Updated Benefits for Humanity, Third Edition (B4H3), from the International Space Station (ISS)

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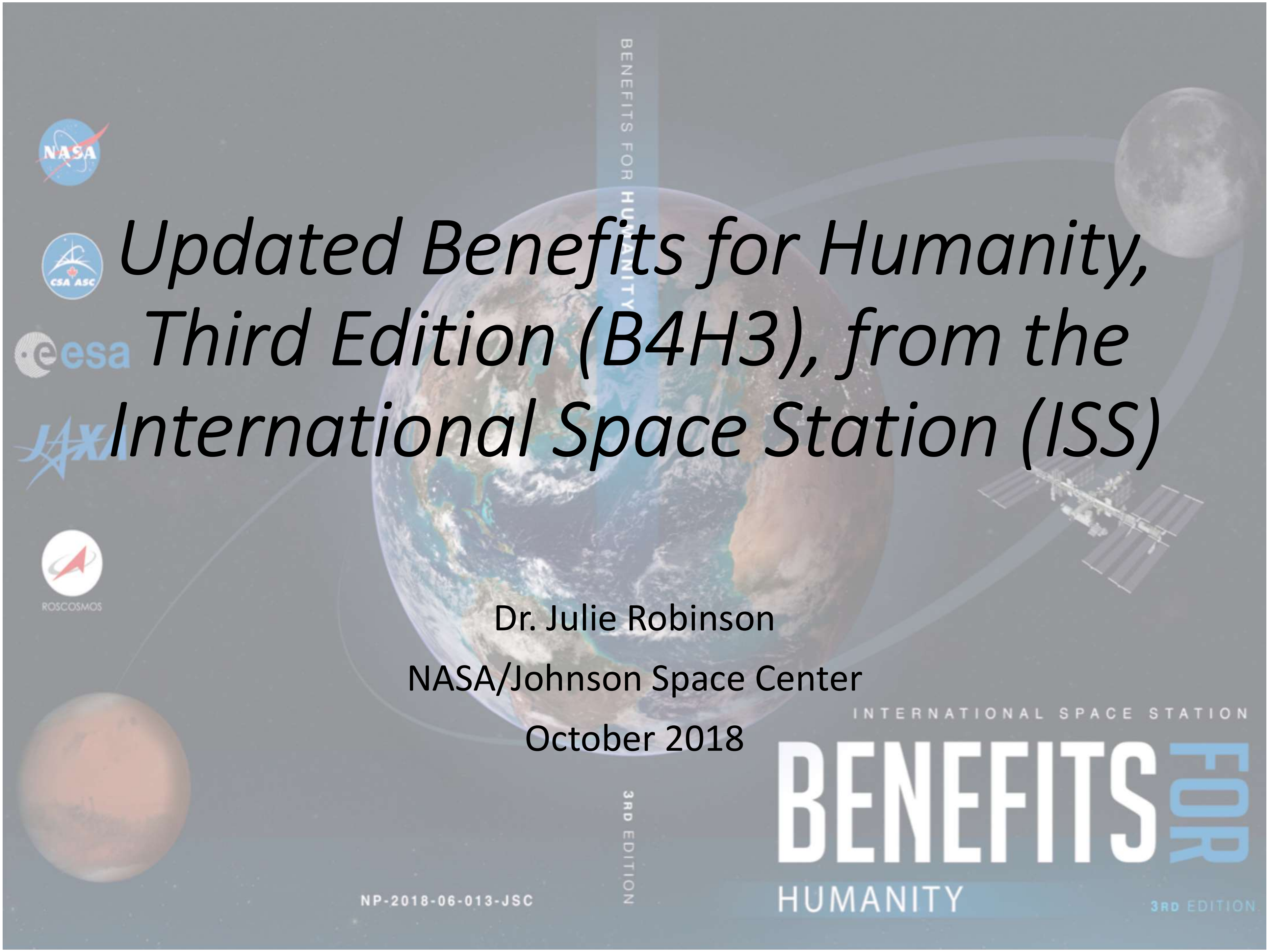

Presentation Overview

- B4H3 Objective/Description
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- B4H3 Scientific Valuation (SV) Results
- B4H3 Benefits Section Description/Examples
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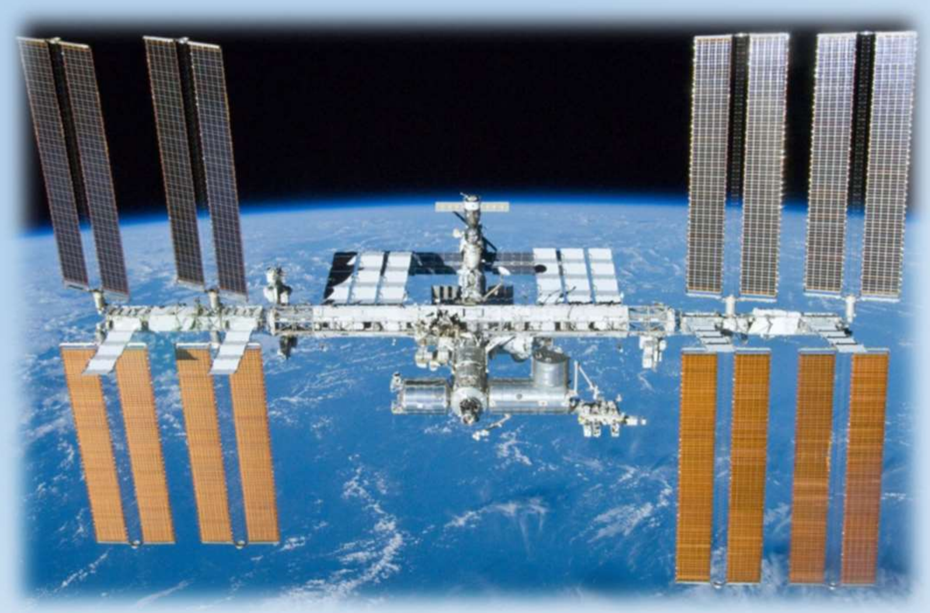


B4H3 Objective/Description

- The ISS Program Science Forum (PSF)* will soon complete a Third Edition of the **ISS Benefits for Humanity (B4H3) book**
    - Designed to be used for ISS life extension discussions, in addition to documenting benefits accrued via ISS research
- B4H3 format – **three major sections**:
    - **Economic Valuation (EV)** – unique (new) to the Third Edition
    - **Scientific Valuation (SV)** – unique (new) to the Third Edition
    - **Benefits** – new and updated narrative stories from:
        - Economic development of space
        - Innovative technology
        - Human health
        - Earth observations and disaster response
        - Global education

*PSF consists of senior science representatives across the ISS international partnership

B4H3 Economic Valuation (EV) Results

- Navigant Consulting, Inc. provided a description of how benefits evolve with ongoing research - emerging vs. mature value
- Significant growth in global space economy

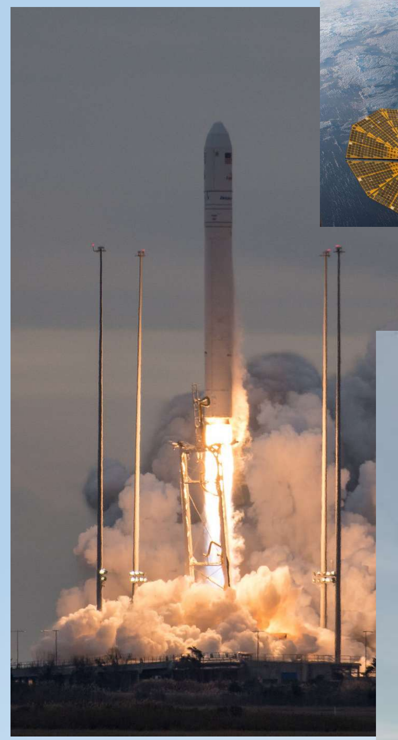
  $176B in 2006 ➲ $345B in 2016

- Private sector’s increasing interest demonstrated by growth of venture capital (VC) investment in space start-up companies

  $1.1B in 2000-2014 ➲ $1.8B in 2016 ➲ $3.9B in 2017

B4H3 Economic Valuation (EV) Results

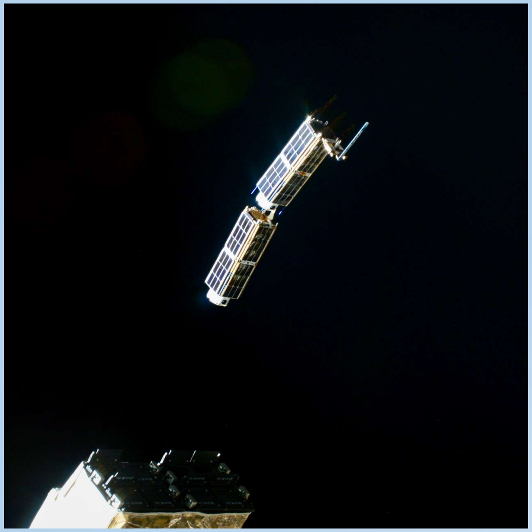
- ISS contributions to the emerging space economy include more affordable, reliable access to space
  - 2006: Commercial Orbital Transportation Services (COTS)
  - 2008: Commercial Resupply Services (CRS)

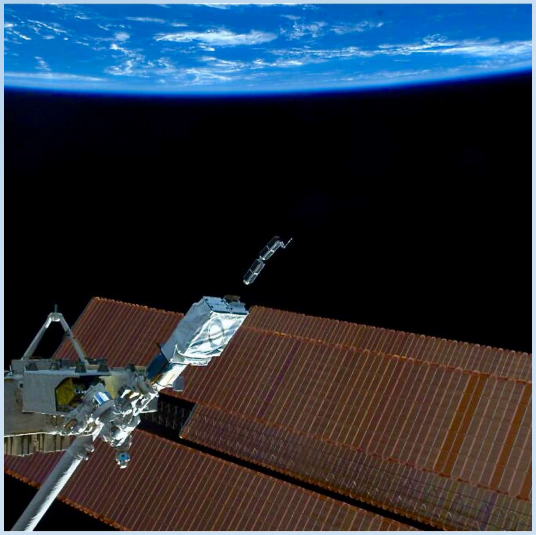


B4H3 Economic Valuation (EV) Results

- ISS contributions to the emerging space economy also include:
  - Commercially-operated research facilities
    - Currently 13 providers (12 U.S. and 1 ESA)
  - Commercial payload and payload integration providers
    - For example, the Research, Engineering, Mission Integration Services (REMIS) contract (16 providers)
  - Small satellite market development - helped to mature capabilities, triggering rapid growth, which in turn has supported LEO commercialization
    - Before ISS: <50 CubeSats deployed
    - Since ISS (2012): CubeSat deploys increased 66% annually
    - From 2012 to 2017: >700 CubeSats deployed (~200 from ISS)
    - 2017: 67% of all small satellites were for commercial services

B4H3 EV Results Example: Planet Labs, Inc.





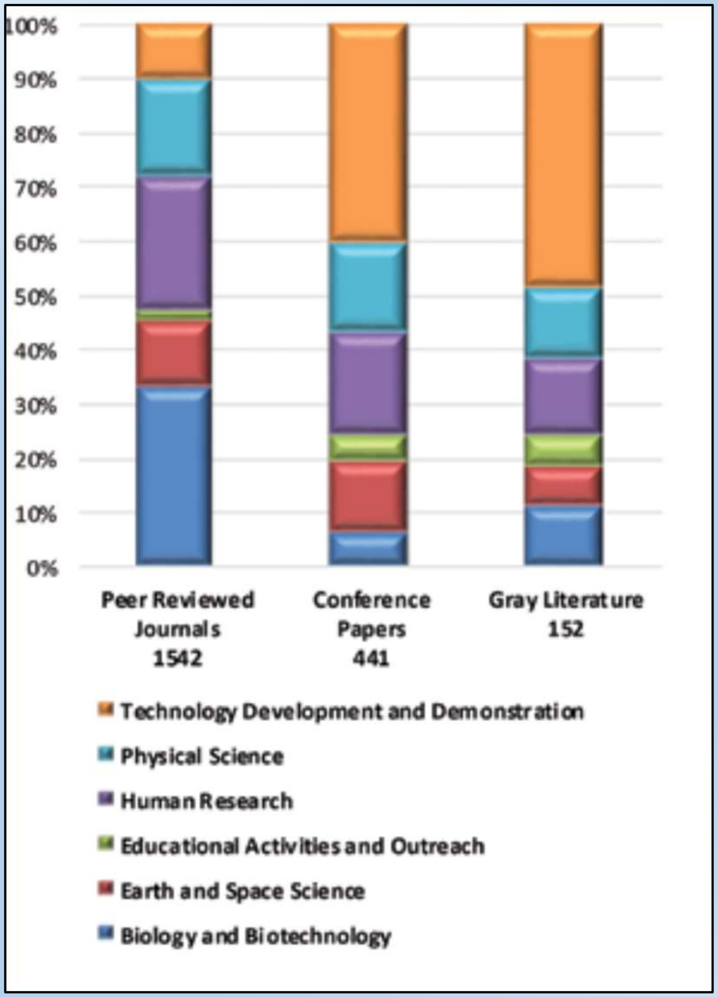
- Started in 2010, Planet (Planet Labs, Inc.) provides LEO Earth observation photography using hundreds of small satellites
- Beginning in 2013, Planet started using the space station as a technology development testbed
- As of March 2018, Planet has:
  - A fleet of >175 satellites and employs >470 people
  - Annual revenues of ~$64M and an estimated value of >$1B
  - Achieved its original goal of being able to photograph the entire surface of the Earth every day
- Planet now uses commercial launch providers, but its story illustrates how the ISS provides access to space, allowing new business models to prove themselves and attract the investment capital needed to establish themselves in the marketplace

B4H3 SV Results: Valuation Methodology

- SV methodology: content generated using the same methodology used for our ISS Annual Highlights of Results publication

- One method used to evaluate ISS scientific output is to track article citations and Eigenfactor®
  - As of May 2018, 135 ISS publications have been listed in the top 100 journals by Eigenfactor; 85 of those were in the top 10 journals as reported by Clarivate Analytics®

B4H3 SV Results: ISS Research is Impactful



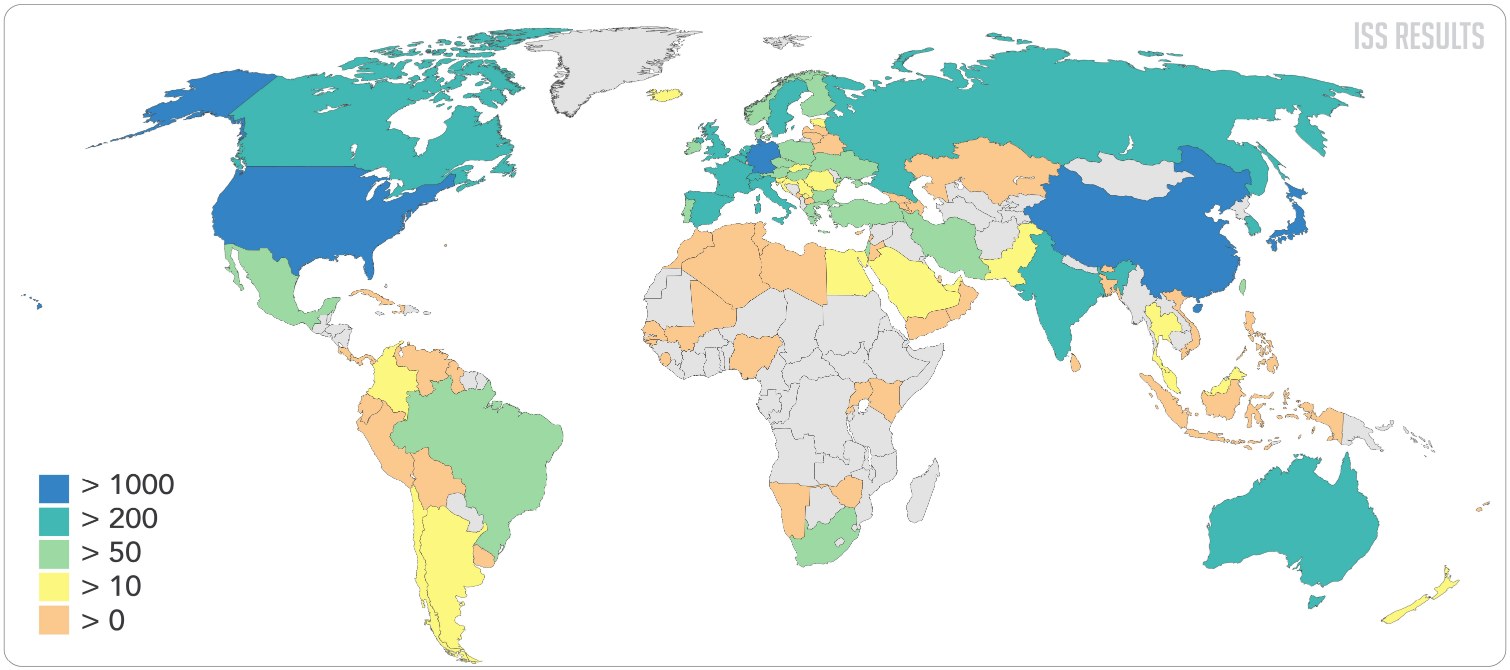
ISS Publications Collected Through May 31, 2018

ISS Publications in the Top 100 Global Journals, by Eigenfactor

	Clarivate Analytics® Ranks	Source (# of ISS Articles)
ISS Articles in Top 10 Sources	1	PLOS ONE (42)
	2	Nature (2)
	3	Proceedings of the National Academy of Sciences of the United States of America (4)
	4	Science (3)
	6	Physical Review Letters (32)
	7	Nature Communications (1)
	8	New England Journal of Medicine (1)
ISS Articles in Top 100 Sources	13	Journal of Biological Chemistry (2)
	14	Scientific Reports (21)
	15	The Astrophysical Journal (1)
	17	Chemical Communications (1)
	20	Advanced Materials (1)
	22	Journal of Neuroscience (1)
	35	RSC Advances (1)
	38	Astronomy and Astrophysics (2)
	41	Optics Express (2)
	42	Chemistry - A European Journal (1)
	53	Geophysical Research Letters (4)
	55	NeuroImage (1)
	60	The Journal of Chemical Physics (5)
	70	Physical Review E (2)
	74	Langmuir (3)
	82	Biomaterials (1)
	94	Journal of Clinical Endocrinology and Metabolism (1)

ISS Publications in the Top 100 Global Journals, by Eigenfactor, as reported by 2016 Journal Citation Reports®

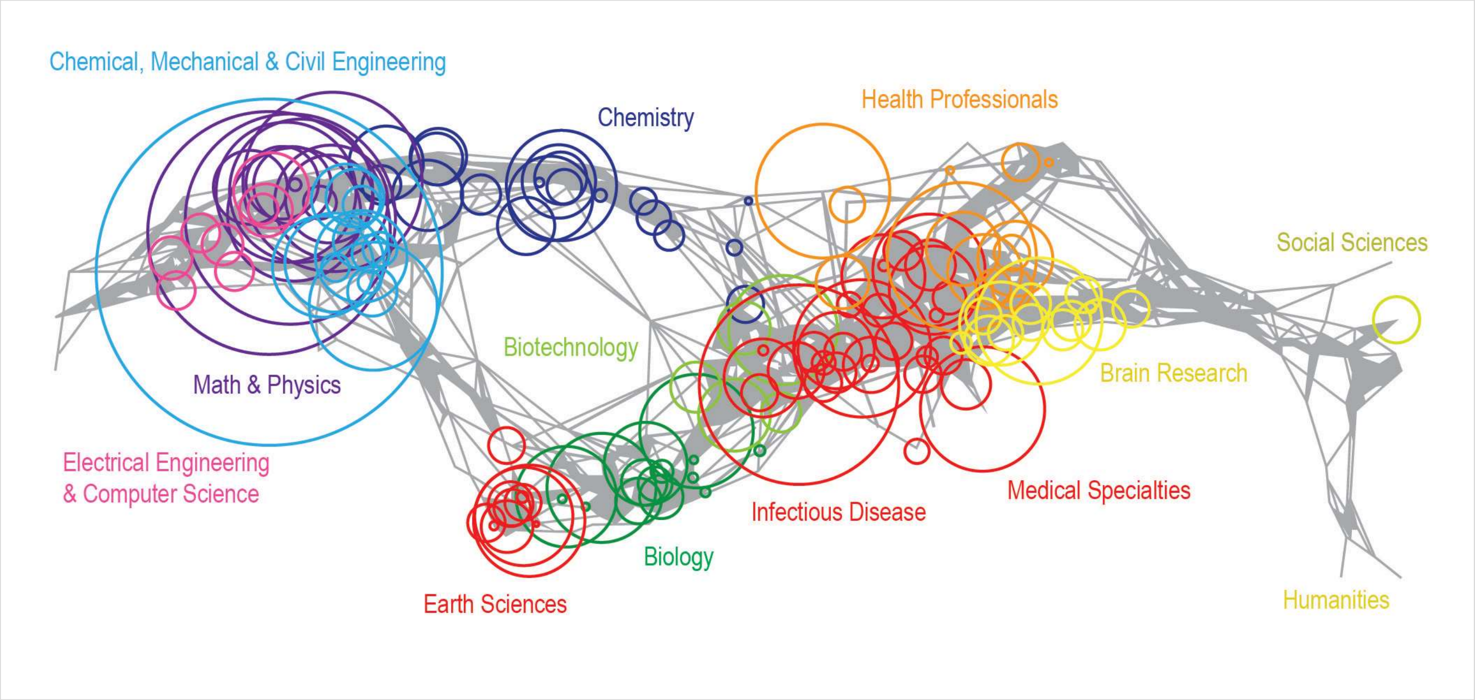
B4H3 SV Results:
ISS Research Impacts are Global



Heat Map of All ISS Results Citations

ISS research affects scientific advancement outside the countries whose agencies sponsored it. This illustrates that impact in the 112 countries of the scientists who have cited ISS research results published in scholarly journals.

B4H3 SV Results: ISS Research Impacts are Diverse

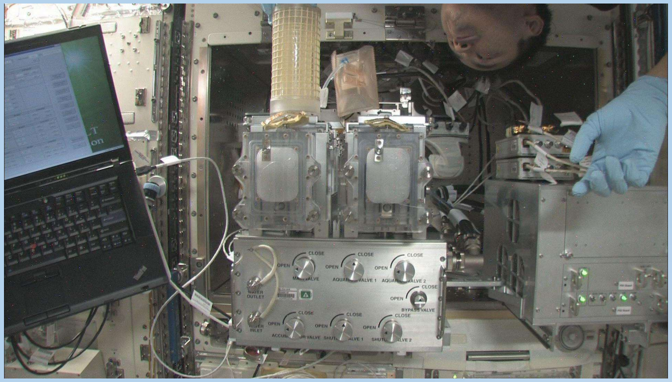


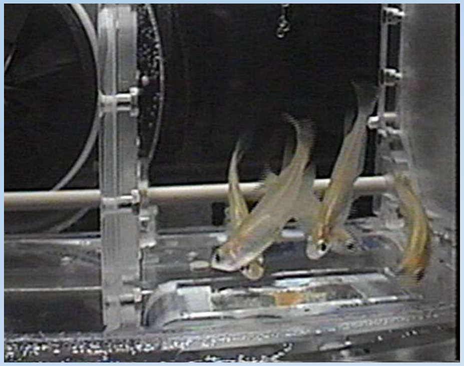
ISS Map of Science

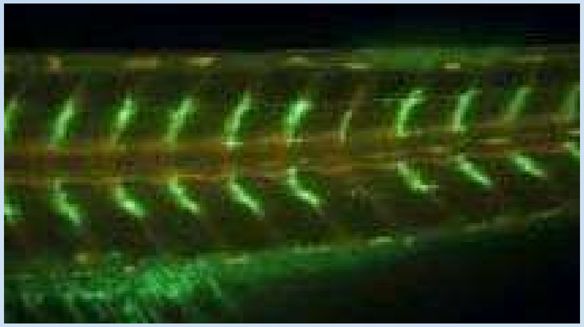
This illustrates the spread of knowledge from ISS research across the many different disciplines of science. ISS research has **impacted 12 of the 13 primary disciplines** in the base map (humanities is the exception) and includes both space-related and non-space-related scientific disciplines. The underlying base map is the widely used disciplinary classification system and layout algorithm known as the University of California, San Diego (UCSD) Map of Science.

B4H3 SV Results Example: Medaka Osteoclast

- The medaka fish (*Oryzias latipes*), a model organism, was used to study the effects of microgravity on the mechanisms behind bone density and organ tissue changes in space. Published results include:
  - Mineral density decreased after 56 days (~24% in upper pharyngeal bone and the tooth region) while osteoclast volume increased and osteoblast activity decreased. Chatani, M., et. al. Scientific Reports. 2015 September 21; 5(14172).
  - Analysis of genes from multiple tissues revealed highly tissue-specific space responsiveness and suggests common immuno-regulatory and stress responses during space adaptation. Chatani, M., et. al. PLOS ONE. 2015 October 1; 10(10).
  - Exposure to microgravity immediately induced dynamic alteration of gene expression levels in osteoblasts and osteoclasts. Chatani, M., et. al. Scientific Reports. 2016 December 22; 6(39545).
- Understanding action of microgravity's affect on bone loss should contribute to progress in the fields related to the effect of mechanical stress on bone, as well as possible clinical applications for osteoporosis.

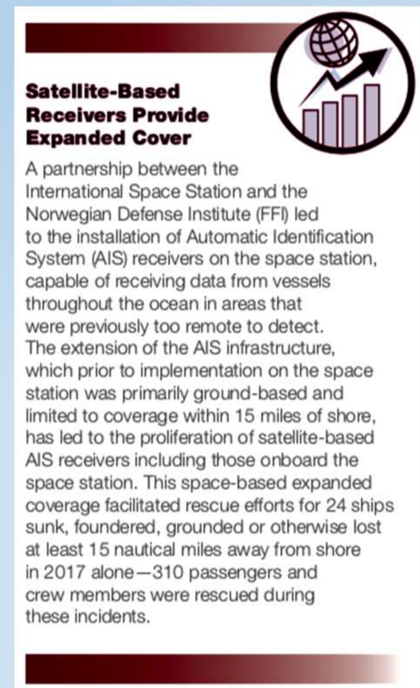






B4H3 Benefits Section Description

- New and updated narrative stories (like the First and Second Editions) in the following benefit areas
    - Economic development of space
    - Innovative technology
    - Human health
    - Earth observations and disaster response
    - Global education
- EV and SV sidebars (boxed briefings) alongside their associated narrative stories

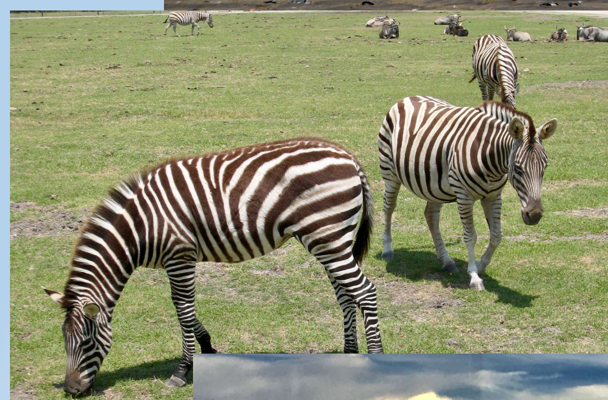


Satellite-Based Receivers Provide Expanded Cover

A partnership between the International Space Station and the Norwegian Defense Institute (FFI) led to the installation of Automatic Identification System (AIS) receivers on the space station, capable of receiving data from vessels throughout the ocean in areas that were previously too remote to detect. The extension of the AIS infrastructure, which prior to implementation on the space station was primarily ground-based and limited to coverage within 15 miles of shore, has led to the proliferation of satellite-based AIS receivers including those onboard the space station. This space-based expanded coverage facilitated rescue efforts for 24 ships sunk, foundered, grounded or otherwise lost at least 15 nautical miles away from shore in 2017 alone—310 passengers and crew members were rescued during these incidents.

B4H3 Benefits Example: ICARUS

- The International Cooperation for Animal Research Using Space (ICARUS) seeks to observe global migratory movements of small animals via a dedicated ISS antenna
    - The low ISS orbit (400 km or ~250 miles) provides capability to detect relatively-weak transmissions, which reduces the power and size requirements of the transmitter - allowing researchers to track smaller organisms than ever before
    - Provides greater insights into the large-scale, long-term migratory patterns of animals as well as their food supplies
- The ICARUS antenna, installed on the ISS Russian segment in August 2018, will track more than 15M transmitters—a significant improvement over the current limit of 22,000
- Among other benefits, ICARUS may help identify ongoing variations in climate change, as well as facilitate improved natural disaster preparedness and warning systems.



B4H3 Benefits Example: Vascular

- Cardiovascular Health Consequences of Long-Duration Space Flight (Vascular) investigates the impact of long-duration space flight on the blood vessels of astronauts.
- Space flight accelerates the aging process and can cause stiffening of the arteries, affecting the body's ability to control blood pressure, so it is important to understand this process to develop specific countermeasures. Data is collected before, during, and after space flight to assess inflammation of the artery walls, changes in blood vessel properties, and cardiovascular fitness.
- This experiment contributes to obtaining a better understanding of the mechanisms that might contribute to premature aging of the cardiovascular system in all humans, not just astronauts, and to detect early markers of potential atherosclerosis (condition in which fatty material collects along the walls of arteries) and inflammation.

Closing Thoughts

- The ISS enables benefits, discoveries and space exploration by virtue of the unique environment in which it exists.
- Establishment and maintenance of the spacecraft is a monumental achievement unto itself, and its achievements continue to expand via its contributions to science, technology, and the economic development of space.
- By challenging human ingenuity to live and work in new extreme environments, space exploration requires innovation, which results in discovery. Innovation creates new technology and discovery results in new knowledge, and both of these create economic opportunity.
- In the third edition of the *International Space Station Benefits for Humanity* (B4H3) book, we share these successes with our colleagues in the global community.

Backup Charts

B4H3 Economic Valuation (EV) Methodology and EV Section Description

- A collaborative process with an EV specialist, Navigant Consulting, Inc., to identify EV in at least one of three areas:
  - **Innovation**, e.g., new knowledge, novel approaches, creation of unique niche, and research leadership
  - **Social value**, e.g., quality of life improvements, health benefits, environmental benefits, cultural and community cohesion, and inspiration
  - **Economic value**, e.g., addressable market, market penetration, revenue generation, and ability to leverage across other applications or customer groups
- **Detailed EV Results** include aspects of emerging commercial market in low Earth orbit (LEO), like:
  - Space access
  - Commercial companies role in research, research facilities and integration services
  - ISS role in small satellite (e.g., CubeSat) market development
- **Perspectives of PSF and National Lab representatives**
  - CSA, ESA, ASI, JAXA, ROSCOSMOS, CASIS, and NASA
- **Short summaries of EV findings (sidebars**; boxed briefs) are compiled in a table at the end of this section, in addition to being part of their associated story in the Benefit section (see example)

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University of California, San Diego (UCSD) Map of Science

- The UCSD Map of Science is a reference-standard, disciplinary classification system derived from articles and citations contained in more than 25,000 journals tracked and indexed by Thomson Reuters Web of Science and Scopus.
- In the UCSD visualization, each article is located within a network of 554 subdisciplines, which are then aggregated into 13 primary disciplinary classifications. Each colorful circle therefore represents a unique subdiscipline and is sized by how many scientific articles are present within that subdiscipline.
- The UCSD Map of Science was originally produced in 2005 at the request of UCSD, and updated in 2012. Its map and classification system are distributed under the Creative Commons Attribution-Non Commercial- ShareAlike 3.0 Unported (CC BY-NC-SA 3.0) license (https://creativecommons.org/licenses/by-nc-sa/3.0/).

ISS Research Goals/Areas

- NASA/ISS Goals
  - Advancing **benefits to humanity** through research
  - Enabling a **commercial demand-driven market in LEO**
  - Enabling **long duration human spaceflight (HSF)** beyond LEO
  - Being a basis for **international HSF exploration partnerships**
- Space Research Benefits : B4H, Discovery, Exploration
- ISS Achievements: Engineering, International Cooperation, Scientific, Economic Development of Space
- ISS Research areas:
  - Biology/Biotechnology
  - Human Research
  - Earth and Space Science
  - Physical Science
  - Technology Development
  - Education

ISS Vehicle Information

- Mass: ~925,000 lbs (~419,000 kg)
- Pressurized Volume: 32,333 ft^3 (915 m^3)
- Altitude: ~260 miles (~415 km)
- Orbital Inclination: 51.6°
- Velocity: 17,500 mph (28,200 kph)
- Science Capability - laboratories from four space agencies:
  - Europe (ESA)
  - Japan (JAXA)
  - Russia (ROSCOSMOS)
  - US (NASA)