National Aeronautics and Space Administration

NASA'S VISION FOR EXPLORATION

William H. Gerstenmaier

2018 April 23

NASA'S PLACE IN THE NATION AND WORLD

- Making new discoveries, expanding human knowledge, and pushing human presence deeper into space
- Strengthening global engagement and diplomacy
- Enhancing the nation's security and industrial base
- Catalyzing economic development and growth
- Addressing societal challenges
- Engaging the public
- Optimizing capabilities and operations

SPACE POLICY DIRECTIVE-1

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.

Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

DEEP SPACE EXPLORATION SYSTEM

NASA tests ensure astronaut, ground crew safety before Orion launches

Thermal cycle test completed on Orion crew module

SLS core stage pathfinder arrives at NASA Michoud

The four RS-25 engines that will power SLS

Orion crew access arm prepared to move to mobile launcher

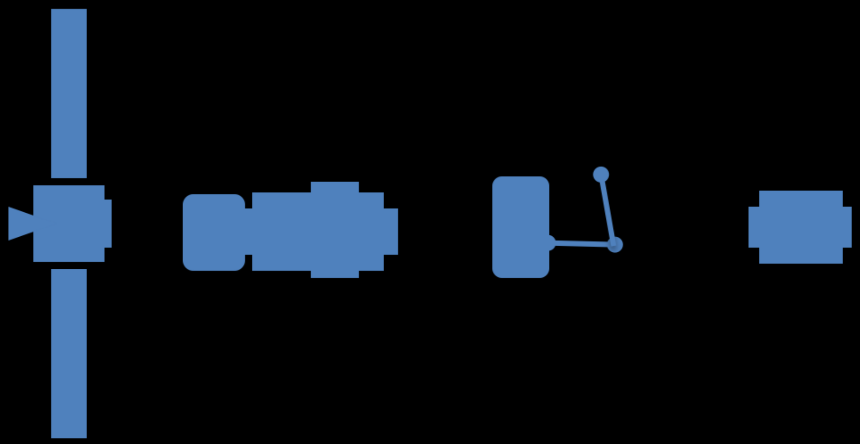
Liquid Oxygen tanking operations begin at Launch Pad 39B

GATEWAY DEVELOPMENT

Establishing leadership in deep space and preparing for exploration into the solar system

FOUNDATIONAL GATEWAY CAPABILITIES

2022	2023	2024+



These foundational gateway capabilities can support multiple U.S. and international partner objectives in cislunar space and beyond.

CAPABILITIES

- Supports exploration, science, and commercial activities in cislunar space and beyond
- Includes international and U.S. commercial development of elements and systems
- Provides options to transfer between cislunar orbits when uncrewed
- External robotic arm for berthing, science, exterior payloads, and inspections

OPPORTUNITIES

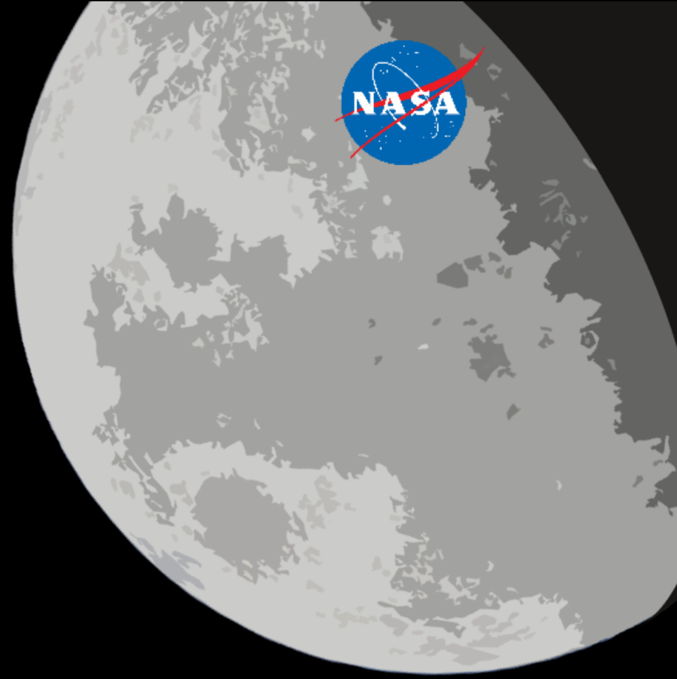
- Logistics flights and logistics providers
- Use of logistics modules for additional available volume
- Ability to support lunar surface missions

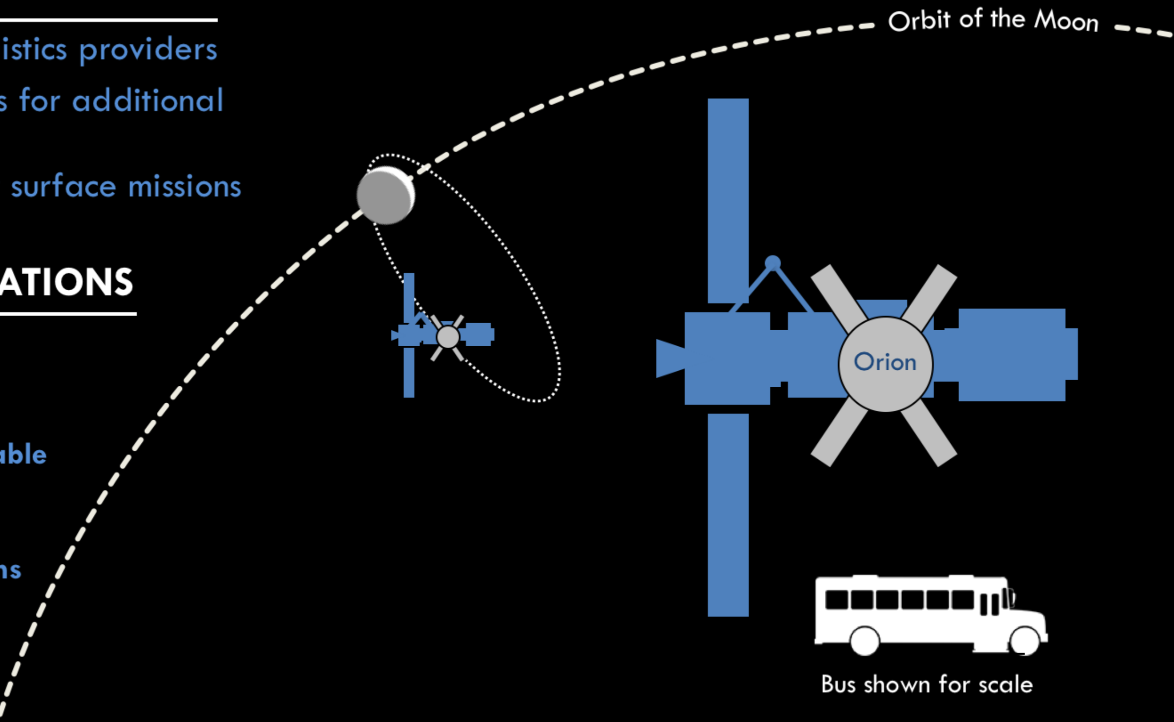
INITIAL ACCOMMODATIONS

4 Crew Members

At least 55 m^3 Habitable Volume

30 Day Crew Missions





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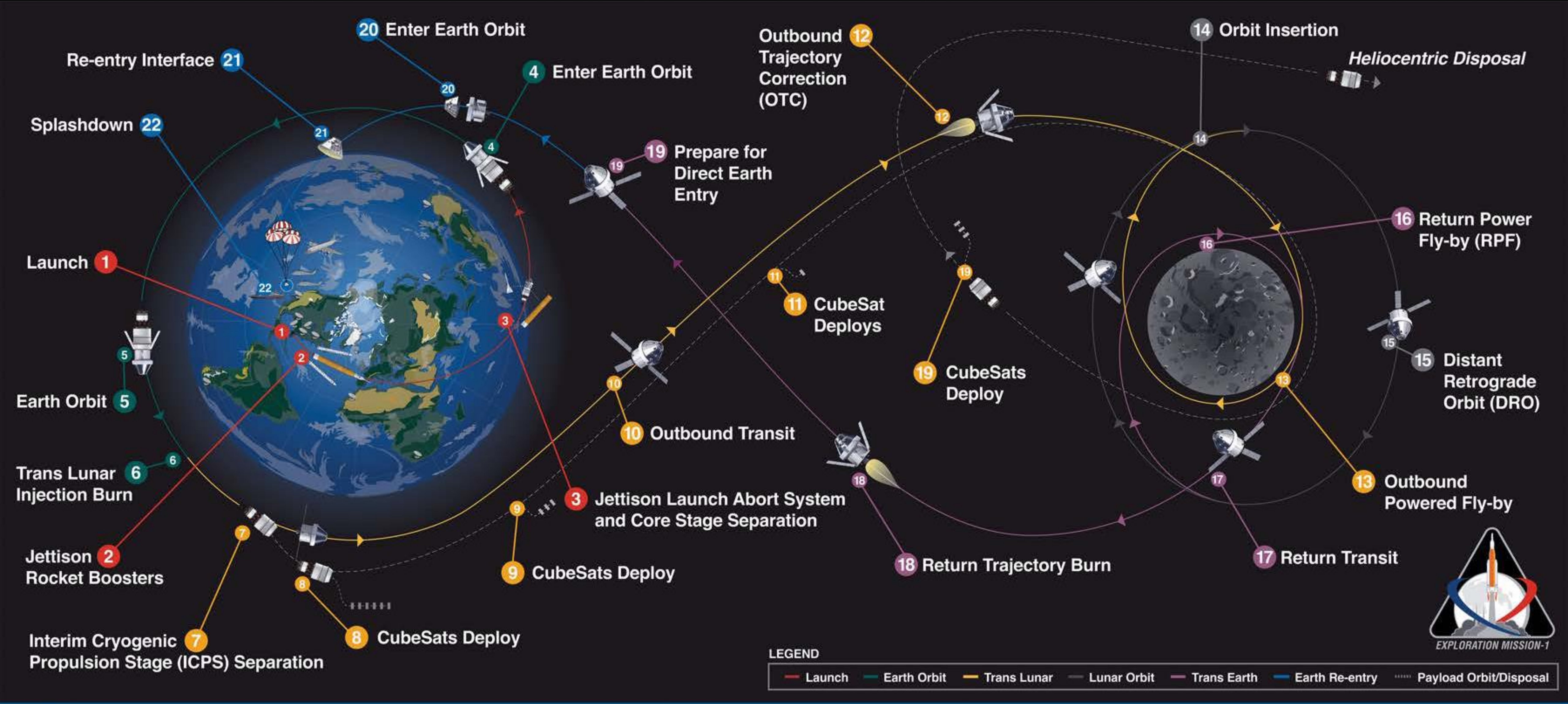
EXPLORATION MISSION-1 SUMMARY

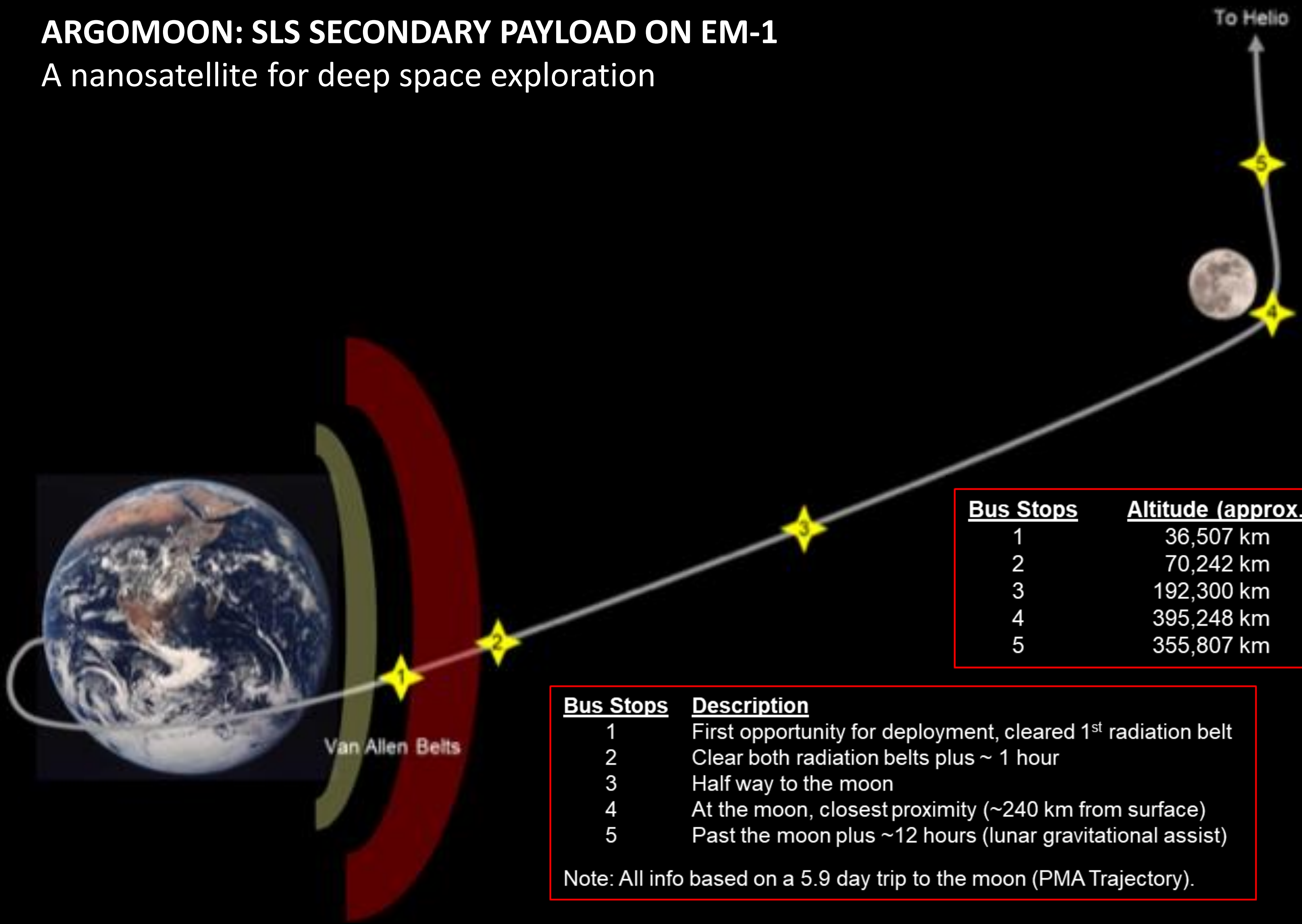
The first uncrewed, integrated flight test of NASA's Deep Space Exploration Systems. The Orion spacecraft and Space Launch System rocket will launch from a modernized Kennedy spaceport



Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

ARGOMOON: SLS SECONDARY PAYLOAD ON EM-1

A nanosatellite for deep space exploration



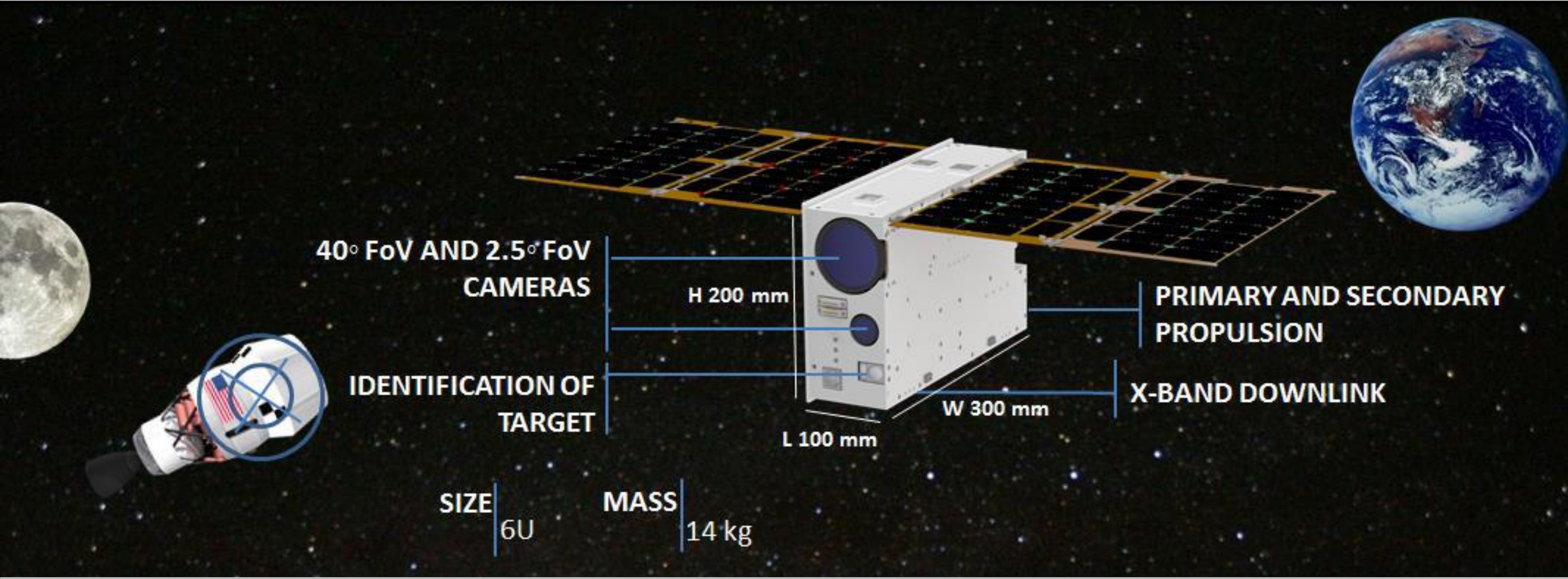
Bus Stops	Altitude (approx.)	Flight Time (PMA Based)
1	36,507 km	4 Hrs. & 1 Min.
2	70,242 km	6 Hrs. & 59 Min.
3	192,300 km	1 Days, 0 Hrs. & 54 Min.
4	395,248 km	5 Days, 21 Hrs. & 50 Min.
5	355,807 km	6 Days, 9 Hrs. & 49 Min.

Bus Stops	Description
1	First opportunity for deployment, cleared 1st radiation belt
2	Clear both radiation belts plus ~ 1 hour
3	Half way to the moon
4	At the moon, closest proximity (~240 km from surface)
5	Past the moon plus ~12 hours (lunar gravitational assist)

Note: All info based on a 5.9 day trip to the moon (PMA Trajectory).

ARGOMOON: AN ITALIAN EYE ON THE EM-1

A nanosatellite for deep space exploration

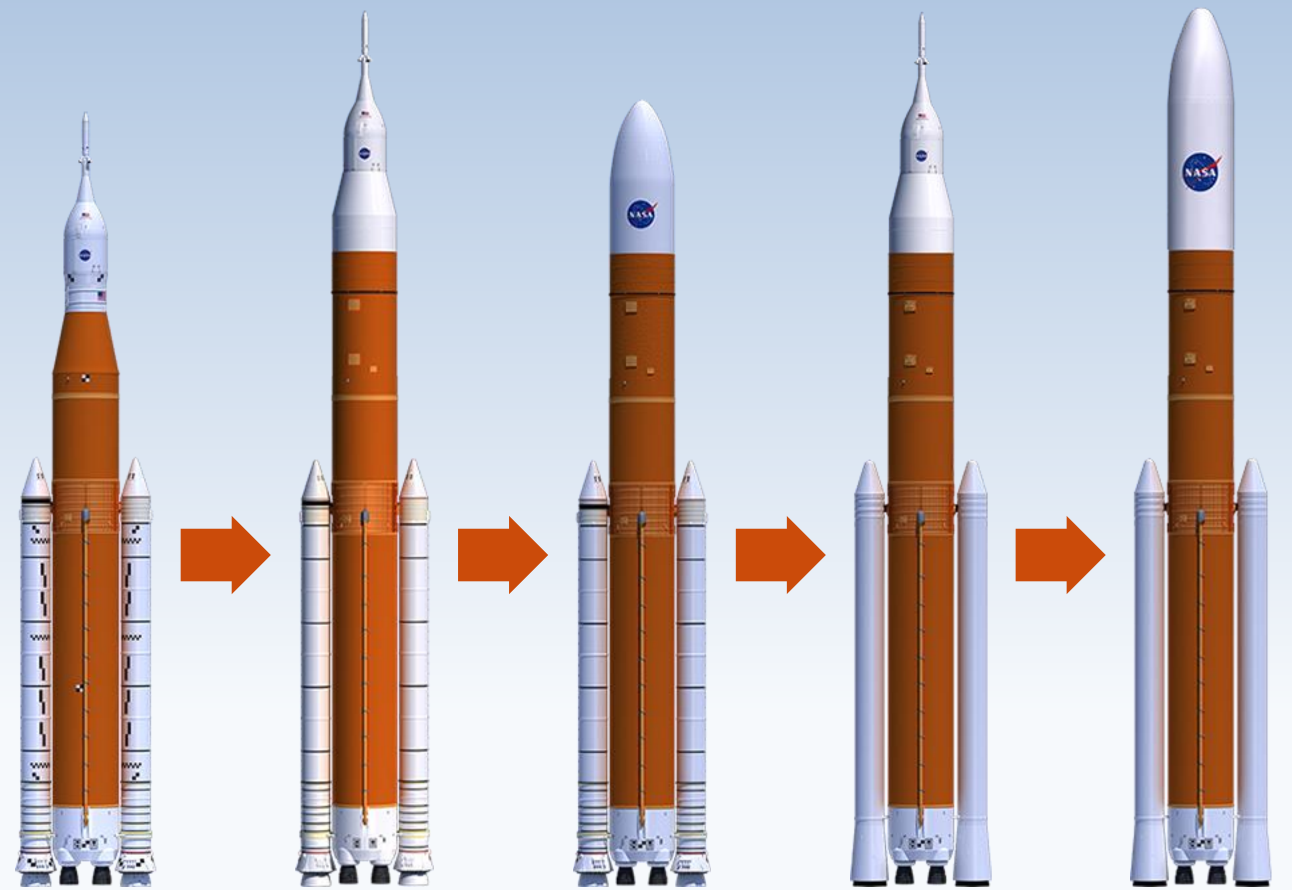


SPACE LAUNCH SYSTEM LIFT CAPABILITIES

Trans-Lunar **Injection (TLI)** is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. A spacecraft performs **TLI** to begin a lunar transfer from a low circular parking orbit around Earth.

The numbers depicted here indicate the mass capability at the Trans-Lunar Injection point.

	SLS Block 1	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Payload to TLI/Moon	> 26 t (57k lbs)	34–37 t (74k–81k lbs)	37–40 t (81k–88k lbs)	> 45 t (99k lbs)	> 45 t (99k lbs)
Payload Volume	N/A**	10,100 ft³ (286m³)**	18,970 ft³ (537 m³)	10,100 ft³ (286m³)**	31,950 ft³ (905 m³)
Maximum Thrust	8.8M lbs	8.8M lbs	8.8M lbs	11.9M lbs	11.9M lbs

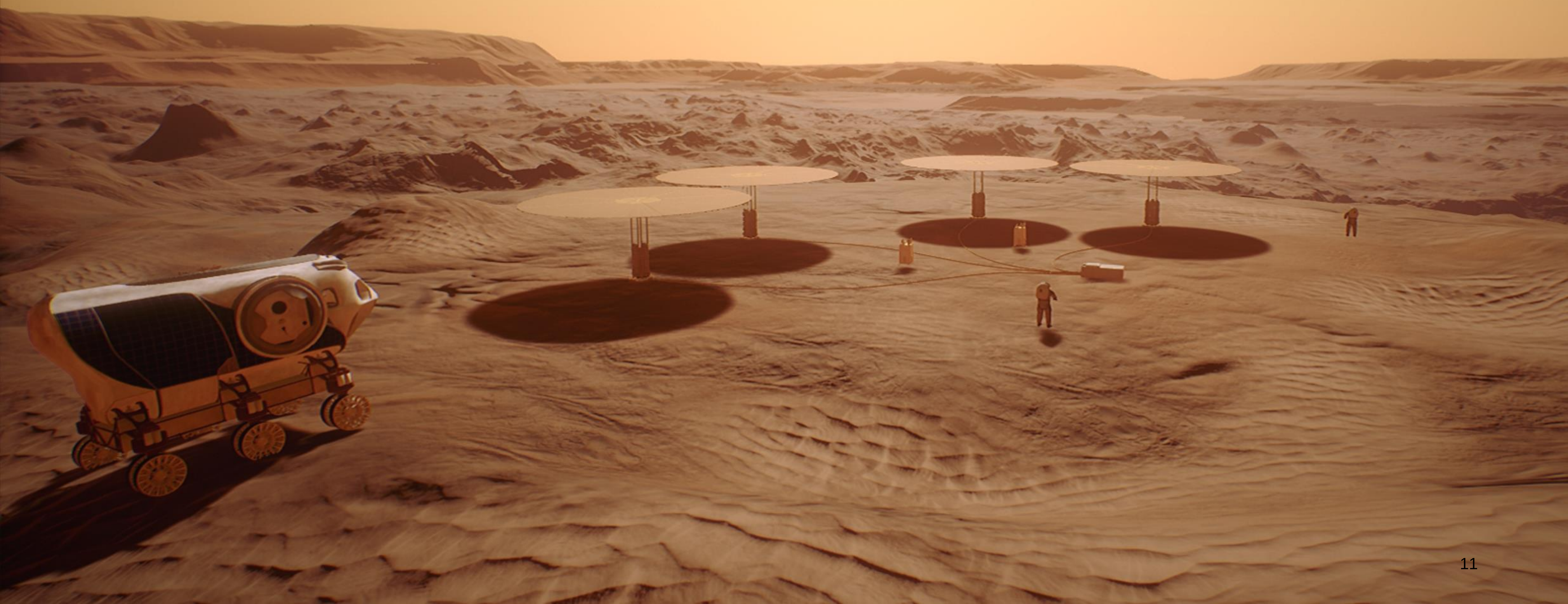


SLS Block 1 SLS Block 1B Crew SLS Block 1B Cargo SLS Block 2 Crew SLS Block 2 Cargo

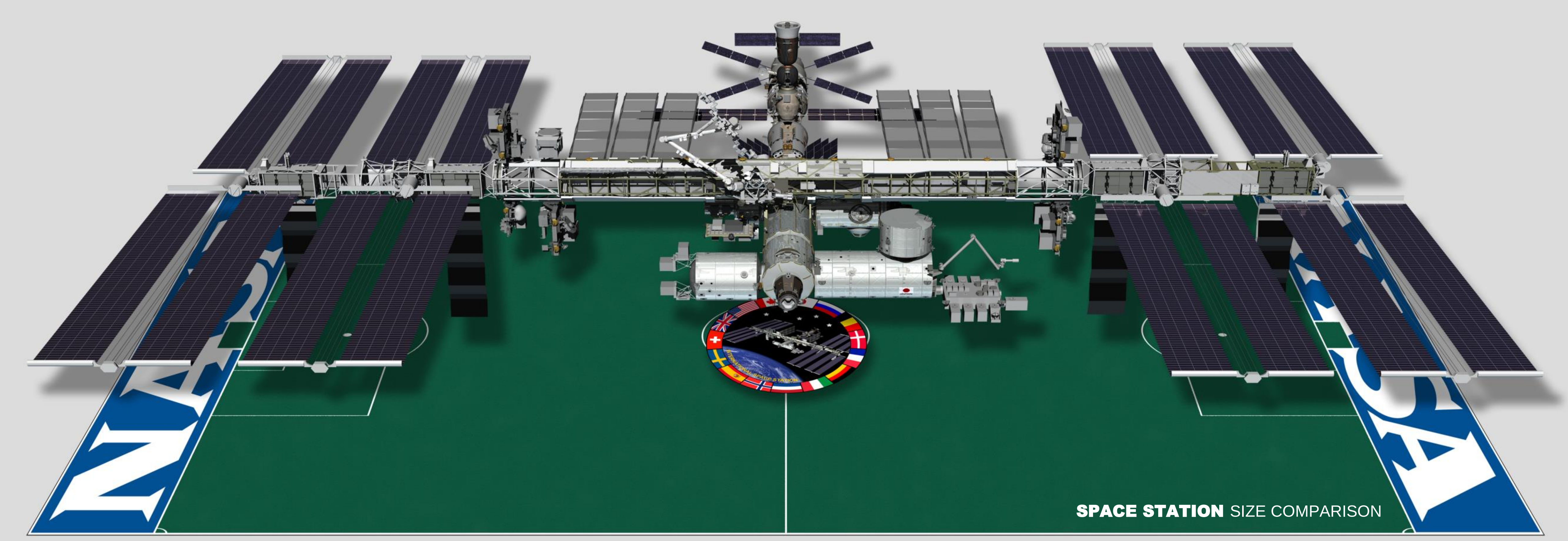
HOW ARE WE LEADING FUTURE EXPLORATION

- Building a platform that will orbit the Moon
- Sending landers to the lunar surface in preparation for a human return
- Stimulating the low-Earth orbit commercial space economy
- Developing technologies needed for exploration and resolving human health and performance challenges
- Expanding U.S. leadership through partnerships with commercial industry and other nations

MARS IS STILL OUR LONG-TERM GOAL



SPACE STATION FACTS AND FIGURES



DIMENSIONS
- Approx 240 ft long x 350 ft wide x 45 ft. high
- Volume is 32,333 cubic ft., equivalent of 5 bedroom house or Boeing 747.

ORBITAL INCLINATION/PATH
- 51.6 degrees, covers 90% of the world's population, orbiting Earth 16 times a day…an equivalent distance to the Moon and back.

ALTITUDE & SPEED
- Approximately 220 miles above the Earth, traveling at 17,500 mph.

ASSEMBLY, SUPPLY, AND VISITORS
- 41 assembly flights (1998-2011), and >192 successful launches to ISS to date.
- 230 different people from >18 countries, continuous presence since 2000.
- Involves > 100,000 people. 500 contractor facilities. 37 states, 16 countries.

EDUCATION

Space Station research and educational activities have involved over 42 million students and 2.8 million teachers across 44 countries (35 million students in the US).*

EXPLORATION HABITATION SYSTEMS

Habitation Systems Elements

LIFE SUPPORT

Excursions from Earth are possible with artificially produced breathing air, drinking water and other conditions for survival.

Atmosphere Management · Water Management · Waste Management

ENVIRONMENTAL MONITORING

NASA living spaces are designed with controls and integrity that ensure the comfort and safety of inhabitants.

Pressure O_2 & N_2 · Moisture · Particles · Microbes · Chemicals · Sound

CREW HEALTH

Astronauts are provided tools to perform successfully while preserving their well-being and long-term health.

Monitoring · Exercise · Diagnostics · Treatment · Food Storage & Management

EVA: EXTRA-VEHICULAR ACTIVITY

Long-term exploration depends on the ability to physically investigate the unknown for resources and knowledge.

Mobility · Life Support · Science and Exploration

	TODAY Space Station	FUTURE Deep Space
Life Support	~50% O_2 Recovery from CO_2 90% H_2O Recovery < 6 mo mean time before failure (for some components)	75%+ O_2 Recovery from CO_2 98%+ H_2O Recovery >30 mo mean time before failure
Environmental Monitoring	Limited, crew-intensive on-board capability Reliance on sample return to Earth for analysis	On-board analysis capability with no sample return Identify and quantify species and organisms in air & water
Crew Health	Bulky fitness equipment Limited medical capability Frequent food system resupply	Smaller, efficient equipment Onboard medical capability Long-duration food system
EVA	Upper body high mobility for limited sizing range Low interval between maintenance, contamination sensitive, and consumables limit EVA time Construction and repair focused tools; excessive inventory of unique tools	Full body mobility for expanded sizing range Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time Geological sampling and surveying equipment; common generic tool kit

EXPLORATION HABITATION SYSTEMS

Habitation Systems Elements

TODAY Space Station

FUTURE Deep Space

RADIATION PROTECTION

During each journey, radiation from the sun and other sources poses a significant threat to humans and spacecraft.

Monitoring, Tracking, Modeling, Mitigation

Today – Space Station:
- Node 2 crew quarters (CQ) with polyethylene reduce impacts of proton irradiation.
- Large multi-layer detectors & small pixel detectors – real-time dosimetry, environment monitoring, tracking, model validation & verification
- Bulky gas-based detectors – real-time dosimetry
- Small solid-state crystal detectors – passive dosimetry (analyzed post-mission)

Future – Deep Space:
- Solar particle event storm shelter, optimized position of on-board materials and CQ
- Small distributed pixel detector systems – real-time dosimetry, environment monitoring, and tracking
- Small actively read-out detectors for crew – real-time dosimetry

FIRE SAFETY

Throughout every mission, NASA is committed to minimizing critical risks to human safety.

Detection, Protection, Suppression, Cleanup

Today – Space Station:
- Large CO_2 Suppressant Tanks
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

Future – Deep Space:
- Water Mist portable fire extinguisher
- Single Cartridge Mask
- Exploration combustion product monitor
- Smoke eater

LOGISTICS

Sustainable living outside of Earth requires explorers to reduce, recycle, reuse, and repurpose materials.

Tracking, Clothing, Packaging, Trash

Today – Space Station:
- Manual scans, displaced items
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

Future – Deep Space:
- Automatic, autonomous RFID
- Long-wear clothing/laundry
- Bags/foam repurposed w/3D printer
- Resource recovery, then disposal

CROSS-CUTTING

Powerful, efficient, and safe launch systems will protect and deliver crews and materials across new horizons.

Robotics, Power, Communication, Docking, Avionics, Autonomy & Software, Thermal, Materials

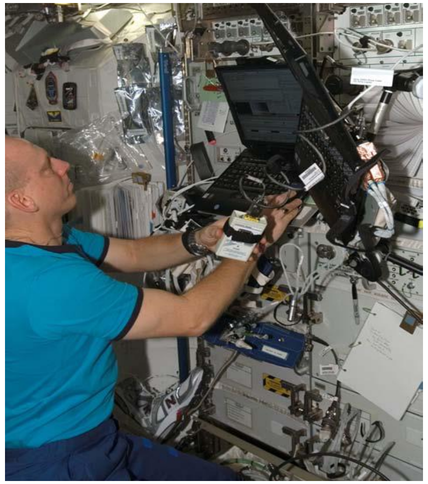
Today – Space Station:
- Minimal on-board autonomy
- Near-continuous ground-crew communications
- Some common interfaces, modules controlled separately

Future – Deep Space:
- Ops independent of Earth & crew
- Up to 40-minute comm delay
- Widespread common interfaces, modules/systems integrated
- Manufacture replacement parts in space

ISS RESEARCH: CRITICAL TO MITIGATING MARS MISSION HUMAN HEALTH AND PERFORMANCE RISKS

Medical Imaging

Cardiovascular Function Experiment



Muscle Physiology Facility

Bone Loss Countermeasure

Crew Sleep/ Performance

Nutritional Requirements

Ocular Surveillance Flight Study

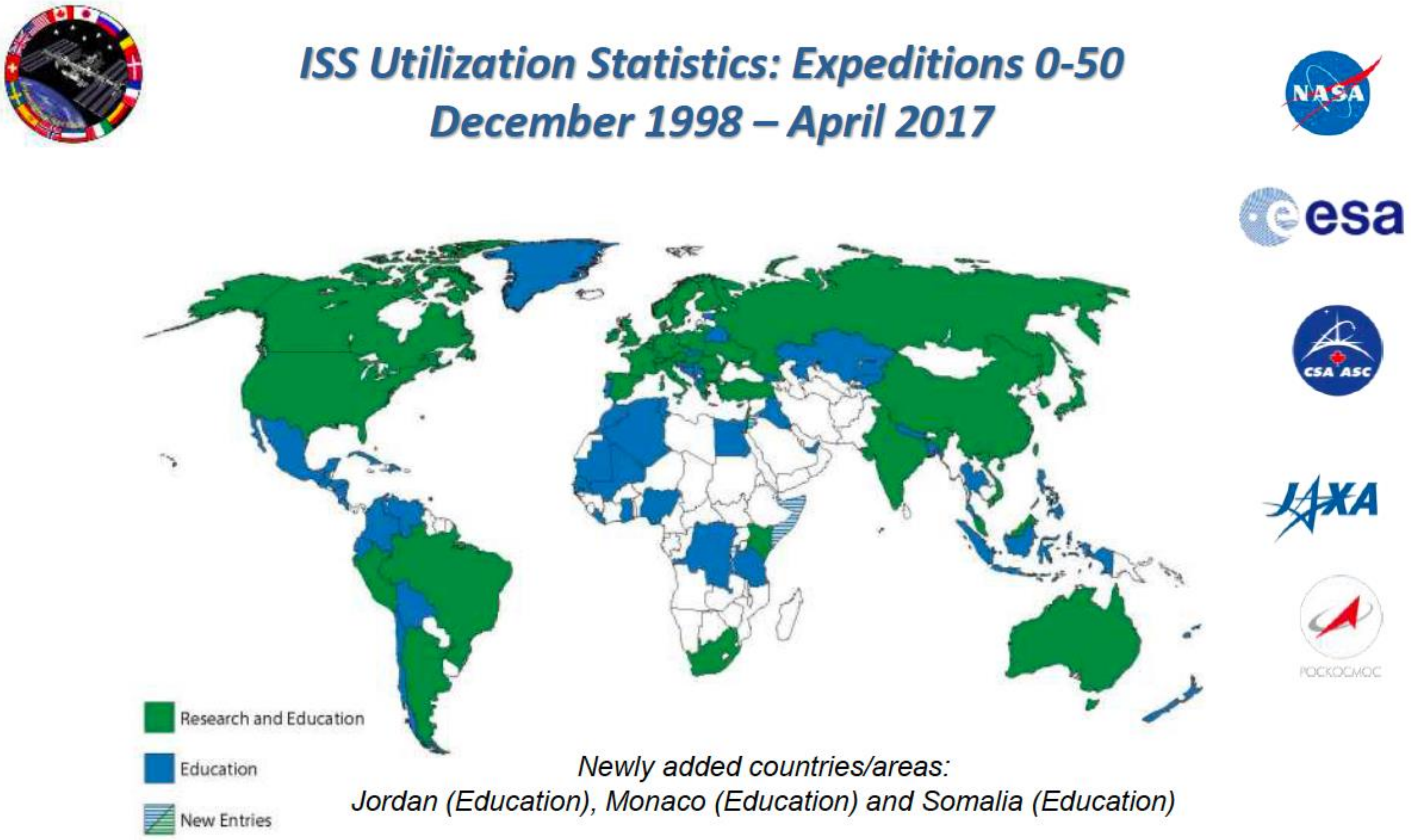
Fluid Shift Experiment

Physiological Changes/ Exercise Countermeasures

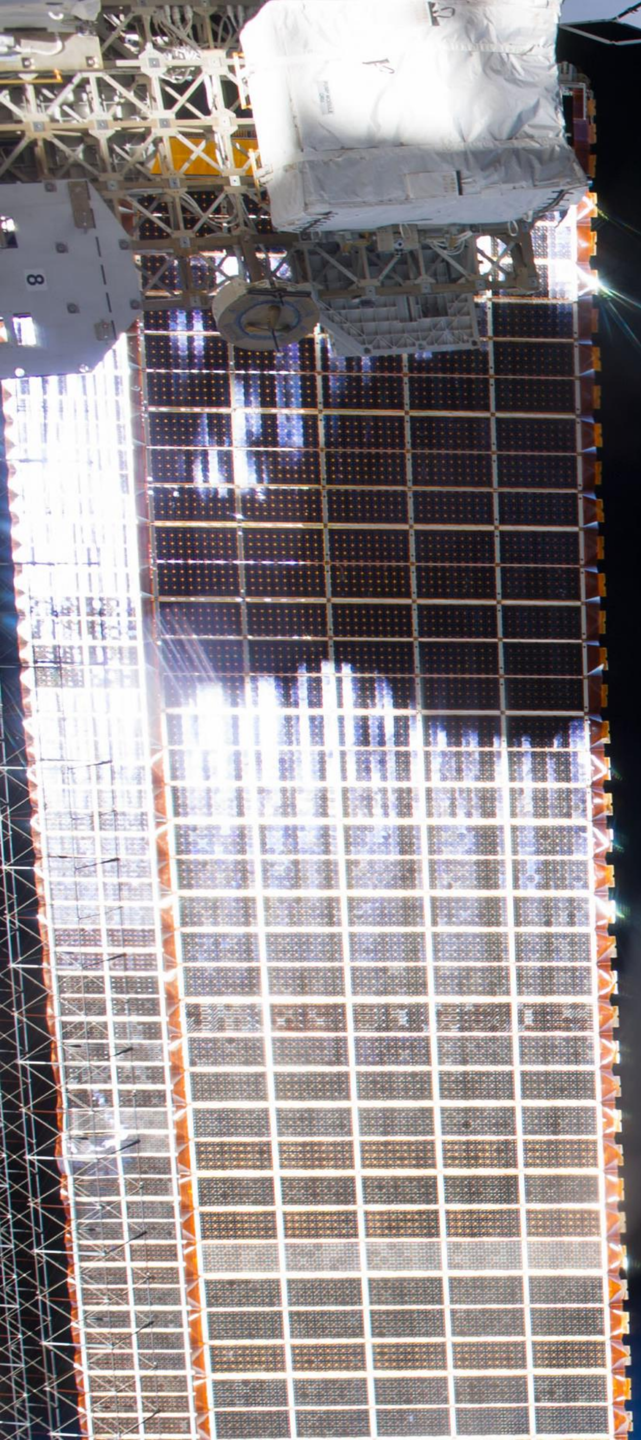
Immunological Changes

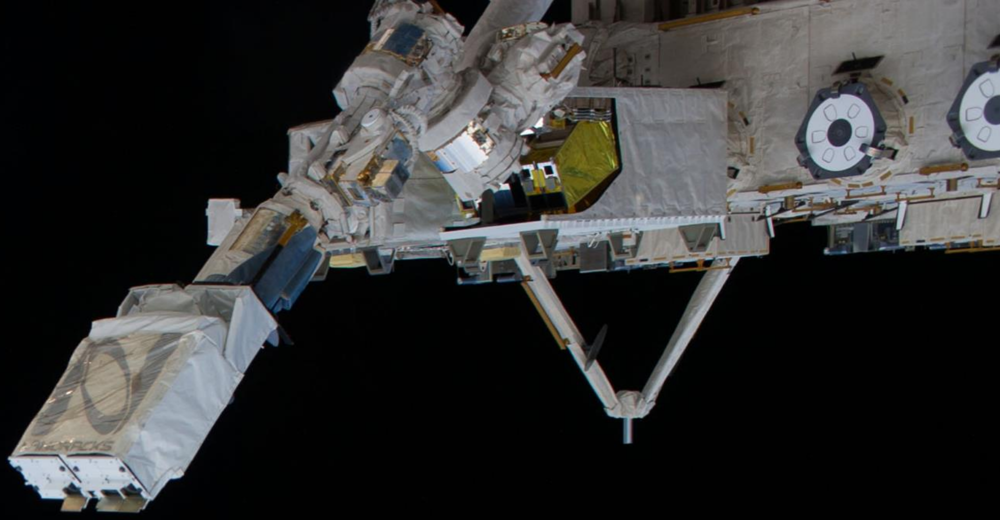
Each U.S. Orbital Segment crewmember participates in 10-15 separate experiments

WORLDWIDE PARTICIPATION



103 highlighted countries and areas have participated in ISS Research and Education activities





ISS CUBESATS: LOW COST PHYSICS RESEARCH

- Less expensive than traditional satellites
- Appealing to new users – students, amateurs, non-space industry
- Performance has rapidly improved at a low cost over the last 18 years
- Are productive scientific spacecraft

CUBESAT LAUNCH INITIATIVE

Provides launch opportunities to educational, non-profit organizations and NASA Centers that build CubeSats to fly as auxiliary payloads on previously planned missions or as International Space Station deployments.

- 151 CubeSat missions selected
- 85 organizations in 38 states
- 42 CubeSats to be launched over the next 12 months

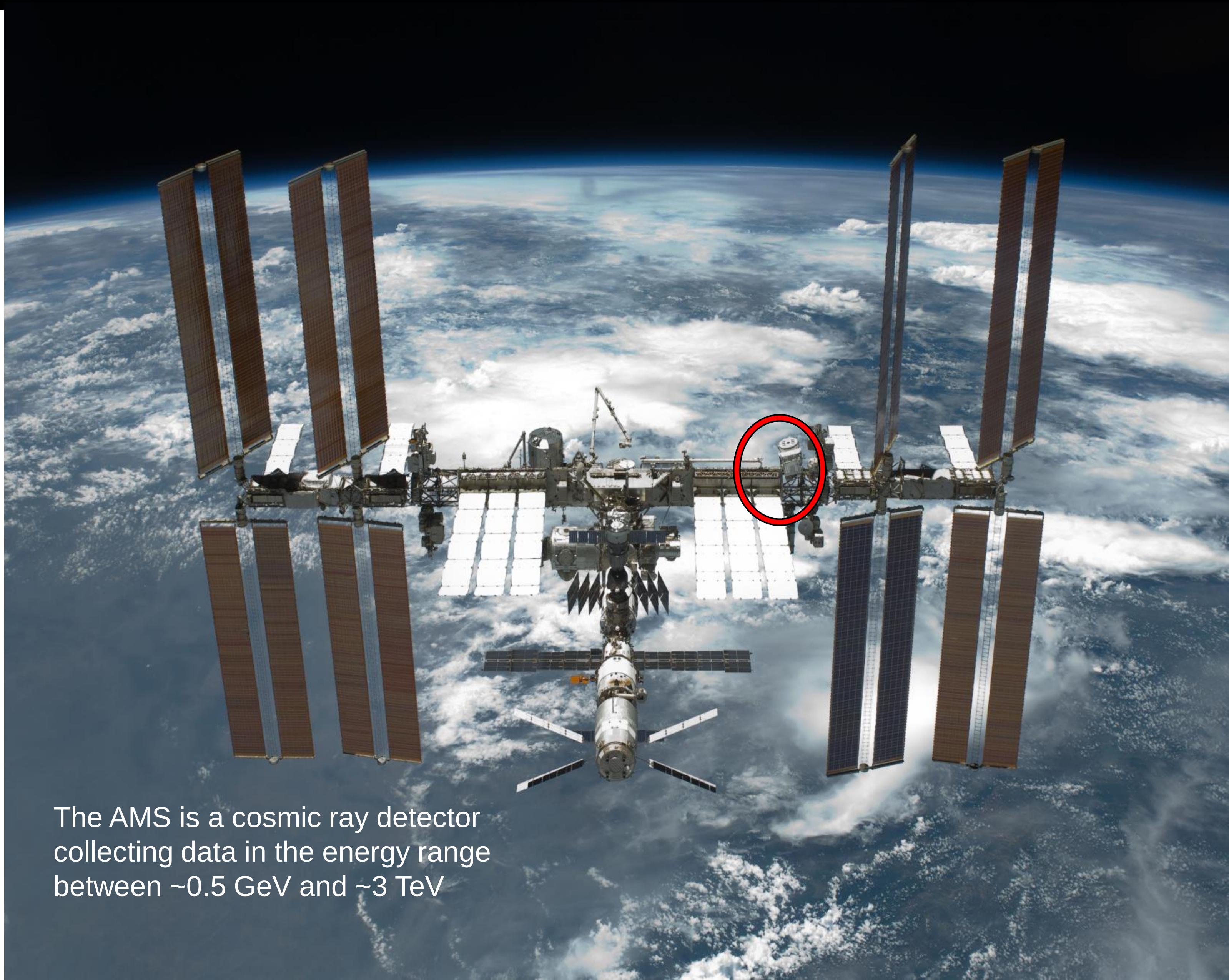
CONTINUED ISS OPERATION IS ESSENTIAL FOR SCIENCE AND HUMAN EXPLORATION

ISS ENABLES UNIQUE PHYSICS RESEARCH

- Astrophysics
- Fundamental Physics
- Heliophysics
- X-ray Astronomy

ISS Platform

- Full services (power, data, thermal)
- Positioned above atmospheric interference
- External sites for zenith, ram and wake
- Stability, contamination, and vibration can be managed for many users
- Well-suited for test bed concepts

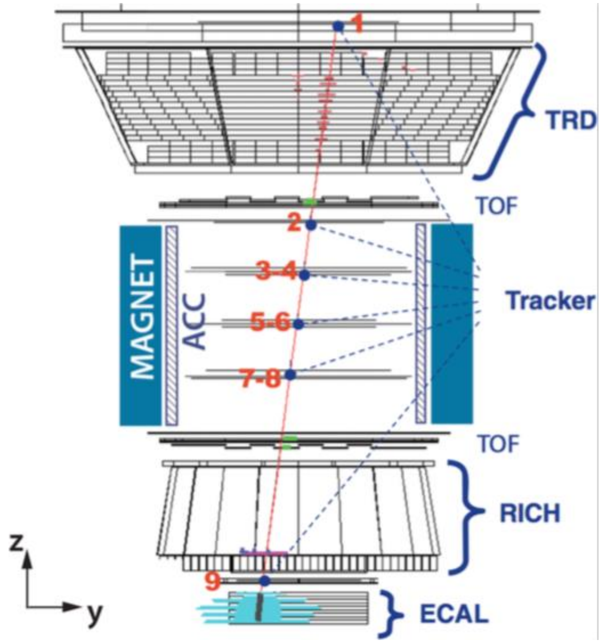


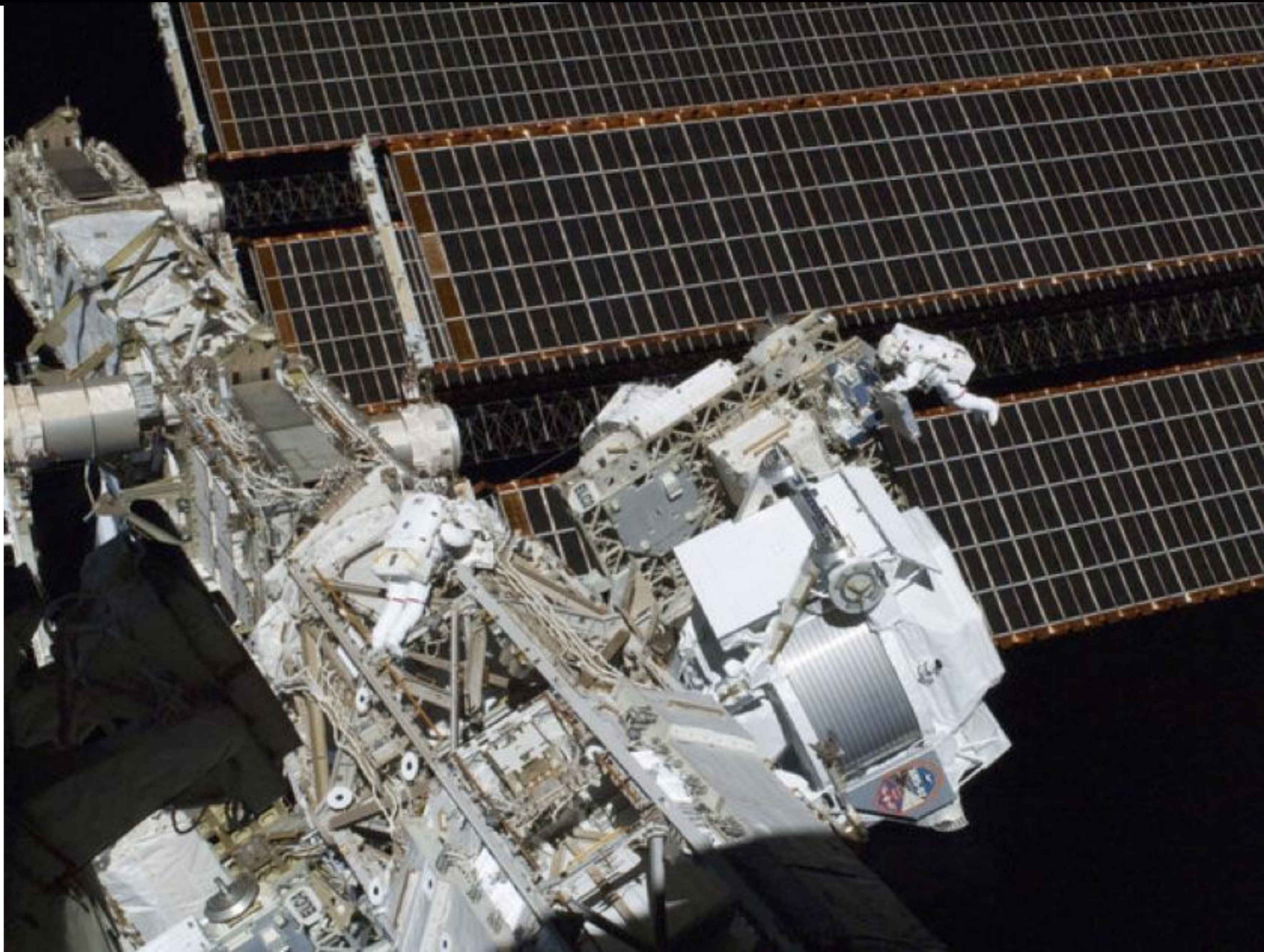
The AMS is a cosmic ray detector collecting data in the energy range between ~0.5 GeV and ~3 TeV

THE ALPHA MAGNETIC SPECTROMETER (AMS-02)

- High-energy physics experiment mounted on starboard truss of ISS

- Built for antimatter & dark matter studies, also provides precision measurements of radiation environment outside ISS





PHYSICS RESEARCH PUBLICATIONS ON ISS ARE AMONG THE MOST CITED

Citations from the Top 10 Ranked Global Journals from October 2016 – April 2017

- Antibiotic Effectiveness in Space-1 (**AES-1**) demonstrated that *E. coli* in microgravity formed in clusters which may be associated with enhanced biofilm formation in microgravity potentially leading to increased pathogenicity of microbes. (Zea L, et al, PLOS ONE, 2016)
- Chitinase was examined by **JAXA PCG** and demonstrated that a number of gram-positive soil-dwelling bacteria possess similar cell-surface-expressed multi-modular enzymes for cell wall polysaccharide degradation which have potential as renewable resources of energy, fuels and functional materials. (Itoh T, et al, PLOS ONE, 2016)
- **Micro-7** demonstrated in vivo cells in microgravity experience mechanical loading from varying blood pressures that cells in vitro do not, suggesting that DNA damage response in space may be dependent on the cell type and cell growth conditions. (Lu T, et al, PLOS ONE, 2017)
- **NanoRacks-CellBox-PRIME** exhibited that the lack of long-term cytoskeletal changes, together with stable metabolic function (suggesting cellular adaptation in microgravity) has important implications for human health and performance during long-term missions. (Tauber S, et al, PLOS ONE, 2017)
- **The Alpha Magnetic Spectrometer** (AMS) has collected cosmic ray data from 1.9GV to 2.6TV for millions of boron and carbon nuclei over the last five years of operations on ISS, allowing the rigidity dependence of the boron to carbon flux ratio (B/C) to be analyzed for the first time. The rigidity provided information for scientists to compare the major turbulence models used in cosmic ray modeling, and found that the results are in agreement with the Kolmogrov theory of interstellar turbulence that can be used in further analysis of AMS data (Aguilar-Benitez M, et al, Physical Review Letters, 2016)
- Constrained Vapor Bubble (**CVB**) results allow researchers to develop simple models of bubble formation, which could help develop more efficient microelectronics cooling systems. (Kundan A, et al, Physical Review Letters, 2017)

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Top 5 Most Cited ISS Results Publications Overall

- **AMS-02** has collected and analyzed billions of cosmic ray events, and identified 9 million of these as electrons or positrons (antimatter), providing data that may lead to the solution of the origin of cosmic rays and antimatter, increasing the understanding of how our galaxy was formed. (Aguilar-Benitez M, et al, Physical Review Letters, 2013. Times Cited = 463)
- **Subregional Bone** found that the greatest space-induced bone loss occurs in pelvis, hip, and leg bones, which should be the focus of countermeasures and surface activities designed for space explorers on future missions beyond low Earth orbit. (Lang TF, et al, Journal of Bone and Mineral Research, 2004. Times Cited = 367)
- **Astrovaktsina** showed that the localization of the V-antigen in Yersinia plays a crucial role in the translocation process and its efficacy as the main protective antigen against plague. (Mueller CA, et al, Science, 2005. Times Cited = 231)
- **Microbe** implicated that the Hfq (RNA chaperone) protein acts as a major post-transcriptional regulator of Salmonella gene expression. (Sittka A, et al, Molecular Microbiology, 2007. Times Cited = 226)
- **MAXI** revealed the existence of a hypernova remnant estimated to be 3 million years old, believed to be the first in our galaxy. (Burrows DN, et al, Nature, 2011. Times Cited = 211)

Data accurate as of September 15, 2017

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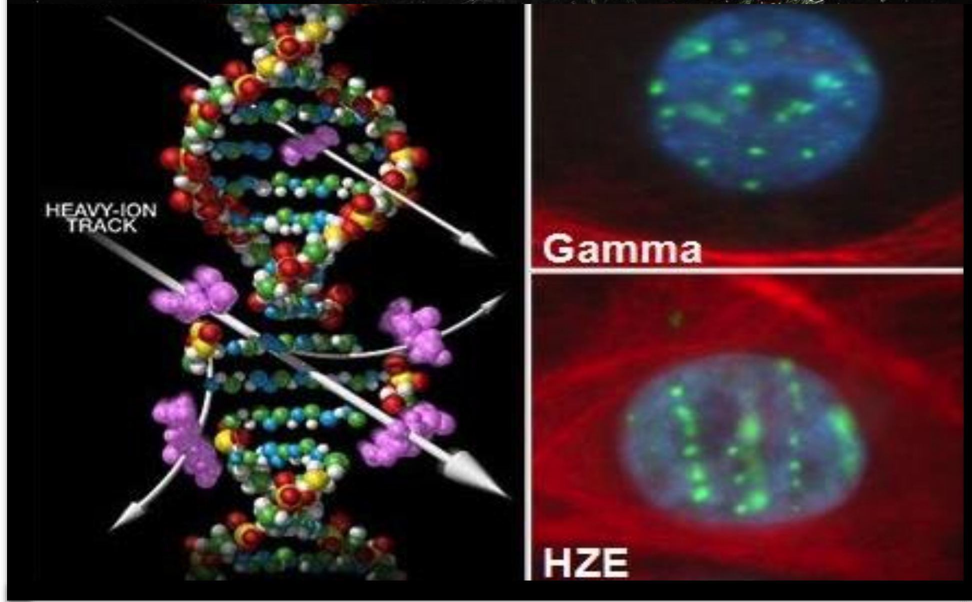
SPACE RADIATION CHALLENGE

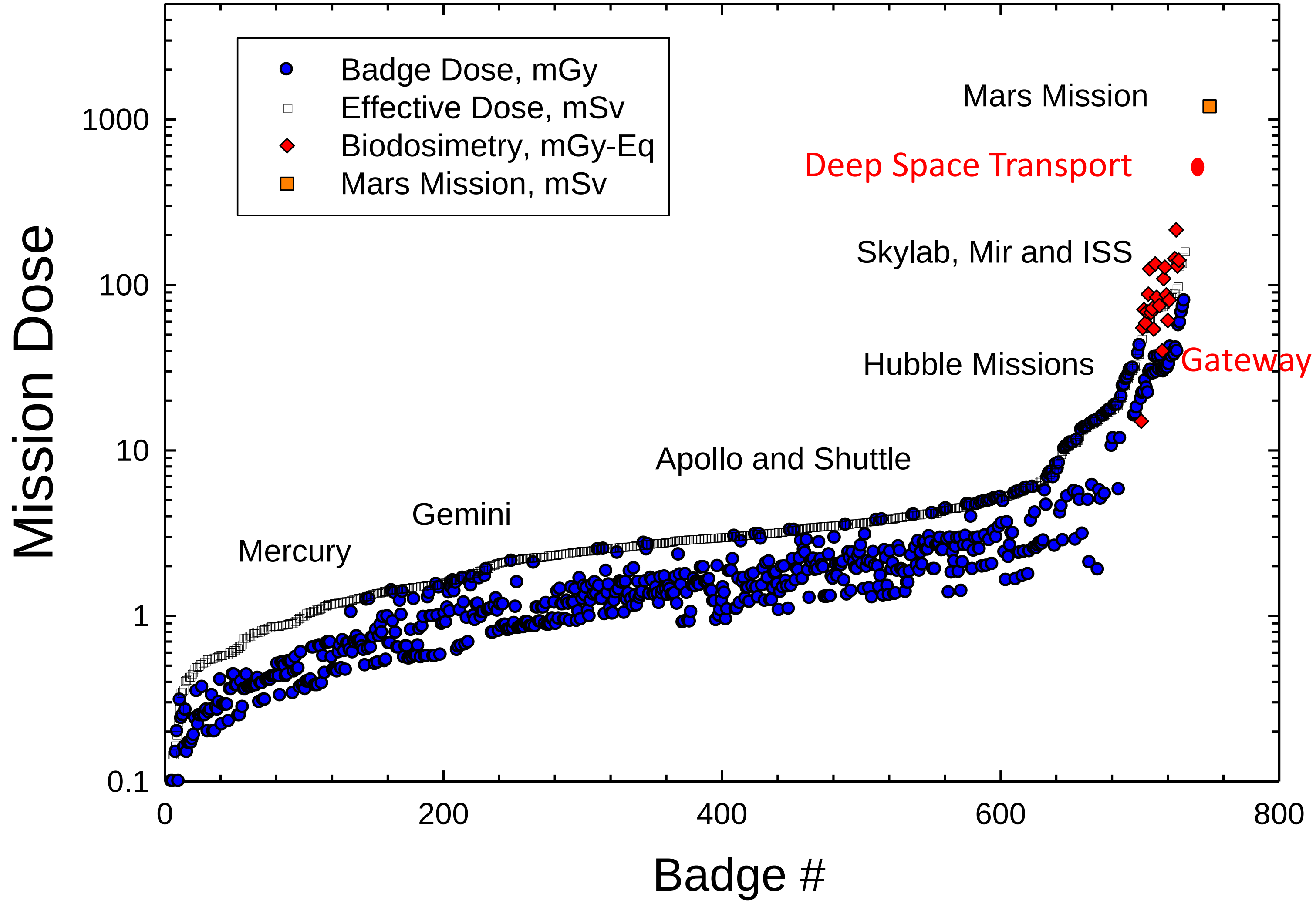
- Space radiation produces potential increased health risks of cancer, cardiovascular disease, CNS effects, and acute radiation syndromes
  - Damage to cells is different from terrestrial sources of radiation
  - Translating experimental data to humans

- Understanding Individual Radiation Sensitivity
  - Small Crew Population

- NASA’s Science and Human Exploration and Operations Mission Directorates measurements to accurately characterize the space radiation environment are needed to optimize mitigation strategies



NASA CREW MISSION DOSES



NASA EXPERIENCE:

- Single ISS mission approximately 1/10 of Mars mission exposure
- Crew with multiple missions have accumulated 30% of Mars exposure risk

Update from Cucinotta et al. Radiat Res (2008)

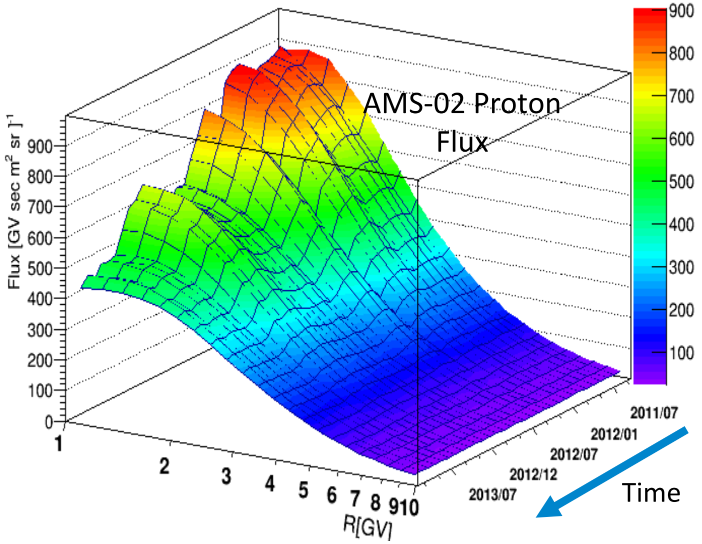
AMS-02 DATA

- First-ever continuous measurement of GCR protons (and alphas) over an extended time period and energy range of importance to human space flight
  - GCR protons (and alphas) make up a substantial portion of the overall astronaut exposure behind shielding

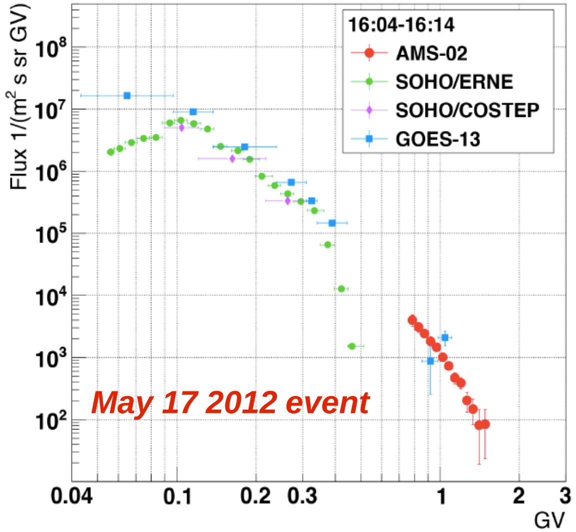
- Provides detailed insight into the high-energy region of space radiation unavailable from other satellites
  - Peak (high flux) primary proton spectra measurements are in an important energy range of interest for human protection

- Measures specific cosmic particle fluxes with unprecedented uncertainty and accuracy providing Gold Standard Data

- Improvement in data quality will provide new scientific insights in cosmic ray and solar activity research



University of Hawaii, Veronica Bindi

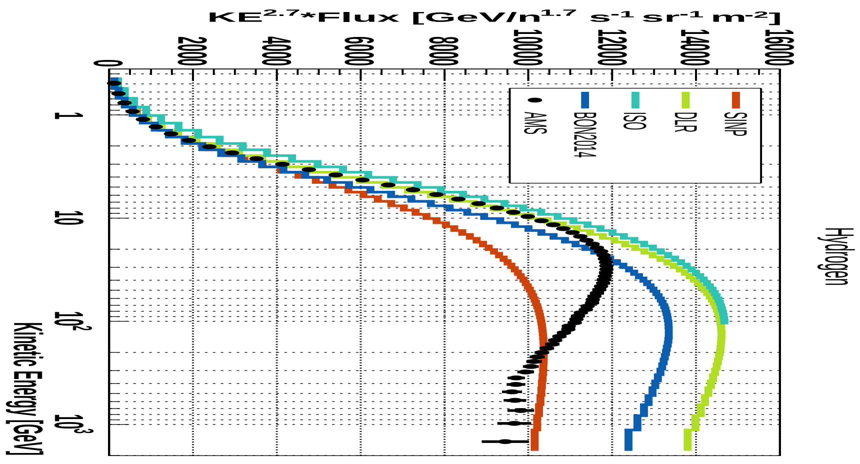


Energy range is unavailable from other satellites

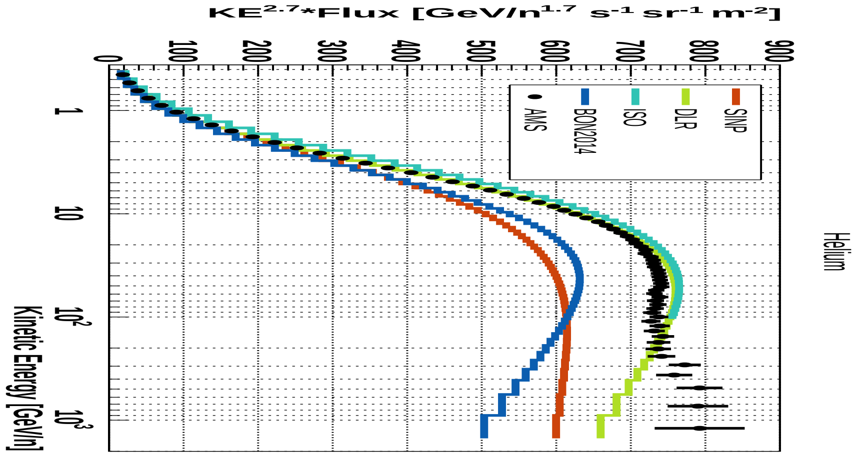
AMS-02 PRECISION MEASUREMENTS AND VALIDATION OF GCR MODELS

- AMS is providing new precision measurements of primary and secondary cosmic rays fluxes
  - Observation of New Properties of Secondary Cosmic Rays Lithium, Beryllium, and Boron by the Alpha Magnetic Spectrometer on the International Space Station, Physical Review Letters, Vol 120, Issue 2 (2018)
  - Precision Measurement of the Boron to Carbon Flux Ratio in Cosmic Rays from 1.9 GV to 2.6 TV with the Alpha Magnetic Spectrometer on the International Space Station, Physical Review Letters, Vol 117, 231102 (2016).
  - Proton and Helium fluxes published in Physical Review Letters in 2015

- AMS measurements are critical for validating and improving GCR models
  - Comparison of space radiation GCR models to recent AMS data, Norbury et al., Life Sciences in Space Research (submitted 2018)



Comparison of AMS Hydrogen with GCR Models



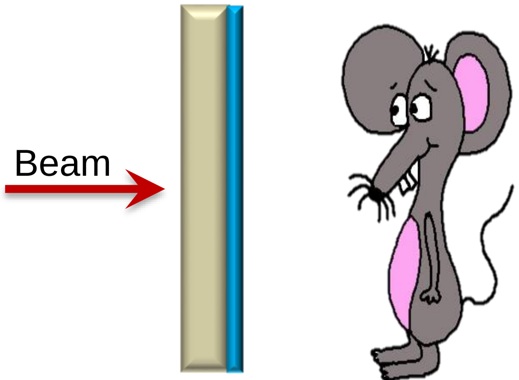
Comparison of AMS Helium with GCR Models

Norbury et al. LSSR (2018)

EXPLORATION APPLICATION OF AMS DATA

- Improve models of the ambient GCR environment used in integrated tool sets for vehicle design, shield optimization, risk assessment
  - Current GCR models use a limited set of balloon & satellite data taken at sporadic time intervals with varying degrees of quality & dynamic range
- Inform the beam delivery parameters of Galactic Cosmic Ray Simulator at the NASA Space Radiation Laboratory
  - Increase fidelity of animal radiobiology experiments to validate risk models and test countermeasures
- Enable high-fidelity design and testing of the Hybrid Shield approach for Deep Space Transport
- Design Mars 900 Simulation Campaign (deep space, Mars surface, deep space exposures) for countermeasure testing

Thick Shielding Testing at NSRL

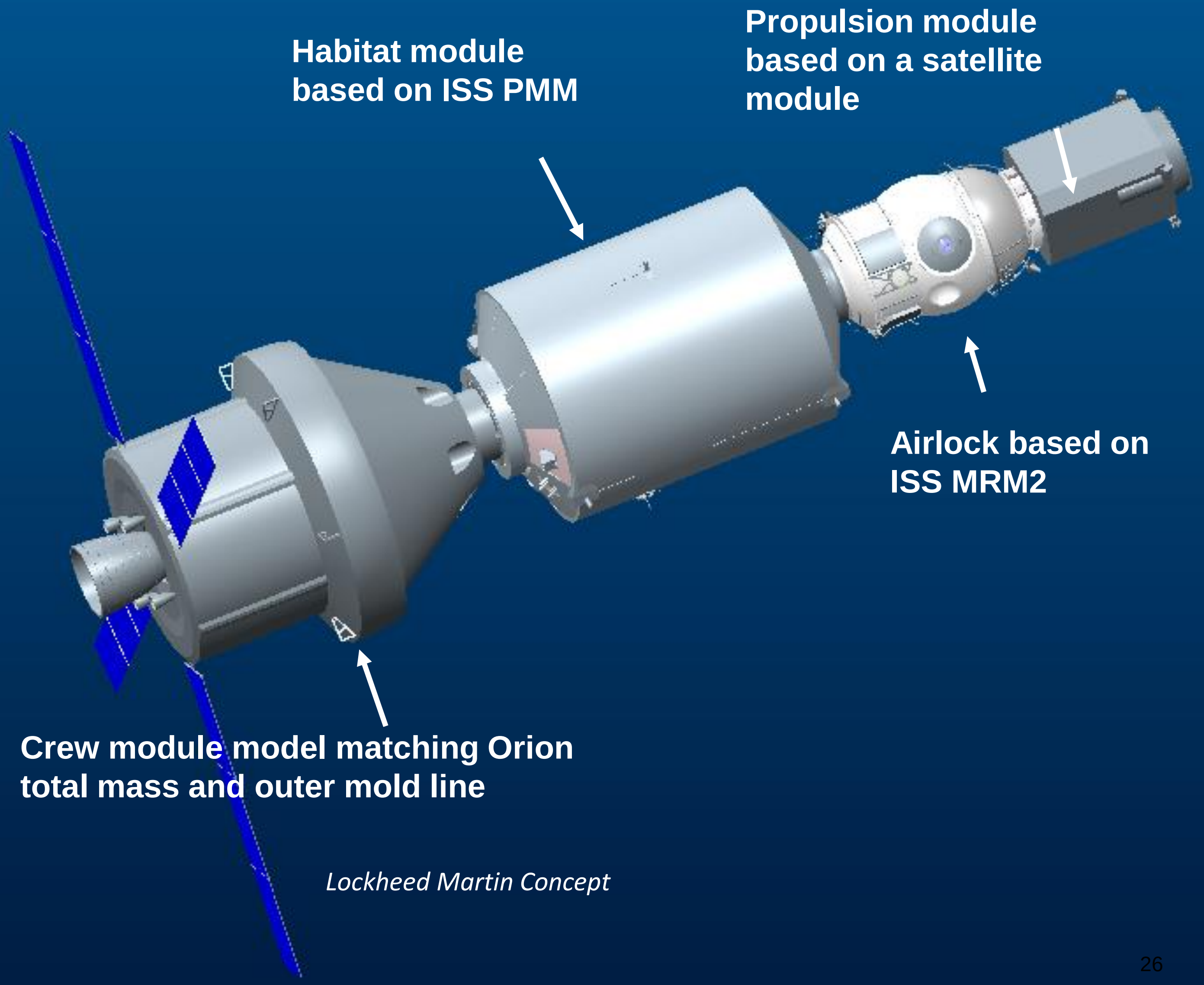


Hybrid Shield:
Aluminum/water

AMS DATA SUPPORTS MODELING, ANALYSIS, AND VALIDATION OF DEEP SPACE HABITAT SHIELDING PROTECTION

DEEP SPACE RADIATION PROTECTION

- NASA is analyzing the space radiation shielding protection for Gateway and human systems for use beyond low Earth orbit
- Incorporating vehicle systems, equipment, and supplies as shield options
- Verifying whether enough materials onboard during a 30-day mission to provide adequate SPE shielding without adding parasitic mass

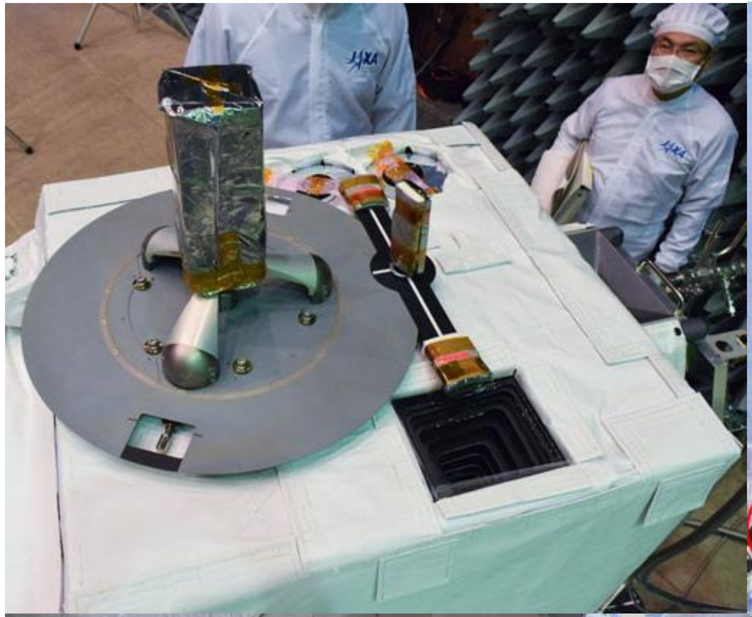


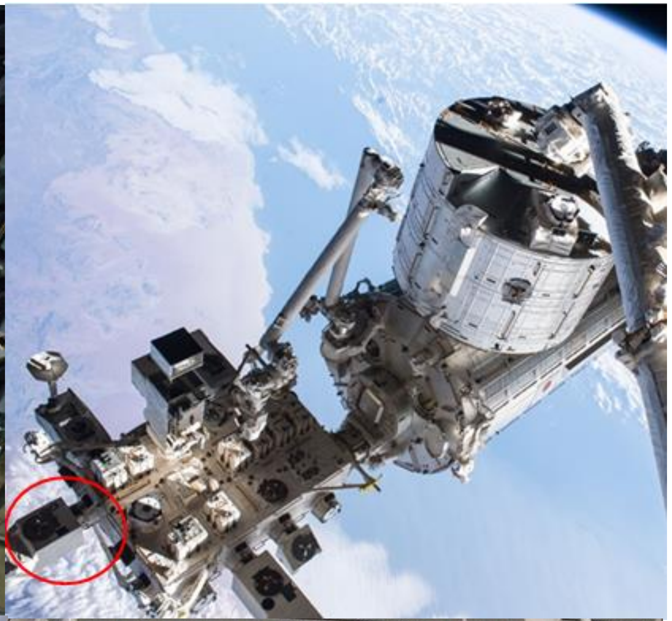
Lockheed Martin Concept

JAXA'S CALORIMETRIC ELECTRON TELESCOPE (CALET)

Searches for signatures of dark matter in the energy range of 1 GeV to 20 TeV with a 2% energy resolution above 30 GeV

Provides high energy direct measurements of the cosmic ray electron spectrum in order to observe discrete sources of high energy particle acceleration in our local region of the Galaxy.

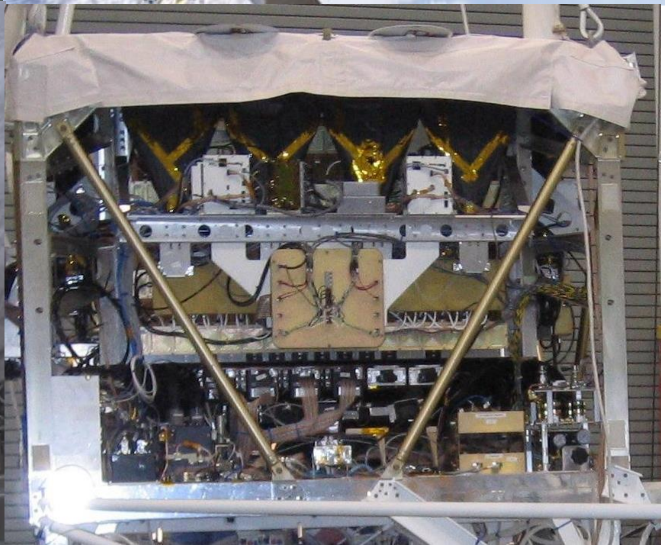




NASA'S COSMIC-RAY ENERGETICS AND MASS FOR THE INTERNATIONAL SPACE STATION INVESTIGATION, (ISS-CREAM)

Uses balloon-borne instrument to gather an order of magnitude (ten times) more data, in its placement outside Earth's atmosphere.

CREAM's instruments measure the charges of cosmic rays ranging from hydrogen up through iron nuclei, over 10^{12} eV to $>10^{15}$ eV

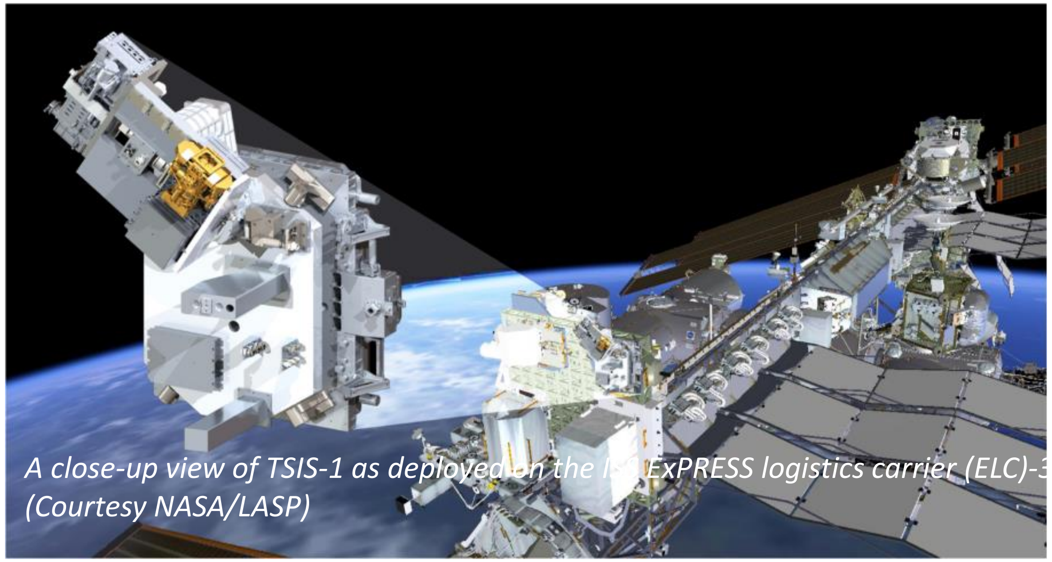


ISS HELIOPHYSICS

TOTAL AND SPECTRAL SOLAR IRRADIANCE SENSOR (TSIS)

Measures total solar irradiance (TSI) and solar spectral irradiance (SSI). TSI helps establish Earth's total energy input while SSI contributes to understanding how Earth's atmosphere responds to solar output changes.

Solar irradiance represents one of the longest climate data records derived from space-based observations – nearing 40 years of data – and researchers anticipate maintaining continuity of that record with TSIS.

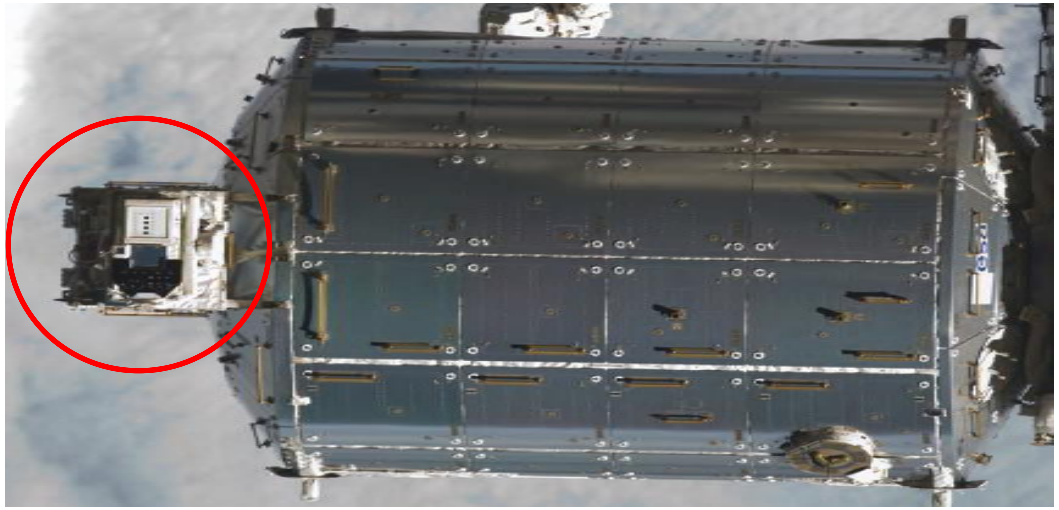


A close-up view of TSIS-1 as deployed on the ISS ExPRESS logistics carrier (ELC)-3 (Courtesy NASA/LASP)

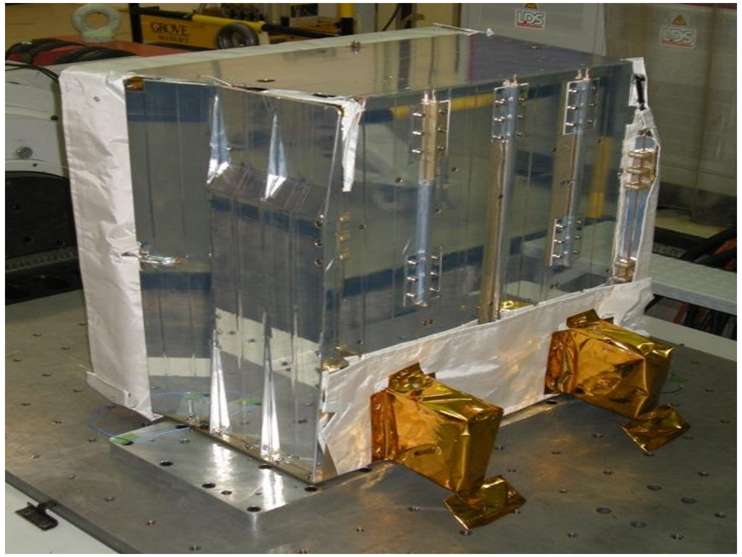
ESA'S SUN MONITORING ON THE EXTERNAL PAYLOAD FACILITY OF COLUMBUS – SOLAR SPECTRAL IRRADIANCE MEASUREMENTS (SOLSPEC)

Covers 96% of the total solar spectrum and measures solar irradiance with high accuracy by correcting changes to the instrument's responsivity.

Accurate and continuous solar irradiance measurements from space not only contribute to our understanding of Earth's climate, but can also inform the development of solar energy technologies



ISS GAMMA-RAY



ESA'S ATMOSPHERE-SPACE INTERACTIONS MONITOR (ASIM)

Earth observation facility for the study of severe thunderstorms and their role in the Earth's atmosphere and climate. The low energy detector is sensitive in the spectral band from 15 keV to 400 keV and the high energy detector is sensitive from 200 keV to 40 MeV.

STP-H5 LIGHTNING IMAGING SENSOR (LIS) ON ISS

Provides first-ever observations of the individual lightning strokes responsible for Terrestrial Gamma-ray Flash (TGF) events on a millisecond time scale, by correlating its lightning observations with the TGF observations from the ISS Atmosphere-Space Interaction Monitor (ASIM) experiment.

ISS X-RAY ASTRONOMY

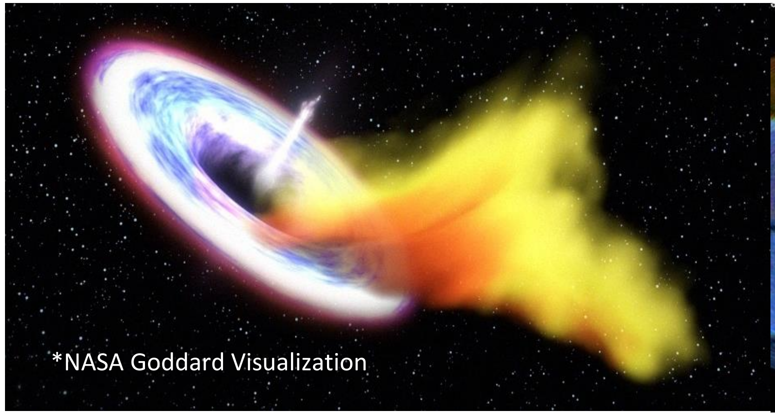
JAXA’s MAXI monitors the sky on time intervals ranging from a day to a few and was the first time objects inside and out of our galaxy were monitored by X-rays with such short intervals. MAXI (with NASA’s SWIFT) had the first observation of relativistic x-ray burst from a black hole consuming a star*.

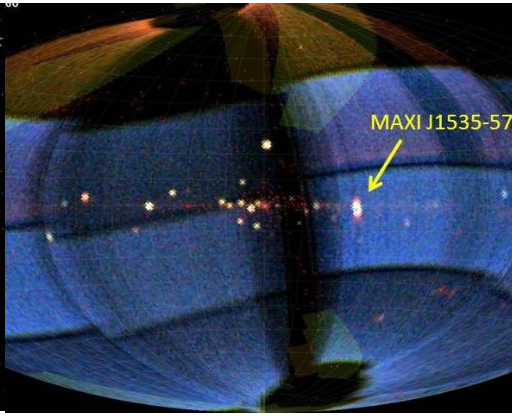
MAXI also revealed the existence of a hypernova remnant that occurred 3 million years ago, (believed to be the first remnant in our galaxy)**, and has recently spotted the brightest black hole (MAXIJ1535-571) since 1999***.

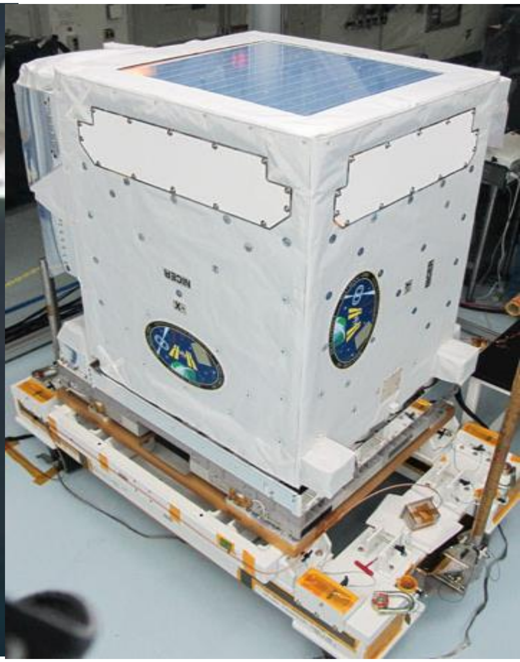
NASA’S NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)/SEXTANT

Provides high-precision measurements of neutron stars (and other X-ray astrophysics phenomena) through observations in 0.2 – 12 keV X-rays. Addresses fundamental science questions about new states of matter at high densities and temperature, cosmic accelerators, and activity of stellar remnants.

Station Explorer for X-ray Timing and Navigation Technology, or SEXTANT, showed that millisecond pulsars could be used to accurately determine the location of an object moving at thousands of miles per hour in space, similar to how GPS works on Earth.





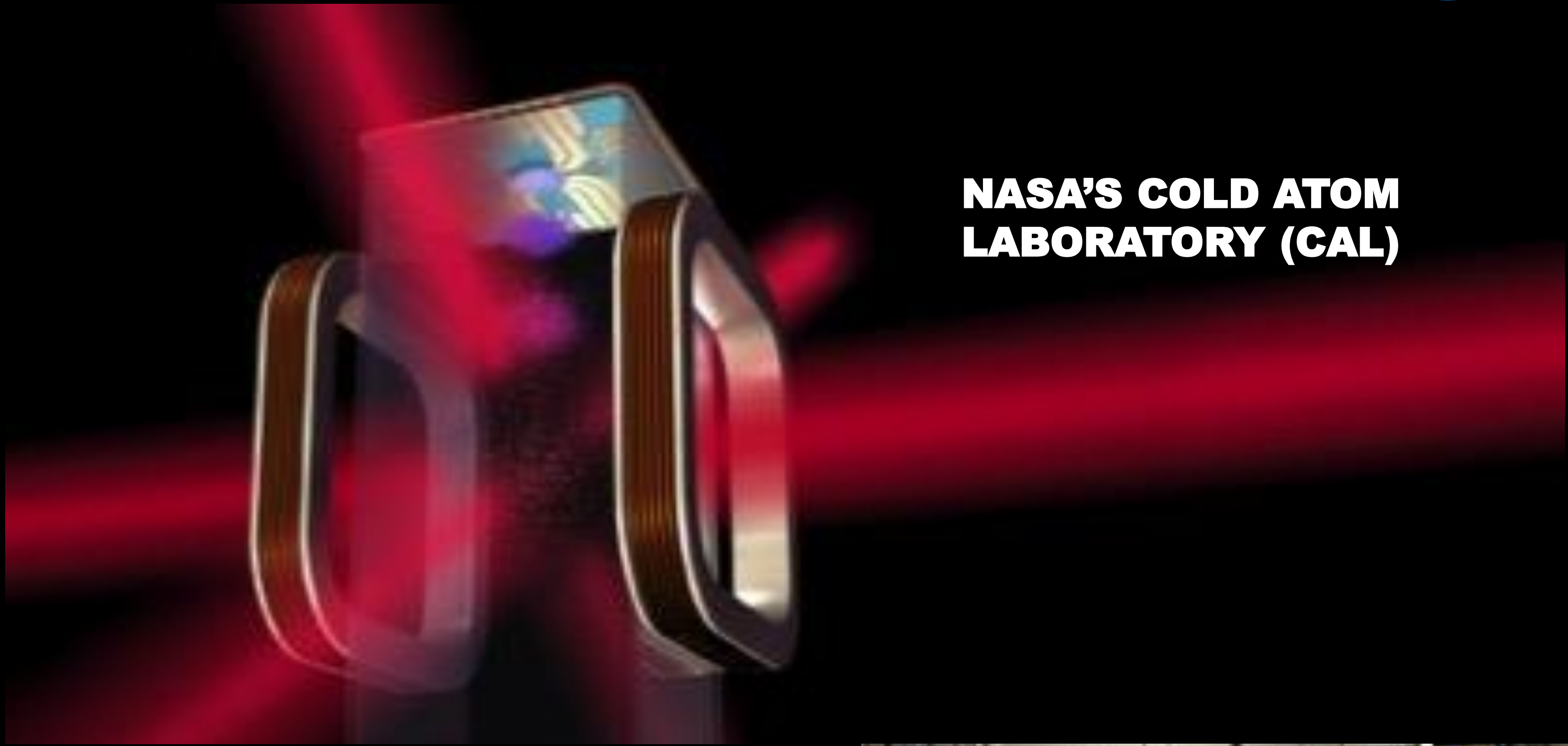


ISS EXTREME LOW TEMPERATURE QUANTUM PHYSICS

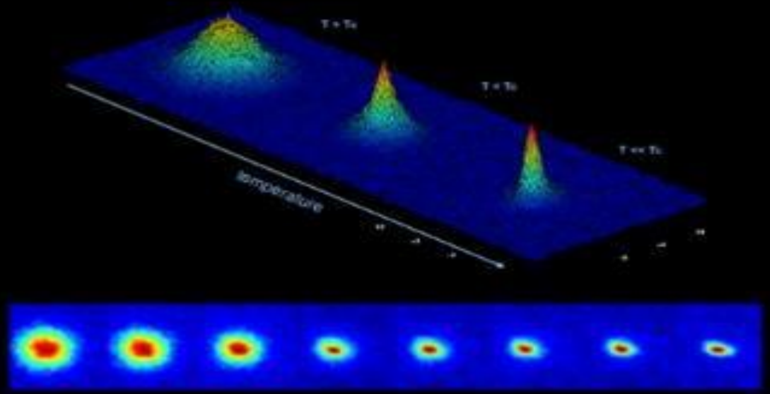
Multi-user facility designed to study ultra-cold (pico-Kelvin) quantum gases in the microgravity environment of the International Space Station (ISS)

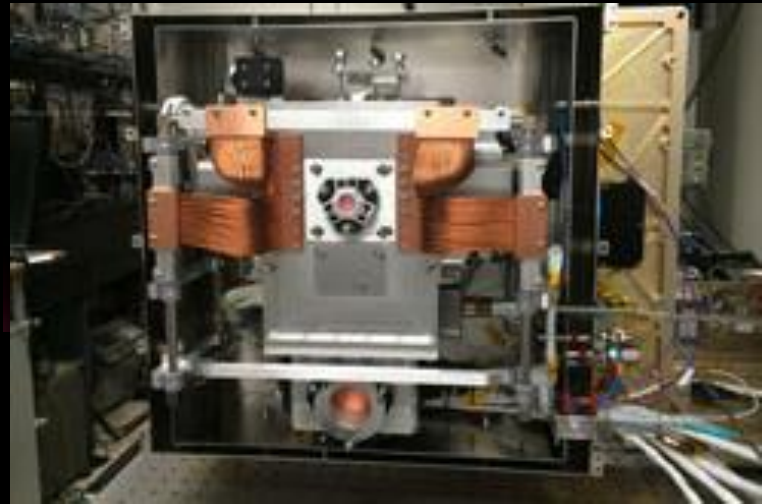
Space Environment enables many quantum investigations, not feasible on Earth

One of the primary goals of this facility will be to explore a previously inaccessible regime of extremely low temperatures where interesting and novel quantum phenomena can be expected



NASA'S COLD ATOM LABORATORY (CAL)





NASA