Radiation Environments for Low Earth Orbit Space Stations

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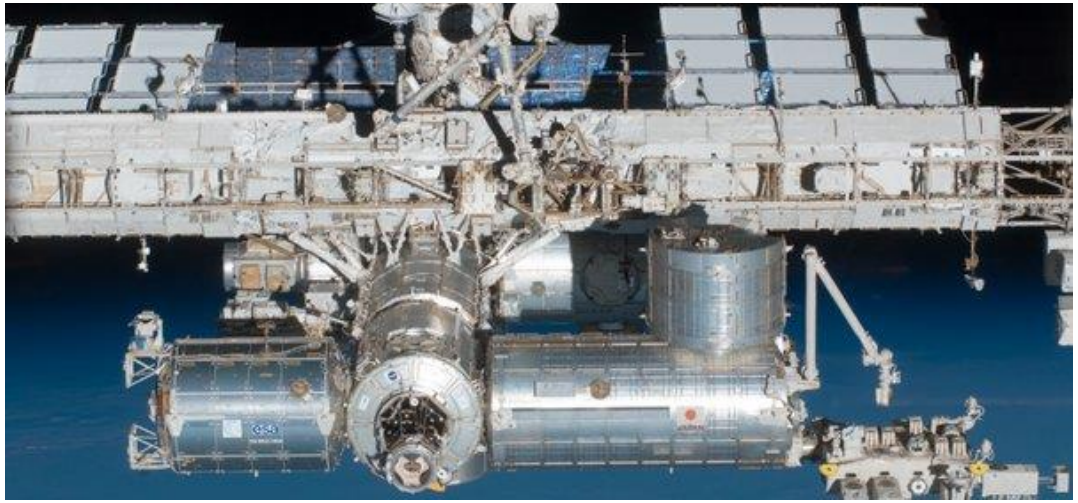
Introduction

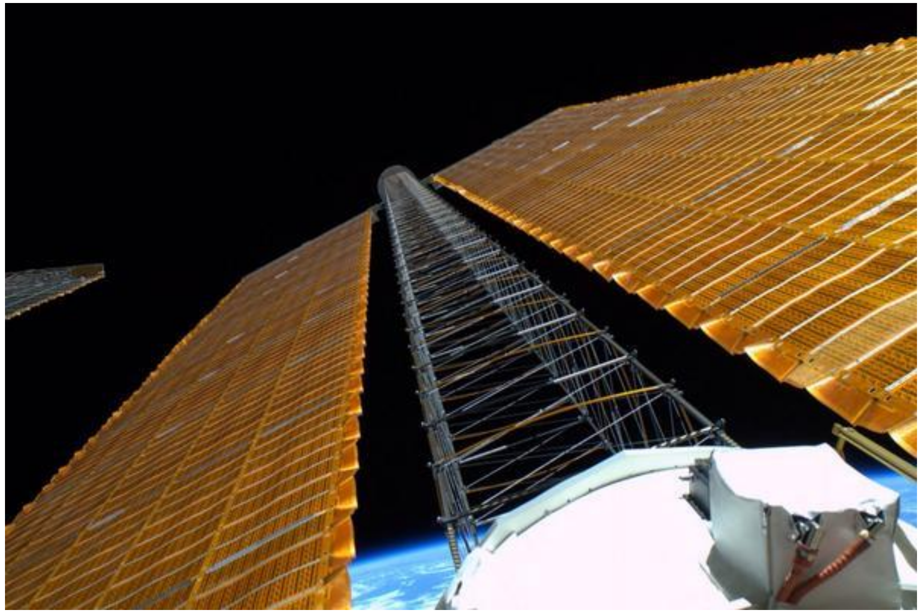
- There is a **growing interest in development and deployment of commercial space stations in low Earth orbit (LEO)** as the planned operation life of the International Space Station comes to an end at the close of this decade

- **Ionizing radiation in the form of energetic ions and electrons trapped in the Earth's radiation belts, solar particle events, and galactic cosmic rays** have been a design consideration for space stations in the past, both for threats to avionics and materials as well as the health of crews

- **Space radiation will continue to be a factor for both design and operation of the new generation of space stations** as we move into a new era of commercial exploitation of the LEO environment due to:
    - — Radiation impacts on materials
    - — Radiation damage to photovoltaic power systems
    - — Single event effects in avionics
    - — Crew dose

- **Space exposed materials are the primary concern for radiation damage of materials in LEO**
    - — Paints
    - — Coatings
    - — Thermal control materials
    - — Photovoltaic power systems





Past and Present Space Stations

- **A space station is a spacecraft resident in orbit that is visited by human crews for extended periods of time, applications include:**
  - Scientific research
  - Military
  - Commercial applications

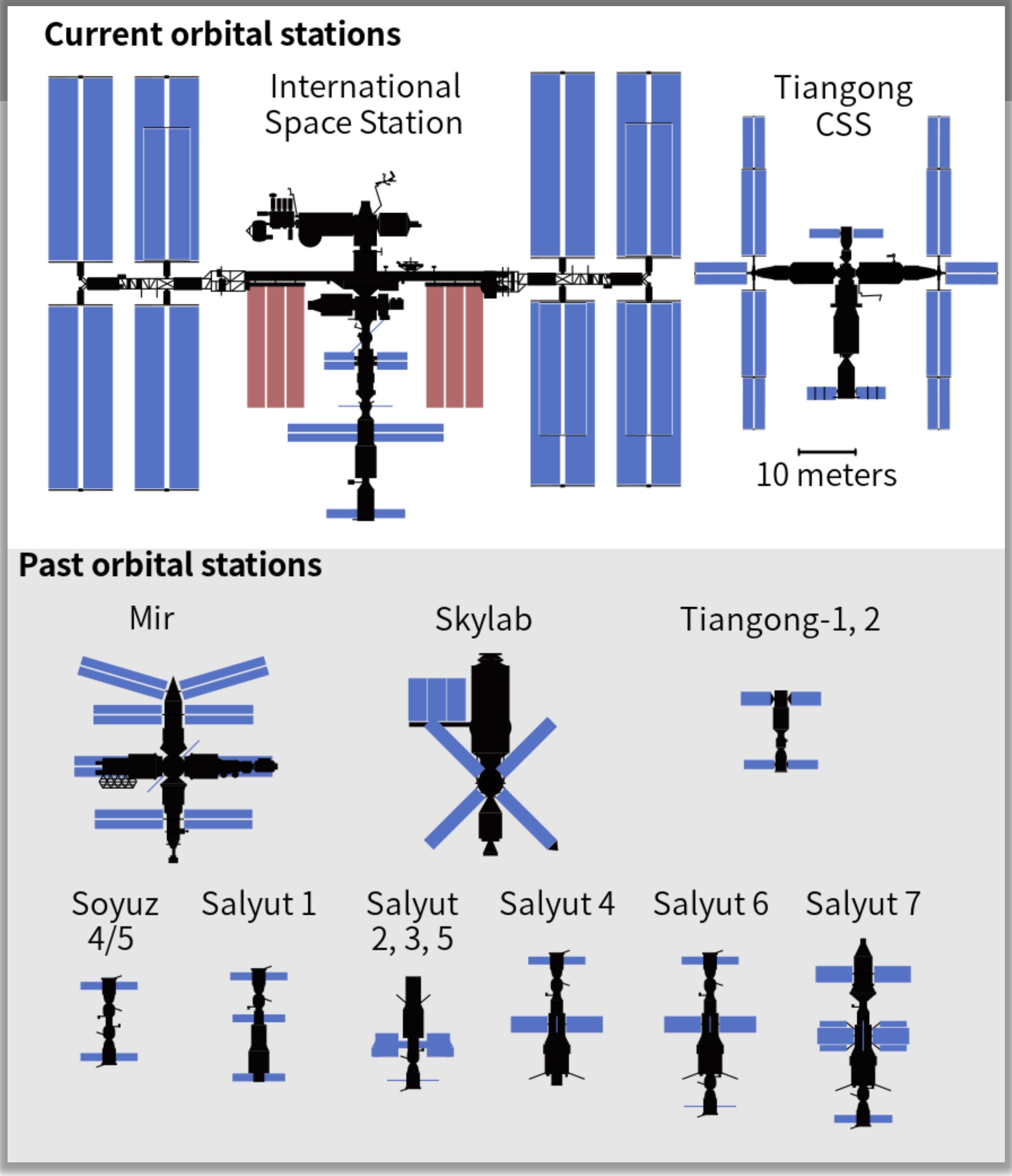
- **Past space stations (11) include the series of Salyuts and Mir (Russia), Skylab (US), and Tiangong-1 and 2 (China) – all have deorbited**

- **Space stations currently in orbit (4):**
  - International Space Station — US, Russia, Japan, ESA, CSA
  - Tiangong Space Station — China
  - Genesis I and II* — Bigelow Aerospace

  **Prototype without provision for crews*

- **Current plans are to discontinue use and deorbit the International Space Station in 2030**

- **Multiple entities in private industry are now pursuing plans to build and operate commercial space stations** that will continue the legacy of space station destinations for research and commerce in low Earth orbit



Credit: Thomas Shafee
https://en.wikipedia.org/wiki/File:Space_station_size_comparison.svg

Past and Present Space Stations

Station	COSPAR ID	Launch	Re-enter	Orbit	Days in Orbit	Crew Size*	Total Crew
Past							
Salyut 1	1971-032A	19/04/1971	11/10/1971	220 x 220 x 51.6	175	3	6
Salyut 2 (failed)	1973-017A	03/04/1973	1973-05-28	257 x 278 x 51.6	54	3	0
Skylab	1973-027A	14/05/1973	11/07/1979	434 x 442 x 50.0	2249	3	9
Salyut 3	1974-046A	25/06/1974	24/01/1975	219 x 270 x 51.6	213	2	2
Salyut 4	1974-104A	26/12/1974	03/02/1977	219 x 270 x 51.6	770	2	4
Salyut 5	1976-057A	22/06/1976	08/08/1977	223 x 269 x 51.6	412	2	4
Salyut 6	1977-097A	29/09/1977	29/07/1982	219 x 275 x 51.66	1764	2	33
Salyut 7	1982-033A	19/04/1982	07/02/1991	219 x 278 x 51.6	3216	3	22
Mir	1986-017A	19/02/1986	23/03/2001	354 x 374 x 51.6	5511	3	125
Present							
International Space Station	1998-067A	20/11/1998	---	~400 x 400 x 51.6°	9354**	7 (13)	280
Tiangong-1	2011-053A	29/09/2011	02/04/2018	~400 x 400 x 42.8°	2377	3	6
Tiangong-2	2016-057A	15/09/2016	19/07/2019	369 x 378 x 42.8°	1037	2	2
Tiangong Space Station	2021-035A	29/04/2021	---	386 x 392 x 41.47	1158	3 (6)	21**

*Nominal crew (maximum crew)
*As of 30 June 2024

Future Space Stations (Planned and Proposed)

Station	Entity	Launch Date	Orbit	Crew Size	CLDP	Notes
Gateway	NASA, ESA, CSA, JAXA	2024	Lunar NLRO	4		Construction in progress
Axiom Station	Axiom Space	2026	LEO	TBD	X	Attached to ISS, will separate in 2030's to form independent station
Russian Orbital Service Station	Roscosmos	2027	LEO	TBD		Announced in April 2021
Starlab	NanoRacks, Voyager Space, Lockheed Martin, Airbus	2028	LEO	4	X	Commercial platform for business, science, and manufacturing
StarMax	Gravitics	2026	LEO	TBD		Large commercial platform (~50% ISS volume)
Orbital Reef	Blue Origin, Sierra Space	2025 to 2030	LEO	10	X	Commercial platform for research, industrial, international, and commercial customers
Bharatiya Antariksha Station	ISRO	~2035	LEO	3		Announced in 2019
Lunar Orbital Staton	Roscosmos	After 2030	Lunar orbit	TBD		
Haven-1	Vast	2025	LEO	4		Commercial space station
LIFE Pathfinder	Sierra Space	2026	LEO	TBD		Precursor to Orbital Reef

Sources:
- https://en.wikipedia.org/wiki/List_of_space_stations
- https://www.nasa.gov/humans-in-space/commercial-space/low-earth-orbit-economy/commercial-destinations-in-low-earth-orbit/

LEO Ionizing Radiation Environments

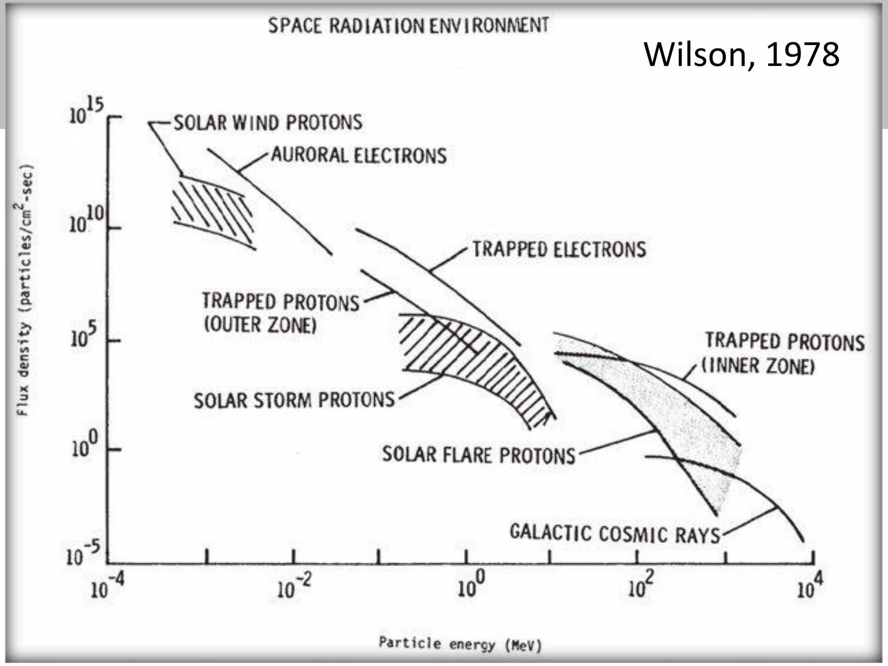
- **Radiation environments relevant to LEO missions** in approximate order of decreasing energy and increasing flux:
    - — Galactic cosmic rays (GCE) 100's MeV to GeV
    - — Solar particle events (SPE) 10's MeV to 100's MeV
    - — Earth radiation belts (transit) 10's keV to 100's MeV

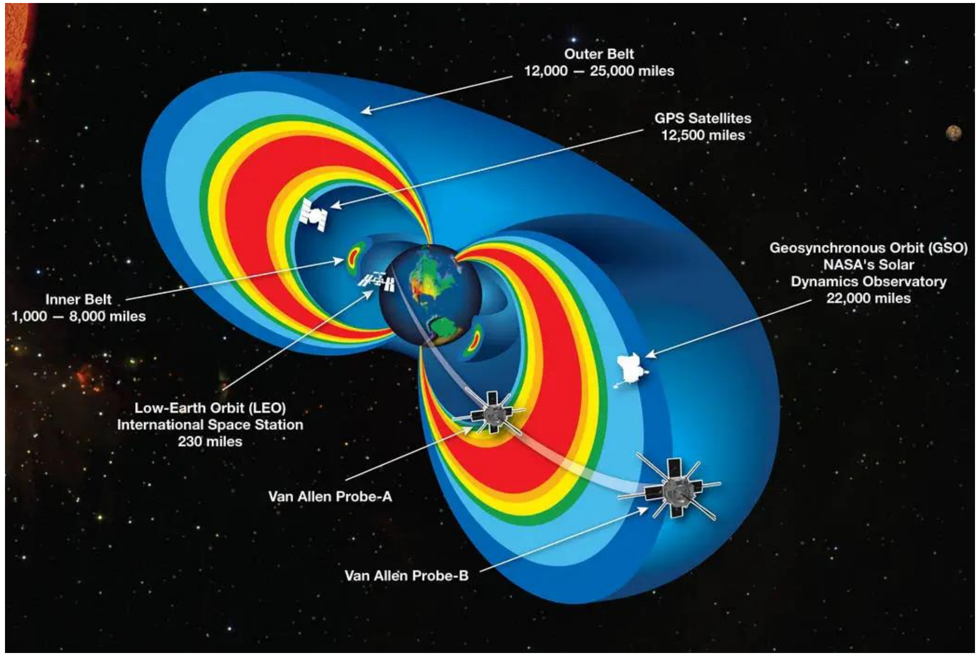
- **Earth's magnetic field provides shielding** to protect low latitude LEO from some GCR and SPE particles

- **Albedo neutrons are an additional radiation environment in spacecraft** due to nuclear interactions of the primary ions with the spacecraft shielding

- **Trapped electrons and protons in the Earth's radiation belt are the primary source of concern for LEO space environments for long duration missions**

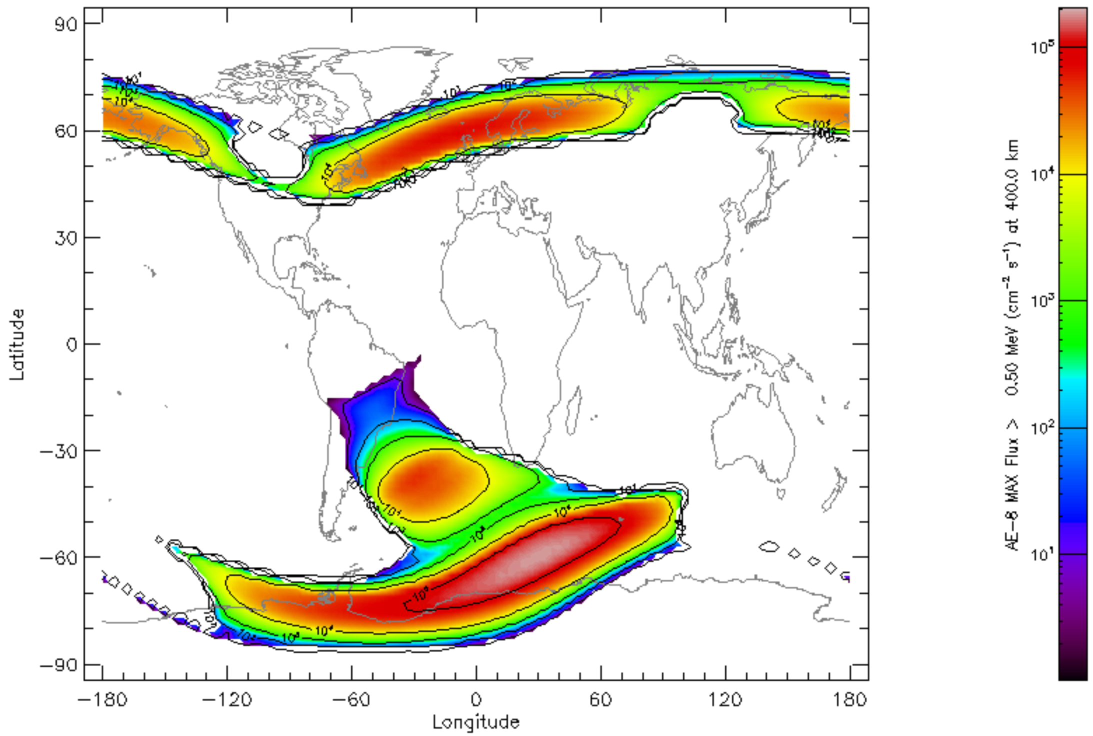
Since this is a materials in the space environment session, the remaining presentation will focus on radiation environments of primary concern to materials



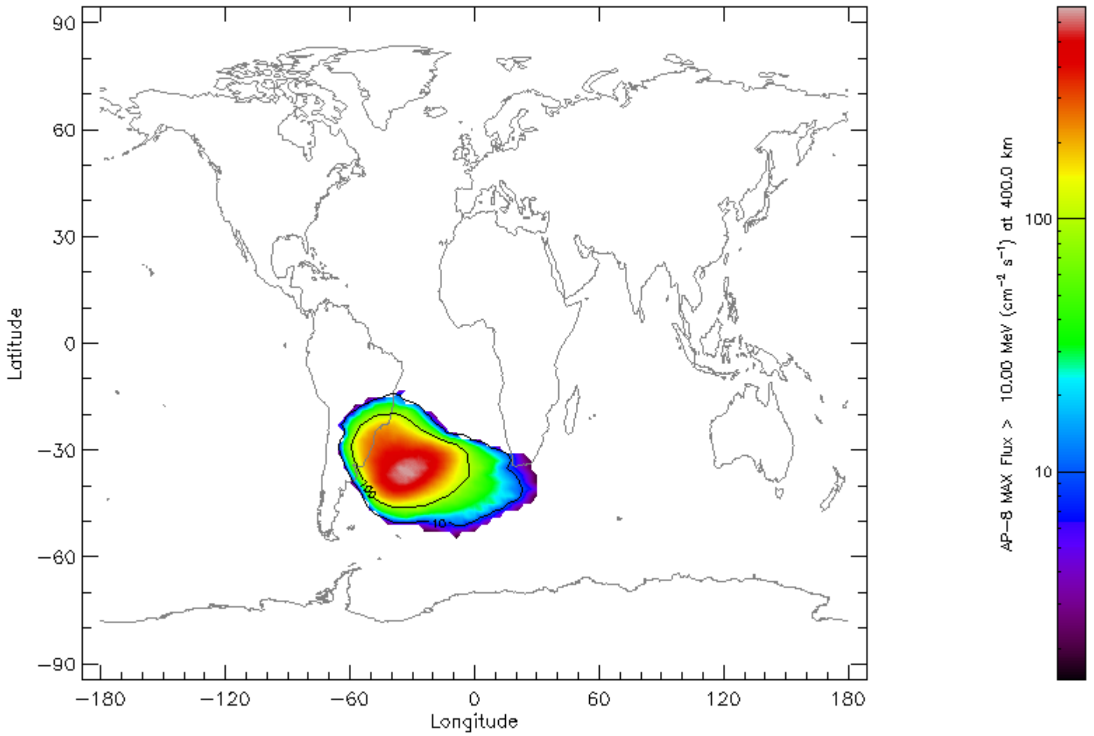


https://www.nasa.gov/image-article/radiation-belts-with-satellites/

Trapped Radiation – 400 km

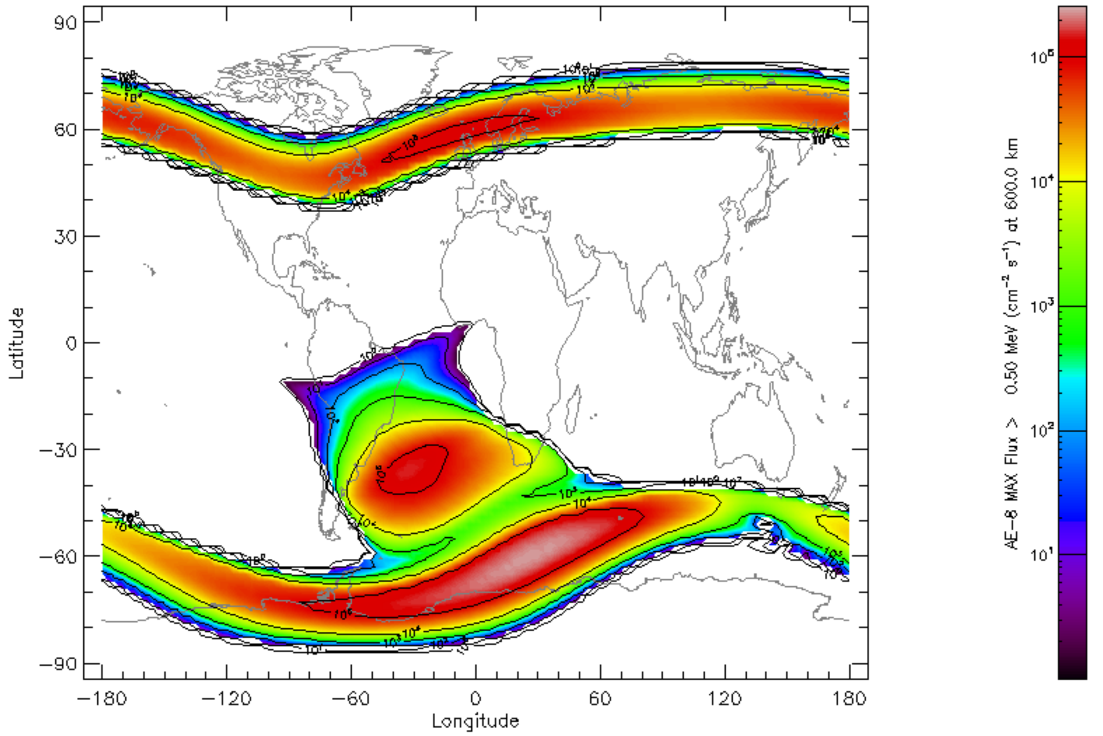


Electrons > 0.5 MeV

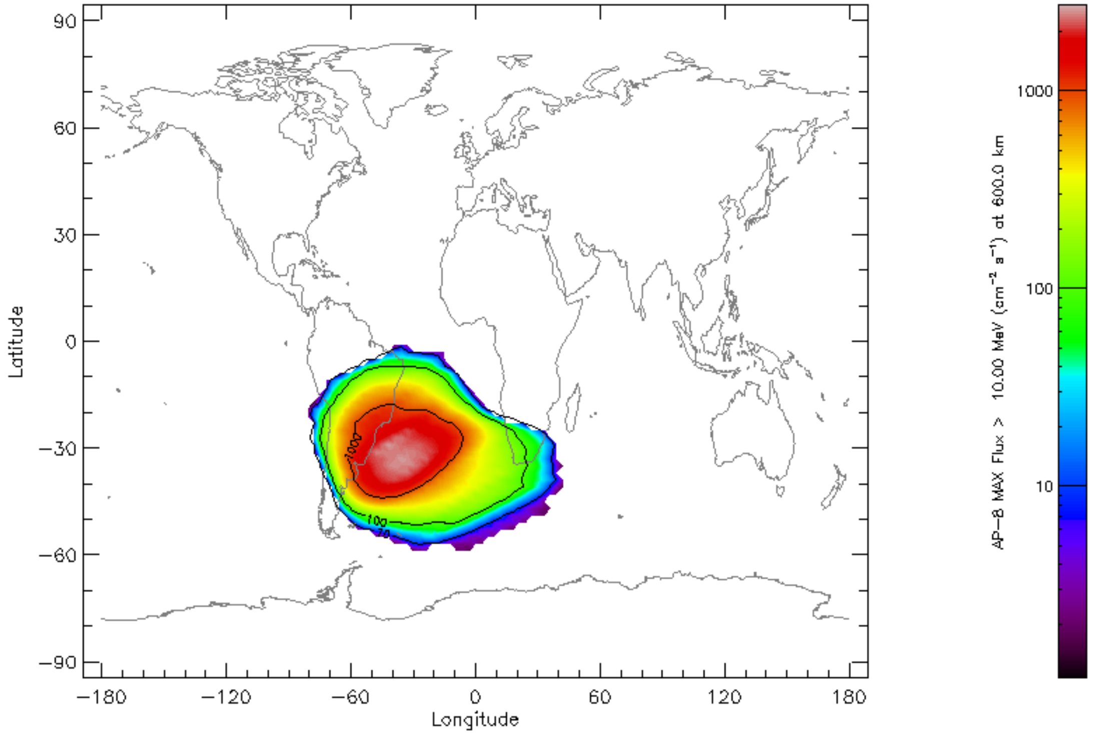


Protons > 10 MeV

Trapped Radiation – 600 km

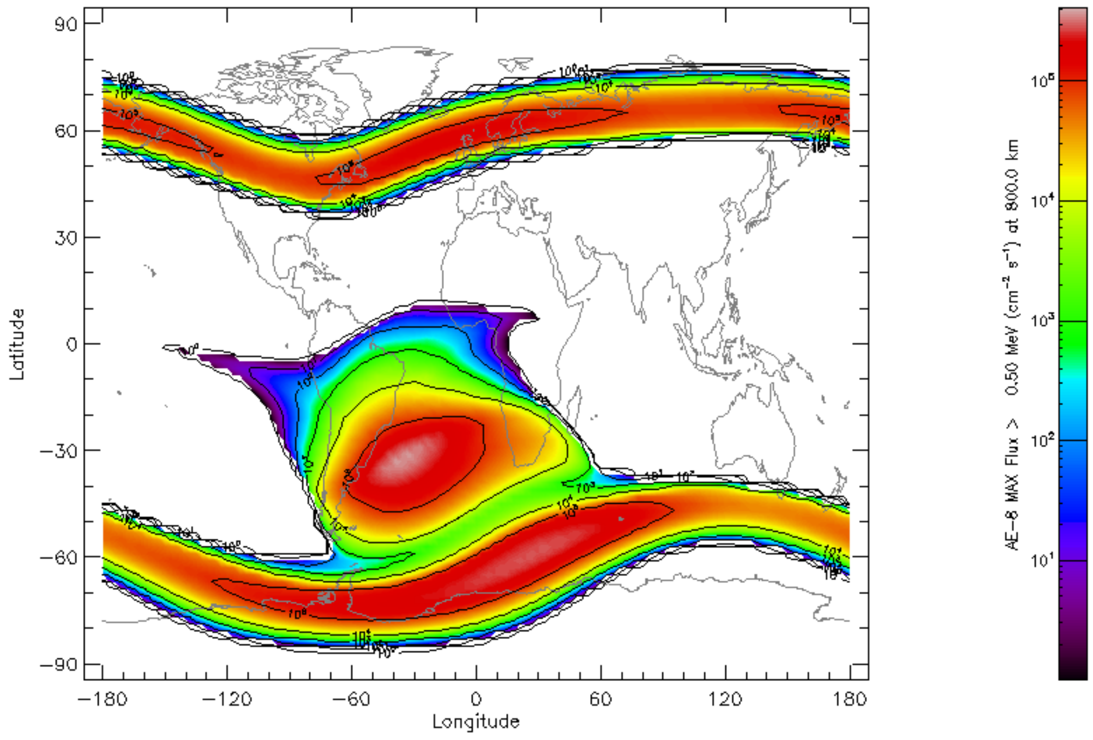


Electrons > 0.5 MeV

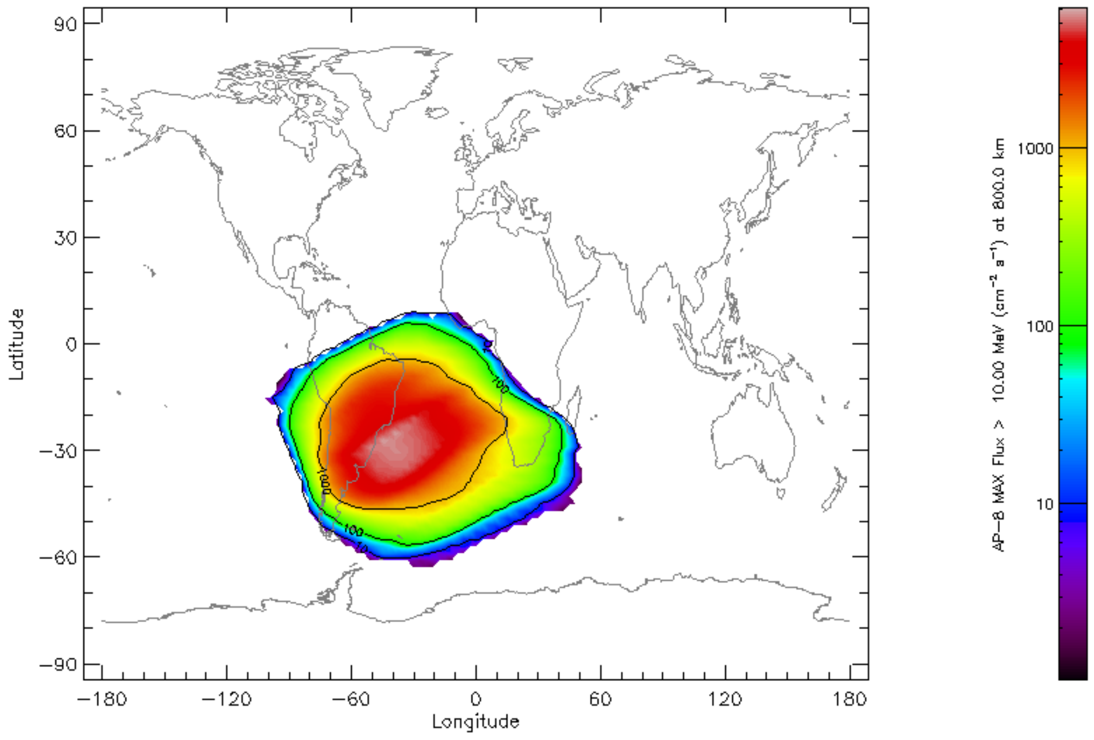


Protons > 10 MeV

Trapped Radiation – 800 km

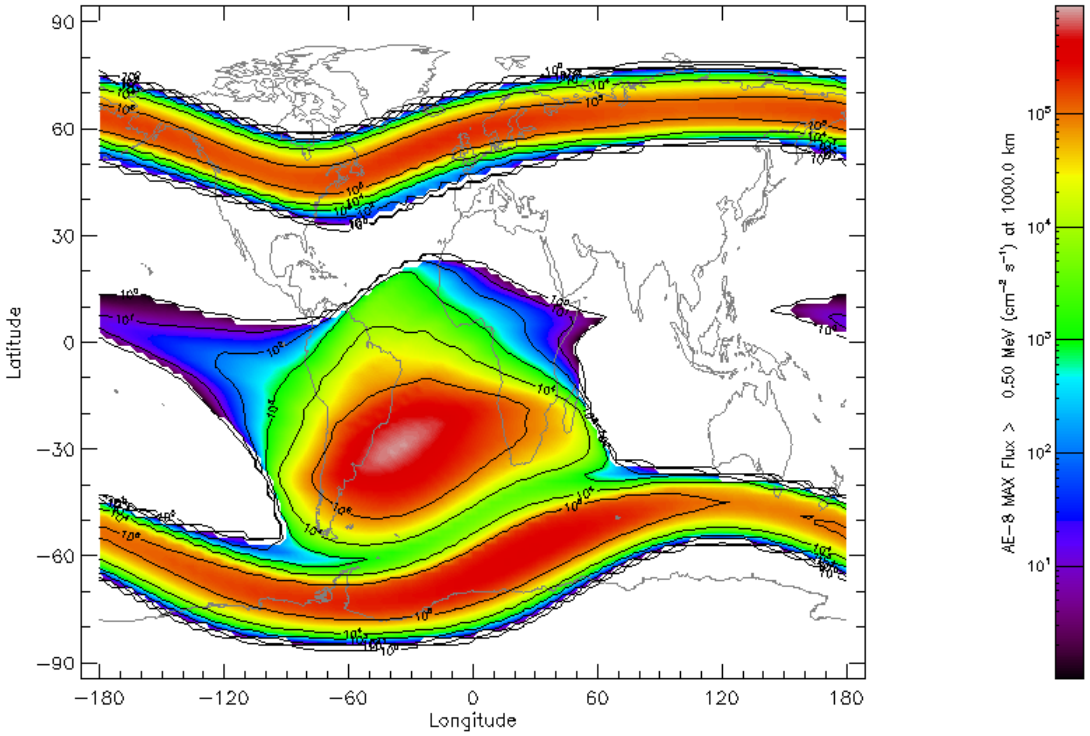


Electrons > 0.5 MeV

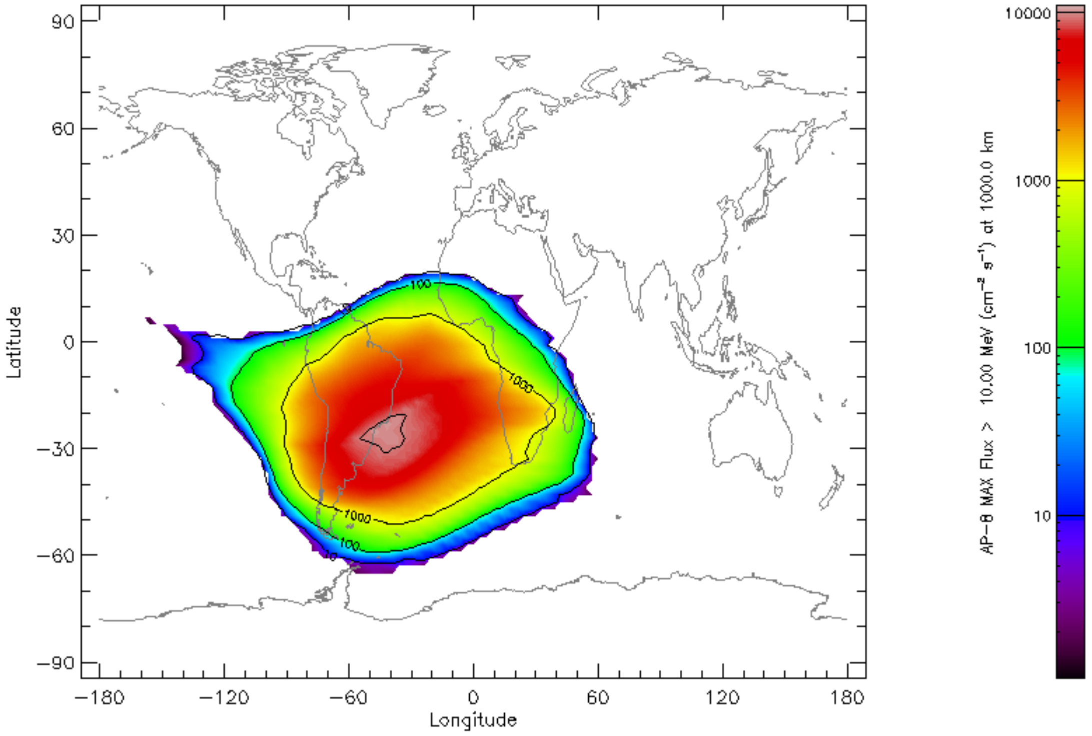


Protons > 10 MeV

Trapped Radiation –1000 km



Electrons > 0.5 MeV



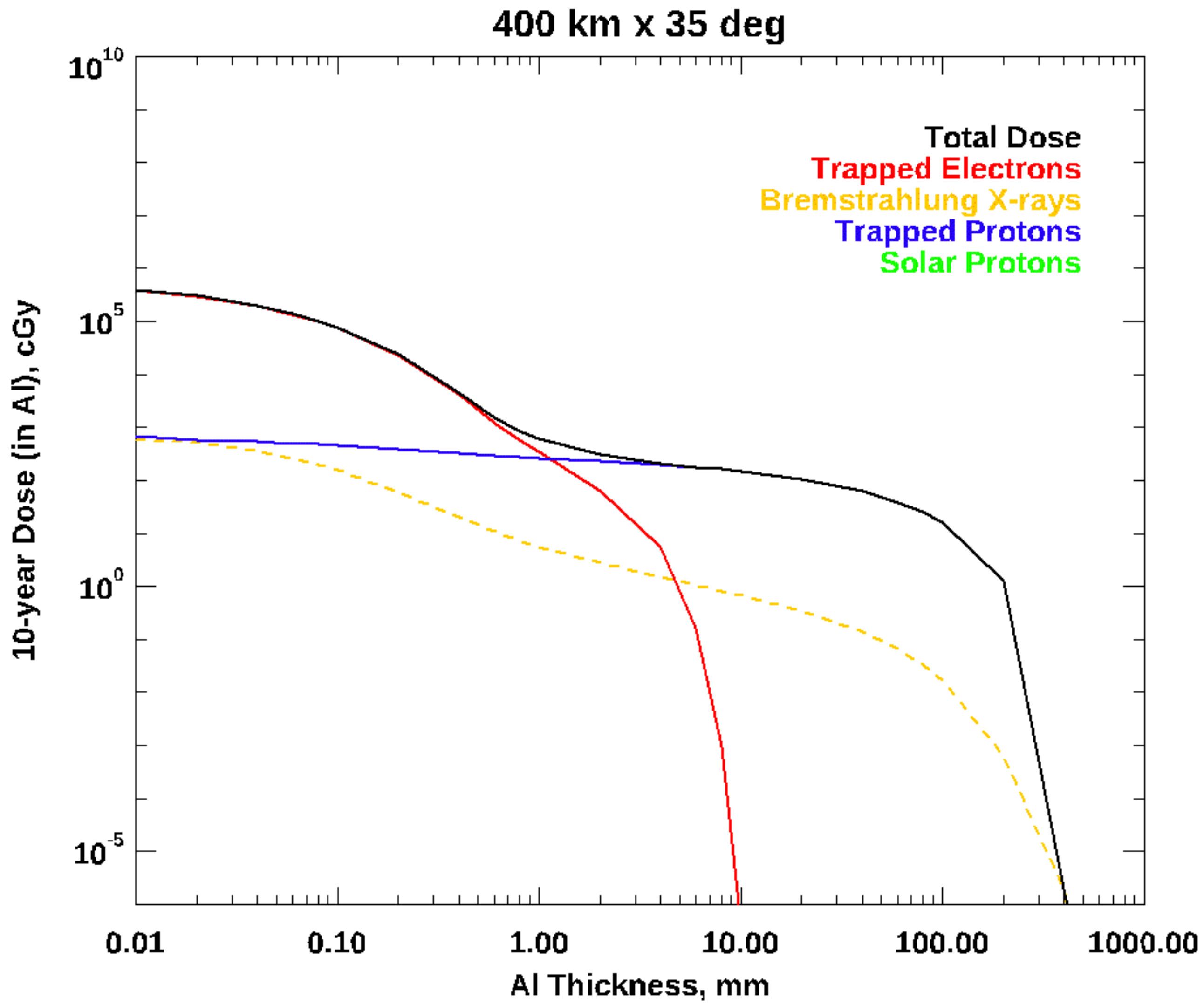
Protons > 10 MeV

Dose from Trapped Radiation and SPE: Altitude

Radiation Environments
- AE8 trapped electrons + bremsstrahlung (solarmax)
- AP8 Trapped protons (solarmax)
- SPE: SAPPHIRE, H to U, 1/100 years event

Circular Orbit
- Altitude: 400 km, 600 km, 800 km
- Inclination: 35 deg, 60 deg, 98 deg
- Duration: 10 years

Shieldose-2 Radiation Transport
- Infinite flat plane
- Aluminum shielding
- Radiation dose in aluminum



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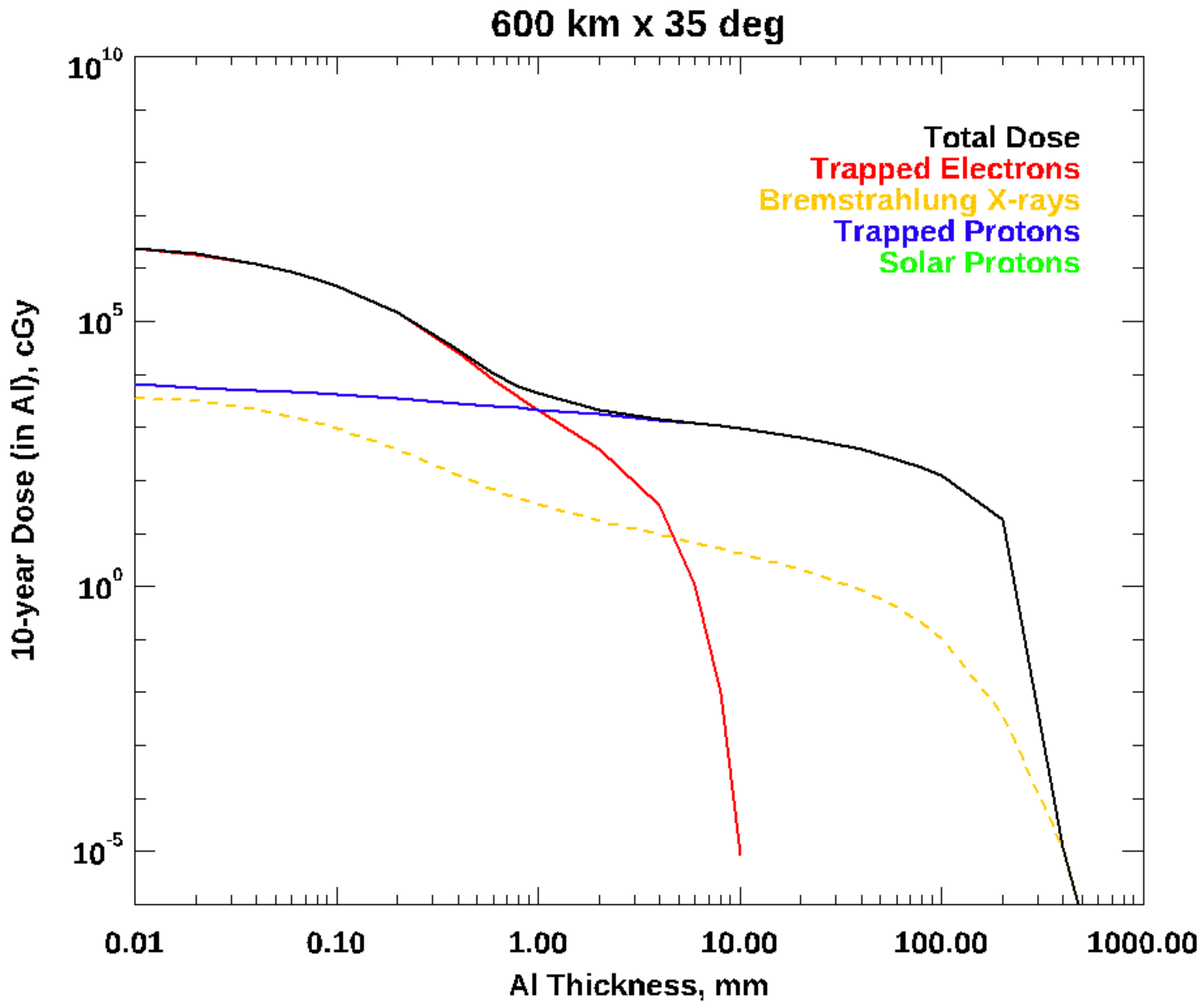

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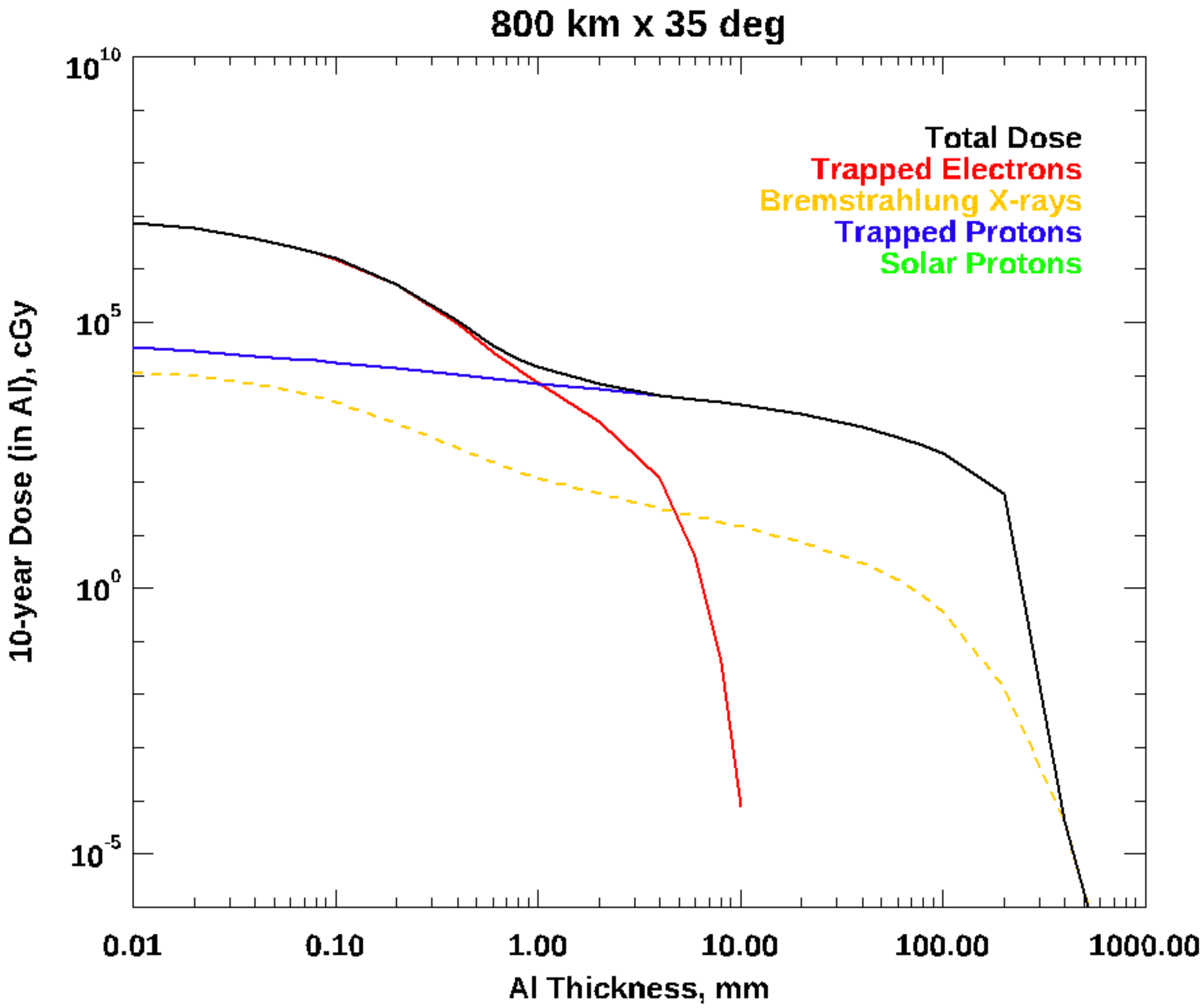


- Radiation dose only approaches ~Mrad levels of importance to materials for very thin shielding
- Primary concern for LEO space station materials is space exposed materials on surface such as paints, coatings, and thermal control materials

Dose from Trapped Radiation and SPE: Inclination

Radiation Environments

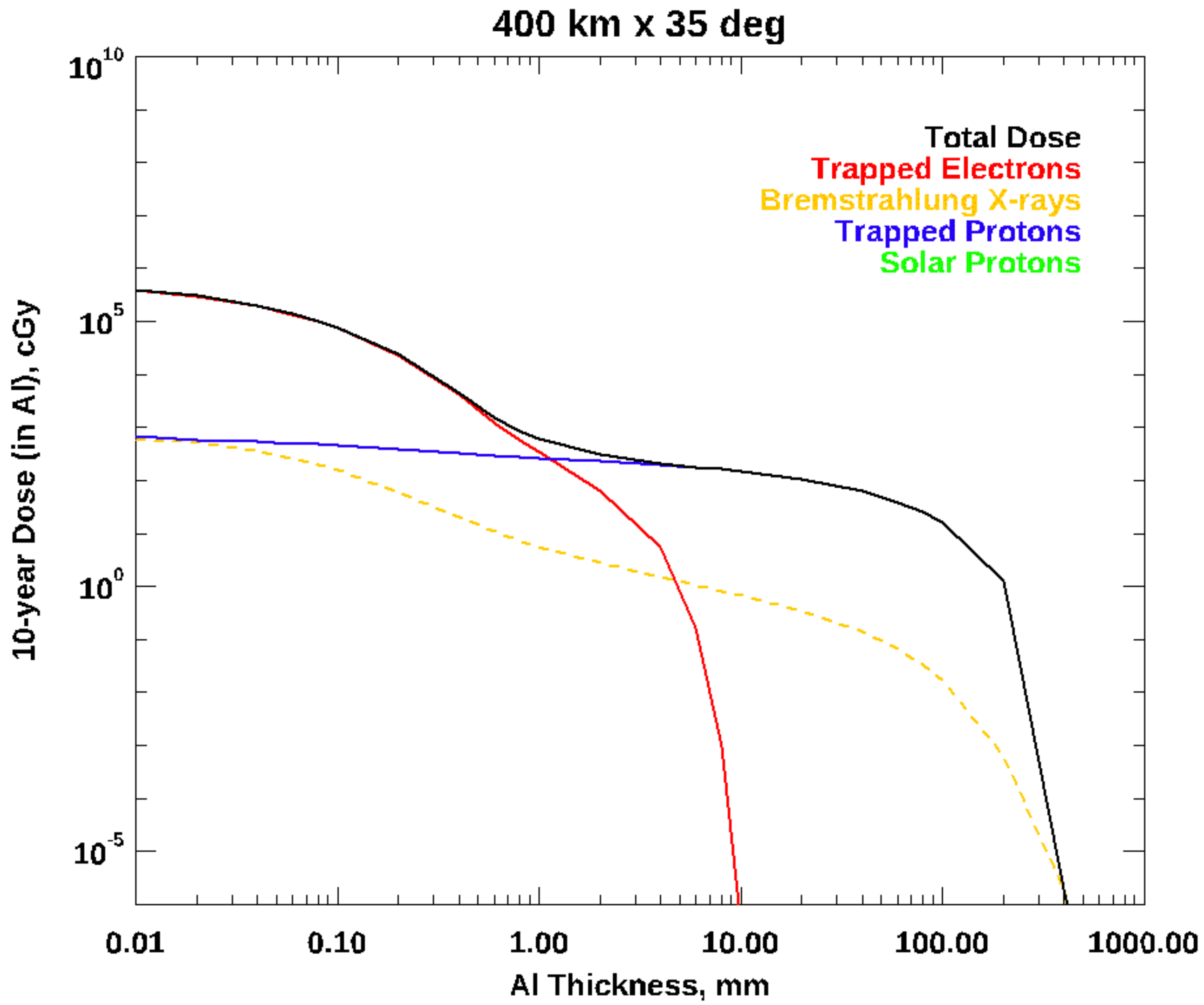
- AE8 trapped electrons + bremsstrahlung (solarmax)
- AP8 Trapped protons (solarmax)
- SPE: SAPPHIRE, H to U, 1/100 years event

Circular Orbit

- Altitude: 400 km, 600 km, 800 km
- Inclination: 35 deg, 60 deg, 98 deg
- Duration: 10 years

Shieldose-2 Radiation Transport

- Infinite flat plane
- Aluminum shielding
- Radiation dose in aluminum



Dose from Trapped Radiation and SPE: Inclination

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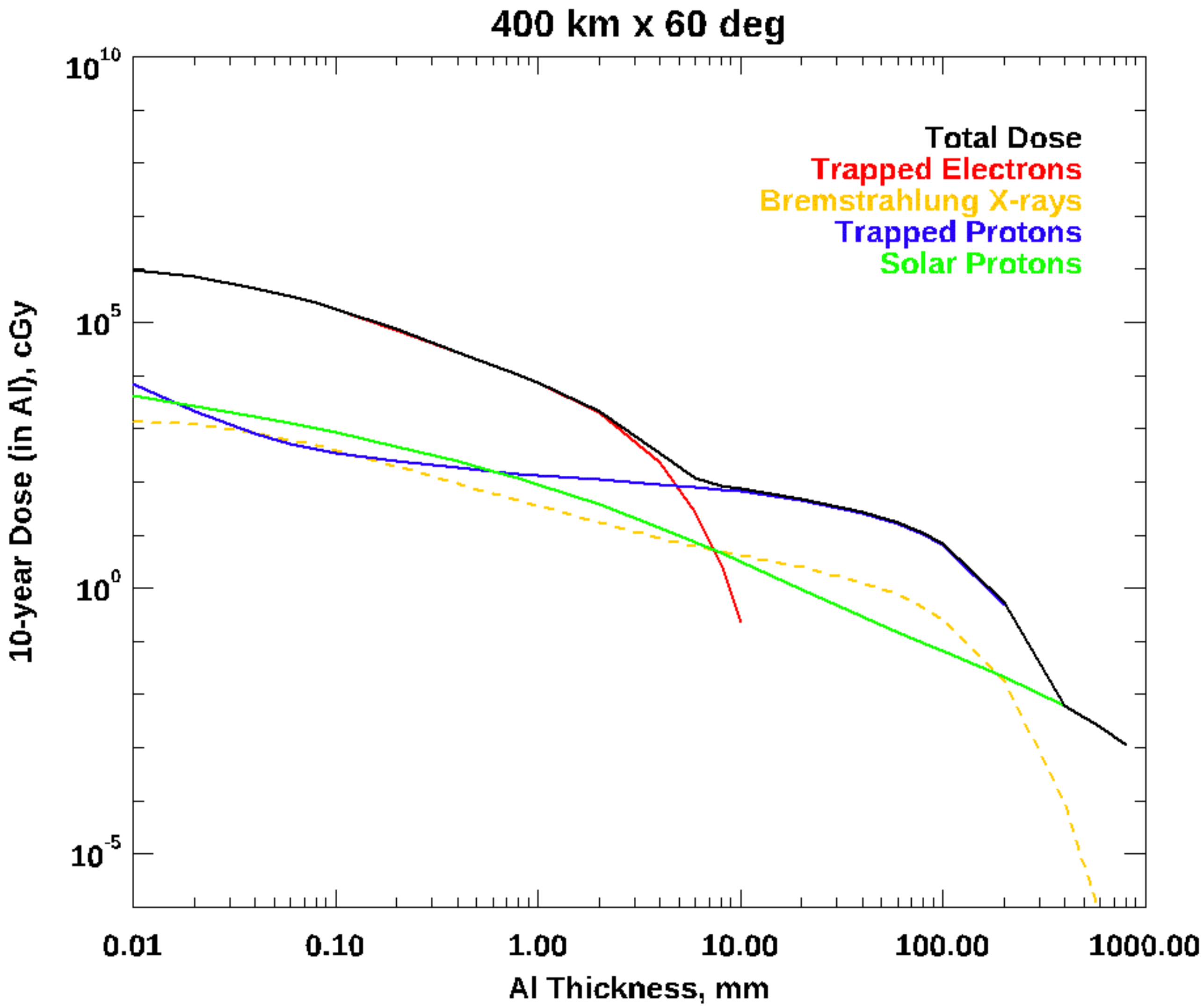

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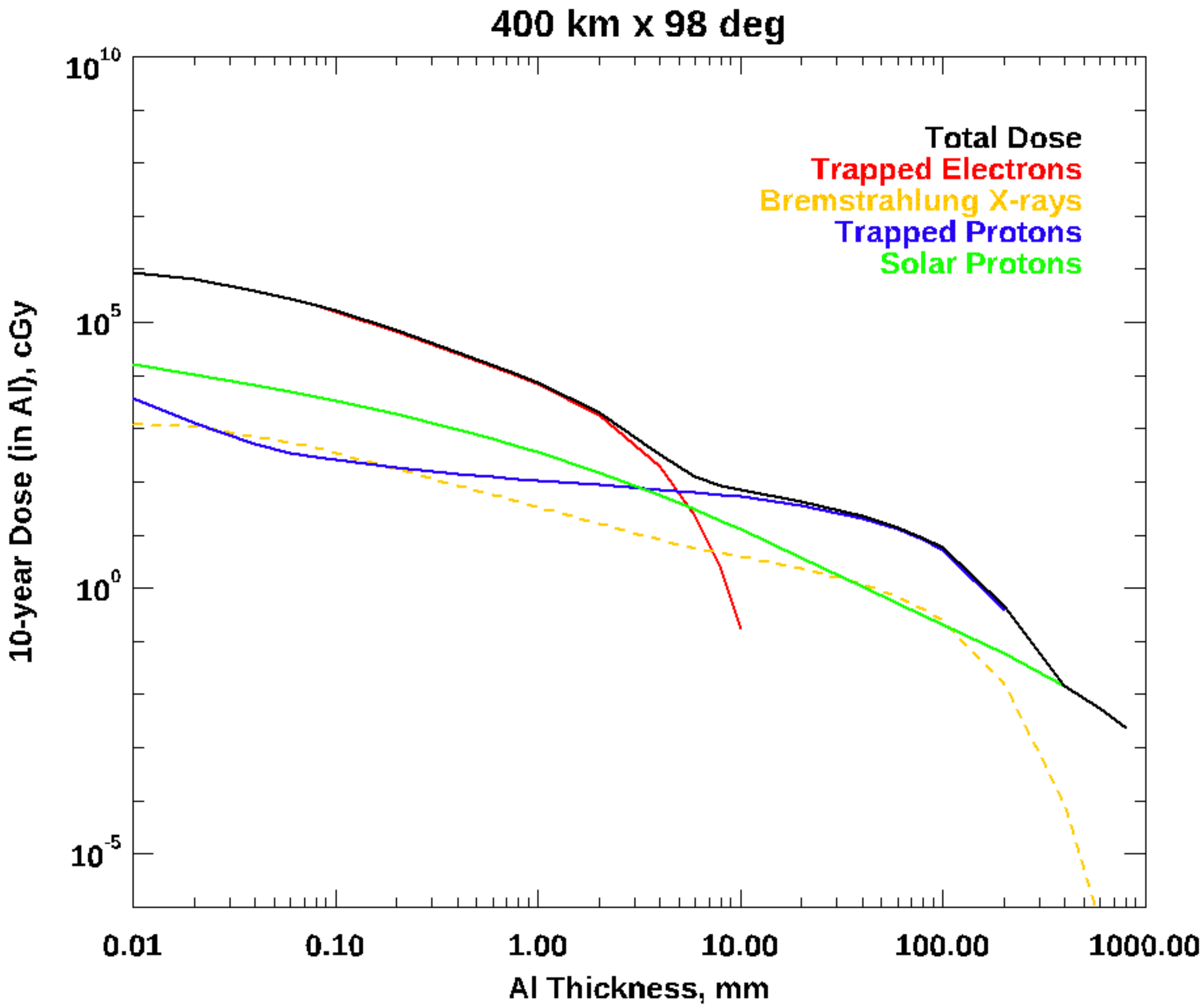
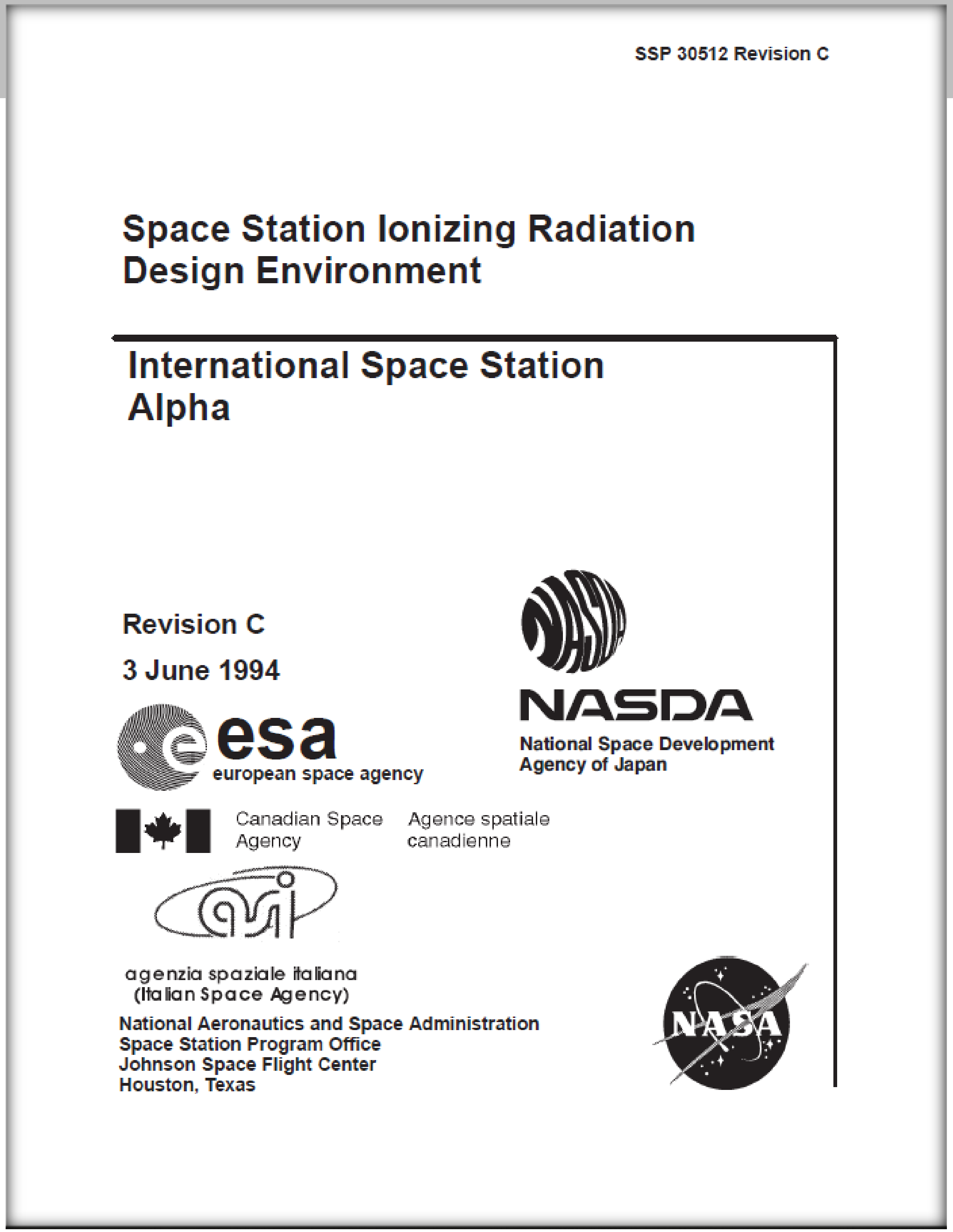


- Radiation dose only approaches ~Mrad levels of importance to materials for very thin shielding
- SPE protons are contributors to total dose at higher inclinations but are always dominated by trapped protons and electrons over long periods of time

NASA LEO Design Environments

- *SSP 30512 (Revision C) International Space Station Ionizing Radiation Design Environment* document contains space radiation environment specifications for ISS in LEO
- Developed and maintained by the International Space Station Program, Revision C (June 1994) is the current release version
- Total ionizing dose due to trapped protons and electrons are defined for an orbital altitude of 500 km, higher than the ISS orbit that is maintained between 370 km and 460 km giving a conservative environment for design
- Document is available for use in planning LEO missions:
  — No restrictions on distribution


SSP 30512 Revision C

Space Station Ionizing Radiation Design Environment

International Space Station Alpha

Revision C

3 June 1994

esa
european space agency

NASDA
National Space Development Agency of Japan

Canadian Space Agency   Agence spatiale canadienne

agenzia spaziale italiana
(Italian Space Agency)

National Aeronautics and Space Administration
Space Station Program Office
Johnson Space Flight Center
Houston, Texas

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SSP 30512 Revision C

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APPENDIXES

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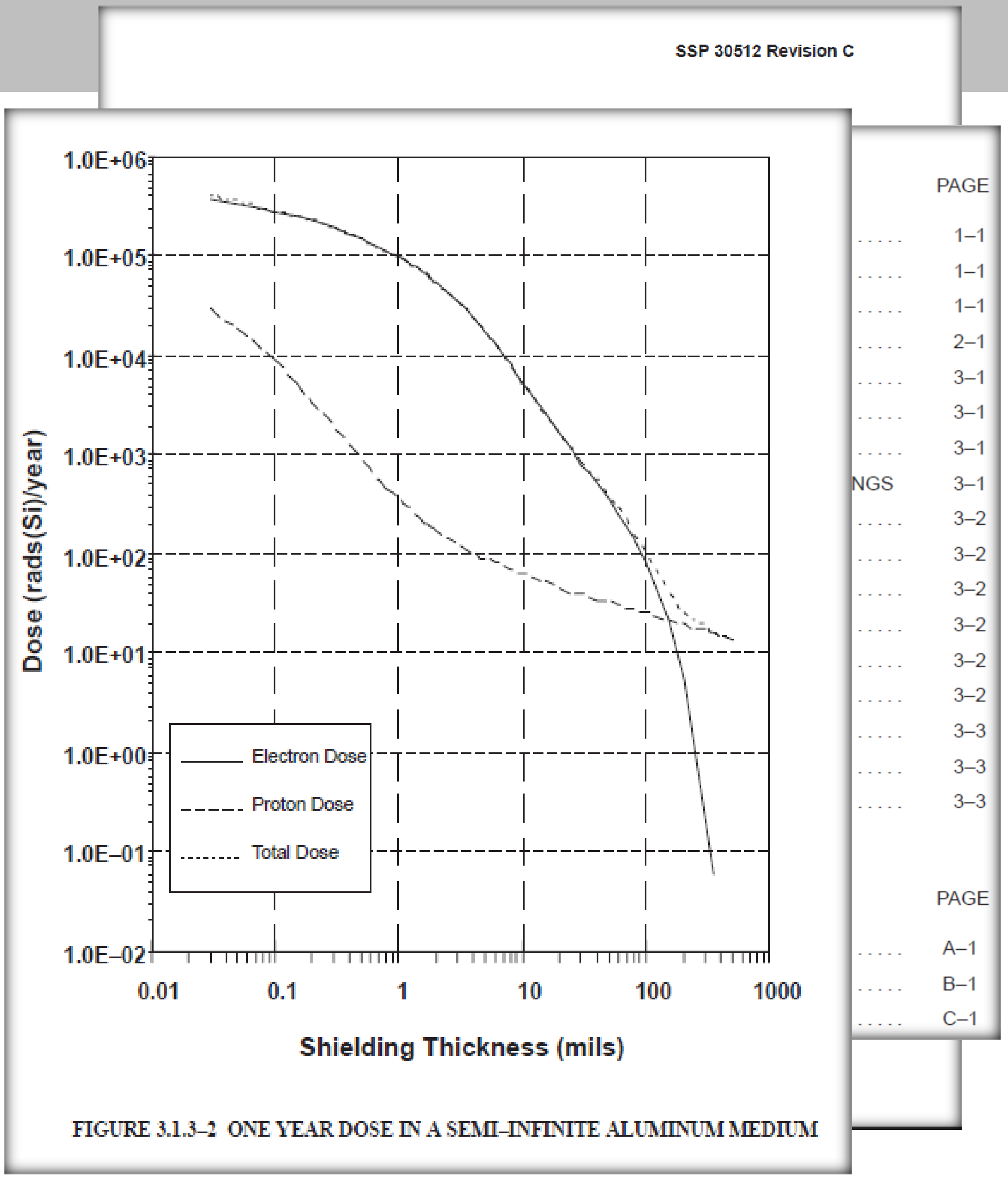
ISS design environments are less than ~1 Mrad for annual dose, only exceeds ~1Mrad dose levels for thin materials and durations of 5 to 10 years or more



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- DSNE contains environment specifications for all relevant environments encountered during a lunar mission:
  - — 3.1 Prelaunch – Ground Processing Phases
  - — 3.2 Launch Countdown and Earth Ascent Phases
  - — 3.3 In-Space Phases
  - — 3.4 Lunar Surface Operational Phases
  - — 3.5 Entry and Landing Phases
  - — 3.6 Contingency and Off-Nominal Landing Phases
  - — 3.7 Recovery and Post-Flight Processing Phases

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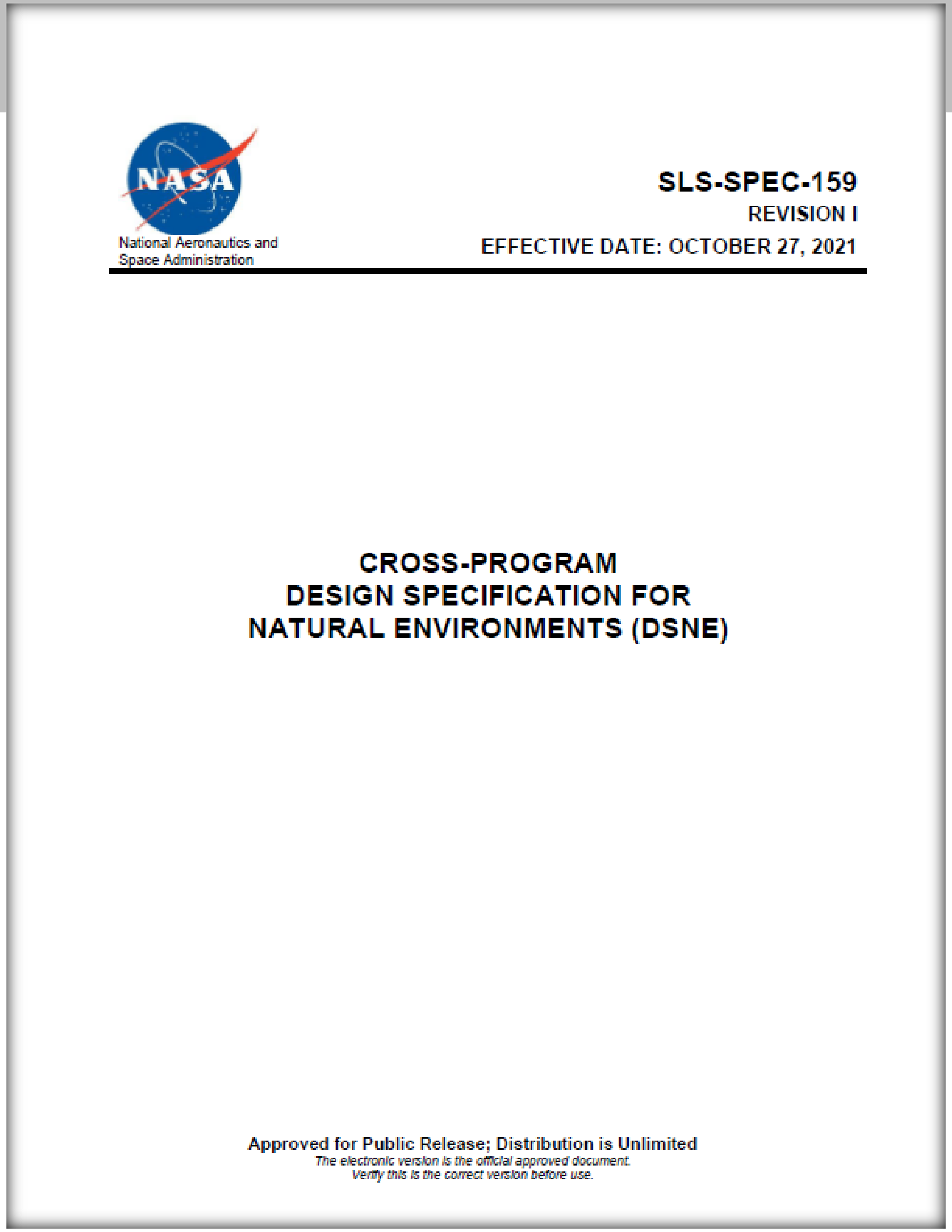

National Aeronautics and Space Administration

SLS-SPEC-159
REVISION I
EFFECTIVE DATE: OCTOBER 27, 2021

CROSS-PROGRAM DESIGN SPECIFICATION FOR NATURAL ENVIRONMENTS (DSNE)

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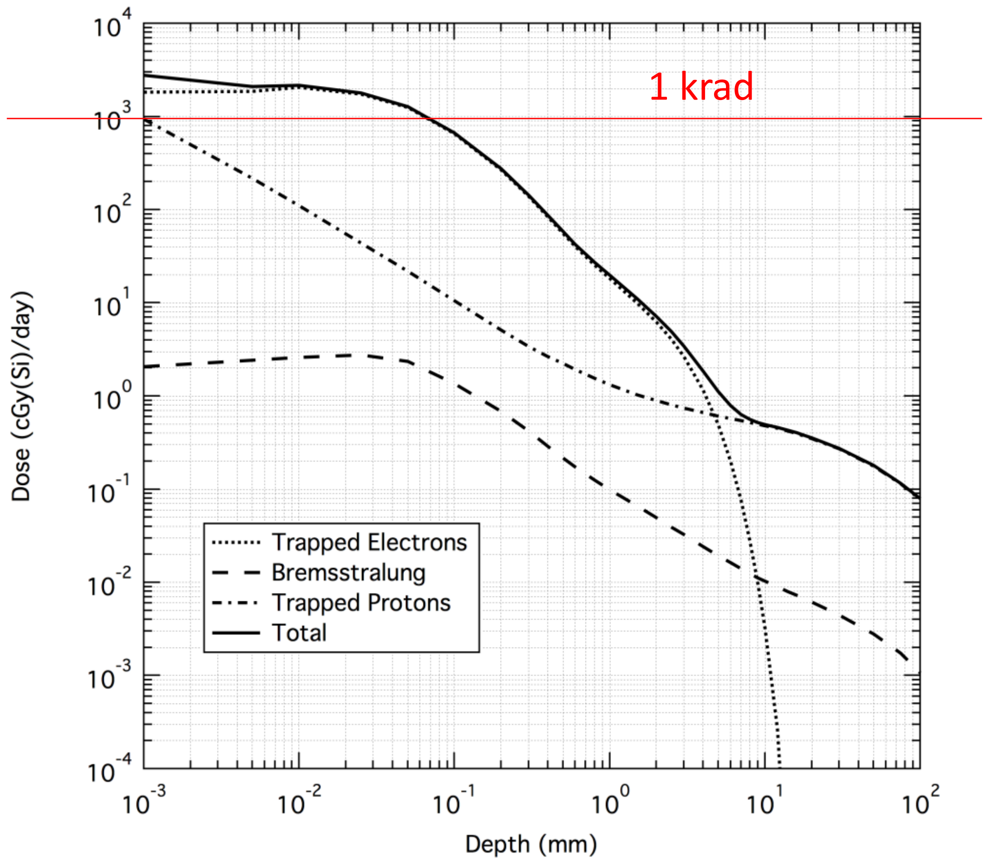
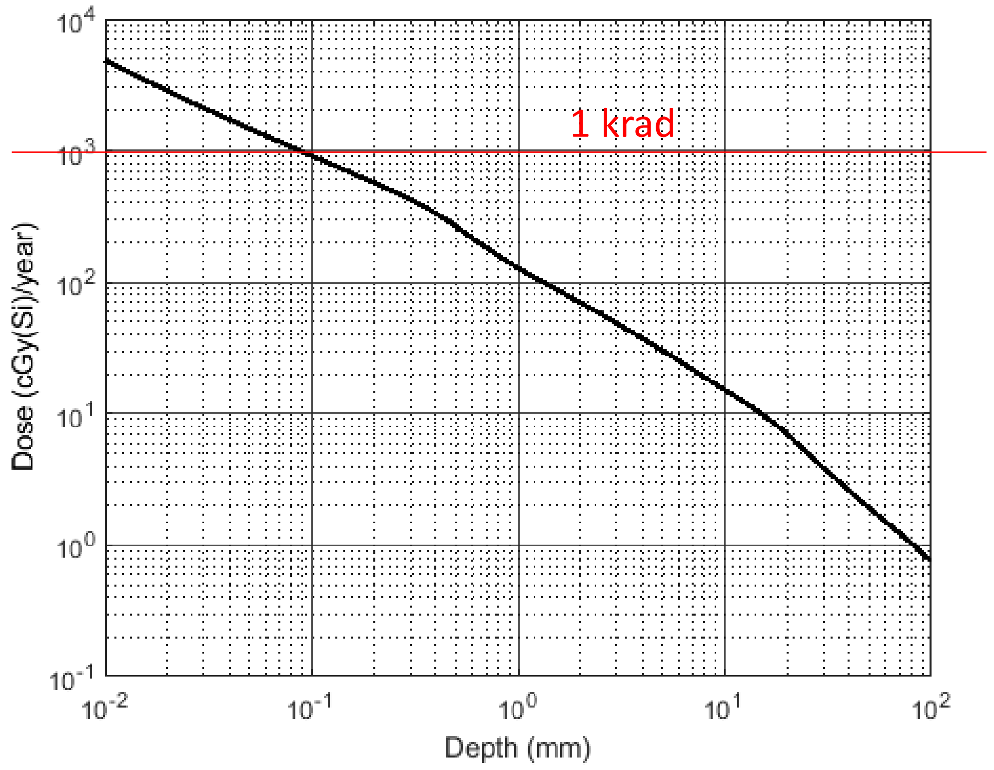
SLS-SPEC-159
REVISION I

NASA LEO ISS Radiation Environments

Trapped Protons, Electrons



Solar Particle Event Protons



1 krad/day * 365.25 day/year = 365.25 krad/year
365.25 krad/year * 10 years = 3.65 Mrad/10 years
365.25 krad/year * 15 years = 5.48 Mrad/15 years

Questions?