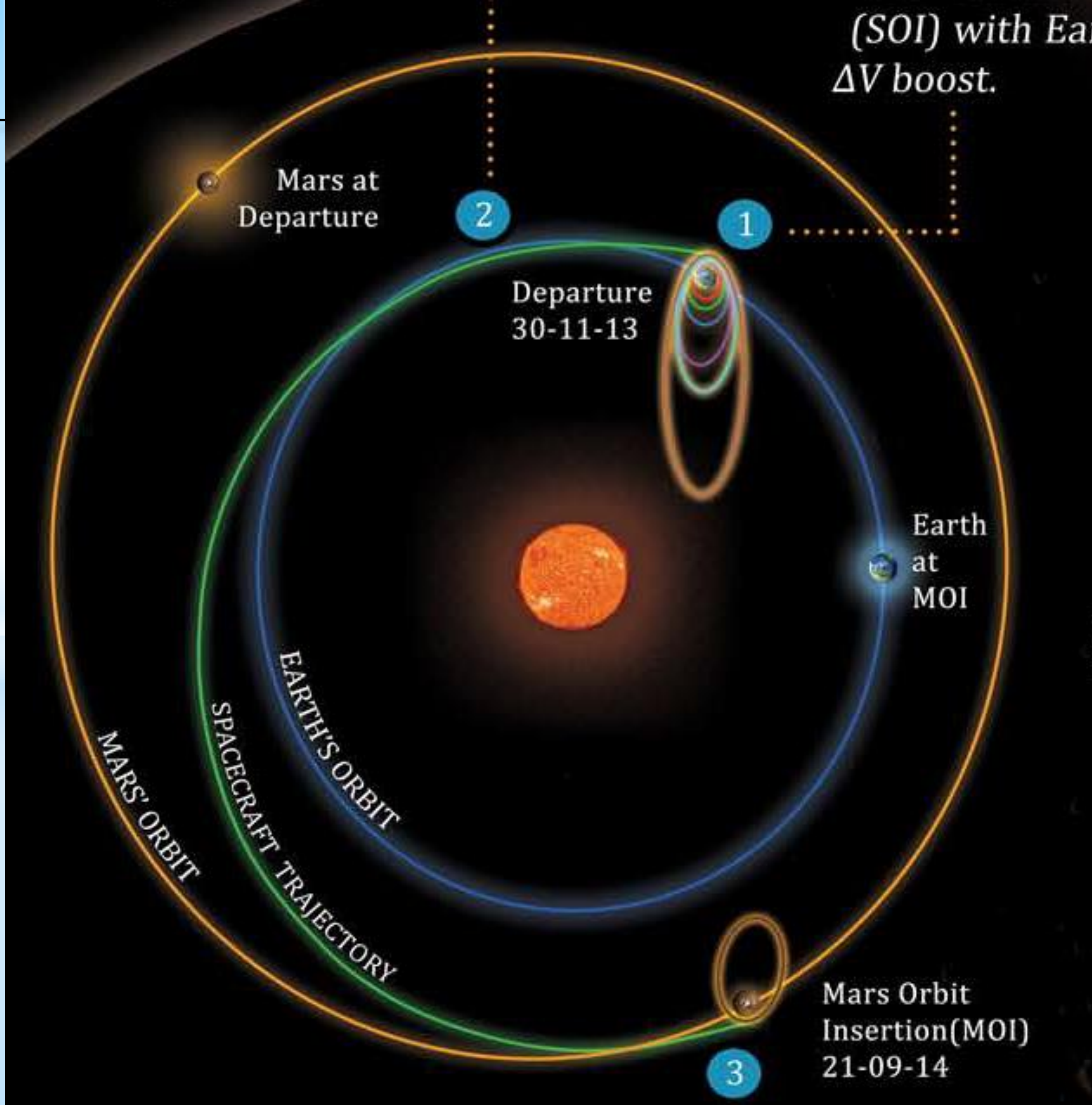
Human Space Exploration : Challenges and Opportunities

Antony Jeevarajan, Ph.D.
Johnson Space Center
National Aeronautics and Space Administration
Houston, TX 77058
Email: antony.s.jeevarajan@nasa.gov

India’s Mars Mission

A. Jeevarajan/NASA


(SOI) with Ear
ΔV boost.
Mars at
Departure
2
1
Departure
30-11-13
Earth
at
MOI
EARTH'S ORBIT
SPACECRAFT TRAJECTORY
MARS' ORBIT
Mars Orbit
Insertion(MOI)
21-09-14
3

Mars Mission Exploration Tools

Lyman Alpha Photometer (LAP)

Lyman Alpha Photometer (LAP) is an absorption cell photometer. It measures the relative abundance of deuterium and hydrogen from Lyman-alpha emission in the Martian upper atmosphere (typically Exosphere and exobase). Measurement of D/H (Deuterium to Hydrogen abundance Ratio) allows us to understand especially the loss process of water from the planet.

Methane Sensor for Mars (MSM)

MSM is designed to measure Methane (CH_4) in the Martian atmosphere with PPB accuracy and map its sources. Data is acquired only over illuminated scene as the sensor measures reflected solar radiation. Methane concentration in the Martian atmosphere undergoes spatial and temporal variations.

Atmospheric studies

Mars Exospheric Neutral Composition Analyser (MENCA)

MENCA is a quadruple mass spectrometer capable of analysing the neutral composition in the range of 1 to 300 amu with unit mass resolution. The heritage of this payload is from Chandra's Altitudinal Composition Explorer (CHACE) payload

Particle environment studies

Mars Color Camera (MCC)

This tri-color Mars Color camera gives images & information about the surface features and composition of Martian surface. They are useful to monitor the dynamic events and weather of Mars. MCC will also be used for probing the two satellites of Mars – Phobos & Deimos. It also provides the context information for other science payloads.

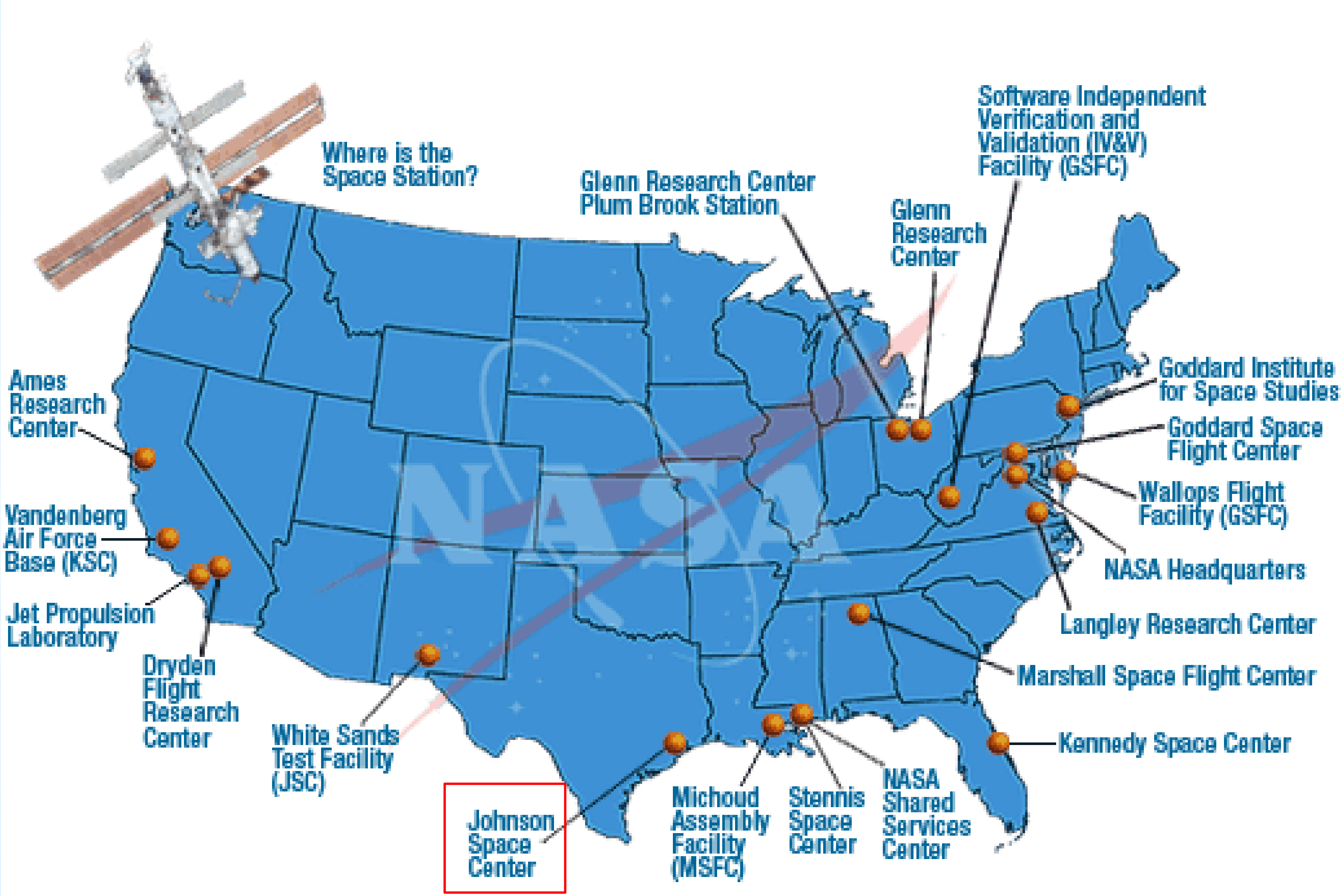
Thermal Infrared Imaging Spectrometer (TIS)

TIS measure the thermal emission and can be operated during both day and night. Temperature and emissivity are the two basic physical parameters estimated from thermal emission measurement. Many minerals and soil types have characteristic spectra in TIR region. TIS can map surface composition and mineralogy of Mars.

Surface Imaging Studies

A. Jeevarajan/NASA

NASA Centers



Shuttle Launch

Shuttle Landing

Precursor to Human Space Flight (May 2016)

Mars Landing

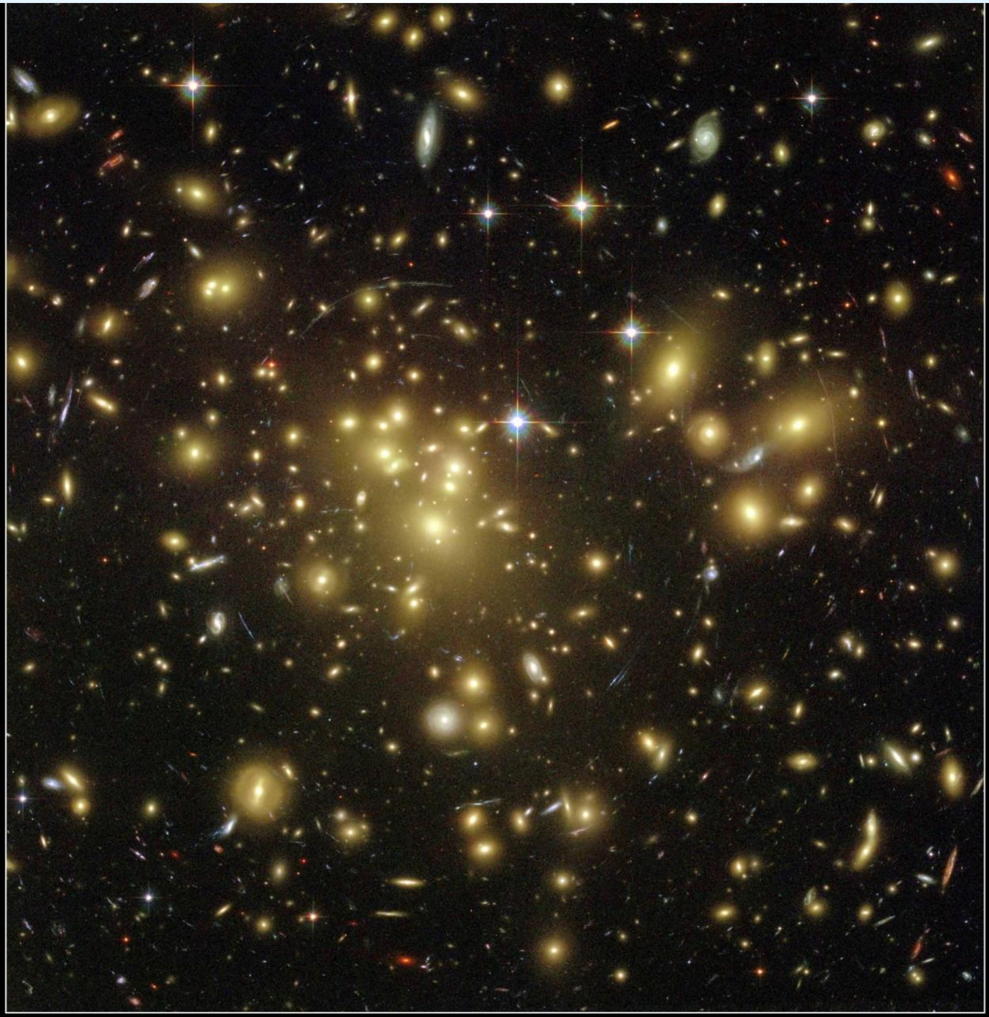
Orion Launch

A. Jeevarajan/NASA

Orion

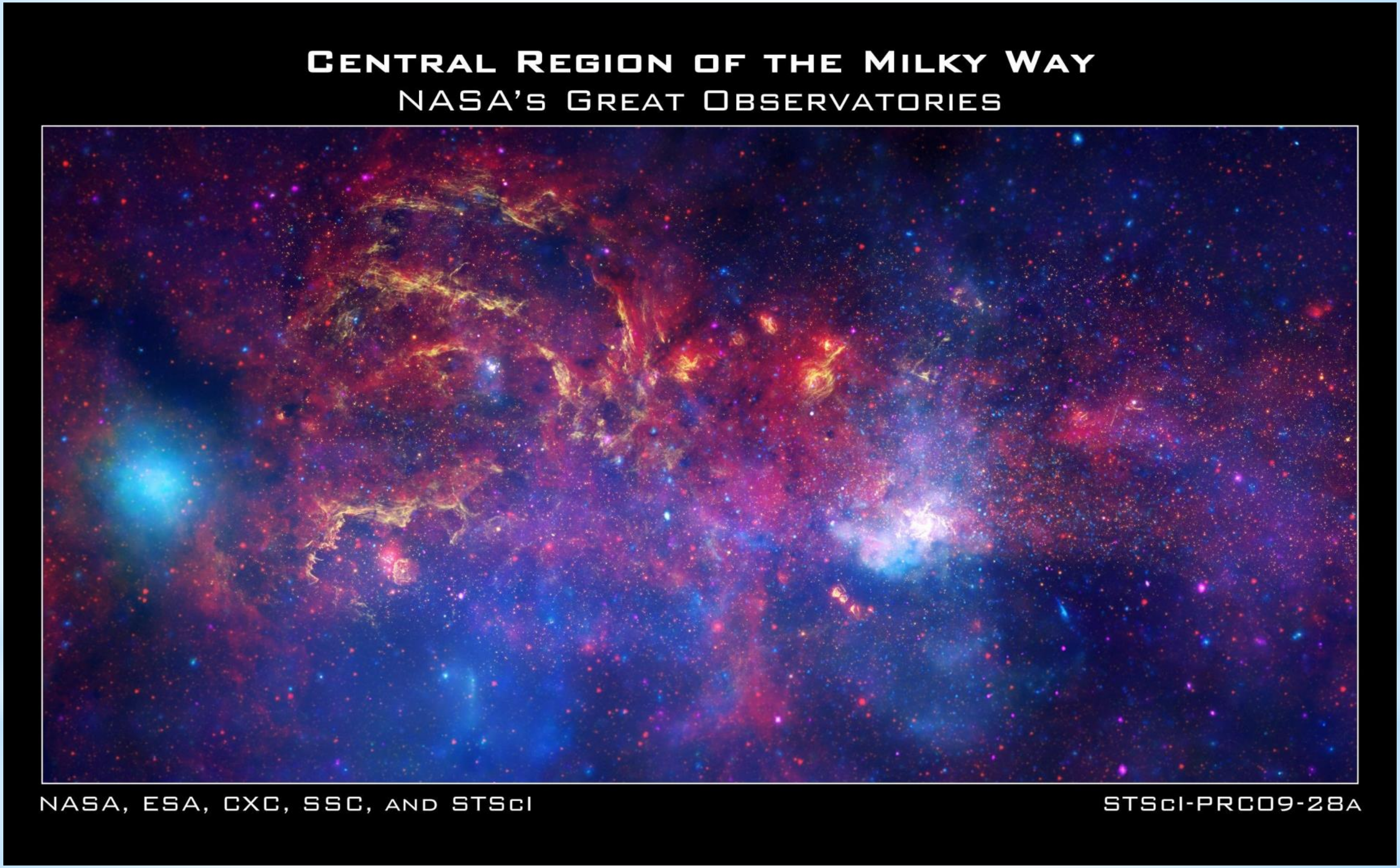
A. Jeevarajan/NASA

Cluster of Galaxies

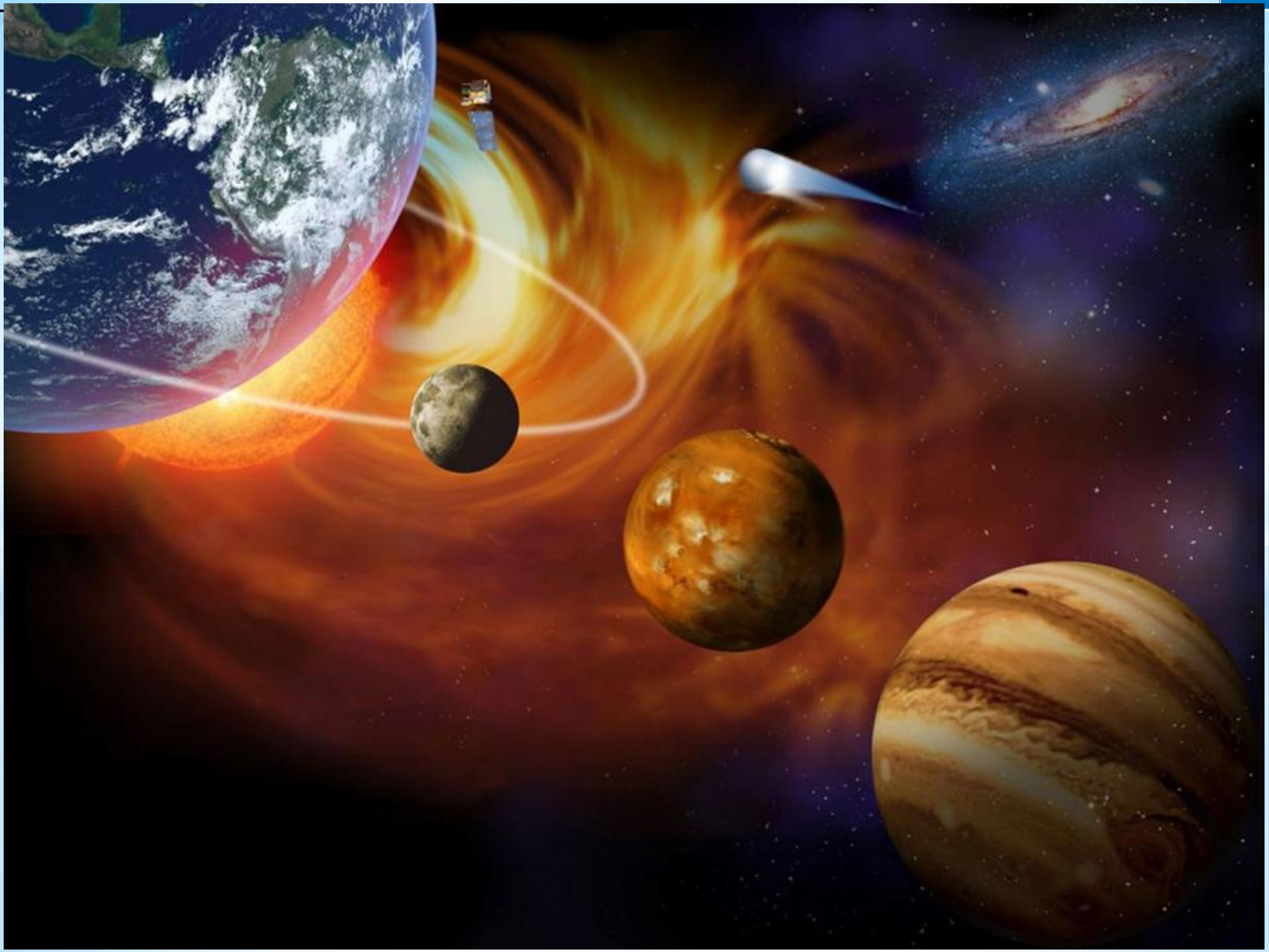


Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

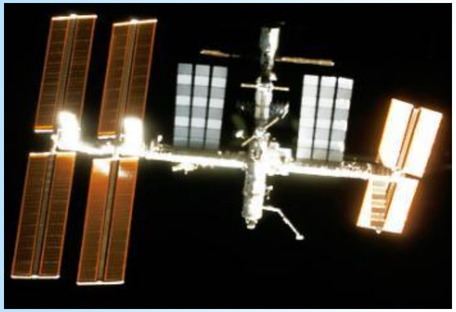

Central Region of the Milky Way
NASA's Great Observatories
NASA, ESA, CXC, SSC, and STScI
STScI-PRC09-28a

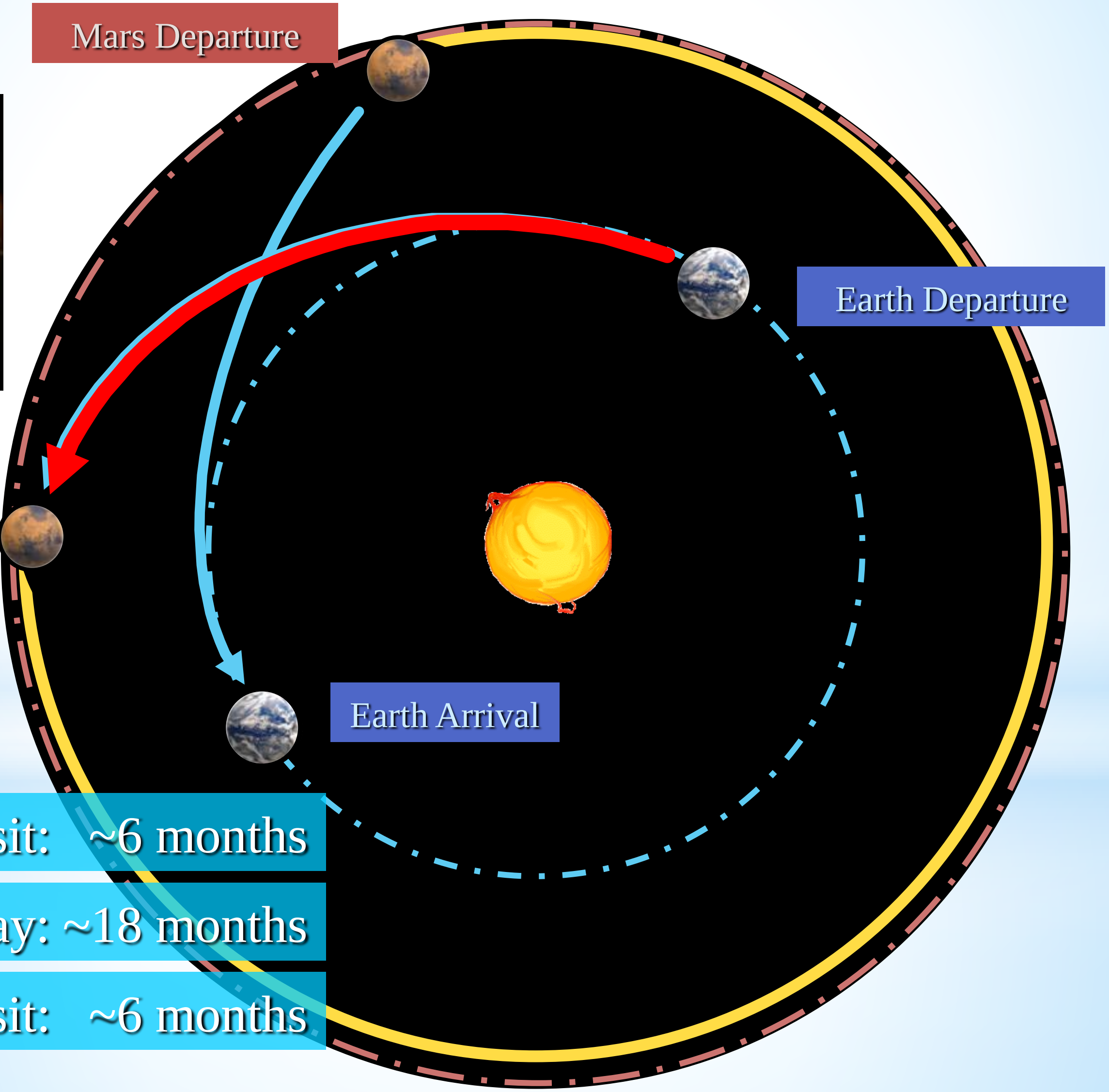
Near-term Human Exploration Domains



A. Jeevarajan/NASA

Overview of Notional Mars Expedition





Life Support Requirements Mass Breakdown

5.02 - 30.74 kg per person-day

11.3 Metric Tons Per Person-Year

DAILY INPUTS - NOMINAL

	kg
Oxygen	0.84
Food Solids	0.62
Water in Food	1.15
Food Prep Water	0.79
Drink	1.62
Hand/Face Wash Water	1.82
Shower Water	5.45
Clothes Wash Water	12.50
Dish Wash Water	5.45
Flush Water	0.50
TOTAL	30.74

DAILY OUTPUTS - NOMINAL

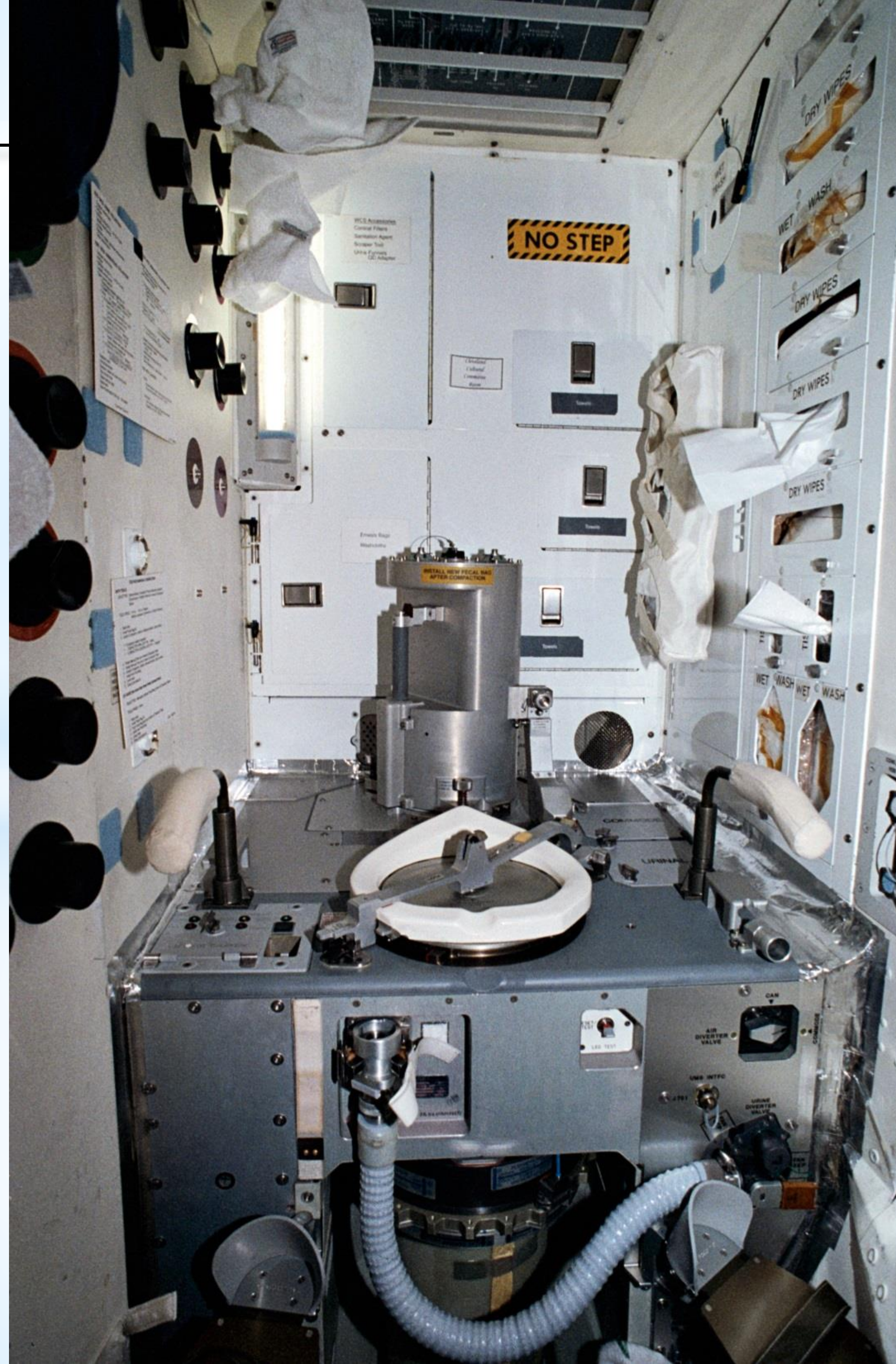
	kg
Carbon Dioxide	1.00
Respiration and Perspiration Water	2.28
Urine	1.50
Feces Water	0.09
Sweat Solids	0.02
Urine Solids	0.06
Feces Solids	0.03
Hygiene Water	6.68
Clothes Wash Water	11.90
Clothes Wash Latent Water	0.60
Other Latent Water	0.65
Dish Wash Water	5.43
Flush Water	0.50
TOTAL	30.74

Resources and Recycling

- Water Regeneration Reactors
- Air Revitalization Reactors
- Environmental Sensors (Chemical)
- Microbial Monitors

Hygiene

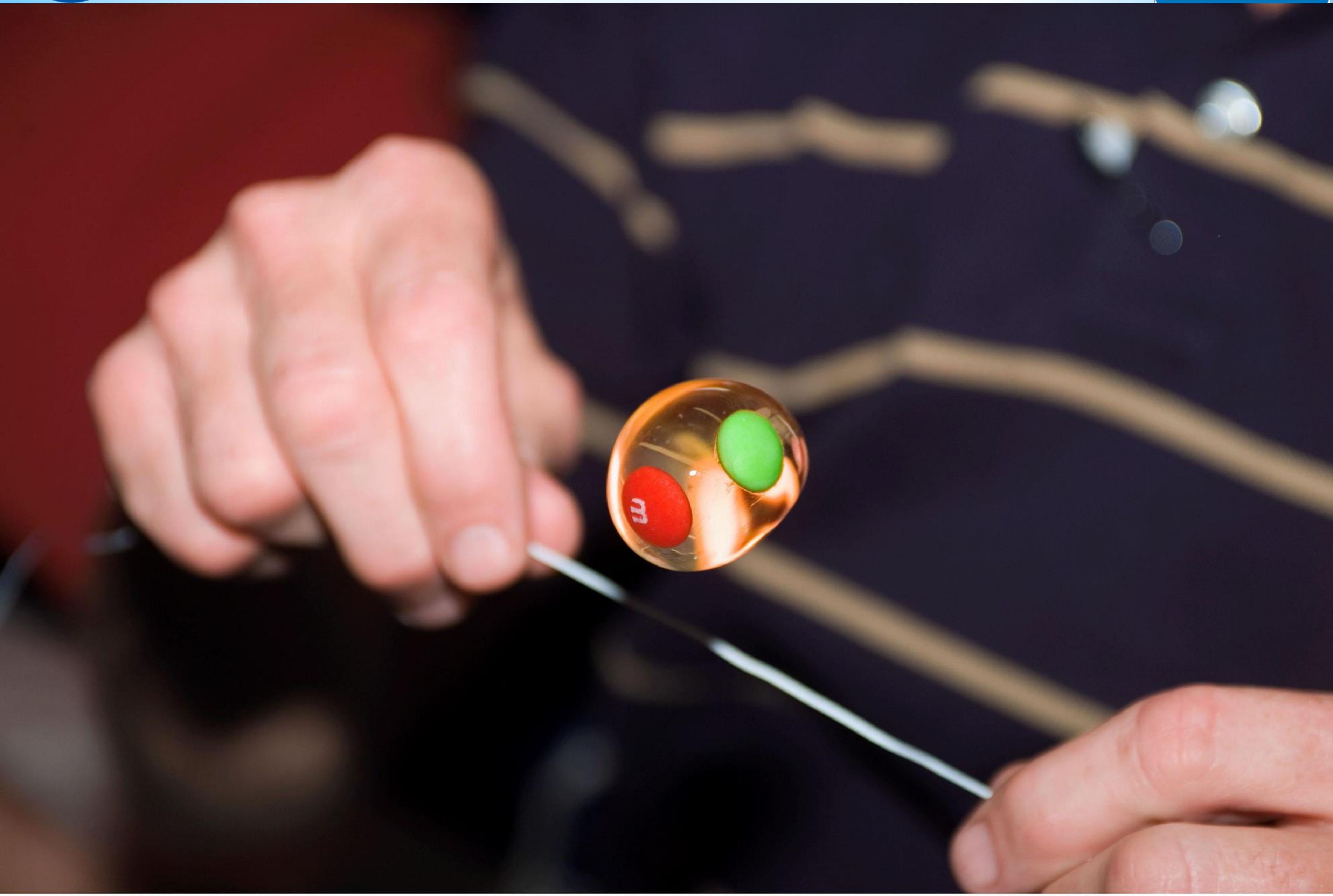
Hair-do


NO STEP
DRY WIPES
WET WASH

Garbage Handling

Salt and Pepper

Candies in water bubble



S123E006144

Dinner at his Lap

One of the Favorite Foods

Yummy Dinner

Scott Kelly (1 Year Mission) Twin Studies

Food for Space Missions

Refrigerators and freezers not available to maintain food safety and quality

Natural Form Foods

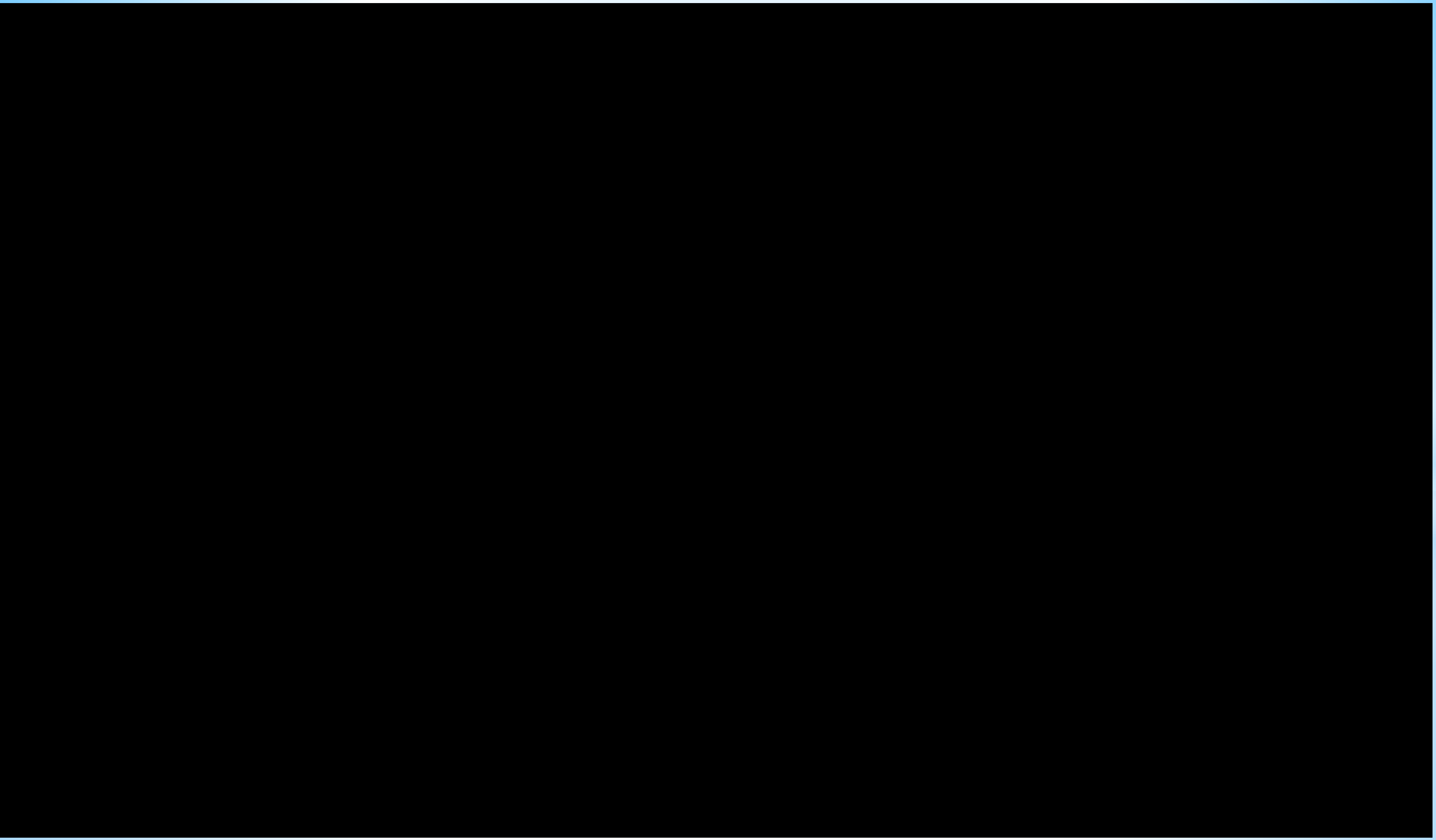
Rehydratable Foods

Intermediate Moisture Foods

Beverages

Irradiated & Thermo-stabilized Foods

Space Food Systems Video



Weightlessness

Weightlessness

Super-Woman

Sleep

Hazards of Spaceflight

Hazards Drive Human Spaceflight Risks

Altered Gravity - Physiological Changes

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

Space Radiation

Acute In-flight effects
Long term cancer risk

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

* Summary of Human Risks of Spaceflight Grouped by Hazards – 30 Human Risks, 2 Concern/Watchlist Items

Altered Gravity Field

Primary Effect

1. **Spaceflight-Induced Intracranial Hypertension/Vision Alteration**
2. Urinary Retention
3. **Space Adaptation Back Pain**
4. Renal Stone Formation
5. **Risk of Bone Fracture due to spaceflight Induced bone changes**
6. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance
7. **Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity**
8. Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with space flight.
9. **Cardiac Rhythm Problems**
10. Orthostatic Intolerance During Re-Exposure to Gravity
11. Adverse Health Effects due to Alterations in Host Microorganism Interaction

Concerns/Watchlist

1. Concern of Clinically Relevant Unpredicted Effects of Medication
2. Intervertebral Disc Damage

Radiation

Primary Effect

1. **Risk of Space Radiation Exposure on Human Health**

Distance from Earth

Primary Effect

1. **Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities**
2. Risk of Ineffective or Toxic Medications due to Long Term Storage

Isolation

Primary Effect

1. **Risk of performance decrements due to adverse behavioral conditions**

Hostile/Closed Environment-Spacecraft Design

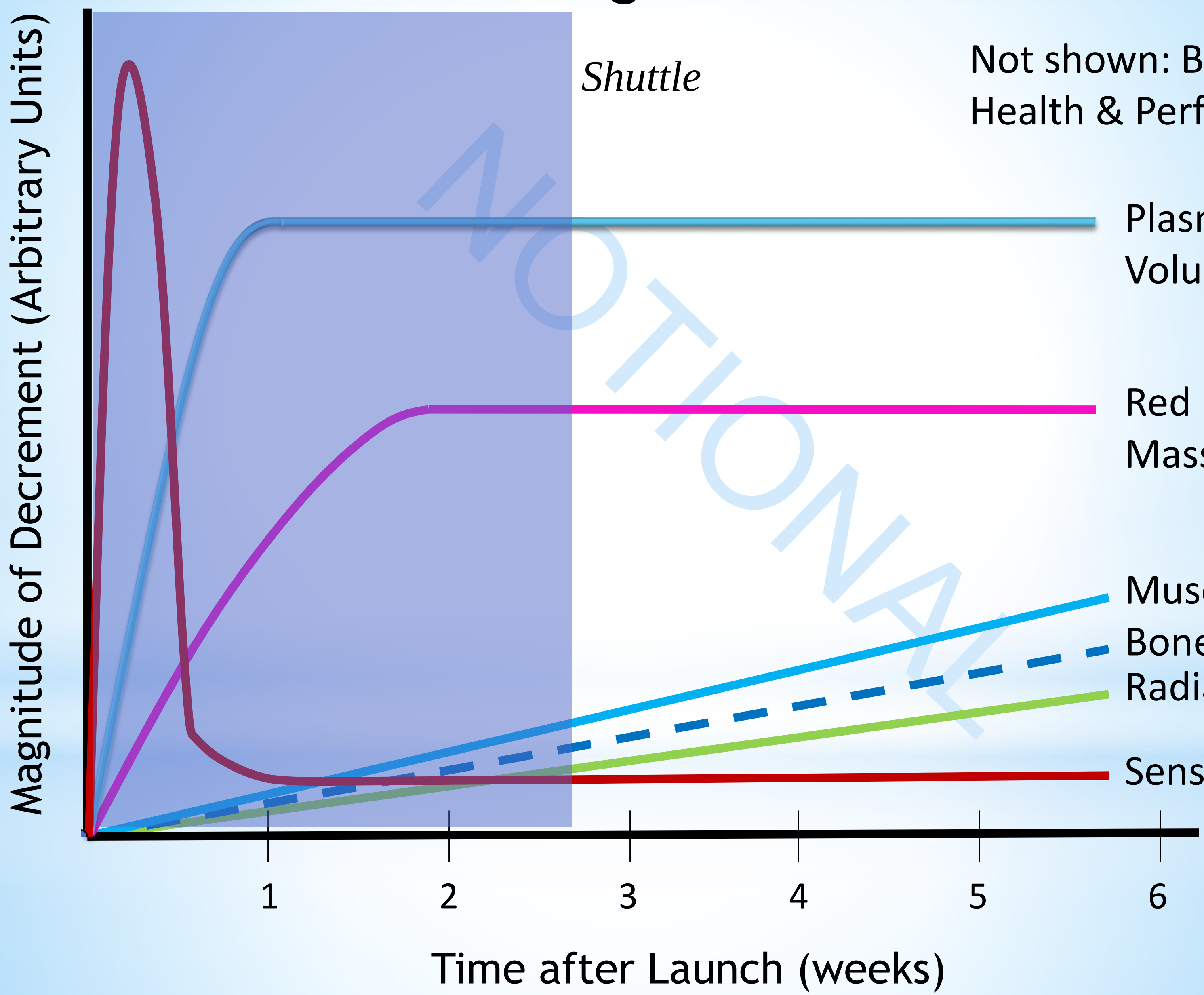
Primary Effect

1. **Toxic Exposure**
2. Acute and Chronic Carbon Dioxide Exposure
3. **Hearing Loss Related to Spaceflight**
4. Risk of reduced crew performance prior to adaptation to mild hypoxia.
5. **Injury and Compromised Performance due to EVA Operations**
6. Decompression Sickness
7. **Injury from Sunlight Exposure**
8. Incompatible Vehicle/Habitat Design
9. **Risk of Inadequate Human-Machine Interface**
10. Risk to crew health and compromised performance due to inadequate nutrition
11. **Adverse Health Effects of Lunar (Celestrial) Dust Exposure**
12. Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload
13. **Injury from Dynamic Loads**
14. Risk of Altered Immune Response
15. **Risk of electrical shock**

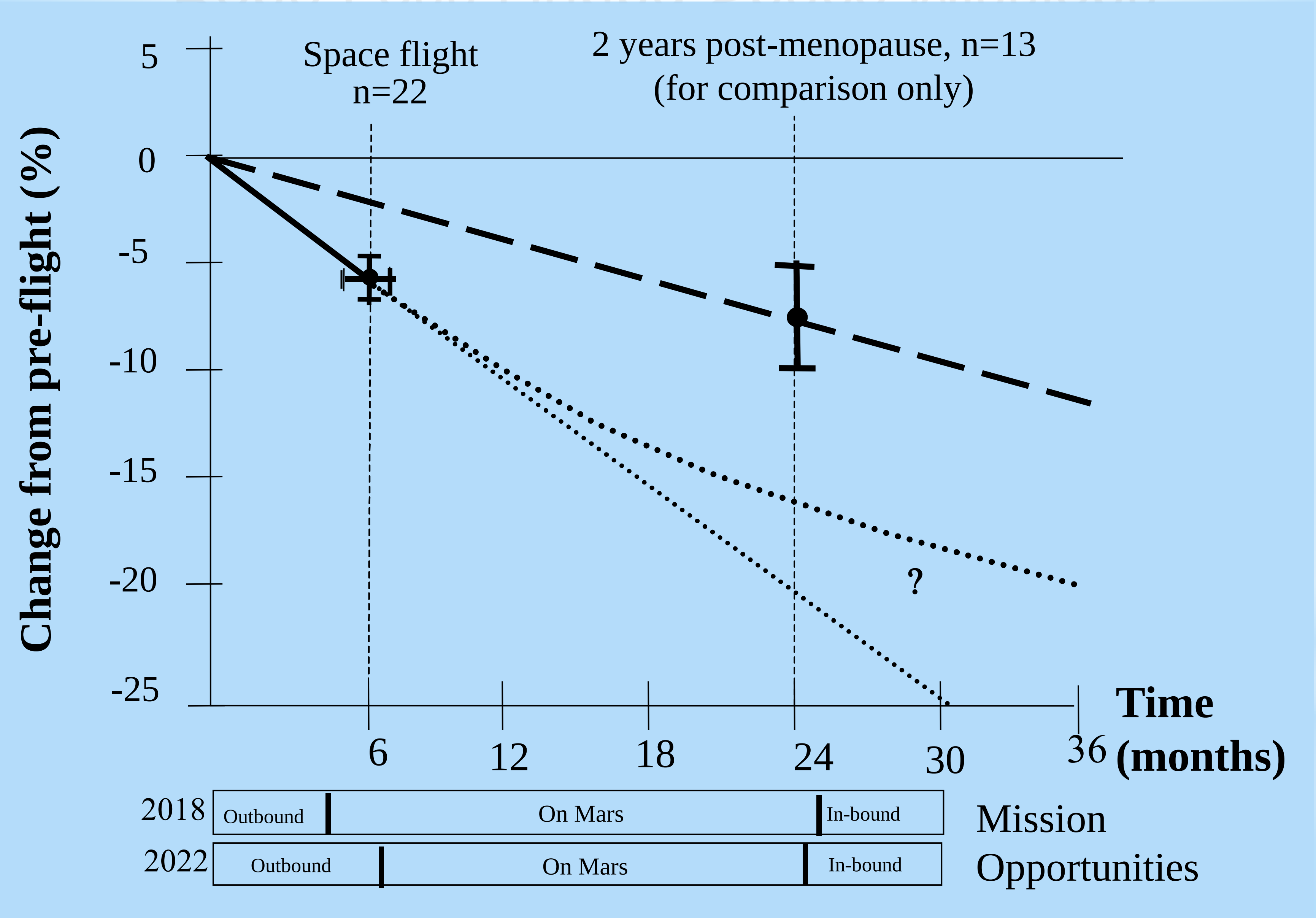
Standards	
★ (yellow)	NASA-STD-3001, VOLUME 1, CREW HEALTH
★ (green)	NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH
★ (blue)	Clinical Practice Guidelines

★ Standards in process of review/change/addition

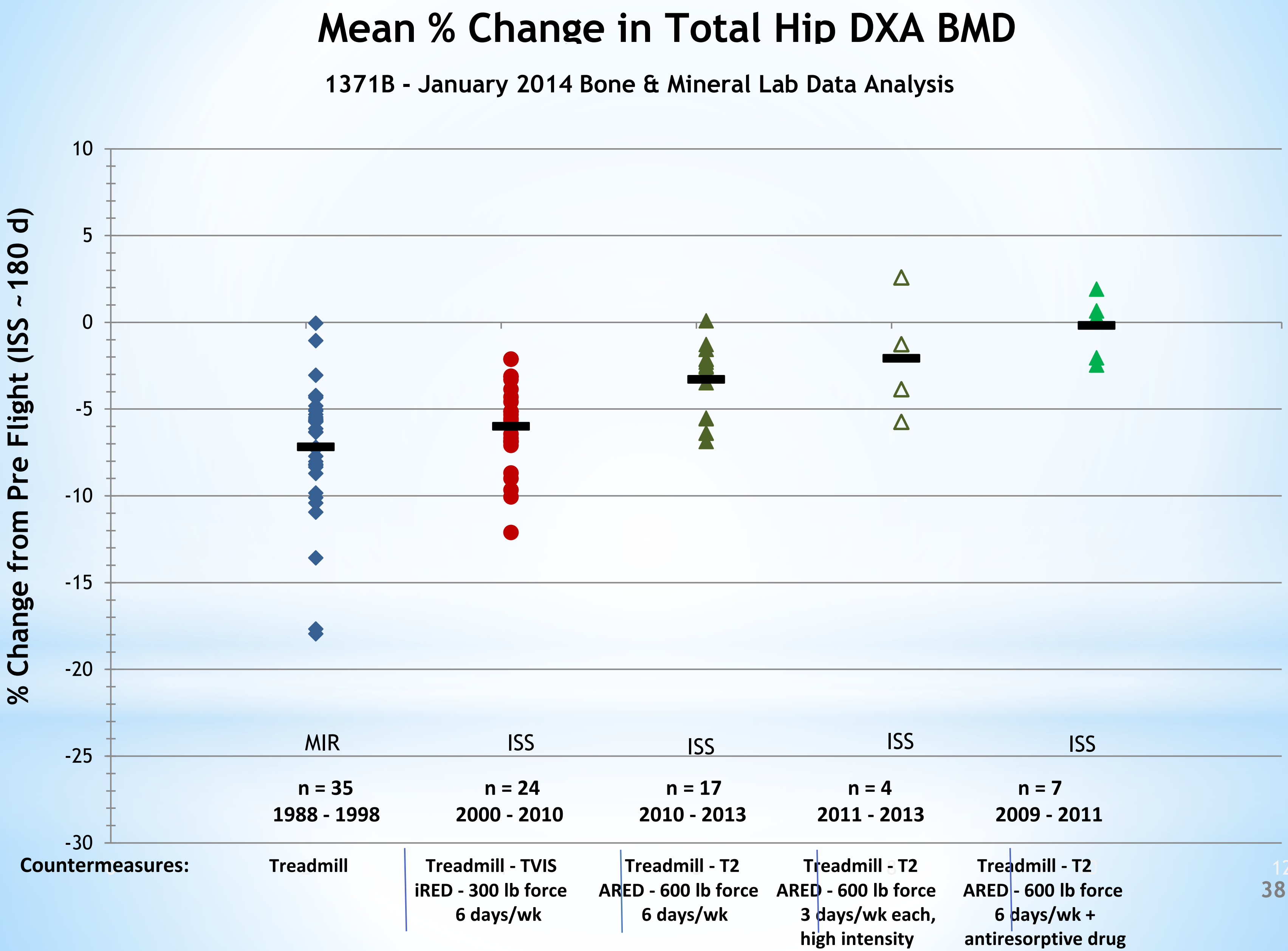
Changes during short-duration space flight



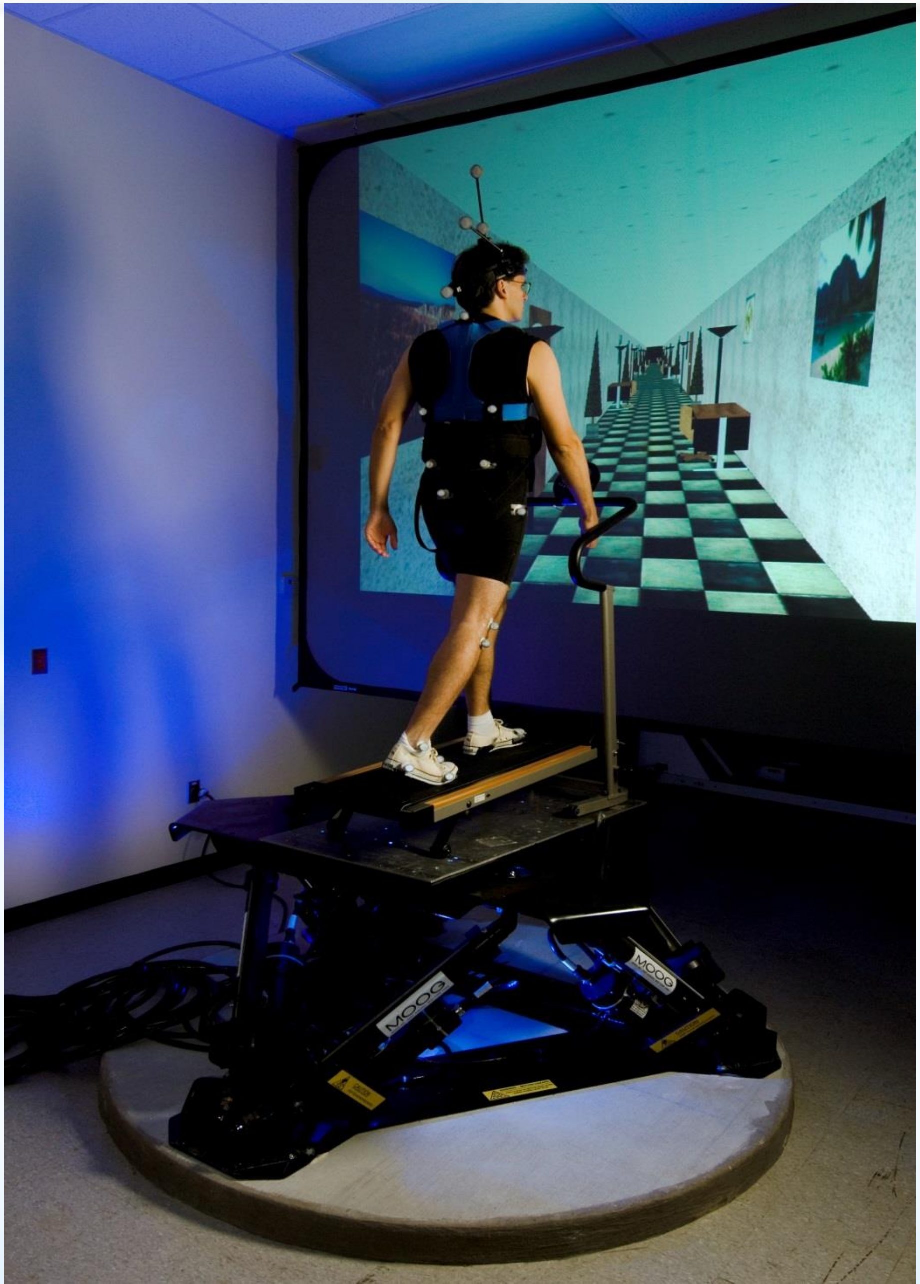
Bone Loss During Space Missions



Risk of Bone Fracture due to Spaceflight-induced Changes to Bone



Treadmill in a six-degree of freedom Platform



ISS026E018823

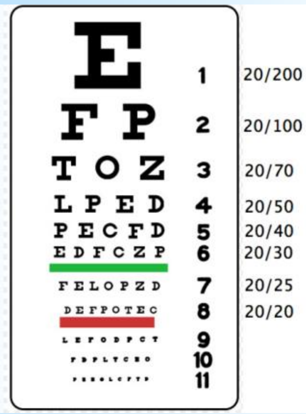
Resistive Exercise Device

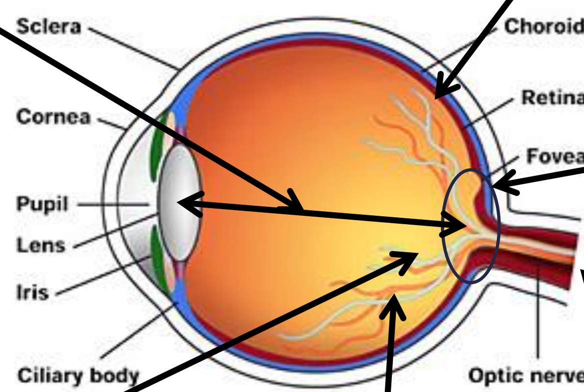
Treadmill in International Space Station

A. Jeevarajan/NASA

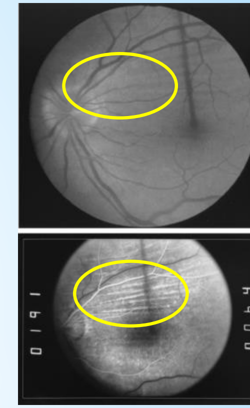
Integrated Visual Impairment/Intracranial Pressure

- **Hyperopic Shifts**
  - Up to +1.75 diopters

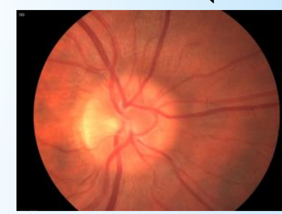




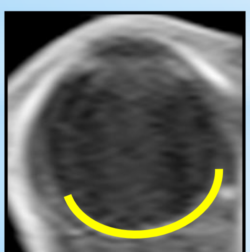
- **Choroidal Folds** - parallel grooves in the posterior pole



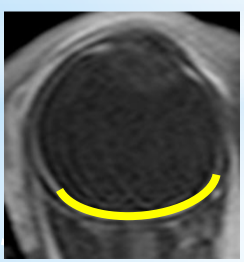
- **Optic Disc Edema (swelling)**



- **Globe Flattening**



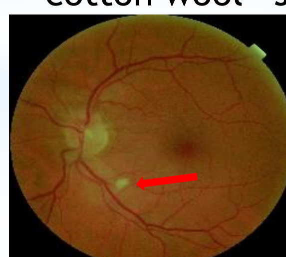
Normal Globe

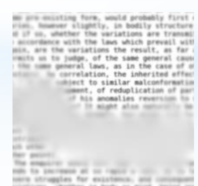


Flatten Globe

MRI Orbital Image showing globe flattening

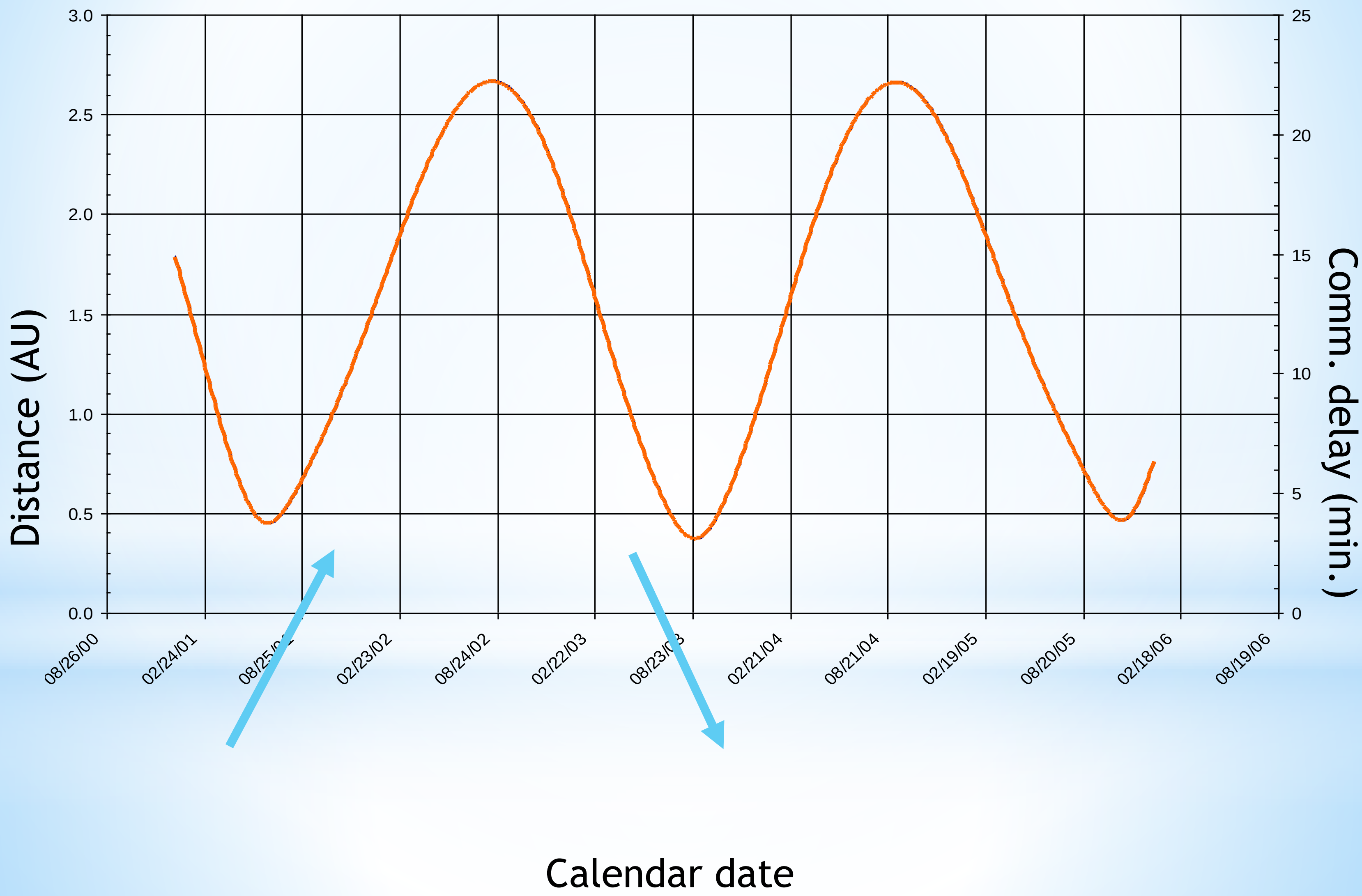
- **Altered Blood flow**
  - "cotton wool" spots



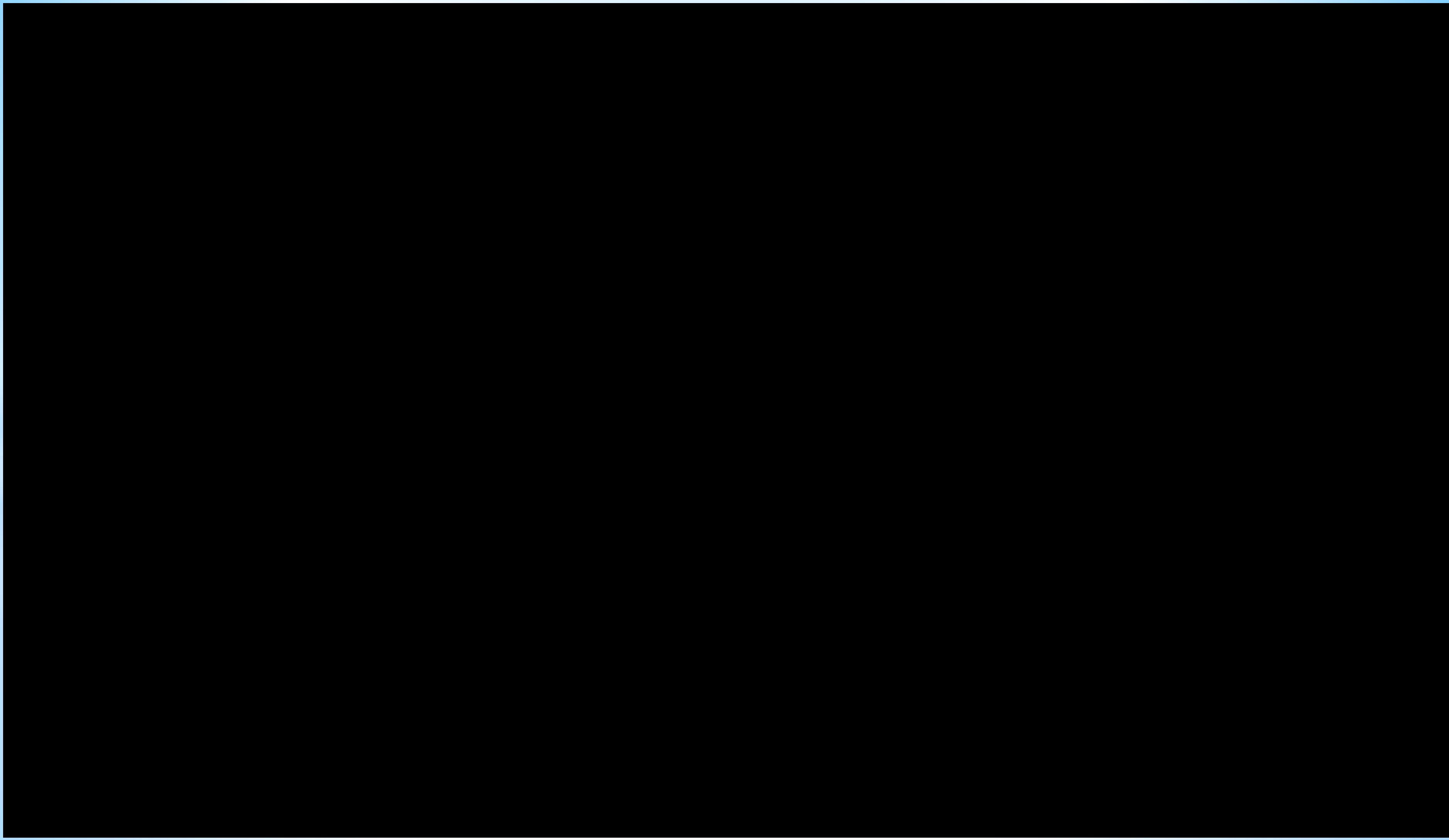


- **Increased Optic Nerve Sheath**

Variation in Distance and Communications Delay Between Earth and Mars



Biomedical Labs Video




BRAINTREE
SCIENTIFIC, INC.
2015
SPEED
LIMIT
17500
MPH

Space Radiation Environment

- **Galactic Cosmic Rays (GCR):**

  - highly penetrating protons and heavy ions of extra-solar origin

  - large amounts of secondary radiation

  - largest doses occur during minimum solar activity in 11 year solar cycle

  - low level background radiation: protons (85%), Helium (14%) and HZE particles (1%)

- **Trapped Radiation in South Atlantic:**

  - medium energy protons and electrons

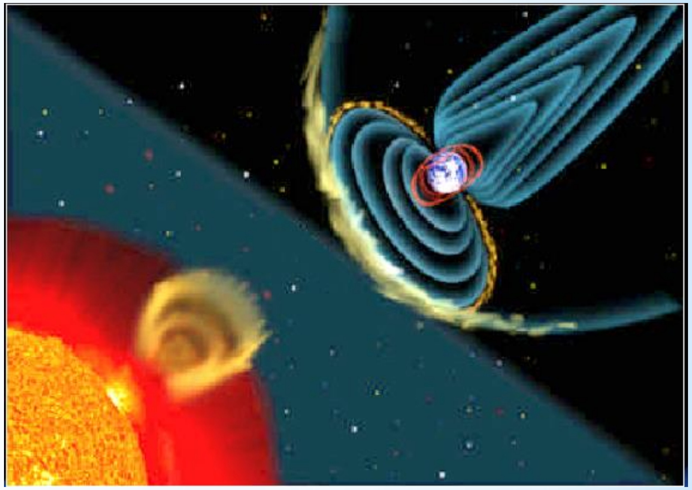
  - effectively mitigated by shielding

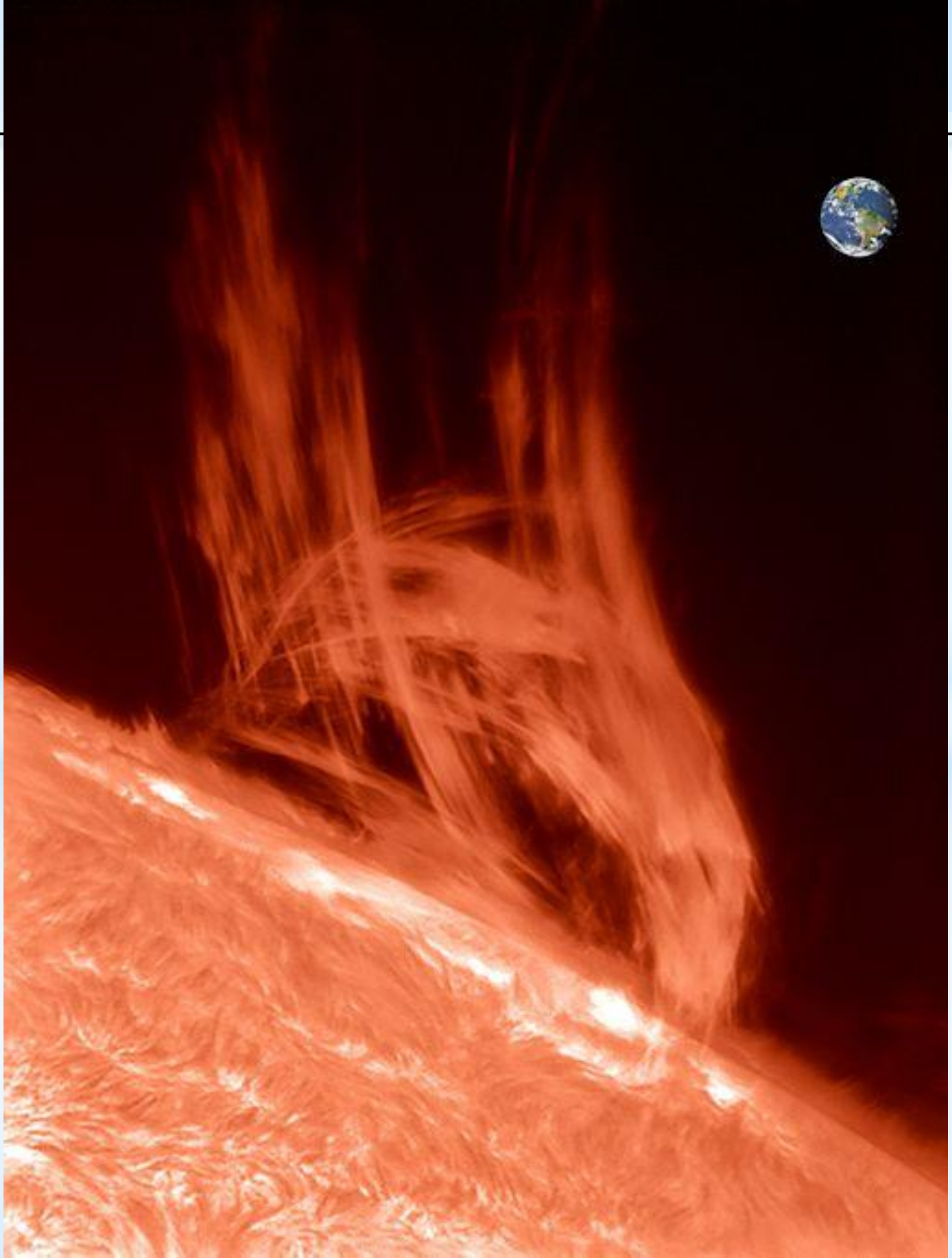
- **Solar Particle Events (SPE):**

  - medium to high energy protons

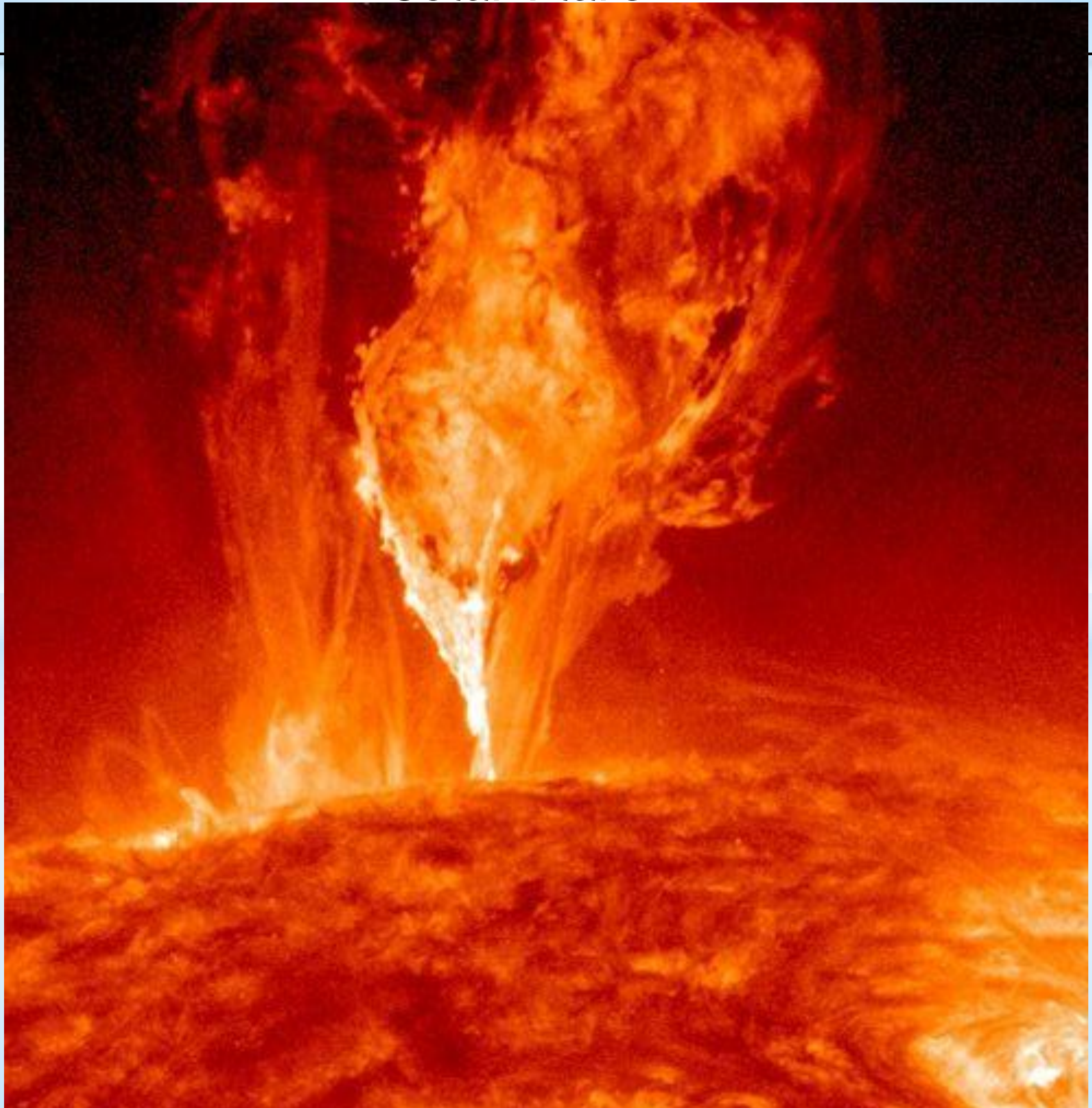
  - occur during maximum solar activity

  - Solar protons from the Coronal Mass Ejections and HZE

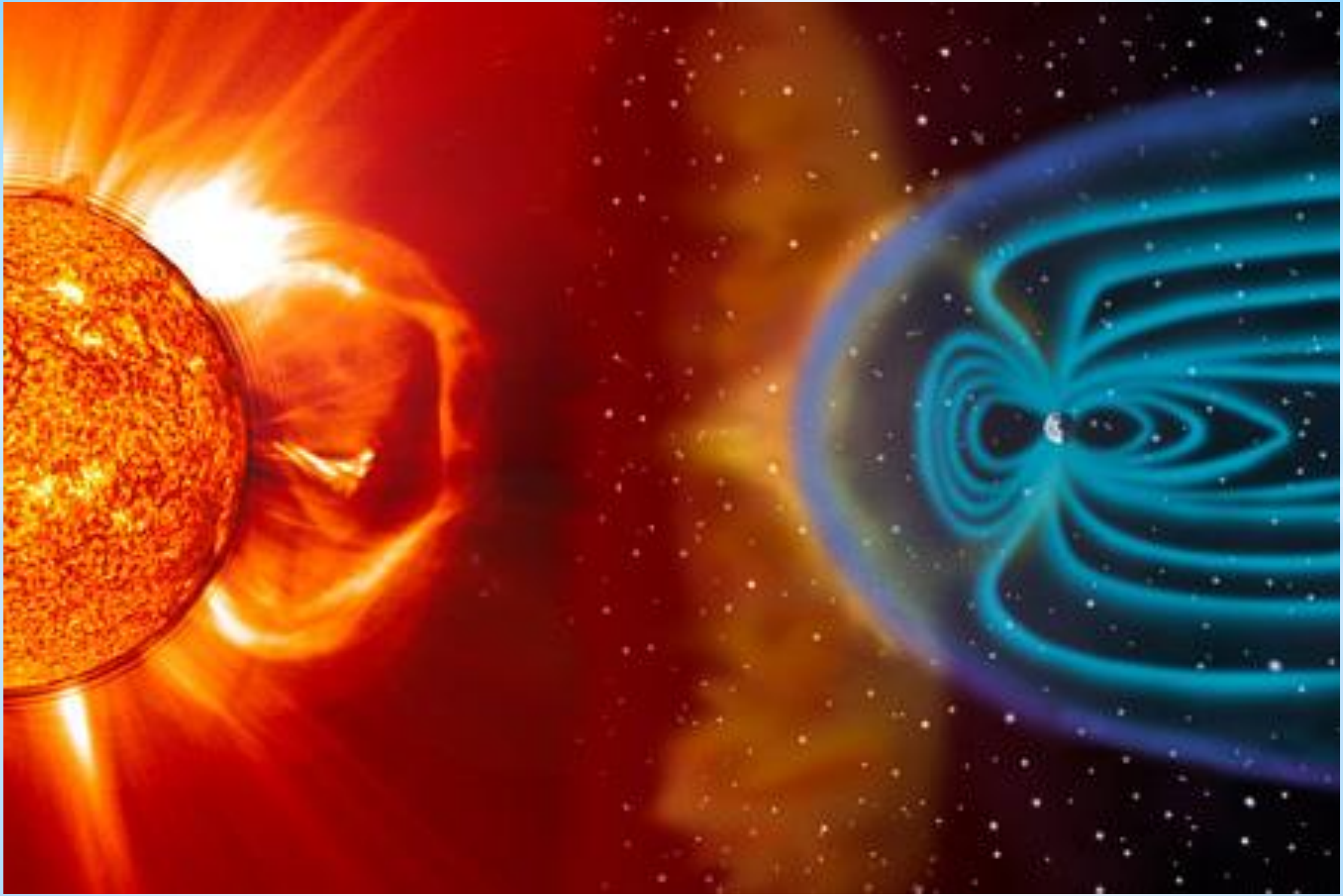




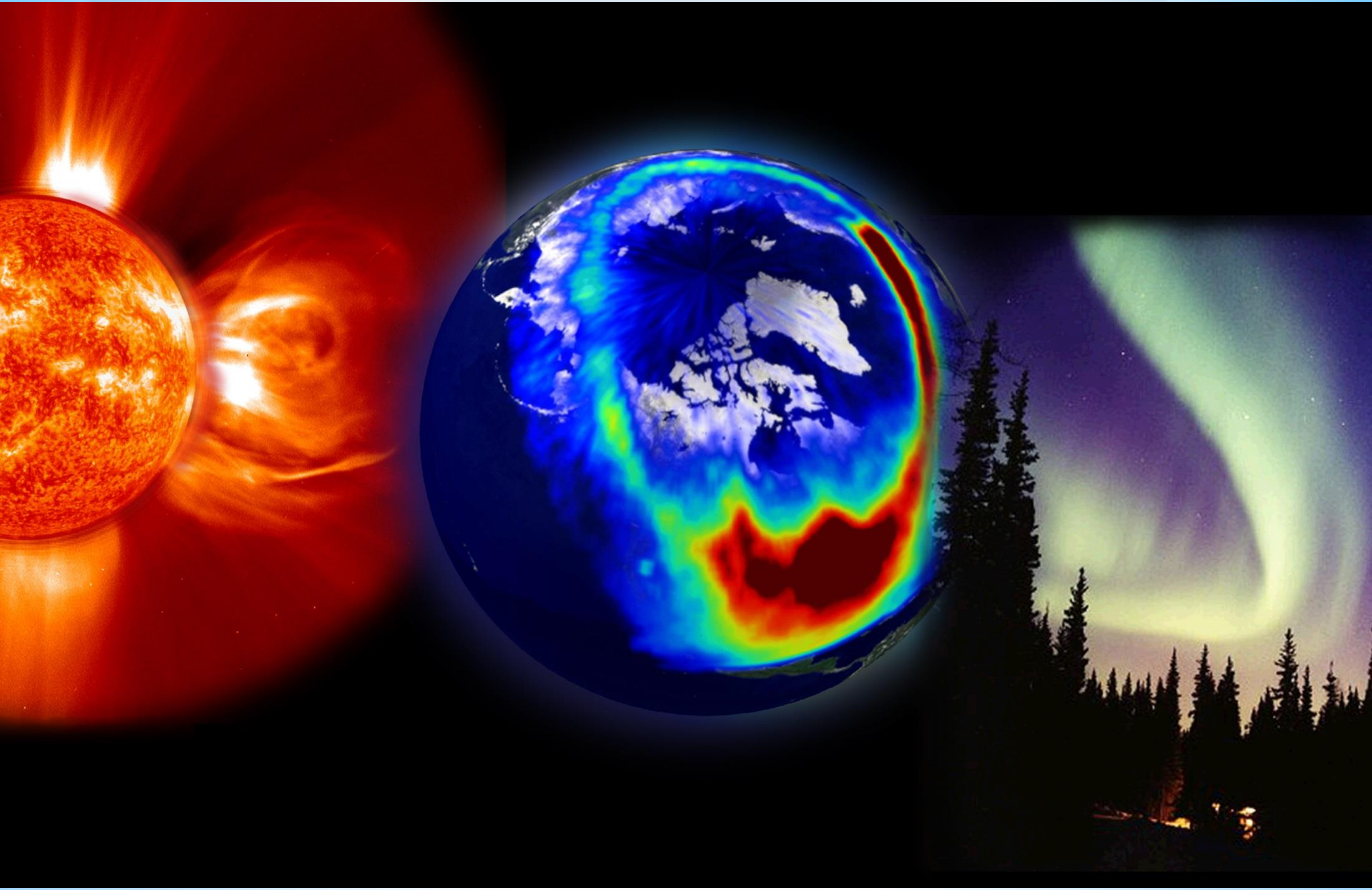
Solar Flare



Solar Flare



Solar Flare/Aurora from Space/Earth

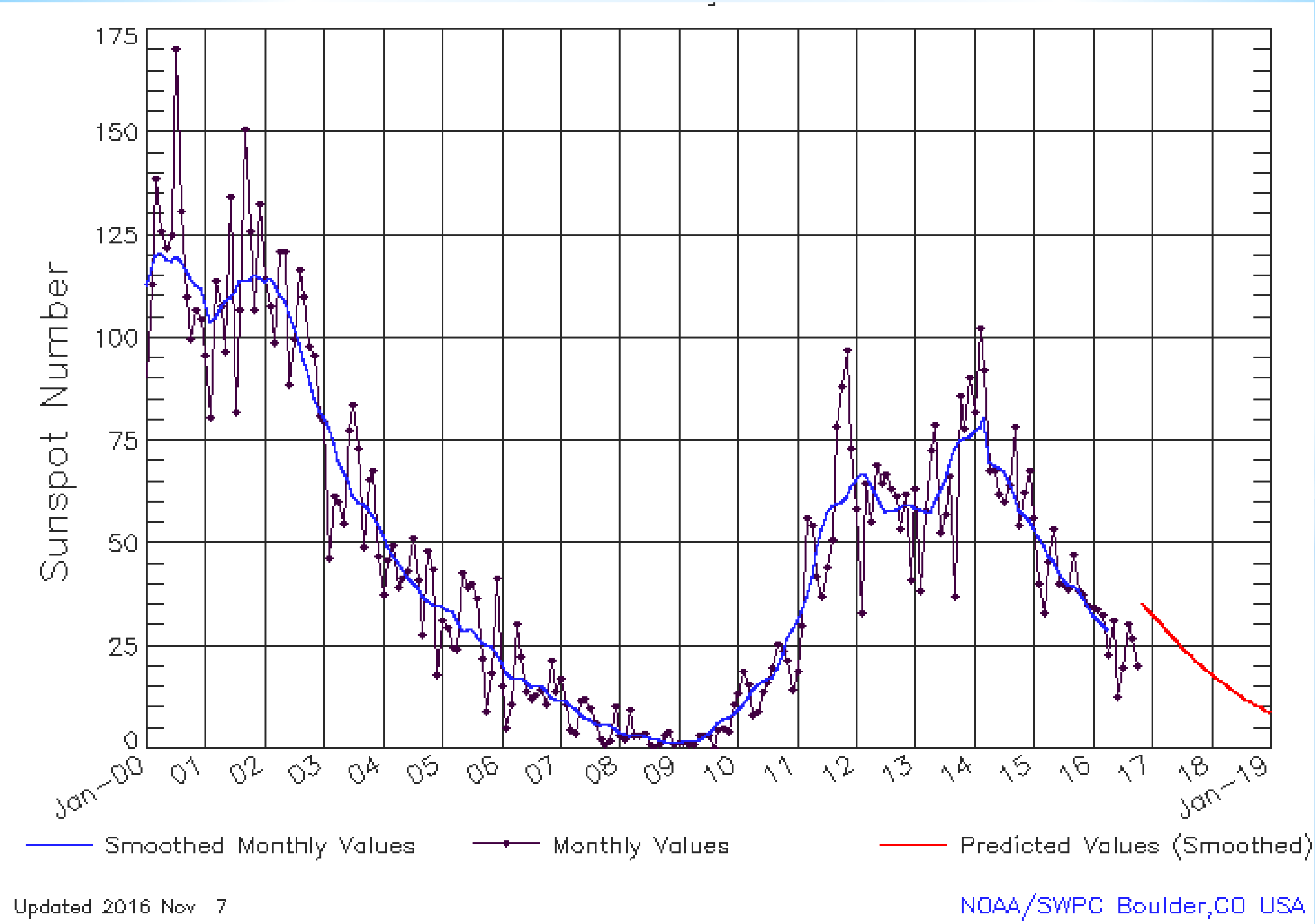


Aurora from ISS

Aurora from Northern Hemisphere

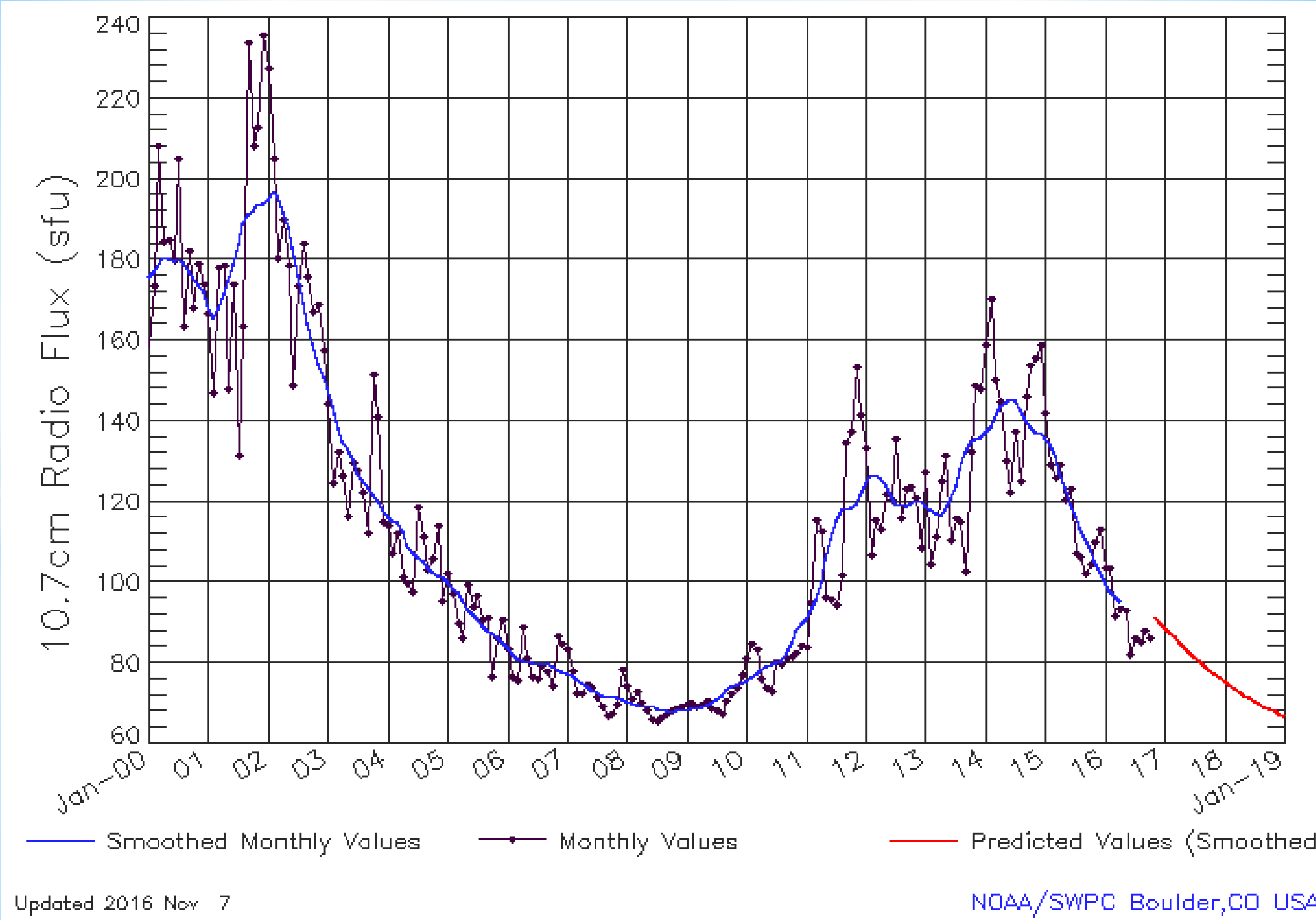
A. Jeevarajan/NASA

Solar Cycle Status Nov 7, 2016

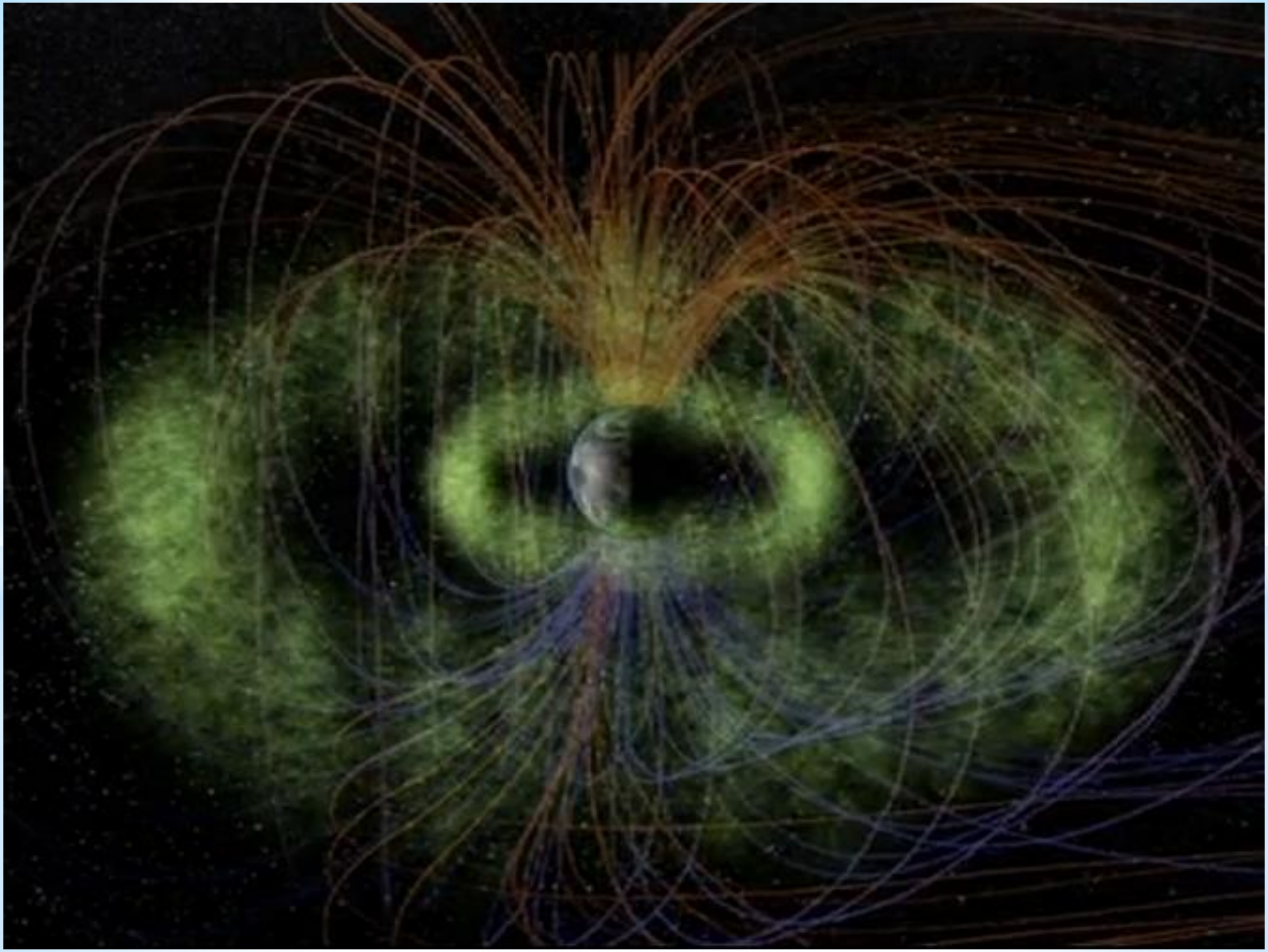


A. Jeevarajan/NASA

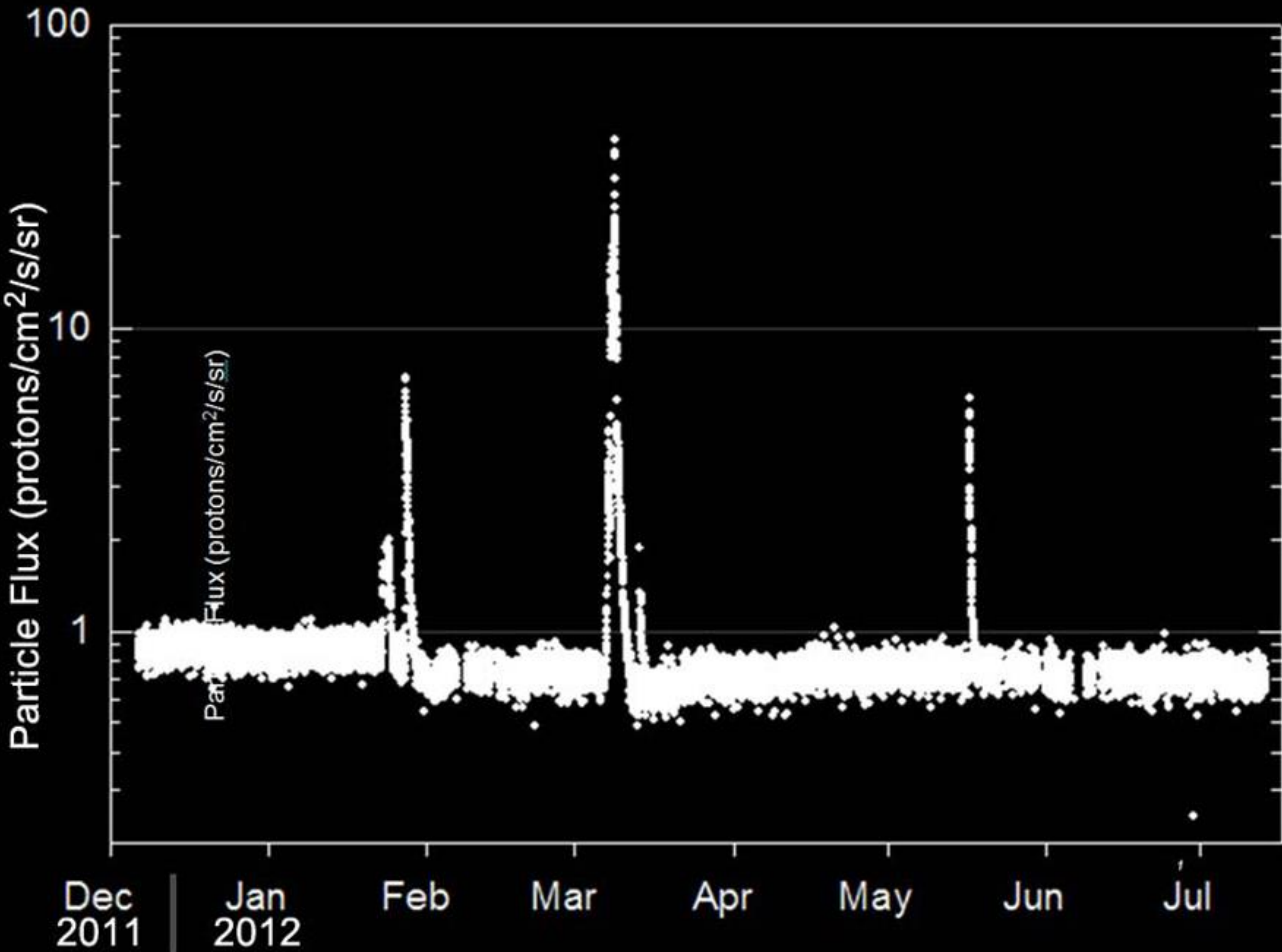
Solar Cycle F10.7 cm Radio Wave Flux, Nov 2016



Van Allen Belt

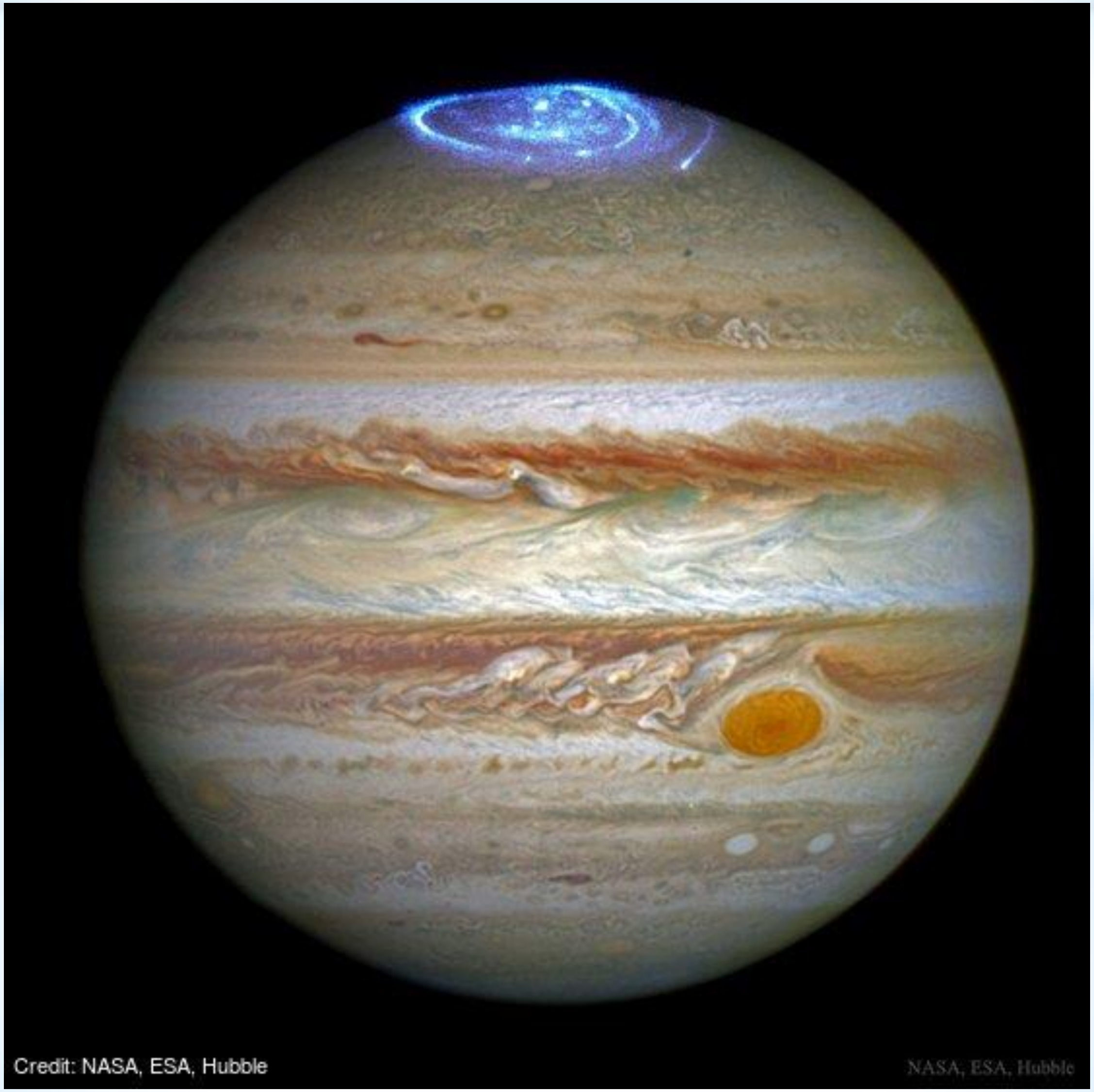


A. Jeevarajan/NASA

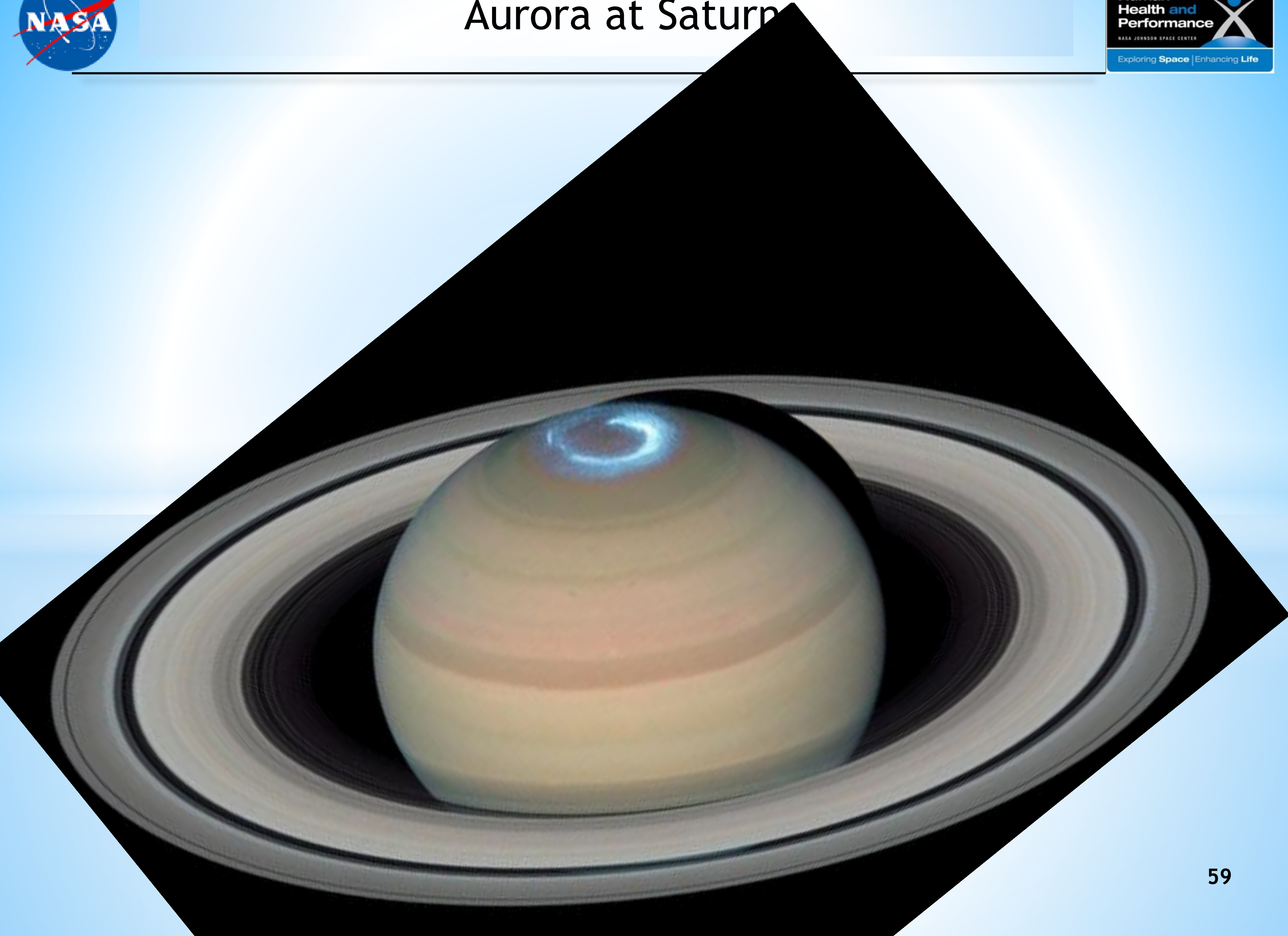


100
10
1
Particle Flux (protons/cm2/s/sr)
Particle Flux (protons/cm2/s/sr)
Dec
2011
Jan
2012
Feb
Mar
Apr
May
Jun
Jul

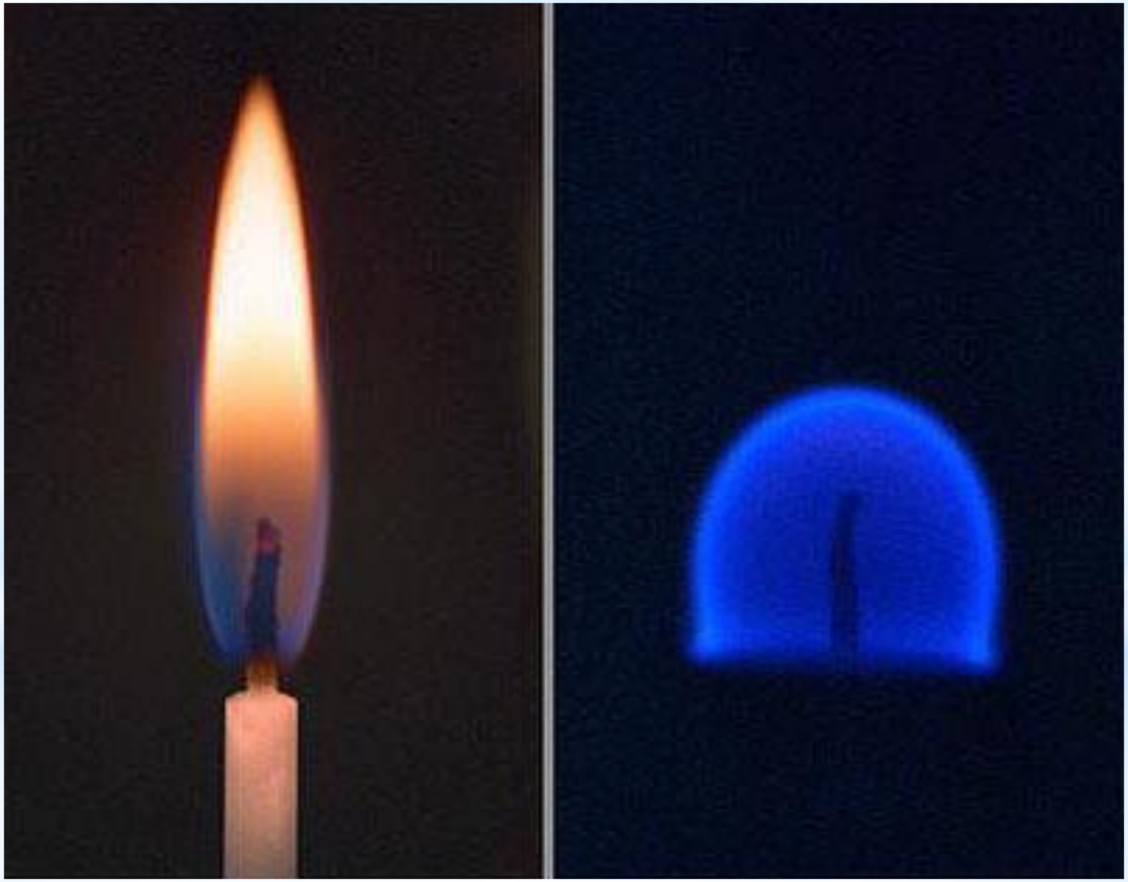
Aurora at Jupiter



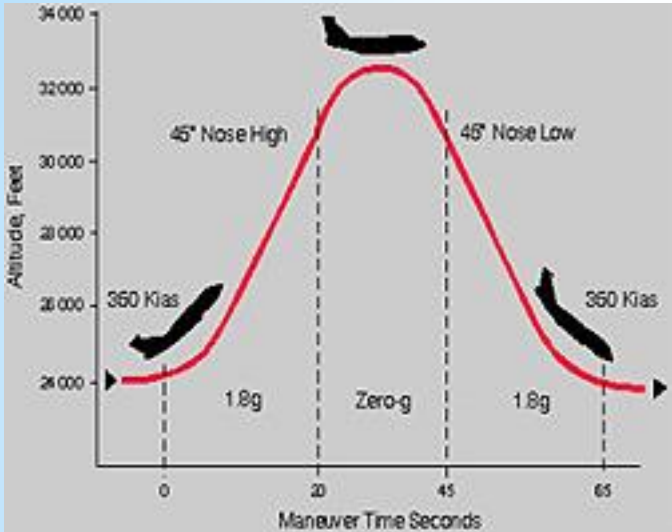
Aurora at Saturn



Flame Behaviour



The Vomit Comet



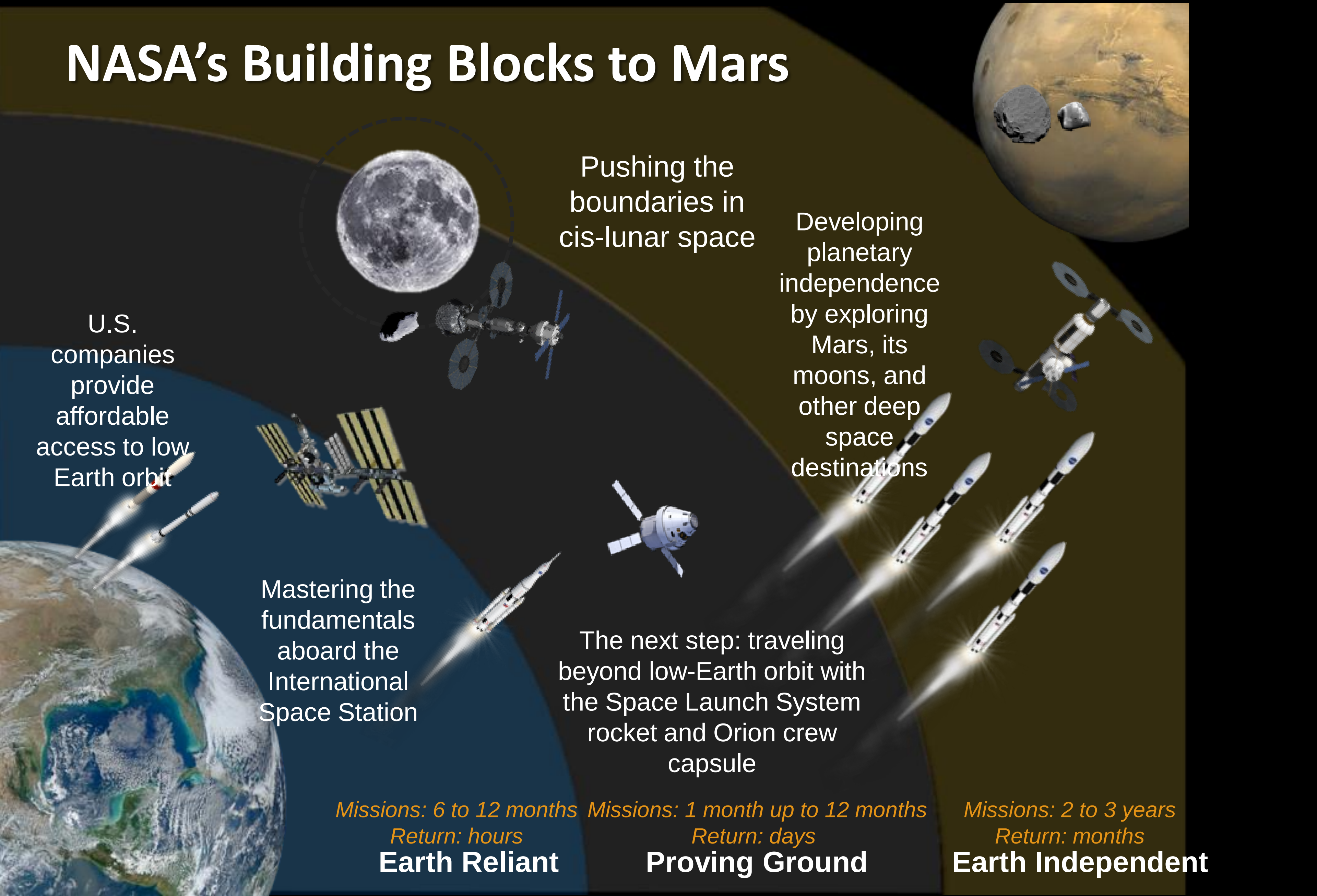
Zero-Gravity Aircraft

A. Jeevarajan/NASA

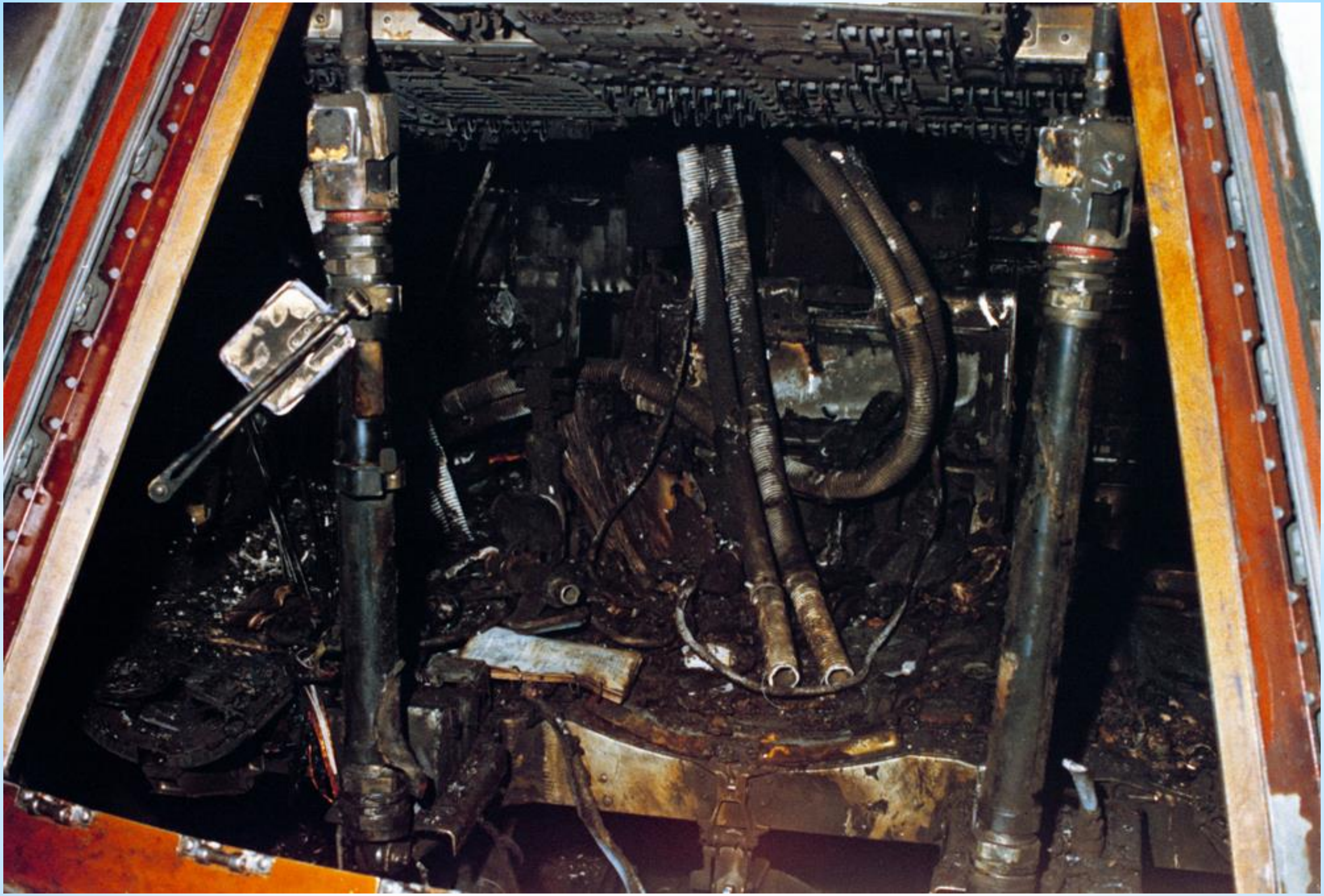
Space Simulation at Earth - Exercise

A. Jeevarajan/NASA

International Space Station


NASA's Building Blocks to Mars
U.S. companies provide affordable access to low Earth orbit
Mastering the fundamentals aboard the International Space Station
Pushing the boundaries in cis-lunar space
Developing planetary independence by exploring Mars, its moons, and other deep space destinations
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule
Missions: 6 to 12 months
Return: hours
Earth Reliant
Missions: 1 month up to 12 months
Return: days
Proving Ground
Missions: 2 to 3 years
Return: months
Earth Independent

Apollo-1 Fire Accident



A. Jeevarajan/NASA

Apollo-1

A. Jeevarajan/NASA



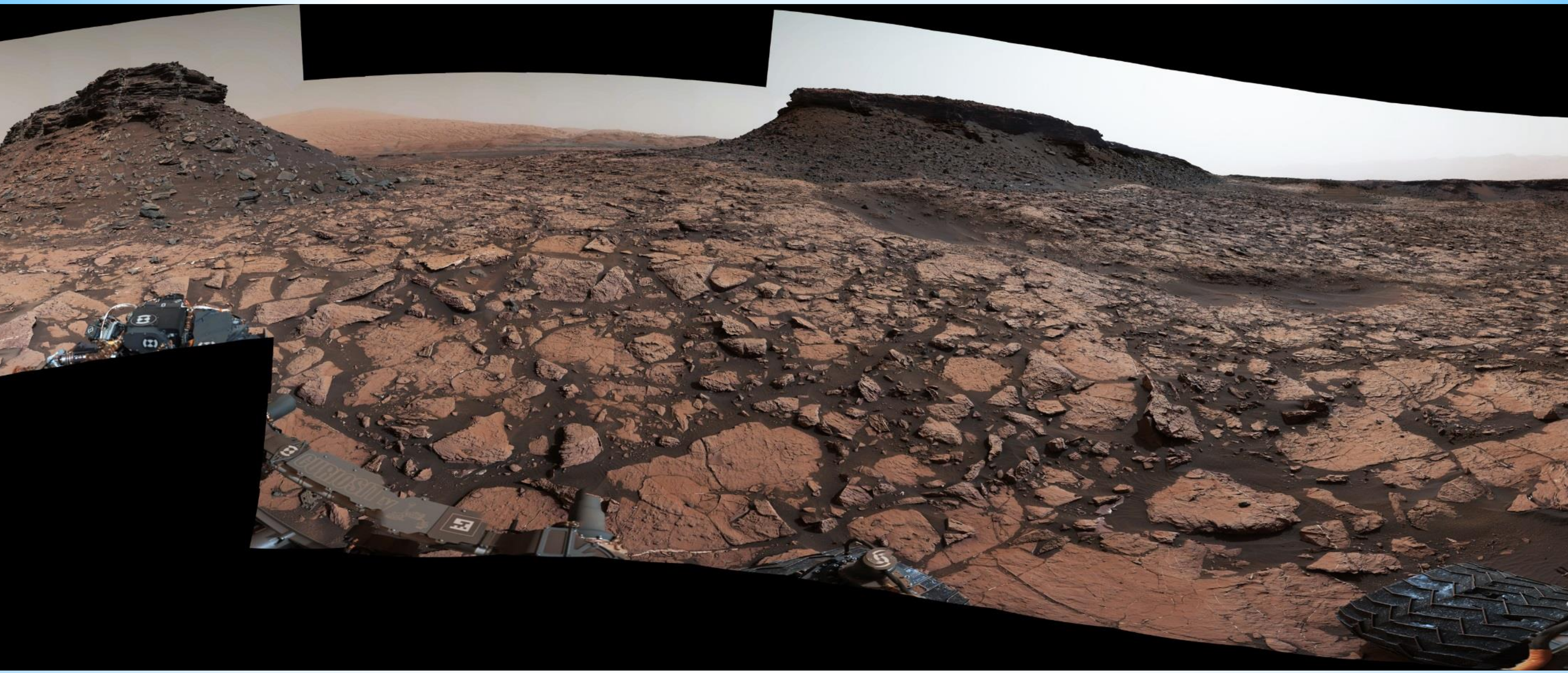
NASA
EL ONIZUKA
GREG
MIKE SMITH
DICK
RON McNAIR
USA


BROWN CLARK CHAWLA
ANDERSON
RAMON
HUSBAND
MCCOOL
STS 107

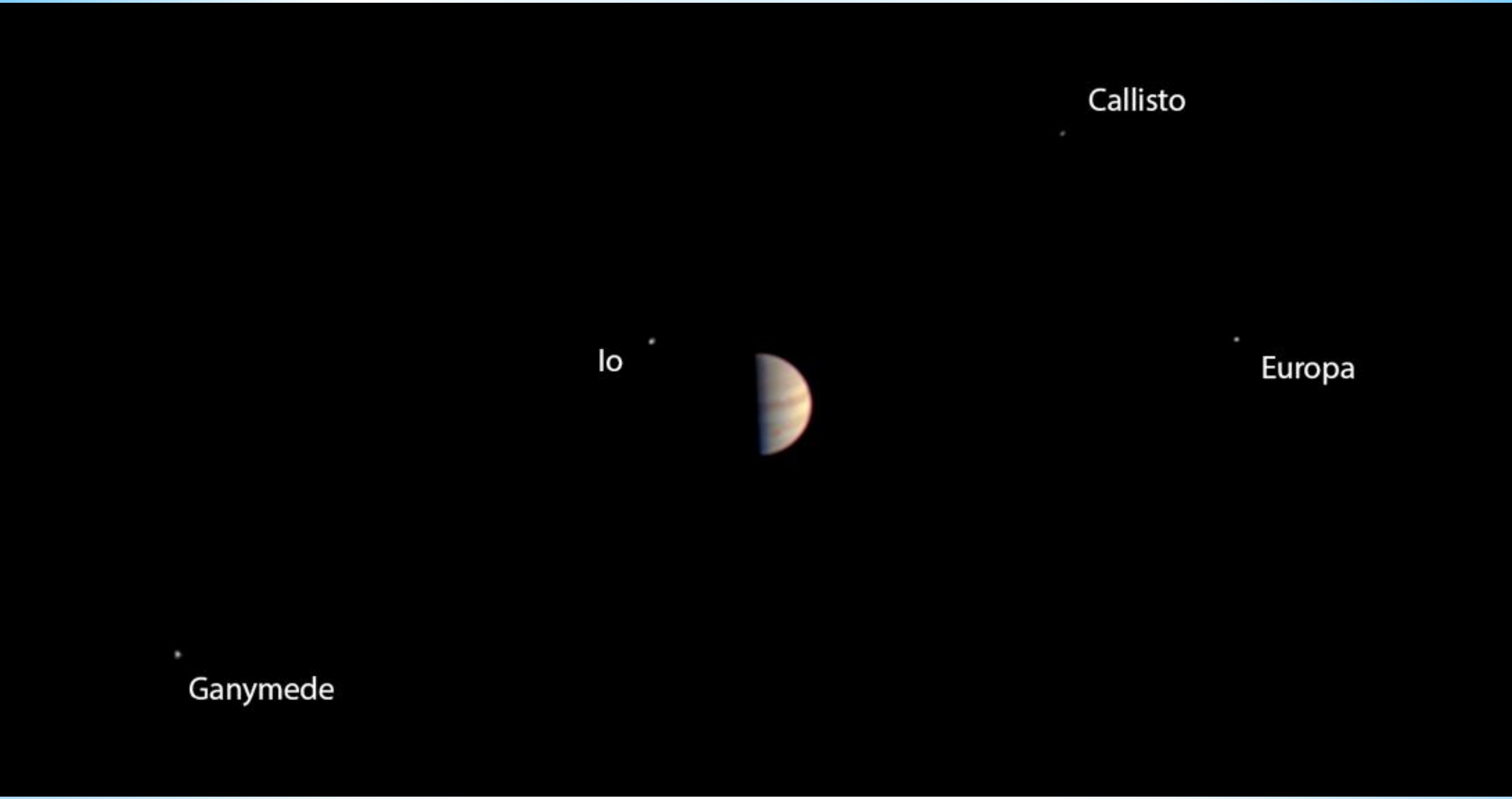
Mars – New Destination

A. Jeevarajan/NASA

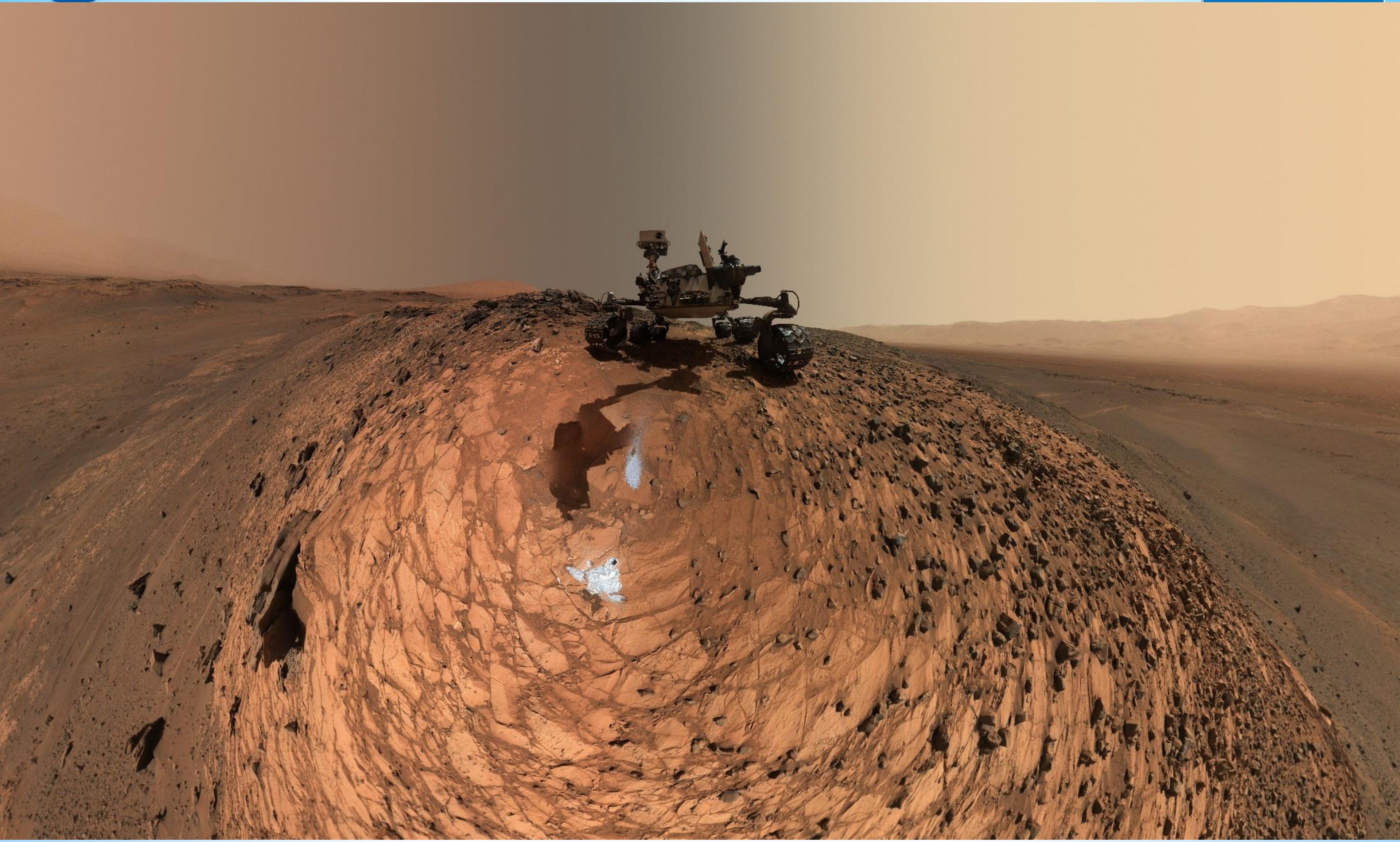
Mars Panoramic View (Images from Curiosity



Jupiter's Moons : Europa



Mars 20ft Mount

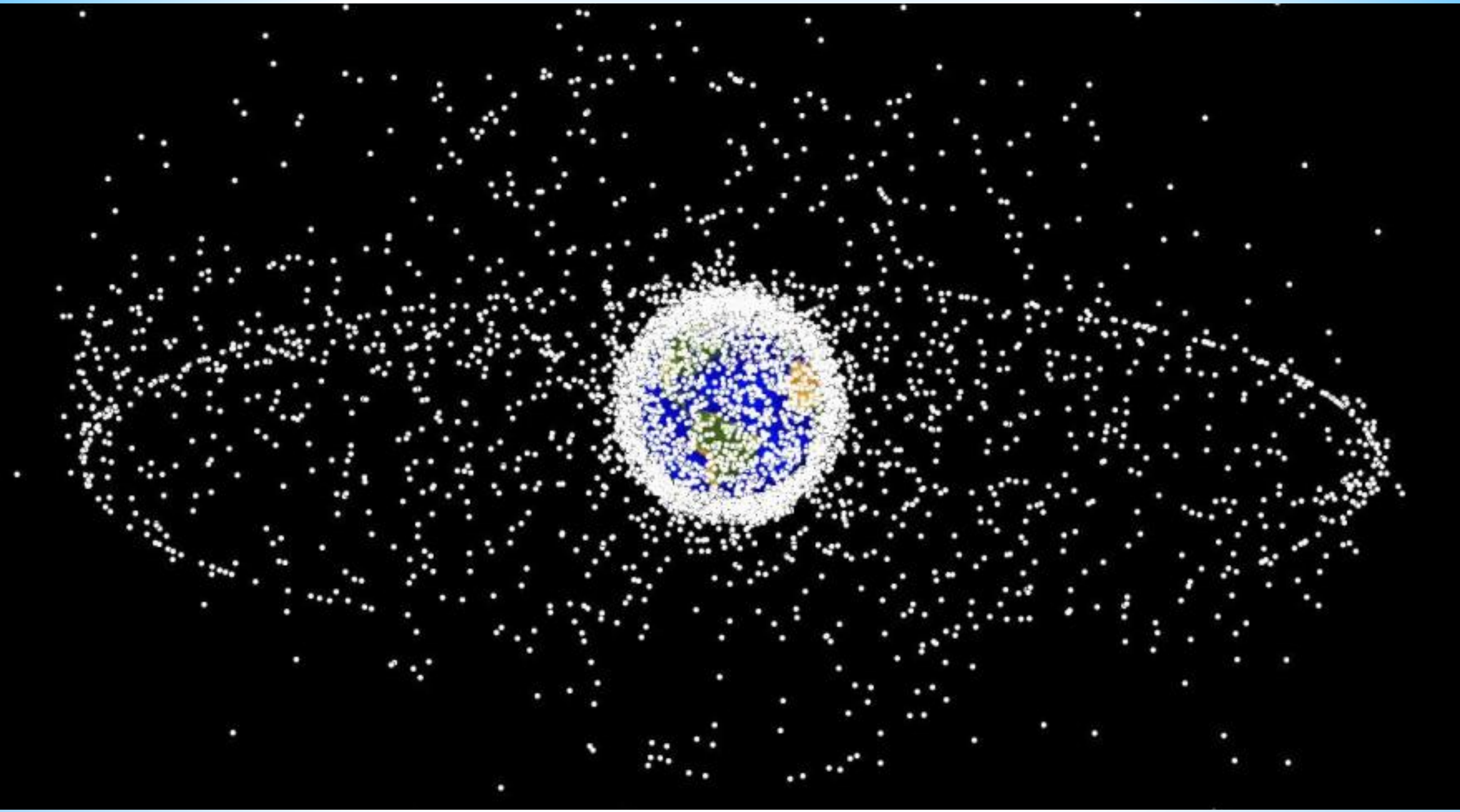


A. Jeevarajan/NASA

Necessary Skills for Long-term Space Exploration

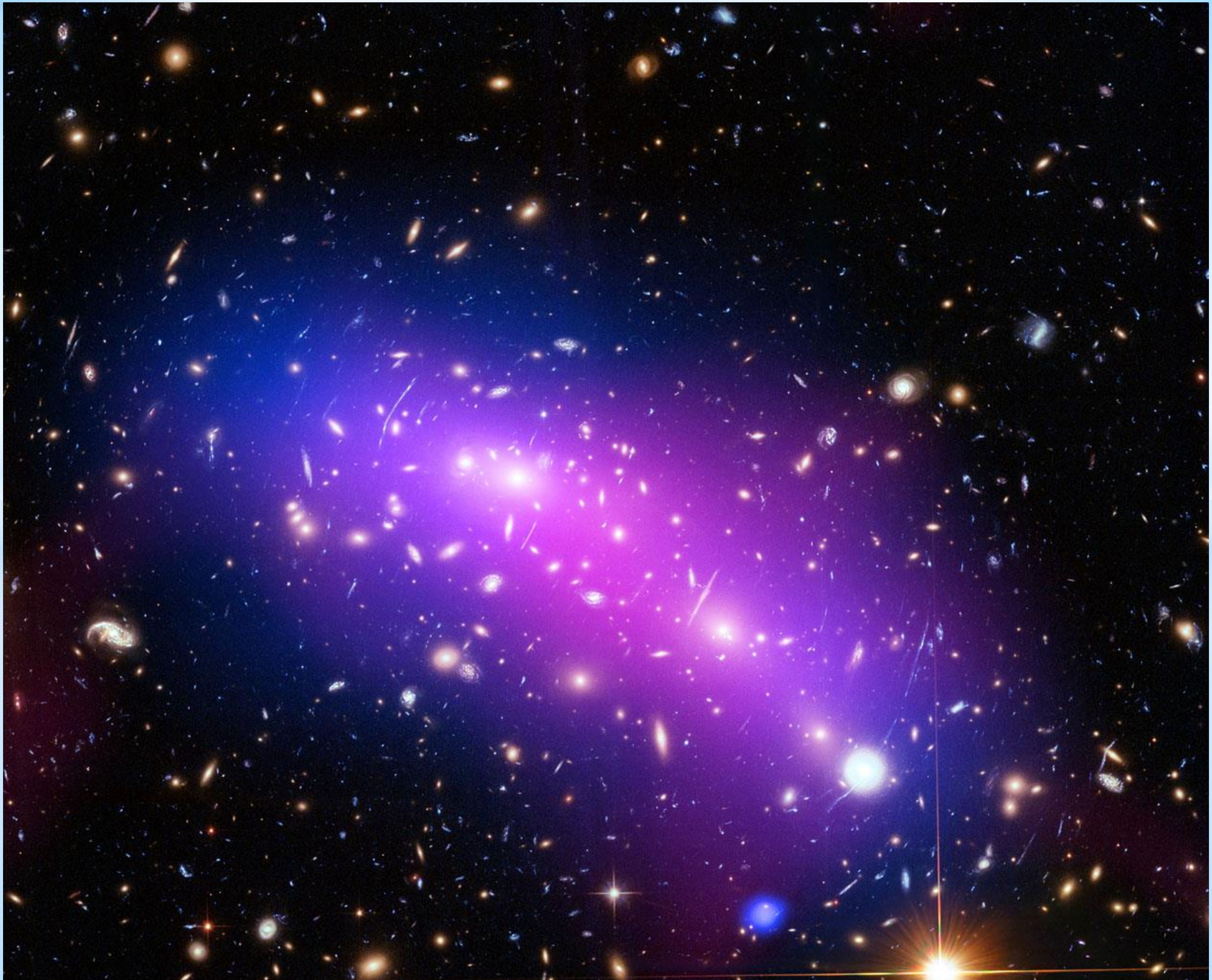
- Group Living Skills
- Teamwork Skills
- Performance under Stress
- Self-regulation
- Motivation
- Judgment/Decision-making
- Conscientiousness
- Communication Skills
- Leadership Skills

Space Debris

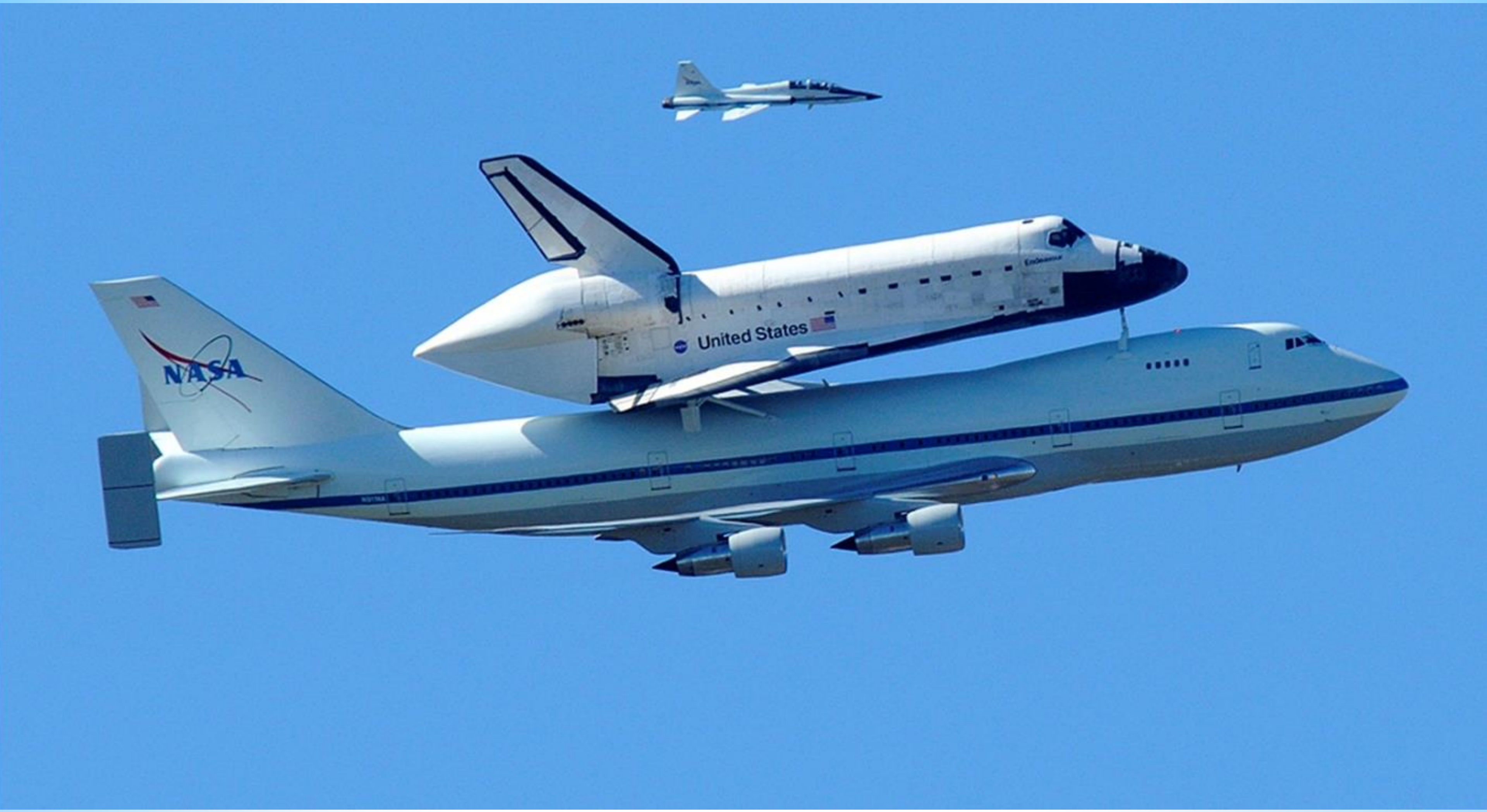


A. Jeevarajan/NASA

Interaction of Dark Matter with Galaxies



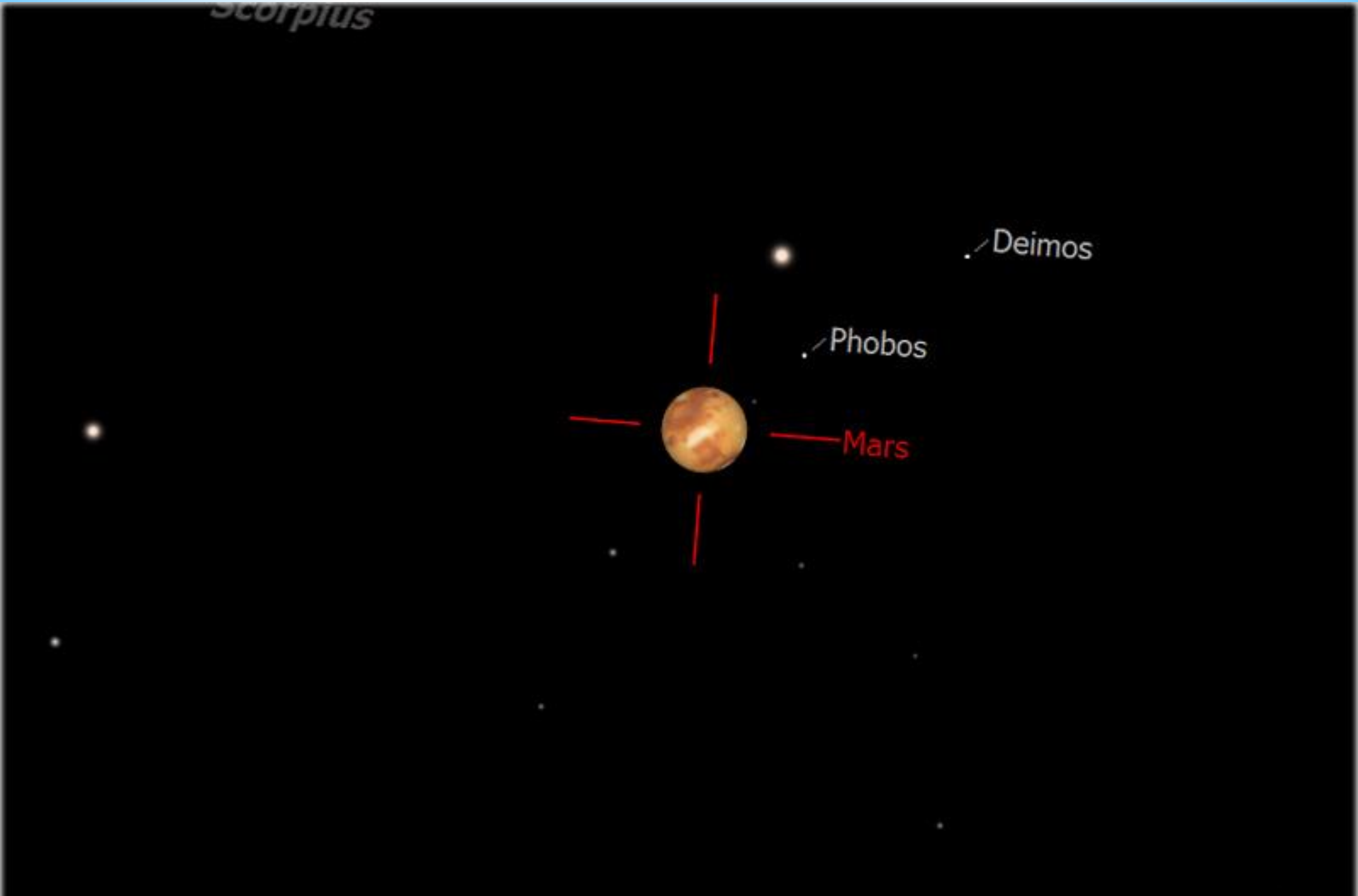
T-38 and Space Shuttle Transfer



A. Jeevarajan/NASA

Guppy

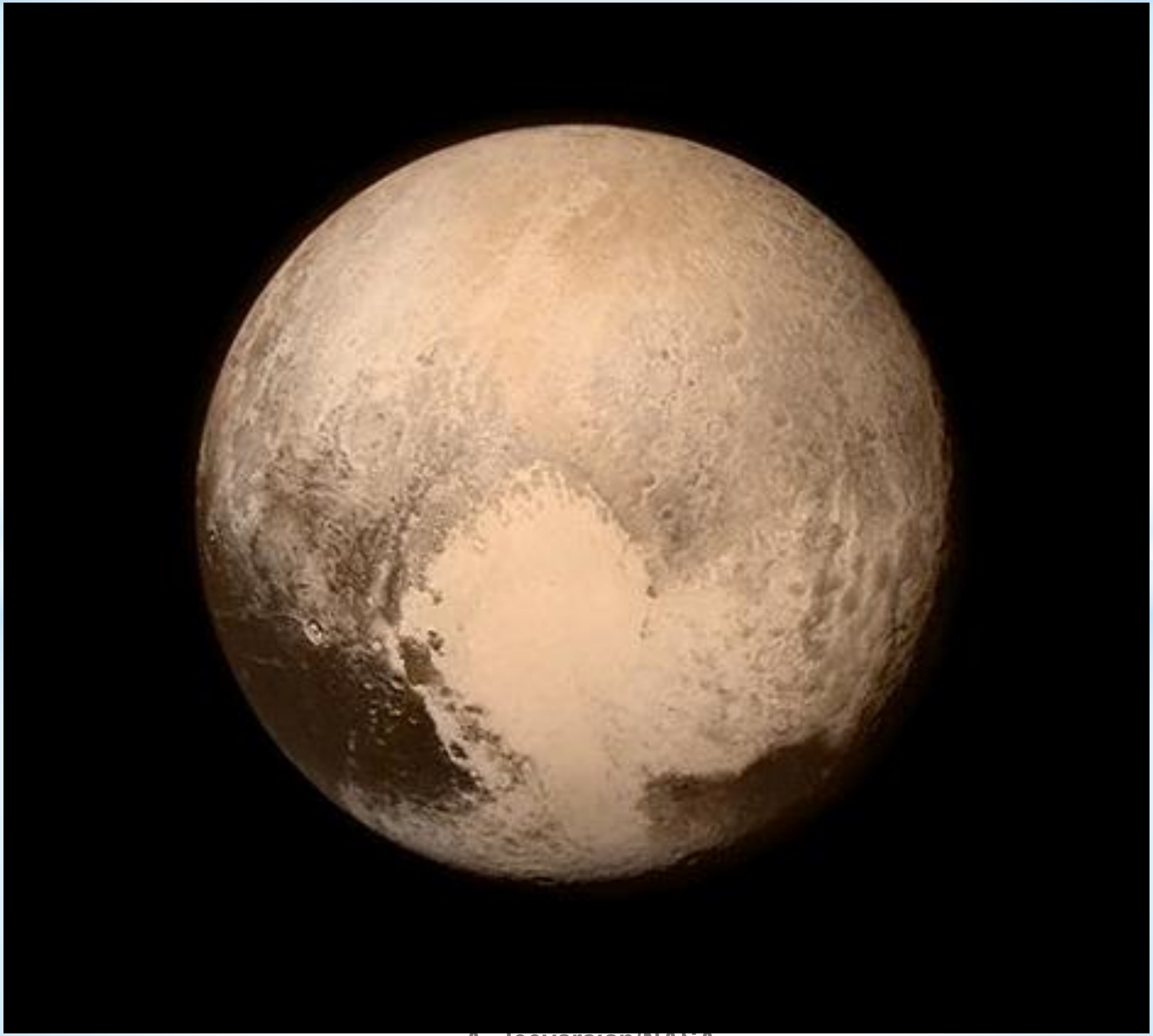
Moons of Mars



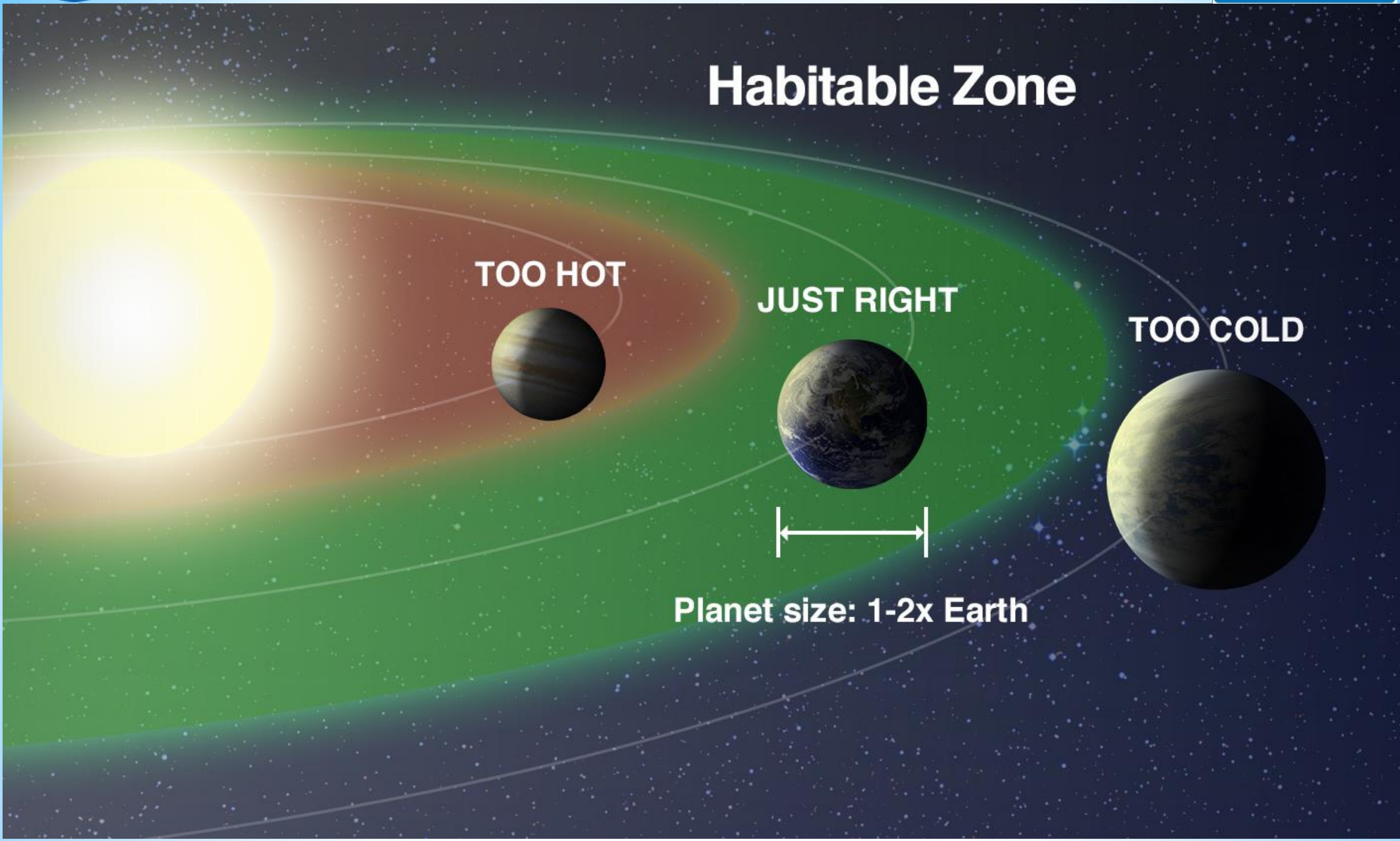
Phobos (Mars' Moon)

A. Jeevarajan/NASA

Pluto

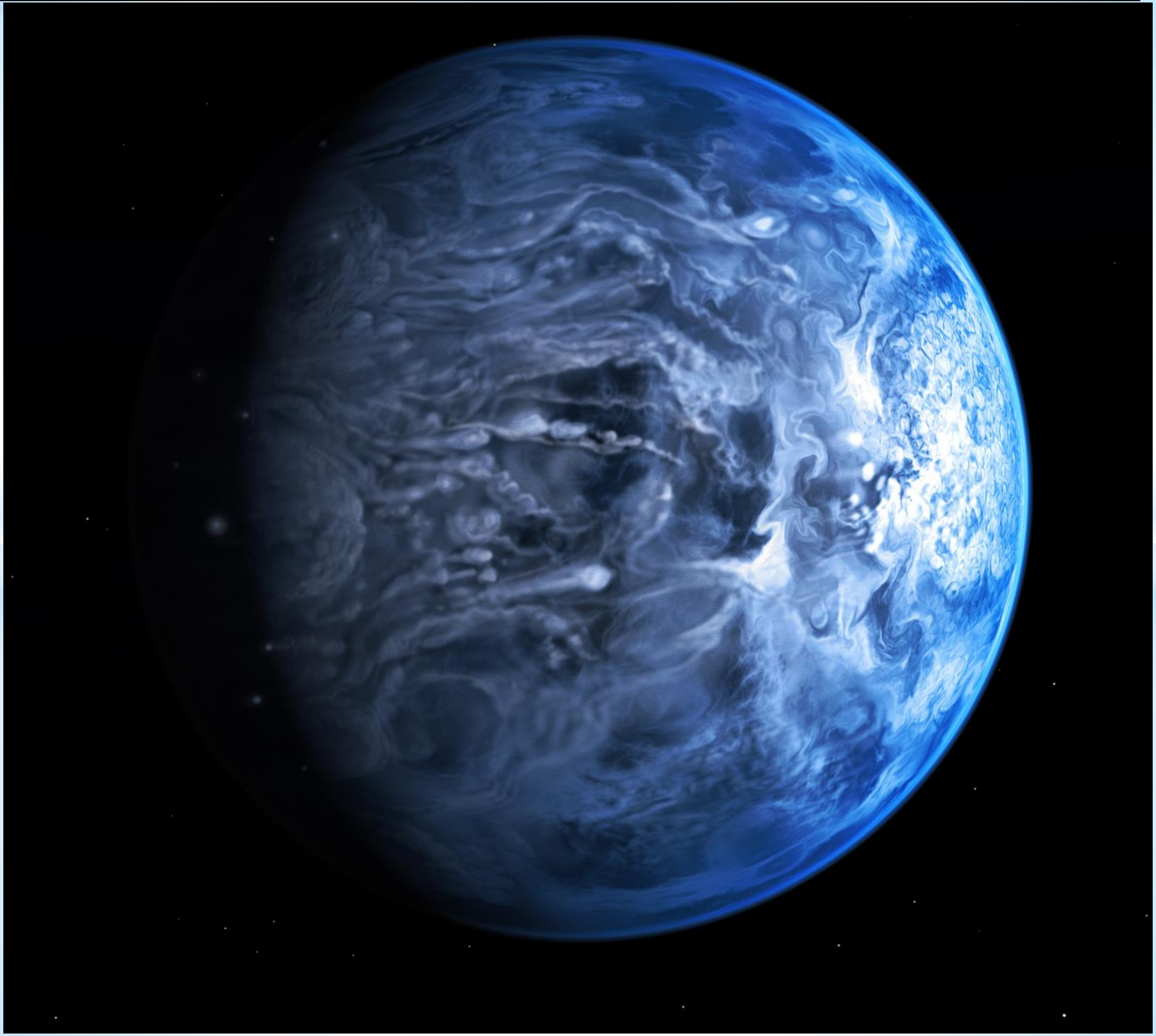


Habitable Zones in the Galaxies



A. Jeevarajan/NASA

Exo Planet



Pluto


Still
daylight in
California.
Chicago
Cities of Boston, New
York, Philadelphia and
Washington.
Dallas
Houston
Miami
Puerto Rico

Beautiful Fragile Blue Planet

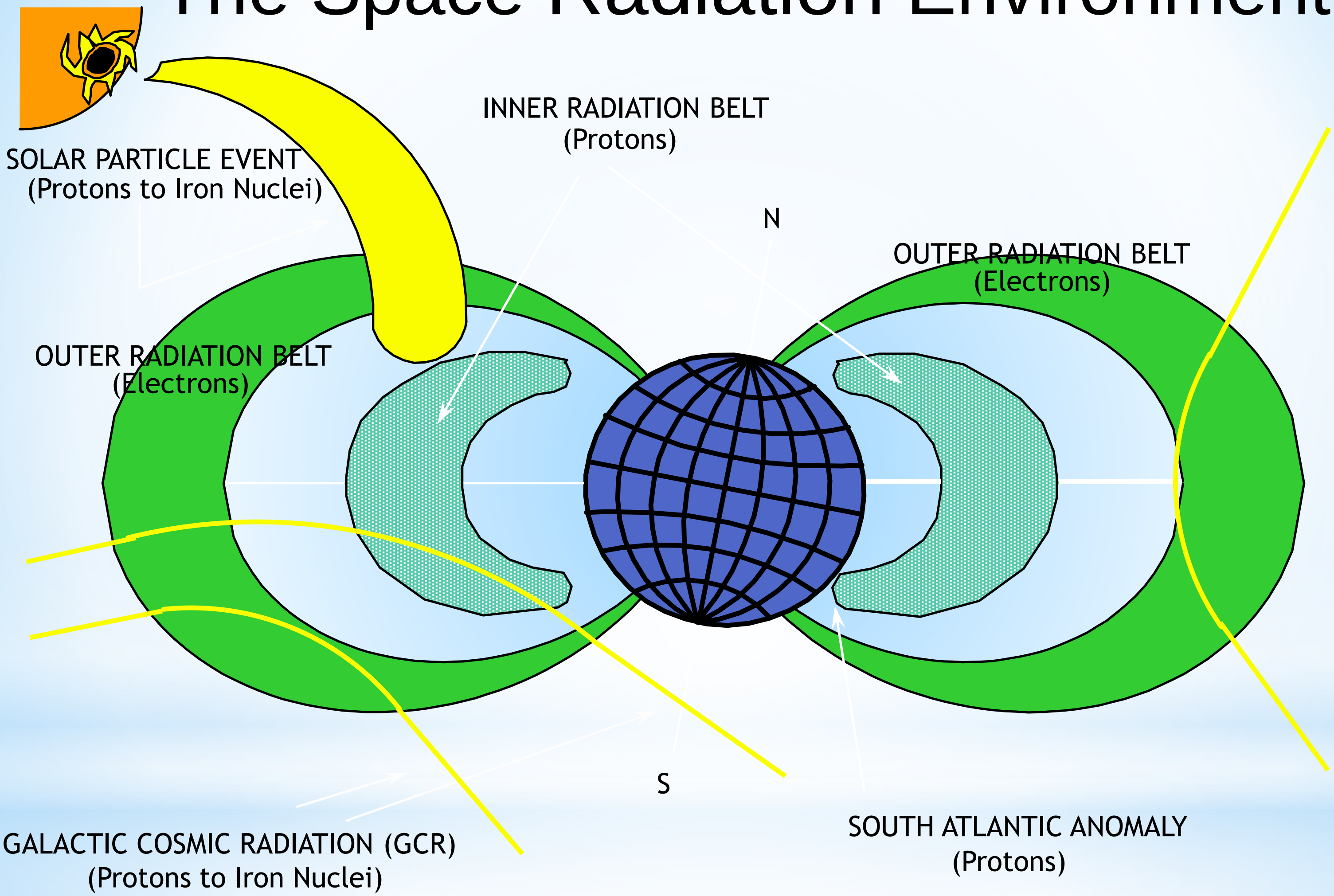
Zebra Larvae

A. Jeevarajan/NASA

Expandable Polymers at the White House

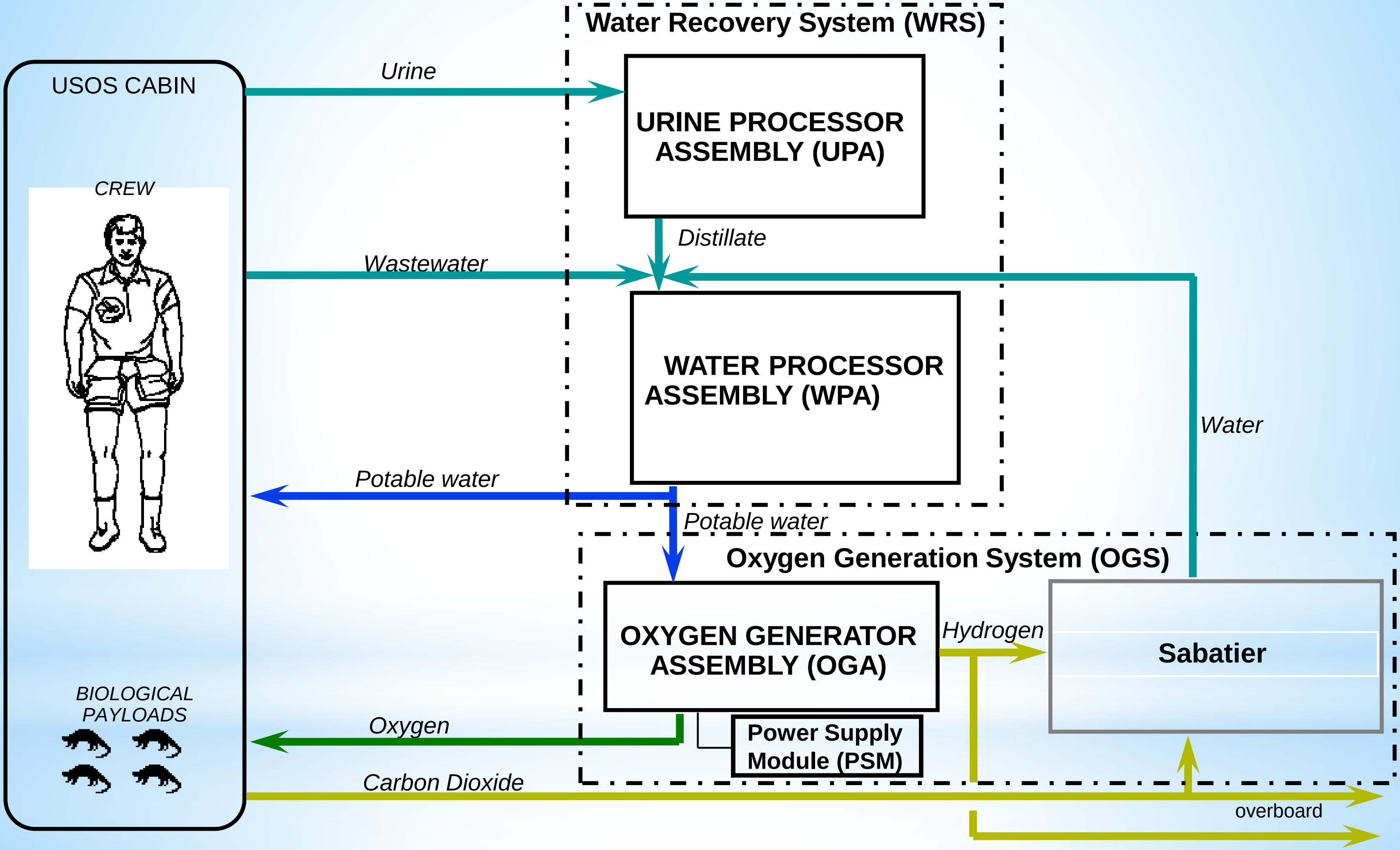
Two Shuttles in the Launch Pad

The Space Radiation Environment



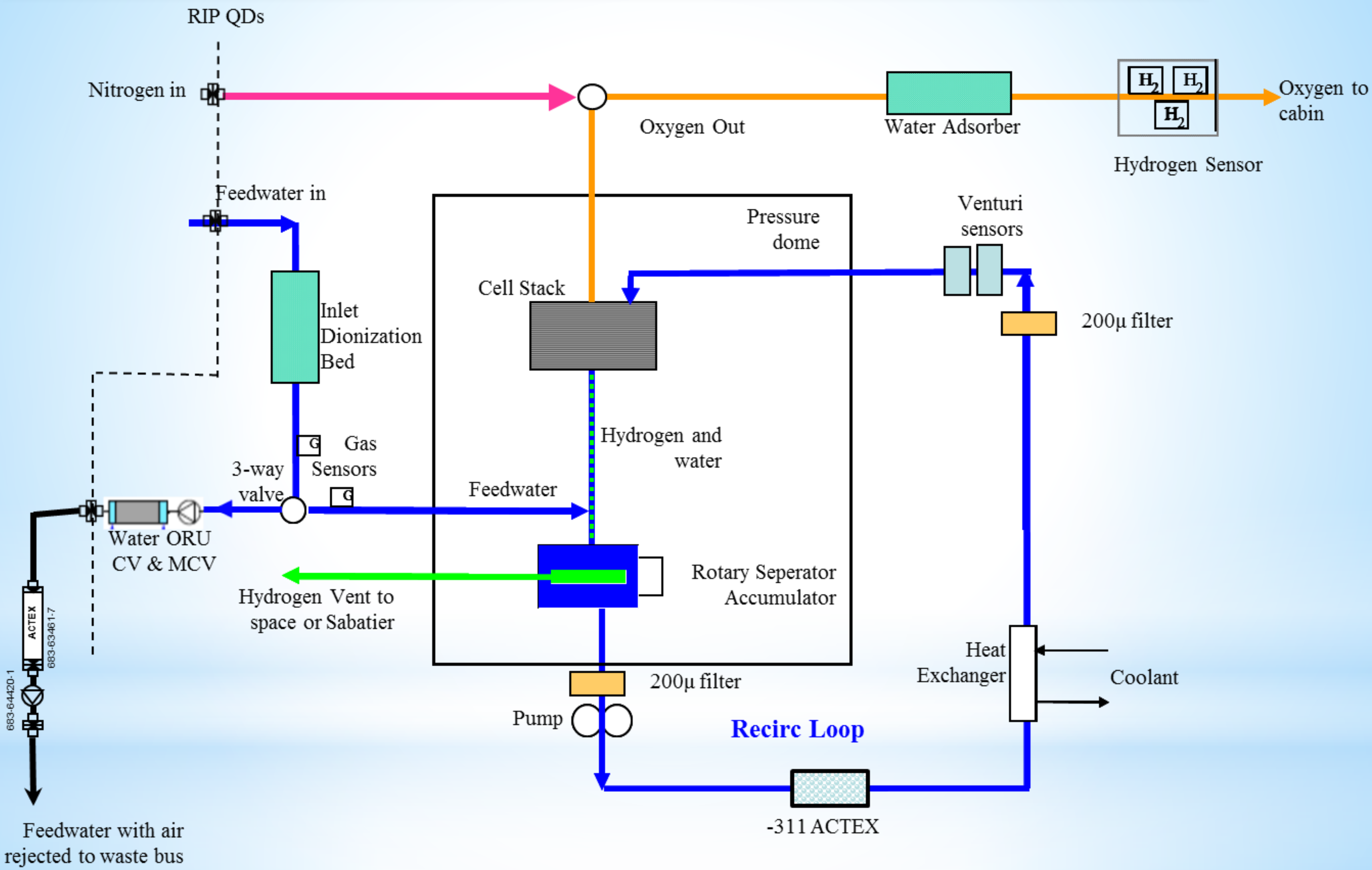
Space radiation : Energetic charged particles, high-LET (linear energy transfer)

Water and CO2 Recycling

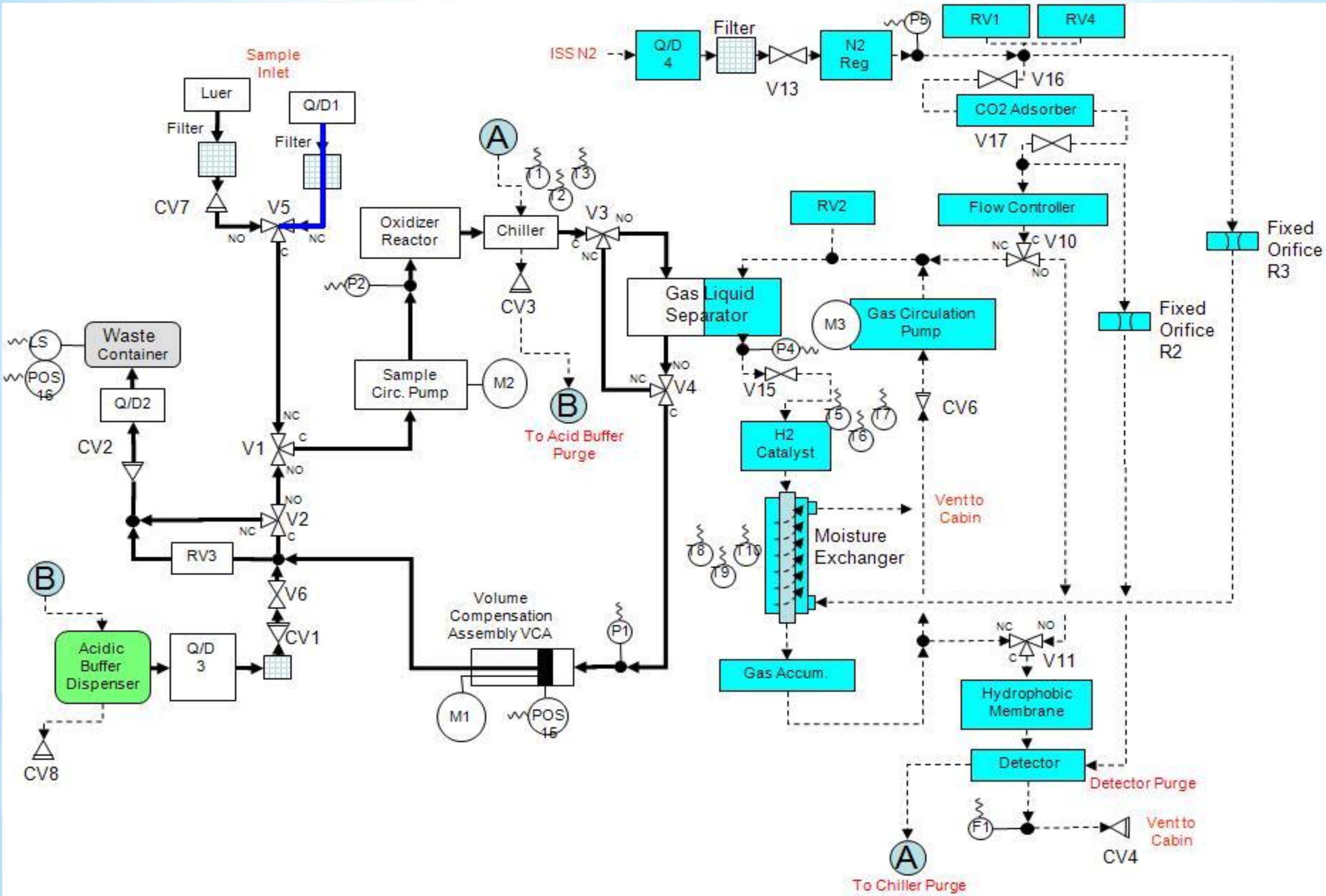



United States
Discovery

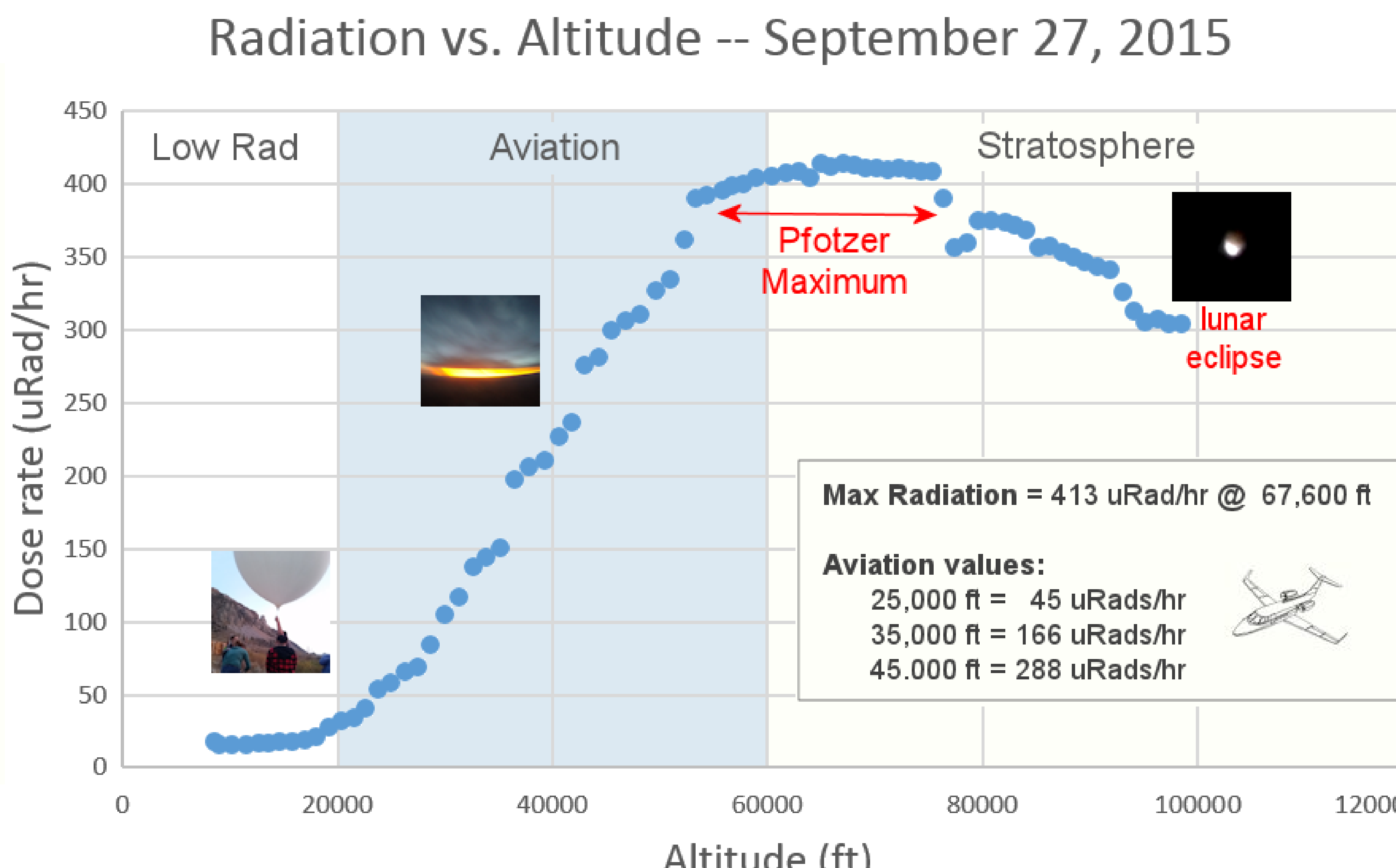
Oxygen Generation System



Total Organic Carbon Analyzer

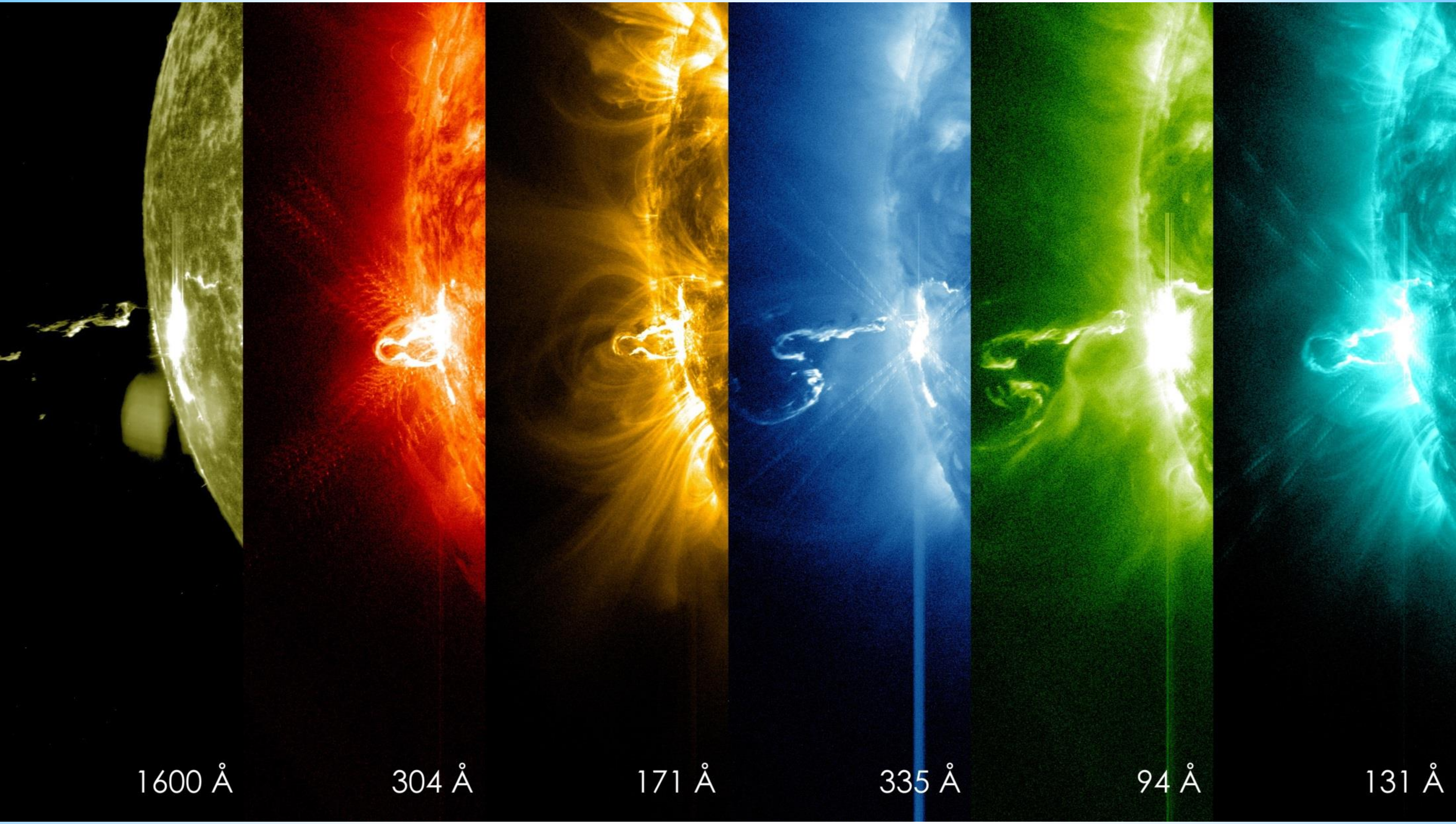


Radiation Vs Altitude



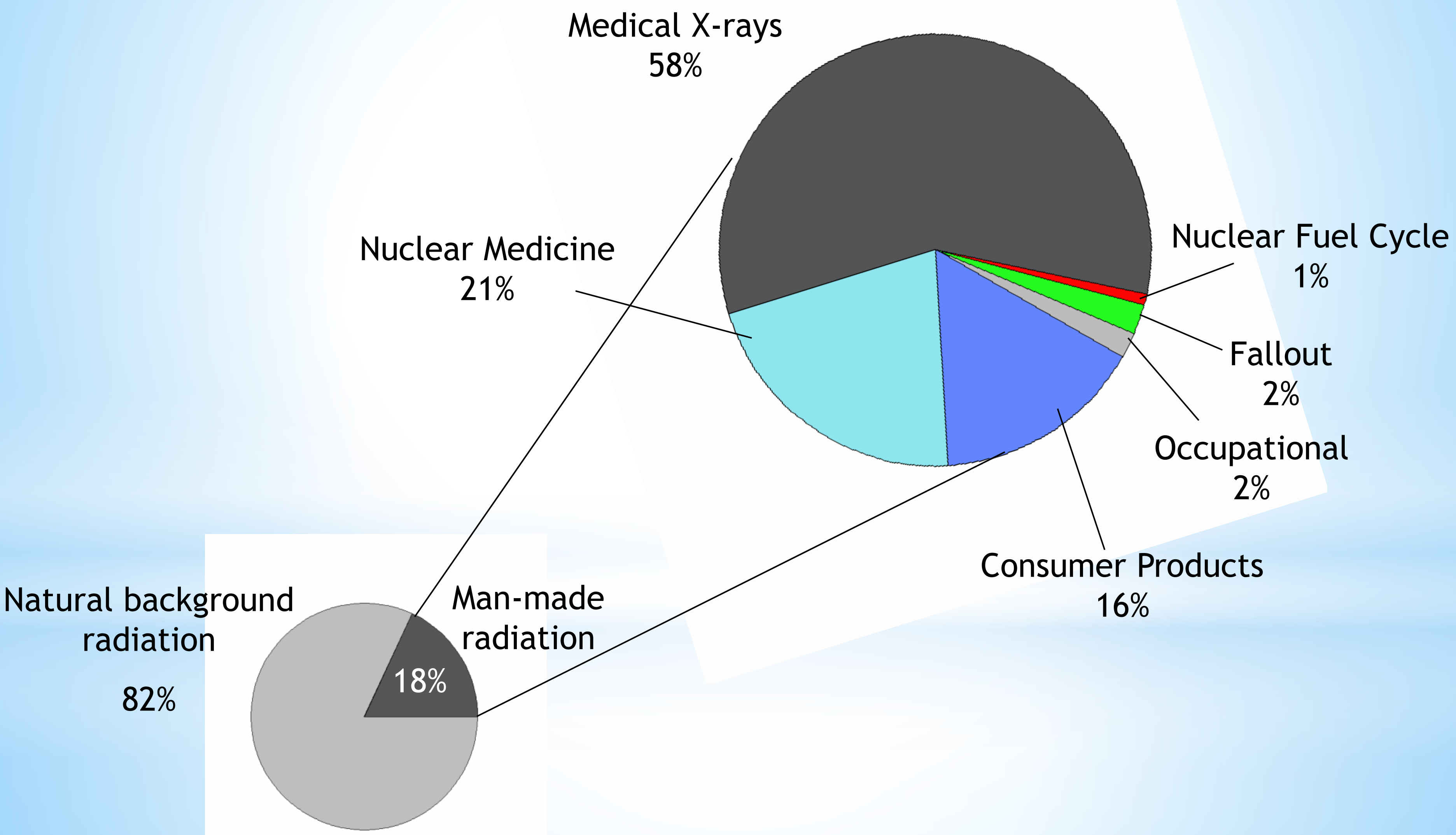
A. Jeevarajan/NASA

Solar Flare Observed at Various Wavelengths



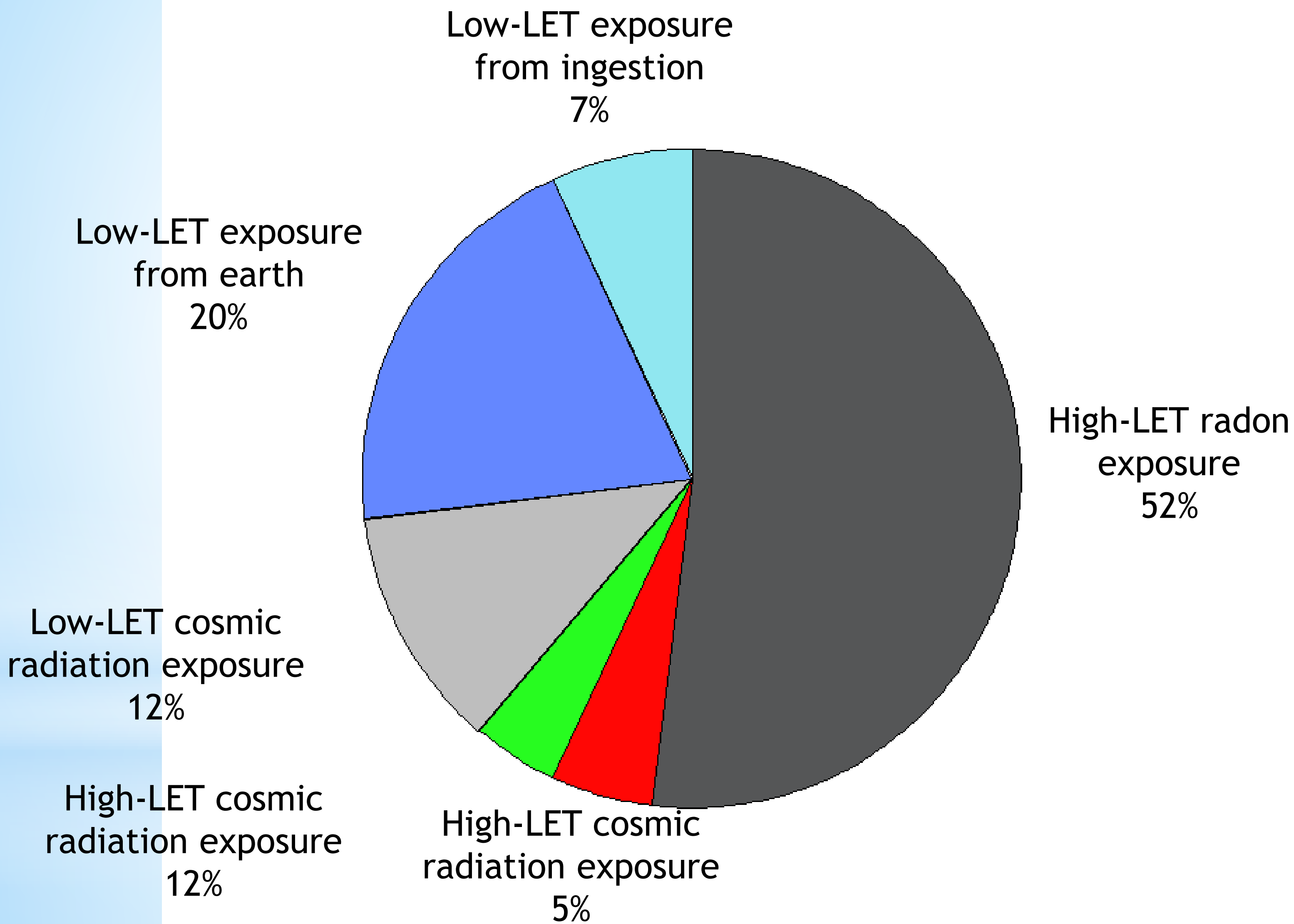
A. Jeevarajan/NASA

Contribution to exposure from man-made Radiation sources in USA



Data: BEIR VII 2006, NCRP 1987

Environmental exposure to natural background radiations: 2.4 mSv/year



Data: BEIR VII 2006, UNSCEAR 2000

Approximate Response of a single Mammalian Cell to 1Gy of Radiation

Radiation	***Low-LET***	***High-LET***
Tracks in nucleus	10^3	4
total SSB	10^3	10^3
total DSB	~ 40	< 40
Complex DSB	20%	70%
DSB per lethal lesion	87	22
Chrom. Aberration	1	3
Dicentric per cell	0.1	0.4
Cell Inactivation	30%	85%

Nikjoo *et al*

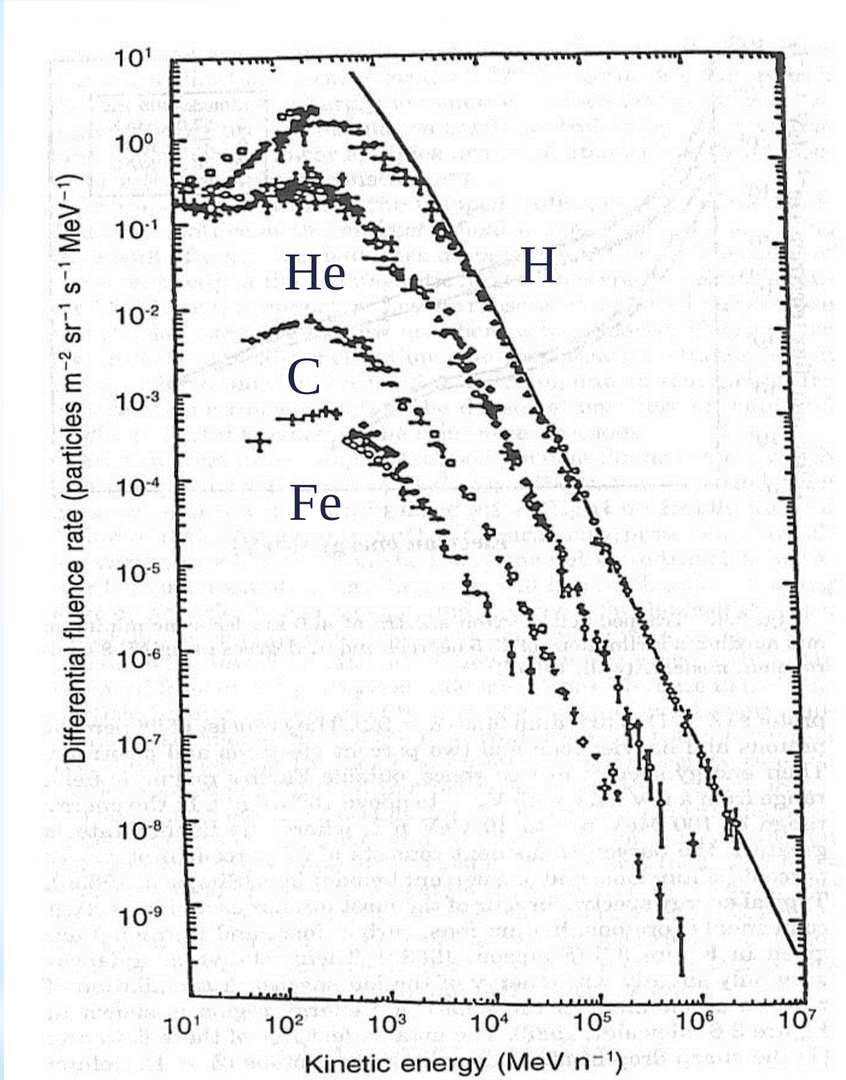
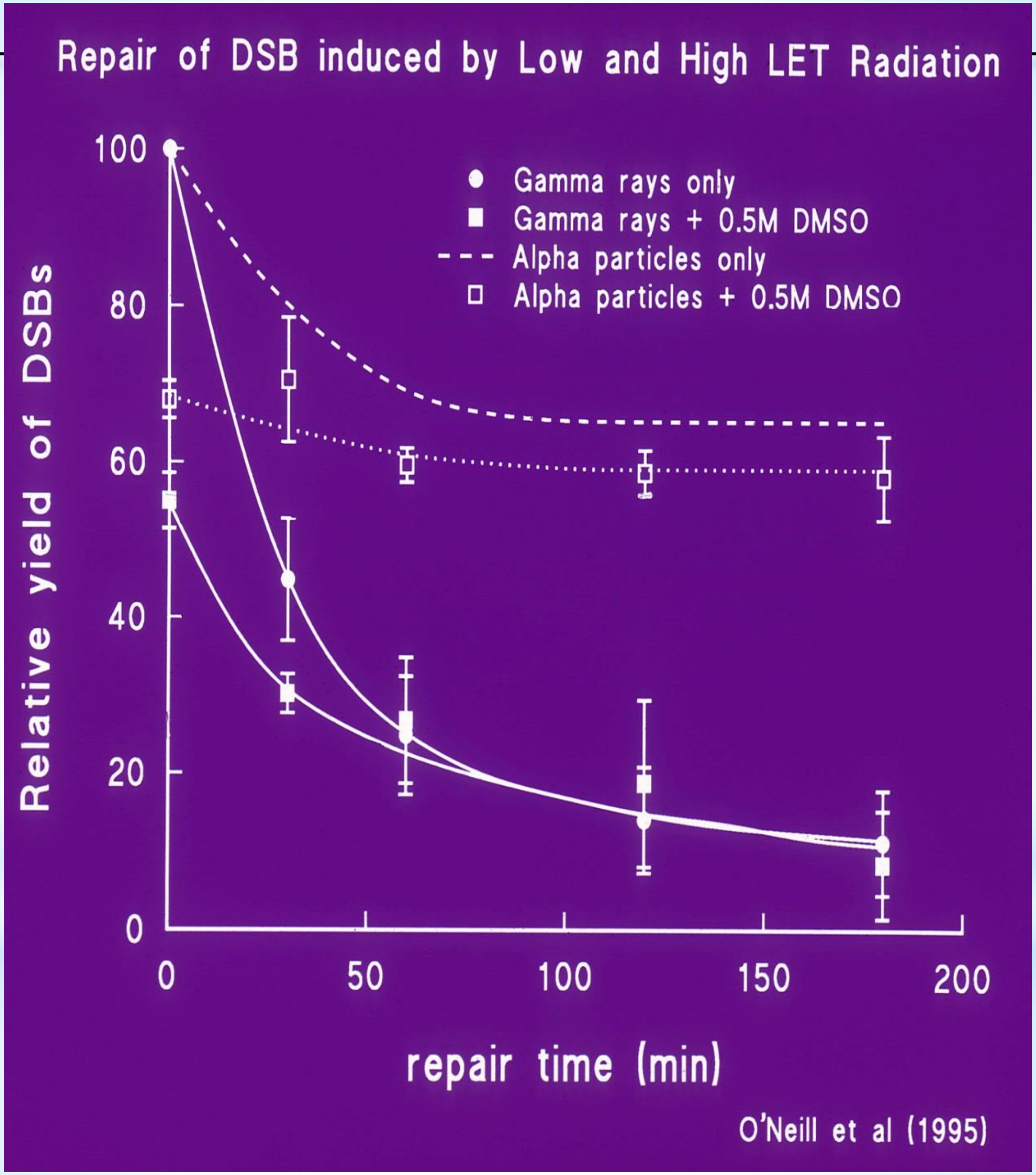


Fig. 3.5. Typical energy spectra for protons, helium ions, carbon ions, and iron ions from "top to bottom," respectively, at solar minimum. The solid line is the local interstellar spectrum (Simpson, 1983a).

Energy Spectra for protons, helium, carbon, and iron.


Repair of DSB induced by Low and High LET Radiation
Gamma rays only
Gamma rays + 0.5M DMSO
Alpha particles only
Alpha particles + 0.5M DMSO
Relative yield of DSBs
100
80
60
40
20
0
0
50
100
150
200
repair time (min)
O'Neill et al (1995)

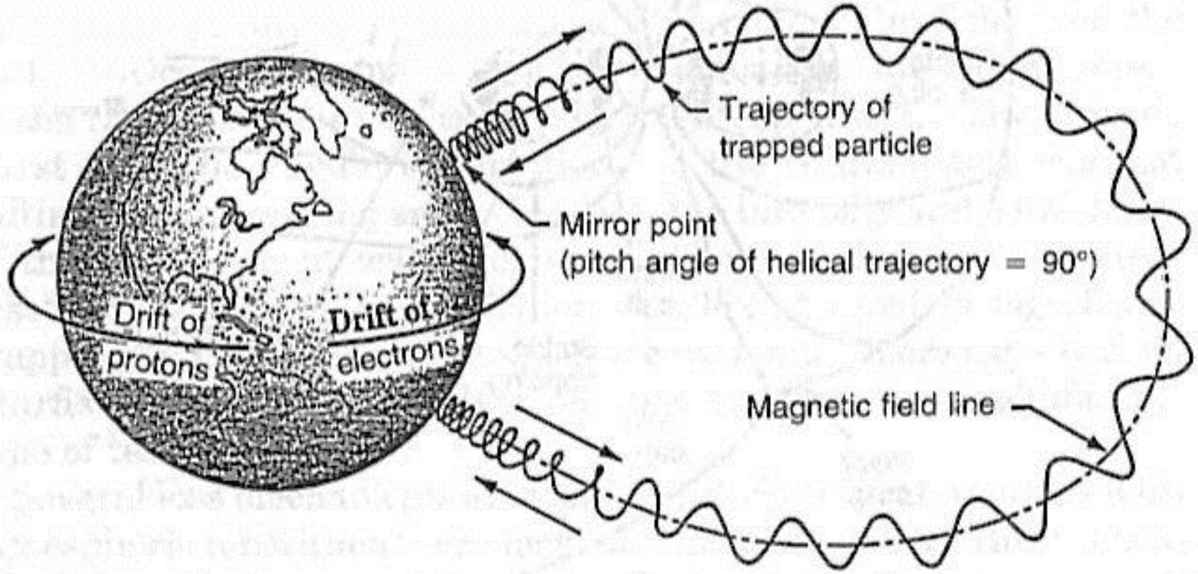


Fig. 3.2. The motion of a charged particle in a dipole magnetic field consists of three components; a helical trajectory about the magnetic field line, a bounce between polar mirror points, and a longitudinal drift around Earth (Hess, 1968).

Charged Particle Motions in Earth's Magnetic Field

Components:

Protons:	~ 0.04 to 500 MeV
Electrons:	~ 0.04 to 7 MeV
Heavier Ions:	Low Energies

Location of peak levels is energy dependent

Location of populations shifts with time

Average counts vary slowly with solar cycle

Counts may increase by orders of magnitude with magnetic storms

van Allen Belt Particles

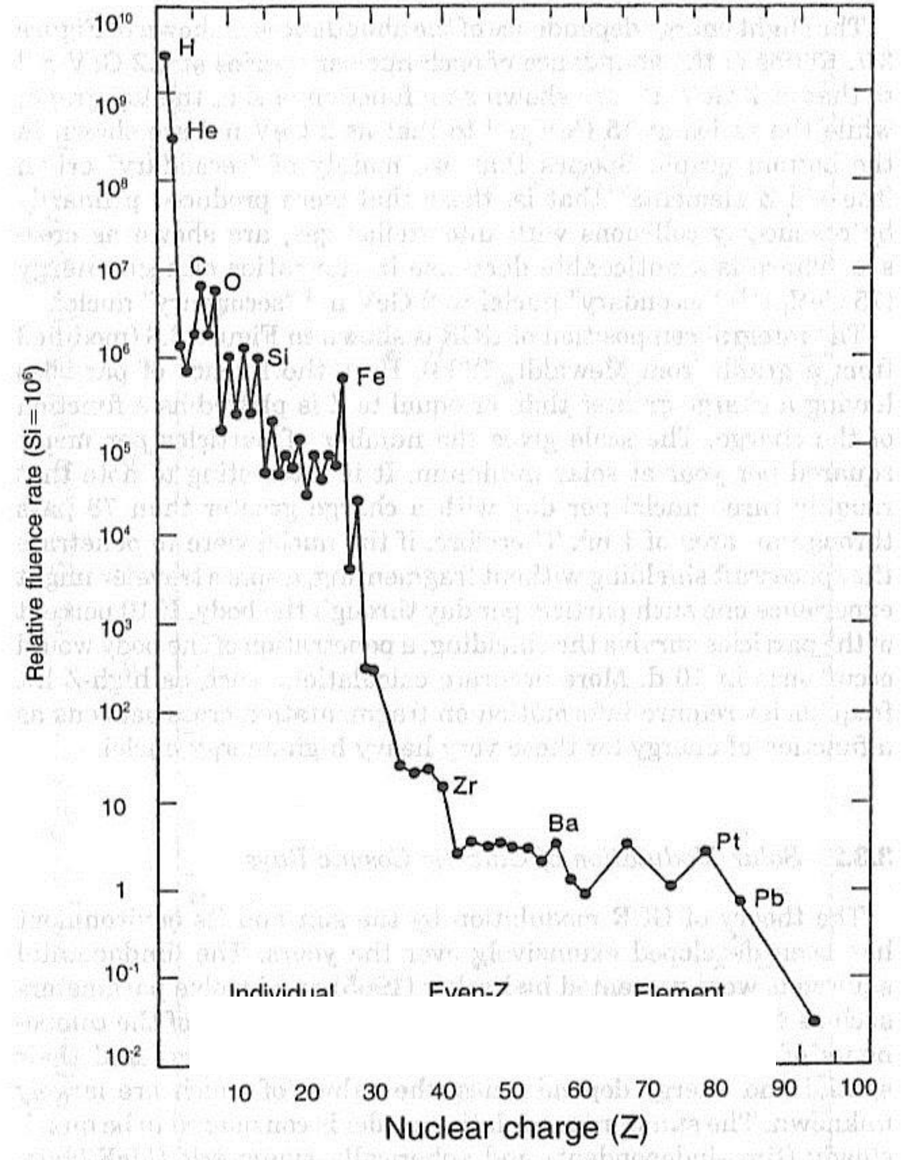


Fig. 3.6. Nuclear composition of GCR (~2 GeV n^{-1}) (Mewaldt, 1988).

Galactic Cosmic Radiation

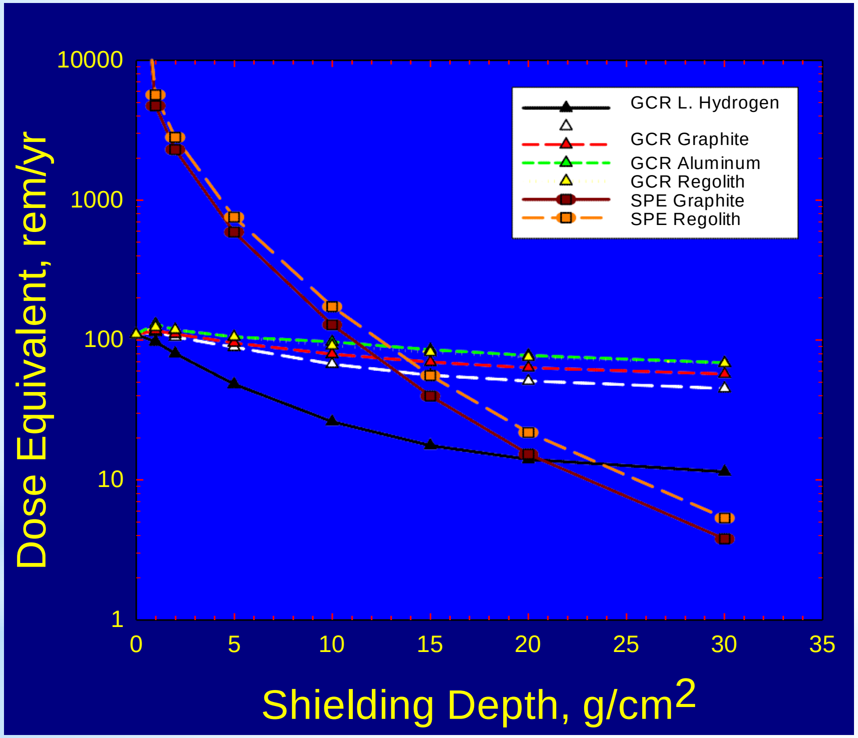
Nuclear composition of galactic cosmic rays.

Log fluence rate vs. atomic number.

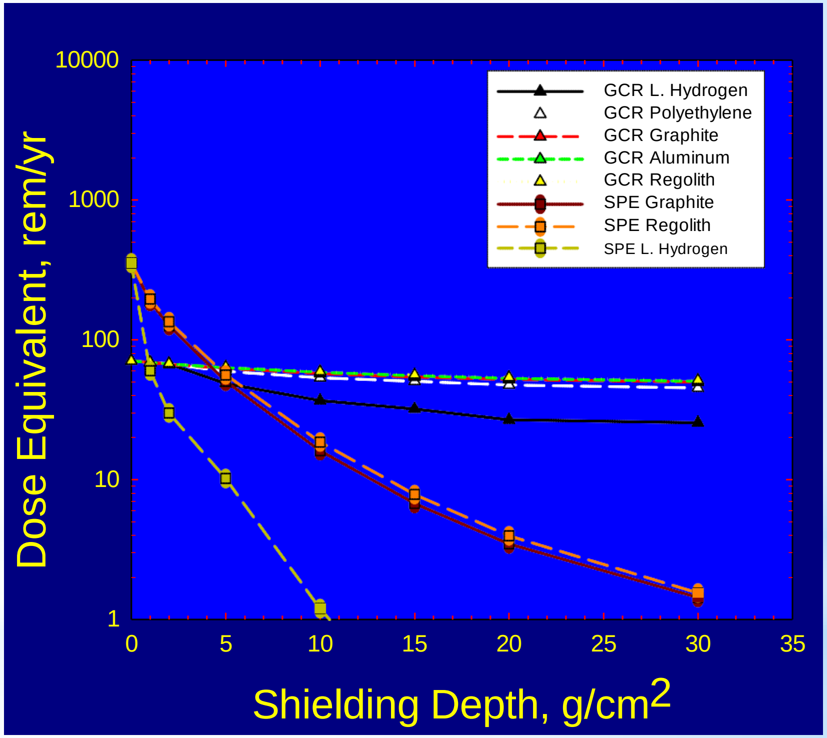
GCR and SPE Doses: Materials & Tissue

- GCR much higher energy producing secondary radiation

No Tissue Shielding



With Tissue Shielding

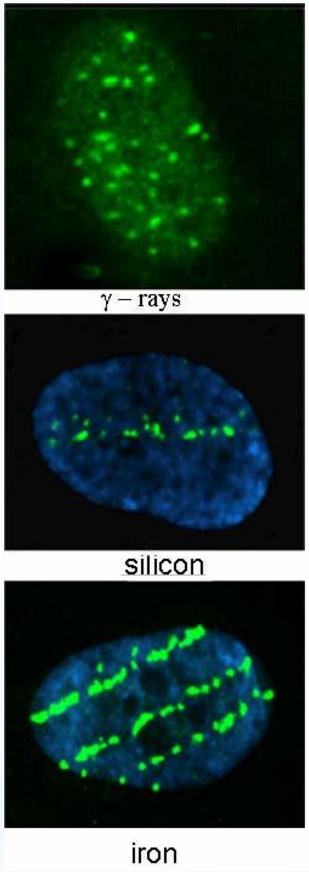


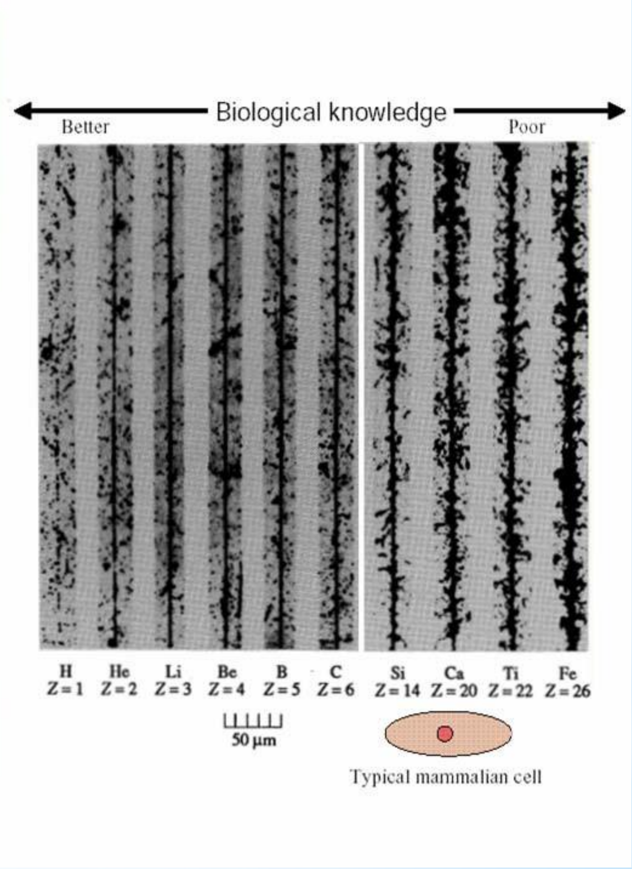
August 1972 SPE and GCR Solar Min

The Space Radiation Problem

Space radiation is comprised of high-energy protons and heavy ions (HZE's) and secondary protons, neutrons, and heavy ions produced in shielding

- **Unique damage to biomolecules, cells, and tissues occurs from HZE ions**
- **No human data to estimate risk**
- **Animal models must be applied or developed to estimate cancer, and other risks**
- **Shielding has excessive costs and will not eliminate galactic cosmic rays (GCR)**



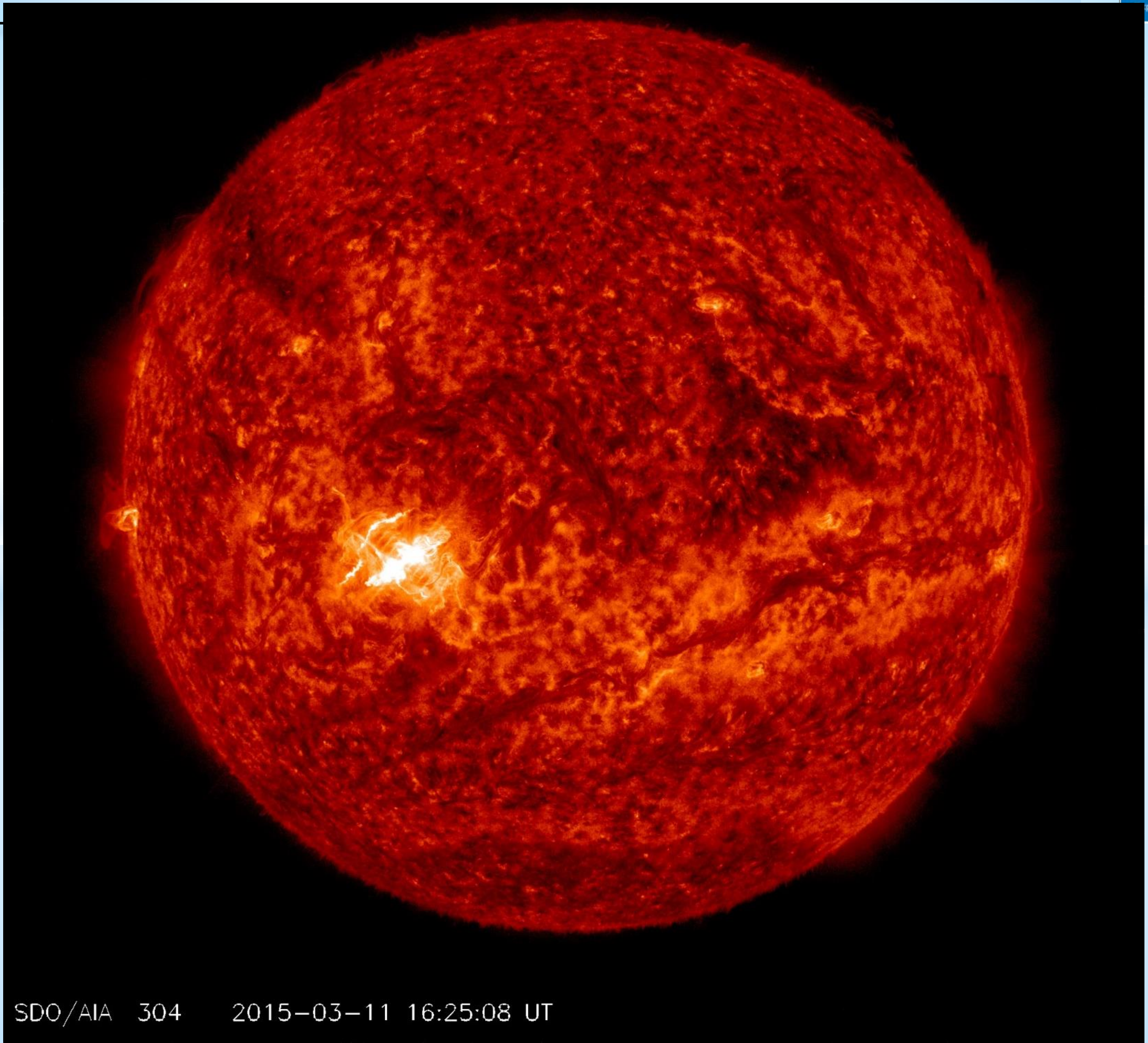


Single HZE ions in cells And DNA breaks

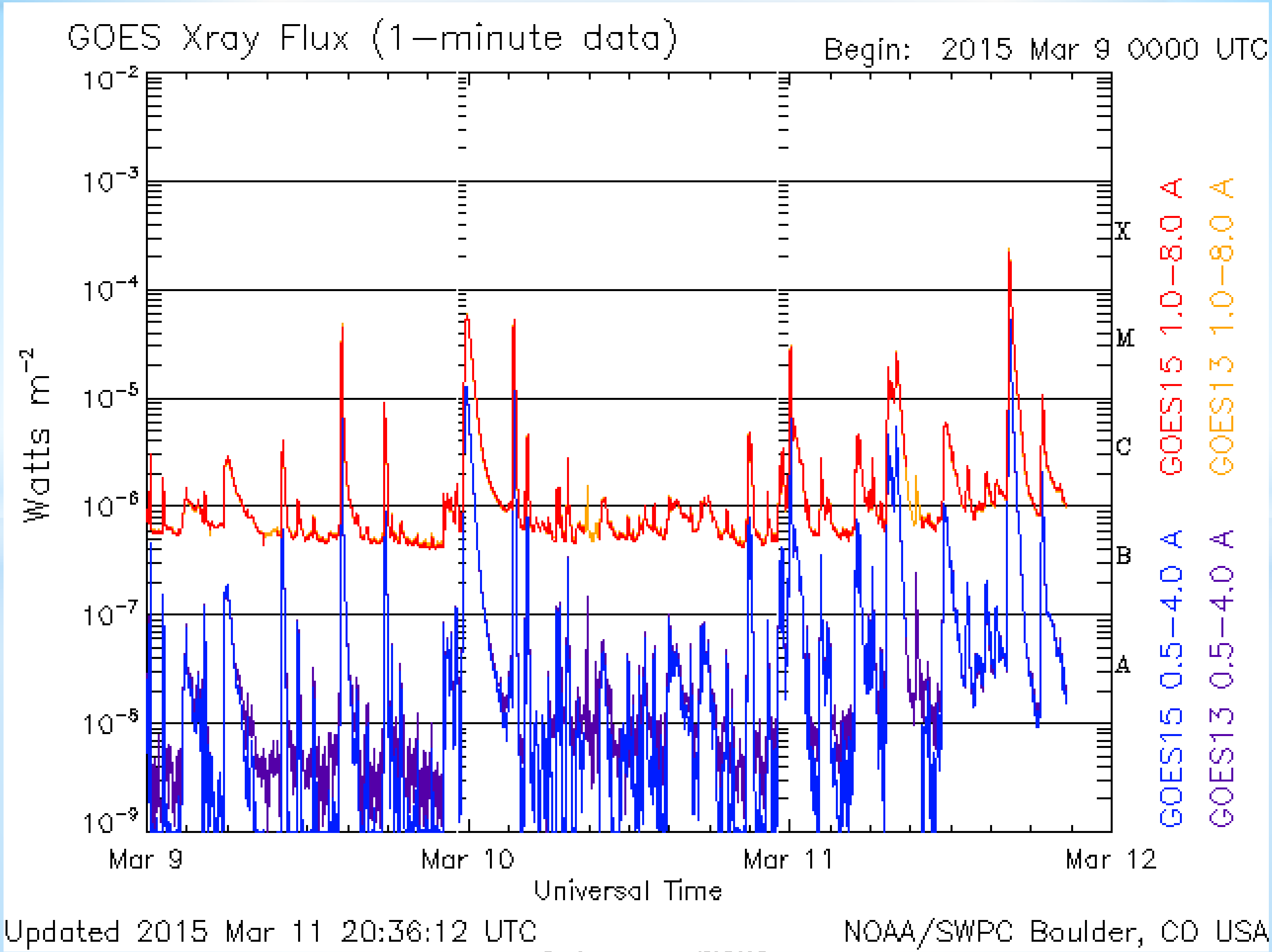
Single HZE ions in photo-emulsions Leaving visible images

Veggie at ISS

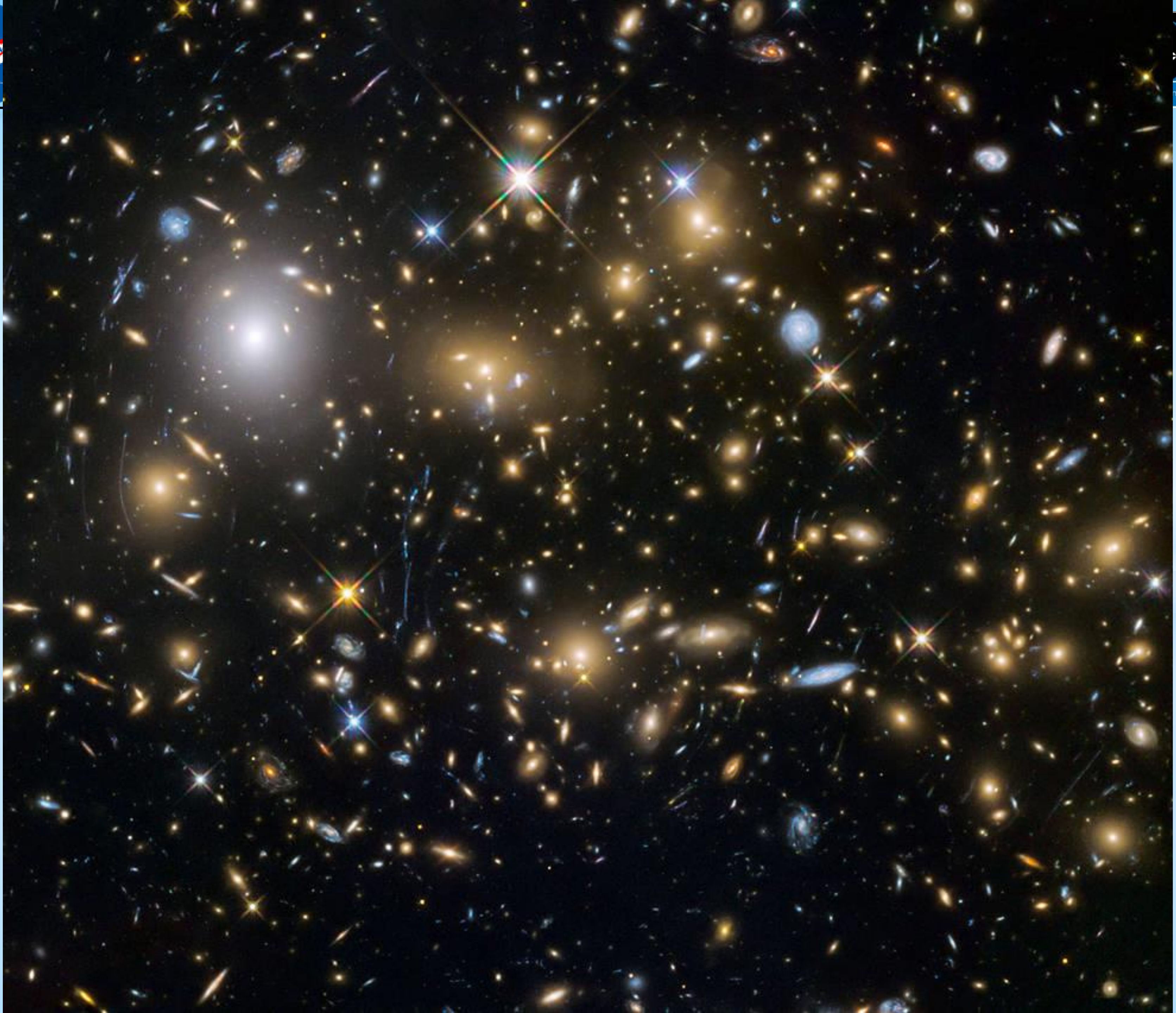
March 11, 2015



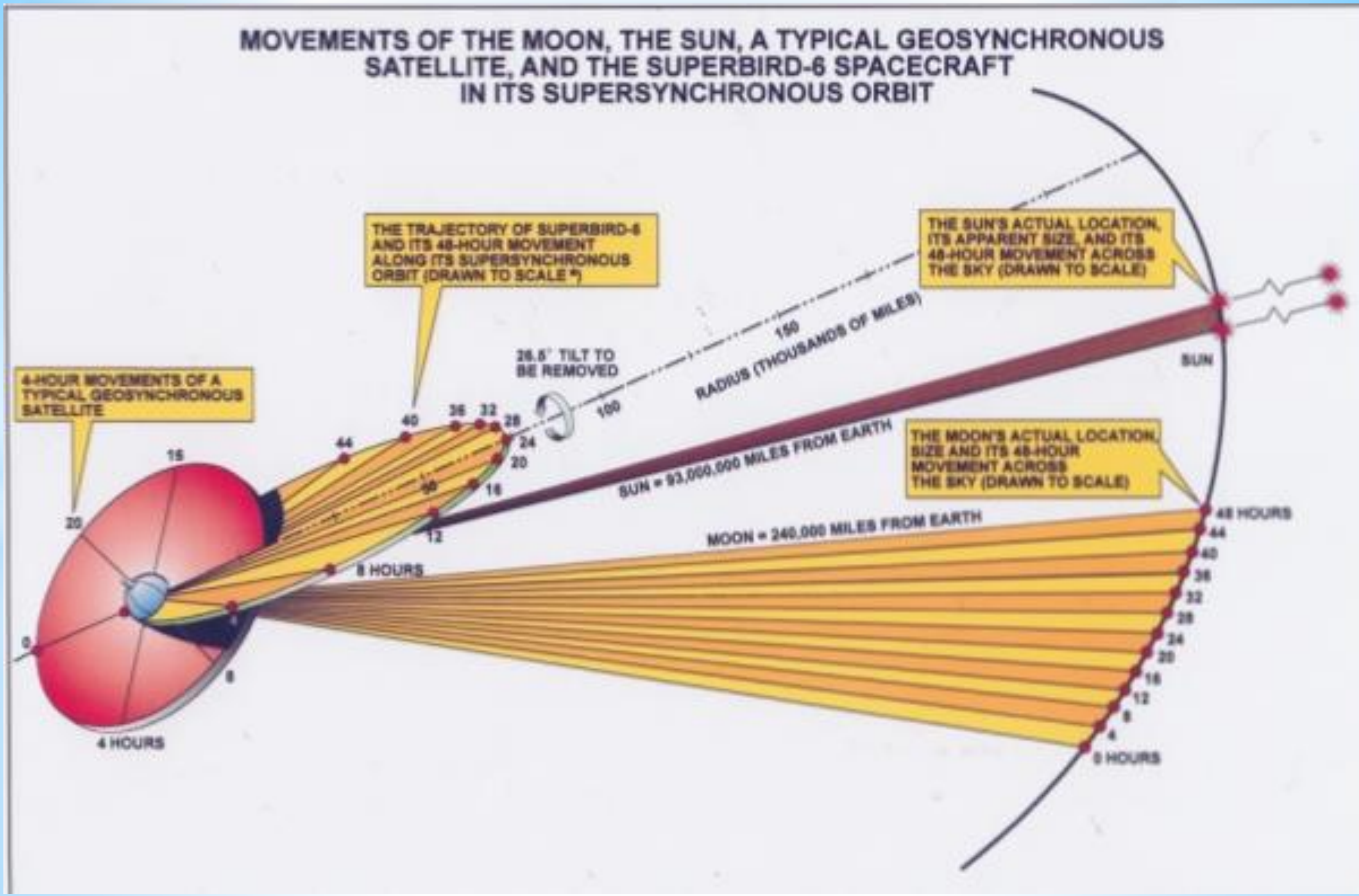
March 11, 2015 X-ray Flux



A. Jeevarajan/NASA

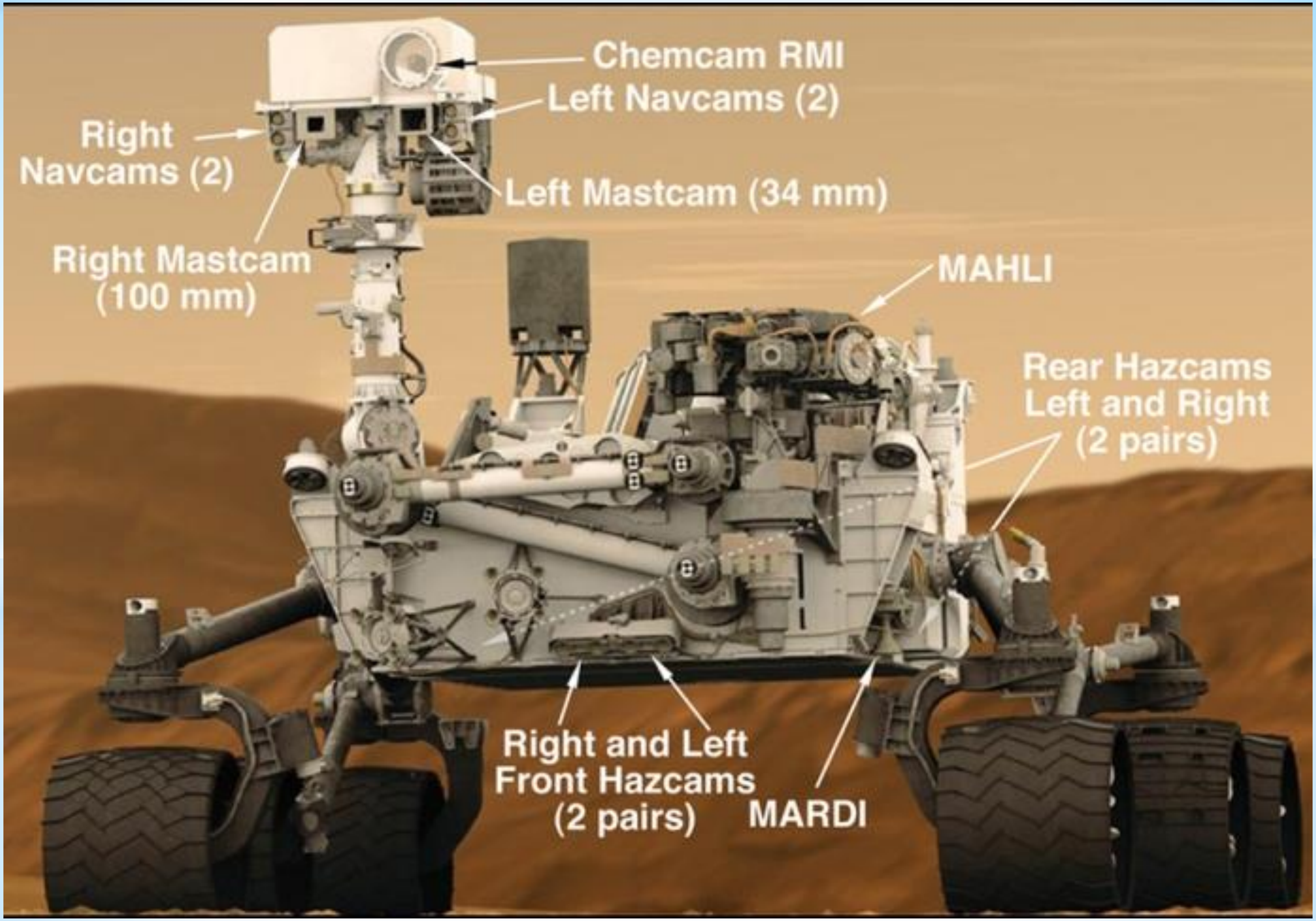


Beautiful Fragile Blue Planet



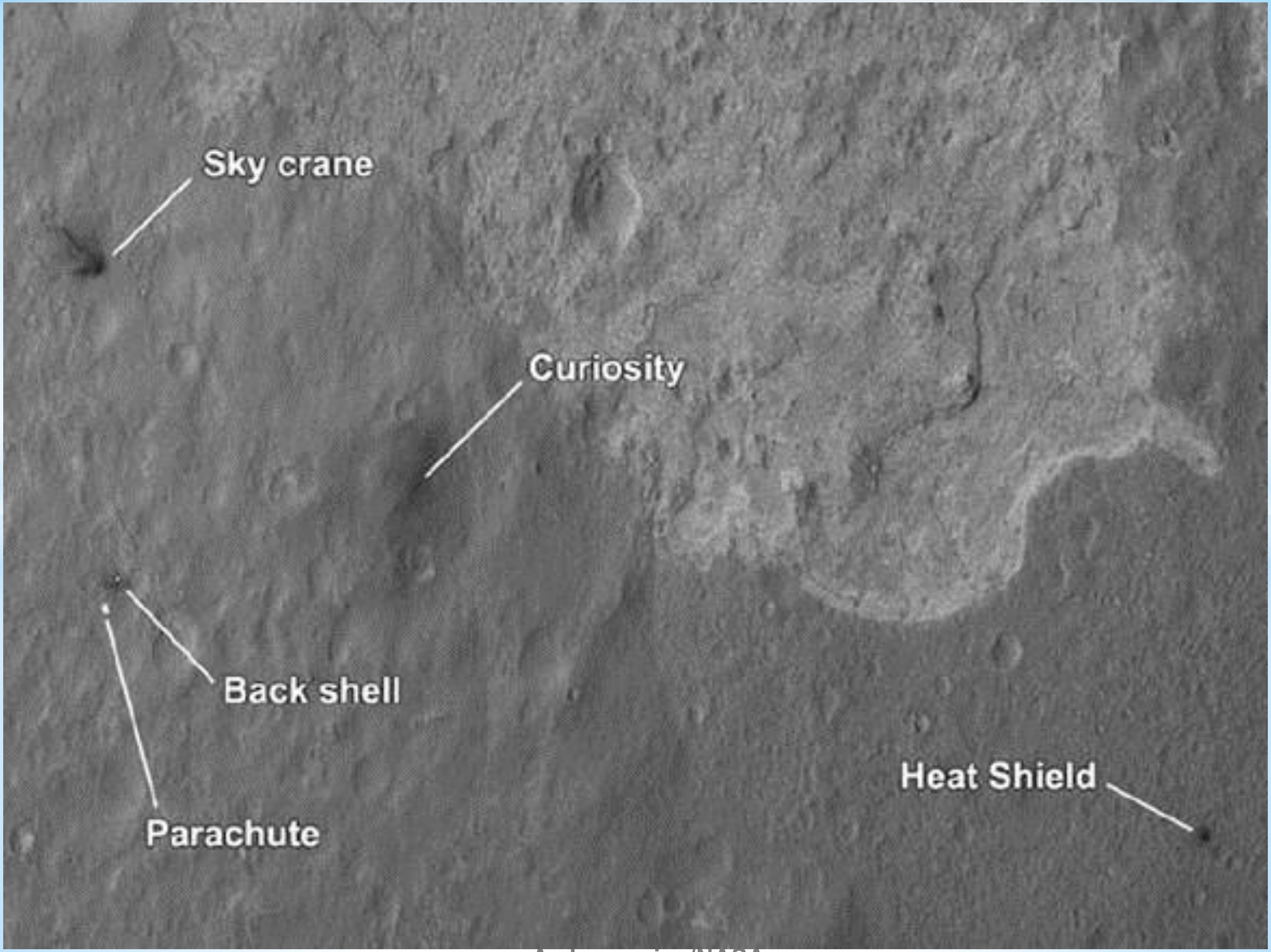
A. Jeevarajan/NASA

Mars Rover Cameras



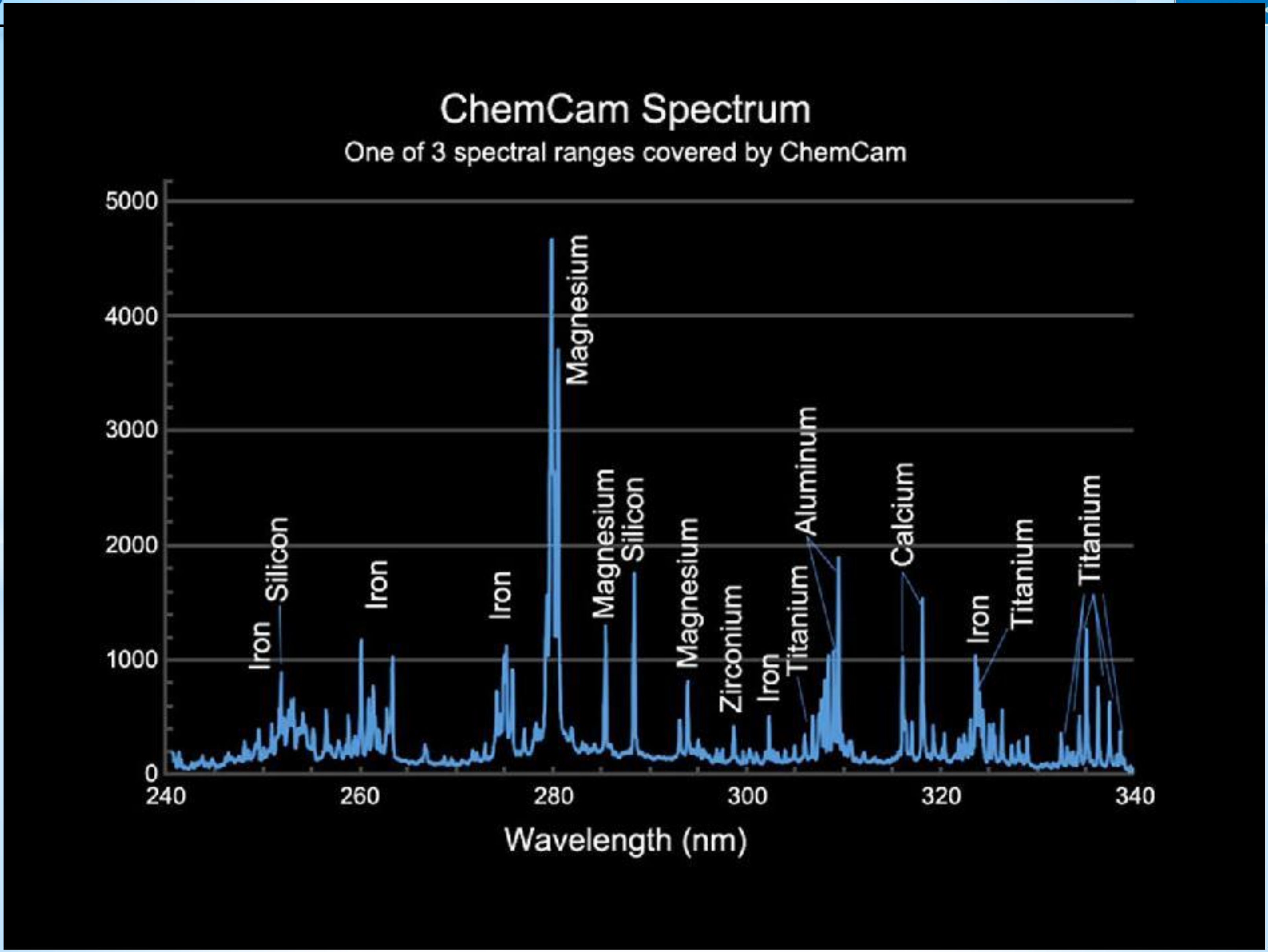
A. Jeevarajan/NASA

Curiosity Landing Site



A. Jeevarajan/NASA

Chem Cam Spectrum - Curiosity



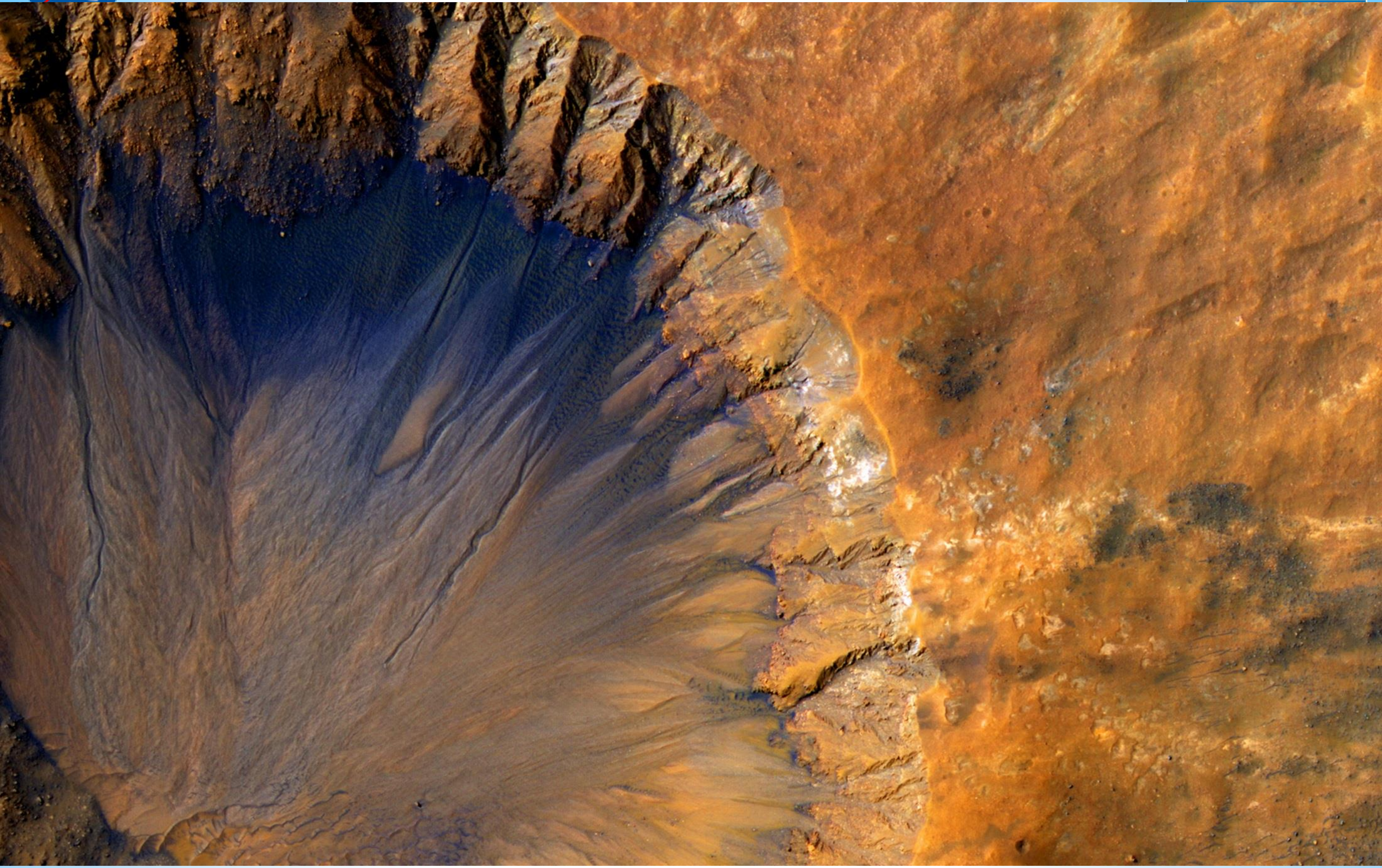
A. Jeevarajan/NASA


HiRISE
hirise.lpl.arizona.edu
Defrosting Polar Sand Dunes
PSP_007043_2650

Mars' Sand Dunes

A. Jeevarajan/NASA

Mars' Crater



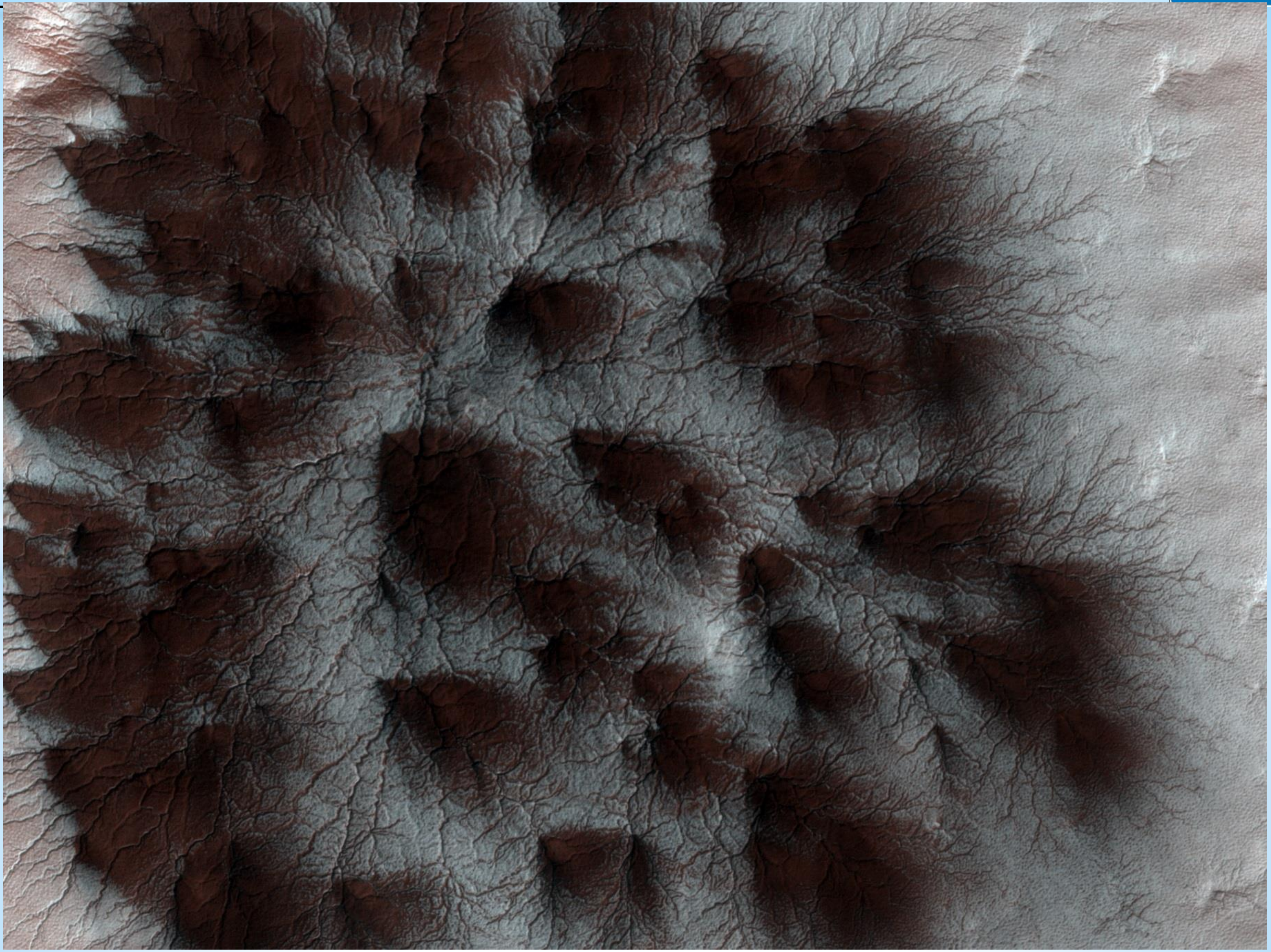
A. Jeevarajan/NASA

Messier 63 Galaxy

Milky Way

A. Jeevarajan/NASA

Mars' Spider

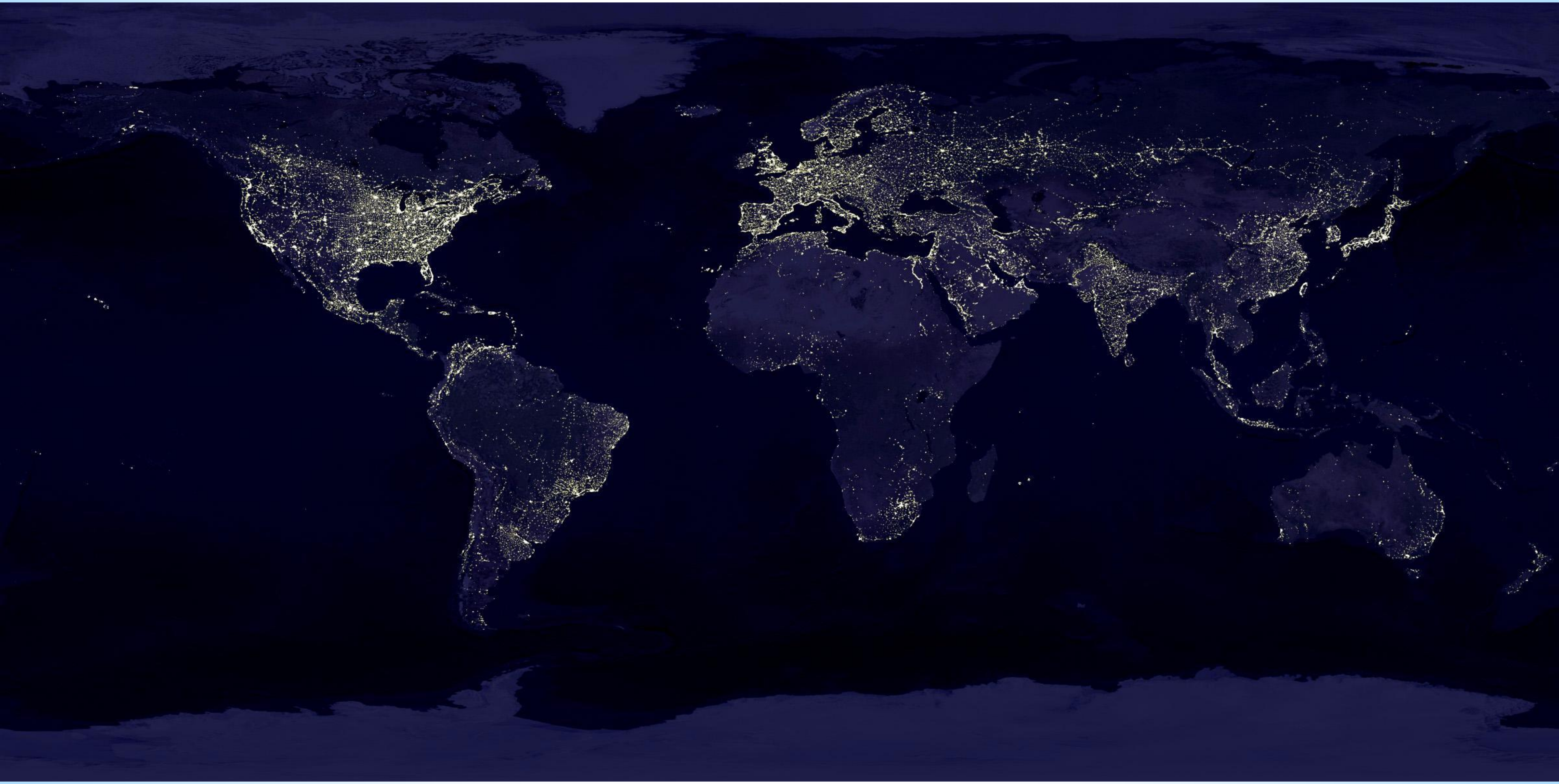


A. Jeevarajan/NASA

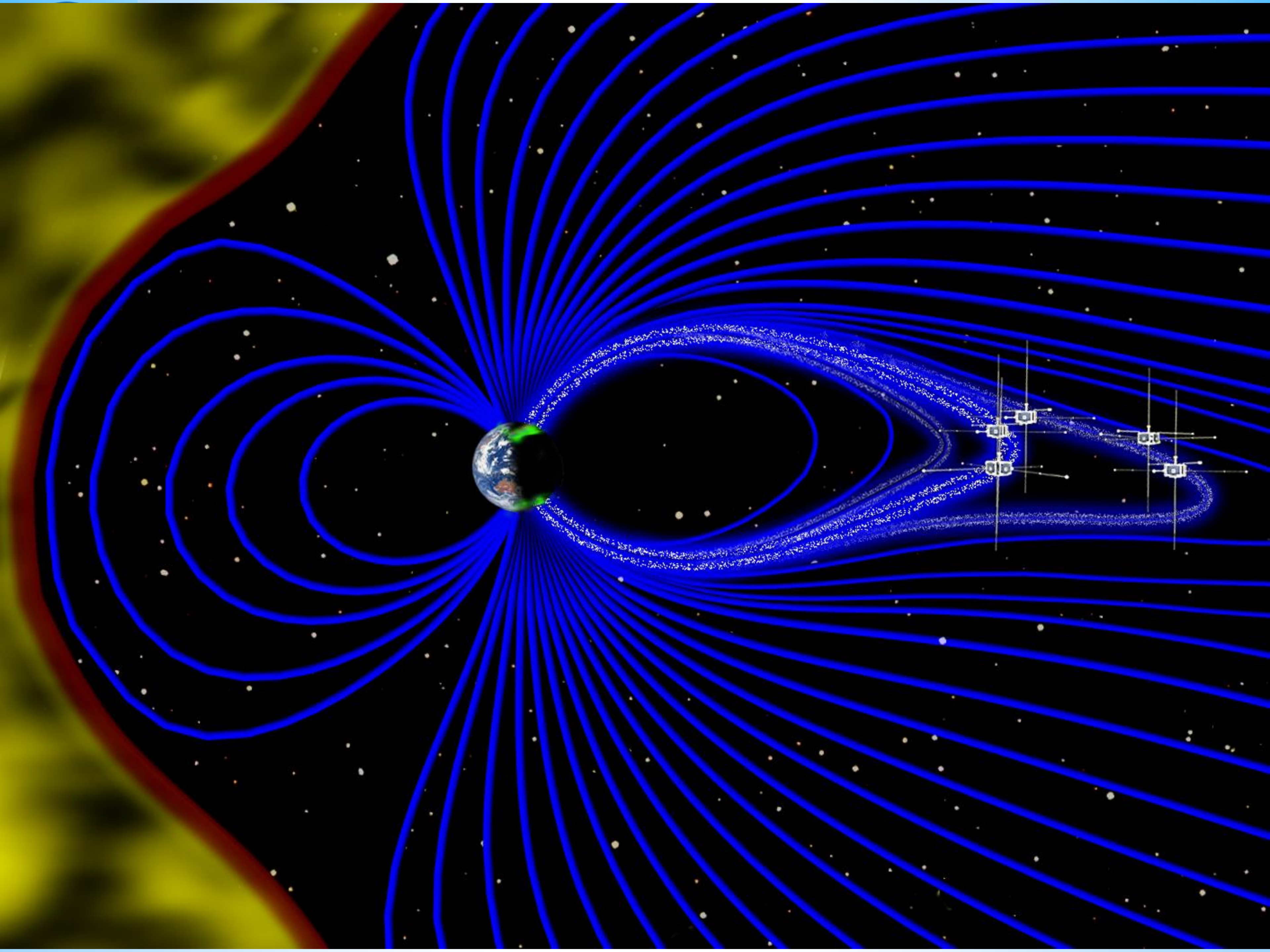
Auroras from ISS

A. Jeevarajan/NASA

Earth at Night



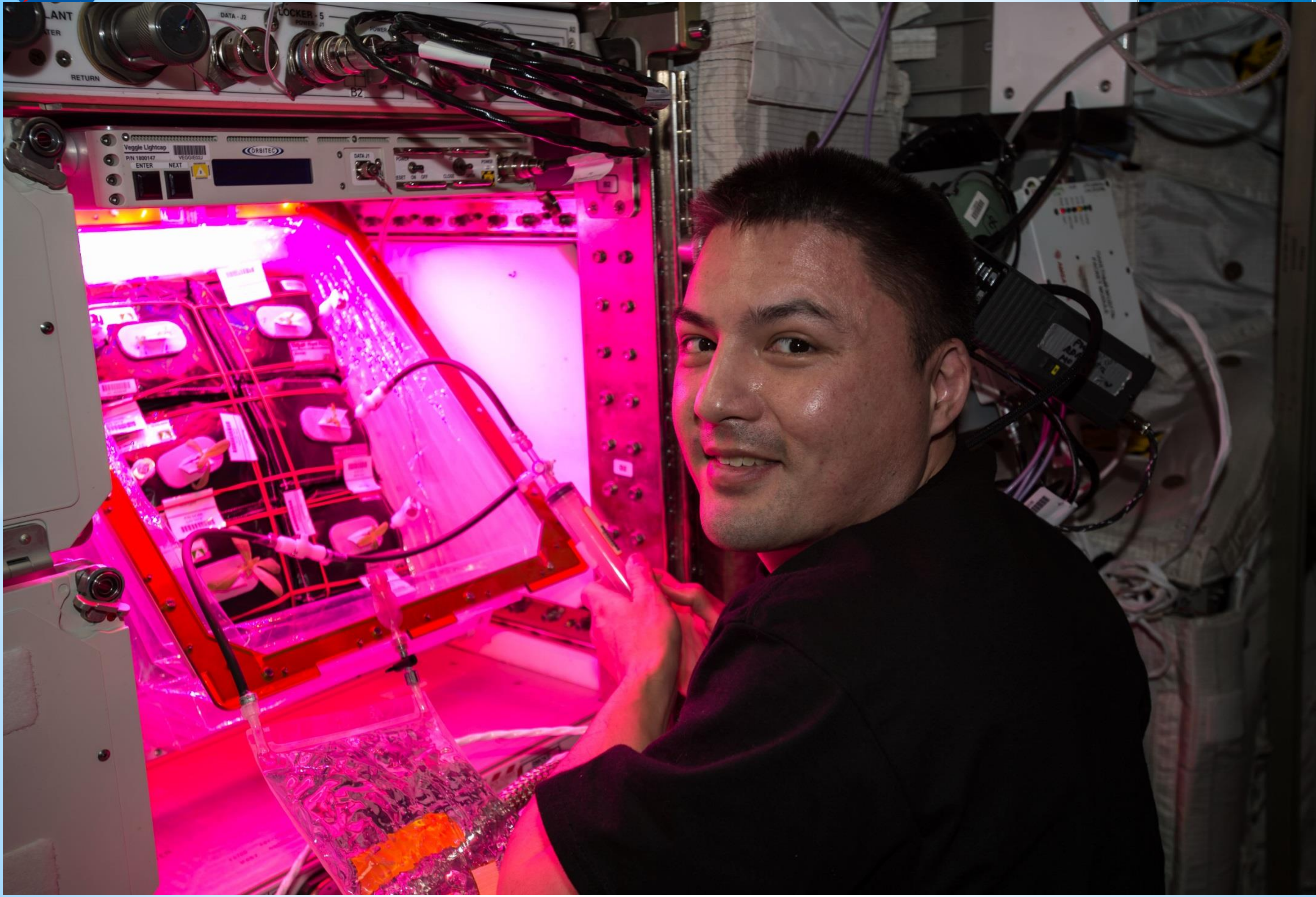
T-38 and Guppy



ISS Crew

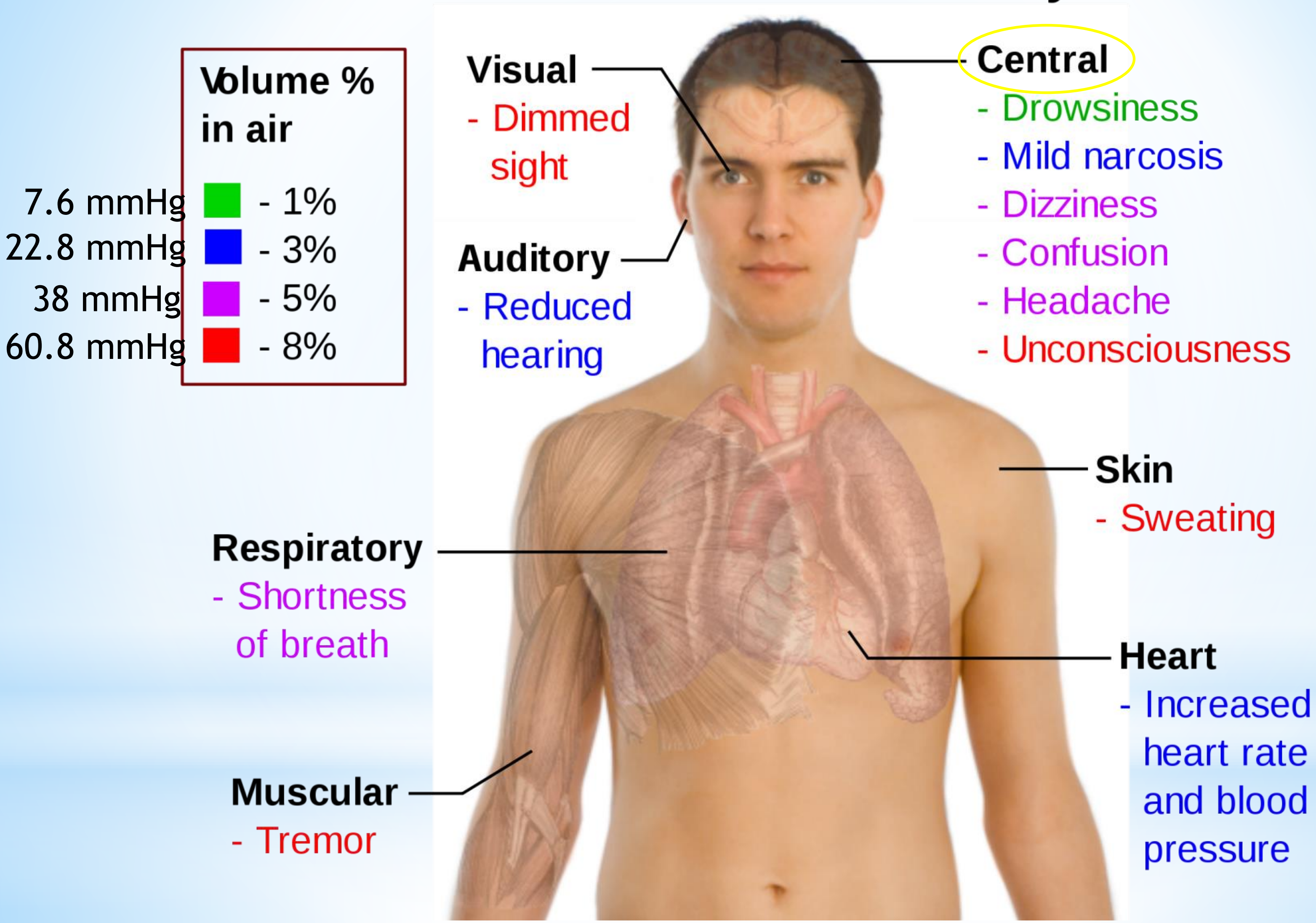
Human Health and Performance
NASA JOHNSON SPACE CENTER

Veggie Production at ISS

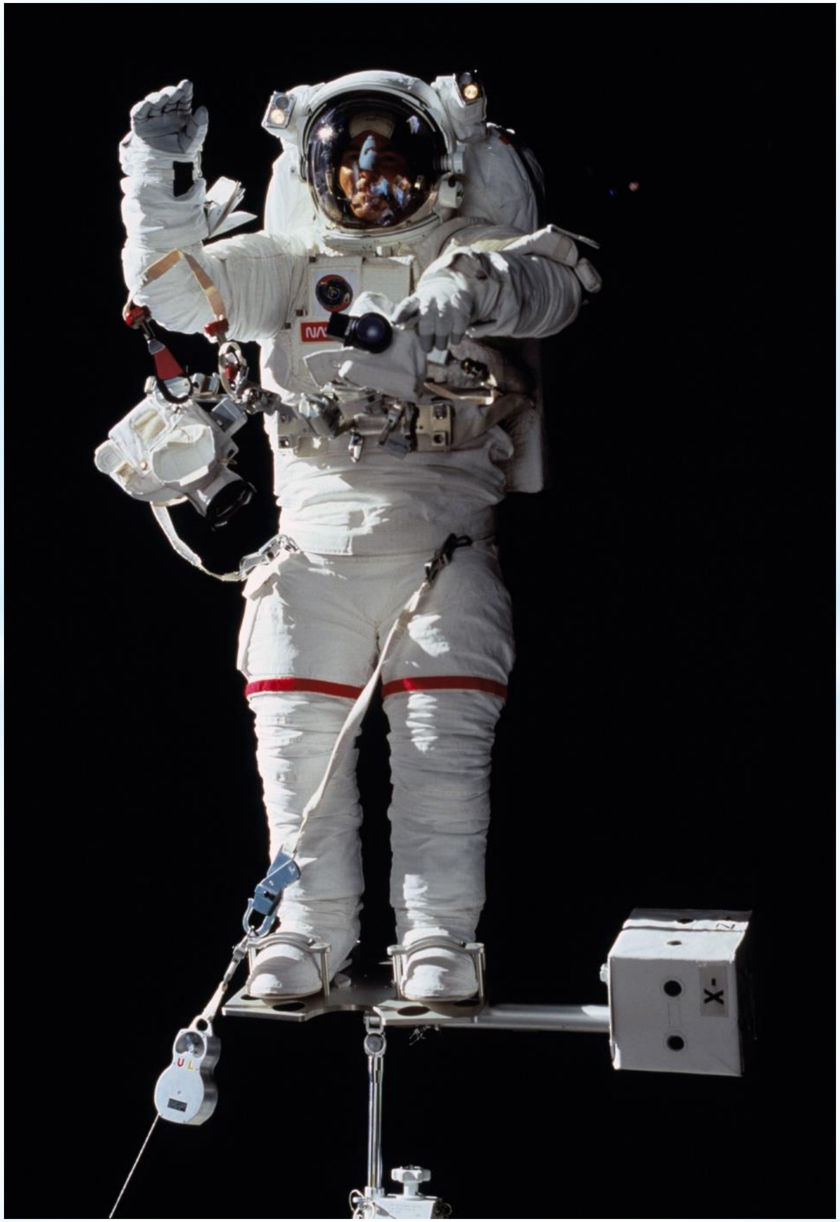


Main symptoms of

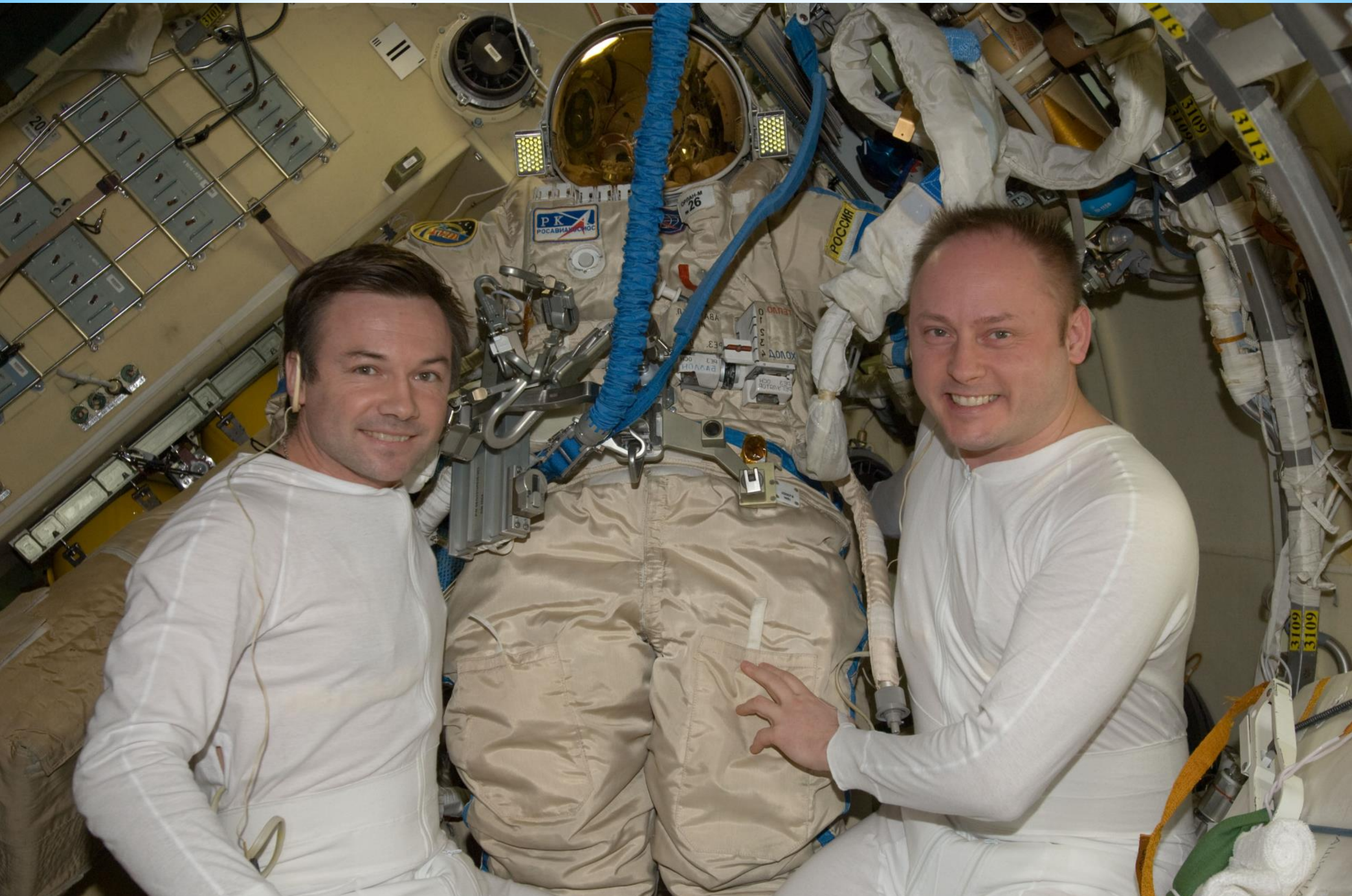
Carbon dioxide toxicity



EVA Suit



EVA suit Cooling Garment



EVA Preparation

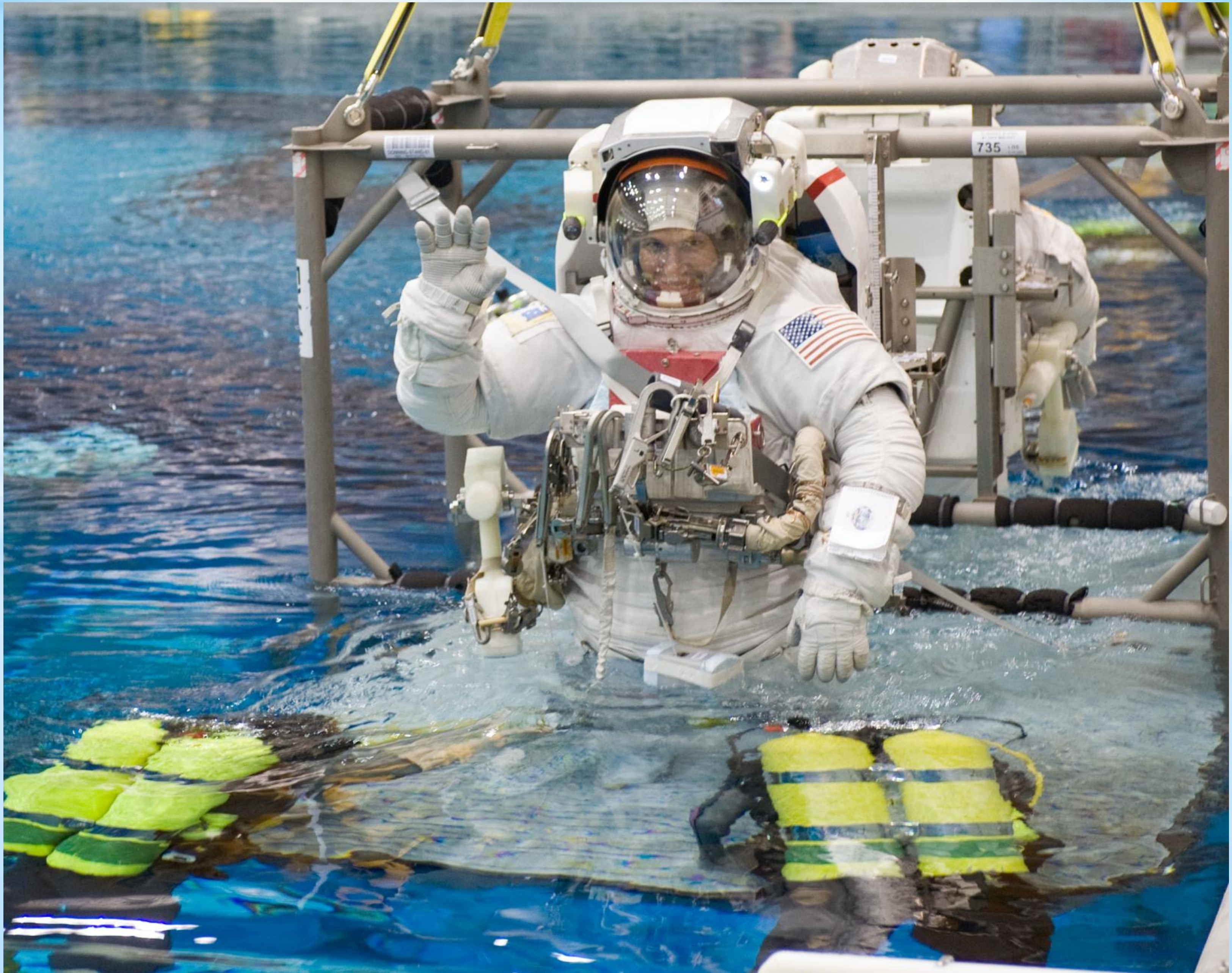
EVA Ready

Pre-breathe Protocol

A. Jeevarajan/NASA

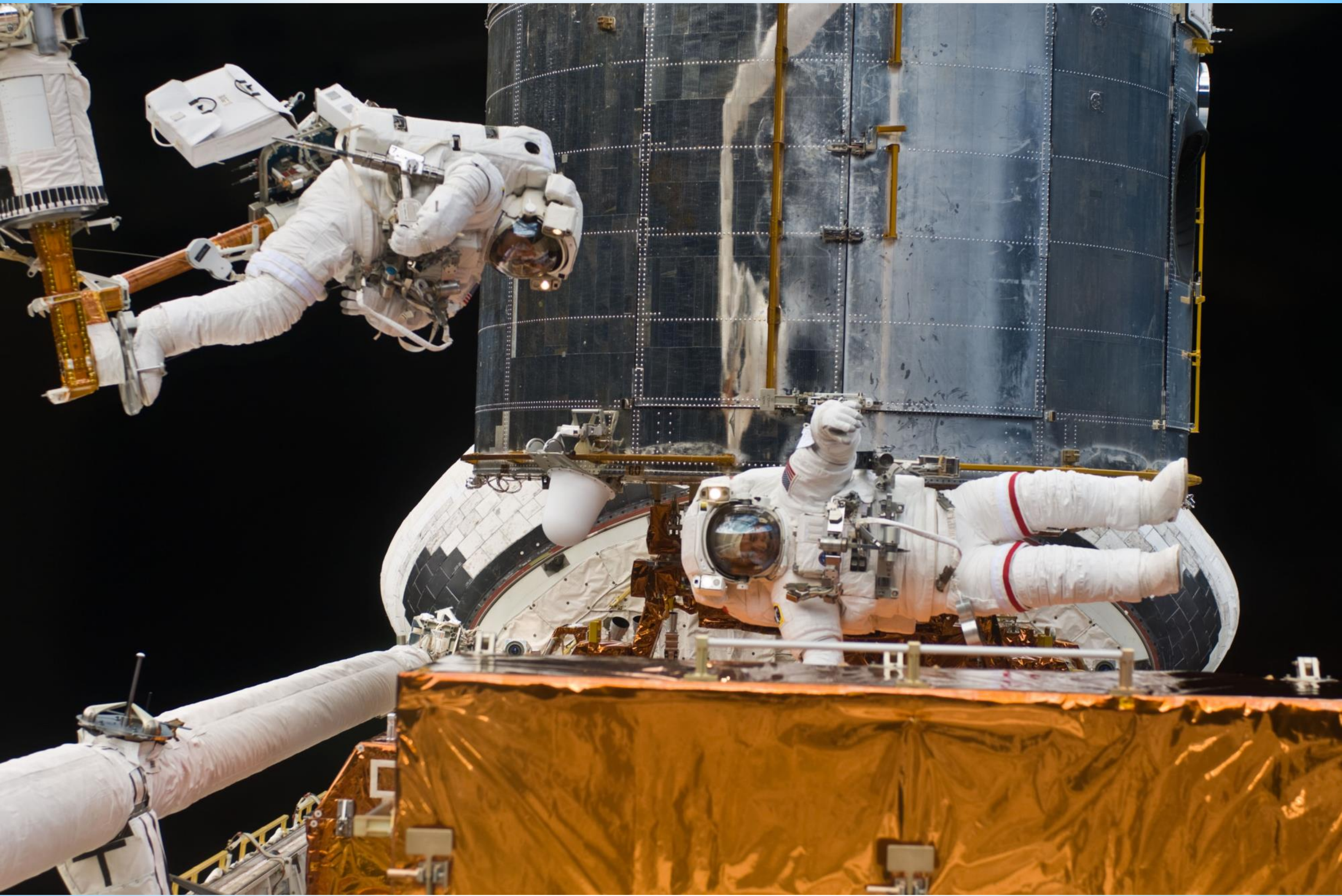
EVA for Action

EVA Training



EVA Activity - ISS

EVA – Hubble Repair at the Shuttle Bay



On the fifth day of STS-54, astronauts spent almost five hours in Endeavour's open payload bay performing a series of tasks designed to increase NASA's knowledge of working in space, necessary for the building of a space station. The astronauts tested their abilities to move freely in the cargo bay and climb into foot restraints without using their hands.

The whole spacewalk experience was incredible. I shuddered, as I peered out into infinity, I really had a sense of The Divine, and it was very strong. I now have a better appreciation for the vastness and enormity of the Universe—I guess you can say I had a firsthand look at God's handiwork.
-Mario Runco, Astronaut

January 13 – 19, 1993


NASA
CHALLENGER

Thanks