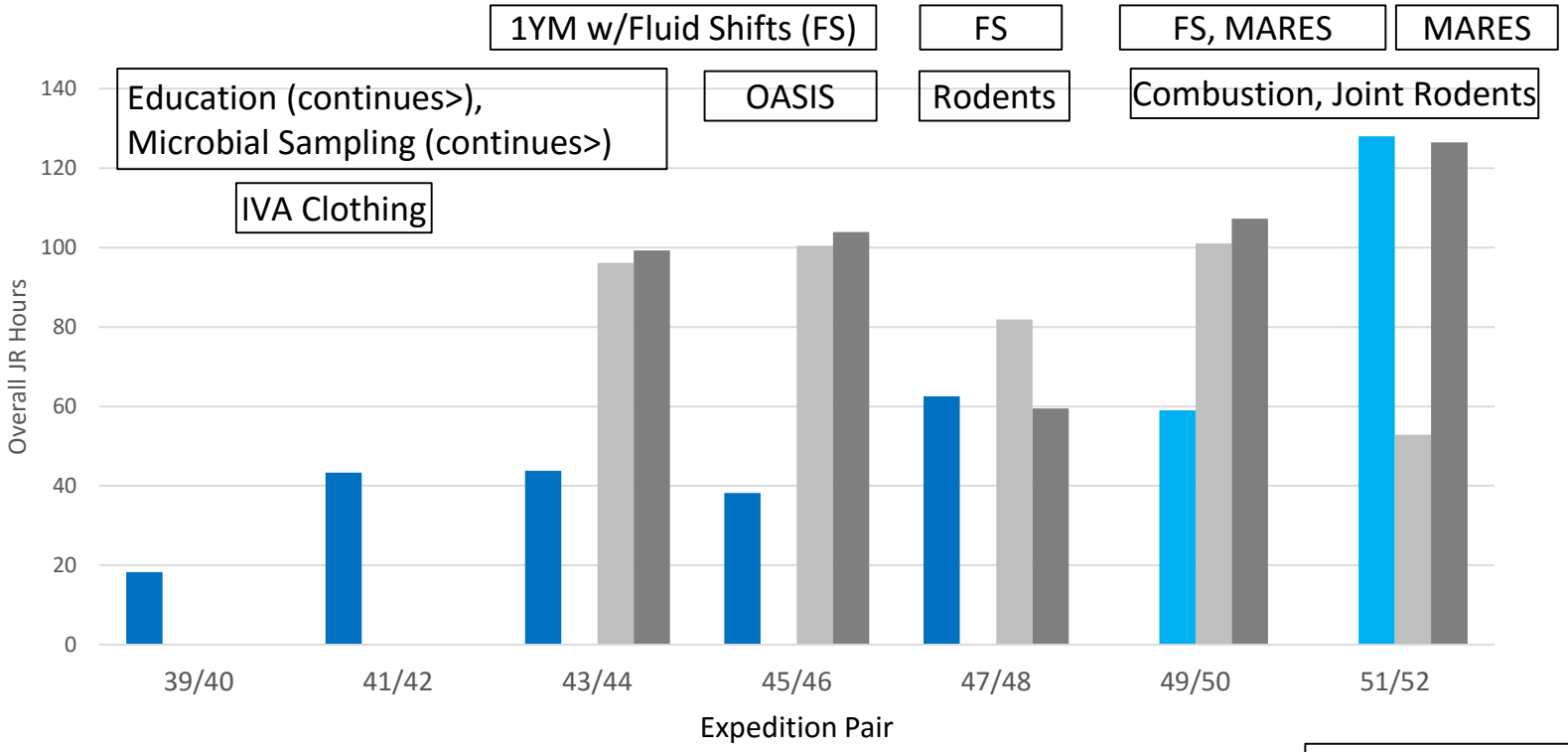
Ellipses show the intersection of Partner collaborations and counts show the increased number of investigations through international collaboration from the point of view of each Partner.

Draft Subject to Change. PSF Approved Nov 2016. SSCB Approved 20 Jan 2017. Pending MCB Approval

Source: ISS Chief Scientist

Russian Research Collaboration benefits for Crew Time

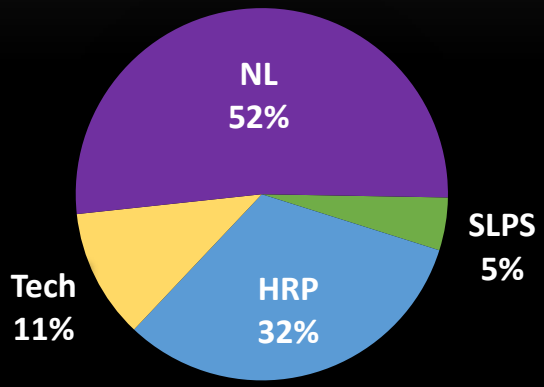
Combining time from USOS and Russian Segment (RS) for collaborative experiments



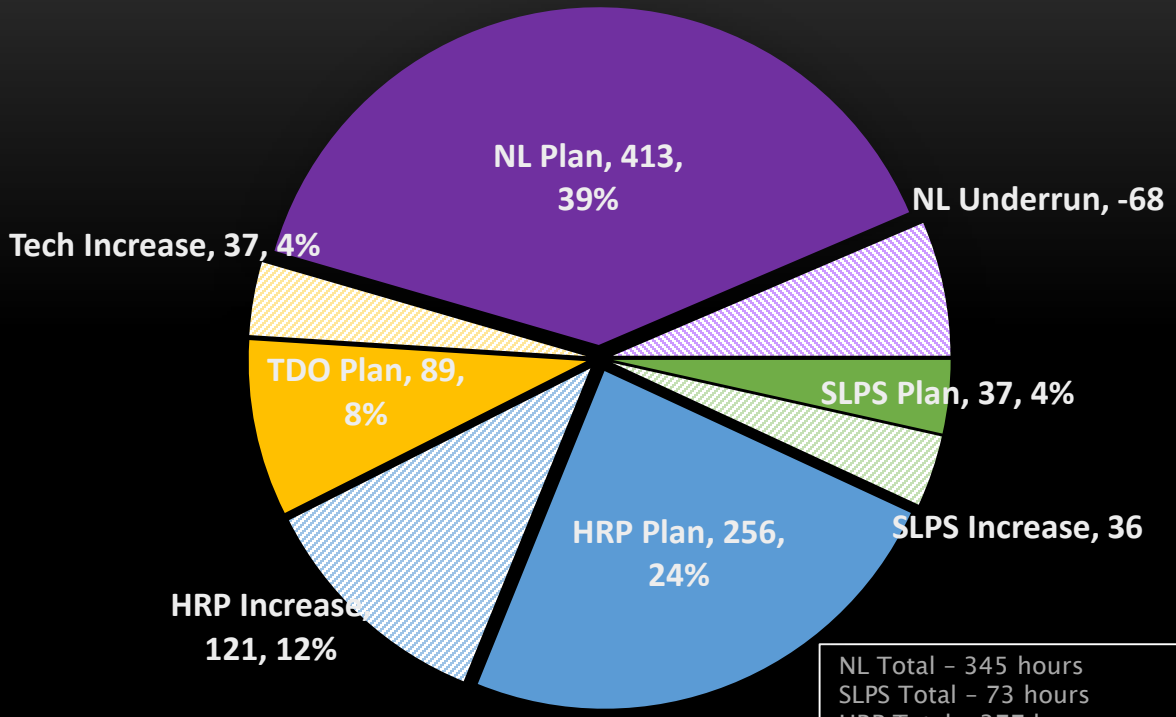
Snapshot: Crew time distribution within U.S. Users

- Snapshot taken Increment 47/48 (mid-2016)
- Pre-increment plans can be altered by many variables
  - Cargo Vehicle traffic (delays can open up time, but also postpone some planned experiments)
  - Reserve Science availability – this can be disproportionally beneficial to physical science which can launch and then wait for opportunities
  - Crew often performs more than planned—when they can
- ISSP continues to remain adaptable to maximize science research
  - Several initiatives in work to maximize capability (hardware and manifest)
  - Efforts underway to get to 4 US Crew more quickly

Planned Hours



Actuals



NL Total – 345 hours
SLPS Total – 73 hours
HRP Total – 377 hours
Tech Total – 127 hours

Assessing the Outcomes of ISS Research

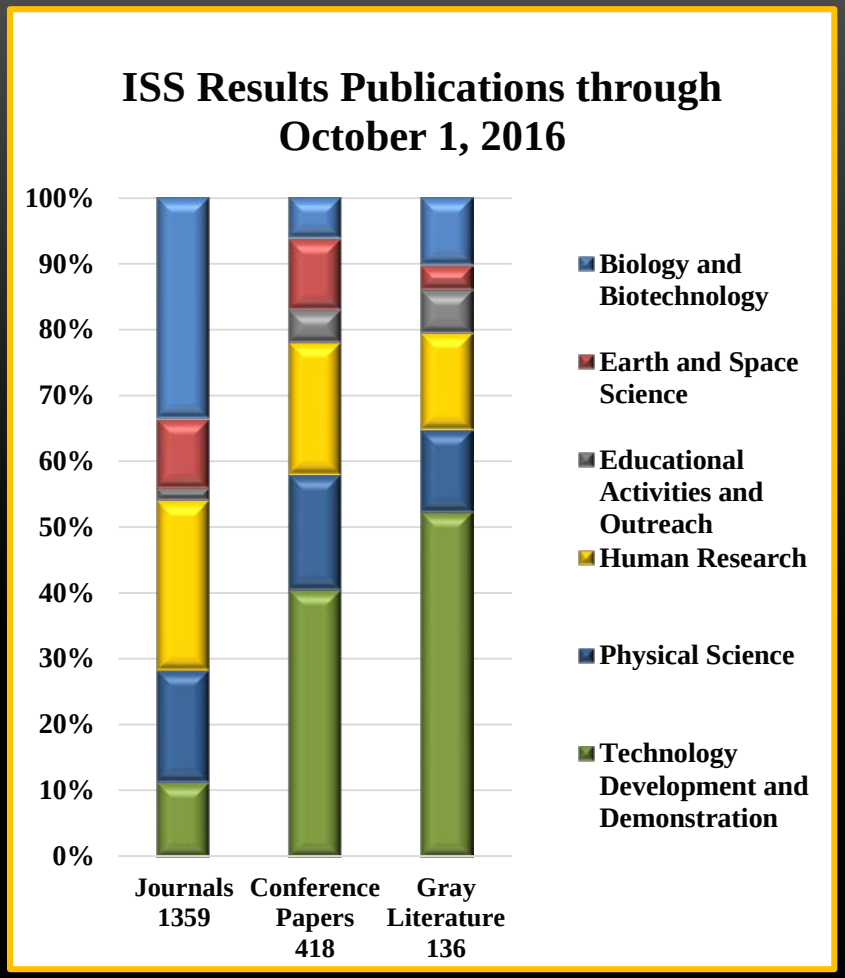
Goal: Enable the clear and broad communication of ISS utilization Results

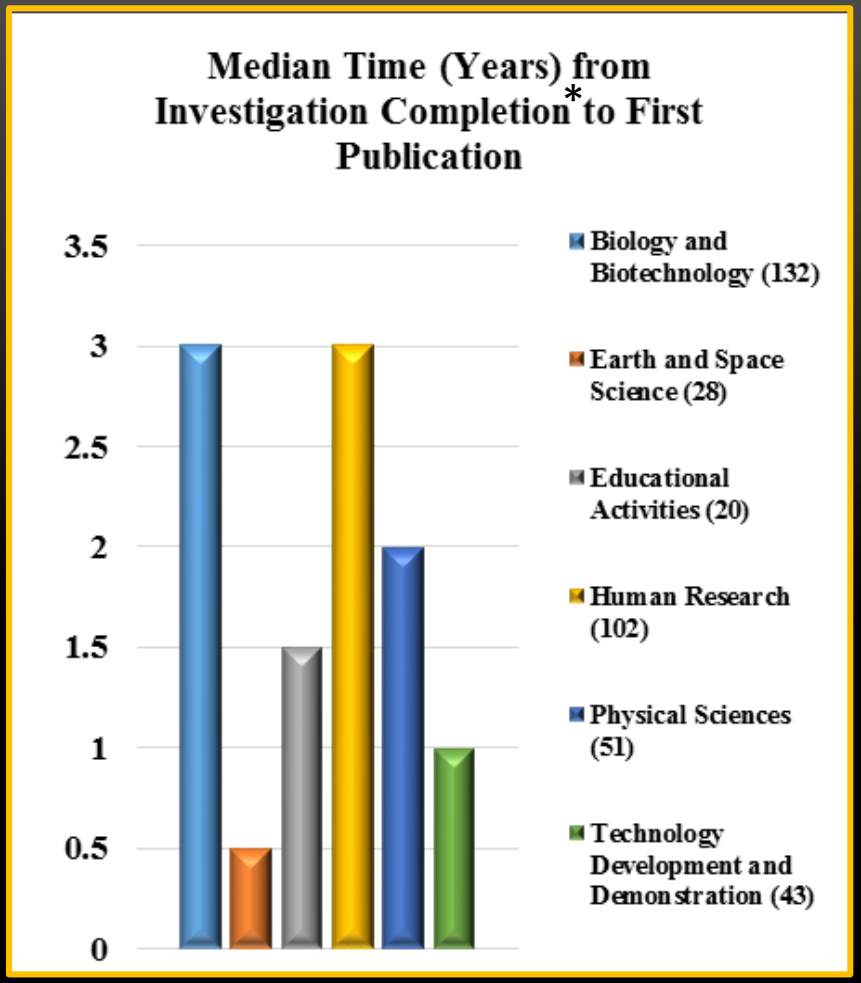
Results Tracking Activities: To develop and maintain an archive of all ISS utilization results in a way that is accurate, interactive, resourceful, and accessible to public.

Objectives:

1. Maintain a public Research Results archive online that offers real-time accuracy, user interaction, and useful resources on ISS results.
2. Develop processes to reflect outcomes of ISS utilization through analyzing scientific publications, tracking knowledge flow from ISS activities, analyzing ISS patents, and benchmarking against other governmental programs and national laboratories.

ISS Science Publications (2000-2016)





* Completion of flight phase

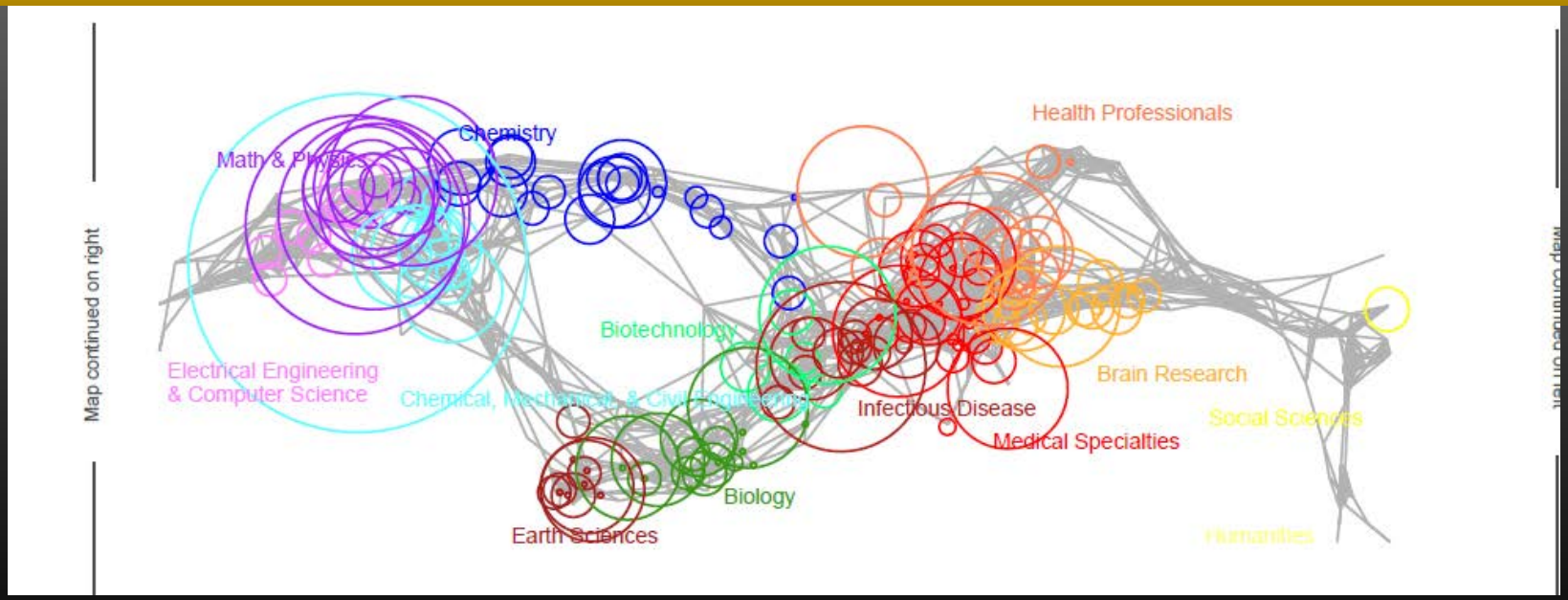
Assessing the Outcomes of ISS Research

Current Work:

- Developing partnerships with “science of science” experts at the NIH to leverage their experience in publication analysis/Bibliometrics.
- “Maps of Science (knowledge maps) can be used as a reference system to chart career trajectories, the location of emerging research frontiers, or the expertise profiles of institutes or nations”*.
  - Resources For the Future contract complete.
  - Now being made operational with continuous updates.
- Currently reviewing NASA Research Announcement Proposals for:
  - Methodologies and processes for patents, products and applications, and covering ISS design, assembly, operations, and research.
  - Performing benchmark analyses and develop methodologies to compare research outcomes from ISS to other government-funded research programs, national laboratories, and existing multidisciplinary laboratories and programs.
- Partnership with CASIS to include applications from the broader set of ISS research activities by all sponsors into their “Economic Valuation” Post-assessment process

*Borner et al. 2012. *PLoS One July 7(7):*e39464

ISS Publications and the Map of Science

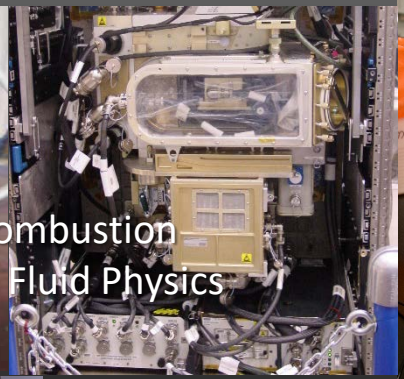


Colors = disciplines.
Nodes = subdisciplines.
Node size = #articles published

- As of January 31, 2017
- 1300+ journal articles (by DOI) through the UCSD program = 348 journals ("records").
- 271 Journals used to create this map.
- 77 journals need to be classified because they are not in the UCSD database (some new since 2012 etc.)
- Online tools being released throughout the coming 12 months

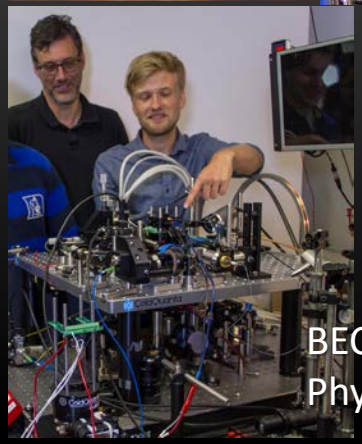
Current and Future Capabilities

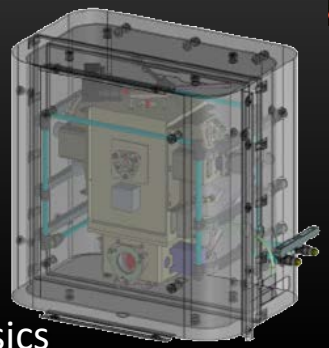
Freezers



Combustion
& Fluid Physics

Genetic Analysis

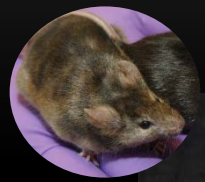


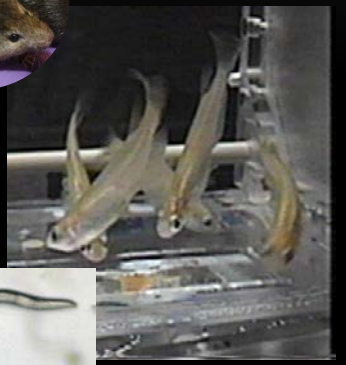


BEC
Physics

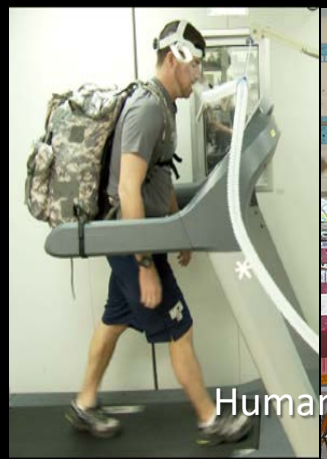
Microscopes

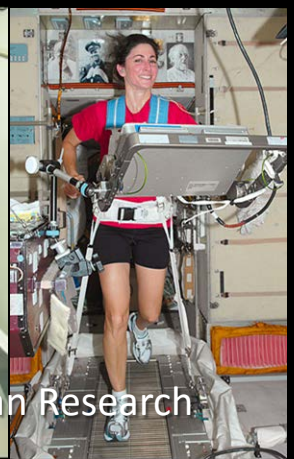
Model Organisms





Incubators





Human Research

Major Internal Research Facilities ("Racks")

Current US ISS Racks on ISS

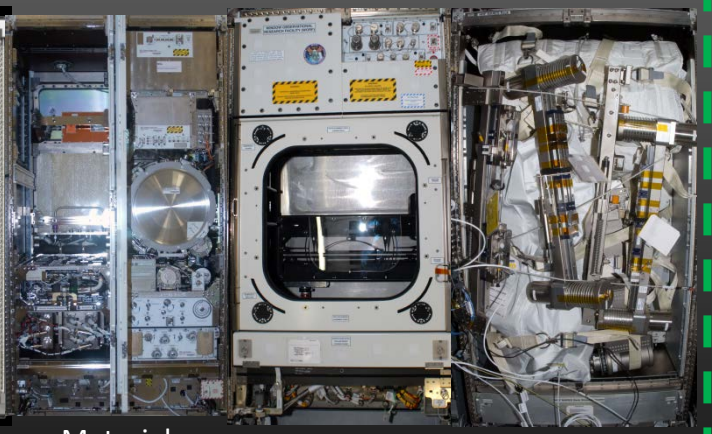
EXPRESS (x8)

MELFI (x3)

Human Research Facility (x2)

Combustion Integrated Rack

Microgravity Science Glovebox



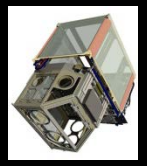
Material Science Research Rack

Window Observation Rack Facility

Muscle Atrophy Research & Exercise System

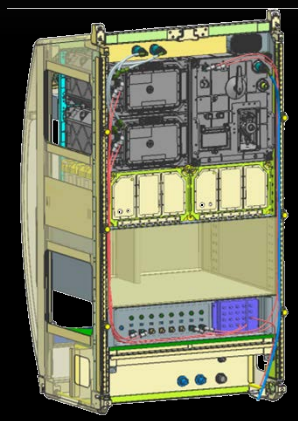
Fluids Integrated Rack

2018



Life Sciences Glovebox

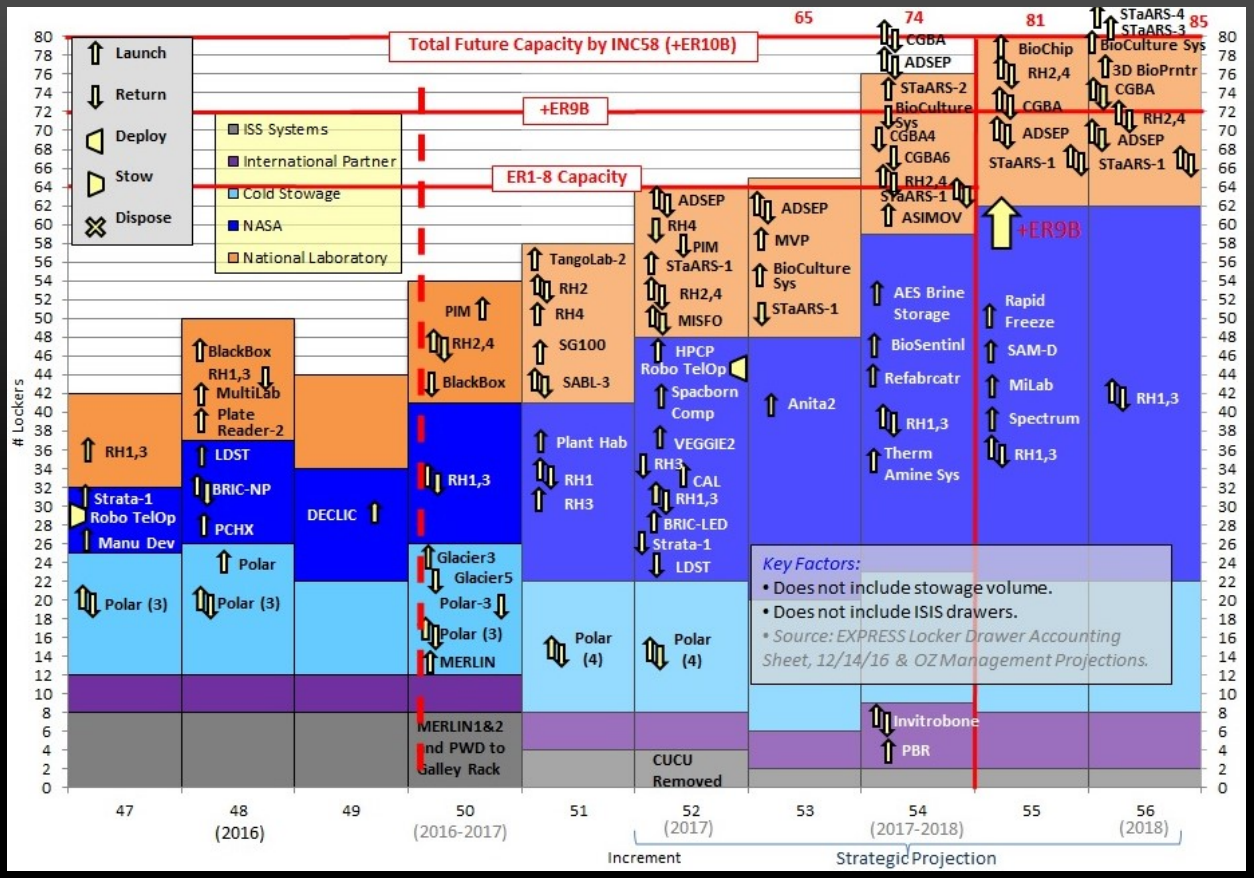
2018



Basic EPRESS Rack (x2-3)

Express Rack Expansion

Number of EXPRESS Inserts in Available EXPRESS Accommodations



Source: Management Performance Level Indicators, 20 January 2017

- Starting in late 2017-2018, the Express Racks will be full during the Space X docked timeframe as payloads come up powered and are transferred to ISS for operations before return on that same mission.
- Launching additional basic express rack capability on HTV-7 (2018) and HTV-8 (2019)
- Three additional options being considered
  - Moving non-research items out of the ER where possible
  - Developing additional equivalent capabilities in other locations
  - Reviewing all the subrack research facilities in the ER with plan to rotate those that may only be used periodically

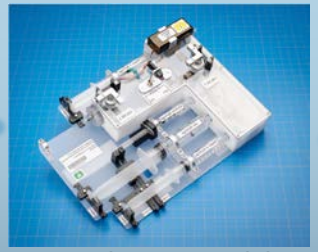
Life Sciences Glovebox (LSG)

The Life Science Glovebox. Image courtesy of Bradford Engineering.

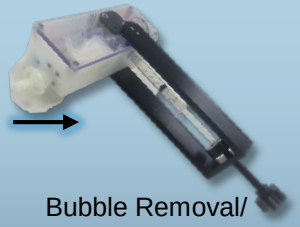
- Microgravity Science Glovebox (MSG) throughput has become a limiting factor because uses for life science compete with long dwell-time physical science investigations
- LSG goes up on HTV7, early 2018
- Primary workplace for rodent research missions/operations and other biological experiments, such as Cell Science and other cell growth experiments.

Life Sciences Sample Analysis Capabilities

Sample Transfer Tool
(from PI experiment)



Sample Prep Module
Extracts RNA or DNA



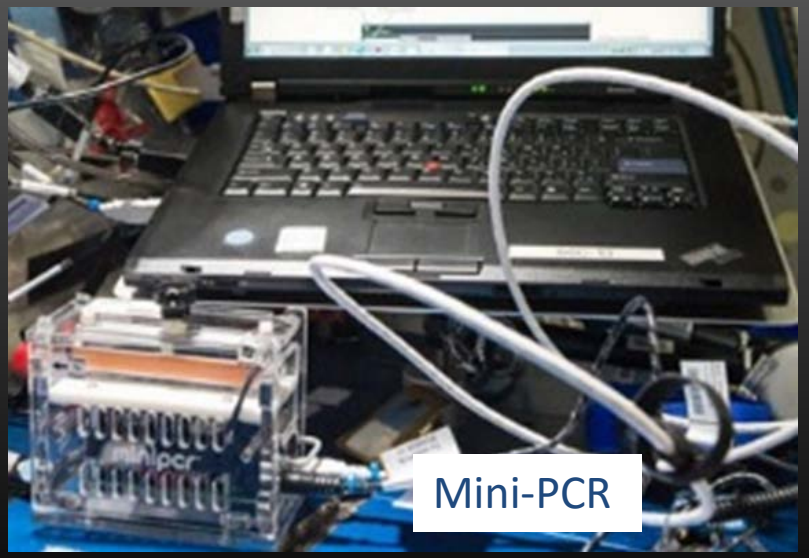
Bubble Removal/
Pipette Loader

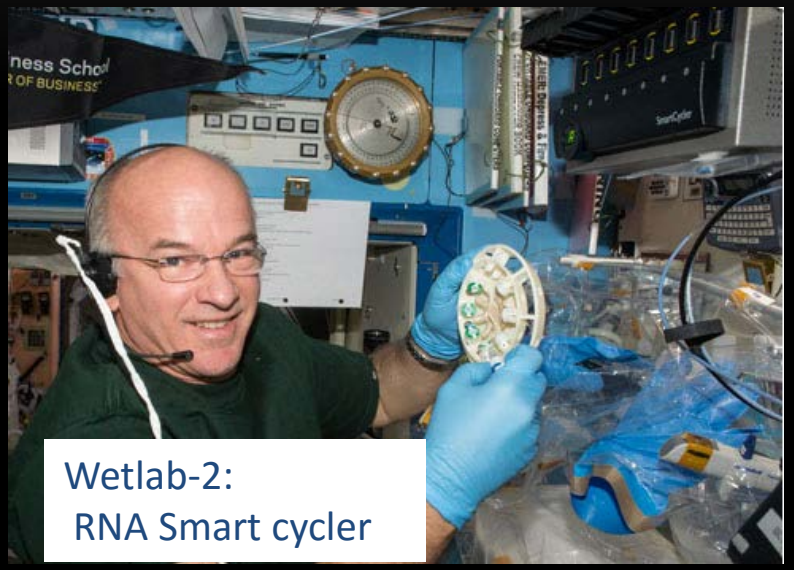
Tubes, Rotor

Reaction Tube Assay

SmartCycler
Provides qRT-PCR
analysis capability

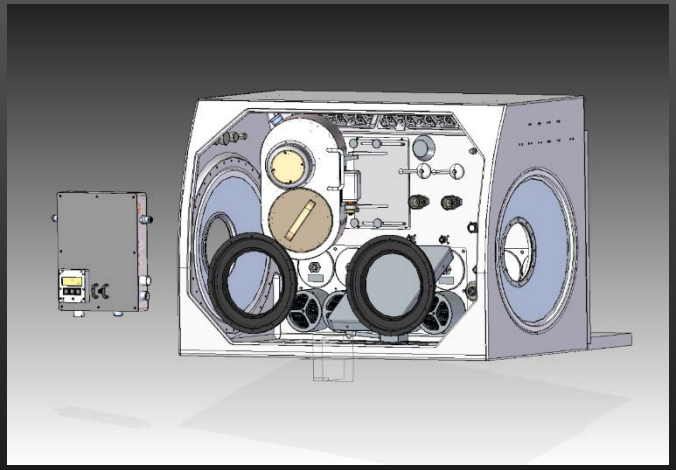
Sample Preparation System: extracts RNA or DNA and prepares samples to be analyzed

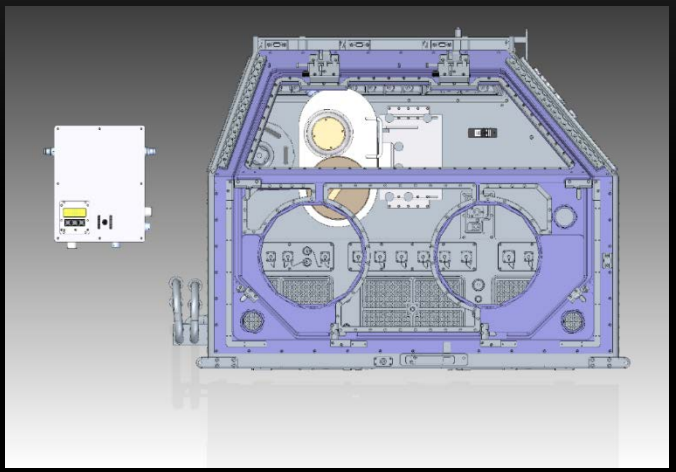




Flash Freeze

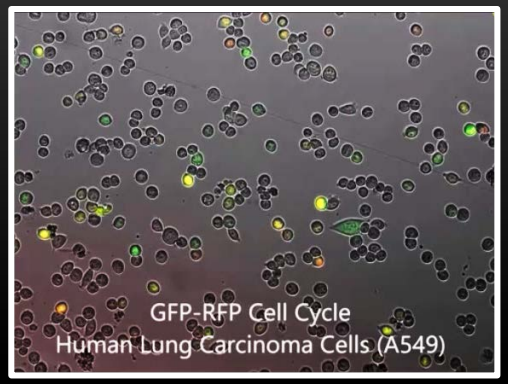
- Single Mobile Rapid Freeze (SMRF) for gloveboxes (MSG and LSG)
- Transportable Express Rapid Freeze (TERF) for transport
- Awarded to UAB, recently passed preliminary design review
- Capability to rapidly freeze biological samples on the ISS
  - Provide freeze rates approaching LN2
  - Freeze multiple samples over short period of time
  - Freeze many samples during a crew workday
  - Maintain consistent freeze rate from sample to sample
  - Enable transfer of frozen samples to ISS storage freezer

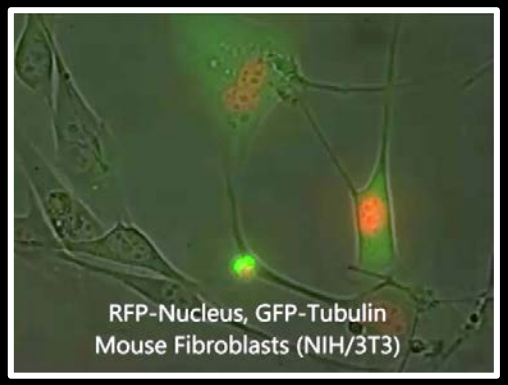


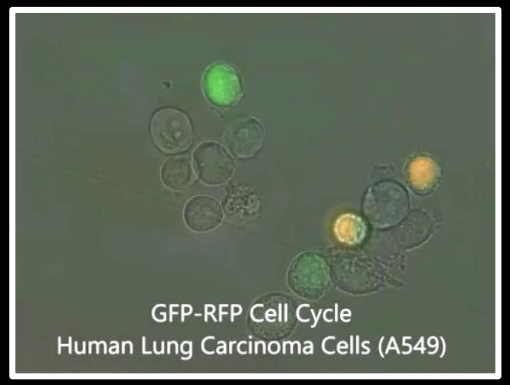


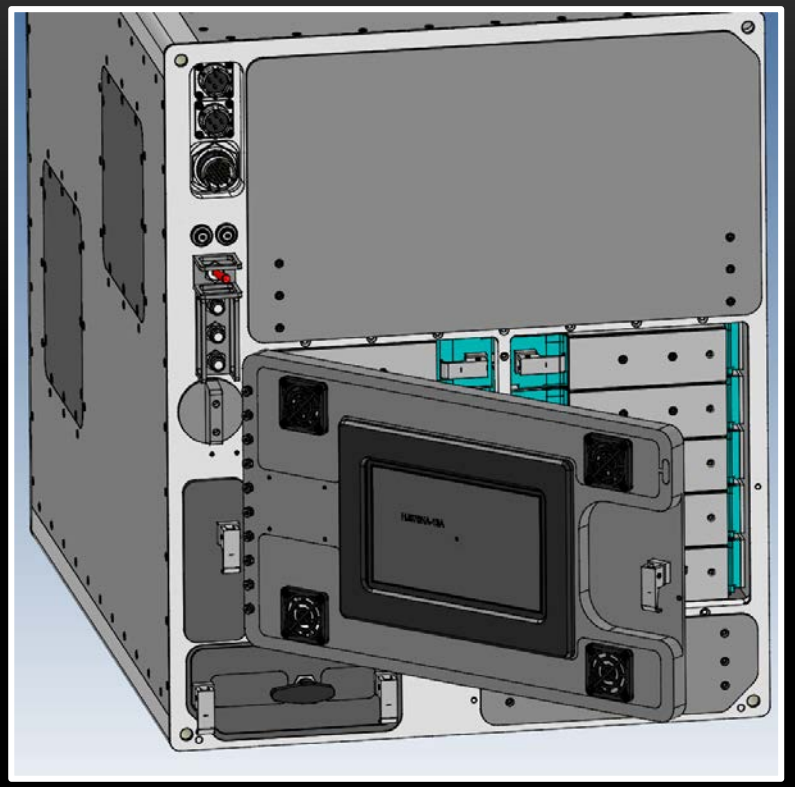
BioChip SpaceLab: An Automated Cell Biology Platform in Space

The BioChip SpaceLab (BCSL) is an automated cell biology platform that enables short and long-term experiments to run on-board the International Space Station National Lab (ISS-NL), incorporating microfluidic delivery of multiple reagents, 1g controls, and high resolution time-course fluorescence imaging.









Vented Fly Box (VFB) for *Drosophila*

Original Design – Heart Flies

New Design – Heart Flies II

Side View with fly vials

Rodent Research System Informing Recommendations

AH3 – Bone loss studies of genetically altered mice exposed to weightlessness are strongly recommended

AH5 – Conduct studies to identify underlying mechanisms regulating net skeletal muscle protein balance and protein turnover during states of unloading and recovery

AH8 – Determine the basic mechanisms, adaptations, and clinical significance of changes in regional vascular/interstitial pressures (Starling forces) during long duration space missions

AH12 – Determine the amount and site of the deposition of aerosols of different sizes in the lungs of humans and mammals in microgravity

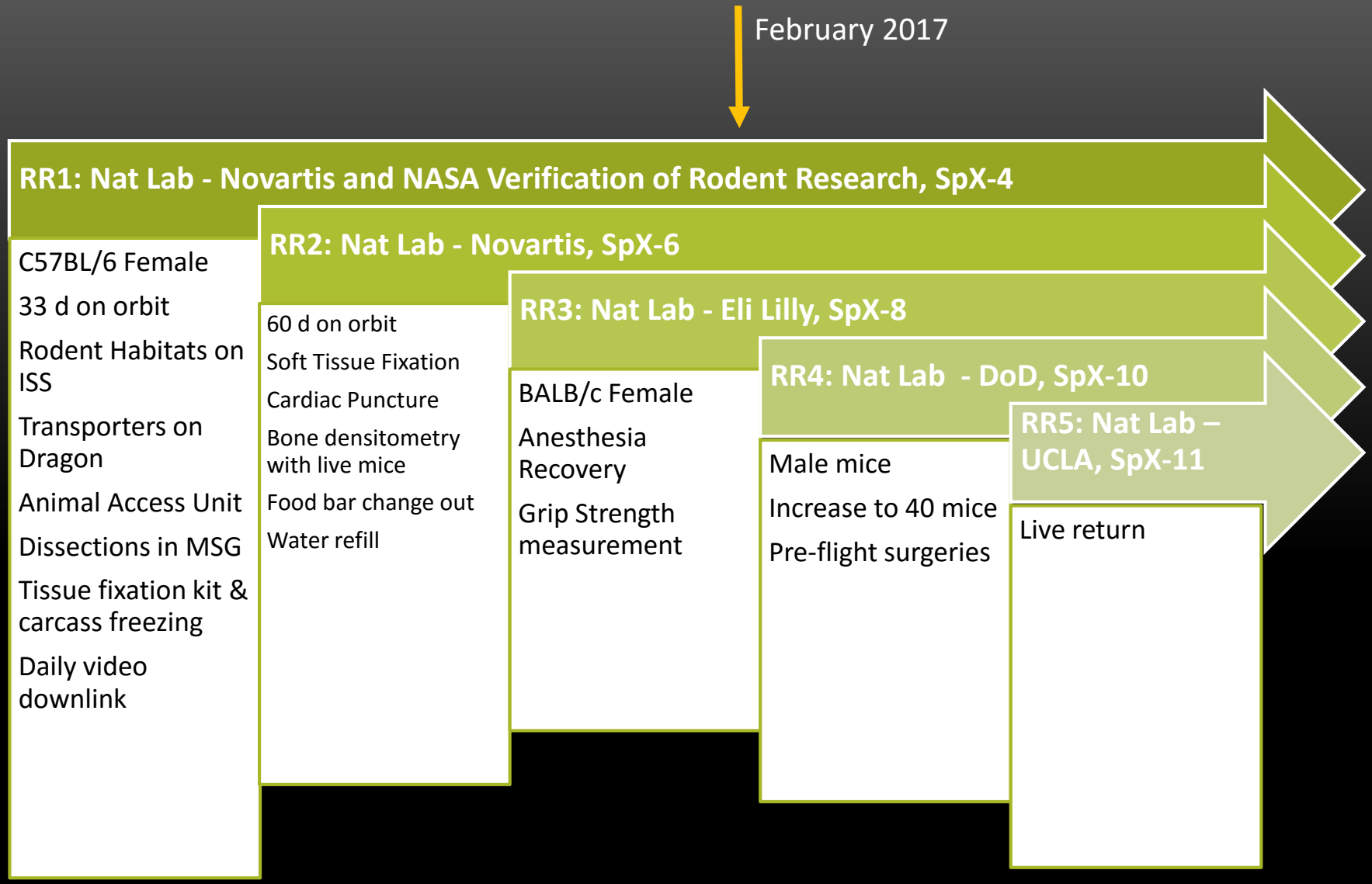
AH14 – To both address the mechanism(s) of the changes in the immune system and to develop measures to limit the changes, data from multiple "organ/system-based" studies need to be integrated

AH15 – Perform mouse studies, including immunization and challenge, with immune samples acquired both prior to and immediately upon re-entry on the ISS to establish the biological relevance of the changes observed in the immune system. Parameters examined need to be aligned with those influenced by flight in humans

AH16 – Studies should be conducted on transmission across generations of structural and functional changes induced by exposure to space during development. Ground-based studies should be conducted to develop specialized habitats to support reproducing and developing rodents in space

Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era (National Research Council, 2011)

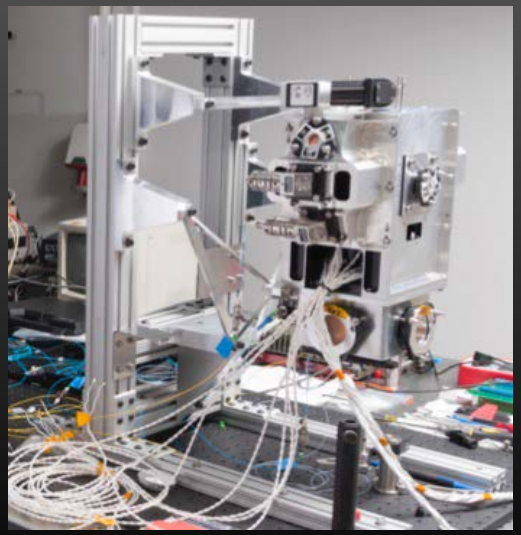
Laddering capabilities for Rodent Research

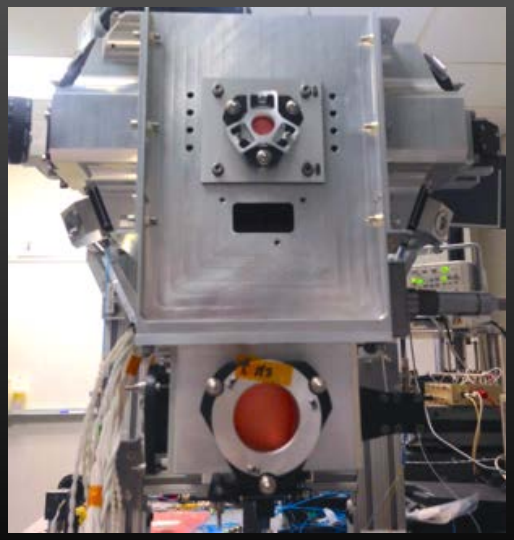


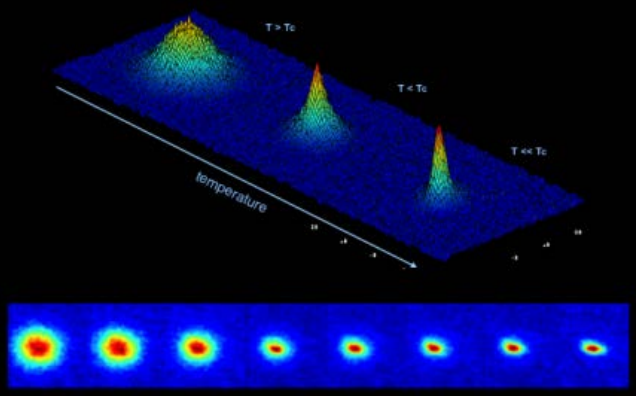
Cold Atom Laboratory (Bose Einstein Condensates)

Cold Atom Lab (CAL)

The coldest spot in the known universe…





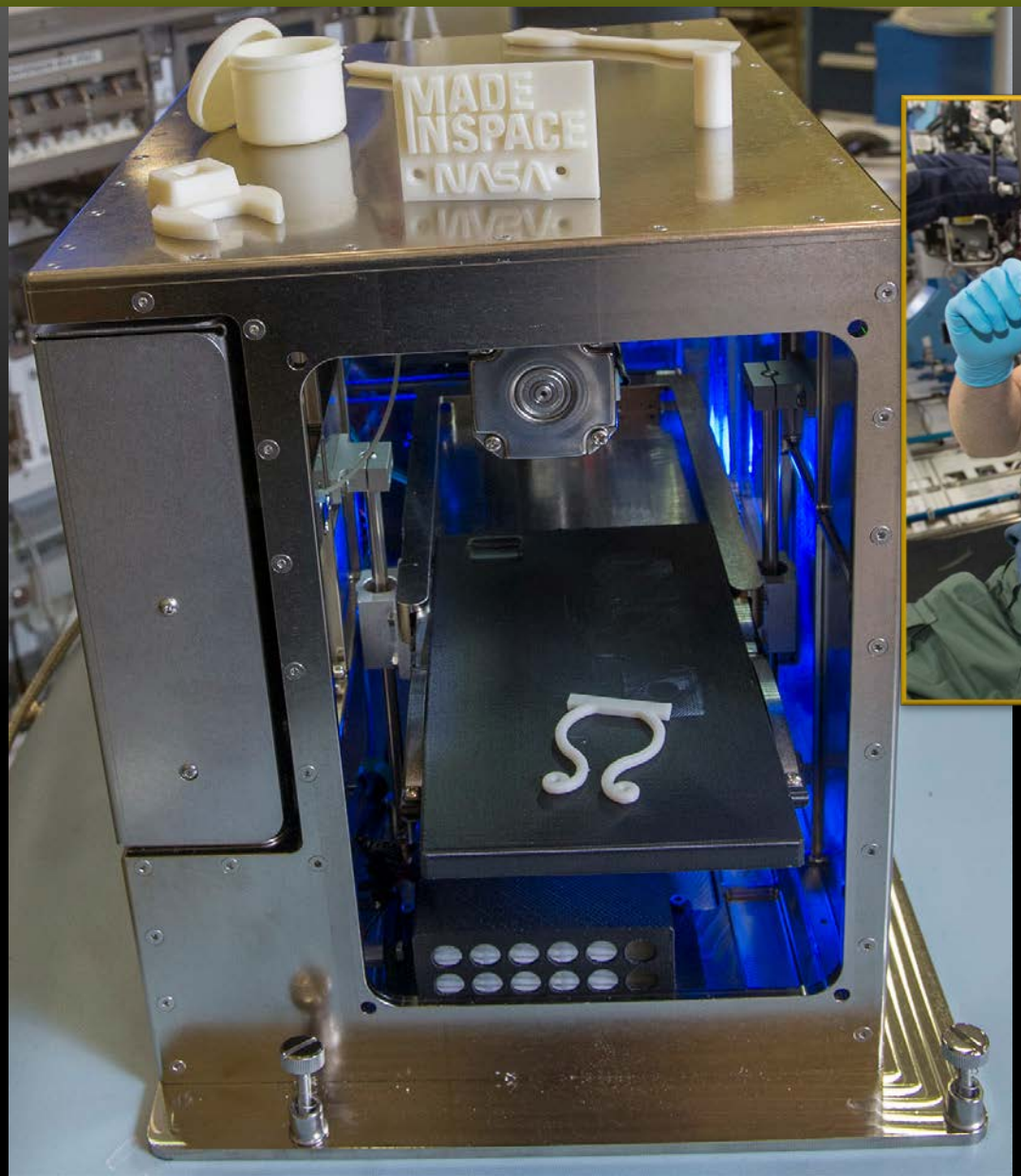


Microgravity enables laser cooling technology to reach temperatures colder than ever achieved on earth and to therefore analyze atom wave functions never observed.

Exploring this realm will help scientists to answer some of the most fundamental questions in science:

-How does complexity arise in the universe?
-What is the nature of dark energy?
-Did Einstein have the last word on gravity?
-How did the universe begin?
-How do high temperature superconductors work?
-Facilitate development of future ultra-cold atom-based quantum sensors for gravitational and magnetic fields, rotations, and tests of the equivalence principle.

Additive Manufacturing Technology Demonstrations



ISS and Low Earth Orbit Transition

- Adopt transition indicators rather than a specific date for ISS completion and cislunar development
  - Short term crewed habitation missions (i.e. EM-1 and EM-2) have been initiated in Cislunar space while ISS is still operational and being utilized.
  - Exploration research and technology/system development activities requiring ISS as a test bed are essentially complete or can be accomplished in a more effective and efficient manner.
  - Expanded opportunities have been explored for commercial markets and broad private/government/academic demand for LEO-based platforms that are based on private and/or public/private business models.

- LEO Commercialization Vision: Sustained economic activity in LEO enabled by human spaceflight, driven by private and public investments creating value and benefitting Earth through commercial supply and public and private demand

ISS Information Resources

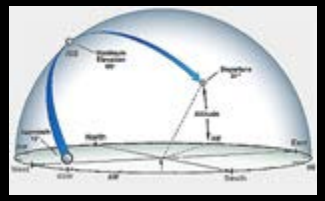
http://www.nasa.gov/iss-science/

ISS Research (Customer) Helpline
Phone: 281-244-6187
Email: jsc-iss-research-helpline@mail.nasa.gov

@ISS_Research

ISS Research Blog "A Lab Aloft"
https://blogs.nasa.gov/ISS_Science_Blog/

See the ISS over Your Town
http://spotthestation.nasa.gov/



Space Station Research Explorer App

- iPad
- Android

Apple:
https://itunes.apple.com/us/app/space-station-research-explorer/id934070569?mt=8

Google Play:
https://play.google.com/store/apps/details?id=gov.nasa.jsc.igoal.ISSResearchExplorer&hl=en