Research and Modeling at the Air Force Research Laboratory

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AFRL's Role in the Space Weather Enterprise

The Air Force Research Laboratory is a core-funded DoD space weather science and technology investment

- Basic Research – AFOSR
- Applied Research and Advanced Technology Development – Space Vehicles Directorate
- Subject Matter Expertise Support to Major Commands, Program Offices, and Operational Units

AFRL invests in, creates, and matures technology toward space weather operations

- **In-house research**
- **Grants, contracts and other agreements**
- Program office-funded maturation and prototyping

AFRL is key bridge between the research community and DoD operations

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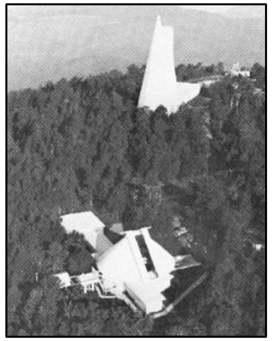
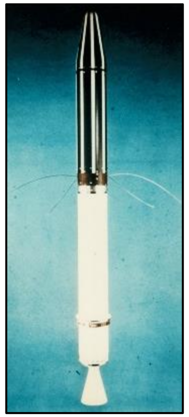
AFRL Space Weather



▲**1949-present:** Sacramento Peak Observatory, New Mexico, solar telescopes

1958: Micro-meteoroid ▼ detector on Explorer 1



1963-present: Arecibo ionosphere, deep space observations ▼

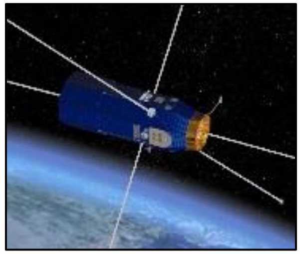
1971: Cannonball-2, atmospheric drag observations ►

1984: Auroral photography experiment on STS-41G ►

◄**1990-91:** CRRES discovery of radiation belt injections

2003-11: SMEI solar ► ejection monitor on Coriolis

◄ **1996:** TSS-1R tethered satellite and SPREE experiment on STS-75



2019: DSX high power VLF transmissions in radiation belt slot region ▼

◄ **2008-15:** C/NOFS observations of ionospheric scintillation

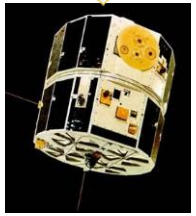
1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010

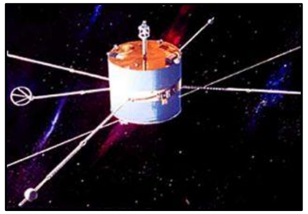
◄ **1950:** Aerobee sounding rocket, solar constant measurement

▲**1957-58:** International Geophysical Year monitoring, Greenland

1962: STARAD satellite▲ observes Starfish radiation belt decay

1973-81: ► EUVS solar monitor on Atmosphere Explorer-C/D/E



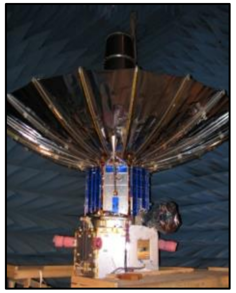


1979-86▲**:** SCATHA explores spacecraft charging and mitigation

1991: Critical Ionization ► Velocity, CIRRIS-1A airglow and IBSS experiments on STS-39

1982-present: SSIES ionosphere observations from DMSP ▼

1990-2014: ► HAARP ionospheric heating experiments, Alaska



◄**2011-14:** CEASE space environment sensor on TacSat-4

▼**2013:** MOSC ionospheric chemical release from rocket, Kwajalein

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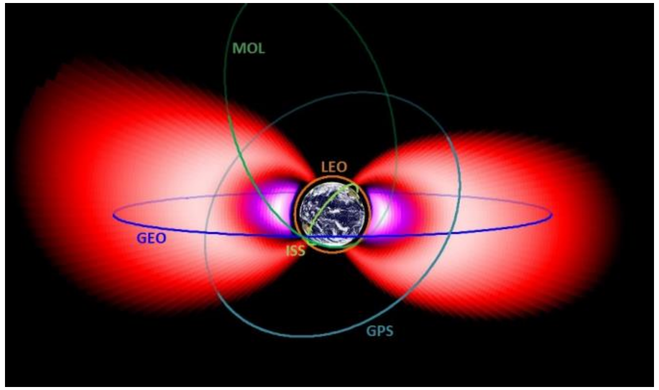
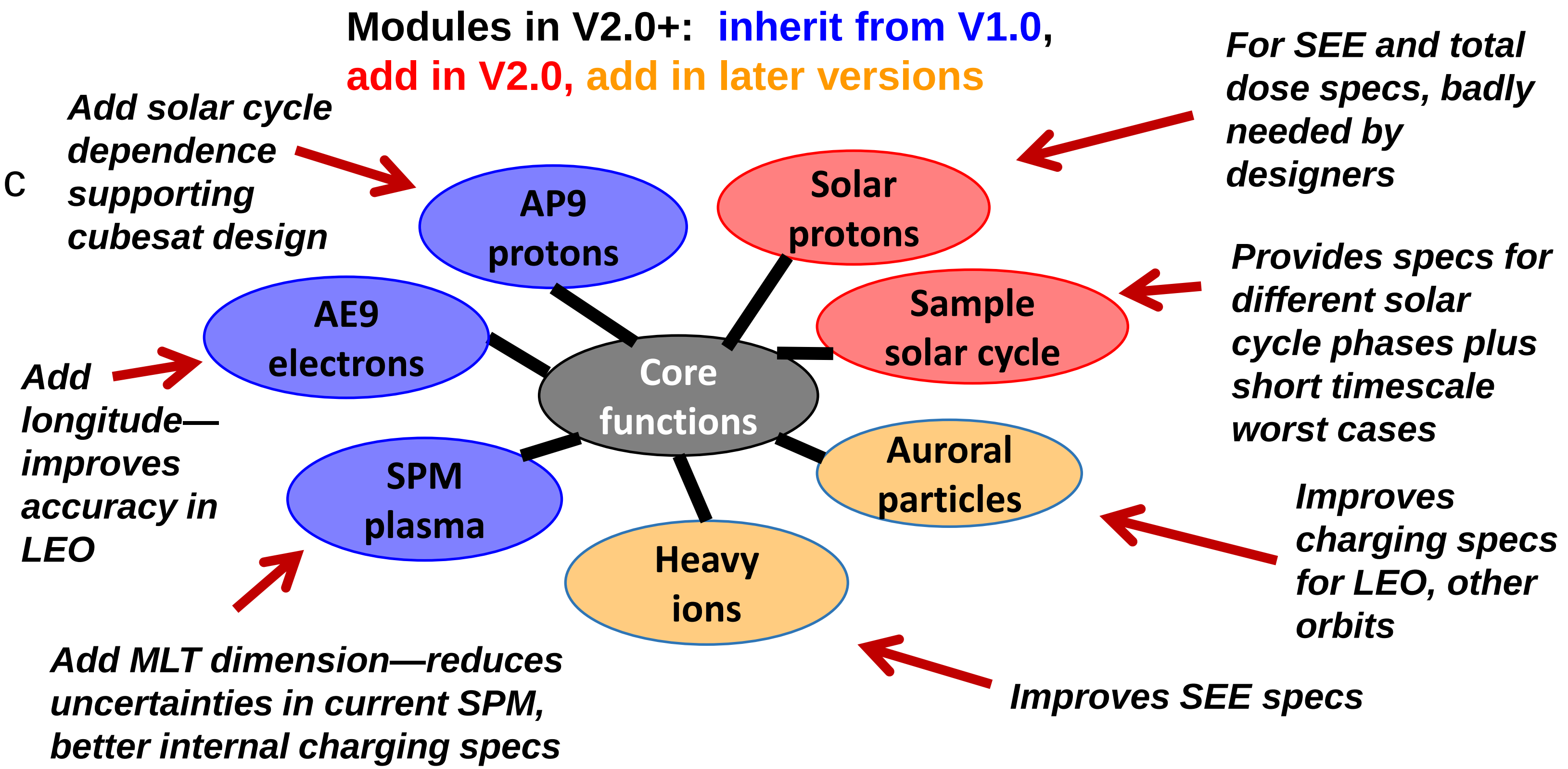
AE9/AP9-IRENE



- AE9/AP9-IRENE model suite—particle radiation environment specification for spacecraft design and mission planning
  - Latest version V1.55 introduces first effects "kernel" for faster effects calculations
- Technical efforts include:
  - Implementation of stochastic solar proton event module
  - Sample solar cycle using historical reanalysis for realistic short timescale hazards
  - Local time dependence in plasma model
  - Improved representation of gradients in LEO

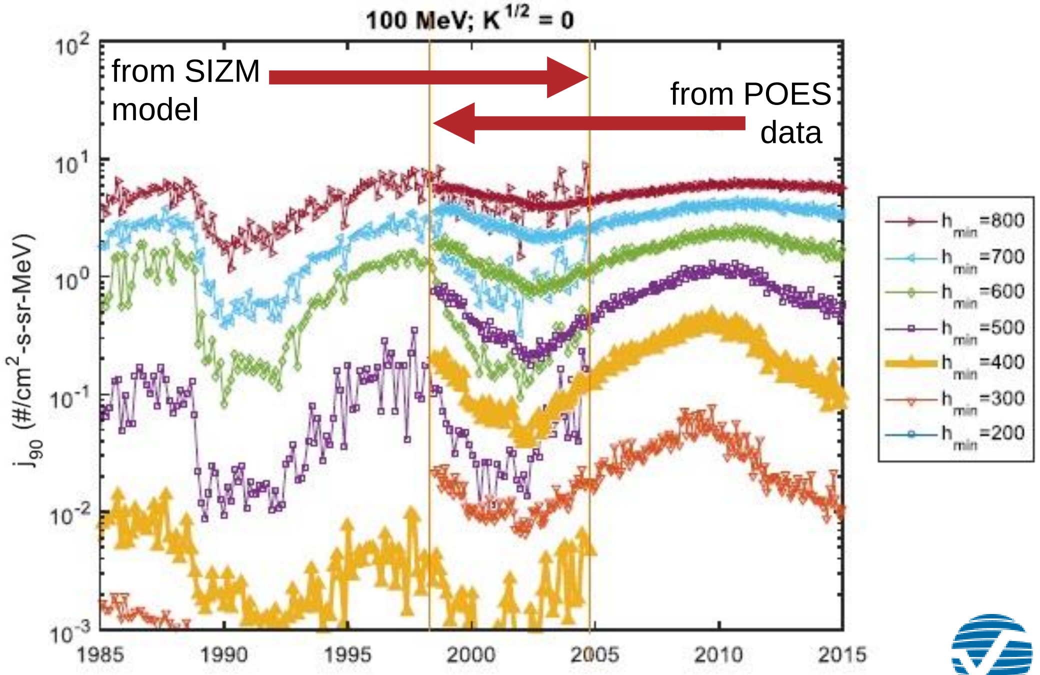


New standard model for satellite design used for national security space and beyond

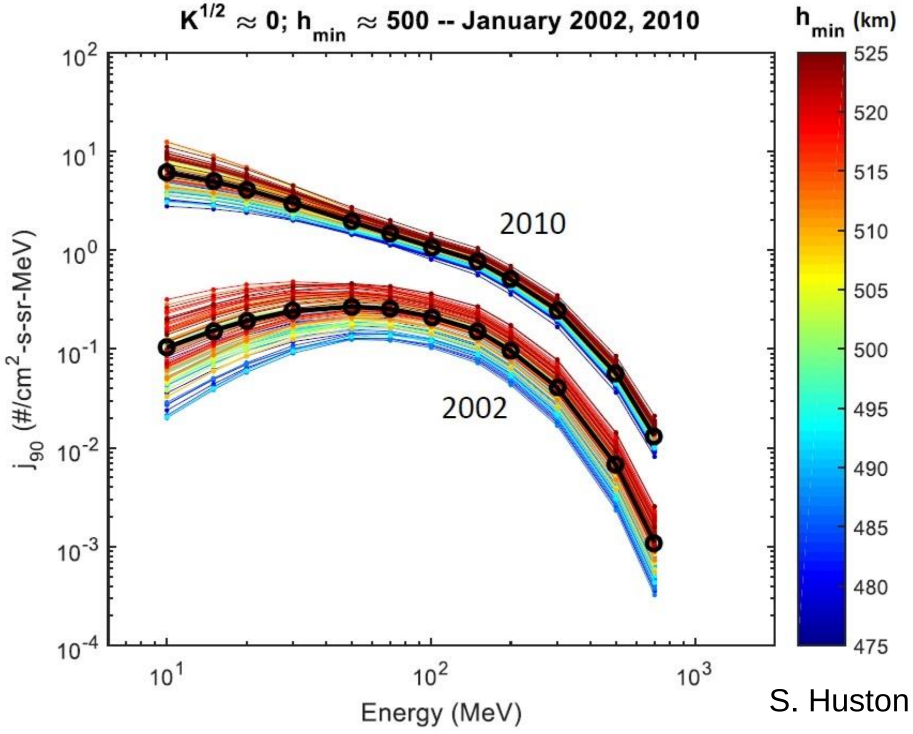
AE9/AP9-IRENE: Solar cycle variation of LEO protons in AP9

- No solar cycle dependence in AE9/AP9-IRENE now
  - Statistics capture ranges across all solar cycle phases
- Users needs solar cycle dependence for trapped protons
  - Design for short duration LEO missions
  - Supports use of AP9 for nowcast estimates

- Work progressing towards solar cycle modulation of AP9:
  - Use stochastic model for future phase/intensity of solar cycle drivers of LEO protons
  - Use models (Selesnick Inner Zone Model) and data (POES SEM-2) to relate drivers to energy- and location-dependent variability
  - Use results to modulate AP9 flux maps (representing all data sets)

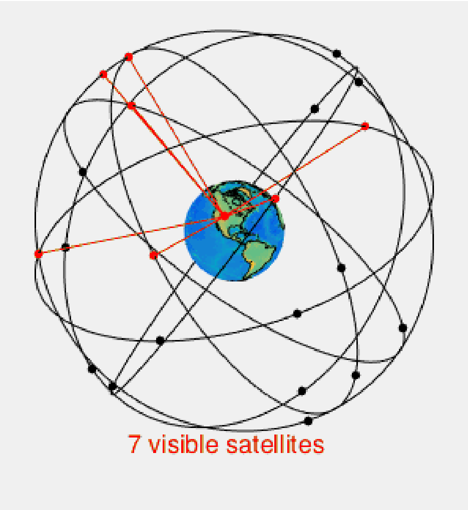


S. Huston

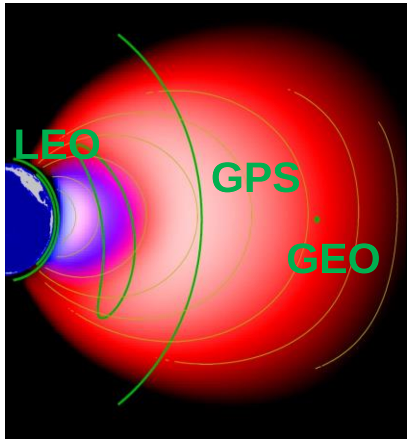


S. Huston

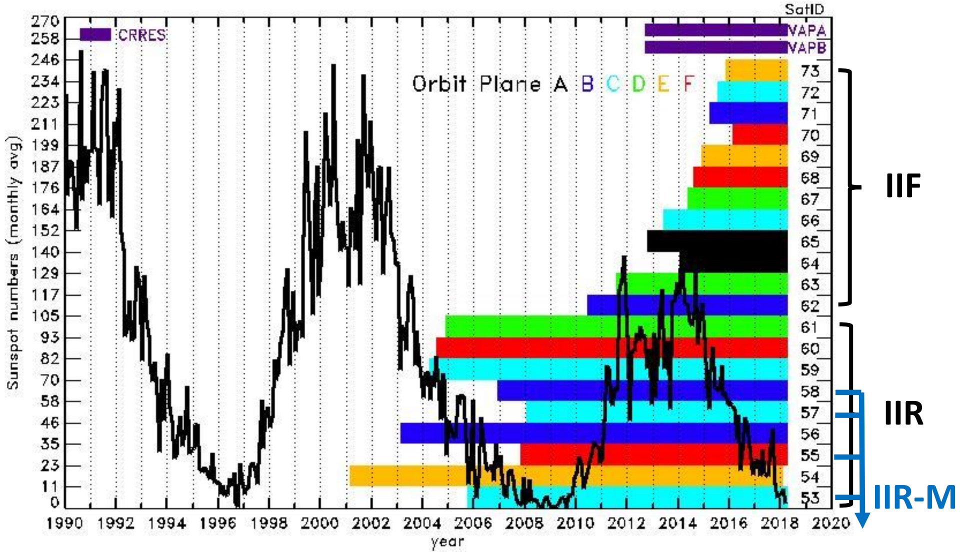
GPS Flux specification model

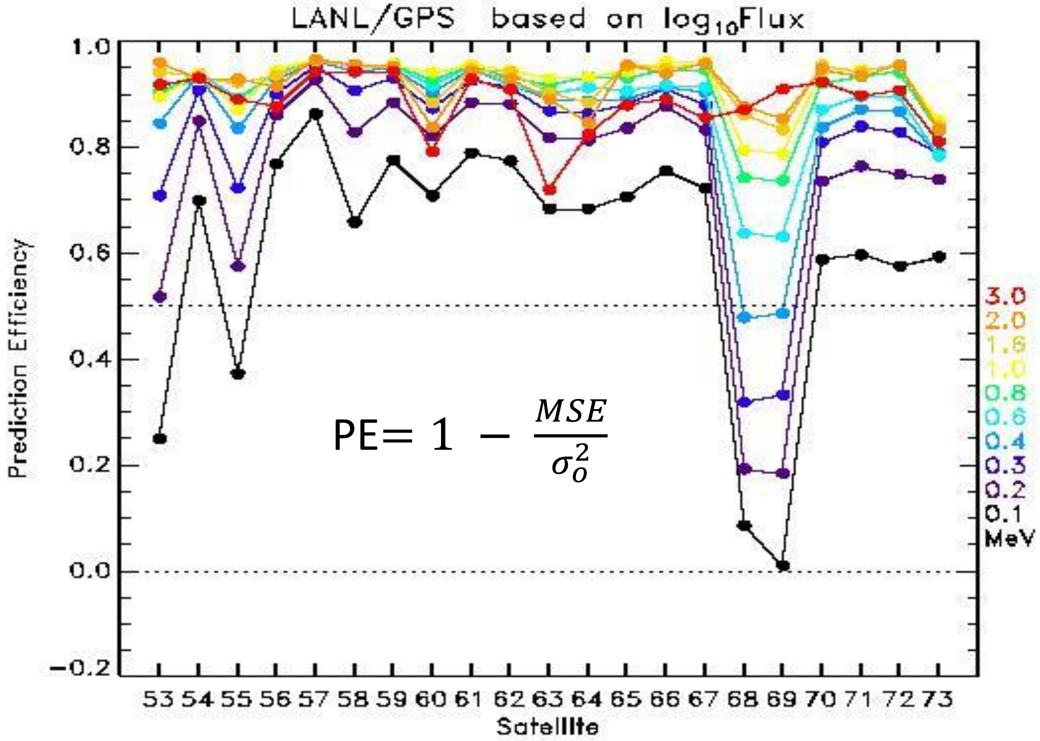


- Specifies flux at a given GPS location via data from rest of fleet
  - Bin flux in L-shell and average over a specified time window
  - Interpolate spectra from neighboring bins when no data available in bin of interest



Combined X-ray Dosimeter: 21 active





Provides a specification for the GPS regime to support prototyping while model development efforts continue

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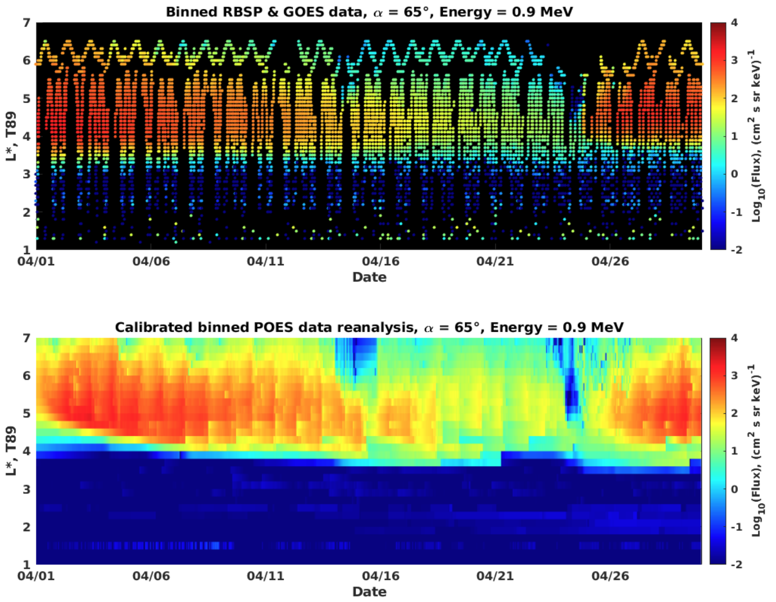
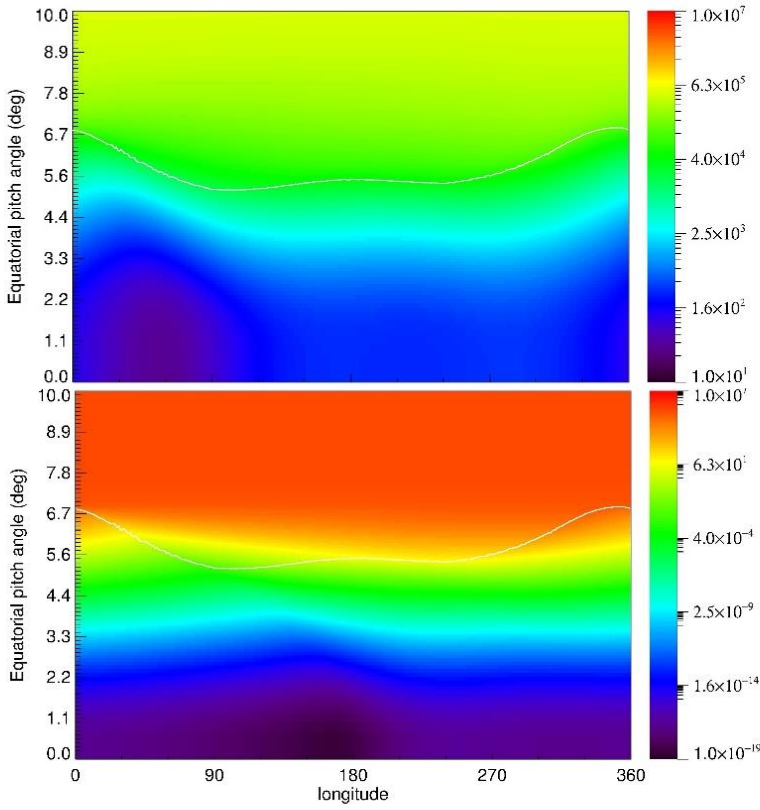
Outer Zone Model STTR program



(top) Van Allen Probes and GOES measurements of 0.9 MeV
(bottom) Reanalysis using NOAA POES LEO data only

- Phase I STTR effort on operationalizing outer zone electron models has recently concluded
- Phase II selection occurring and work will soon commence
- The conclusion of Phase II will be marked by a basic ops capability
- Potential phase III opportunities exist across DoD and civilian agencies
- OZM has been a fruitful “pathfinder” for model transition from research to operational contexts



(top) Flux with fast diffusion of 1.0 MeV electrons in the LEO regime
(bottom) Flux from slow diffusion of the same population

SPACE SCIENCES INNOVATIONS
UCLA

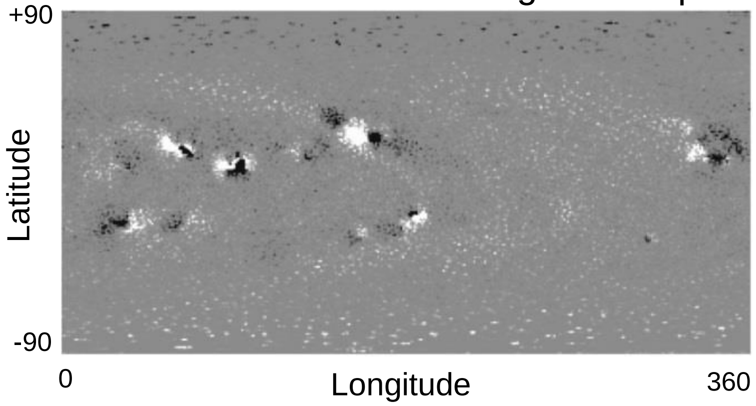
These efforts will be part of an assessment of models for promotion to operations

arc

ADAPT Solar Magnetic Map Model

- The **ADAPT** (Air Force Data Assimilative Photospheric Flux Transport) model generates global solar magnetic maps using **flux transport** & **data assimilation**:

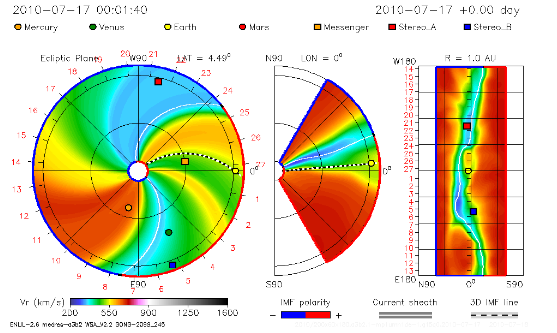
ADAPT Global Solar Magnetic Map



Original Goal

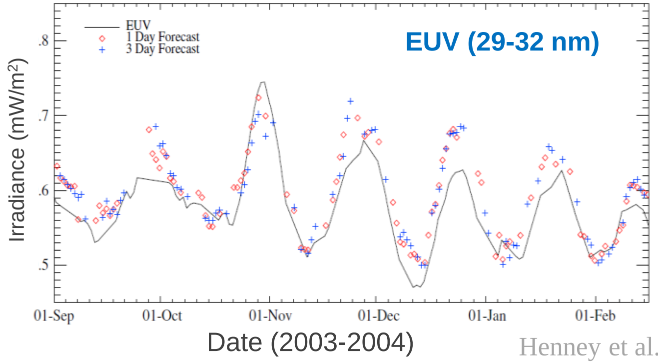
Byproduct

Solar Wind Modeling/Forecasting



Credit: WSA-Enlil

EUV Modeling/Forecasting



Henney et al.

- Originally developed to drive solar wind forecasts
- Now, maps also drive solar F10.7 and EUV forecasts
  - Irradiance modeling w/ **SIFT** (Solar Indices Forecasting Tool)
- Prototyping operations at the NSO, with data gathering & model run autonomously 24/7
- Currently transferring model to NOAA/SWPC for validation (w/ CCMC) and transitioning to operations to input WSA-Enlil

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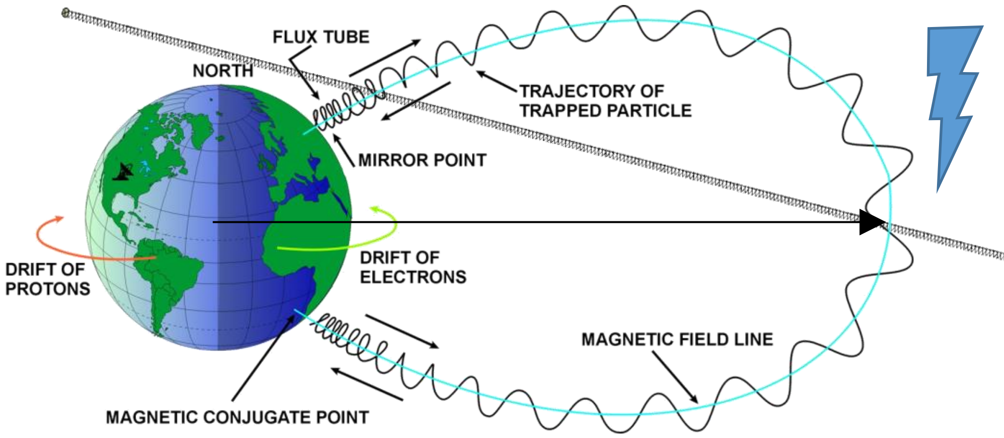
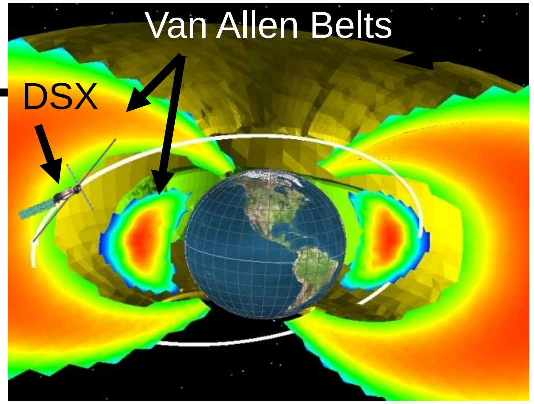
Demonstration and Science Experiments (DSX) Mission

Planned Launch: Summer 2019



STP-2



ASSESSING DIRECT INJECTION OF VLF WAVES

- Radio waves in the VLF range are produced naturally from lightning and instabilities in trapped particle populations
- VLF waves can modify the mirror point of radiation belt electrons, resulting in losses to the atmosphere
- DSX will test direct radio wave injection to influence natural processes governing the radiation belts

MAPPING MEO RADIATION ENVIRONMENT

- DSX will provide robust data on both the wave environment and the particle populations that drive and/or respond to it
- DSX achieves best-ever characterization of this poorly-mapped orbit regime to support system radiation survivability analyses
- NASA SET-1 Payload allows testing of spacecraft materials and components *in situ*

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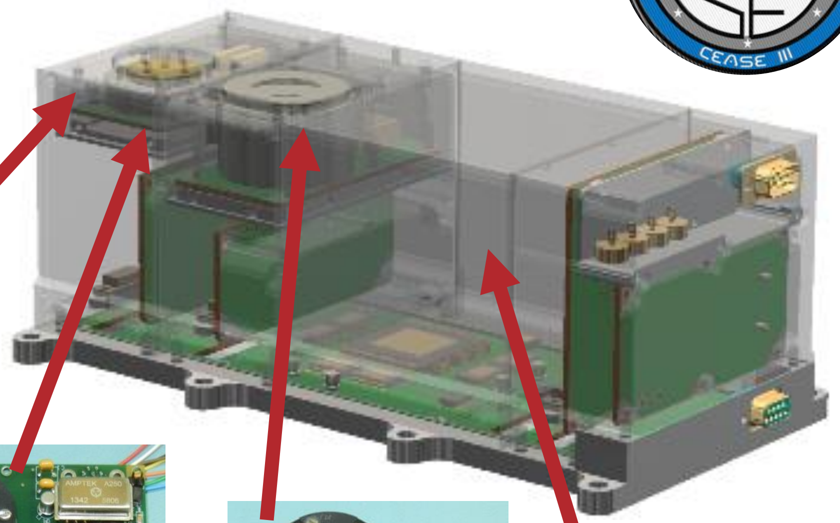
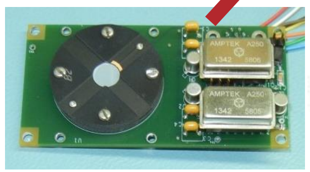
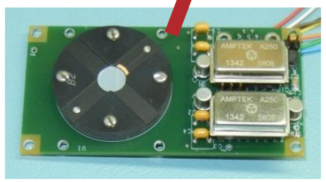
CEASE3: ECP sensor for all orbit regimes

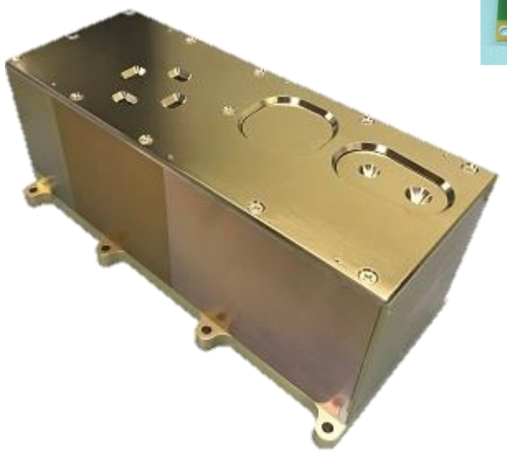
- Compact Environmental Anomaly Sensor-3 (CEASE3) under development
- Designed to monitor energetic charged particles (ECPs) that cause spacecraft anomalies
- CEASE3-RR (Risk Reduction) prototype currently operating on EAGLE (2018 launch)
- CEASE3 flights planning in next few years to GEO and LEO
- Four sensors for wide range of electron/proton energies
    - 3 telescopes (4+ channels each) covering protons 2-150 MeV, electrons 90 keV-5 MeV
    - Electrostatic analyzer covering electrons 100 eV-50 keV
- Time sampling and dynamic ranges suited for monitoring hazards in LEO, MEO, GTO, HEO, GEO

- Size **11 x 11 x 30 cm**
- Weight **4 kg**
- Power **8 W** average, **10 W** peak



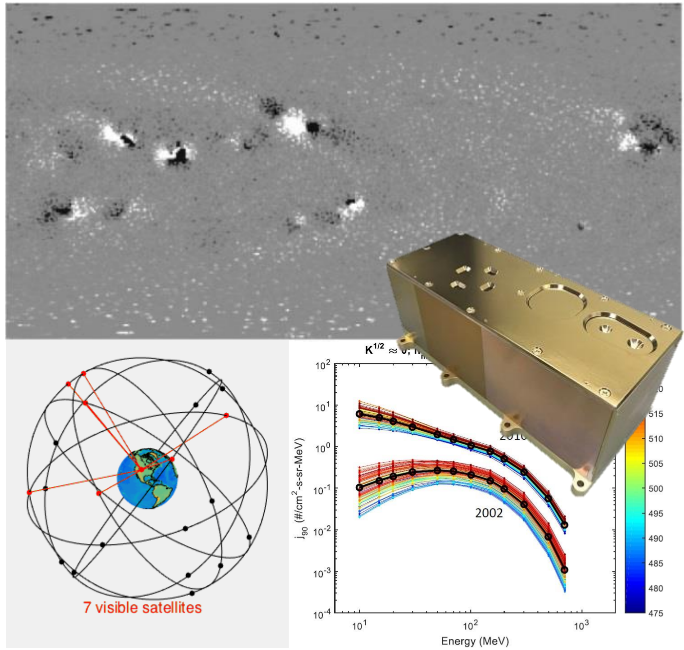




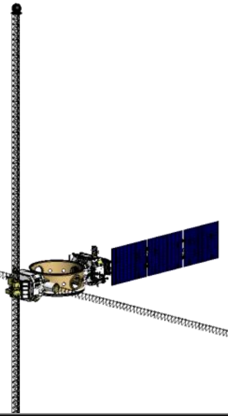


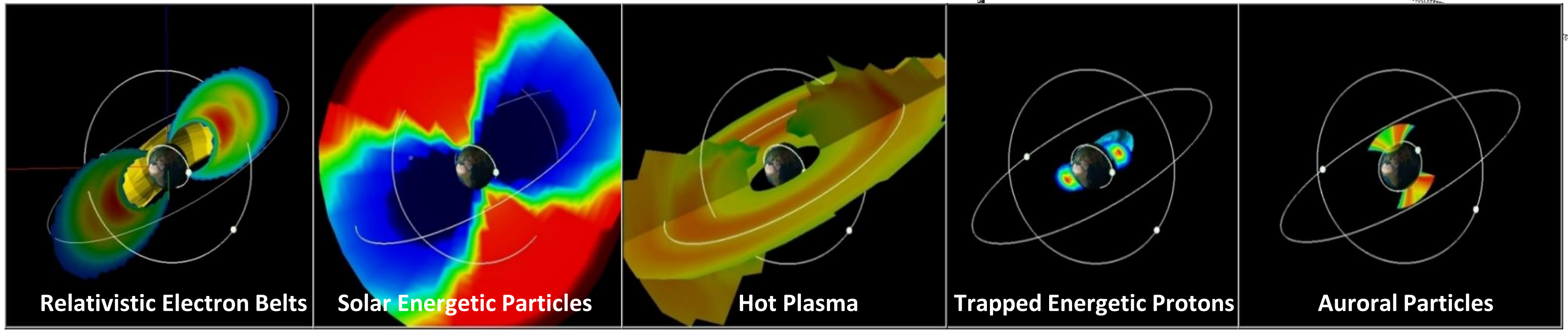
Reference design transferred to industry in support of deployment of sensors on all future USAF spacecraft

Conclusion



- AFRL performs basic research, applied research, and model development for various space weather phenomena in support of the DoD space mission
- AFRL scientists and engineers are working many efforts in the near term to enhance capabilities
- AFRL is also pressing ahead with strategic concepts for generation-after-next capabilities





AFRL S&T development relies on partnerships within the space weather research community and communication among stakeholders

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Questions?

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