National Aeronautics and Space Administration

Passive Space Radiation Shielding: Mass and Volume Optimization of Tungsten-Doped PolyPhenolic and Polyethylene Resins

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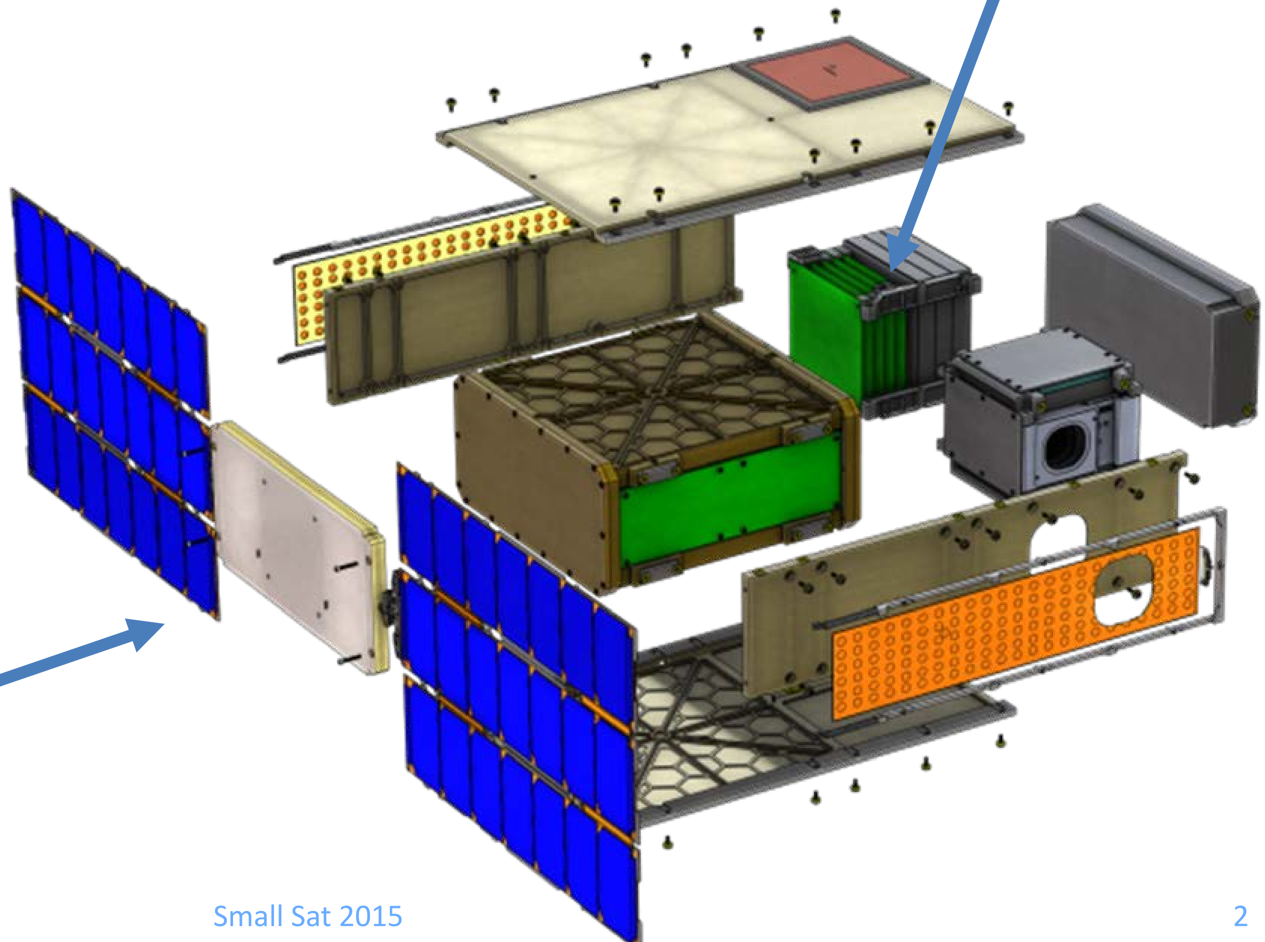
Radiation Mitigation Motivation

Minimal space between boards

- Small Sats are volume constrained



BioSentinel

Radiation Mitigation Motivation

- Small Sats are volume constrained
- Desire to use COTS components
  - COTS components vs Rad Hard vs Rad Tolerant
  - COTS are SotA, therefore most efficient and effective at any given task
  - Rad Hard = ☹ => wildly expensive vs. equivalent COTS, often based on decade old technology (inefficient or large or both), require minimum buys and long lead times
  - Rad Tolerant are COTS with inherent rad hardness qualities that have been tested. Good option (if available…not much testing to date but getting better!)

Radiation Mitigation Motivation

- Small Sats are volume constrained
- Desire to use COTS components
- Classic desire for more/better insulation
  - Initiated material trade study
  - Examined shield materials based on volumetric atomic stopping power

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\begin{array}{l} \frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 T_{\max}}{I^2} - \beta^2 - \ldots \\ \frac{\delta(\beta\gamma)}{2} + \frac{C(\beta)}{Z} + zL_1(\beta) + \ldots \\ z^2 L_2(\beta) \end{array}\right]$$

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Proportional to average of each elements electron/nucleon ratio

Material Trade Study

Element or Molecule	Density [g/cm3]	Avg. A	Avg. Z	Z/A	Z^2/A	Density*(Z/A)	Density* (Z^2/A)
tungsten	19.25	183.80	74.00	0.40	29.79	7.75	573.52
tantalum	16.69	180.94	73.00	0.40	29.45	6.73	491.55
lead	11.34	207.20	82.00	0.40	32.45	4.49	368.00
gadolinium	7.90	157.25	64.00	0.41	26.05	3.22	205.78
aluminum oxide	3.95	20.39	10.00	0.49	4.91	1.95	19.38
diamond	3.50	12.00	6.00	0.50	3.00	1.75	10.50
aluminum	2.70	26.98	13.00	0.48	6.26	1.30	16.91
boron carbide	2.52	11.05	5.20	0.47	2.45	1.18	6.17
sucrose	1.59	7.60	4.04	0.74	2.27	1.18	3.60
phenolic novolac	1.36	5.68	3.14	0.80	1.86	1.08	2.53
graphite	2.15	12.00	6.00	0.50	3.00	1.08	6.45
glycerol	1.26	6.57	3.57	0.79	2.07	0.99	2.61
Aramid fiber	1.44	8.50	4.43	0.68	2.39	0.98	3.45
lithium oxide	2.01	10.00	4.67	0.45	2.19	0.91	4.41
PEEK	1.32	8.47	4.41	0.68	2.38	0.89	3.14
polycarbonate	1.21	4.06	4.06	0.71	2.24	0.86	2.71
water	1.00	6.00	3.33	0.83	2.00	0.83	2.00
HDPE	0.97	4.67	2.67	0.83	1.67	0.81	1.62
liquid hydrogen	0.71	1.00	1.00	1.00	1.00	0.71	0.71
lithium nitride	1.27	8.75	4.00	0.45	1.84	0.57	2.34

Material Trade Study

- Requirements
  - Low Cost
  - Easy to manufacture in house
  - High availability
  - Space Qualifiable (Outgassing, thermal stability, etc.)

Material Trade Study

Shields Protons/Ions

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Material Trade Study

Shields Electrons/Photons

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Radiation Simulation

- Study focuses on three trades/variables
  1. Graded-Z versus Composite-Z layering

Radiation Simulation

- Two configuration options
  1. "Graded-Z"
     - Discrete material layers
     - Usually low-high-low Z configuration
  2. "Composite-Z" or "Doped-Z"
     - Semi-homogenous blend of materials in single layer due to microparticle dopant in resin matrix
     - Usually low Z resin with high Z dopant powder

Radiation Simulation

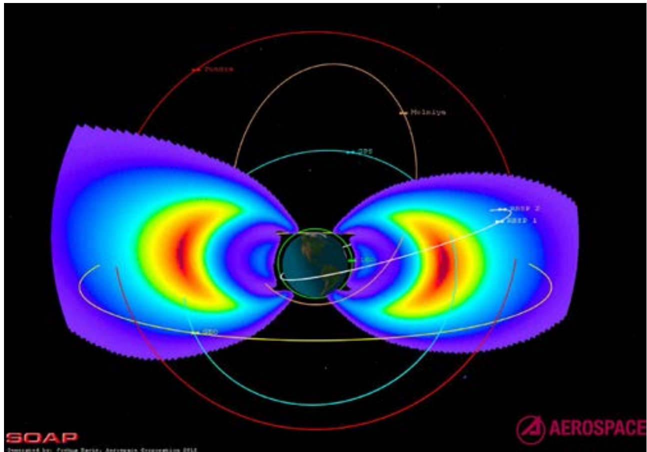
- Study focuses on three trades/variables
  1. Graded-Z versus Composite-Z layering
  2. AND Phenolic versus HDPE low-Z resins

  (1 and 2: 4 Cases)

  3. Increasing percentages of Tungsten microparticle doping in all cases

Radiation Simulation

- Three model environments
  1. Sun Sync
     - Common higher dose LEO orbit -> spends some time in lower proton belt
  2. GPS
     - Very nearly worst case Earth orbit for total dose -> high electron flux
  3. Interplanetary
     - Worst case for high energy particles -> protons/ions



Radiation Simulation

- MULASSIS Setup
  - Omni-directional particle beam impinging on Slab ->

Composite-Z		Graded-Z 12% W avg.		Graded-Z 35% W avg.	
Al chassis	1 mm	Al chassis	1 mm	Al chassis	1 mm
Resin+%W	1 mm	Resin	1 mm	Resin	0.6 mm
Resin+%W	1 mm	Resin+35% W	1 mm	Resin+58% W	1.8 mm
Resin+%W	1 mm	Resin	1 mm	Resin	0.6 mm
Si sensor	2 mm	Si sensor	2 mm	Si sensor	2 mm

  - 3 mm shield thickness was assumed and held constant for all cases

Radiation Simulation

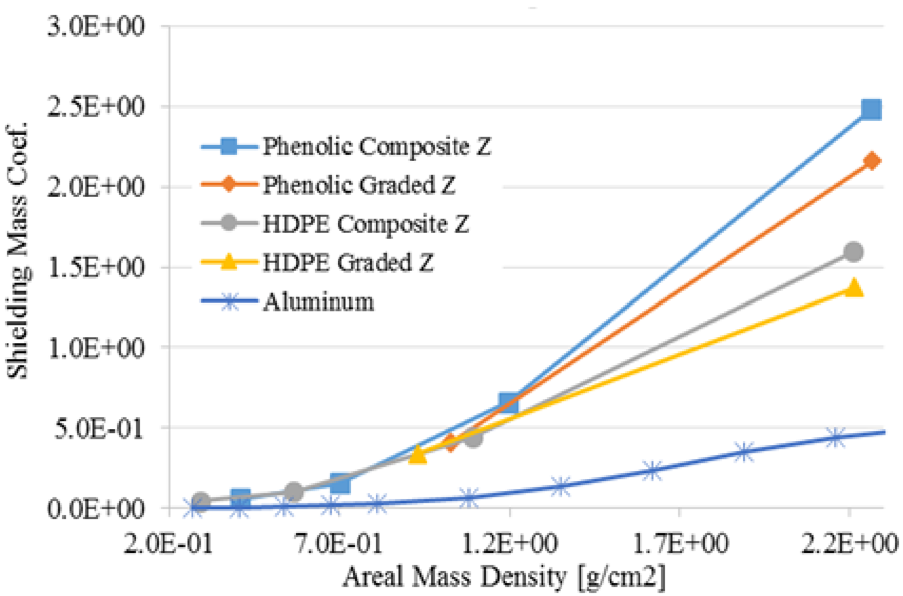
- MULASSIS Setup
  - Coefficient for direct comparison of effectiveness both within and between environments

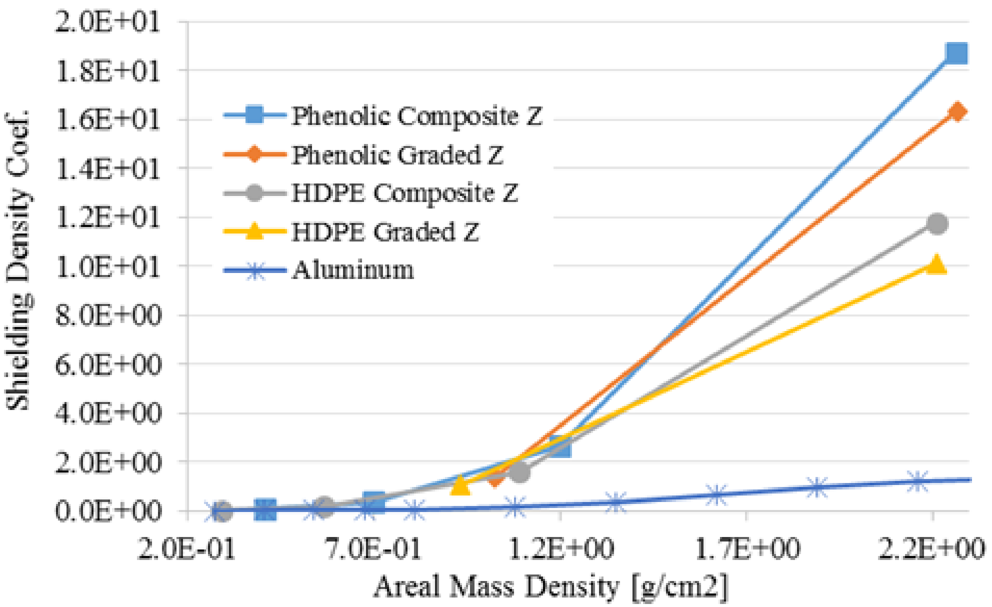
Shielding mass coef. $$\sigma_m = \frac{1}{mD}$$ $[(\text{rad/day})^{-1}(\text{g/cm}^2)^{-1}]$

Shielding density coef. $$\sigma_v = \frac{1}{tD}$$ $[(\text{rad/day})^{-1}(\text{cm})^{-1}]$

Radiation Simulation

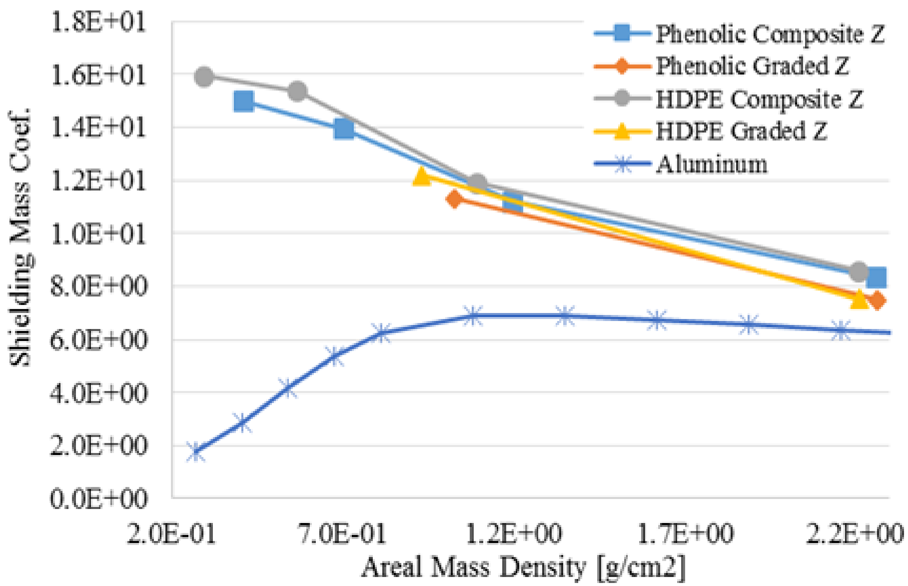
- MULASSIS Results
  - GPS

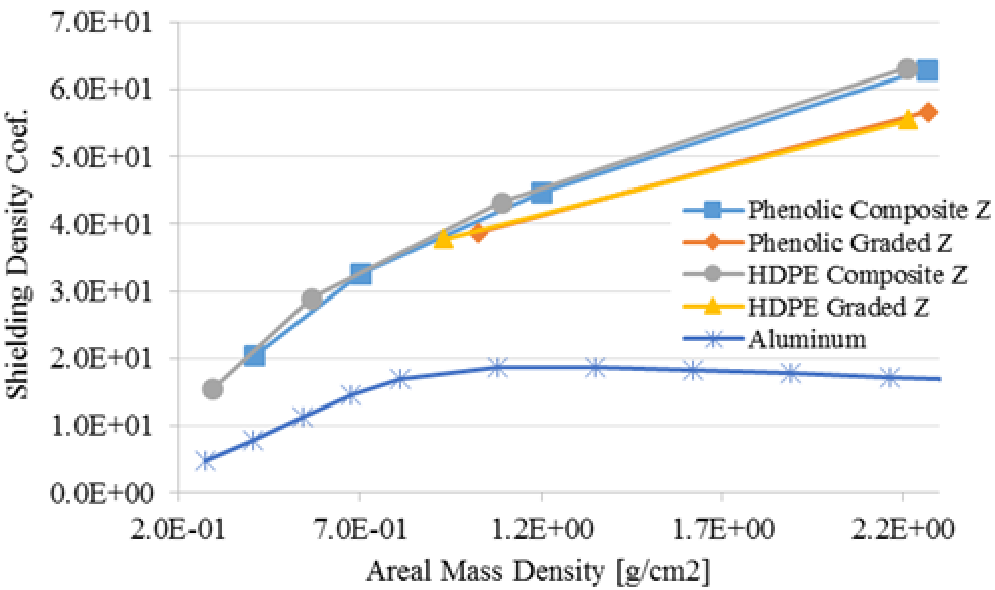




Radiation Simulation

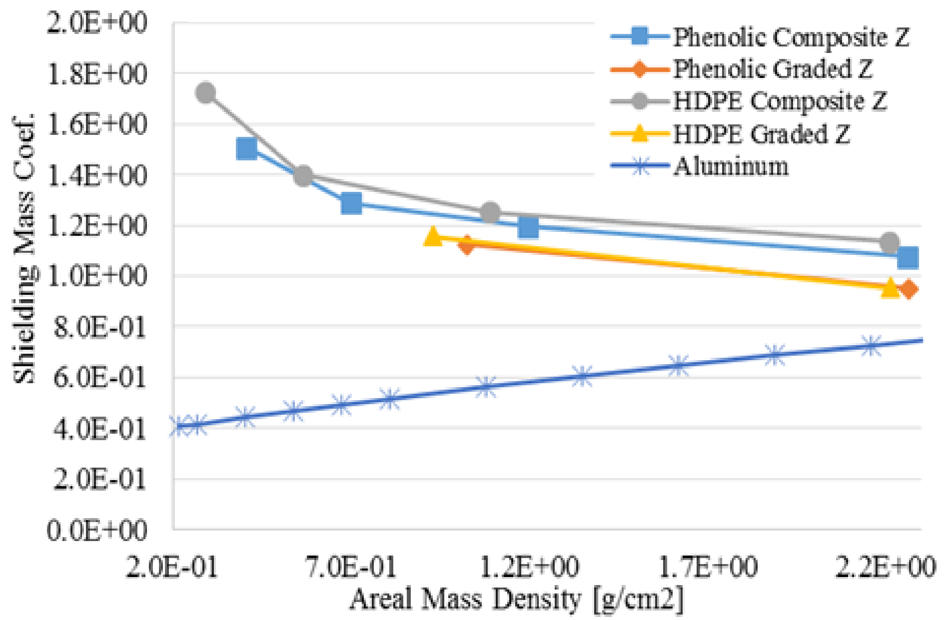
- MULASSIS Results
  - Sun Sync

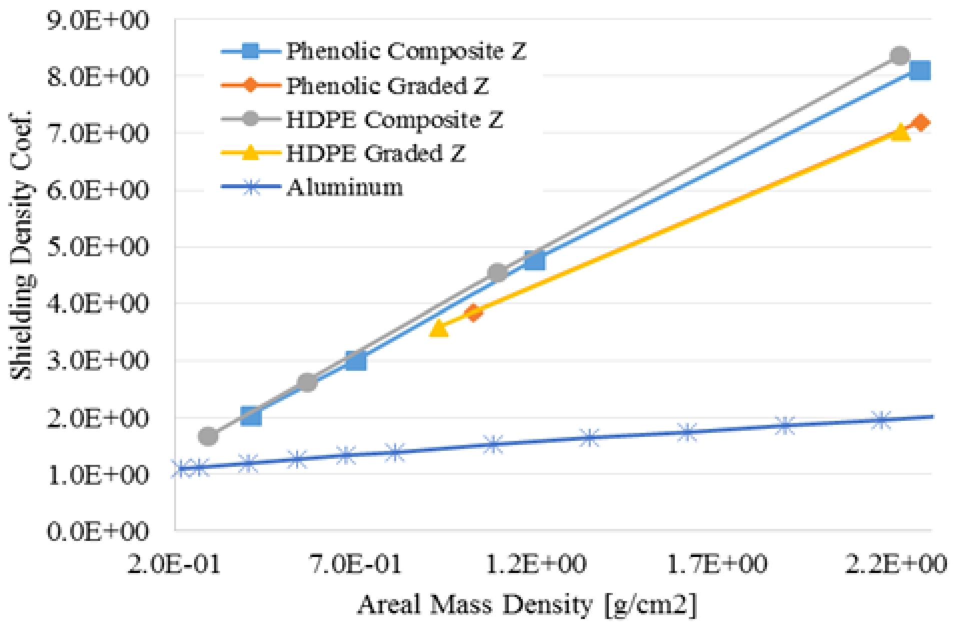




Radiation Simulation

- MULASSIS Results
  - Interplanetary

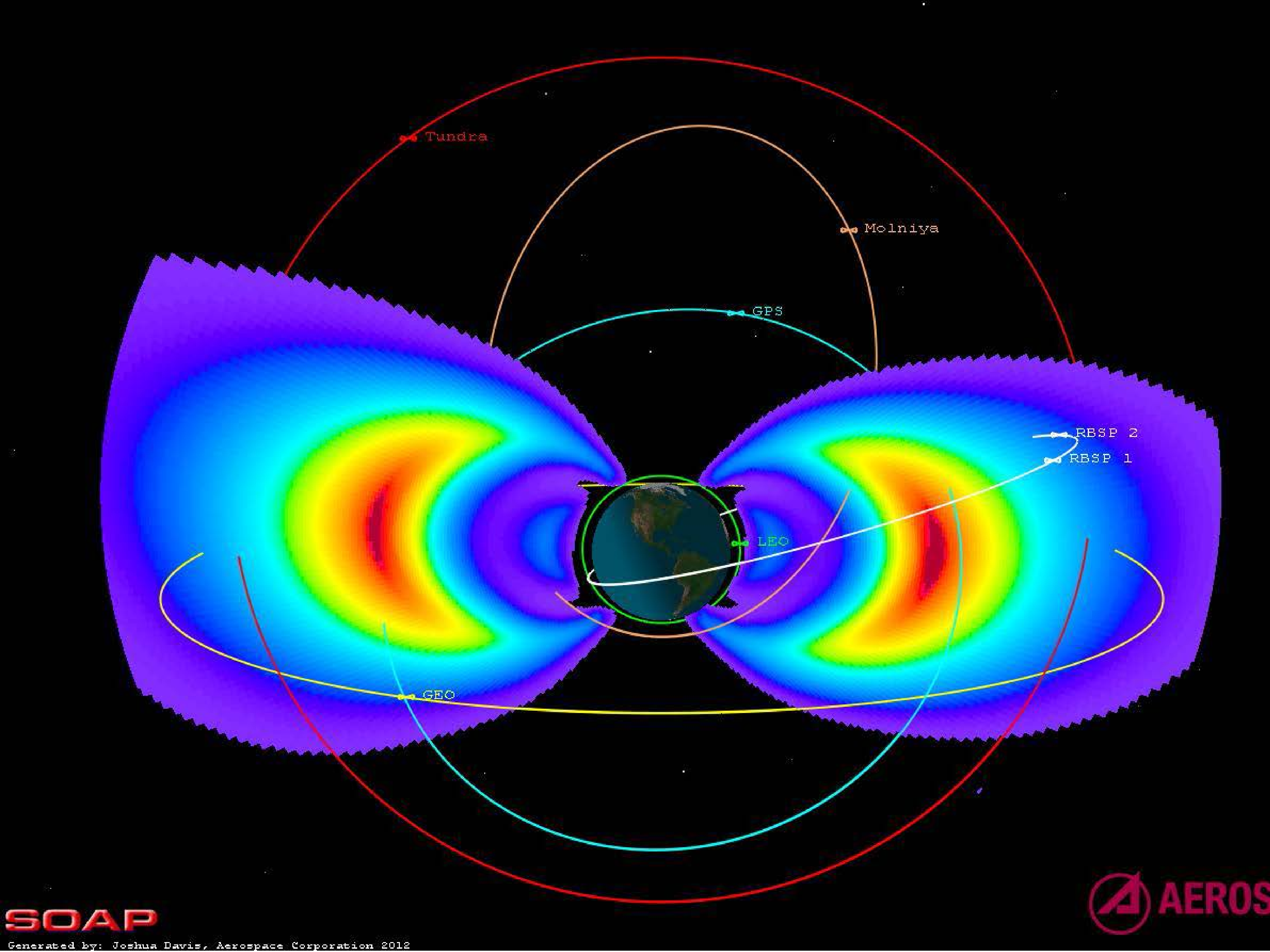




Passive Shielding Optimization

- Major Take-Aways
  - More tungsten == higher volume shielding efficiency
  - More tungsten == lower mass shielding efficiency for protons/ions
  - More tungsten == both higher mass & volume electron shielding efficiency
  - Phenolic better in GPS (electron-rich) than HDPE
  - HDPE very slightly better than Phenolic for proton/ion shielding
  - Composite-Z universally better than Graded-Z option, as examined

Questions


Tundra
Molniya
GPS
RBSP 2
RBSP 1
LEO
GEO
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