

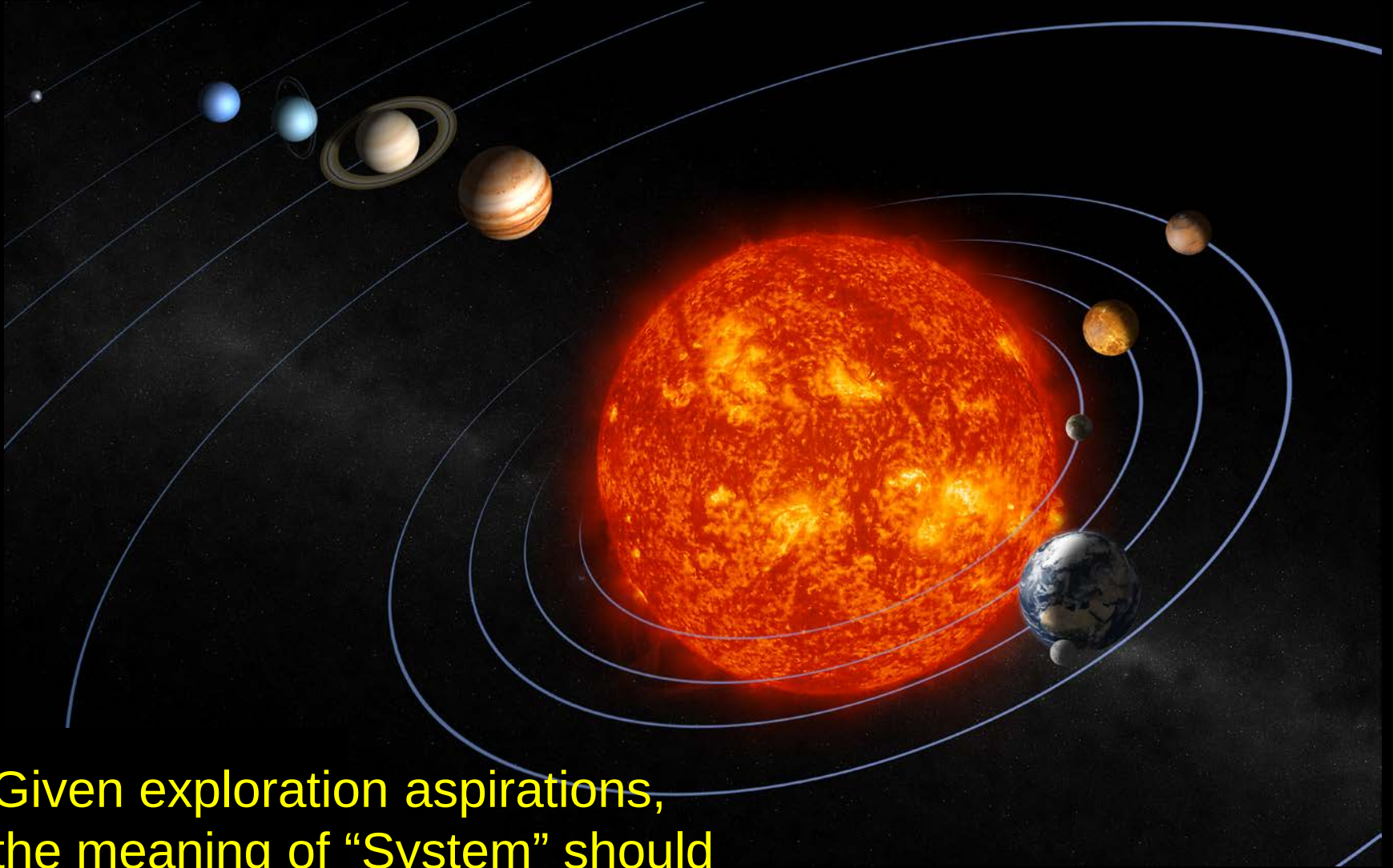
Space Weather Observing Architecture

A Systems View

NOAA Image



Daniel Baker (LASP) and Thomas Berger (SWx TREC)
University of Colorado - Boulder

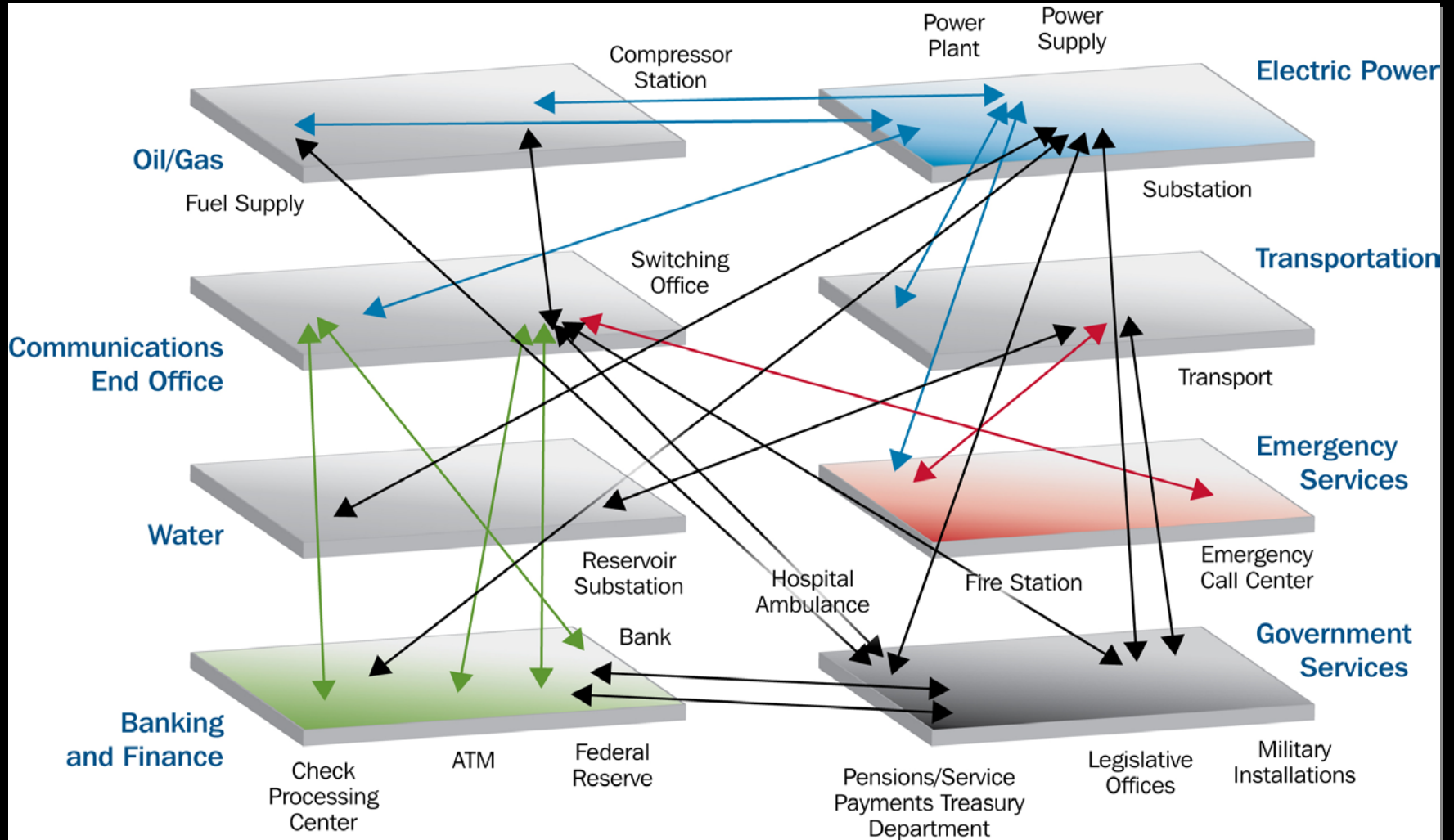


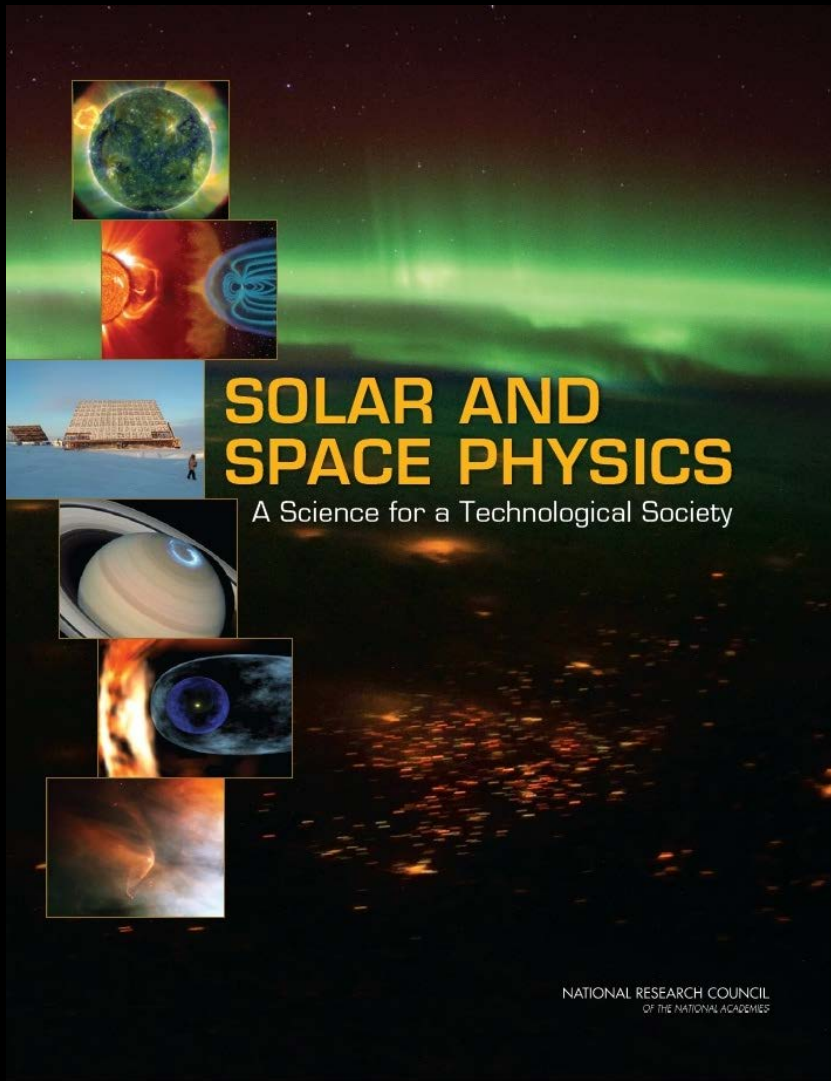
Given exploration aspirations,
the meaning of “System” should
be expanded to a broader view

The Effects of Space Weather



The Interdependencies of Society





Enabling Effective Space Weather and Climate Capabilities:

The 2013-2022 NRC
Decadal Survey

Chapter 7
NRC Decadal Survey

Box 7.2

Continuous Measurements for Space Weather and Climate: Complementing and Preserving Observations of the Space Environment

Solar-Heliosphere System Forcing

- Solar X-ray and extreme ultraviolet
- Ultraviolet spectral irradiance and images
- Solar magnetograms
- Coronal-heliospheric images
- Solar wind (speed, density, temperature, ion composition)
- Interplanetary magnetic fields
- Energetic particles (solar and galactic)

Earth System Forcing

- Gravity waves, tides, polar vortex flows

Box 7.2 (Cont'd)

Continuous Measurements for Space Weather and Climate: Complementing and Preserving Observations of the Space Environment

Atmosphere-Ionosphere-Magnetosphere System Response

- Neutral temperature
- Electron density profile and total electron content
- Total mass density
- Neutral winds
- Electric and magnetic fields
- Ionospheric scintillation (amplitude, phase, morphology)
- Composition of major species (especially O, and O⁺)
- Concentration of minor species (radiatively active gases)
- Wave activity on all scales (gravity/ planetary waves, tides)
- Energetic particles (protons, electrons, ions, neutrals)
- Auroral morphology

Drivers for SWx Forecasts

2020-2030

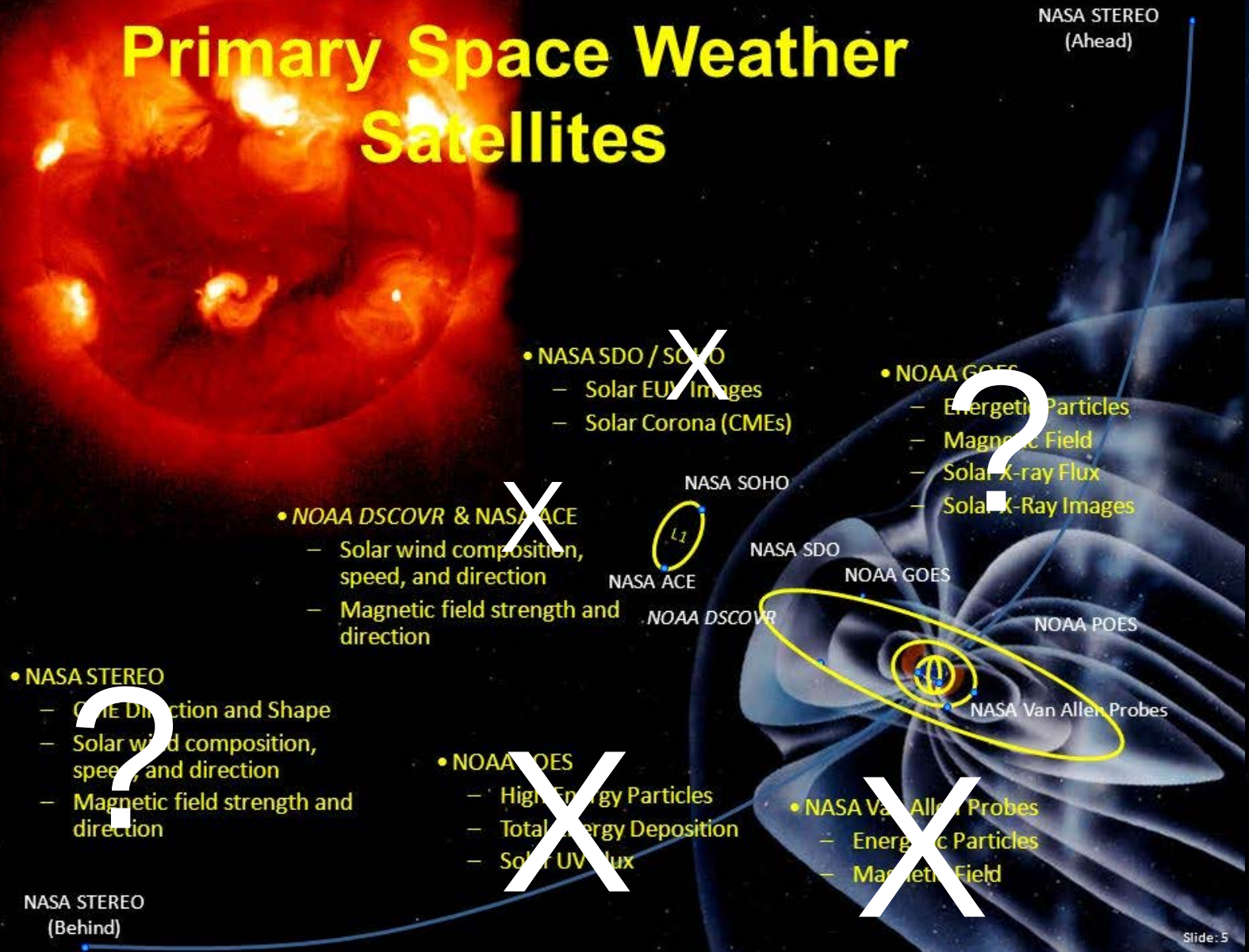
An evolving landscape: New technologies and capabilities will drive demand for space weather products

- Civil Precision GNSS Users
- Next Generation Air Transportation System
- Increased Vulnerability of Power Grid
- Commercial Satellite Industry
- Exploration Missions to the Moon and beyond
- Commercial Space Enterprise
- Arctic Economic Development

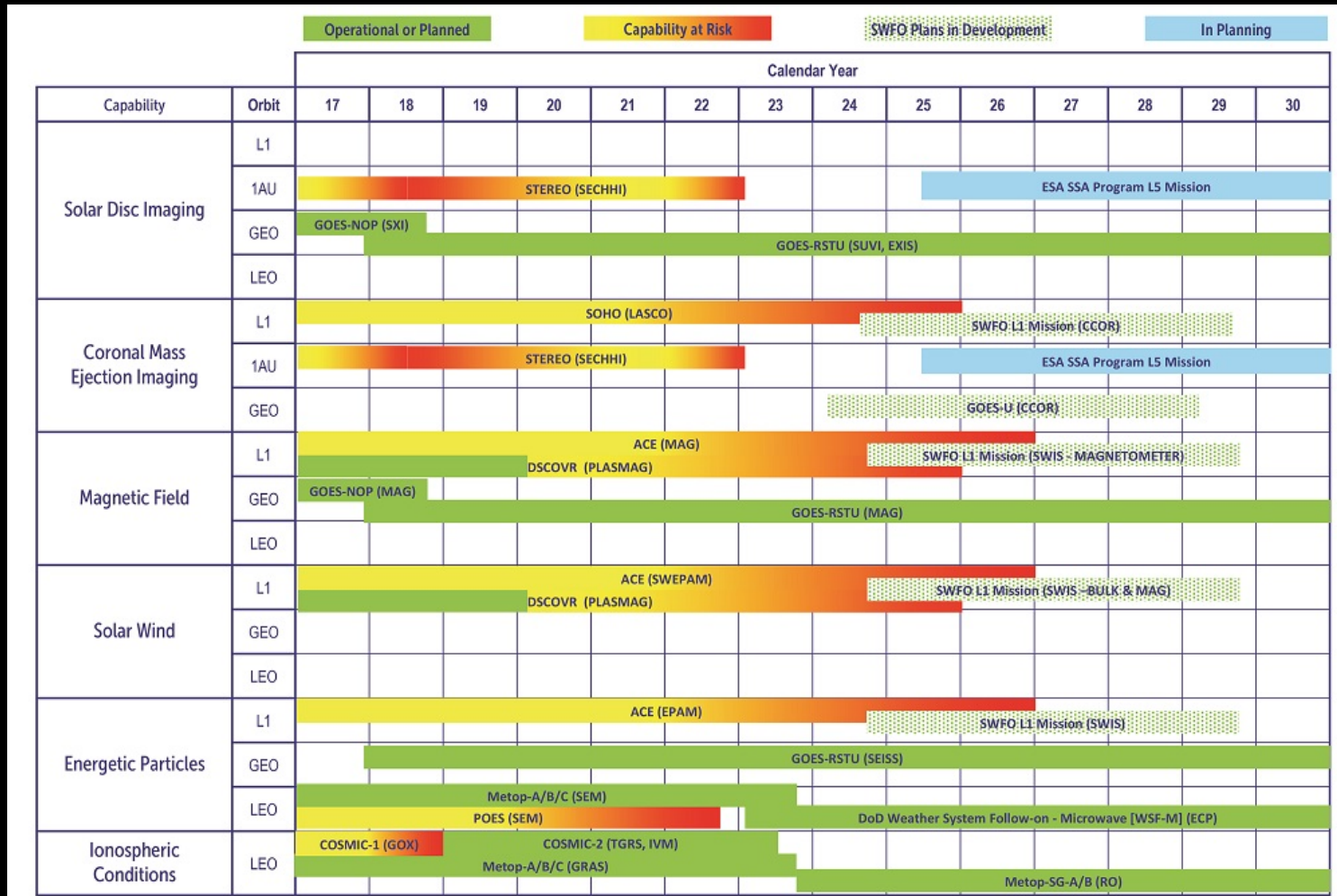


Averting a Bleak Future?

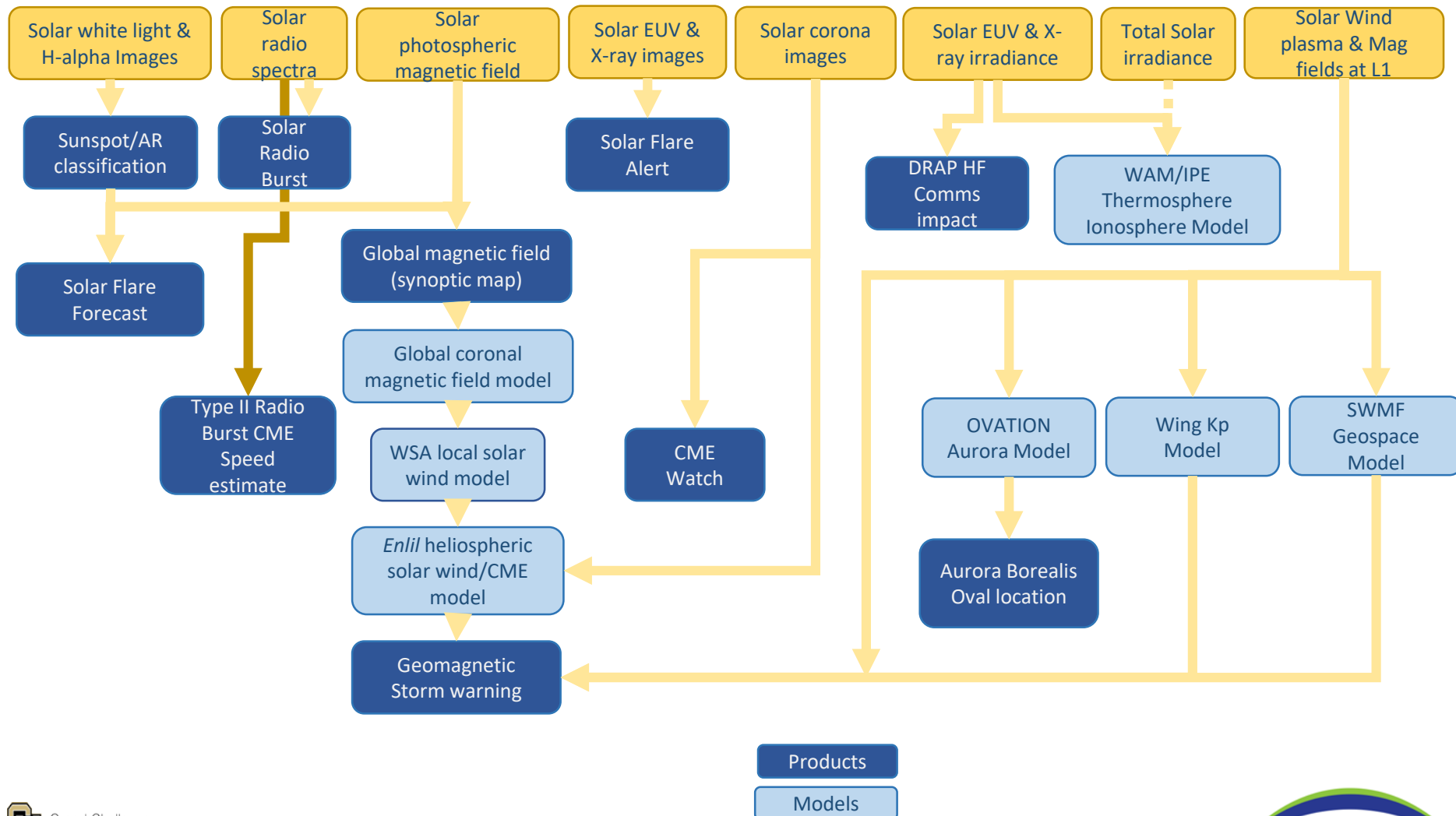
Primary Space Weather Satellites



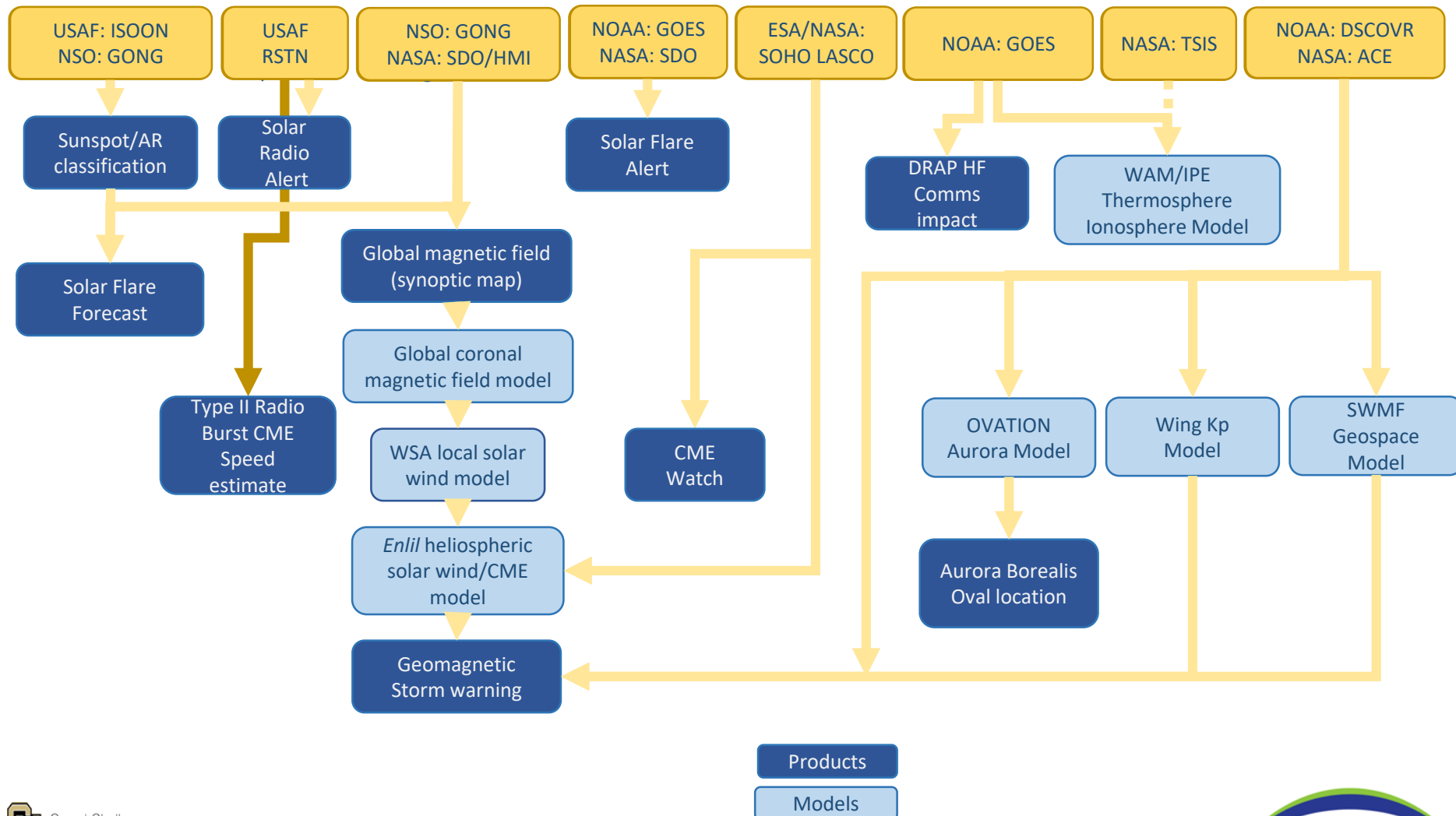
Space Weather Needs and Developing Gaps



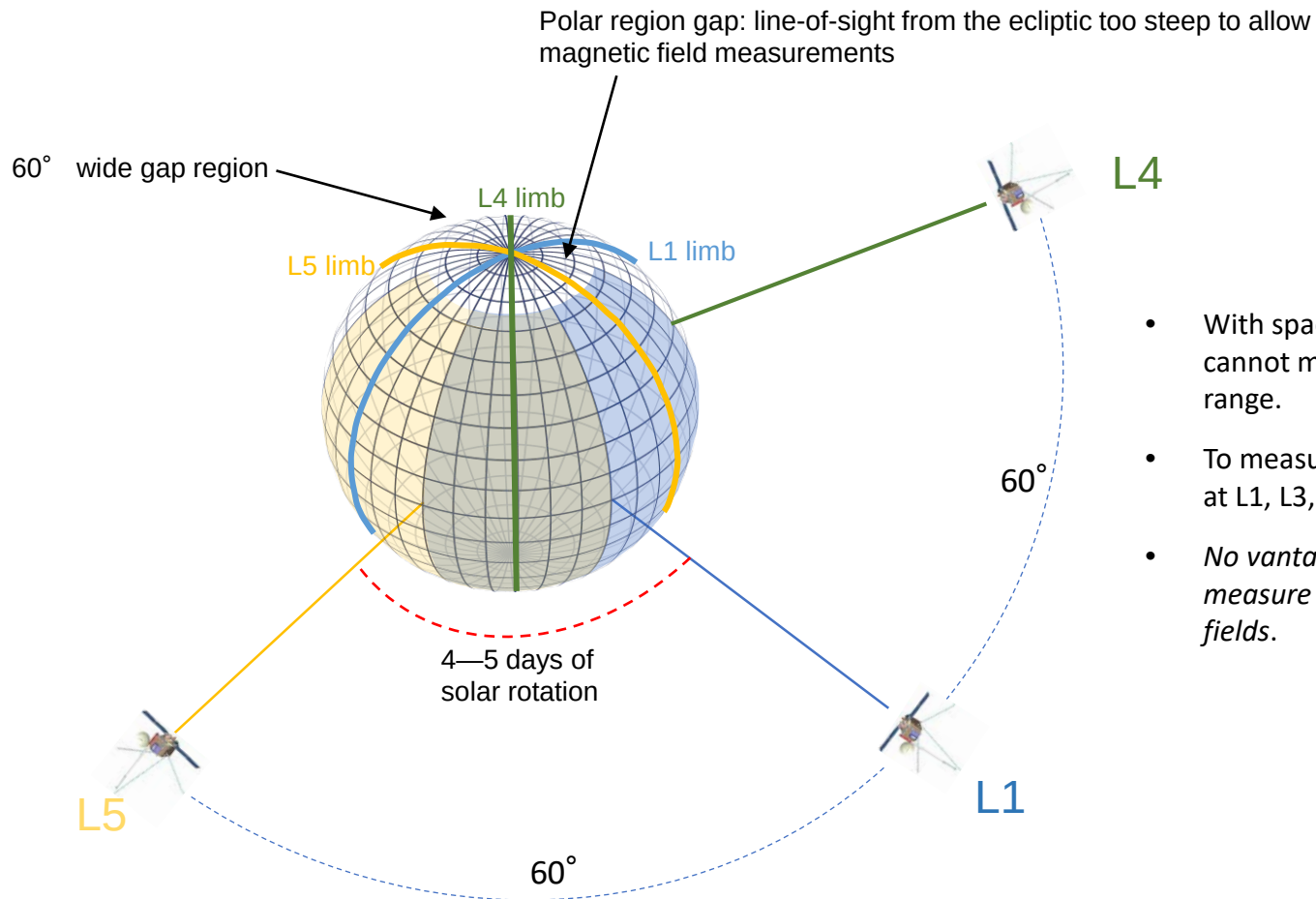
Mapping Solar & Heliospheric Observations to Models/Products



Mapping Solar & Heliospheric Observations to Models/Products

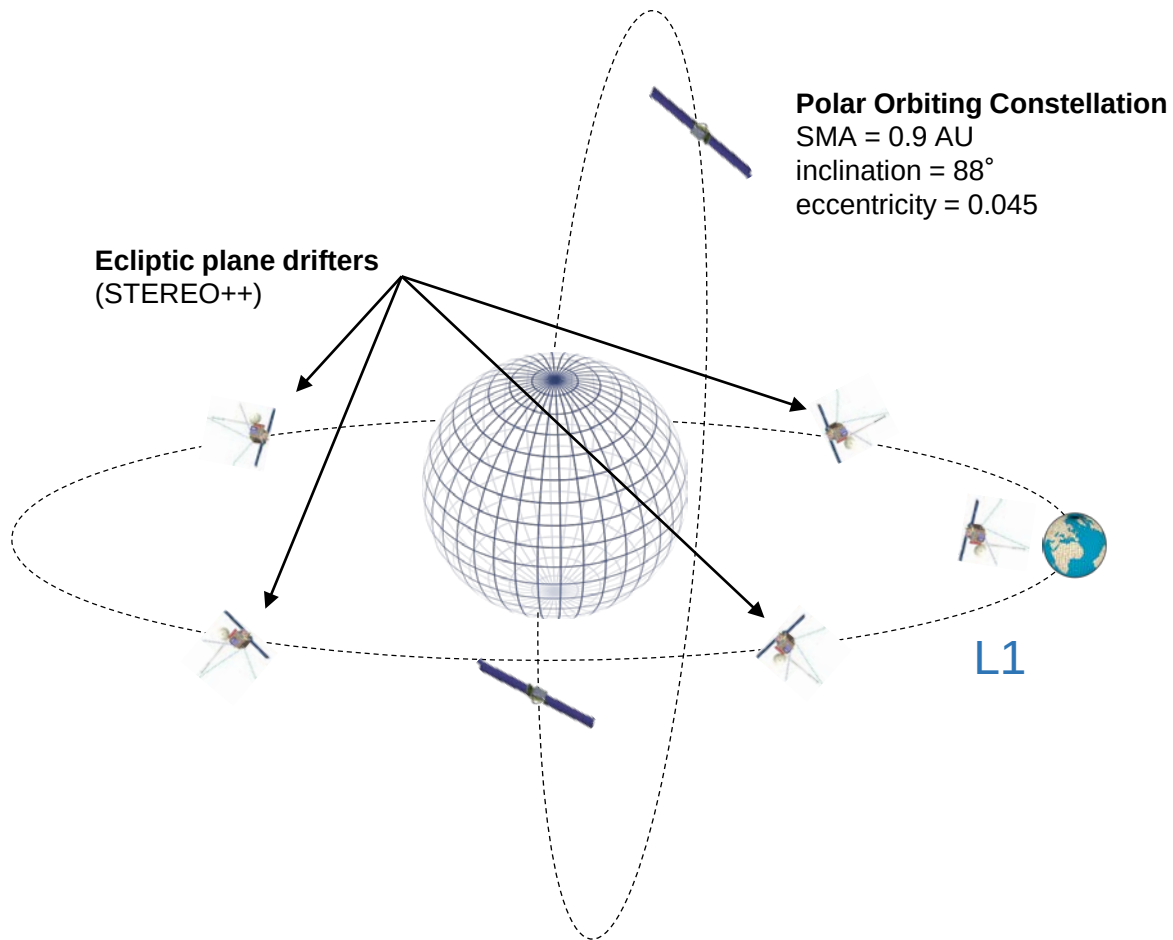


Global Solar Observations: Lagrangian orbits



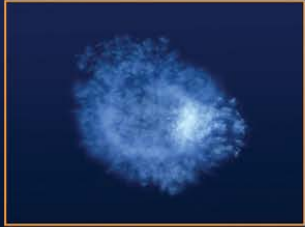
- With spacecraft at L1, L4, and L5, you cannot measure entire solar longitude range.
- To measure full longitude range, spacecraft at L1, L3, L4, and L5 are required.
- *No vantage points in the ecliptic plane can measure the critical polar region magnetic fields.*

Global Solar Observations: Complete coverage fleet



- Continuous complete longitudinal coverage.
- At least one pole under measurement at all times.
- Retains L1 CME sentinel spacecraft.
- Twice per year the polar orbit plane is aligned with Earth with S/C at 0.9 AU.

Plasmas of the Magnetosphere



Ring Current

The ring current is a population of medium-energy particles that drift around the Earth, with protons drifting in one direction and electrons drifting in the opposite direction.



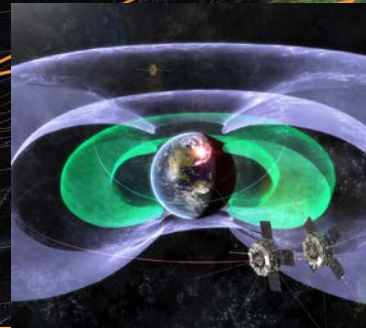
Plasmasphere

The plasmasphere is composed of low-energy particles that drift up from the ionosphere, forming a sphere-like reservoir of very cold, fairly dense plasma that co-rotates with the Earth.



Van Allen Radiation Belts

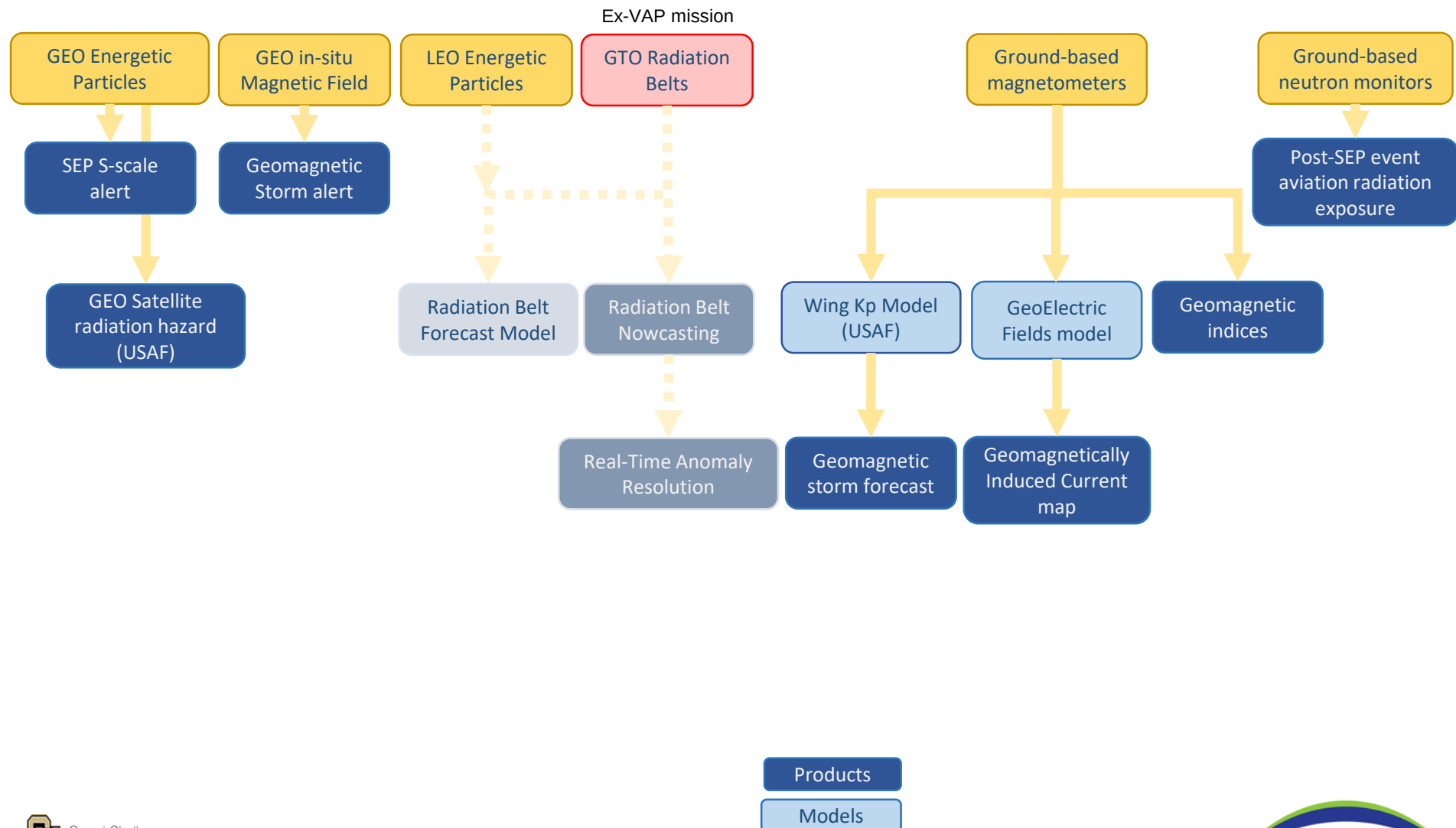
The Van Allen Belts consist of high-energy particles that are trapped in two regions. These particles move along the field lines toward the poles until they are reflected back, creating a bouncing movement. Particles with a high enough velocity along the magnetic field will follow the field lines to the poles and enter the upper atmosphere.



Inner Magnetosphere

The inner magnetosphere is filled with plasmas ranging from the coldest gases (plasmasphere) to the most energetic particles (radiation belts). They are tightly commingled and help shape one another in complex ways.

Mapping Magnetospheric Observations to Models/Products



Van Allen Probes-The Space Weather Movie



End of NASA Van Allen Probes Mission: Risks of Operational Data Gaps

Rapid Anomaly Attribution.

Characterize the radiation environment at any orbit within 3 minutes of a given anomaly.
"Rewind the tape and play back" the particles and mag fields as a function of time for 24 hours leading up to the anomaly.

Space Domain Awareness.

Nowcast the radiation belt conditions and issue prompt alerts to specified radiation threshold crossings categorized by particle type.
Discriminate alerts based on specific orbits: what's the radiation level at my spacecraft right now?

High-Altitude Nuclear Explosion

analysis. Promptly diagnose trapped radiation following a HANE event and characterize the flux of thermal neutron fission electrons as a function of energy. Analyze spectrum of electrons and ions to help determine the device type, yield, core constituents. Predict artificial radiation belt longevity.

Forecast radiation belt conditions from LEO to GEO.

Provide appropriate data to operational radiation belt forecasting models or tools on a continuous, near-real-time delivery basis.
Interface to solar wind models and observations to give battlespace commanders a 24-72 hour warning of enhanced radiation conditions.

Operational Radiation Belt (ORB) Mission

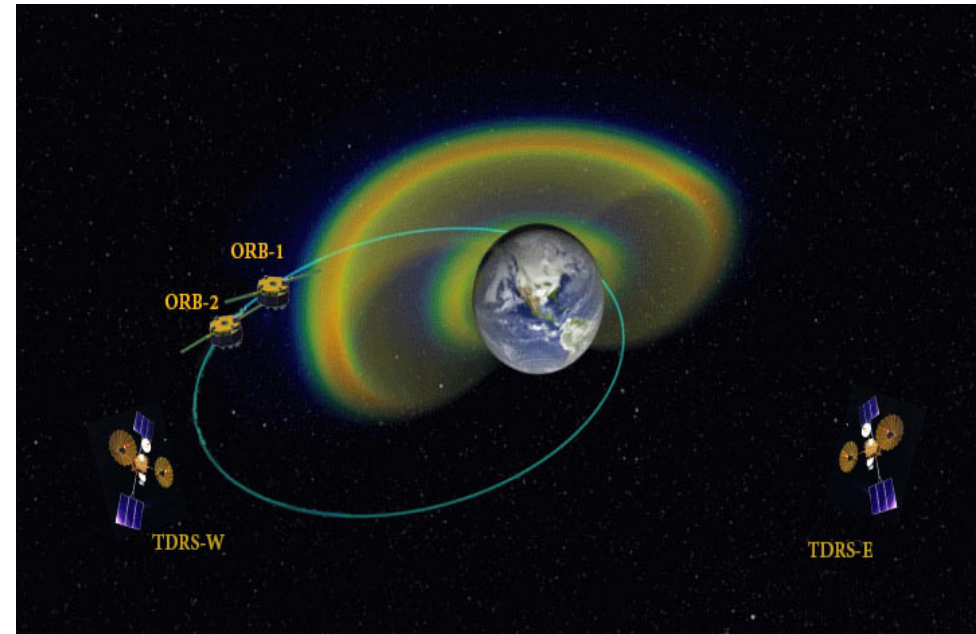
Continuity for Research / Continuous Data for Operations

Vision

- Continue key measurements of the Van Allen Probes
- Enhance Rapid Anomaly Attribution for USAF operations
- Advance radiation belt science via continuous near-real-time data downlink through Solar Cycle 25

Characteristics

- 2 small-sat spacecraft in trailing orbit constellation
- Geo-transfer Orbit (GTO) out to $L \sim 7$ (beyond GEO)
- 24/7/365 near-real-time TDRSS data downlink
- **Full suite of particle measurements**
- **Fluxgate and Search Coil Magnetometers (VLF waves)**



Sun-to-Mud SWx Architecture – the overall requirements

Continuous global solar observations:

- Measure global photospheric magnetic field including polar regions
- Measure global spatially resolved radio, optical, EUV, and X-ray output
- Measure total and spectral irradiance (Sun as a star) from multiple vantage points
- Measure global coronal structure
- Measure global convection zone structure including poles

Continuous Heliospheric observations:

- Measure solar wind speed, density, composition, fields & waves at least 30-min to 1-hour “upstream” of key points (e.g. Earth/Moon, Mars)

Continuous Earth observations:

Magnetospheric observations

- Measure global state (fields and waves) of magnetosphere out to tail region
- Measure global radiation belt conditions (ECP distributions) from LEO to GEO orbits
- Measure global ground-based geomagnetic field and neutron flux
- Monitor SAA evolution

Atmospheric (ITM) observations

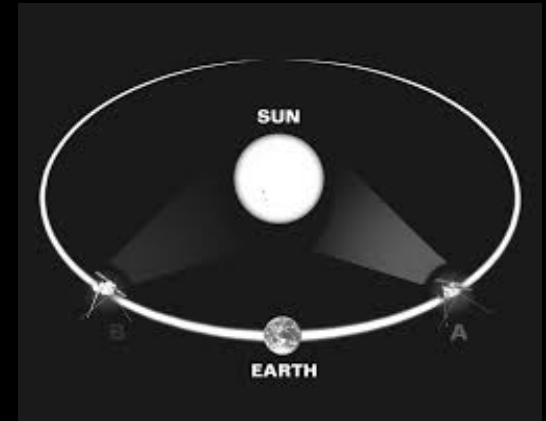
- Measure global ionospheric conditions (electron density, currents, instabilities)
- Measure global thermospheric conditions (temperature, composition, winds, waves)
- Measure polar particle precipitation (aurora) location, intensity, dynamics

Moon observations:

- Measure ECP radiation environment of cis-lunar and lunar-base habitats
- Measure solar wind conditions in cis-lunar space

Future Constellations of SmallSats

- Space Weather needs multi-viewpoint observations
 - Solar activity monitors
 - Solar wind monitors (L1, L4, L5...)
 - Radiation belts missions
 - LEO replacements (POES, DMSP)
 - GEO disaggregation platforms (GTO)
 - Auroral imager missions
- Earth Science needs global coverage
 - Earth Radiation Budget
 - Plus other options to understand water, carbon, and nitrogen cycles



Space-Based Architecture Panelists

- Conrad Lautenbacher, GeoOptics
 - Leveraging the Commercial Sector
- Justin Kasper, BWX Technologies/U of Michigan
 - Solar Wind Particle Measurements
- Jerry Goldstein, SwRI
 - ENA and EUV Imaging
- Robyn Millan, Dartmouth College
 - Distributed LCAS, Cubesats
- David Malaspina, U of Colorado - Boulder
 - Fields and Waves Measurements