

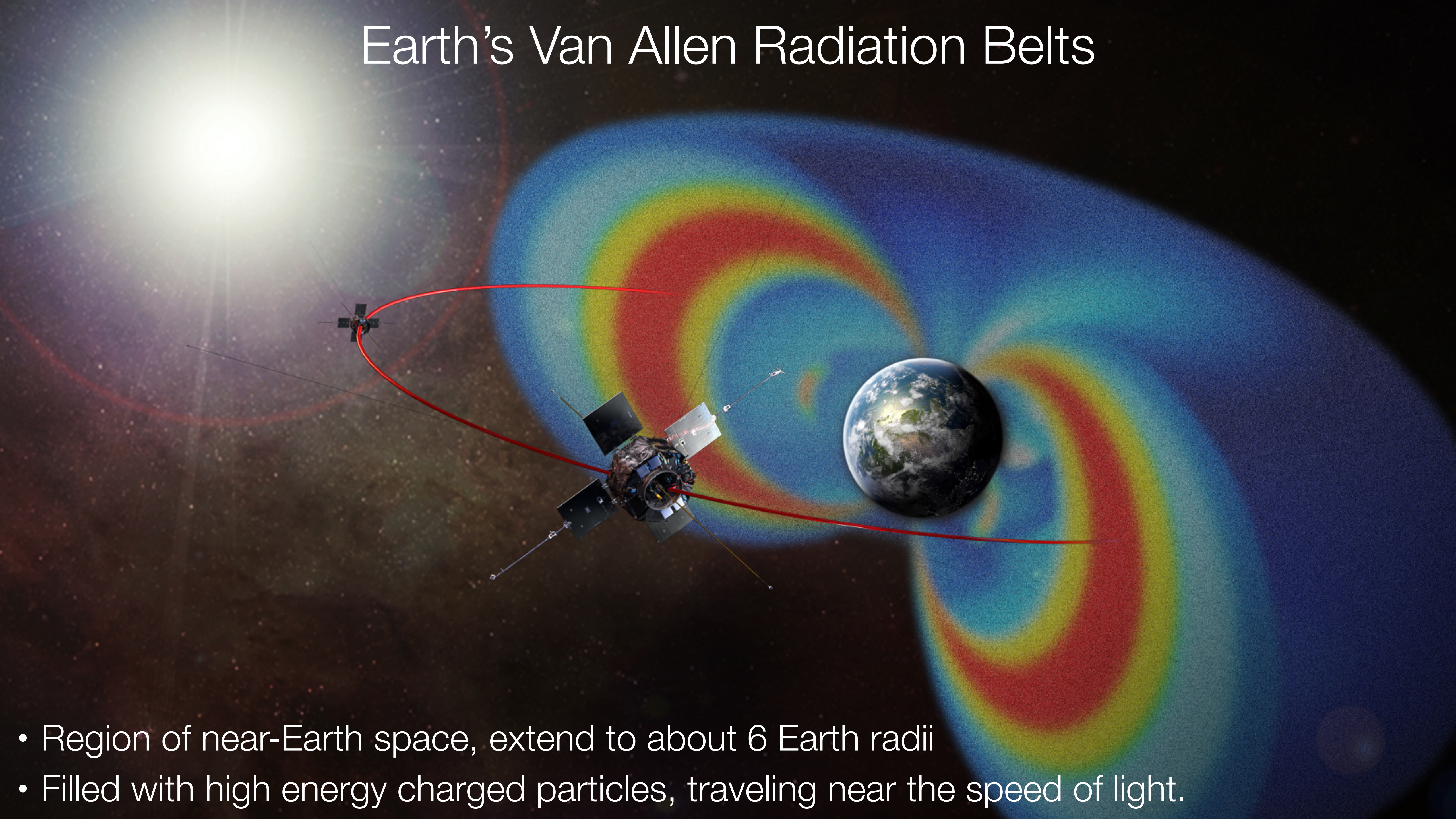
Potential of Small Satellites for SpWx

Space-based Architectural Framework



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Earth's Van Allen Radiation Belts



- Region of near-Earth space, extend to about 6 Earth radii
- Filled with high energy charged particles, traveling near the speed of light.

Space Weather Hazards in the Radiation Belts

- GPS, weather, communications satellites all spend time in the radiation belts
- Natural and man-made radiation trapped
- Spacecraft components can be damaged:
 - single event upsets
 - deep dielectric discharge

Deep Dielectric Discharge

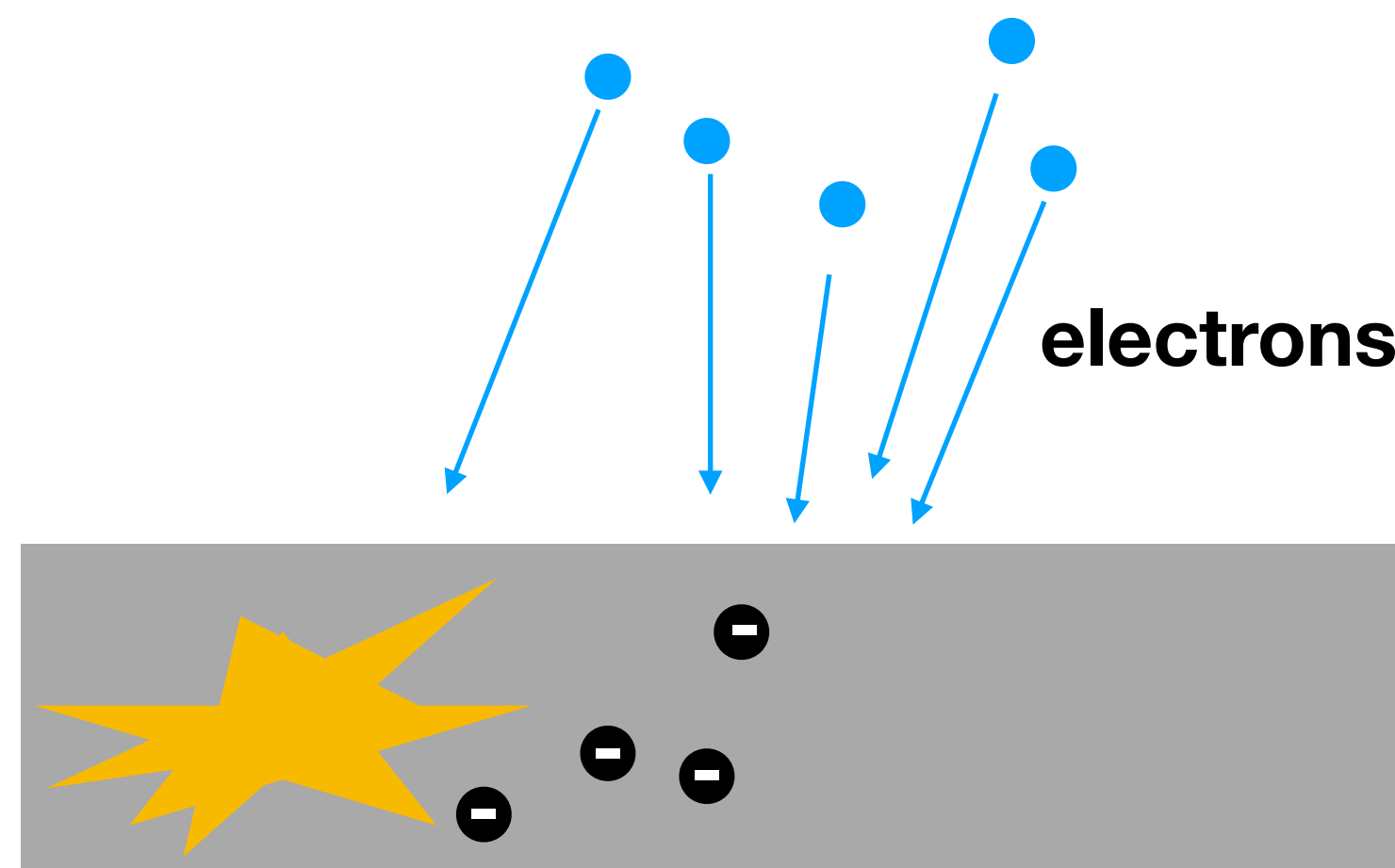
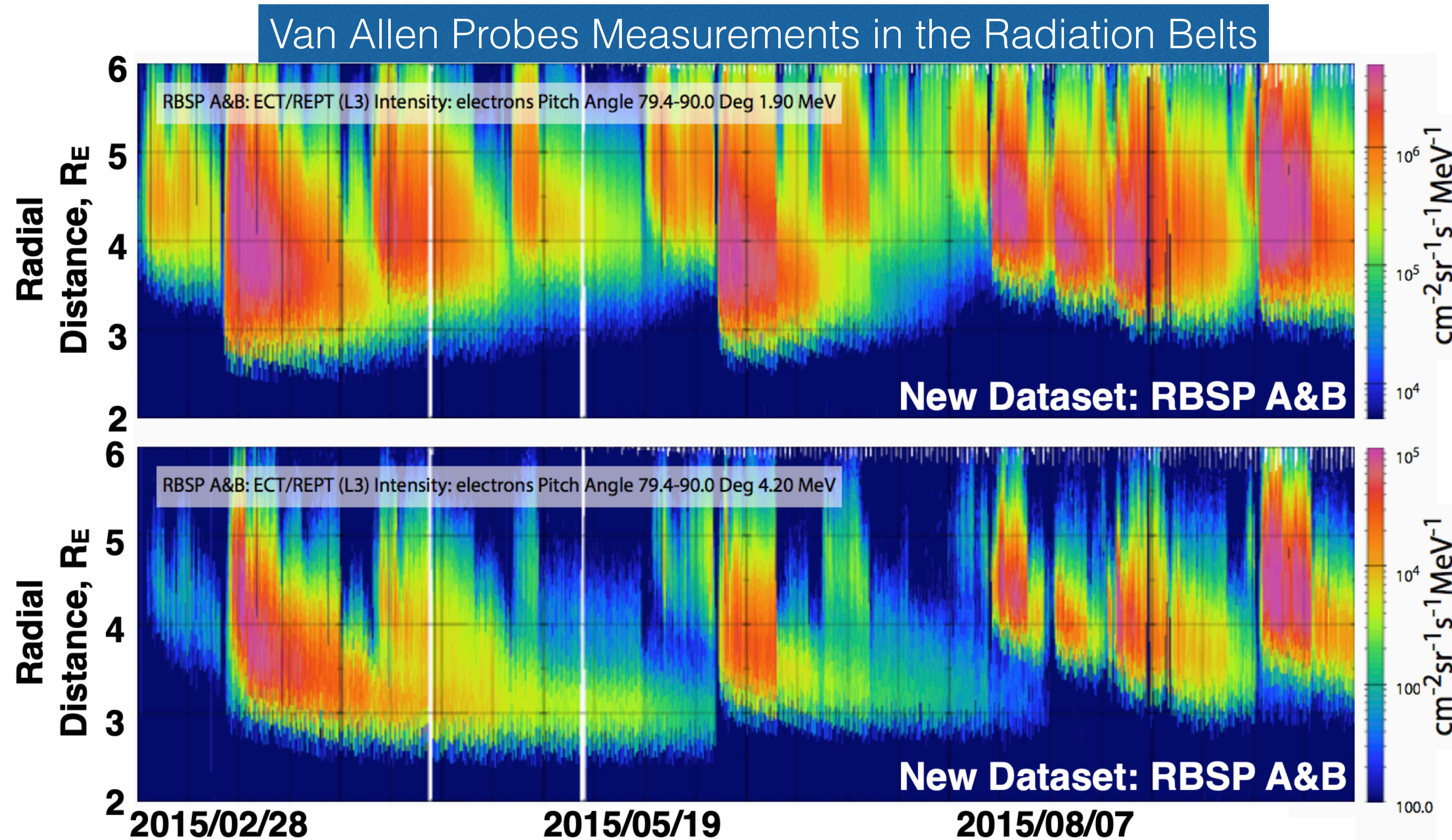


Image credit: Lou Lanzerotti

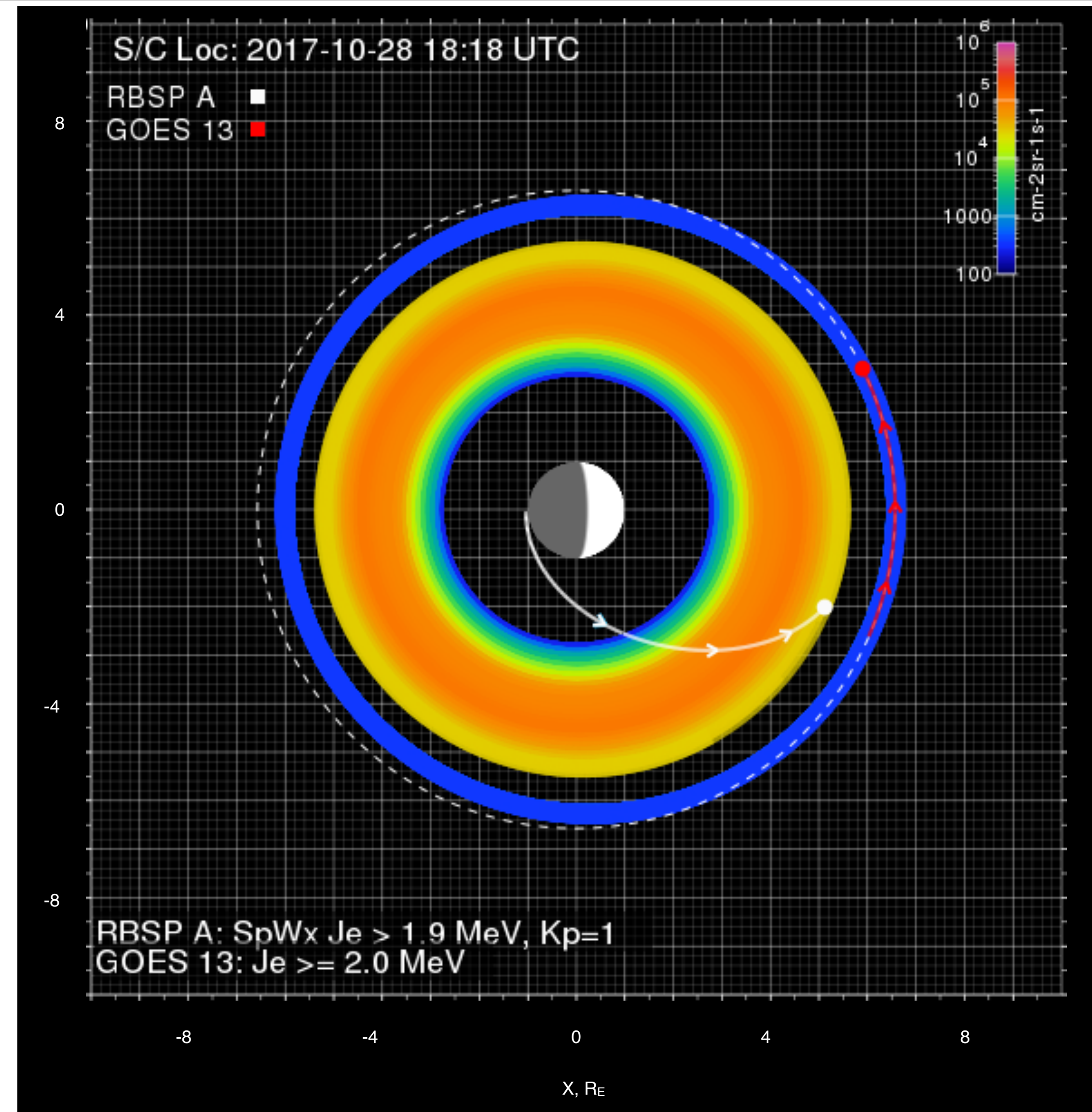
Enhancements of Hazardous Electron Radiation

- Radiation belt intensities can rise to hazardous levels on timescales of minutes or less



Results from Van Allen Probes

- Enhancements can be localized ($\sim R_E$) or extend across the entire system ($\sim 10R_E$)
- Biggest radiation enhancements occur inside GEO and above LEO orbits
- Produced by a wide range of mechanisms
 - interplanetary shocks
 - intense localized particle injections from the magnetotail
 - nonlinear wave-particle interactions in the heart of the radiation belts
- Van Allen Probes mission ended in 2019

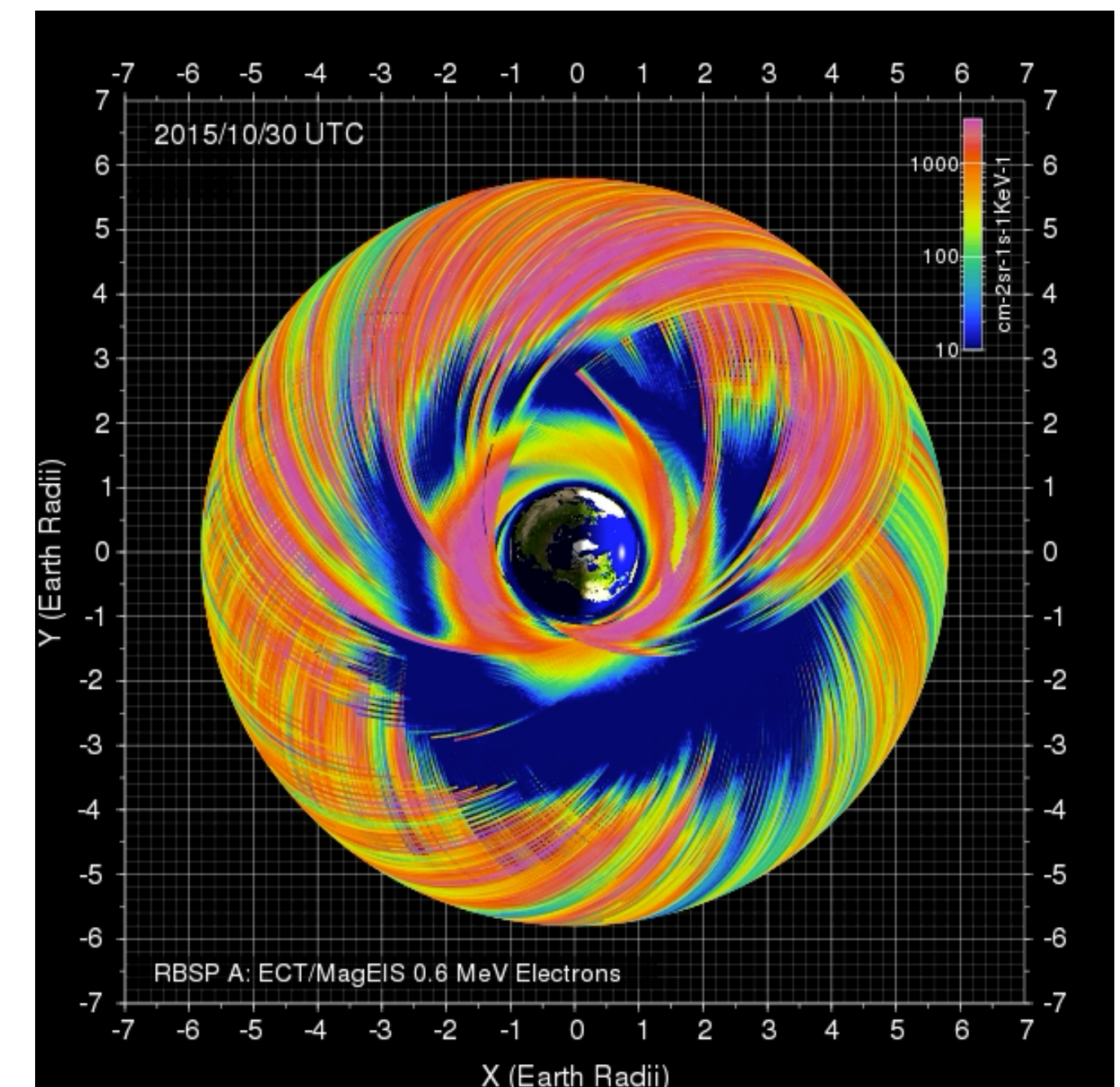
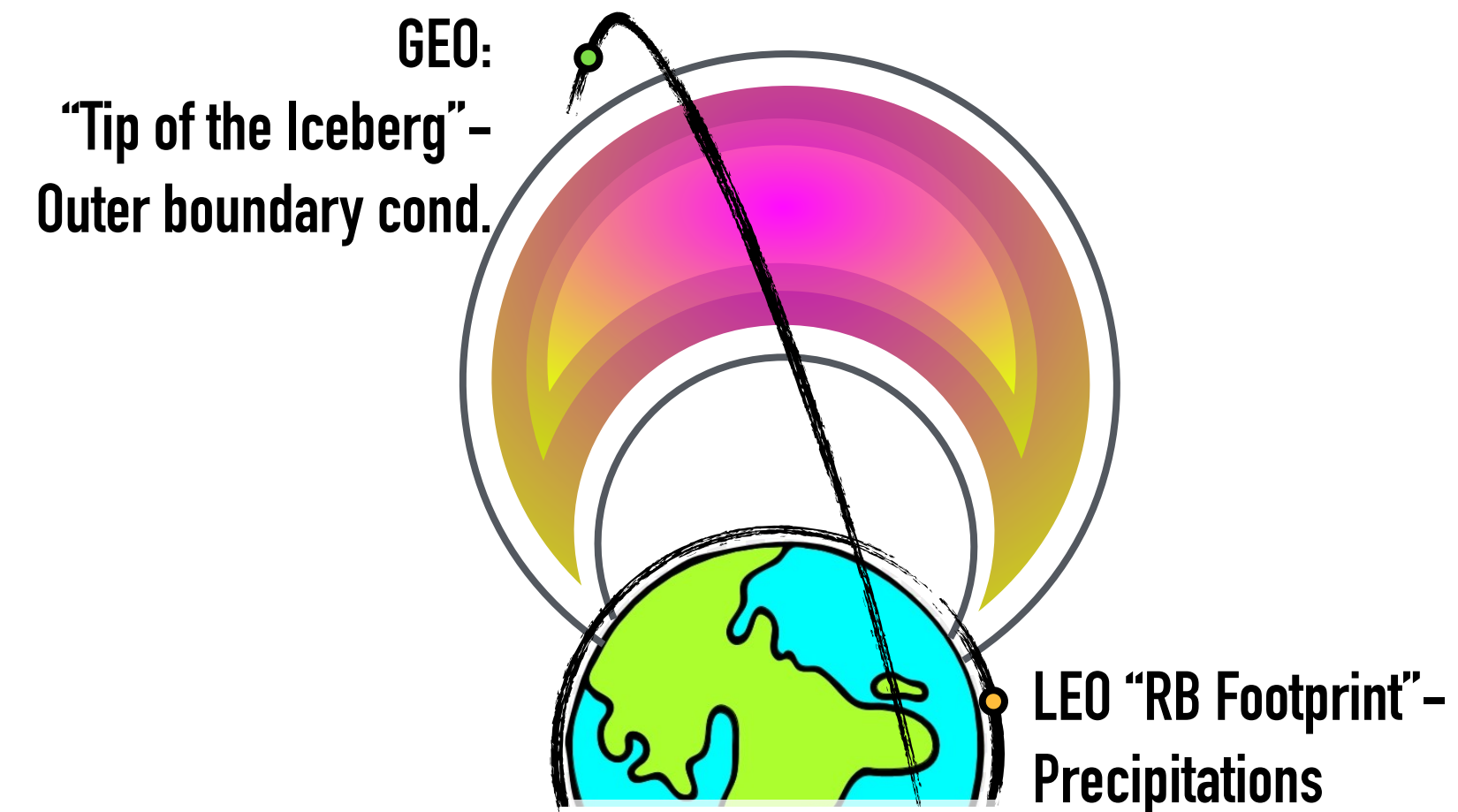


Filling the Gap Between LEO and GEO

From lunar exploration to MEO constellations and LEO-GEO transit launches, an ever increasing number of our Nation's space assets dwell in the heart of RB

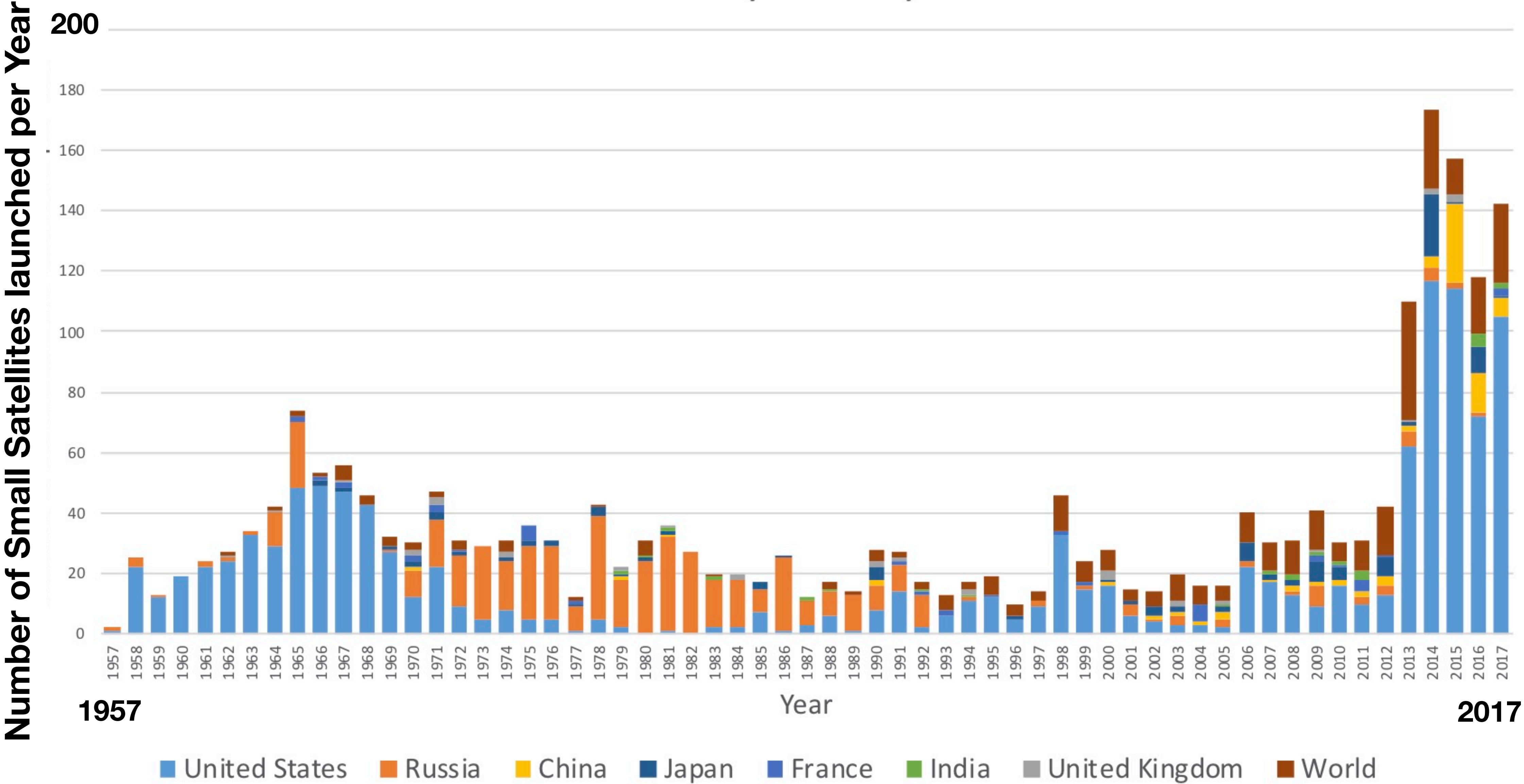
- Needed Capabilities

- Capture the full extent of the radiation belts between LEO & GEO with ~minute “exposure”
- Disentangle spatial and temporal variability of radiation belt intensities with multi-point simultaneous measurements around Earth
- Quantify adverse radiation effects on different materials used in spacecraft manufacturing
- Develop “big-data” capabilities to process operational/scientific data from a massive constellation of simultaneous in situ measurements



Can we leverage the small satellite revolution to fill this gap?

Small Satellites by Country and Year



Lal et al., 2017, IDA Report

Commercial Mega-constellations

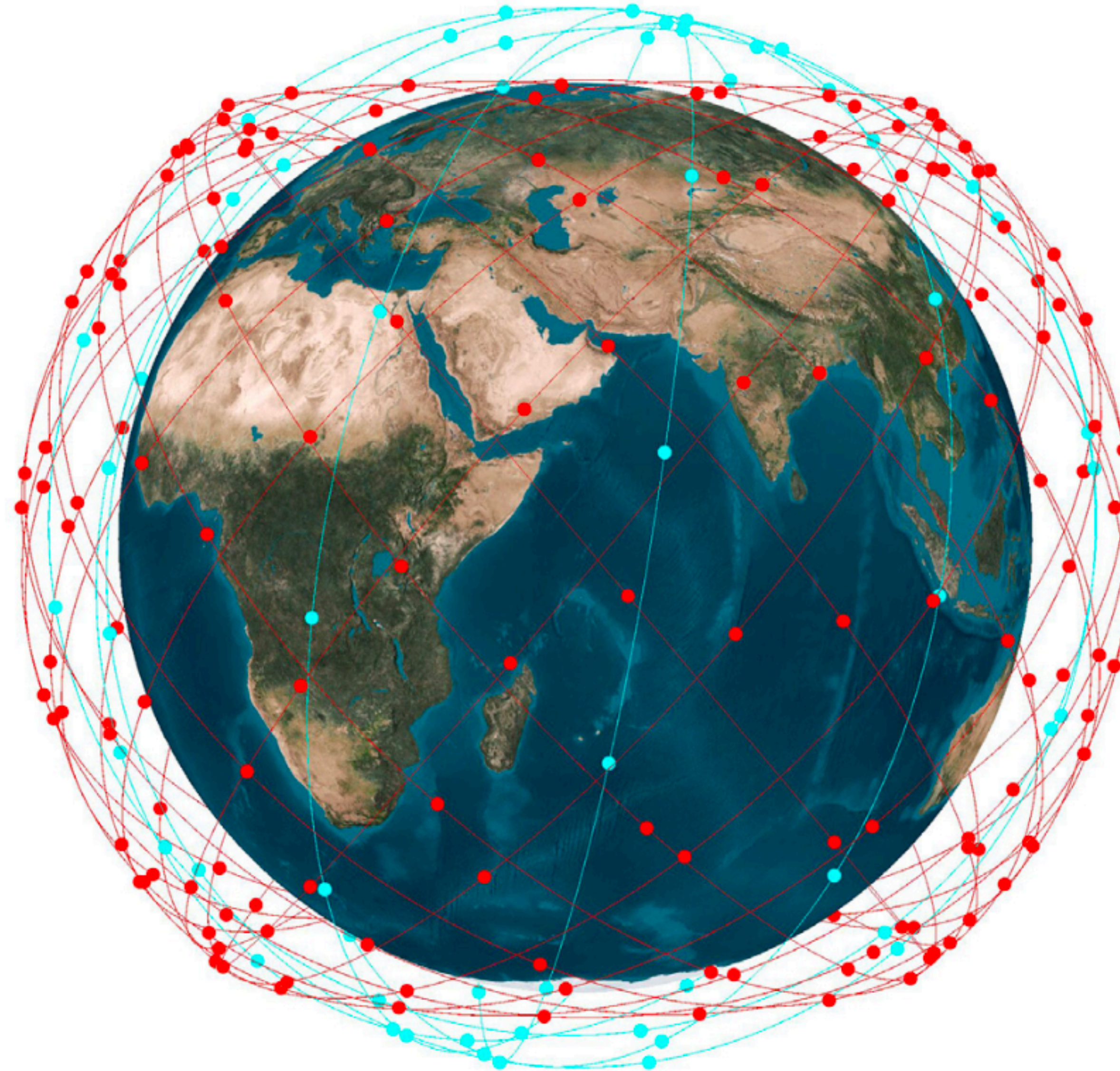
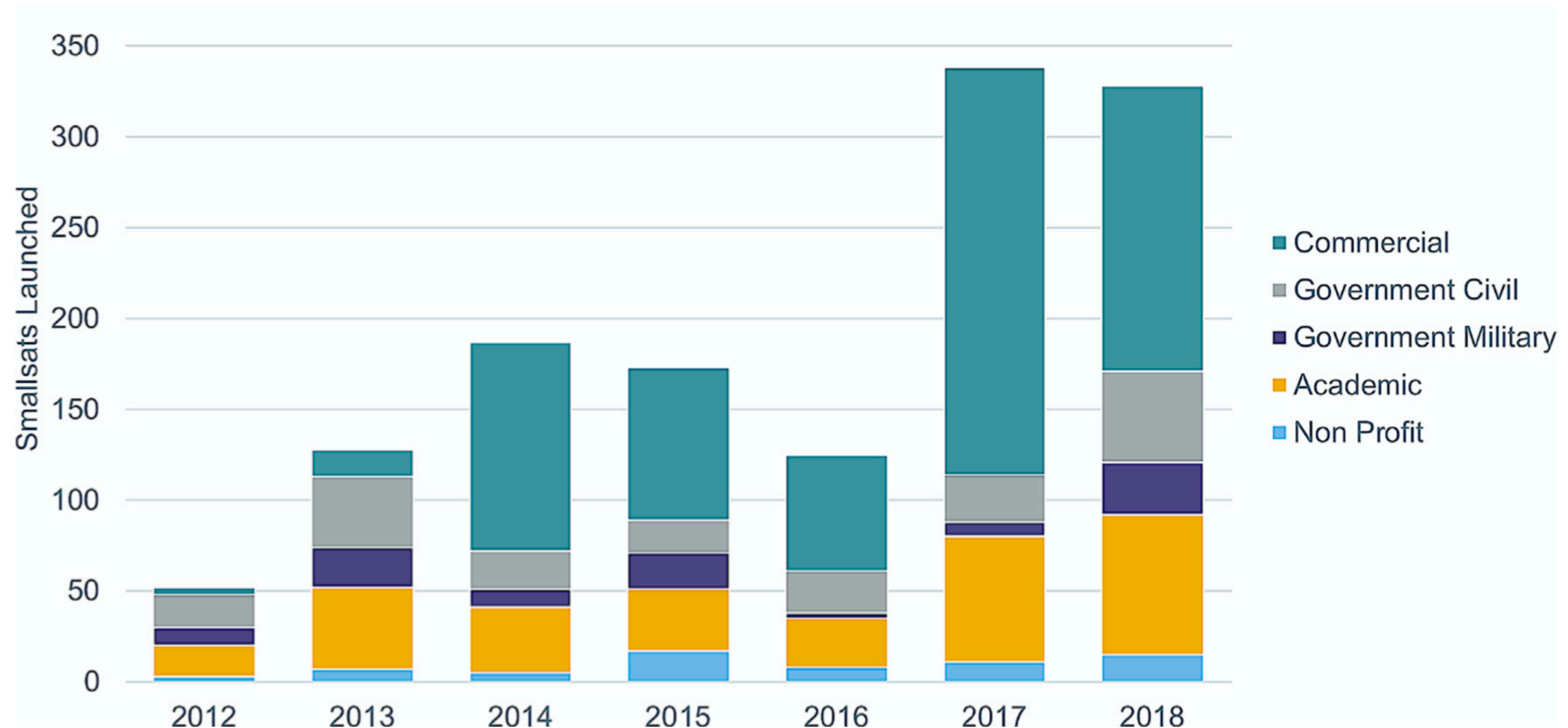


Image Credit: Telesat

Number of Small Sats by Sector

- Most commercial SmallSats are for remote sensing or broadband services



*Image Credit: Bryce Space and Technology
(<https://brycetechnology.com/reports.html>)*

NSF CubeSat Program

Pioneered the use of CubeSats as a platform for Space Weather Science



- 2007 community workshop
- First solicitation in 2008 (NASA Wallops Flight Facility as partner)
- Objectives
 - Science (space weather, atmospheric)
 - Education and training of next-generation STEM workforce



CubeSat:
A spacecraft sized in units or U's
10 cm on a side, ~1 kg

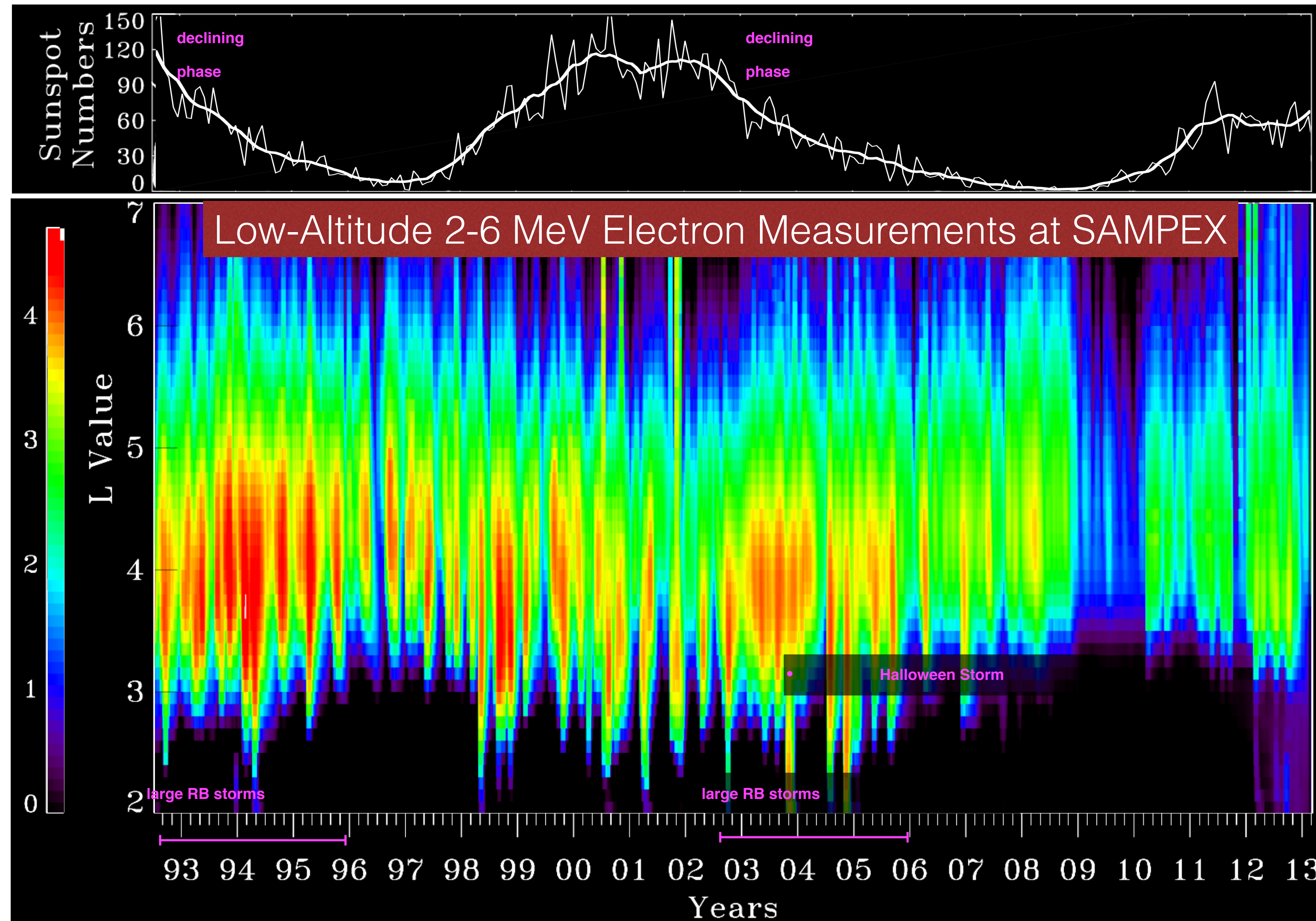
A Disruptive Innovation



- 2016 National Academies Report
 - Targeted investigations
 - Augment capabilities of large missions
 - Enable technologies that benefit larger missions
 - Enable new kinds of measurements (e.g. distributed, low altitude)
- Other Small Satellite Efforts
 - IDA Report “Global Trends in Small Satellites”, July 2017
 - COSPAR Roadmap on small satellites published in 2019: <https://doi.org/10.1016/j.asr.2019.07.035>
 - COSPAR Task Force: <https://cosparhq.cnes.fr/scientific-structure/task-group-on-establishing-a-constellation-of-small-satellites-tgcss/>

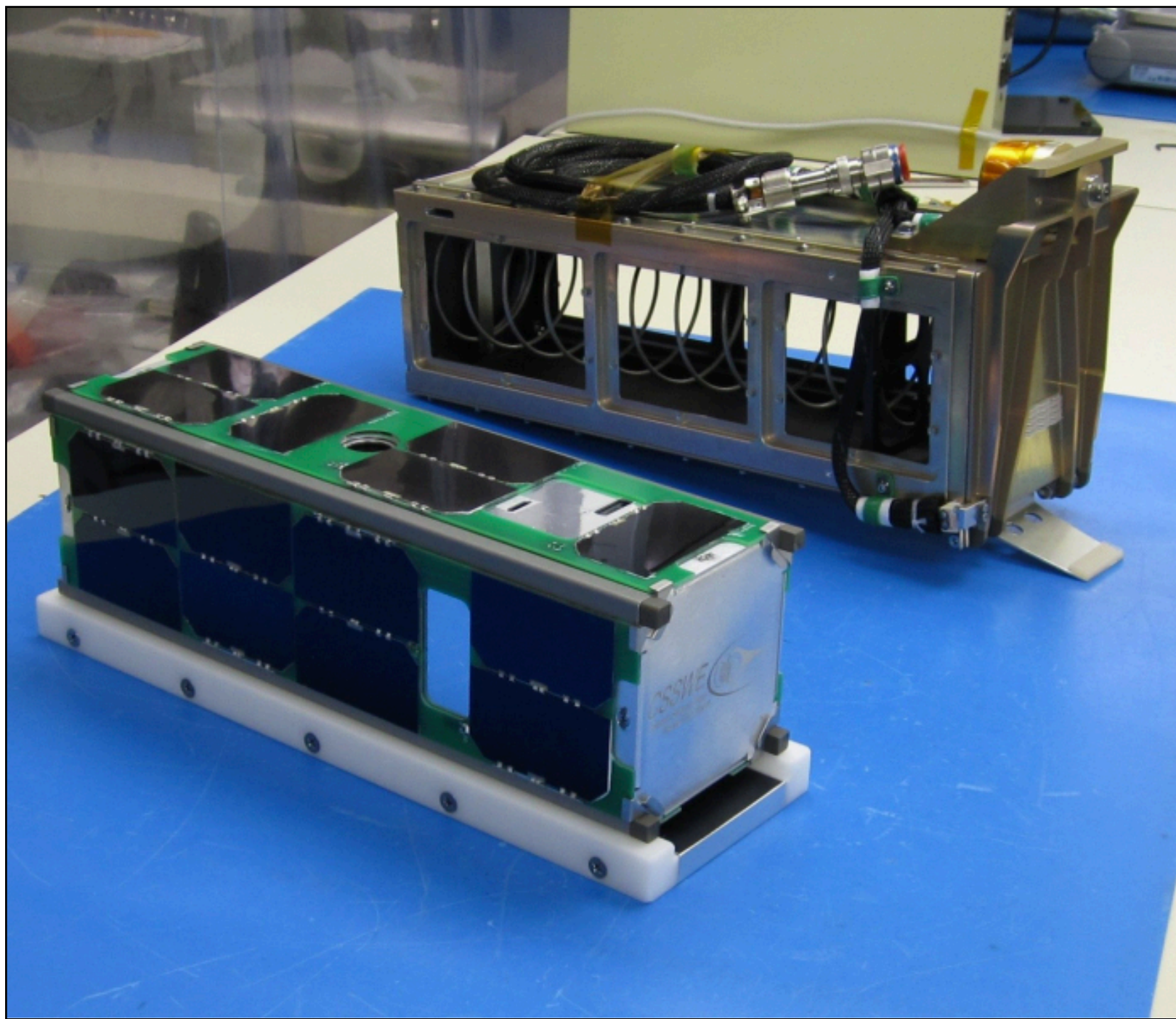
Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX)

- First NASA Small Explorer (SMEX)
- July 3, 1992 - June 30, 2004
- 158 kg

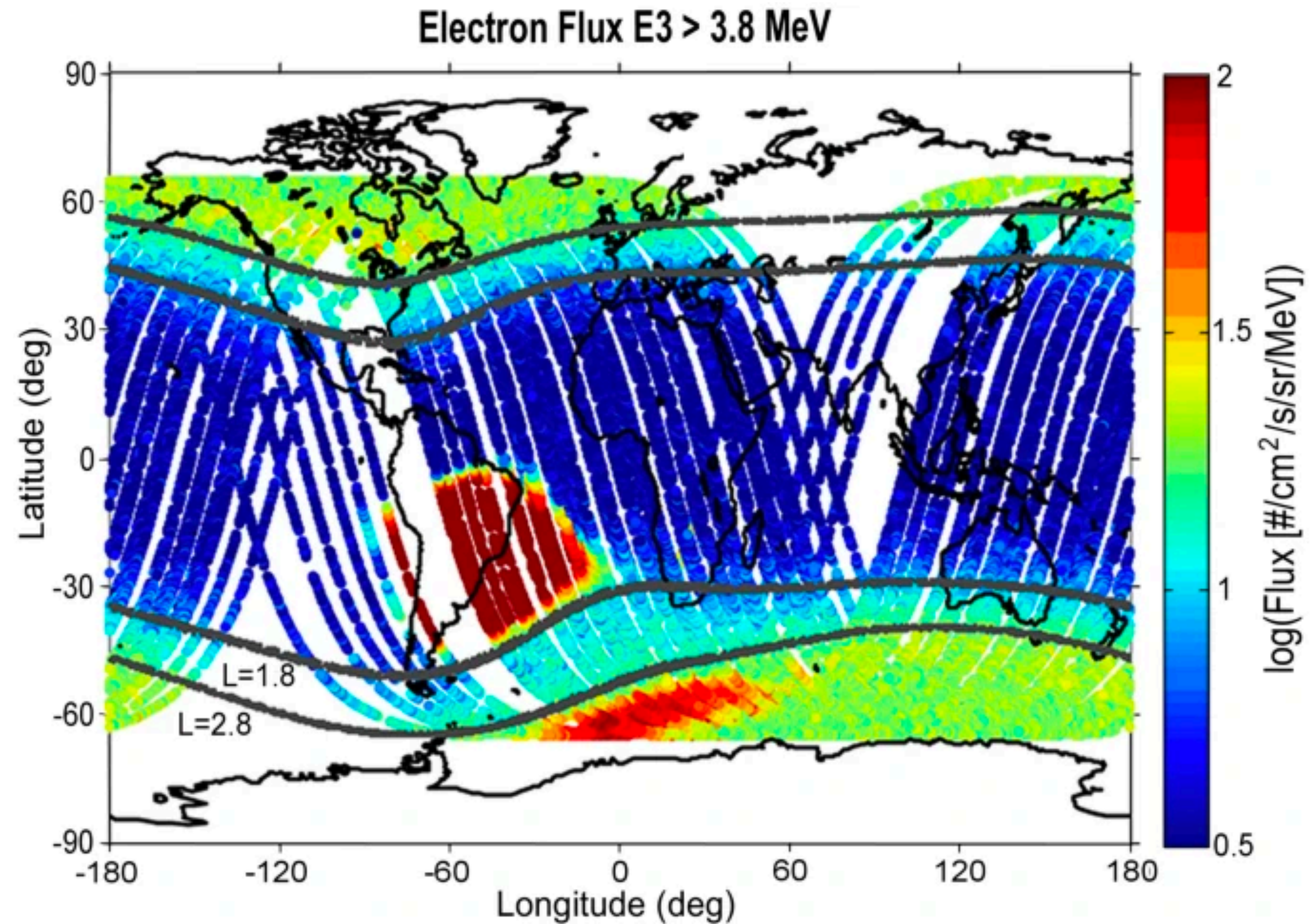


Colorado Student Space Weather Experiment (CSSWE)

- Funded by NSF CubeSat program
- 3U CubeSat (10cm × 10cm × 30cm)
- < 4 kg
- Mission lifetime ~2 years



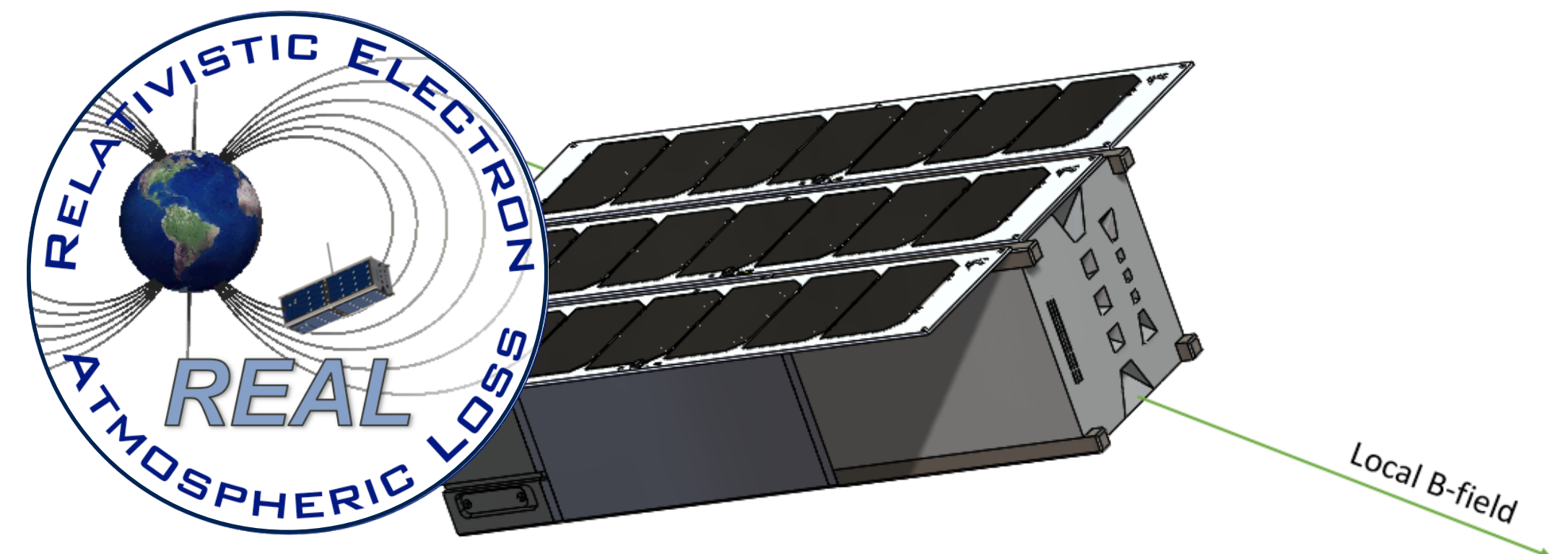
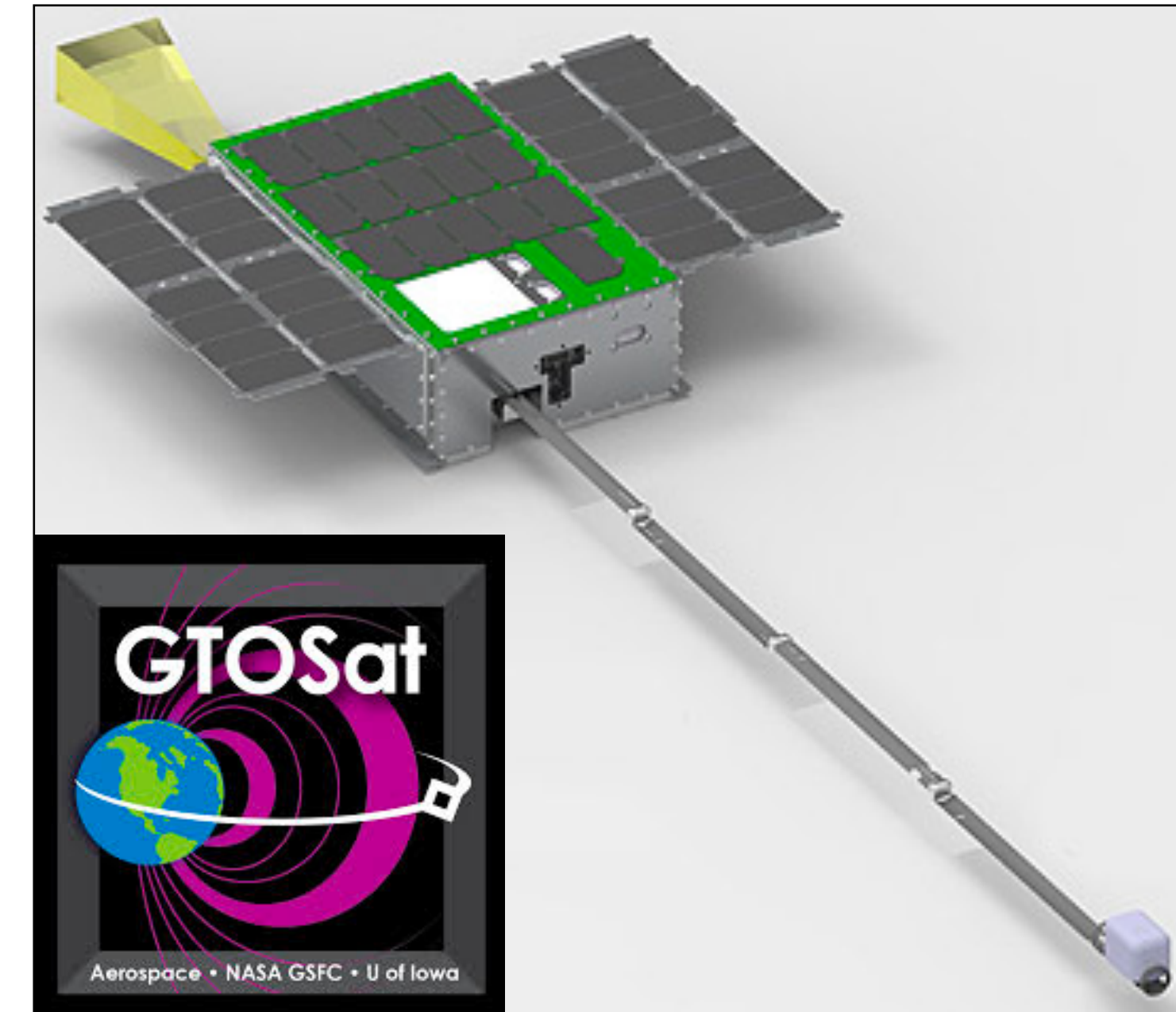
Gerhardt et al., JOSS



Baker et al., 2014, Nature

CubeSats for Radiation Belt Science

- A number of current and upcoming CubeSat science missions
- Demonstrating the capabilities of small satellites



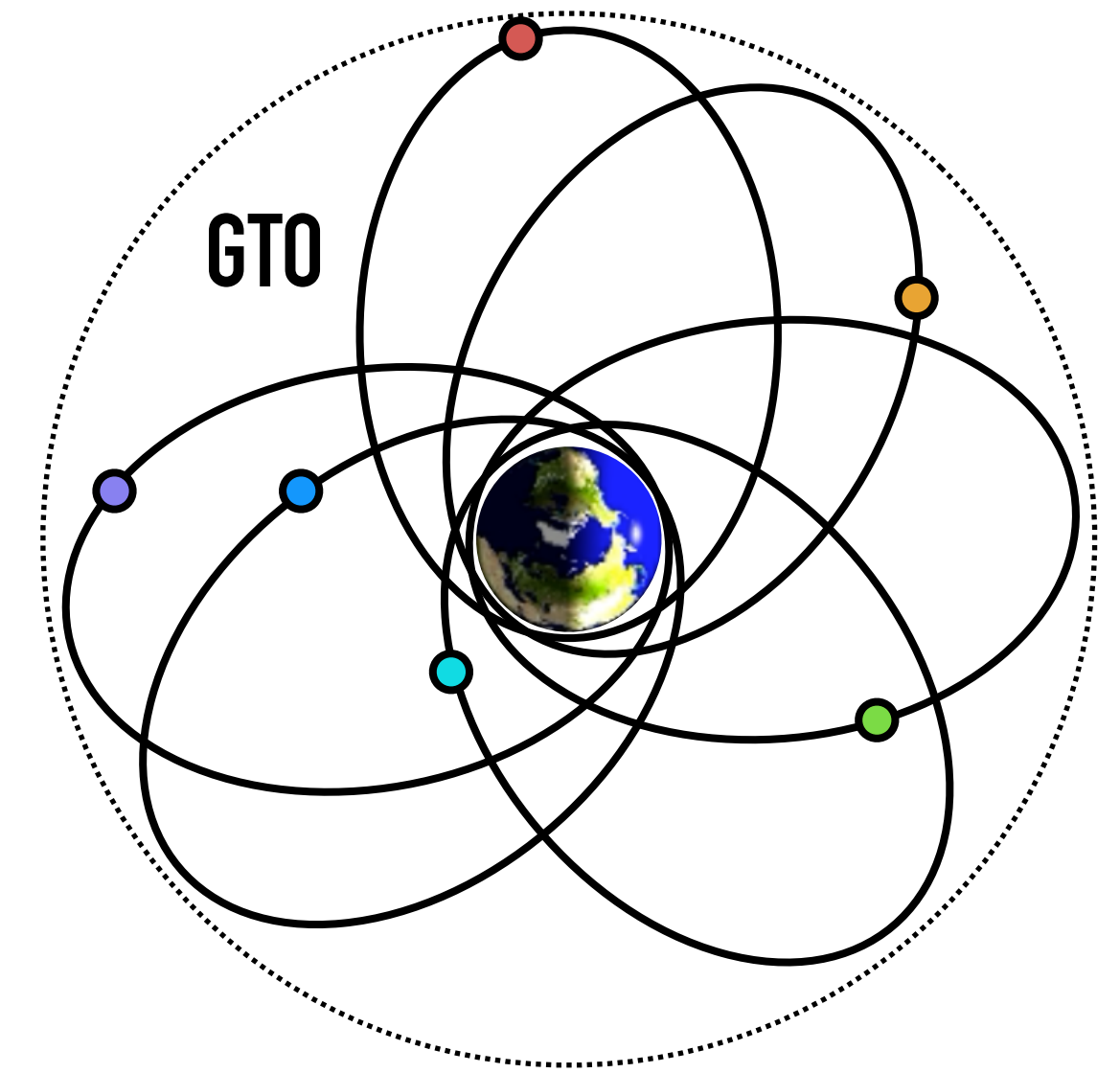
Current Capabilities: LEO hosted payloads

Leveraging commercial constellations for Space Weather Measurements

- Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE)
 - Pioneer in using commercial constellation for space science
 - Partnership between APL and Iridium
- Planet Labs, Inc. magnetometers used for studying auroral currents - see Parham et al., 2019 (<https://doi.org/10.1029/2018JA025966>)
- Responsive Environmental Assessment Commercially Hosted (REACH) constellation
 - 32 hosted sensors on the Iridium NEXT constellation
 - Partnership between the U.S. Air Force, The Aerospace Corporation, Johns Hopkins Applied Physics Laboratory (APL), Iridium Communications and Harris Corporation.
 - unprecedented capability to monitor Earth's radiation environment in low Earth orbit.

Future Capabilities: GTO Constellation

- Rapid development/scalability: Ready for deployment within 1-2 years. Complements existing LEO and GEO assets (e.g., GOES, REACH), but fills the gap in between.
- Broad participation: No requirement for the payloads to be identical. Contributions from multiple players/programs (e.g, NASA-funded MoO, HFORT/HTIDES, international partners) deployed based on available resources.
- Collaboration with commercial sector: Long-term partnerships with the commercial sector for rideshare and/or hosted payloads.
- Simple, streamlined bus design and operations: 8-16 U mass-produced (by one or more manufacturers) busses with common instrument interface.
- Collaboration with SC operators and manufacturers: Develop data products and metrics of success; develop “materials science” payload to quantify charging effects on different materials. Platform can also be used as a test-bed for new technologies.
- Big-data component: Data products from a large constellation of simultaneous *in situ* measurements will require state-of-the art algorithms of machine learning and data-mining.
- Modeling capabilities: Operational products for forecasting and nowcasting radiation intensities leverage data-augmented physics-based and data-driven models.



Target Capabilities

Energetic electrons: ~keV-10 MeV (e.g., SS telescopes, MagSpec, APD)
Ions: keV-100s keV (e.g., puck)
Plasma: ~eV-10s eV (e.g., Faraday cup, ESA)
Magnetometer: DC-10 Hz (fluxgate, scalar)
Plasma waves: kHz-100 kHz (search coil)
Material science: surface/internal charging (dosimeters)