National Aeronautics and Space Administration

The Future of Human Space Exploration

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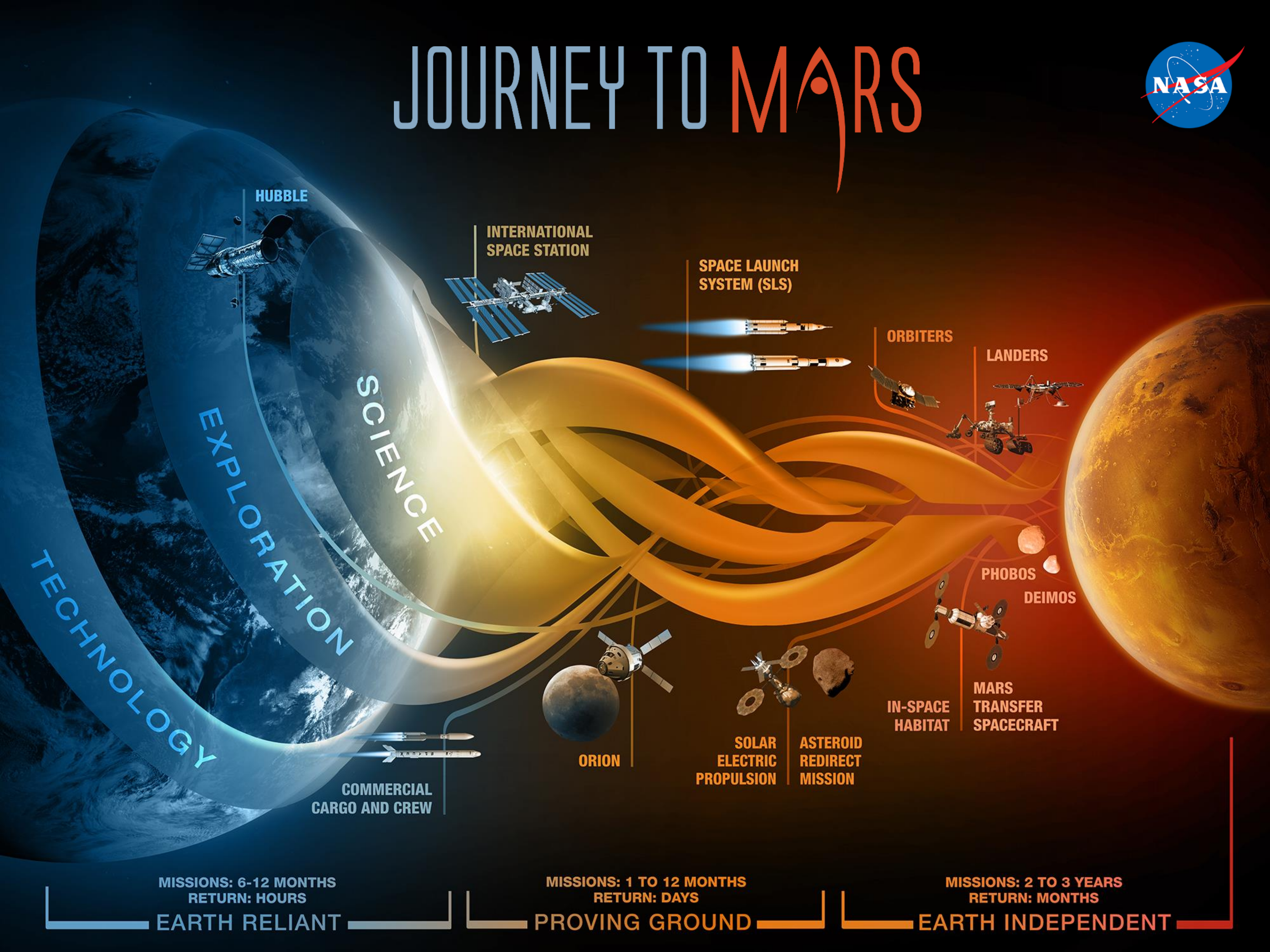

JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
MARS TRANSFER SPACECRAFT
IN-SPACE HABITAT
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
ORION
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

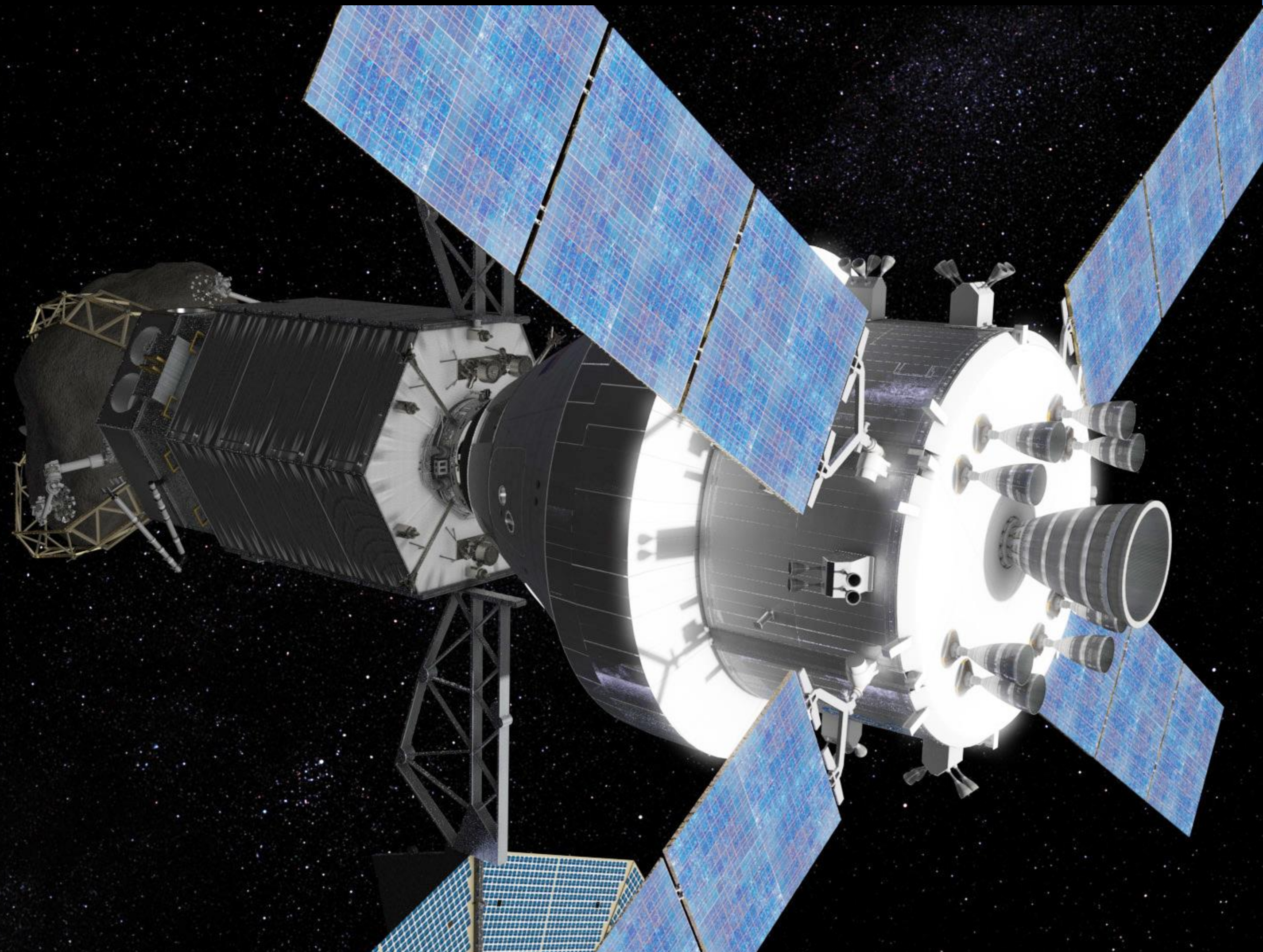
Exploration Flight Test-1

View of plasma surrounding Orion during re-entry.

Qualification Motor-1

Asteroid Redirect Mission

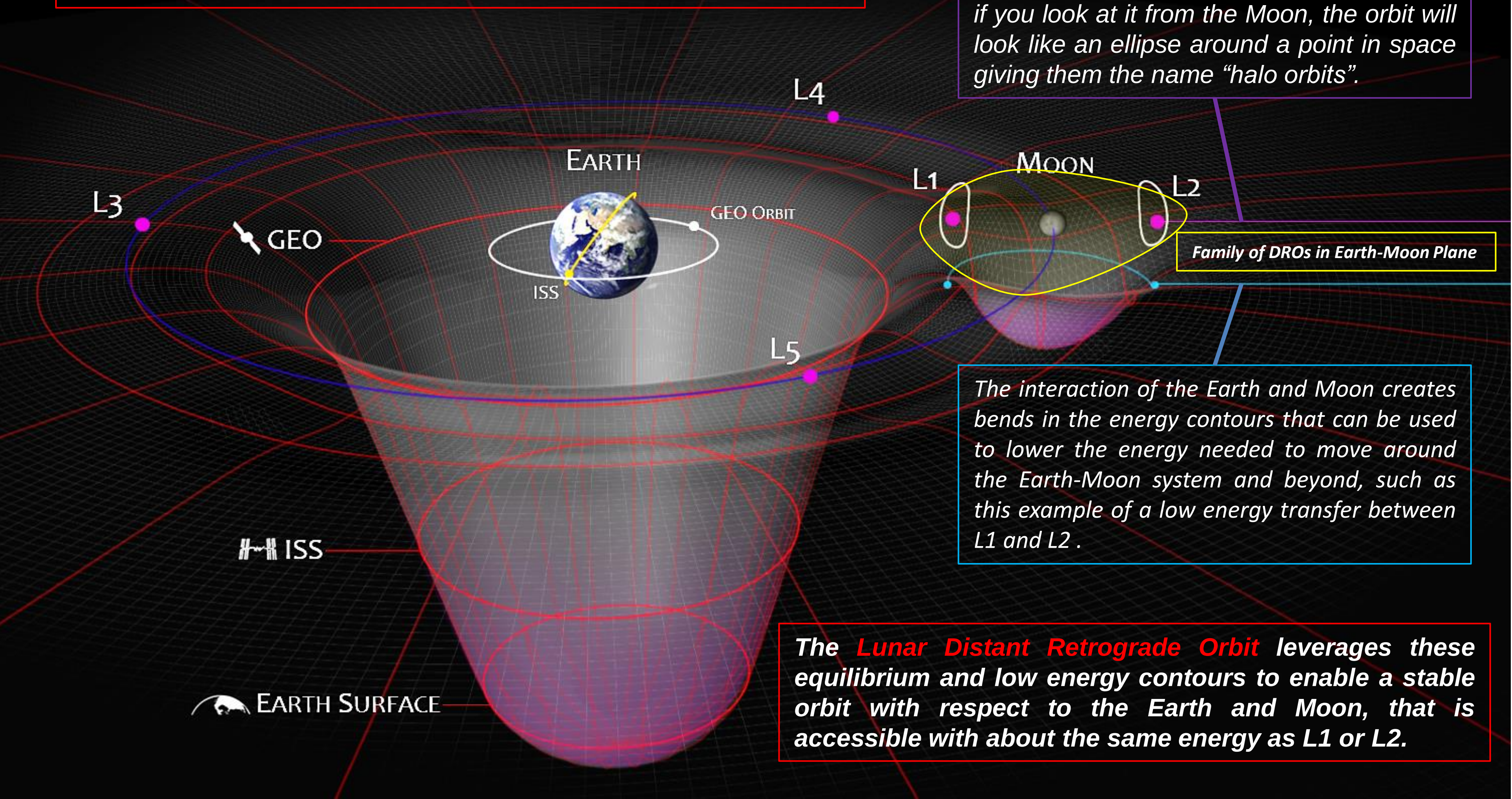
Already, ARM has pointed us to the utility of both SEP and Distant Retrograde Orbits around the Moon for efficiently transporting large masses in space, e.g., from lunar orbit to Mars orbit.



Cis-Lunar Space:
How the Earth and the Moon Interact

The contours on the plot depict energy states in the Earth-Moon System and the relative difficulty of moving from one place to another.

A spacecraft at L2 is actually orbiting Earth at a distance just past the Moon, however if you look at it from the Moon, the orbit will look like an ellipse around a point in space giving them the name "halo orbits".



The interaction of the Earth and Moon creates bends in the energy contours that can be used to lower the energy needed to move around the Earth-Moon system and beyond, such as this example of a low energy transfer between L1 and L2 .

The Lunar Distant Retrograde Orbit leverages these equilibrium and low energy contours to enable a stable orbit with respect to the Earth and Moon, that is accessible with about the same energy as L1 or L2.

ISS One-Year Mission

- **2015 marks the launch of astronaut Scott Kelly and cosmonaut Mikhail Kornienko to the ISS for 12 months – the longest mission ever assigned to a US astronaut**
  - Joint US/Russian ISS research includes studies on: ocular health, immune and cardiovascular systems, cognitive performance testing, and effectiveness of countermeasure against bone and muscle loss

Scott Kelly
STS-103, STS-118,
ISS 25/26

Mikhail Kornienko ISS
23/24

- **HRP study of identical twins astronaut Scott Kelly, and retired astronaut, Mark Kelly**
  - Provides unprecedented opportunity to research effects of spaceflight on twin genetic makeup, and better understand the impacts of spaceflight on the human body

Retired astronaut Mark Kelly (left) and his twin brother, astronaut Scott Kelly, who will spend a year on ISS

http://www.nasa.gov/exploration/humanresearch/index.html

Compare Going to Mars to Where We Are Today with ISS

228,000,000 kilometers

~1 - 3 years transit time

Communications (up to 42 minutes)

~ 2 days transit time

Communications (near real-time)

Crew exchanges

Crew supplies and logistics

Crew and atmosphere samples

Modified hardware

Emergency Crew Return

Trash

" recreate living on Earth capability"

390 kilometers

"extreme car camping in space"

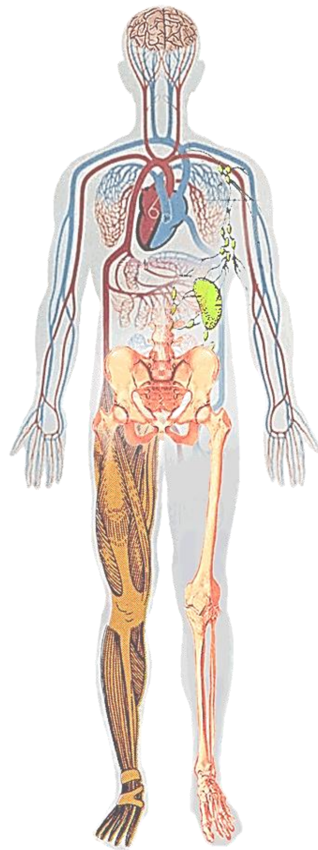
Human Spaceflight Risks are Driven by Spaceflight Hazards

Altered Gravity - Physiological Changes

Balance Disorders
Fluid Shifts
Visual Alterations
Cardiovascular Deconditioning
Decreased Immune Function
Muscle Atrophy
Bone Loss

Space Radiation

Acute In-flight effects
Long-term cancer risk
CNS and Cardiovascular



Distance from Earth

Drives the need for additional "autonomous" medical care capacity – cannot come home for treatment

Hostile/ Closed Environment

Vehicle Design
Environmental – CO_2 Levels, Toxic Exposures, Water, Food

Isolation & Confinement

Behavioral aspect of isolation
Sleep disorders

Mars Mission Human Health Risks

Based On The On-going Human System Risk Board (HSRB) Assessment, The Following Risks Are The Most Significant For A Mars Mission:

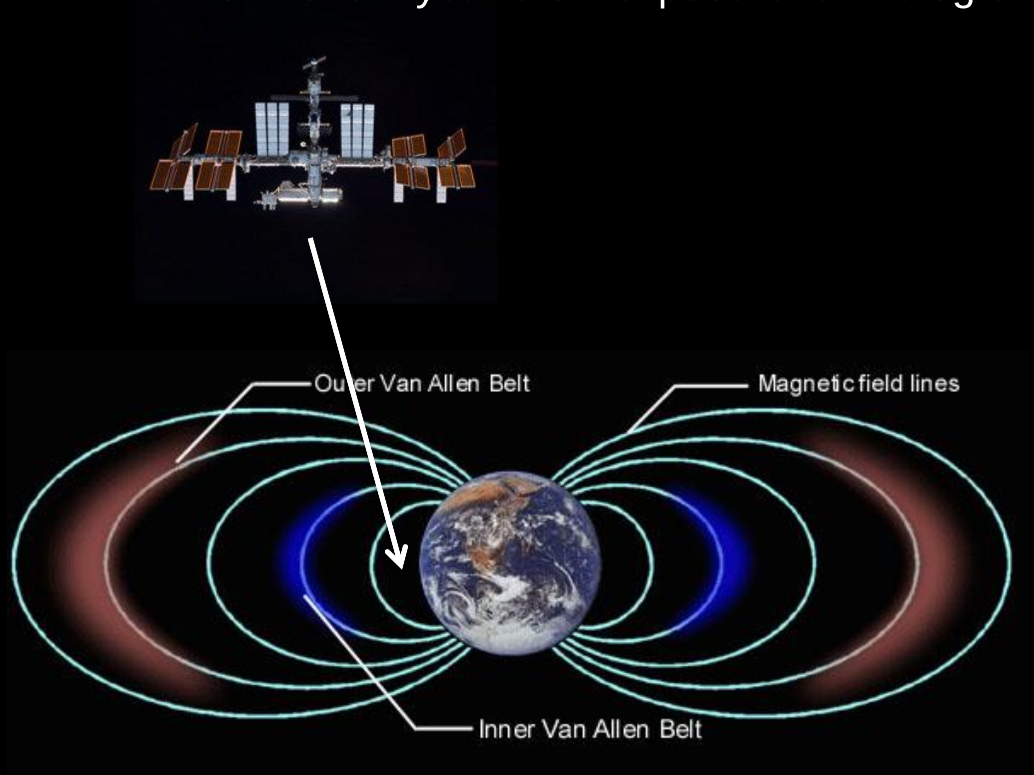
- Adverse affect on health
  - space radiation exposure (long-term cancer risk)
  - spaceflight-induced vision alterations
  - renal stone formation
  - compromised health due to inadequate nutrition
  - bone fracture due to spaceflight induced bone changes
  - acute and chronic elevated carbon dioxide exposure
- Inability to provide in mission treatment/care
  - lack of medical capabilities
  - ineffective medications due to long term storage
- Adverse impact on performance
  - decrements in performance due to adverse behavioral conditions and training deficiencies
  - impaired performance due to reduced muscle and aerobic capacity, and sensorimotor adaptation

Post Mission Risks (first two items under "Adverse affect on health")

In-Mission Risks (remaining items)

Environmental Considerations

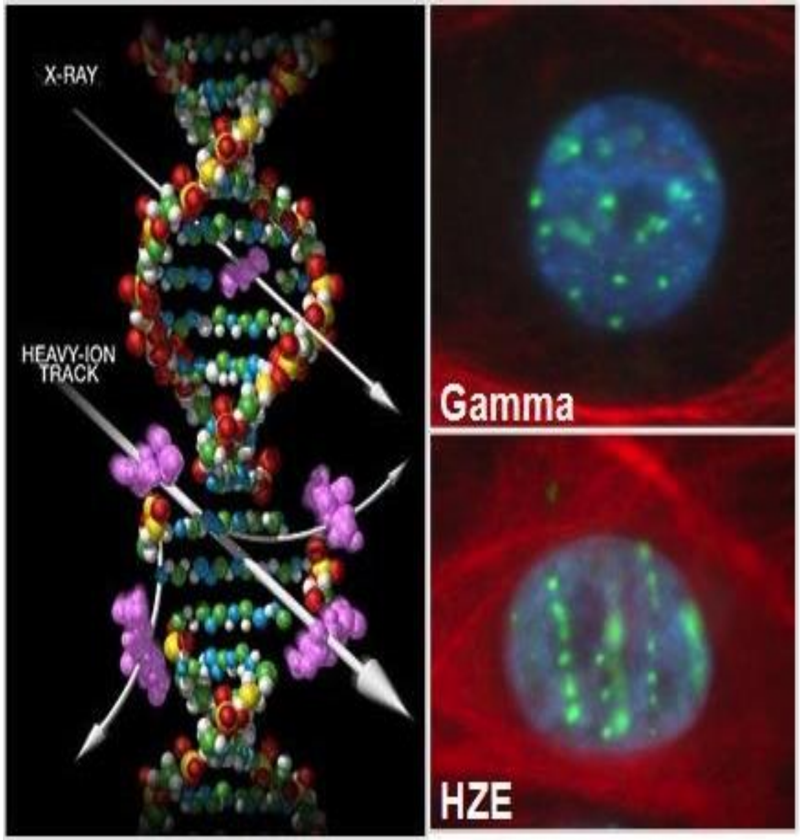
Protection from SPE except high energy
Some protection from GCR low energy
Orbital debris and micro-meteoroid environment
Sun and reflected energy from the earth
6 months to 1 year crew exposure to microgravity



No protection from SPE
No protection from GCR
Micro-meteoroid environment
Energy from sun reduced
1 to 3 years crew exposure to microgravity
Isolation and distance

Space Radiation Challenge

- **Crews are exposed to the space radiation environment**
  - High-energy protons and heavy ions (HZE's) as well as secondary particles produced in shielding and tissue
- **Space radiation produces potential increased health risks of cancer and acute exposure**
  - Damage to cells is uniquely different from terrestrial sources of radiation
- **Measurements to accurately characterize the GCR space radiation at high energies is needed to validate mitigation strategies**
  - AMS-02 can provide this information



DNA Damage in Cells: Space radiation (HZE) dense ionizing particle track

AMS-02 GCR and SEP Studies

Collaboration between NASA space radiation group and AMS-02 research group at the University of Hawaii, Veronica Bindi

Space Station is a unique platform for precision physics research

- AMS-02 is measuring the cosmic ray fluxes with unprecedented uncertainty and accuracy
- University of Hawaii research group is focused on the AMS-02 energy range that supports NASA human space exploration missions and is unavailable from other satellites

Improvement in accuracy will provide new insights in areas such as the study of the cosmic rays and solar activity, and has application to NASA space radiation health assessments and shielding design

Main Research Focus:

- Cosmic Rays Fluxes and their changes with the solar activity
- Heliophysics - Study of the Solar Energetic Particles

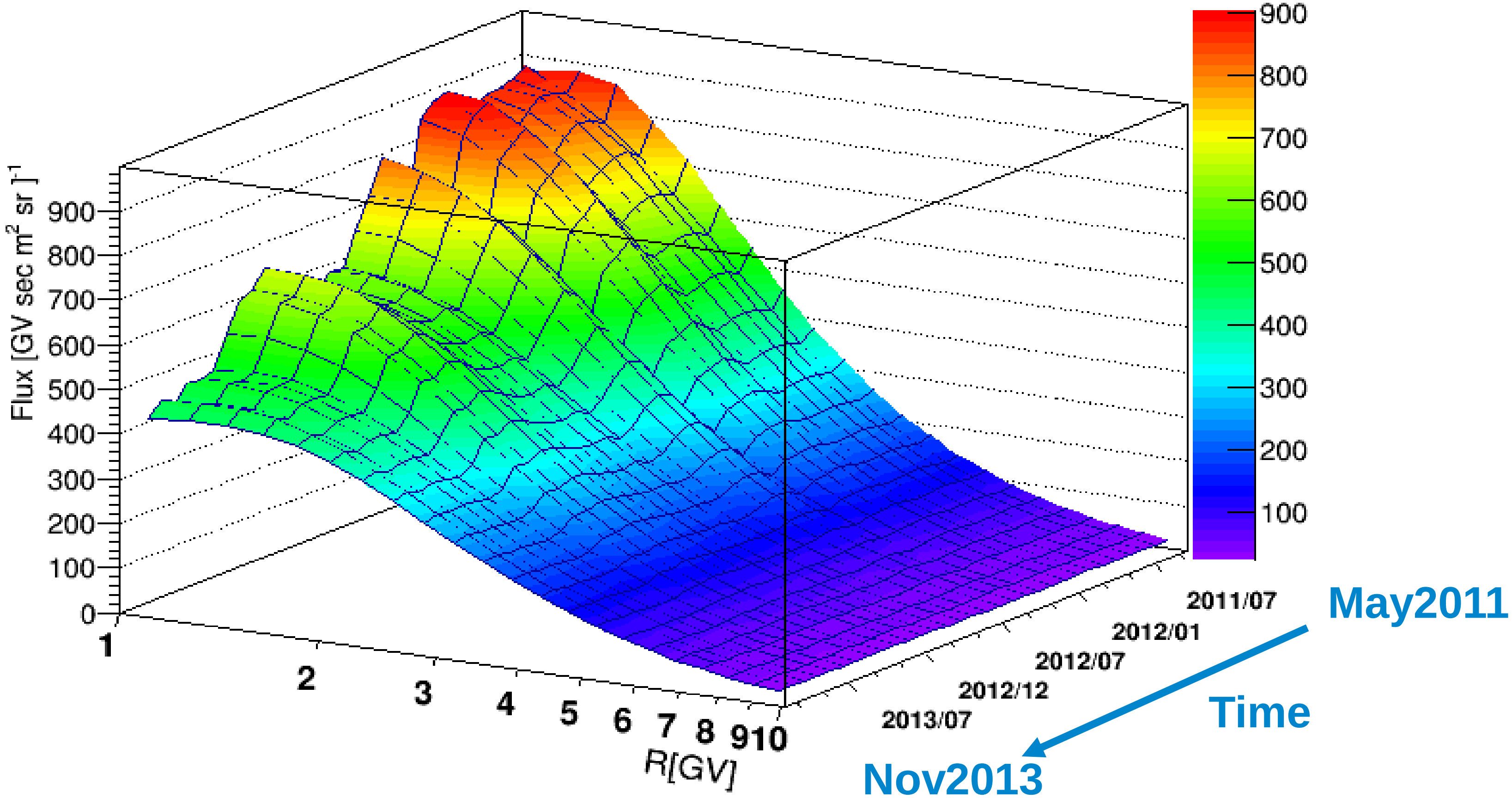
GCR Study Goals

Main goal of this collaboration is to provide to NASA during the next 5 years, the **monthly Proton-Helium-Carbon fluxes measured by AMS-02 from 2011 till 2019, in the energy range from 1 to 10 GV** - where the radiation is expected to be the most harmful.

The radiation group will use the AMS-02 monthly fluxes to improve the GCR models employed to predict the radiation dose absorbed by astronauts for both ISS operations and long duration missions.

AMS-02 Proton Flux

First set of AMS-02 GCR fluxes to be delivered to NASA: Information over this energy range and of this quality is unavailable from any other source



- Graph shows the overall reduction of the proton flux at low energies due to increasing solar activity at unprecedented uncertainty and accuracy
- Monthly fluctuations are the result of short timescale solar activity

Heliophysics with AMS-02

AMS-02 is the largest SEP detector ever flown in Space that can measure Proton and Helium from solar events with unprecedented statistics at energies not always accessible from current satellites

Date Observed by AMS-02	Date of Event	Time of Flare (UT)	Flare Class	CME Linear Speed (km/s)
June 7, 2011	June 7, 2011	06:16	M2.5	1255
Aug 4, 2011	Aug 4, 2011	03:41	M9.3	1315
Aug 9, 2011	Aug 9, 2011	07:48	X6.9	1610
Jan 23, 2012	Jan 23, 2012	03:38	M8.7	2175
Jan 28, 2012	Jan 27, 2012	17:37	X1.7	2508
Mar 7, 2012	Mar 7, 2012	00:02, 01:05	X5.4, X1.3	2684, 1825
May 17, 2012	May 17, 2012	01:25	M5.1	1582
July 17, 2012	July 17, 2012	12:03	M1.7	958
July 19, 2012	July 19, 2012	04:17	M7.7	1631
July 23, 2012	July 23, 2012	-	-	2003
May 23, 2013	May 22, 2013	13:08	M5.8	1466
Oct 28, 2013	Oct 28, 2013	01:25, 15:07	X1.0, M5.1	1201, 1073
Oct 29, 2013	Oct 29, 2013	21:42	X2.3	1001
Nov 2, 2013	Nov 2, 2013	04:40	C8.2	828
Nov 7, 2013	Nov 7, 2013	-	-	1033
Dec 28, 2013	Dec 28, 2013	-	-	1118
Jan 6, 2014	Jan 6, 2014	-	-	1402
Jan 7, 2014	Jan 7, 2014	18:04	X1.2	1830
Feb 25, 2014	Feb 25, 2014	00:39	X4.9	2147

~20 High Energy SEP events observed by AMS-02

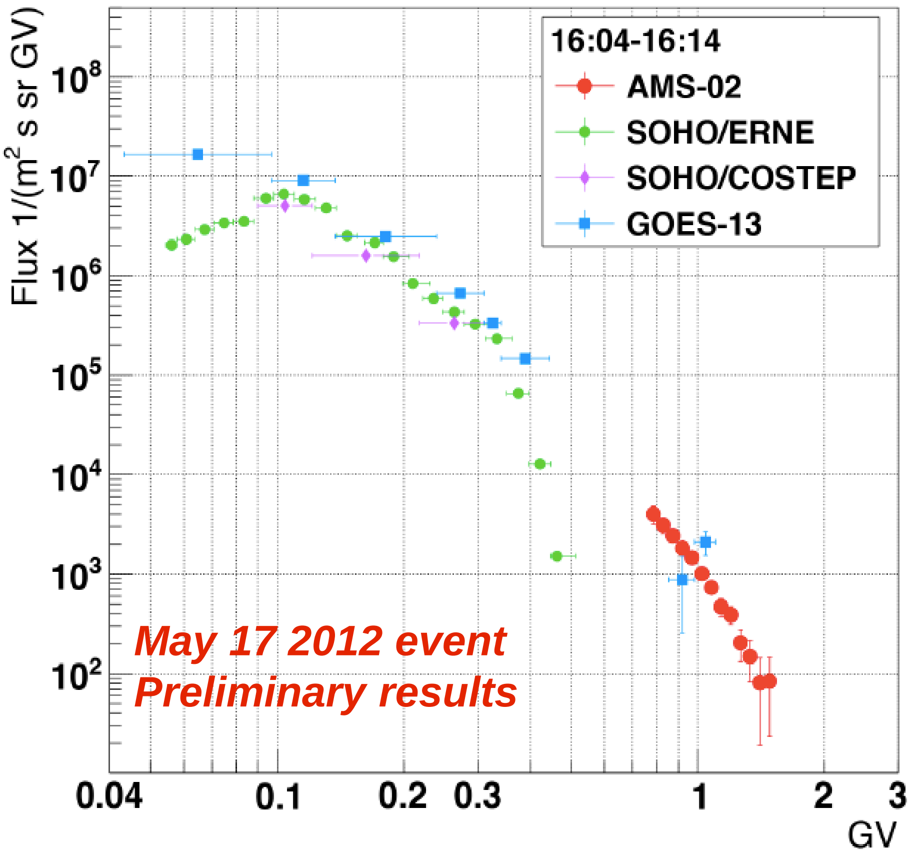
SEP Spectra

SEP spectra measured by AMS-02 cover the highest energy range of SEPs (shown in red on graph)

- AMS data combined with other instruments at lower energy, will provide a baseline for the modeling of SEP energy spectra

Energy range is unavailable from other satellites

- This energy range is critical to understanding potential health effects from SEPs
- Supports design of effective space radiation shielding and storm shelters for space exploration missions



Earth's visualization of particles and atmospheric interaction

Continued ISS operation is essential for science and human exploration