Space Medicine Introduction

USAFSAM Aerospace Medicine Primary

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Objectives

- Recognize the major hazards of spaceflight to astronauts
- Identify the major physiological adaptations in spaceflight
- Appreciate the range of medical operations issues that Flight Surgeons address

Working at NASA

What my parents think I do.

What my friends think I do.

What my kids think I do.

What the government thinks I do.

What I think I do.

What I actually do.

What do NASA Flight Surgeons do?

Provide the medical support necessary for astronauts to perform their required duties to assure mission success

More About NASA Flight Surgeons

Undergrad → Medical School → Primary Residency → Aerospace Medicine → NASA FS Training

Classroom / CBT / Documents / OJT / Sims

- FCR-1 SURGEON
- Mission support
- Selection and certification
- Additional administrative duties (e.g., Training, HMS, Flight Rules, Commercial Crew, Exploration)

ASCRs

Behavioral Health &
Performance

Radiation

Clinical Consultants

“Nuts and bolts”

“Blood and guts”

Nutrition

Toxicology

Acoustics

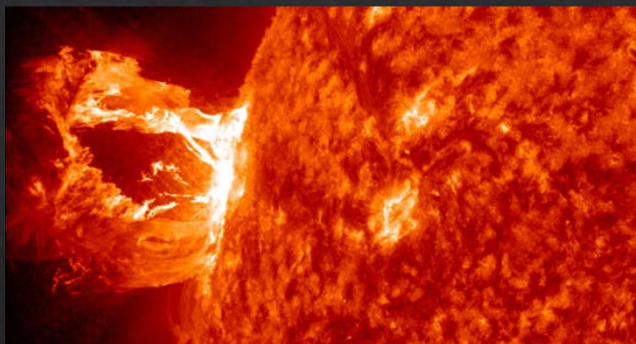
Payloads

Physiology

IP Counterparts

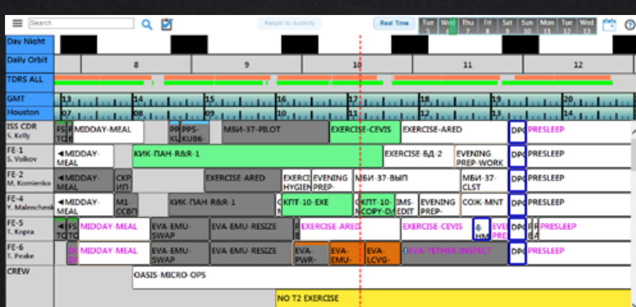
Microbiology

HAZARDS OF SPACEFLIGHT



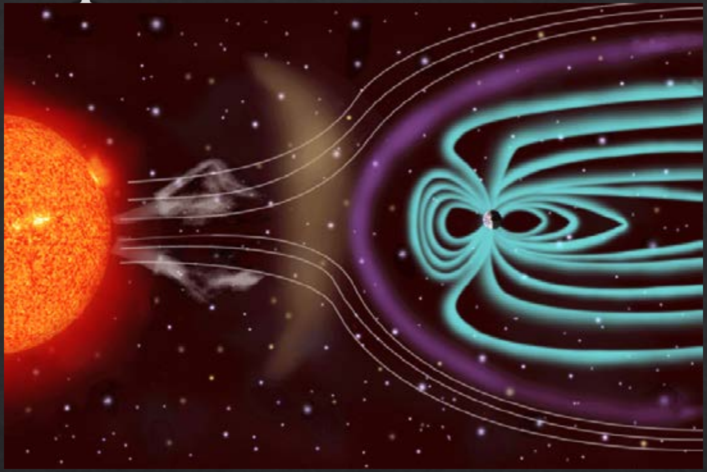
Space Environment

Spacecraft Environment



Spaceflight Mission

Space Radiation



- Three main sources
  - Galactic cosmic radiation **biggest threat to deep space missions**
  - Trapped Radiation
  - Solar particle events
- Exposure based on orbital altitude/inclination, duration, and solar activity
- Shielding from Earth's atmosphere is roughly equivalent to 10 m of water

Galactic Cosmic Radiation (GCR)

- Originates outside the solar system
  - Most likely from supernova explosions
  - Primarily H nuclei (90%), rest mostly He nuclei, and some heavy metal nuclei
- Flux from GCR is low but energy is massive
  - A single GCR particle at the very high end of the spectrum (1.5 x 10^{20} eV) carries 25 joules, enough to raise 1 kg to 2.5 m height on earth
  - Highest levels in open magnetic field areas
  - Very Penetrating; Hard to Shield

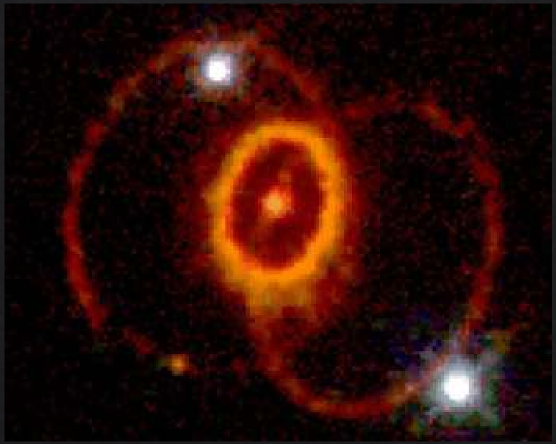
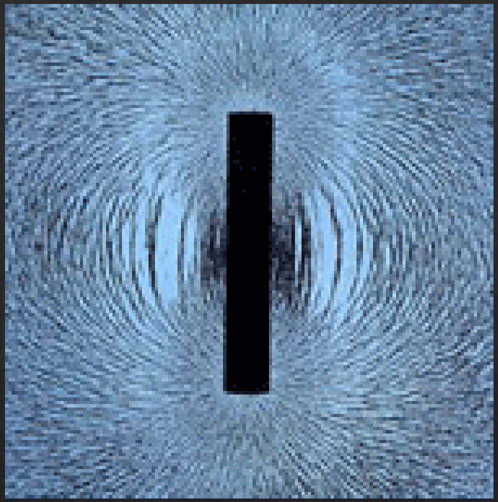
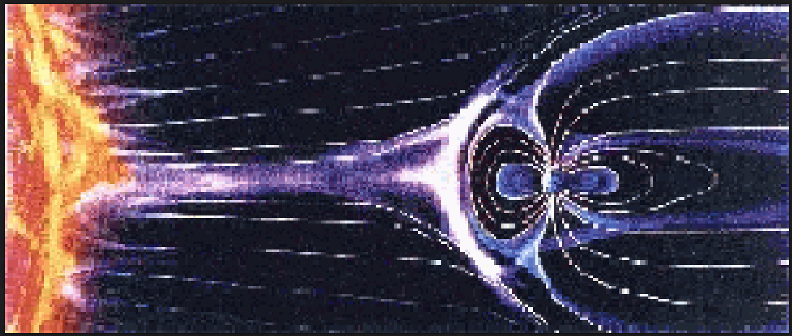


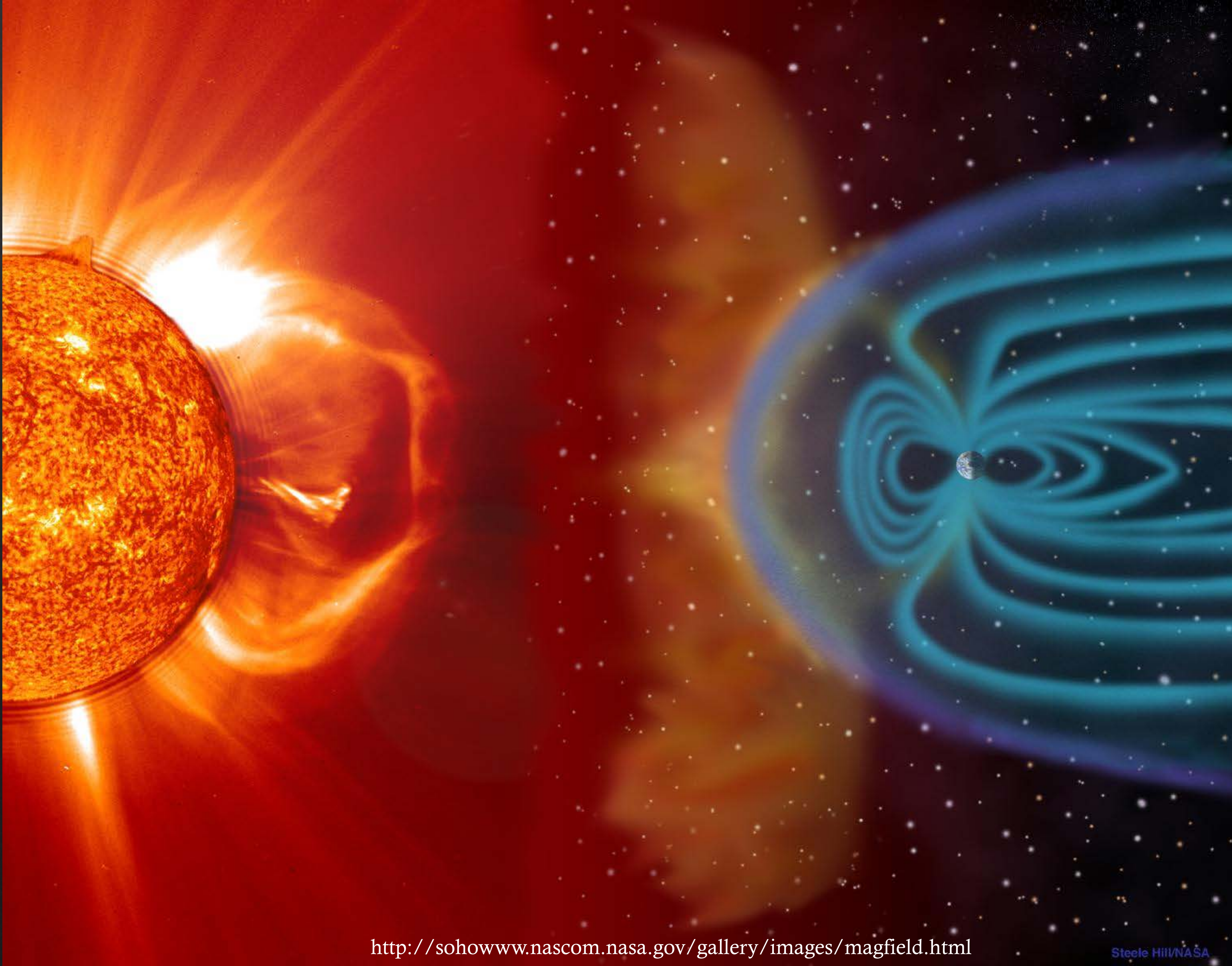
image from NASA/HST

Geomagnetic Field

- Rotation of Earth's molten iron core creates electrical currents, producing a magnetic field
  - Similar to a common bar magnet
  - Field extends several thousand Km
- The sun produces solar wind
  - Primarily protons and electrons
  - Compression of the field by this wind forms the protective magnetosphere



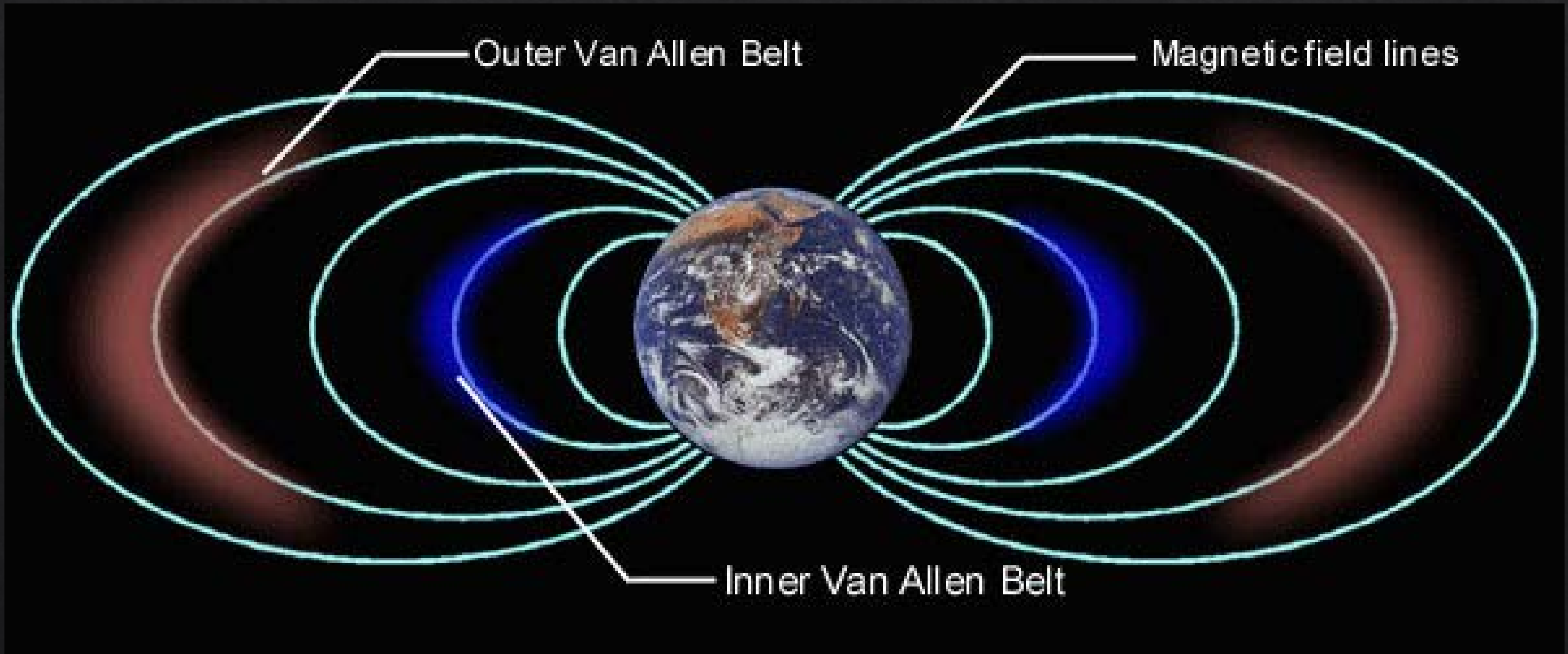




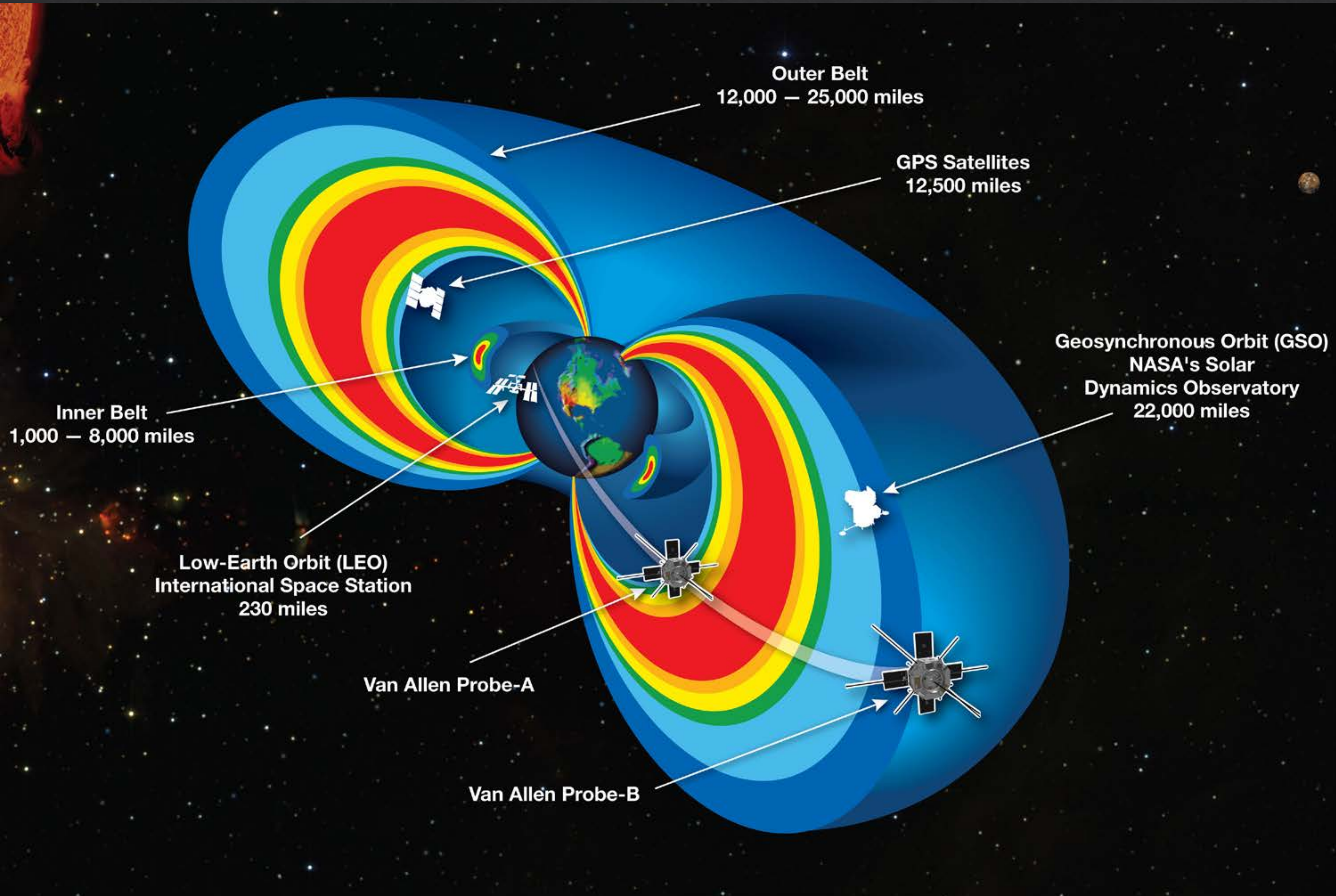
http://sohowww.nascom.nasa.gov/gallery/images/magfield.html

Geomagnetic Field and Trapped Radiation

- Closed field lines shield the Earth from radiation
- Open field lines at poles
  - Allow radiation to penetrate to low altitudes
  - Auroras
- South Atlantic Anomaly
  - Region where the inner proton belt dips into the lower atmosphere (200 km)

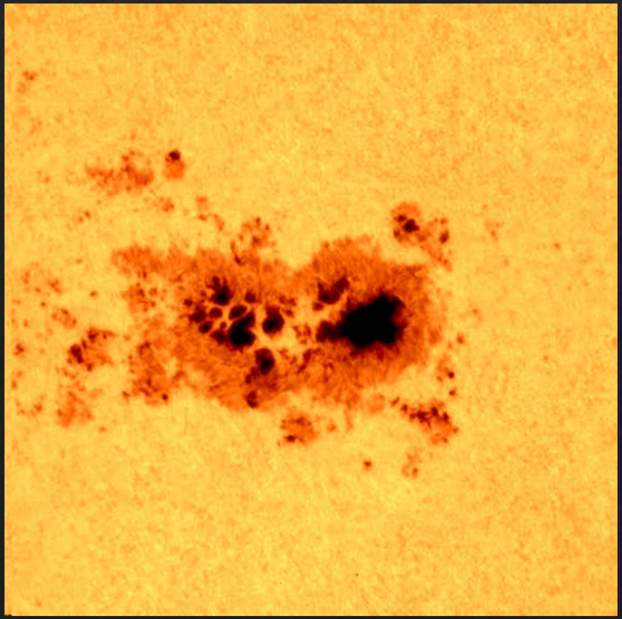


Van Allen Belts

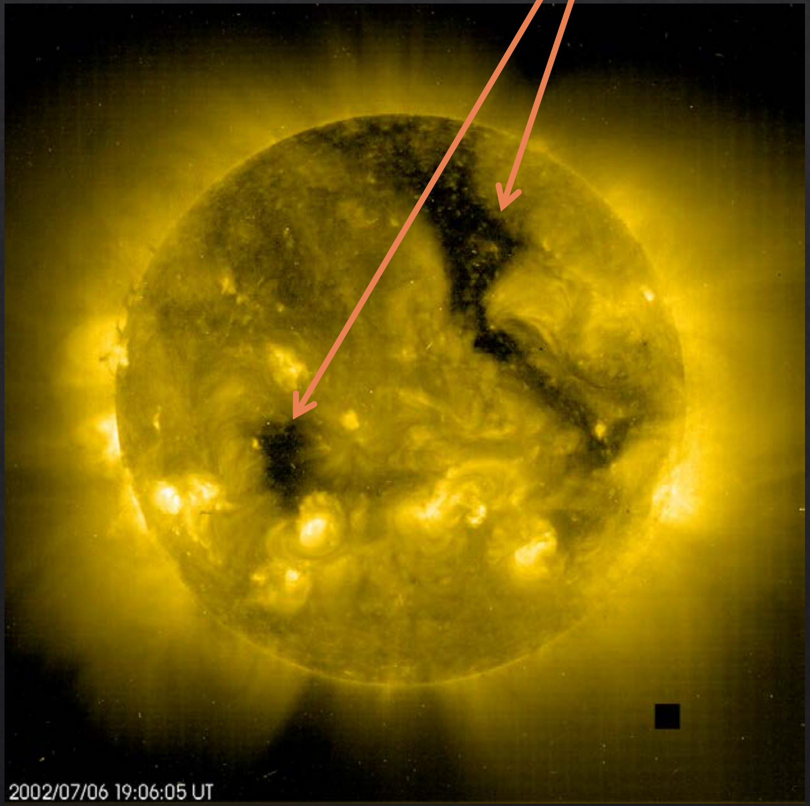


Solar Weather and Radiation

- Solar events:
  - Solar Flare
  - Coronal Mass Ejection (CME)
  - Solar Energetic Particle Event (SEP)
- Solar cycle
  - Average 11 years
  - Magnetic filed polarity reverses during every solar cycle
- Active Regions
  - Regions where negative and positive field become entwined
  - Sunspots: Cool regions with increased magnetic activity



Coronal Holes

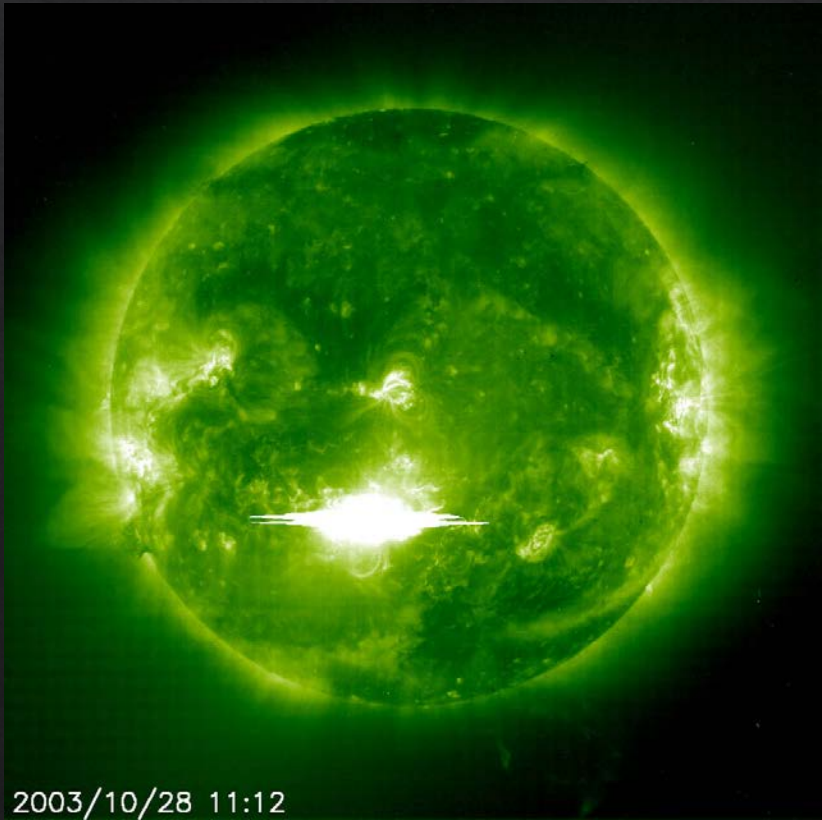


- Magnetic Field Open to Space
- Continuous release of energy
- May cause geomagnetic disturbances

images from SOHO/NASA

Solar Flares

- No direct impacts [to crew] - only an indication of energy release
- Highly concentrated explosive release of X-ray energy
- Happens frequently
- Major events (SEP or CME) are preceded by a flare



Coronal Mass Ejection (CME)

- The release can be observed and determined if Earthbound
  - Takes 1 to 3 days to arrive
  - Increases region area of high risk orbital alignment – low magnetic cutoff (poles)
- Causes Geomagnetic storms:
  - Magnetic field disturbances alter electron belt location and intensity
  - Create auroras and move them to lower latitudes
  - Alters low cutoff zones
- EVA hazard

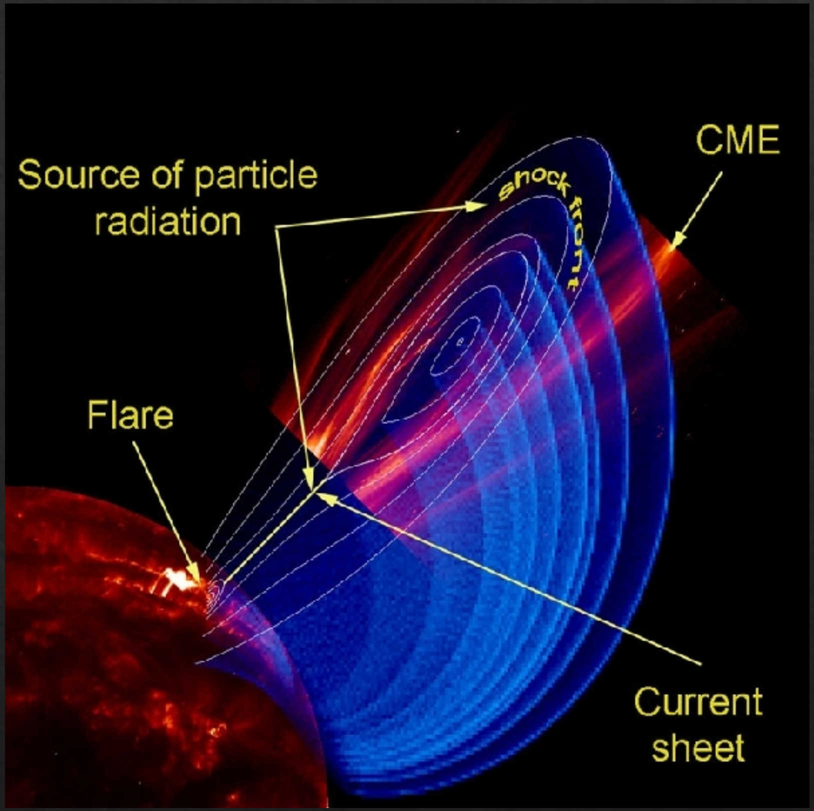
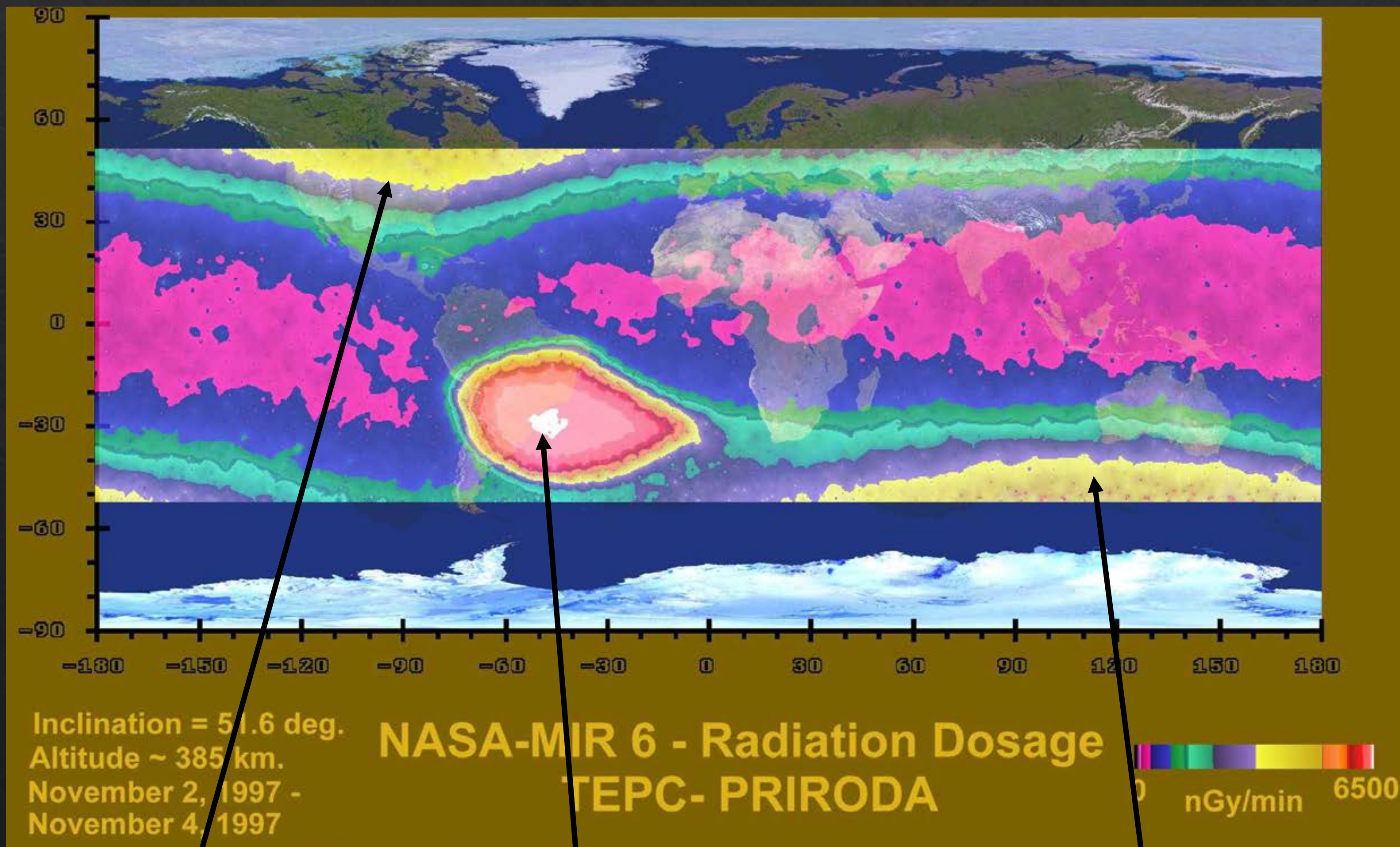


Image taken from sohowww.nascom.nasa.gov

Effects at Earth

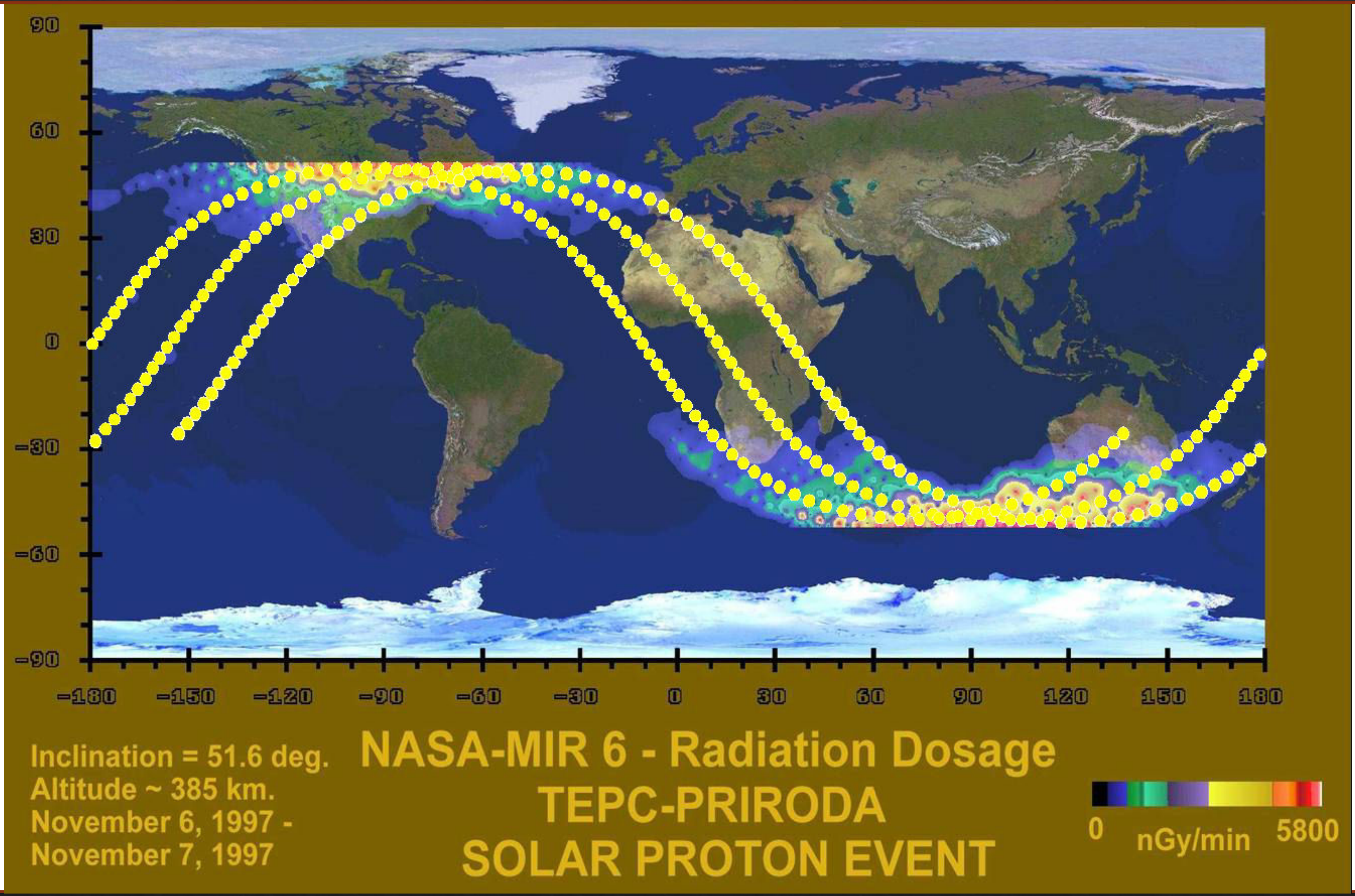


Low Cut-off Zones

SAA

Mir TEPC data

Low Cut-off Zones

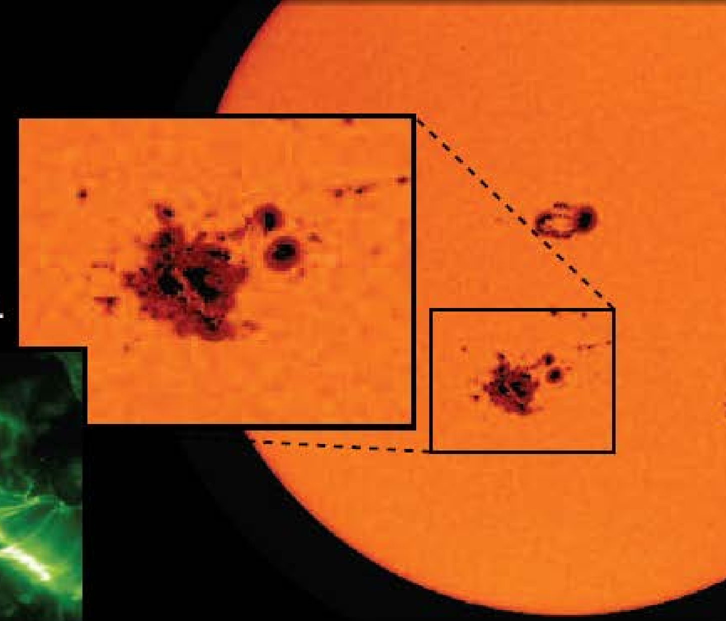


90
60
30
0
−30
−60
−90
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180
Inclination = 51.6 deg.
Altitude ~ 385 km.
November 6, 1997 -
November 7, 1997
NASA-MIR 6 - Radiation Dosage
TEPC-PRIRODA
SOLAR PROTON EVENT
0
nGy/min
5800

Effects at Earth

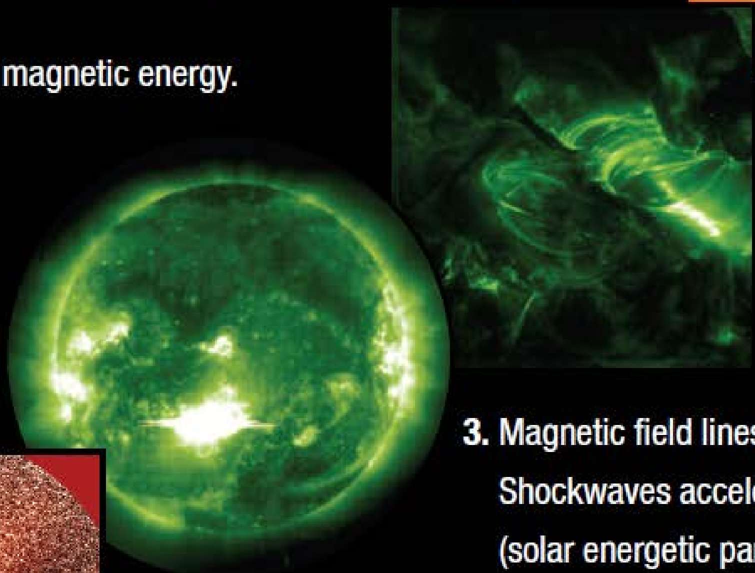
- Geomagnetic storms
  - Compresses the closed magnetic field lines
  - Enhances the electrons in the outer electron belt
- Solar Proton Events
  - Potentially delivers high flux levels of protons
  - Potential hazard to crew and equipment
- Solar cycle effects
  - Solar min
    - Less protection against galactic cosmic radiation
    - Higher trapped radiation levels
  - Solar max
    - More protection against galactic cosmic radiation
    - Lower trapped radiation levels

Anatomy of a Large Solar Energetic Particle Event

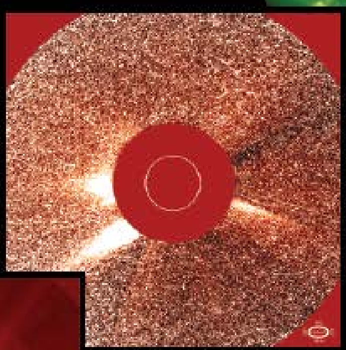


1. A collection of sunspots grows into an active region, intertwining magnetic fields.

2. Magnetic fields grow and store magnetic energy.



3. Magnetic field lines realign, releasing stored magnetic energy. Shockwaves accelerate charged particles to very high energies (solar energetic particles) and eject an expanding cloud of coronal material away from the sun (coronal mass ejection).



4. The most energetic protons can arrive in minutes. Charged particles hitting a satellite camera create the image of "snow."

5. Geomagnetic storms develop as the coronal mass ejection shock passes Earth 1 to 2 days later.

CME with Proton Shower, LASCO C2 (April 1-27, 2001)

Radiation Exposure Career Limits

- Career limits are established to manage risks associated with radiation exposure, primarily stochastic effects.
  - Primary basis of Career Limits is cancer mortality.
  - Career limits are set to maintain lifetime excess cancer mortality to less than 3%
- Recommendation from National Council on Radiation Protection and Measurements (NCRP) Subcommittee 75 in NCRP Report 98 (1989)
  - NCRP Report 132 (2000), (if you read one, read this one)
  - Additional limits are set for Eye (cataract induction) and Skin. (Deterministic effects)

Radiation Dose Ranges

	Typical Dose (rem)
Round-trip NY to London / Chest x-ray (1 film)	0.01
Natural background radiation per year	0.3
CT scan	3-10
Typical mission dose on ISS	**10-15**
Estimated dose for 3-yr Mars mission	100-150
Atomic bomb survivors	Up to 400
Human LD_{50}, no medical intervention	350-550
Human LD_{50}, with medical intervention	500-1000

ALARA

- As Low as Reasonably Achievable (ALARA)
  - A commitment to make all reasonable efforts to minimize exposure, hence reduce risk.
  - Part of the Legal limits. Just as important as the “Numerical limits”
- Why - Any exposure, no matter how small, results in a finite (albeit small) increase in subsequent cancer risk (no threshold theory)
  - “means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest” (10CFR Part 20 §20.1003)

Radiation Protection

- Time, Distance, Shielding
- Hierarchy of controls:
  - Elimination:

    Don't be where the radiation is (avoid SAA, poles)
  - Engineering:

    Radiation resistant regions within ISS
  - Administrative:

    No EVA in SAA or during CME
  - PPE:

    Detection devices, shelter in place

ISS Radiation Shielding

Well Shielded

- Node 2 USOS Crew Quarters
- Service Module, aft of treadmill

Not Well Shielded

- Lab Window
- Cupula
- Airlocks
- Service Module, fore of treadmill (Russian crew quarters)

US ISS Active Radiation Monitors

IV-TEPC, Intra-vehicular tissue equivalent proportional counter – New – two detector volumes

TEPC, tissue equivalent proportional counter

Top in lab with a piece of poly shielding to be used in the crew quarter.

Second is detector

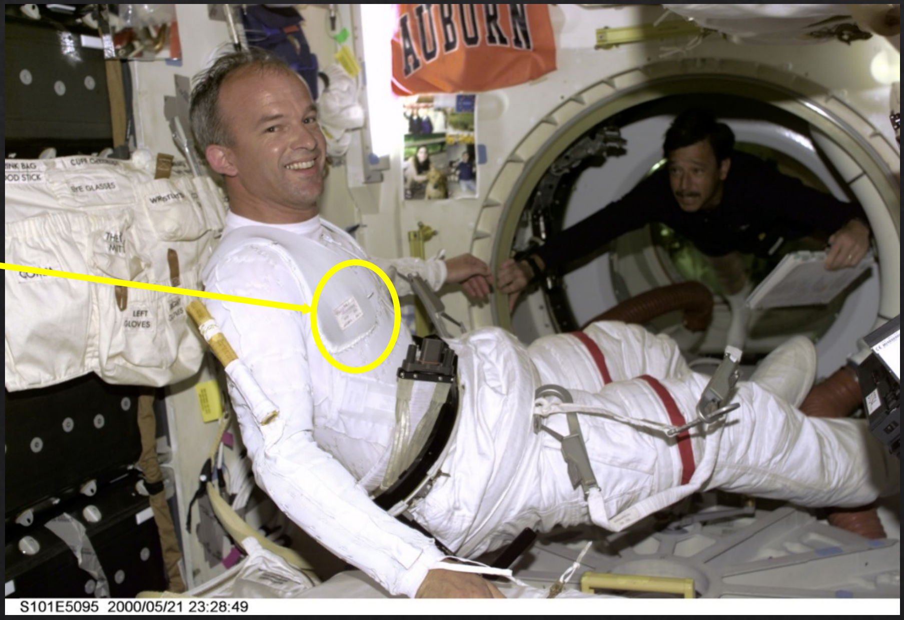
third is spectrometer box

EV-CPDS, Extra-vehicular Charged Particle Directional Spectrometer – Located on STBD side of S-0 truss – Zenith rail. Apertures are forward, behind and Zth

Crew Passive Dosimeters (CPD)

- Records legal dose
- Worn IVA and EVA
- Thermo-Luminescient dosimeters (TLD) (dose)
- CR-39 (LET)

One of our astronauts proudly modeling his crew dosimeter in the EVA suit liquid cooling garment



Spacecraft Environment

Reduced Gravity

"Weightlessness is often misrepresented as a physiologically challenging condition but is more accurately described as an absence of the accustomed physiological challenges with respect to the gravity vector"
– Barratt & Pool, Principles of Clinical Medicine for Space Flight

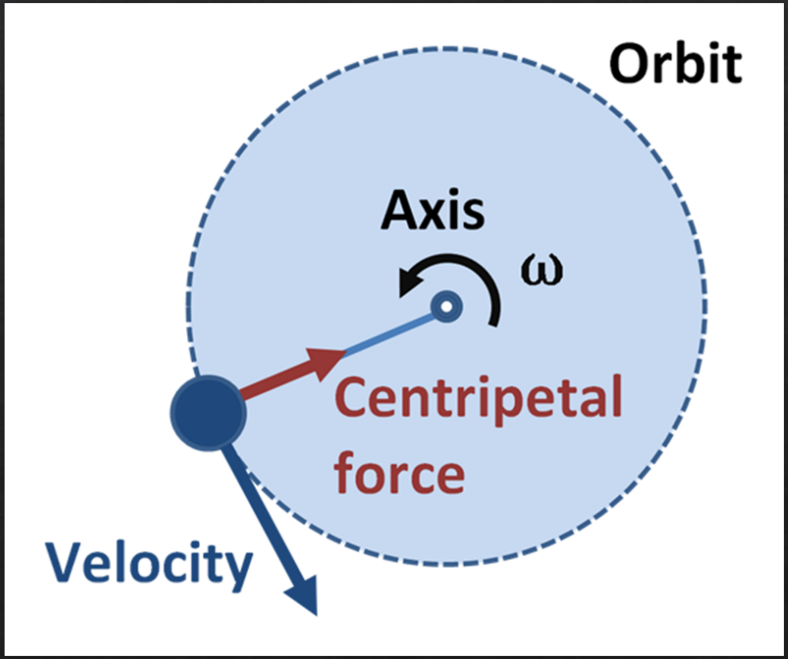
- Absolute effects on the human body are not known
  - Combined effects of microgravity, deliberate exercise countermeasures, environmental parameters, etc.
  - Standard investigative and diagnostic methods are often not available
  - Limitations in launch mass/volume/power, storage, fluid handling techniques, crew time
  - Sample size remains small (543 people in earth orbit)

Is the ISS in “zero G”?

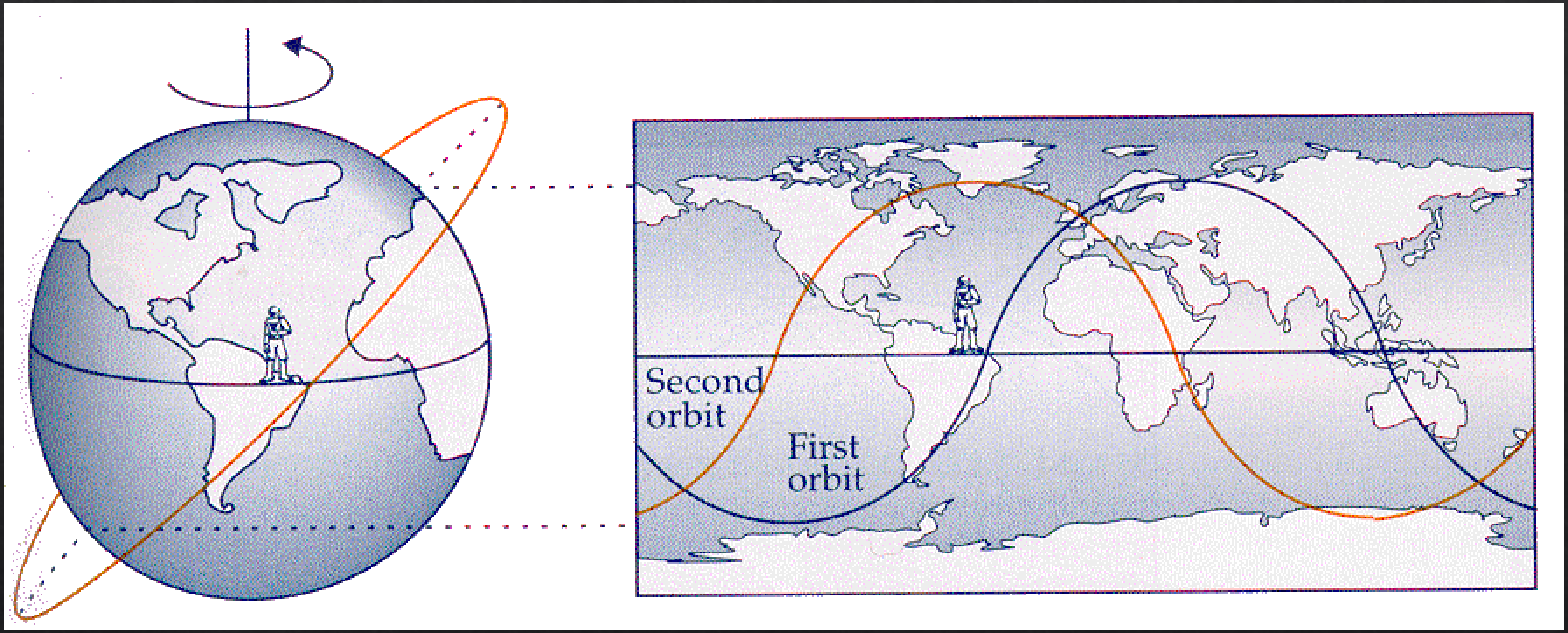
Location	**Gravity due to**			**Total**
	Earth	Sun	Rest of Milky Way	
Earth’s Surface	9.81 m/s^2	6 mm/s^2	200 pm/s^2 = 6 mm/s/yr	9.81 m/s^2
Low Earth Orbit (ISS)	9 m/s^2	6 mm/s^2	200 pm/s^2	9 m/s^2
200,000 km from Earth	10 mm/s^2	6 mm/s^2	200 pm/s^2	up to 12 mm/s^2
6 million km from Earth	10 μm/s^2	6 mm/s^2	200 pm/s^2	6 mm/s^2
3.7 billion km from Earth	29 pm/s^2	10 μm/s^2	200 pm/s^2	10 μm/s^2
Voyager 1 (17 billion km from Earth)	1 pm/s^2	500 nm/s^2	200 pm/s^2	500 nm/s^2
0.1 light-years from Earth	400 am/s^2	200 pm/s^2	200 pm/s^2	up to 400 pm/s^2

Quick Foray into Orbital Mechanics

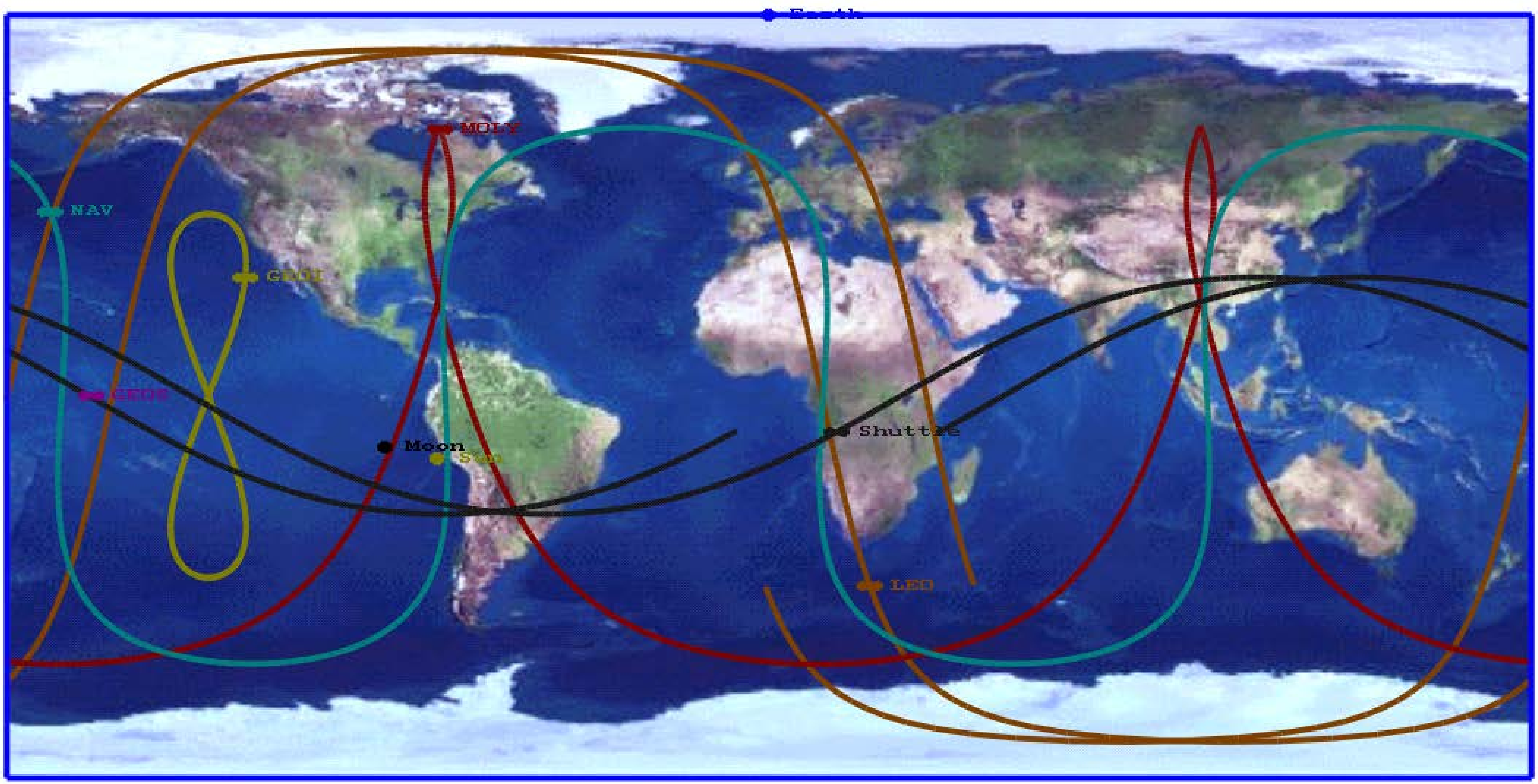
- ISS doesn't "escape gravity"
- Microgravity aboard the ISS a result of freefall
  - The station is constantly falling 'over the horizon'
  - Its vectors oppose one another to prevent it from constantly accelerating



Ground Track



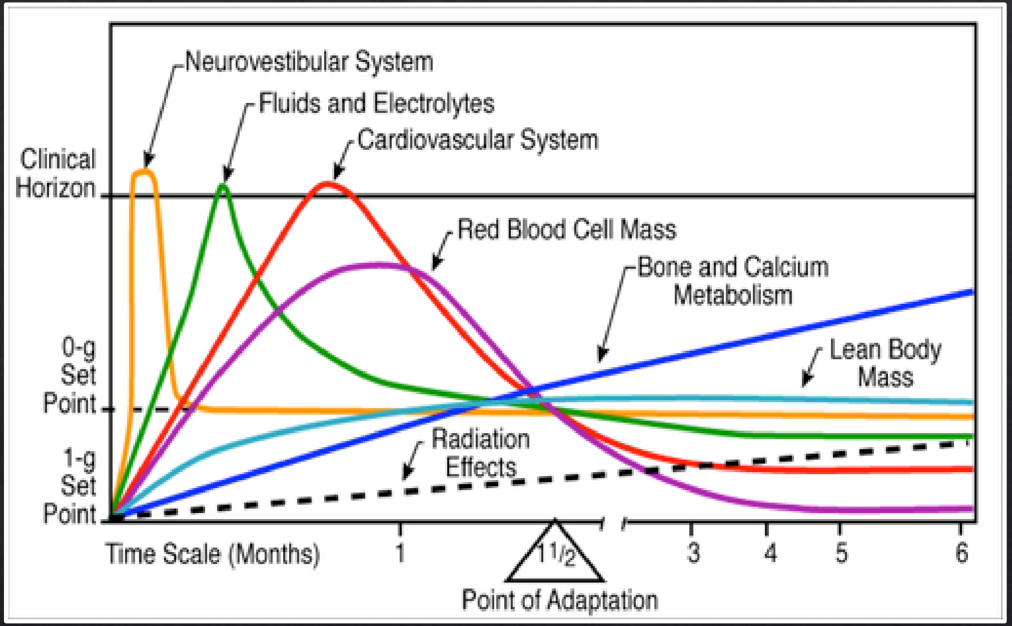
Ground Tracks



HUMAN PHYSIOLOGY OF SPACEFLIGHT

"Normal physiology, abnormal environment"

- Neurovestibular
- Cardiovascular
- Musculoskeletal



- Visual Impairment/Intracranial Pressure (VIIP) Syndrome
- CO_2

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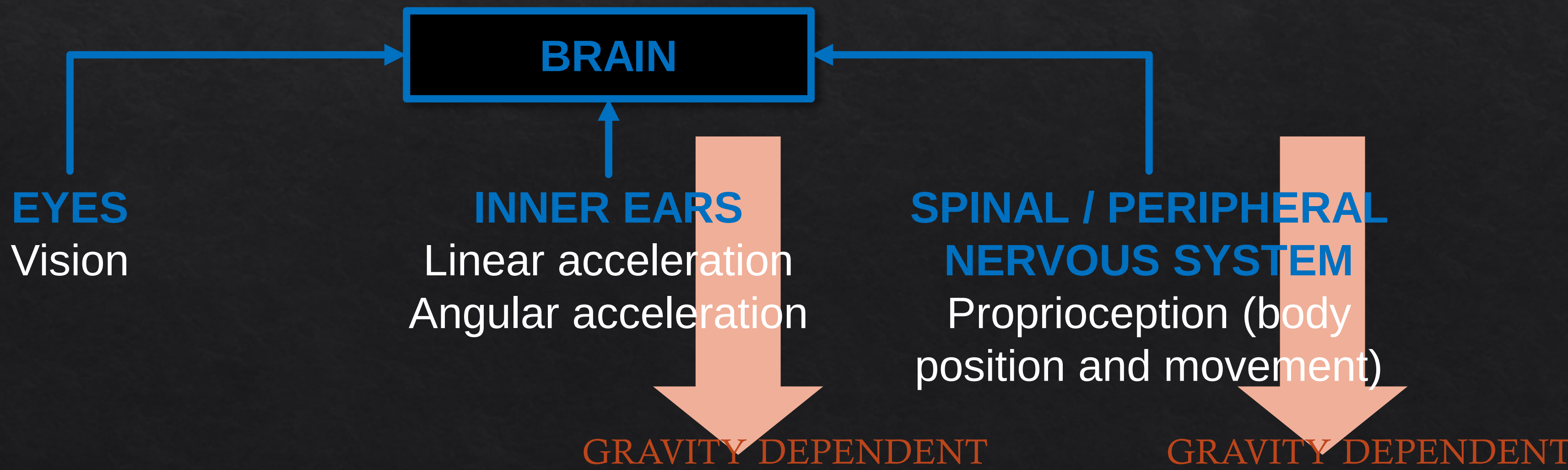
Neurovestibular Physiology

- Sense of orientation
- Balance / posture
- Pursuit tracking / maintaining gaze
- Smooth movement



Space Motion Sickness

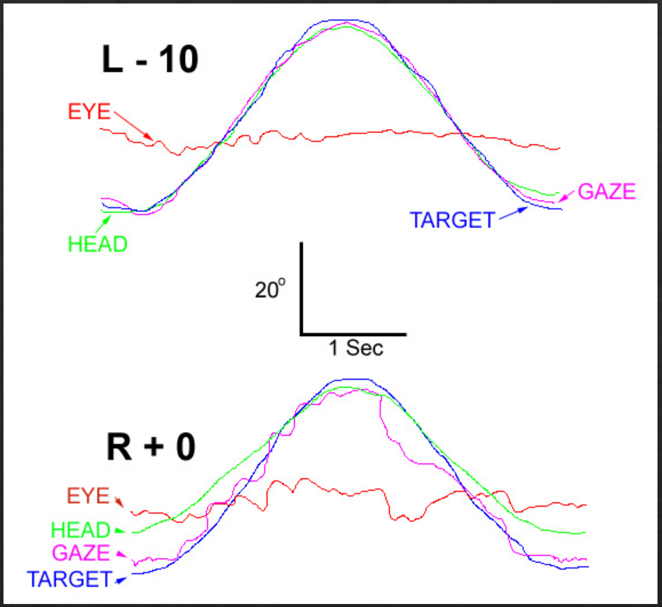
Photo NASA

Space Motion Sickness

- Predominate theory: Sensory conflict
- Incidence
  - Affects approximately 79% of crewmembers
  - 49% cases are mild, 36% moderate, 15% severe
  - Males and females equally affected
- Symptoms: Loss of appetite, nausea, vomiting
- Can occur within minutes of exposure to microgravity
- Typically resolve after 30-48 hrs, resolve completely within 4-7 days
- Treatment
  - 1-G orientation
  - Medications
  - Inactivity/sleep
  - Preflight adaptation training?

Other Neurovestibular Changes Due to Spaceflight

- Disequilibrium, vertigo → nausea, vomiting
- Balance / posture (postflight)
  - Instability upon standing
  - Swaying from side to side while walking
- Pursuit tracking / maintaining gaze
  - Time required to clearly focus on an image increases by up to 1-1.5 sec relative to preflight times
- All crewmembers are affected to some degree

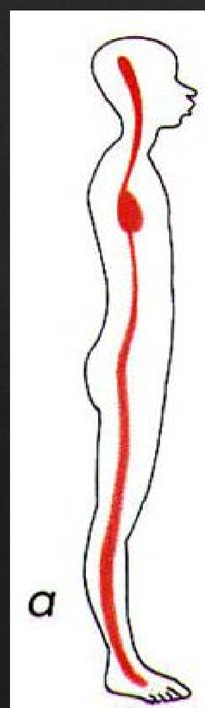


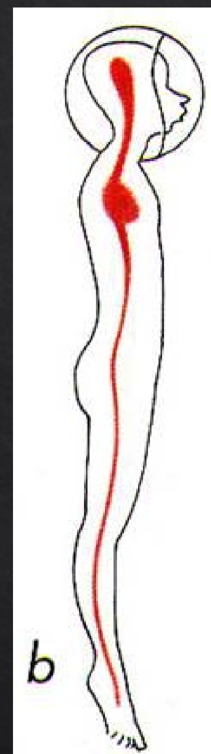
Fluid Shifts During Spaceflight

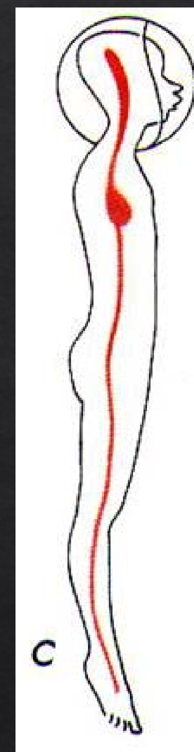
In space, the fluid tends to redistribute toward the chest and upper body. At this point, the body detects a "flood" in and around the heart.

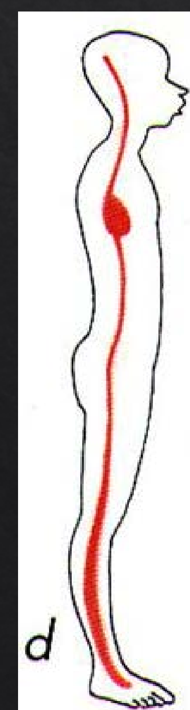
The body rids itself of this perceived "excess" fluid (~10%). The body functions with less fluid and the heart returns to a smaller size.

On Earth, gravity exerts a downward force to keep fluids flowing to the lower body.









Upon return to Earth, gravity again pulls the fluid downward, but there is not enough fluid to function normally on Earth.

Lujan and White (1995)

Think of Hydrostatic Columns:

- When standing, the heart must overcome the hydrostatic column to perfuse the brain
- When lying flat, the column is reduced to zero,

$$P_H = h \ x \ d \ x \ G$$

P_H (hydrostatic pressure gradient in mmHg)
h (height of column in mm)
d (relative density of blood, 1/13.6)
G (acceleration force)

Microgravity simply freezes you in that neutral state

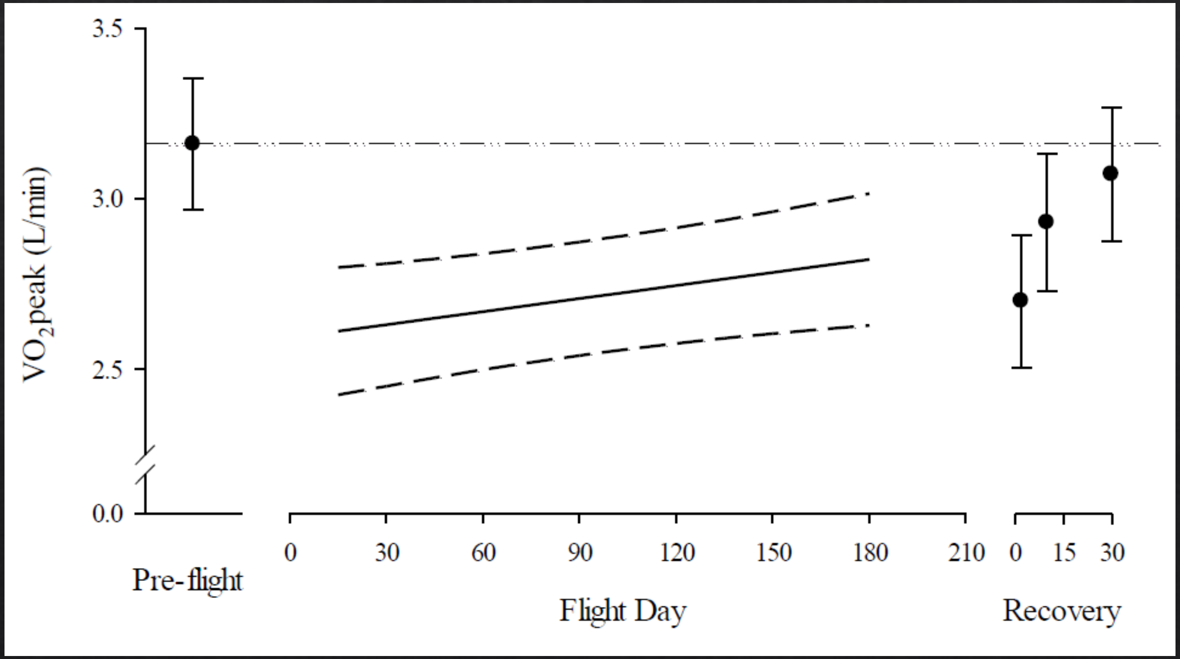
An Example of Fluid Shift

Shortly after reaching orbit:

- Leg volume decreases by ~1 L per leg
- Forehead tissue thickness increases by ~7% compared to preflight supine control

Other Cardiovascular Changes

- Maximal aerobic capacity (VO_2peak)
  - 17% decrease in mean VO_2peak in the first two weeks of spaceflight followed by a trend upward throughout the remainder of the mission
  - Postflight (24-48 hrs after landing) VO_2peak was reduced by ~15% from preflight and fully recovered 30 days after landing



http://humanreseaQrchroadmap.nasa.gov/Evidence/reports/Aerobic.pdf

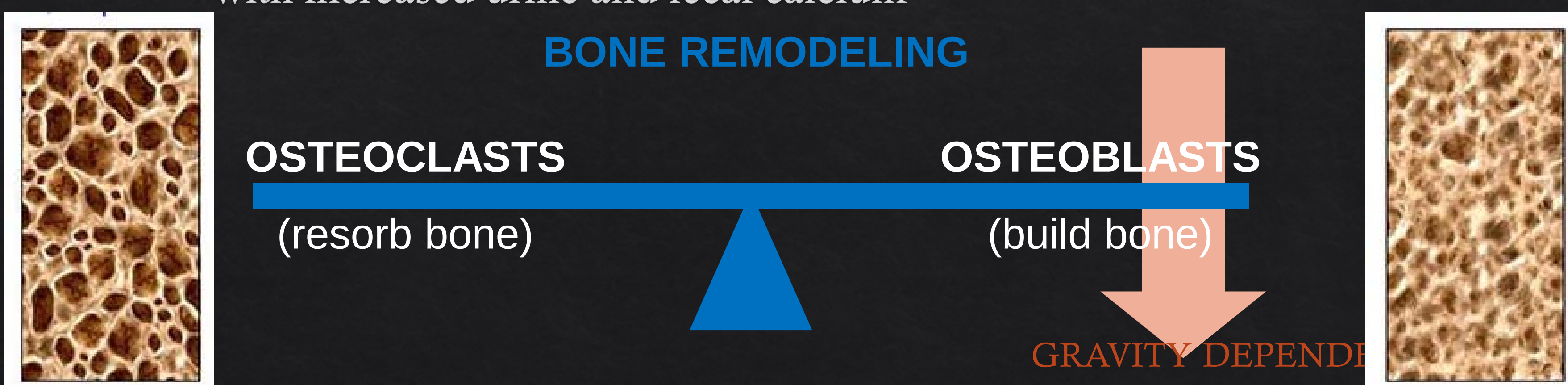
So what?

- After flight, changes in the heart and redistribution of body fluids cause inability of the body to adapt to rapid circulatory changes (orthostatic intolerance)
- Emergency egress capability may be affected

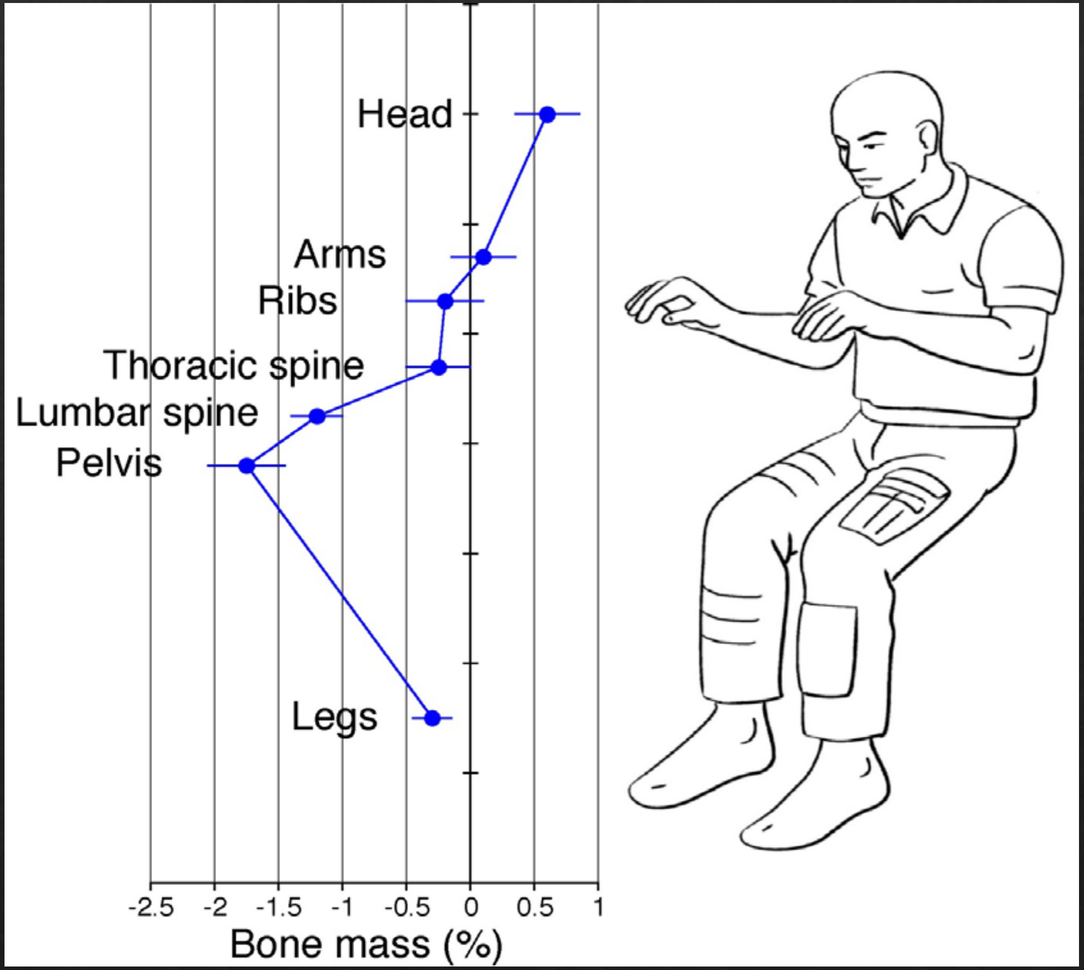
- Incidence: 20% of crewmembers
- Lightheadedness, “gray out,” fainting
- From reentry to several hours post-landing
- Countermeasures:
  - Aerobic exercise in flight
  - Fluid loading prior to deorbit
  - Returning crewmembers supine with the G-load from chest to back
  - G-suits

Musculoskeletal Changes

- Unloading of musculoskeletal system in microgravity
- Postural change with stretching of tendons and ligaments. Increase in on-orbit height by 2-6 cm.
- "Use it or lose it"
- Changes
  - Muscle atrophy (particularly antigravity muscles in back, hips, legs)
  - Bone demineralization 1-3% per month in lower extremities and spine, with increased urine and fecal calcium



Bone Loss During Spaceflight



Post-flight changes in bone density compared to preflight

Potential Problems Secondary to Bone Loss

Altered calcium metabolism

Kidney stones

Fractures

Reduced emergency egress capability

In-Flight Exercise Countermeasures

2.5 hours of exercise scheduled daily

T2
(Treadmill 2)

CEVIS
(Cycle Ergometer with Vibration Isolation & Stabilization)

ARED
(Advanced Resistive Exercise Device)

	T2	CEVIS	ARED
Neurovestibular	✓		
Cardiovascular	✓	✓	
Musculoskeletal	✓	✓	✓

Chronically Elevated CO_2

- On ISS, CO_2 scrubbed using Carbon Dioxide Removal Assembly (CDRA) and Vozdukh
- Terrestrial partial pressure of CO_2: 0.39 mmHg
- Hardware design based on original ISS Flight Rule limit for CO_2 of 7.6 mmHg
  - Consistent with recommendations set by OSHA and NIOSH in the 1980's
  - FR limit revised to 5.3 mmHg in 2008
- Recently limit for 24-hr average was decreased to 3.0 mmHg
  - Typical 24-hour average CO_2 levels during 6-crew ops is 3.1-3.6 mmHg
  - Operational limits for CO_2 continue to be driven by crew symptomatology

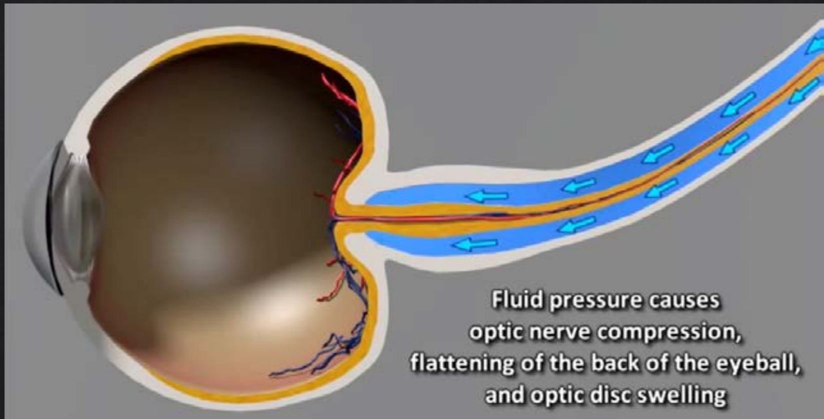
CO_2 Symptoms in Spaceflight

- In spaceflight, symptoms seem to occur at lower CO_2 levels than terrestrially
- Reported symptoms at current ISS operating levels
  - Fatigue
  - Difficulty concentrating
  - Irritability
  - Performance decrements
  - Headache
- Current evidence would suggest that an operational limit between 0.5 and 2.0 mmHg may maintain health and performance—As Low As Reasonably Achievable (ALARA) is the goal

Visual Impairment/Intracranial Pressure (VIIP) Syndrome

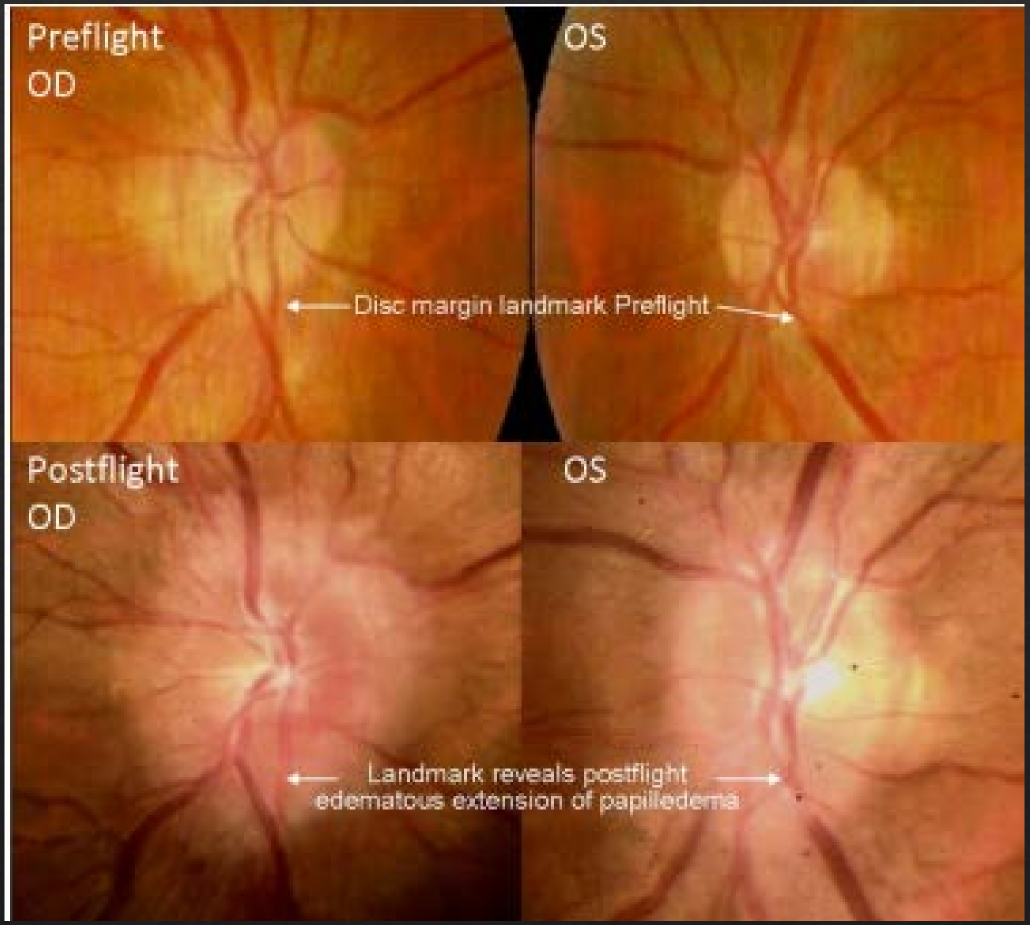
- Headward fluid shift in microgravity appears to cause changes to eye structures
- Anecdotal reports of vision changes in flight previously thought to be minor, temporary
- First documented case of VIIP occurred in an astronaut on ISS
  - Crewmember noticed a marked decrease in near-visual acuity throughout the mission
  - Postflight testing showed pathologic changes, which gradually improved but were still present >5 years postflight

StationLife: Eye-Opening Science
https://youtu.be/2hT-CRevst4



VIIP Syndrome

- Crewmembers participate in complement of eye tests multiple times in flight to better understand VIIP and impacts
- As of April 2015, 22/31 (71%) U.S. astronauts have had findings [Dr. C. Otto]



Environmental Monitoring

- Habitability
- Toxicology
- Radiation

Habitability

- Acoustics
  - Measure background, maximum exposure, daily exposure levels
- Water
  - Tested for total organic carbon, bacterial contamination, trace contaminants
  - Cleaner than most ground-based water sources
- Air
  - Monitor constituent levels (e.g., O_2, CO_2), pressures, volatile organic compounds
  - Sampled for bacterial and fungal contamination
- Surfaces
  - Sampled for bacterial and fungal contamination

Figure 21. Yellow (negative result – Biosafety Level 1)

Figure 22. Magenta (positive result- Biosafety Level 2)

Figure 3. Bacterial Colonies (smooth)

Figure 4. Fungal Colonies (fuzzy)

Toxicology

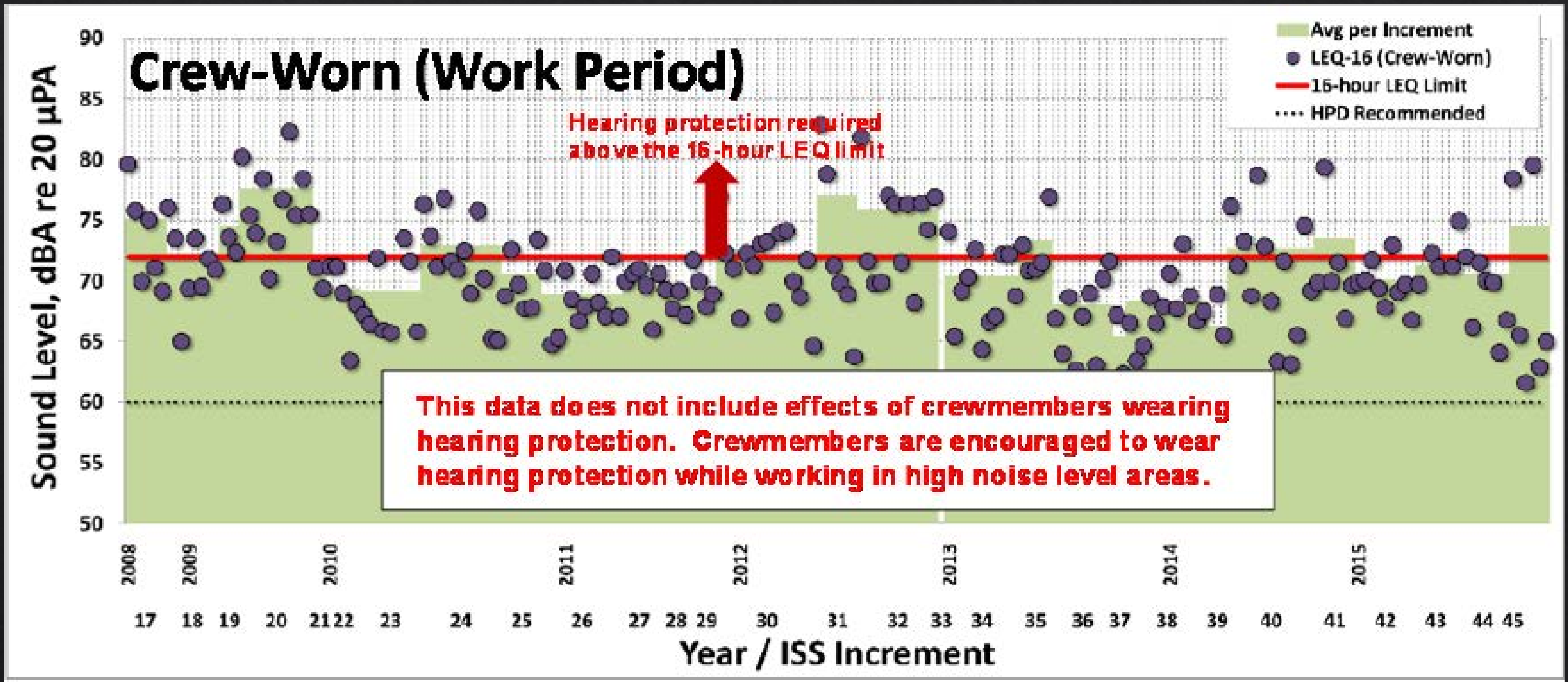
- SURGEON works in conjunction with Toxicology, Payloads, and ETHOS to monitor the environment and mitigate hazards
  - Fire, smoke, and toxic spill procedures
  - Hazmat Database
  - Crew Contamination Protection Kit (CCPK)
    - Personal protective equipment
    - Cleanup supplies
  - Real-time measurements
    - Compound Specific Analyzer-Combustion Products (CSA-CP): monitors CO, HCl, and HCN
    - Portable Oxygen Monitor
    - Carbon Dioxide Monitor
    - Formaldehyde Monitoring Kit
  - Grab Sample Containers (analysis postflight only)

Space Radiation Analysis Group (SRAG)

- Staff the radiation console in MCC (4 hours daily during nominal space weather conditions, and continuously during EVAs and significant space weather activity)
  - Nominal, alert, contingency conditions
  - Higher vs. lower-shielded locations
- Characterize and quantify the radiation environment inside and outside the ISS
- Project preflight and EVA crew exposures
- Evaluate radiological safety with respect to exposure to isotopes and radiation producing equipment carried on the spacecraft

Hazards - Spacecraft Environment

- Noise levels – low risk for permanent hearing damage but may degrade voice communications, alarm audibility, and habitability
  - Above requirements in Russian Segment
  - US Segment meets noise requirements in all modules except in Node 3 due to the Regen ECLSS racks

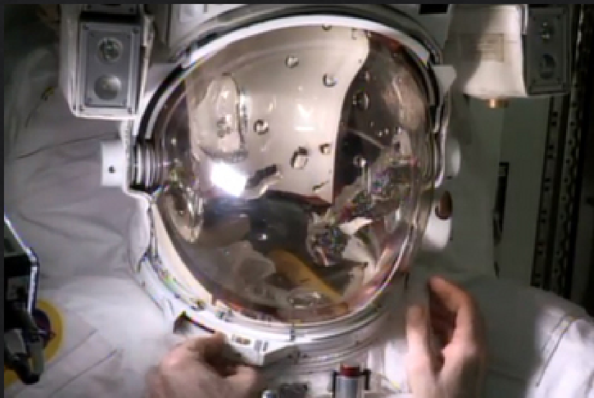


Hazards - Spacecraft Environment

- Cabin atmosphere maintained at sea-level equivalent, with an O_2/N_2 mix similar to terrestrial air (except for CO_2)
- Closed environment
  - No air convection – fans needed for air circulation
  - Scrubbers necessary to remove atmospheric contaminants (e.g., CO_2)
  - Regenerative Environmental Control and Life Support System turns "yesterday's coffee into tomorrow's coffee"
    - Undiluted pretreat: 36.5% sulfuric acid, 9% chromic acid – serious eye and skin injury

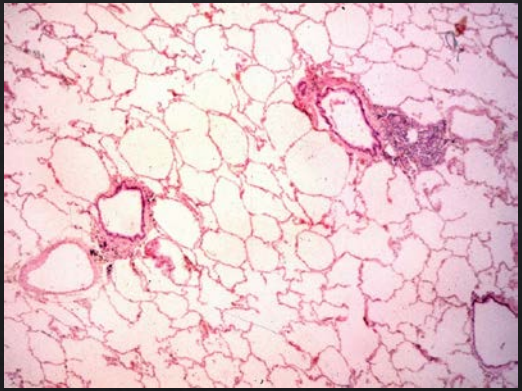
Hazards - Spaceflight Mission

- Launch and reentry forces - Soyuz
  - Launch: typically 3.7 G (plus vibrational forces, noise)
  - Landing: nominally, peak at 4 G, may go as high as 8 G
    - If seat fails to stroke, ~21 G may be experienced
    - "A series of loud bangs followed by a car crash"
- Flight activities
  - Maintenance – e.g., WHC R&R, cargo/rack transfers
  - Payloads – e.g., combustion, animal experiments, blood collections
  - Exercise hardware – e.g., resistive loads (up to 600 lbs on ARED), bungee cords
- Extravehicular Activity (EVA)
  - Reduced pressure
  - Risk of water in helmet

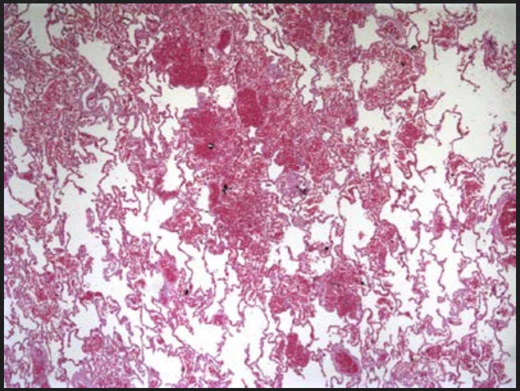


Vacuum

- Evolved gas disorders
  - **Decompression Sickness (DCS):** sudden decompression results in formation of N_2 bubbles, which can affect any part of body
  - **Ebullism:** spontaneous evolution of water from liquid to gaseous state, occurs when ambient pressure is 47 mmHg or less
    - Unconsciousness within 10 sec, circulatory arrest in 10-30 sec, irreversible brain injury/death within 4 min



NORMAL LUNG TISSUE



EBULLISM

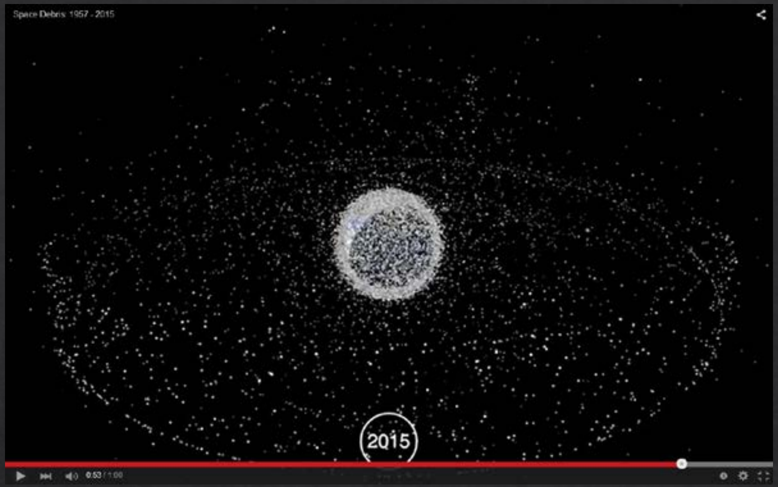


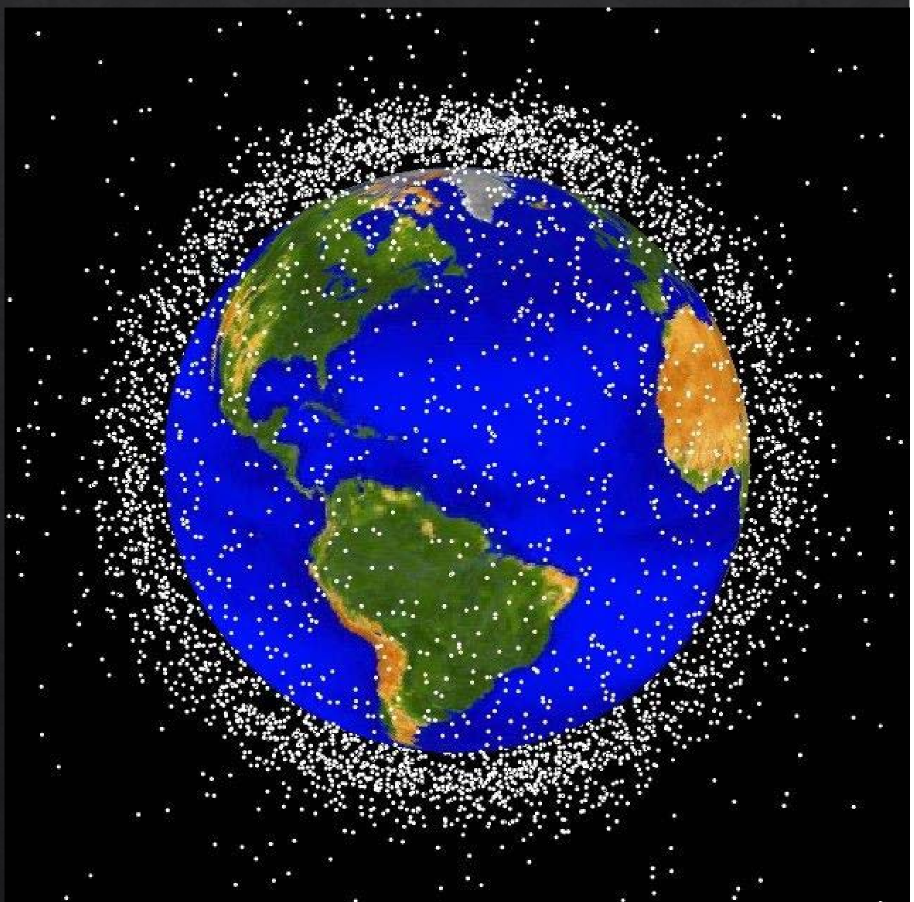
Figure 3. Largest crater found on the PMIA handrail was 1.85 mm diameter with 0.33-mm-high crater lips.

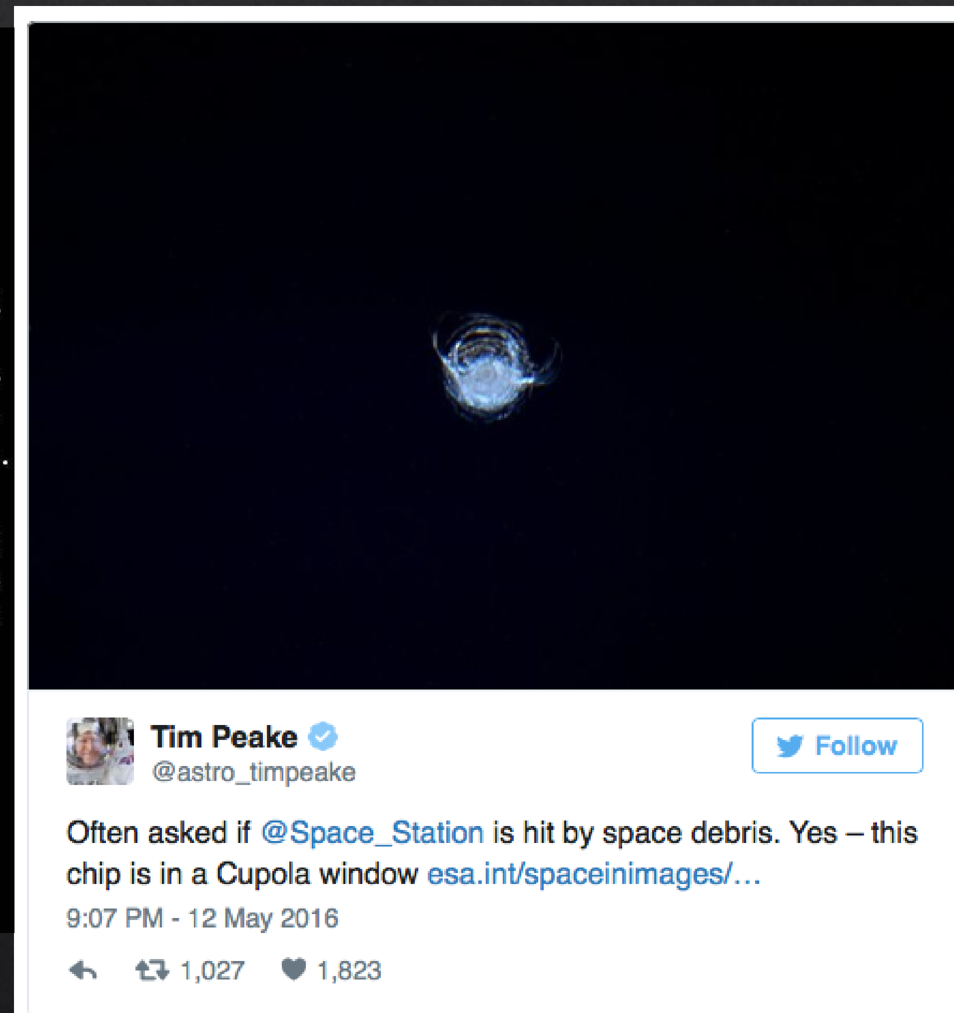
Figure 6. Mastracchio's left glove after STS-118 EVA #3.

Orbital Debris

- Average relative velocity between two objects: 10 km/sec (22,000 mph)
  - 100-gram fragment has kinetic energy equivalent to 1 kg of TNT
- Shielding can be reasonably afforded with objects up to 1 cm in size
- Risk to spacecraft and spacesuits
  - Direct damage
  - Indirect damage (e.g., handrail)
  - Decompression

500,000 pieces of debris and it only takes one…





Preflight, Inflight, Postflight

- Preflight medical evaluations
- Crew training
- Health Stabilization Program
- Launch support

- MCC/on-call
- Mission management
- Private conferences
- Health and fitness evaluations
- On-orbit medical testing

- Landing support
- Direct Return
- Postflight medical evaluations
- Postflight reconditioning

Preflight Crew Medical Training

- Most astronauts are not physicians
- All crewmembers receive ~11 hours of Advanced Life Support training (classroom + mockup simulation)
- 2 Crew Medical Officers (CMO) per Soyuz flight
  - Additional ~25 hours of training


Vision Testing
Tonometry
Fundoscopy
Optical Coherence Tomography (OCT)
Ultrasound

Health Stabilization Program

- 14-day quarantine for crew and supporting personnel in Baikonur
- Crew contacts
  - 3-day observation period prior to direct crew contact
  - Medical screening

Launch

- Suit up
- Bus to launch site
- Launch!

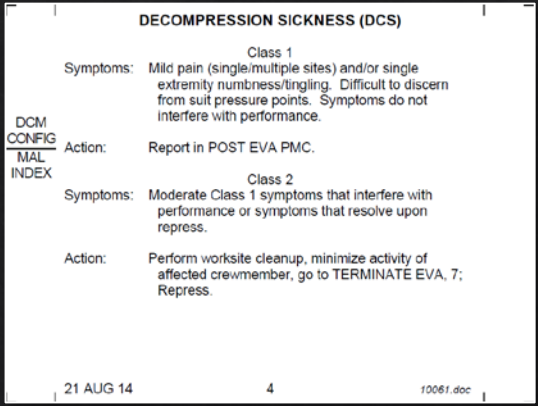
- Crew Surgeons
  - Prime – accompanies crew on bus, in launch viewing area with family and guests for launch
  - Deputy – helo for contingency support
- Coordination with Search & Rescue forces
- First Private Medical Conference (PMC) in Star City and/or Baikonur

On Orbit Medical Support

- Orbit 2 console, on-call 24/7
- "House calls"
  - Private Medical Conferences (PMC) - weekly
  - Private Psychological Conferences (PPC) – biweekly
  - Private Exercise Conferences (PEC) – monthly
  - IP phone calls/emails – as needed
- Periodic health and fitness evaluations
  - Also pre-/post-EVA
- On-orbit medical testing
  - Eye evaluations, hearing tests, body mass measurements, cognitive assessments
- Mission management meetings
- Unscheduled PMC/off-nominal testing as clinically indicated

EVA Support

- Real-time monitoring of biomed data
- Concerns
  - Decompression Sickness (DCS)
    - ISS 14.7 psi; EMU 4.3 psi @ 100% O_2
    - Reduced pressure releases N_2 bubbles into blood, tissues
    - Symptoms range from joint pain to unconsciousness
    - Prevention: Adequate prebreathe of 100% O_2 that lowers N_2 pressure in decompression stages
    - DCS until proven otherwise!
      - Cuff Classes 1-4 define actions
    - Treatment options include repressurization, 100% O_2, Bends Treatment Adapter (BTA), fluids
  - CO_2 symptoms
  - Water in helmet
  - Rapid repressurization



DECOMPRESSION SICKNESS (DCS)

DCM CONFIG
MAL INDEX

Class 1

Symptoms: Mild pain (single/multiple sites) and/or single extremity numbness/tingling. Difficult to discern from suit pressure points. Symptoms do not interfere with performance.

Action: Report in POST EVA PMC.

Class 2

Symptoms: Moderate Class 1 symptoms that interfere with performance or symptoms that resolve upon repress.

Action: Perform worksite cleanup, minimize activity of affected crewmember, go to TERMINATE EVA, 7; Repress.

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USA and Russian Suits

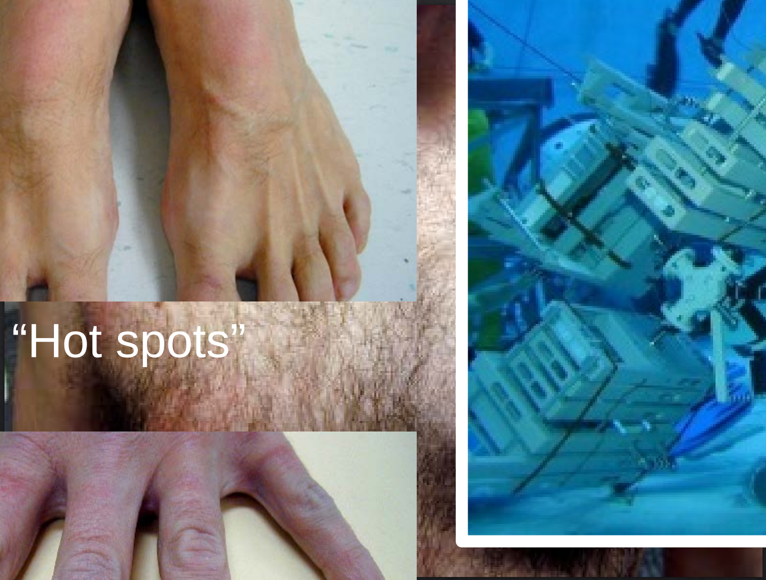
US EMU

- 4.3 PSI – about FL 305
- DCS risk reduced by set prebreathe protocol(s)
- Separate torso and leg units

Russian Orlan

- 5.8 PSI – about FL 235
- Lower DCS risk = faster prep
- Rear entry suit

Extravehicular Mobility Unit (EMU) Issues



“Hot spots”

Fingernail delamination

Shoulder injuries

Figure 3-13 Restricted scapulothoracic motion.

Behavioral Health and Performance Support

- Significant physical and psychosocial stressors
  - Environmental (e.g., noise, odors)
  - Mission (e.g., increased reliance on ground teams, overwork and underwork, monotony of schedule and diet, life-threatening events onboard)
  - Interpersonal (e.g., personality differences, cultural differences, family illnesses)
  - Intrapersonal (e.g., isolation and confinement, reduced personal space, drive to succeed)
- Countermeasures
  - Selection
  - Preflight training: psychological adaptation skills, team building, analog experiences
  - Family support
  - Private Psychological Conferences
  - Exercise
  - Care packages

Common Conditions

- Space motion sickness
- Sleep problems
- Congestion
- Headache
- Overuse syndrome, sprains, strains
- Abrasions/minor cuts
- Skin rashes

Medical Evacuations from Space

- None in NASA history (knock on wood!)
- Soviet/Russian Space Program
  - Salyut 5 (1976) station abandoned 49 days into 54 day mission for intractable headaches
  - Salyut 7 (1985) evacuation at 56 days into 216 day mission for prostatitis and urosepsis
  - Mir (1987) evacuation at 6 months into 11 month mission for cardiac dysrhythmia

Landing & Direct Return

Austere landing environment
on the plains of Kazakhstan

Postflight

- Astronaut Quarantine Facility
- Medical/science data collection
- Reconditioning
  - Astronaut Strength Conditioning and Rehabilitation Specialists (ASCRs)
  - 45-day intensive training designed to return crew to baseline
- Debriefs

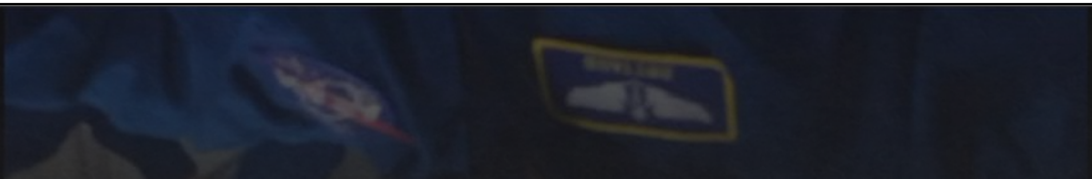
Summary

- Flight Surgeons cover a gamut of areas related to astronaut health and performance
- Physiological changes in spaceflight include
  - Neurovestibular
  - Cardiovascular/fluid shifts
  - Musculoskeletal
  - VIIP
  - CO_2
- Hazards to crew health and performance come from the space environment, spacecraft environment, and spaceflight mission
- Pre-, in-, and post-flight countermeasures are in place to mitigate the risk of medical events

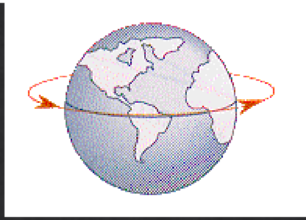
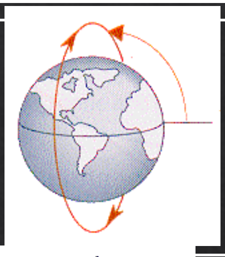
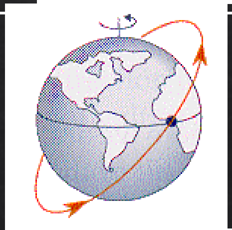
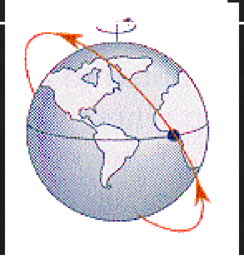
Acknowledgments

- Slides adapted from presentations by other Flight Surgeons, particularly
  - Dr. Stevan Gilmore
  - Dr. Richard Scheuring
  - Dr. Joe Dervay
  - Dr. Jennifer Law

Questions?

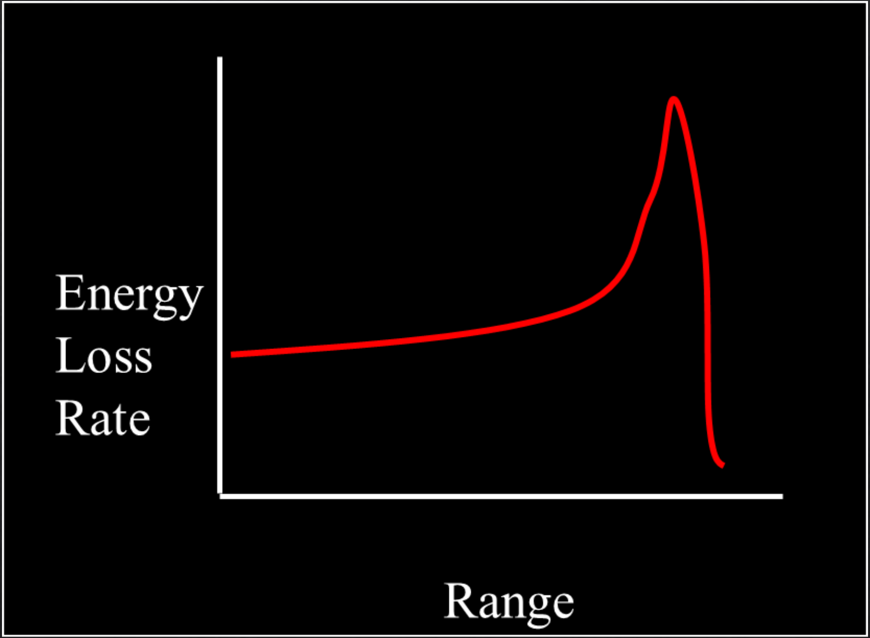


Backup

Inclination	Orbit Type	Diagram
0^o or 180^o	Equatorial	
90^o	Polar	
$0^o \underline{<} I < 90^o$	Direct (Prograde)	
$90^o < I \underline{<} 180^o$	Indirect (Retrograde)	

LET vs. Energy

- Due to high particle velocity, initial energy loss is relatively low
  - As particle slows down (reduced kinetic energy/ velocity) more time to interact with matter and energy transfer rate increases
  - When the particle has lost most of it's energy, the last remaining energy is transferred over a very short distance.   High energy/path length
- Analogy: Skipping Stones



LET vs Energy

- As charged particles travel through matter, kinetic energy of the particle is deposited into the matter
  - Energy is transferred primarily to electrons held by atoms in the medium, stripping them from the atoms
  - Scattering –transfer of some or all the particle energy to the atom
- Secondary radiation is generated by nuclear interactions between the primary particle with matter.
  - Frequently the secondary particles are more damaging than the primary ones

Medical events in Apollo Program

- Apollo 8 crew: 1st Americans to report space motion sickness
- Apollo 9: Space motion sickness caused EVA to be rescheduled (1st timeline change due to medical cause)
- Apollo 11: Type 1 DCS in Command Module Pilot
- Apollo 13: Kidney infection during mission
- Apollo 15: Cardiac dysrhythmia after lunar EVA
- Apollo-Soyuz Test Project: Nitrogen tetroxide chemical pneumonitis on reentry

Inflight Shuttle Medical Events

- A study of 607 astronauts and payload specialists (521 men and 86 women) involved in 106 Space Shuttle missions (STS-1 through STS-108) between April 1981 and December 2001 covering over 5,496 flight days (4,673 days for men and 823 days for women)

- 98.1 % of men and 94.2% of women reported 2,207 separate medical events or symptoms during flight (1,882 events in men and 325 events in women)
  - Space adaptation syndrome (39.6%)
  - Episodic insomnia and fatigue (36%)
  - Nervous system and sensory organs (16.7%)
  - Digestive system (9.2%)
  - Injuries and trauma (8.8%)
  - Musculoskeletal system and connective tissue (8.2%)
  - Skin and subcutaneous tissue (8%)
  - Respiratory system (4.5%)
  - Behavioral signs and symptoms (1.8%)
  - Infectious diseases (1.3%)
  - Genitourinary system (1.5%)
  - Circulatory system (0.3%)
  - Endocrine, nutritional, metabolic and immunity disorders (0.1%)

GCR Continued

- Modulation varies with solar cycle (22 years) so that at solar max, the GCR bathing earth is about ½ the flux at solar min.
  - GCR is attenuated by Earth atmosphere, which has thickness of 1000 g/cm2 and by powerful geomagnetic fields.
  - Particles with > 10 GeV aren't affected as much by solar wind / magnetic fields

- Biologically Most Damaging

Inner and Outer Belt

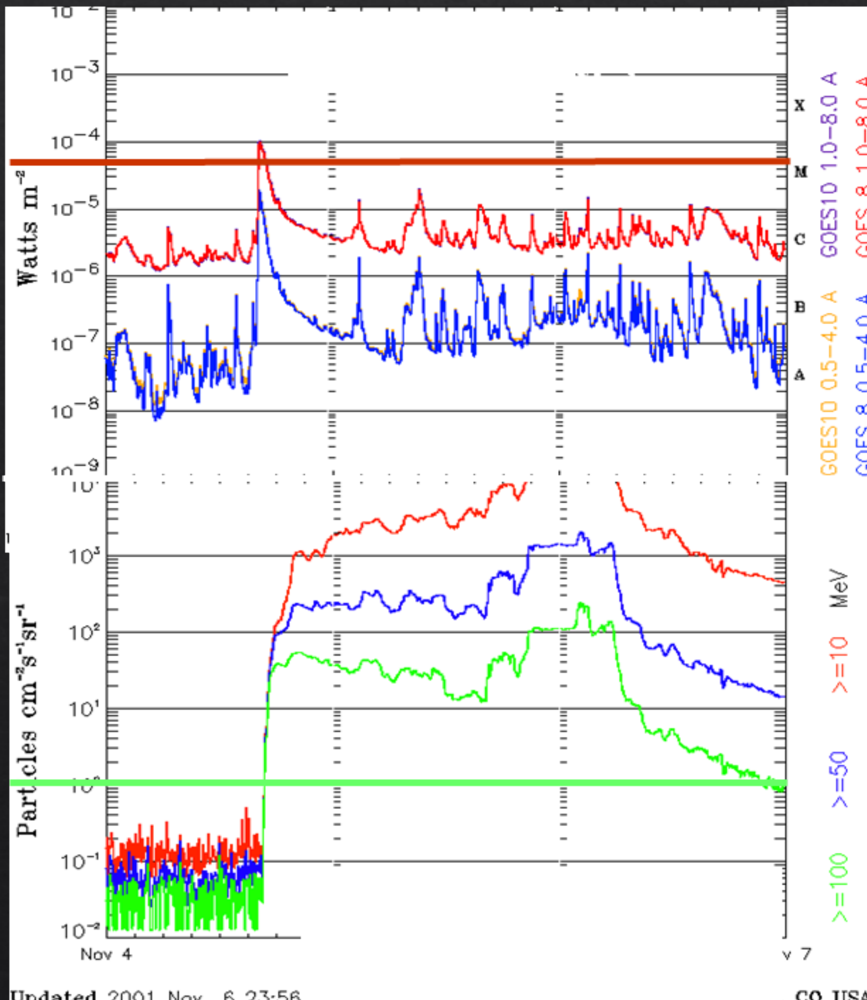
- Inner belt protons are most likely from interaction of GCR with asmostphereic species, forming short lived neutrons.
    - Some decay into protons / electrons, which are then bound.
    - Typically high energy with protons of 50 MeV and electrons of 30 MeV.
- Most human platforms in LEO are well below the floor of the belt.
    - Spacecraft with alt of 225 km have 100x increase in radiation flux in SAA
    - At 440 km, its 1000x.

- Outer belt particles originate from the interaction of solar wind with magnetosphere.
    - More susceptible to dynamic effects of solar wind and SCR.
    - Mostly electrons

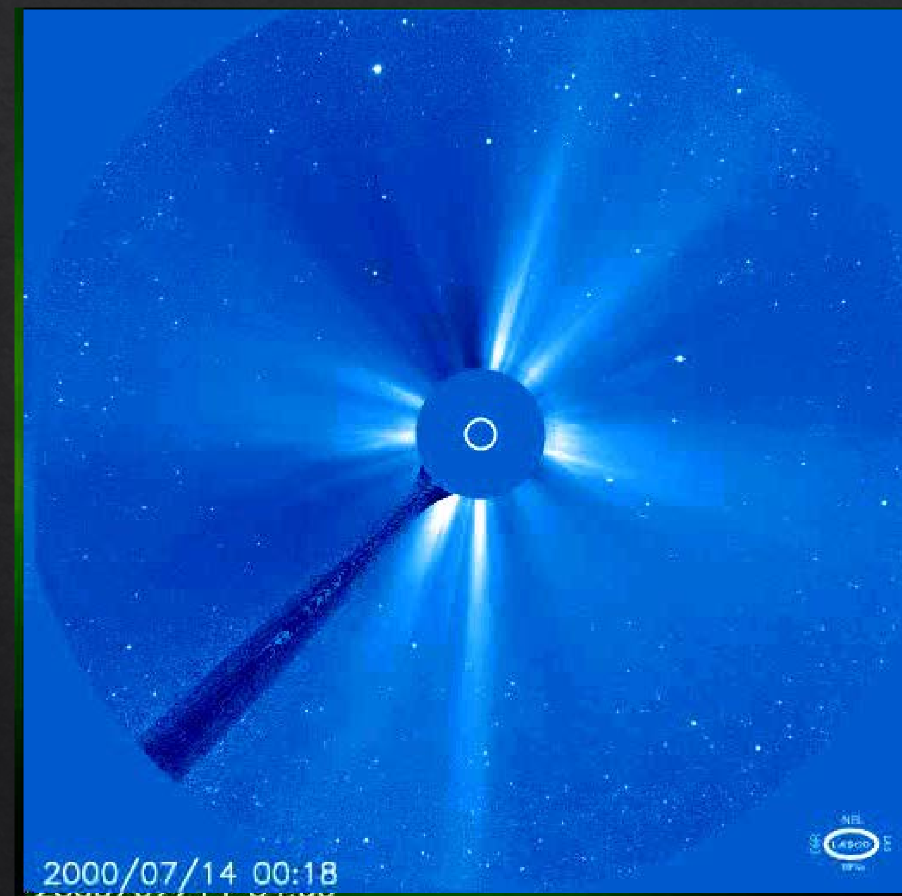
Solar Energetic Particle Events

- About 1% of CME’s deliver SEP events
  - High flux levels of protons
  - Arrival times between minutes to hours. Typically average ~ 30 minutes
  - High proton energies up to 1000 MeV
    - >10 MeV to get inside EVA suit
    - >100 MeV to get inside spacecraft
- Energetic proton events are not predictable..
  - Once an event begins, it is difficult to project how the event will evolve..
- In LEO, Trajectory and timing will influence the total exposures. Intermittent exposures
- In free space, no geomagnetic shielding means constant exposure to a proton event

Solar Particle Events



Horizontal lines (red & green) are alarm/action levels



images from SOHO/NASA

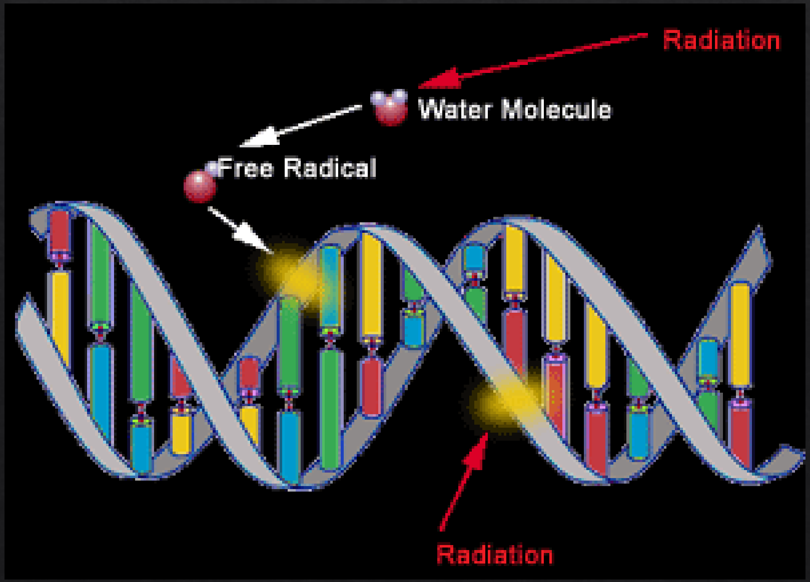
Radiation Exposure Career Limits

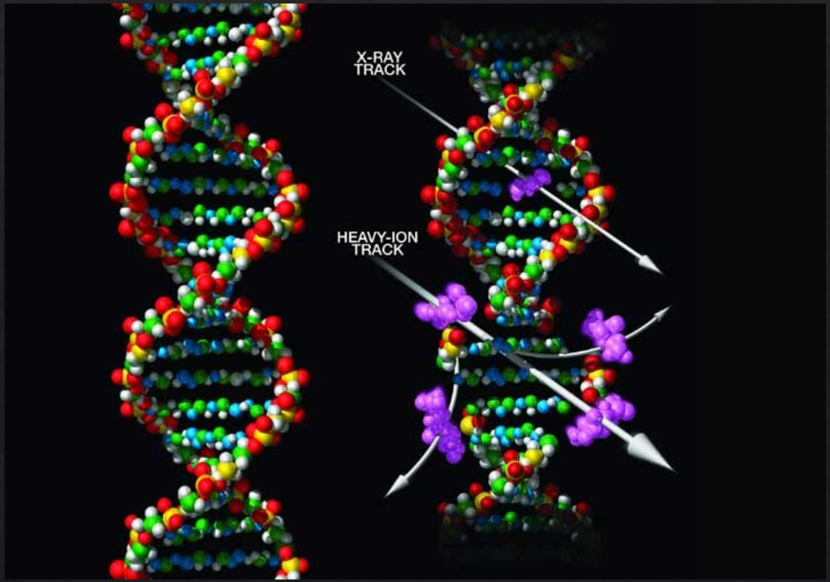
- 3% additional CA mortality risk limit explained
  - To allow for biodiversity and to assure 95% CI, NASA technically uses 1.15%
  - This only includes occupational exposures
  - Any medical, recreational, etc exposure doesn't count toward NASA's limit

<u>Annual and 30 day limits serve to protect against deterministic effects</u>

DNA with Radiation Hit

- Mechanisms of DNA damage
  - Water in the body absorbs a large portion of the radiation and becomes ionized to form highly reactive, water-derived radicals. The free radicals then react with DNA molecules causing the breaking of chemical bonds or oxidation.
  - The radiation collides with the DNA molecule directly.

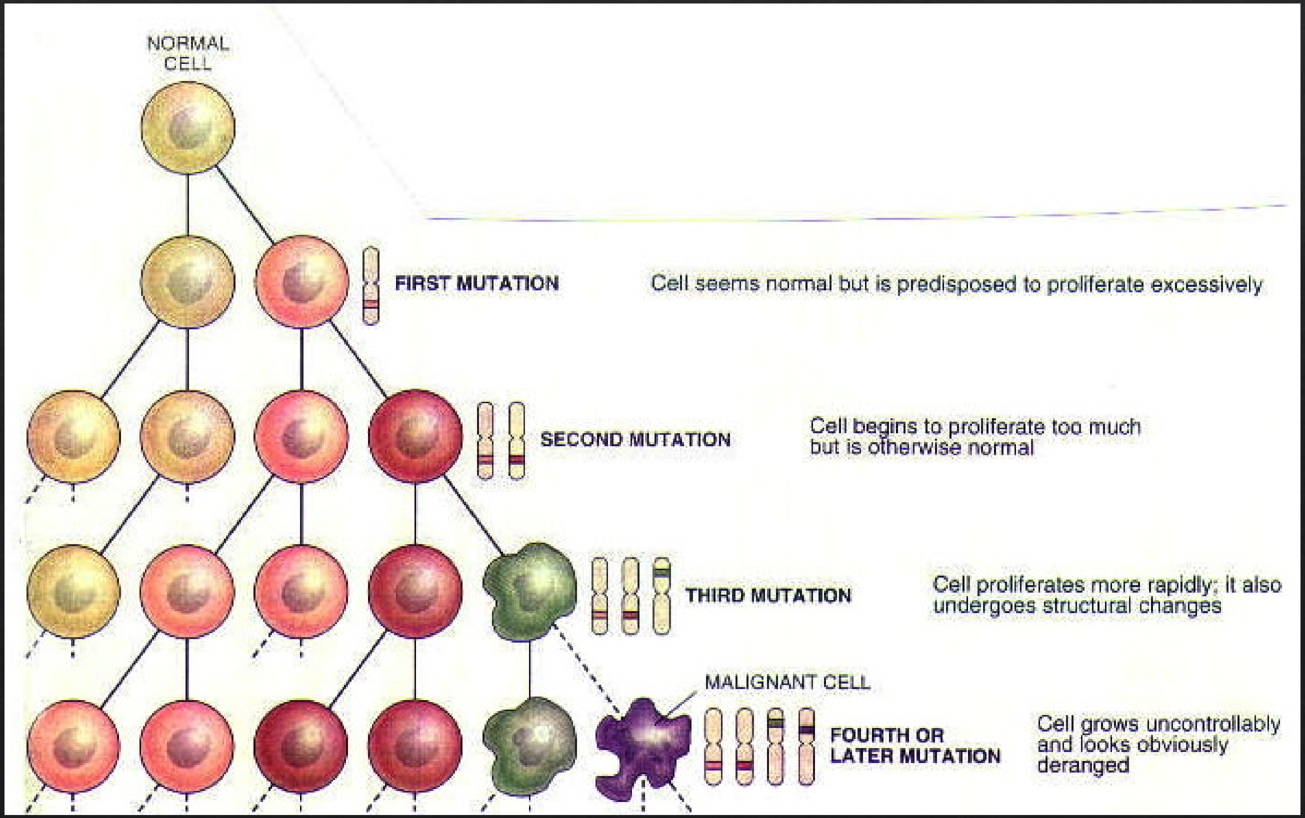




http://srag.jsc.nasa.gov/SpaceRadiation/Why/Why.cfm

Radiation Effects on Cells

- DNA mutations are passed along to subsequent cell lines, ultimately resulting in malignant (cancer) cells

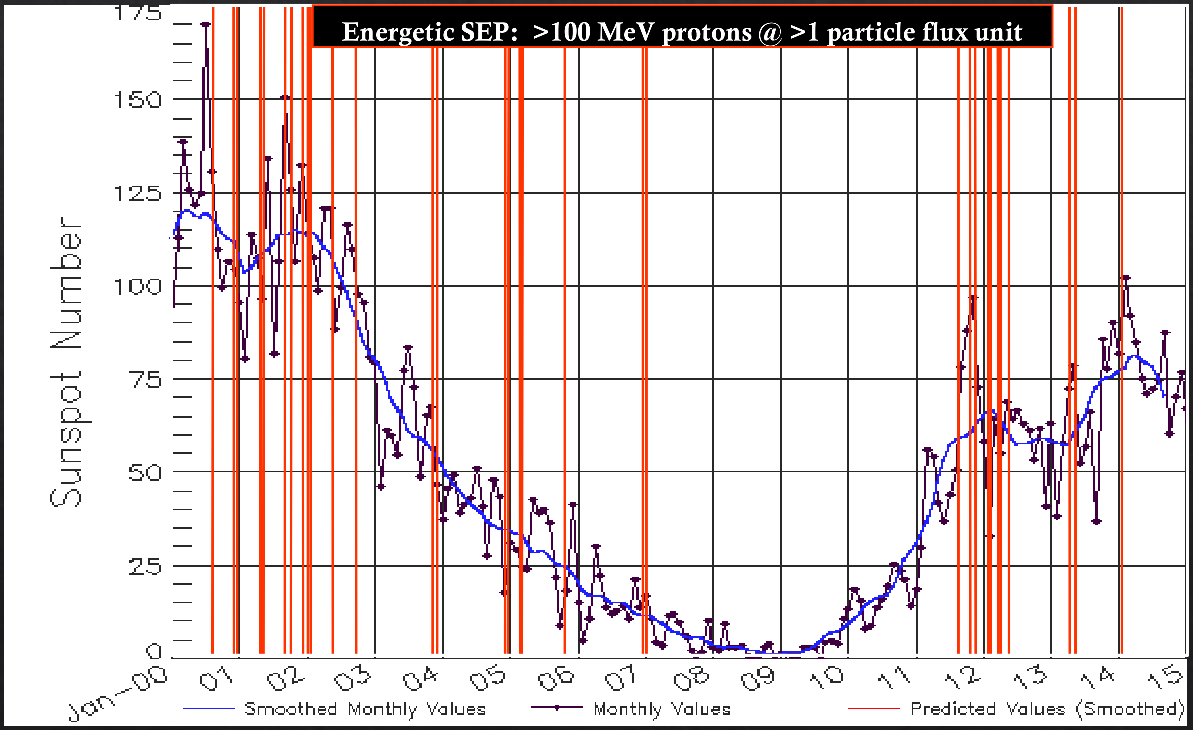


Radiation Protection

- SPE exposures to ISS crew have not been extreme:
  - significant protection by the geomagnetic field
  - Fortunate ISS location within the magnetic field during the most intense time of events.

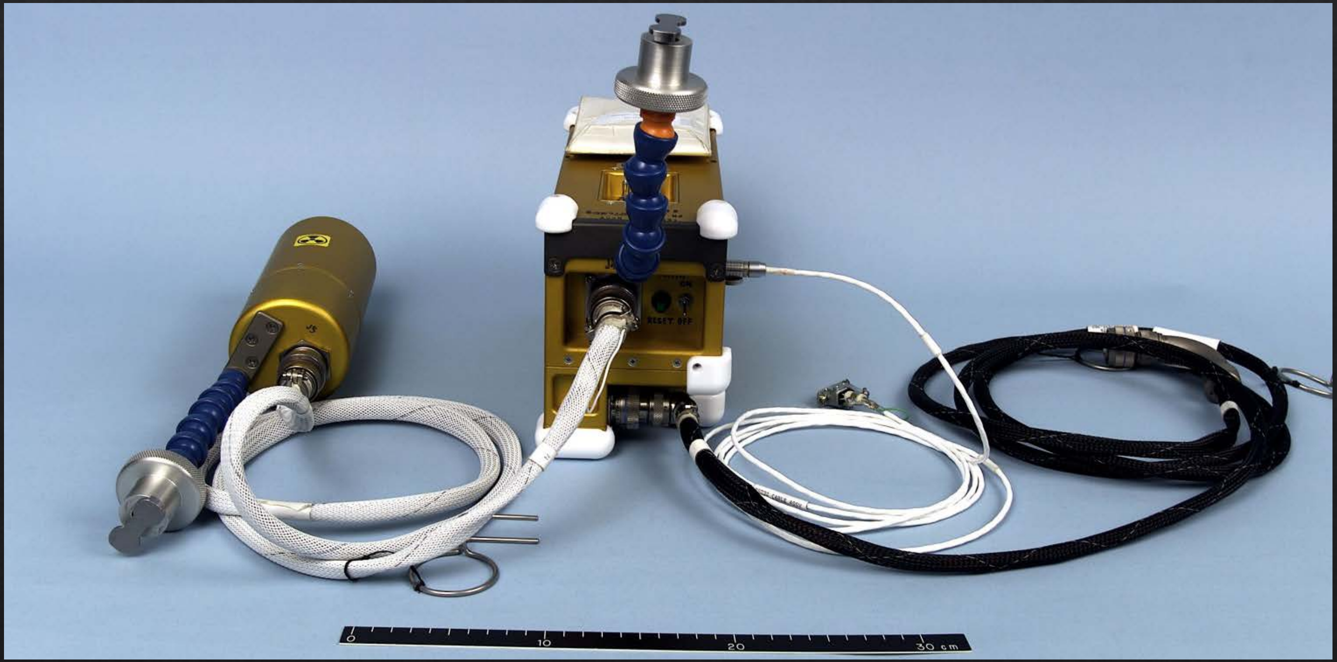
ISS Solar Energetic Particle Events

All Cycle 23 and 24 Events that meet Operational Coverage Criteria



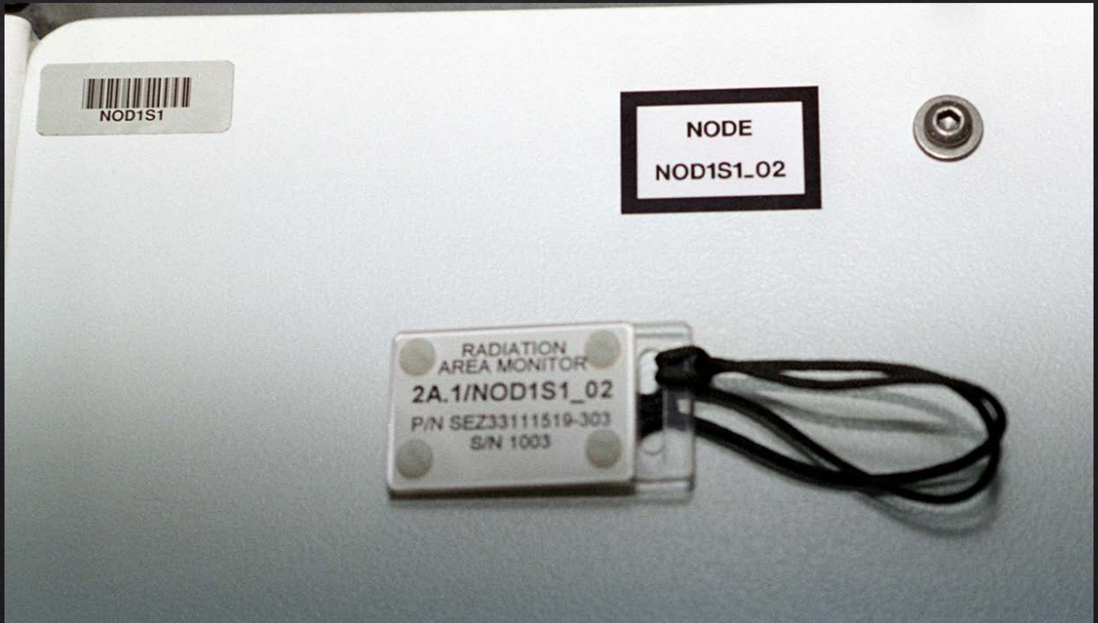
Tissue Equivalent Proportional Counter

- Shuttle and ISS (intravehicular)
  - Omni-directional
  - Contingency evaluation, trend analysis, model validation



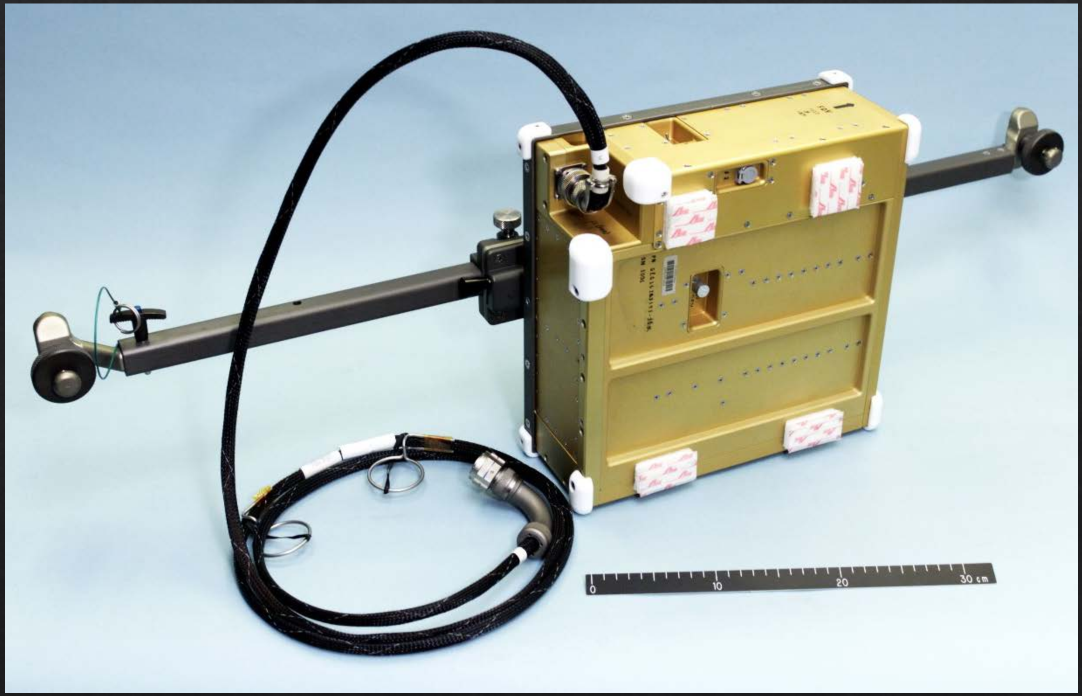
Dosimeters

- Passive Radiation Dosimeter (PRD)
  - ISS - Radiation Area Monitors (RAM)
  - Trend analysis, model validation
- ISS - High Rate Dosimeters (HRDs) only
- Trend analysis, model validation, contingency evaluation



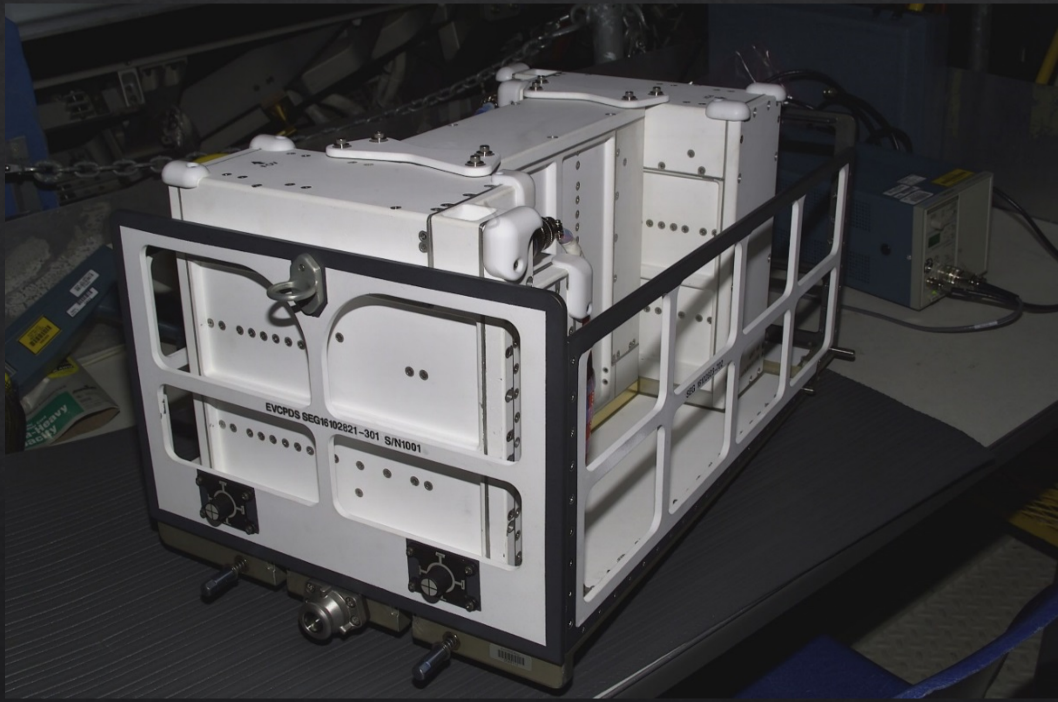
Charged Particle Directional Spectrometers (Internal)

- Real-time time-resolved measurements, model validation, contingency evaluation
- Single axis internal unit



Charged Particle Directional Spectrometers (External)

- Real-time time-resolved measurements, model validation, contingency evaluation
  - Three axis external unit
  - +X, -X, -Z fixed station axes



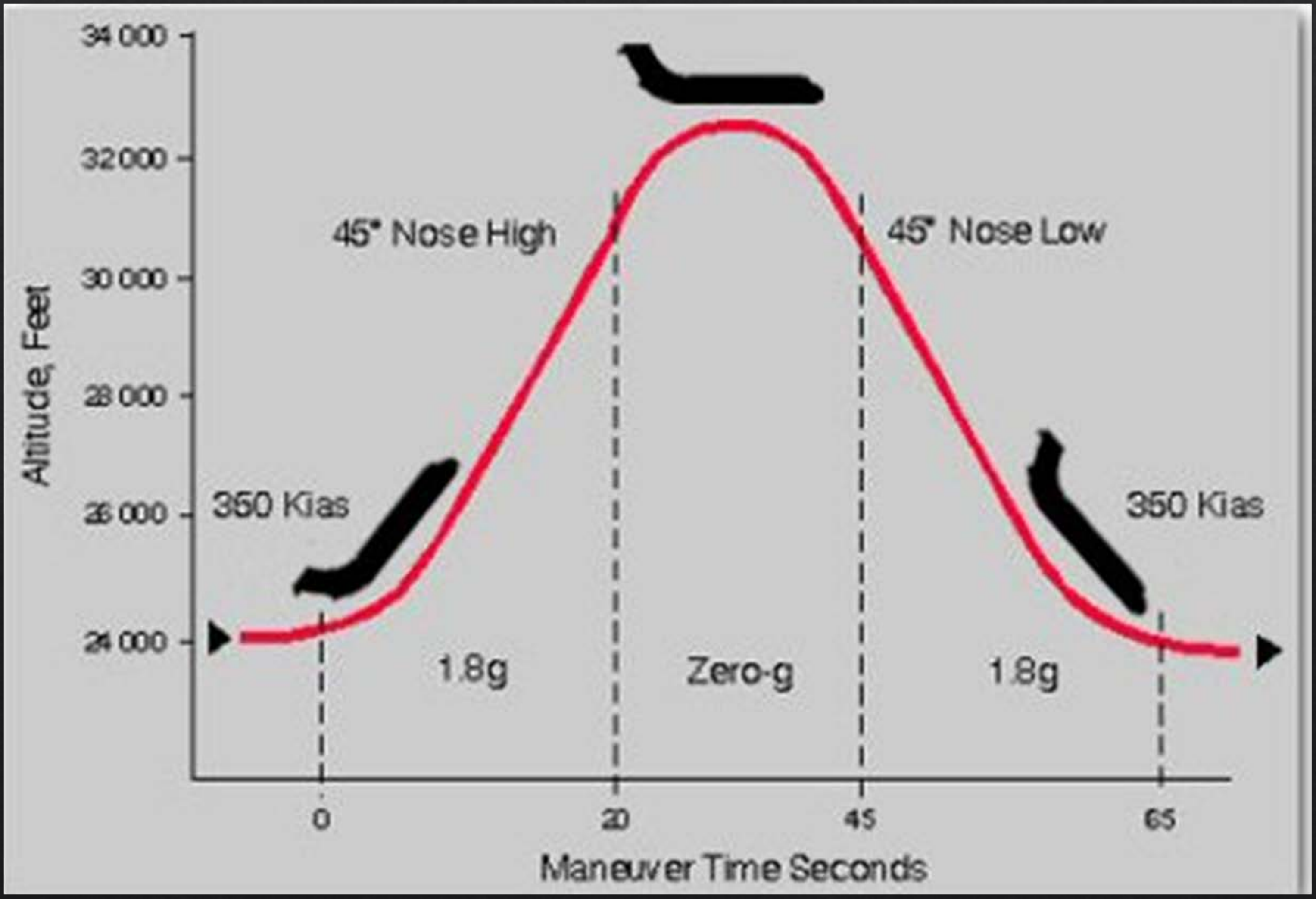
Micro Gravity

- If ISS isn't in "Zero-G", how do astronauts float?

They don't…

…they fall.

Reduced Gravity



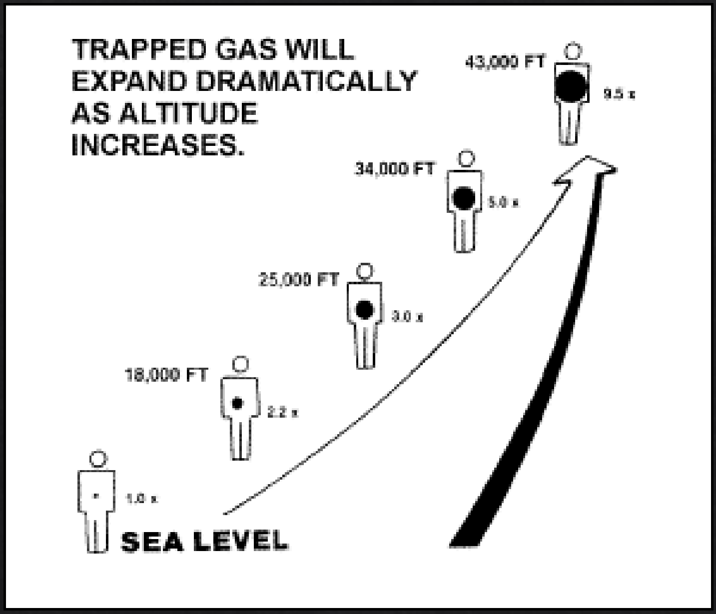
Typical Orbits

Mission	Orbit Type	Semi-major axis	Period	Inclination	Other
-Communications -Early Warning -Nuclear Detection	Geostationary	42,158 km	24 hr	~0°	e≈0
-Remote Sensing	Sun-synchronous	~6500-7300 km	~90 min	~95°	e≈0
-Navigation -GPS	Semi-synchronous	26,610 km	12 hr	55°	e≈0
-Space Shuttle	Low-Earth Orbit	~6700 km	~90 min	28.5° – 57°	e≈0
-Communications -Intelligence	Molniya	26,571 km	12 hr	63.4°	ω=270° e=0.7°

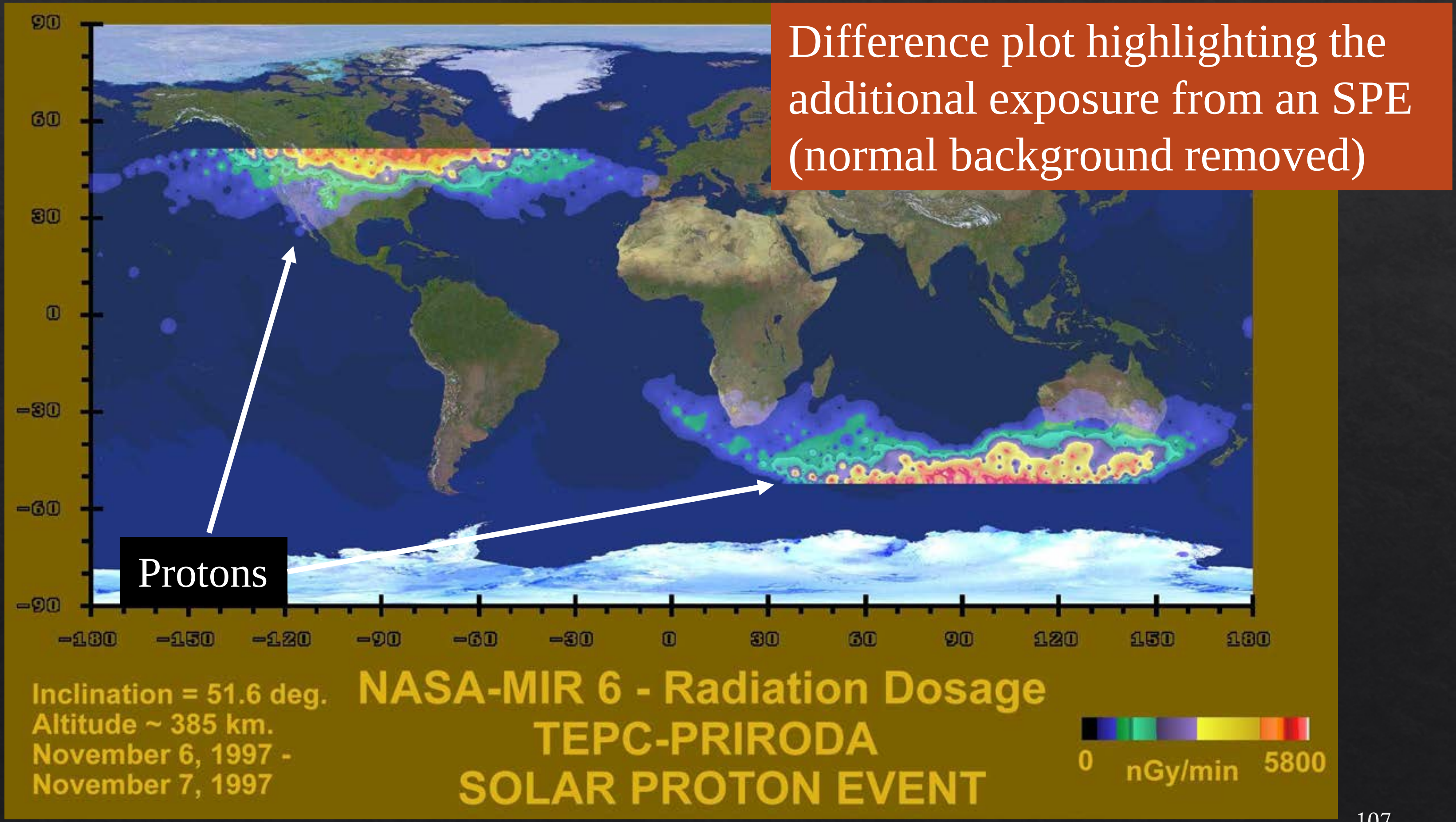
Vacuum

ISS Ambient Pressure: ~760 mmHg (14.7 psi)

- Hypoxia (decreased O_2 to tissues)
- Hypothermia
- Trapped gas disorders (barotrauma)
  - Boyle's Law: $P_1V_1 = P_2V_2$
  - Air-filled spaces in the body: sinuses, ears, lungs, gastrointestinal tract, (teeth)



Effects at Earth



Protons enter at low cut-off zones

These zones get larger (extend equator-ward) during geomagnetic storms