Air Force Research Laboratory

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SCIENCE & TECHNOLOGY

Active Experiments with the DSX Mission

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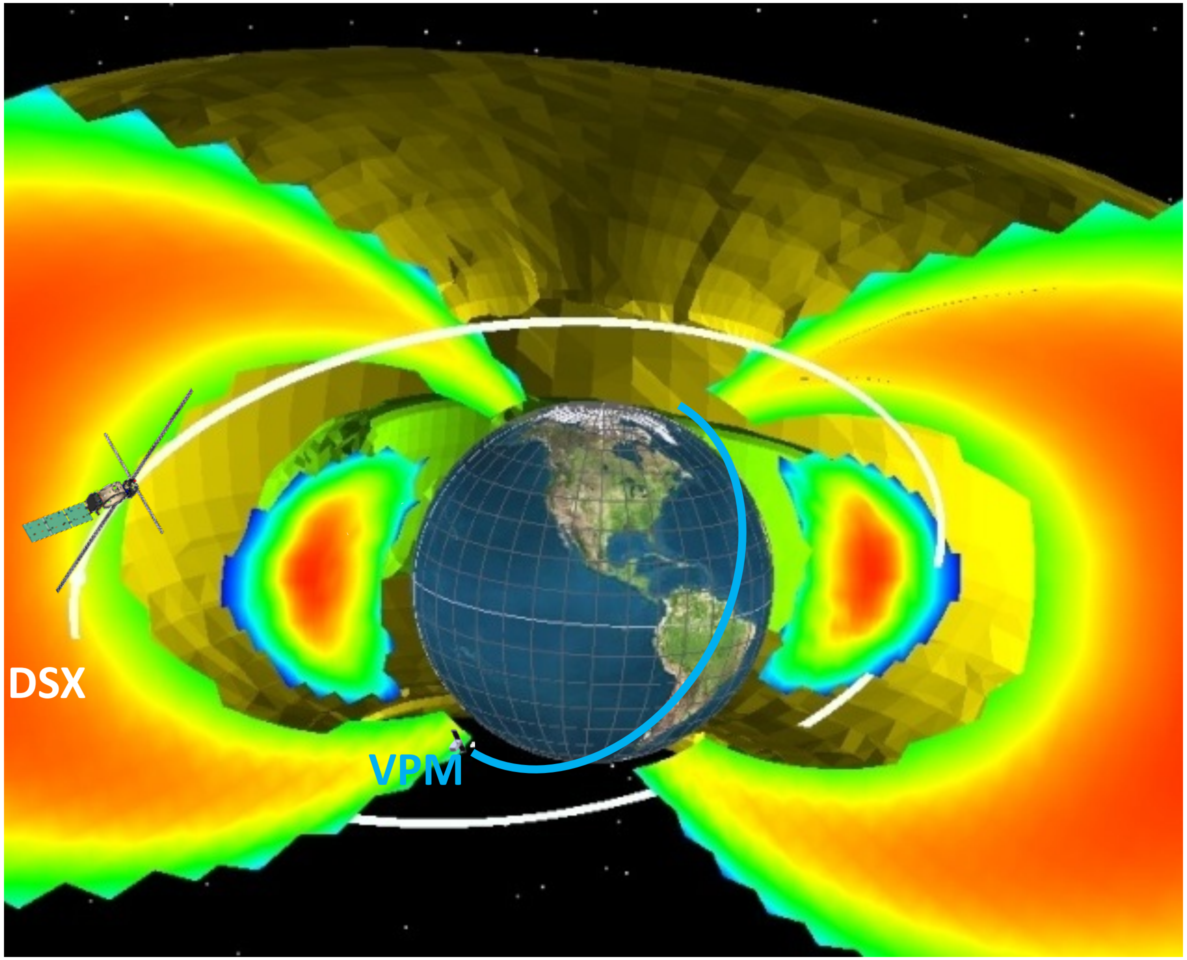
Integrity ★ Service ★ Excellence

DSX Overview

- Planned launch 30 April 2018, nominal one year mission
- 6000 x 12000 km orbit, 42° inclination, 5.3 hour period
- Primary experiment: **Wave Particle Interactions**—high power VLF transmissions in slot region
- Secondary Experiment: **Space Weather**—characterize slot region environment
- Secondary Experiment: **Space Effects**—Understand impacts to components
- Will coincide with VLF and Particle Mapper (VPM) nanosat mission to LEO



DSX Mission Status

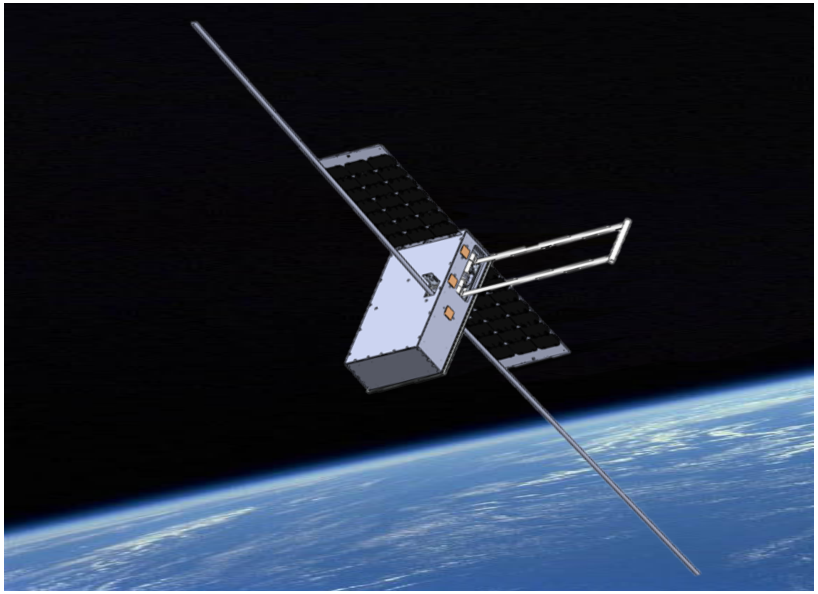
The DSX Mission (2018 aboard SpaceX Falcon Heavy)

- **AFRL DSX mission will provide first comprehensive study of MEO space environment**
- **Innovations:**
  - **Active study of wave-particle interactions with in-situ VLF transmitter**
  - **Unprecedented extended rigid structure**
- **Launch is sponsored by DoD Space Test Program (consistently ranked #1 by DoD SERB)**

The VPM Mission (2018 launch from ISS)

- **Launch and duration to coincide with DSX**
- **First comprehensive far-field measurements of in situ transmitter**

DSX environmental testing at in-house facility

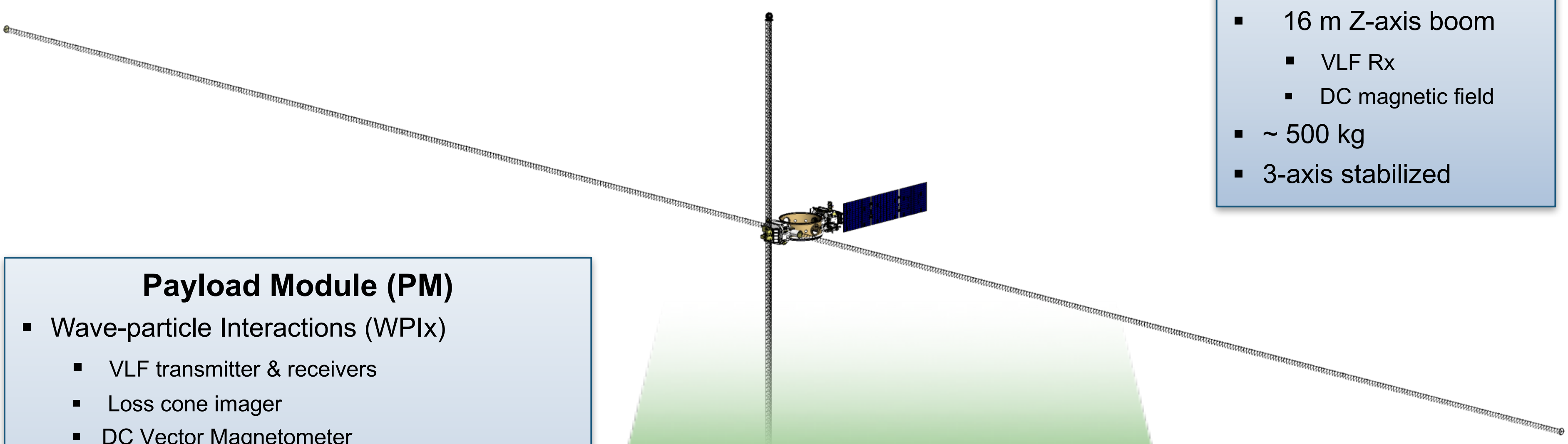


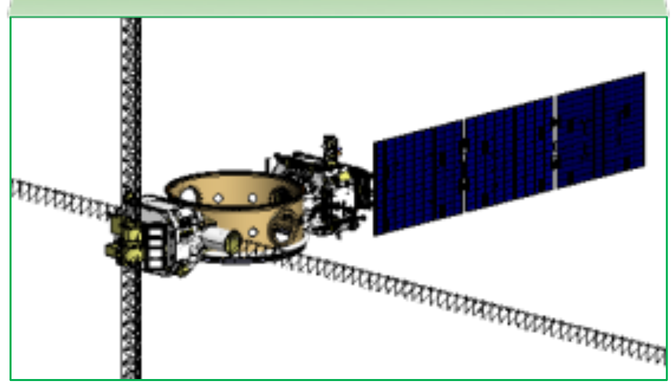
VPM in deployed configuration (rendering)

DSX Spacecraft

Largest unmanned self-supporting structure ever flown in space

- 80 m Y-axis boom
  - VLF Tx & Rx
- 16 m Z-axis boom
  - VLF Rx
  - DC magnetic field
- ~ 500 kg
- 3-axis stabilized





Payload Module (PM)

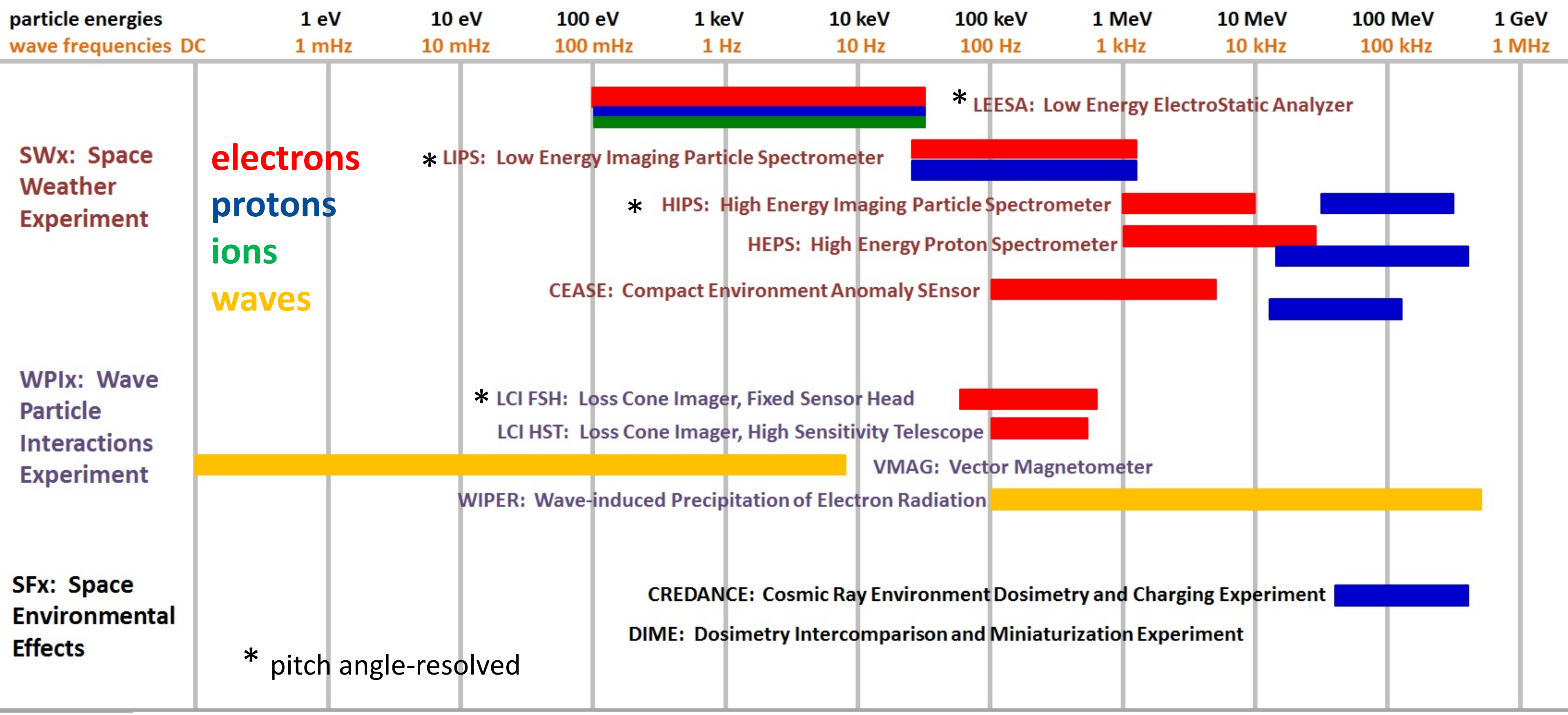
- Wave-particle Interactions (WPIx)
  - VLF transmitter & receivers
  - Loss cone imager
  - DC Vector Magnetometer
- Space Weather (SWx)
  - 5 particle & plasma detectors
- Space Environmental Effects (SFx)
  - NASA/Goddard Space Environment Testbed
  - AFRL effects experiment
- NASA/JPL deployable structures payload

Avionics Module (AM)

- Attitude Control System
- Power
- Thermal Control
- Communications
- Computer/Avionics
- Experiment Computer
- Space Weather (HEPS)

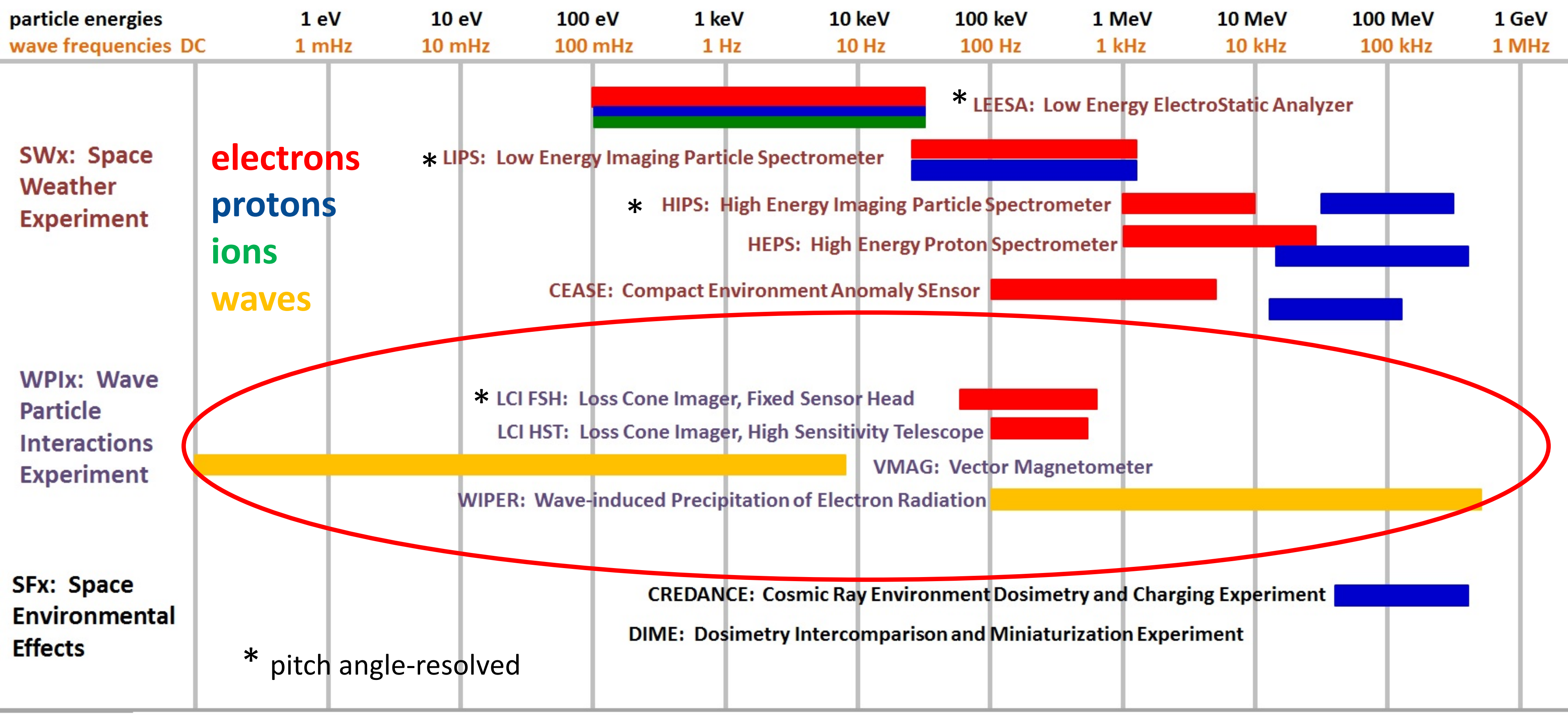
DSX Space Environment Sensors

- DSX has a complete suite of space environment sensors for thorough study at MEO
  - To map the MEO radiation and plasma environment
  - To explore the use of VLF antennae in space



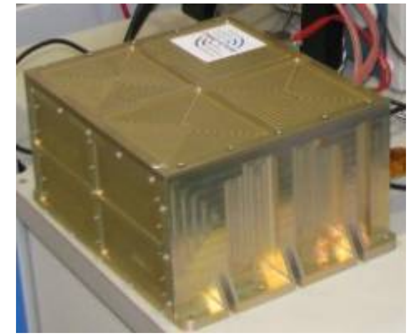
Wave-Particle Interactions (WPIx)

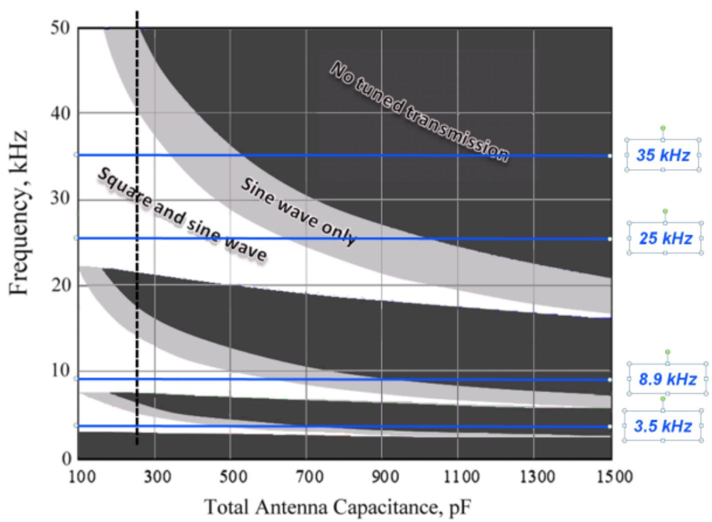
- WPIx will transmit and measure waves and precipitating particles
  - To understand VLF direct injection performance
  - To diagnose VLF effects on particle populations



TNT—Transmitter, Narrowband Rx, and Tuners

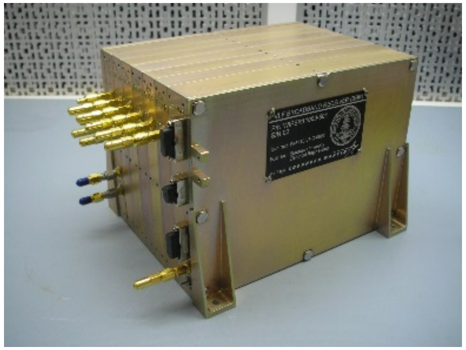
- **Comprised of 80 m dipole antenna, cabling, and control and tuning units for VLF transmitter and narrowband VLF receiver**
- **Transmits 3-50 kHz tuned signals**
  - **Up to ~5 kV during high-power transmissions**
  - **Low-power "sounding" operations at 50-750 kHz**
- **Tuners capable of adaptively maximizing antenna current under variable plasma conditions**





BBR—Broadband Receiver

- Comprised of three search coil magnetometers and two dipole antennae
- Measures 3-component magnetic field and 2-component electric field
  - Frequency range: 100 Hz – 50 kHz
  - Sensitivity 10^{-16} $V^2/m^2/Hz$ (E) & 10^{-11} nT^2/Hz (B)
- Includes onboard Software Receiver (SRx), which produces waveform, spectrogram, and compressed products for telemetry conservation
- 30 Second survey product as well as burst mode products

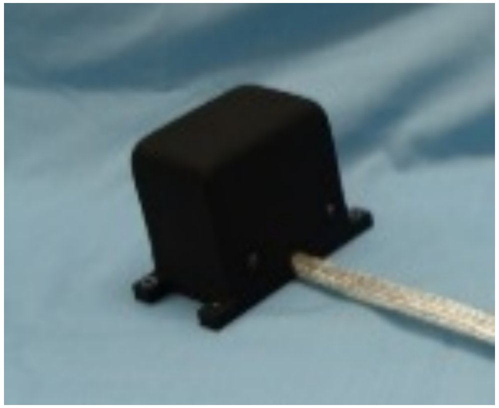


LCI—Loss Cone Imager

- Comprised of two dectors: High Sensitivity Telescope (HST) for measuring loss cone population and Fixed Sensor Head (FSH) for total population
- Measures energetic electron fluxes
  - HST: measures 100 – 500 keV e- with 0.1 cm^2-str geometric factor within 6.5° of loss cone
  - FSH: 130° x 10° of pitch angle distribution for 50 – 700 keV electrons every 167 milliseconds

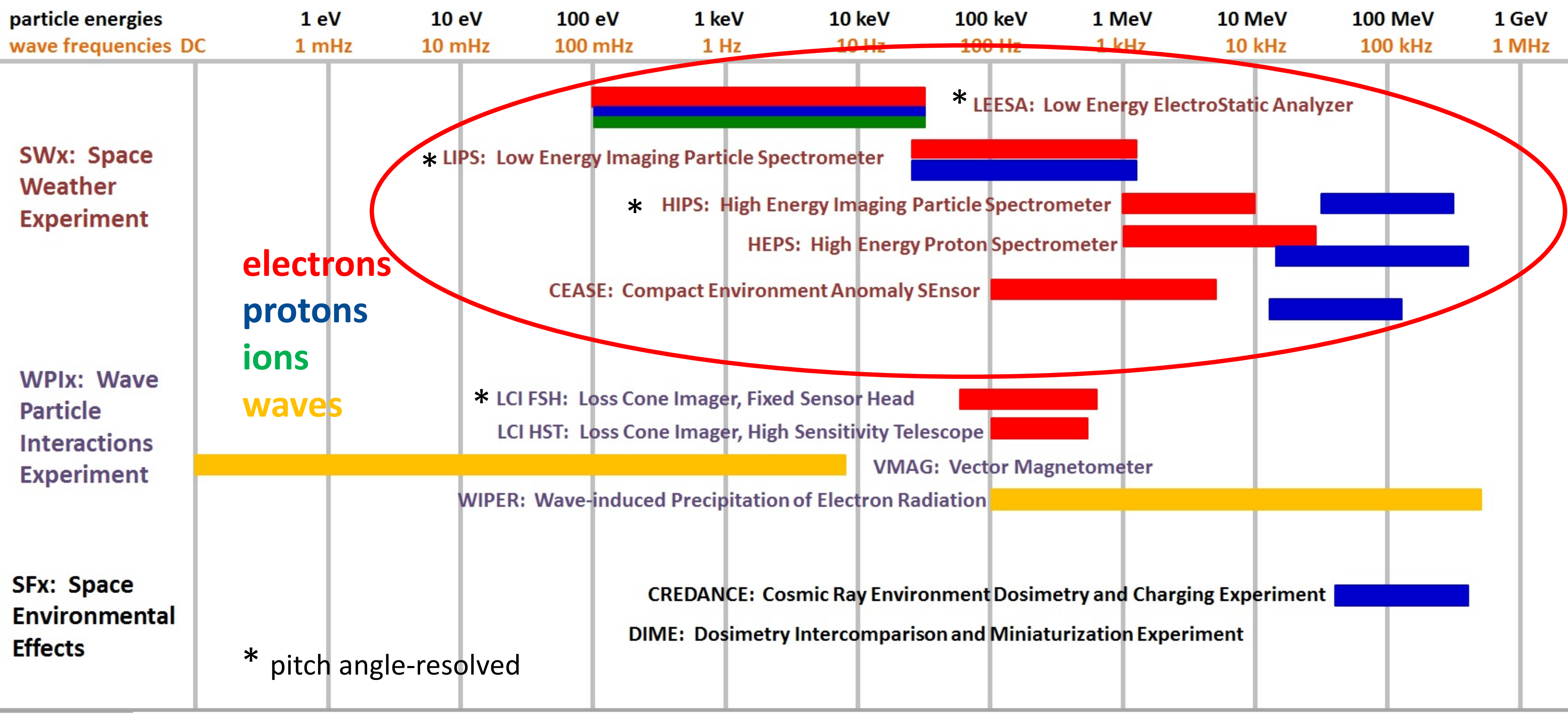
VMAG—Vector Magnetometer

- Comprised of boom-mounted fluxgate sensor head, cable assembly, and electronics unit
- Measures ULF and DC Magnetic field
  - 0 – 8 Hz three-axis measurement at ±0.1 nT accuracy
  - ±1° field direction accuracy



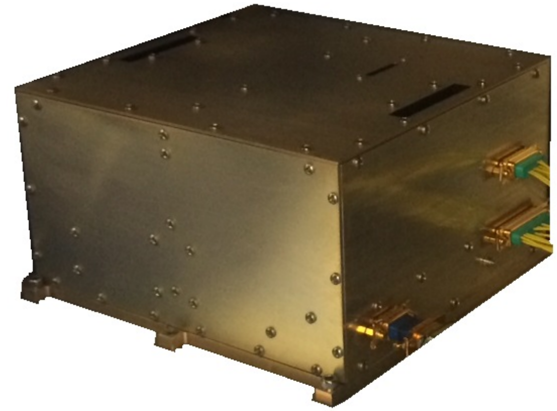
Space Weather Experiment (SWx)

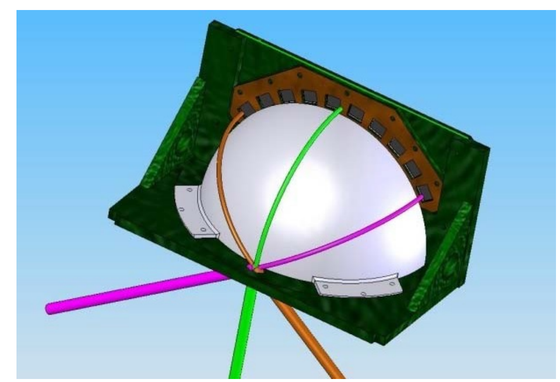
- SWx will measure angular and energy distribution of protons and electrons in MEO
  - To map the MEO radiation and plasma environment
  - To diagnose the in-situ environment for WPIx experiments



LEESA—Low Energy Electrostatic Analyzer

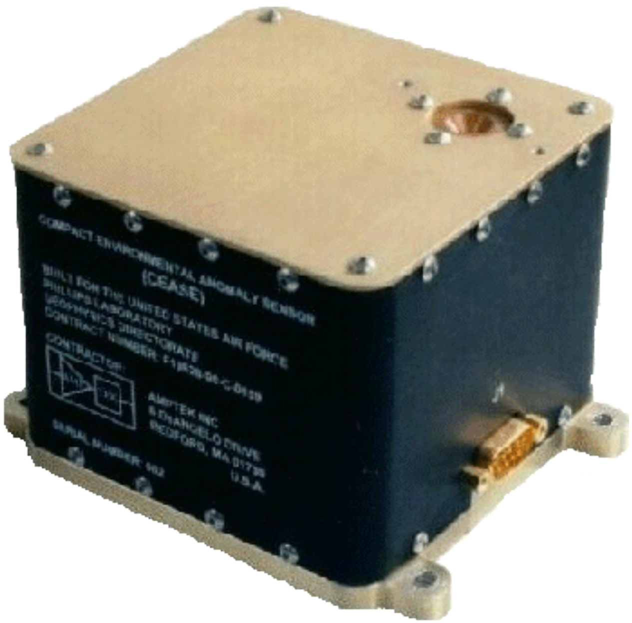
- Comprised of two pairs of concentric quarter spherical electrostatic analyzers, with voltage differences cycled to select particle energies
- Measures electron/ion fluxes for ~20 eV to 50 keV energies
  - 80 energies sampled per sweep from 256 choices of energy
  - Low energy limit in practice will be constrained mostly by spacecraft potential
- Full FOV 120° x 12° in 5 angular zones for each species (electron/ion)
  - FOV spans 105° on one side of B-field line, 15° on the other
- Two modes for cadence: 1 sec/sweep or 10 sec/sweep
- Survey mode is highly programmable
  - Survey energies/sampling are programmable on orbit
  - Typically will survey a subset of energies per sweep with periodic low energy sweeps for spacecraft potential check
  - But can do high resolution energy sampling in limited range
  - Or high resolution time sampling of a subset of energies





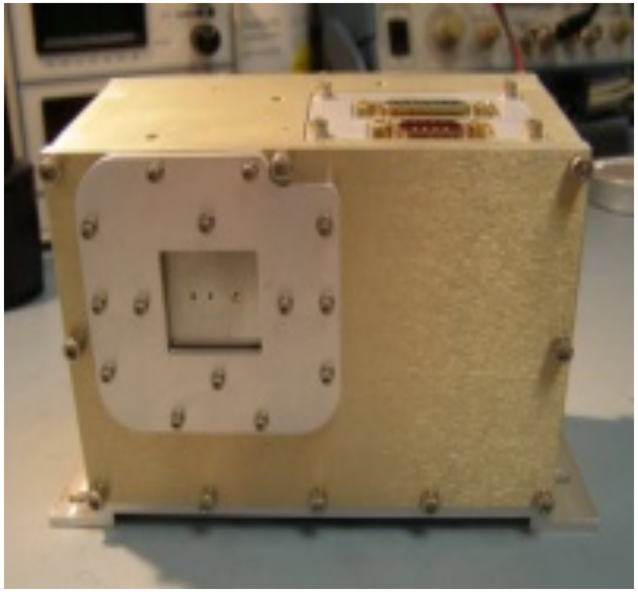
CEASE—Compact Environment Anomaly SEnsor

- Comprises one detector telescope (two elements), two dosimeters, and one SEE monitor
- Telescope measures protons in range 25-102 MeV and electrons in range 11-87 keV
  - 36 logic bins (LBs) reported
  - Includes the 9 nominal proton/electron channels
  - LBs cover protons 0.8-90 MeV, electrons 45 keV-10 MeV
- Dosimeters measure protons in range 21-49 MeV and electrons in range 1.2-6.5 MeV
  - 6 channels per dosimeter
- Full angle FOVs 90° for telescope, 180° for dosimeters
- 5 sec sample cadence
- CEASE units have previously flown on TSX-5, DSP-21, TacSat-4



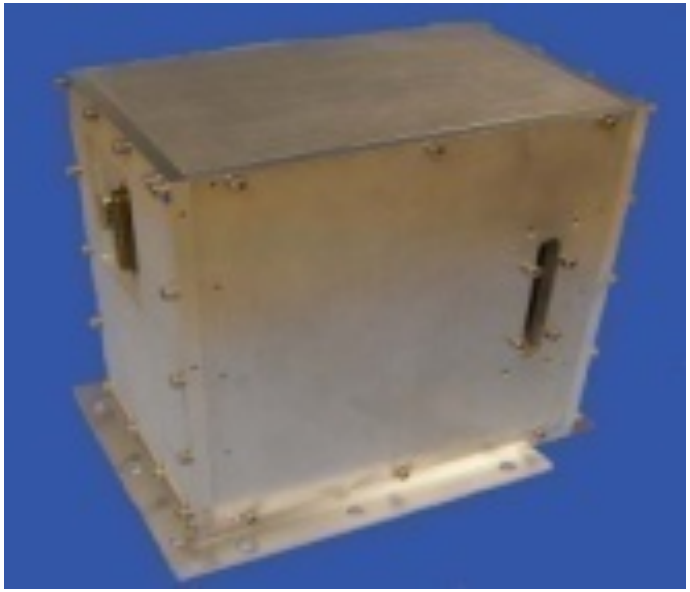
LIPS—Low Energy Imaging Particle Spectrometer

- Comprises scintillator detector pixels imaging fluxes through pinhole apertures
- Measures electrons and protons of energies 60 keV to >2 MeV
  - 6 energy channels
- Full FOV 79° x 8° in 8 angular bins
  - Edge of large FOV angle is aligned with B-field
- 1 sec sample cadence



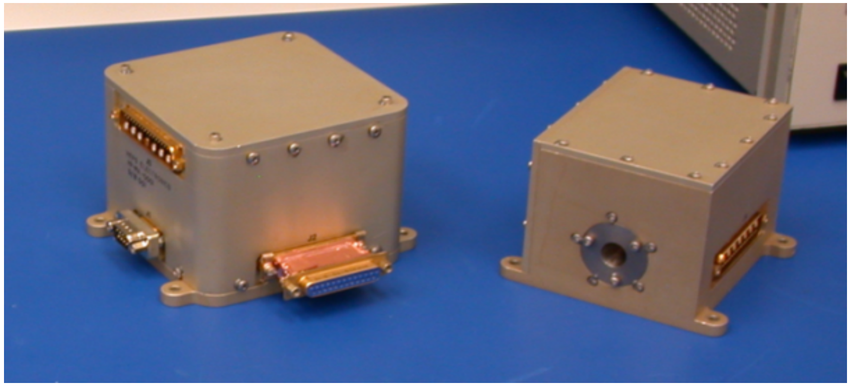
HIPS—High Energy Imaging Particle Spectrometer

- Comprised of three-detector telescope plus anti-coincidence scintillator
- Measures protons of energies 14-300 MeV and electrons of energies 1.1-12 MeV
  - 9 proton channels
  - 11 electron channels (likely only 5 unique)
- FOV 90° x 12.5° in 8 angular bins
  - Edge of large FOV angle is aligned with B-field
  - Default is electron imaging turned off (no angular bin reporting) as electrons likely won't be resolvable into bins—will decide on orbit
- 1 sec sample cadence

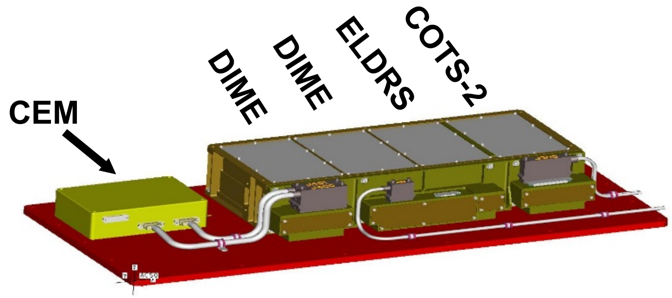


HEPS—High Energy Particle Sensor

- Comprised of four Si detectors, two scintillator detectors, and anti-coincidence scintillator
- Measures protons with energies 20-440 MeV plus >440 MeV channel
  - 22 differential + 1 integral channels
- Full angle FOV 15-25° for 100-200 MeV protons (half peak)
- 10 sec sample cadence

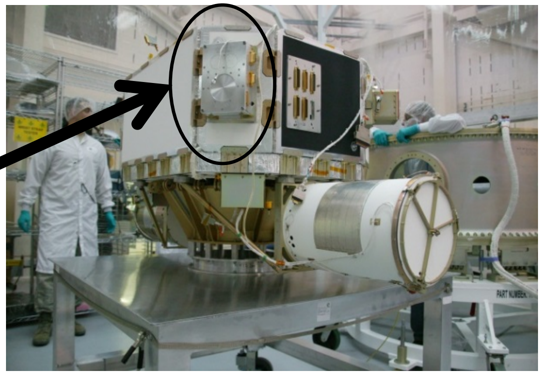


Space Effects



NASA Space Environment Testbed (SET)

- Correlative Environment Monitor (QinetiQ):European dosimeter & deep-dielectric charging instrument
- DIME (Clemson Univ): SEE and total dose environments using miniaturized COTS parts
- ELDRS (Arizona State): Low dose-rate and proton impacts to performance of 24 transistors
- COTS-2 (CNES and NASA): Virtex2 SRAM single event upset sensitivity



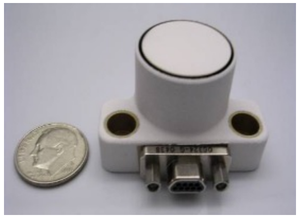
SET on DSX

SET advances our understanding of on-orbit degradation

AFRL "COTS" Sensors

- Objective: directly measure changes due to MEO radiation environment
  - Thermal absorption and emission—heat gain/loss of thermal control paints
  - Optical transmission—erosion of quartz windows, re-deposition of material on adjacent optics
- Results applicable to thin-film photovoltaics

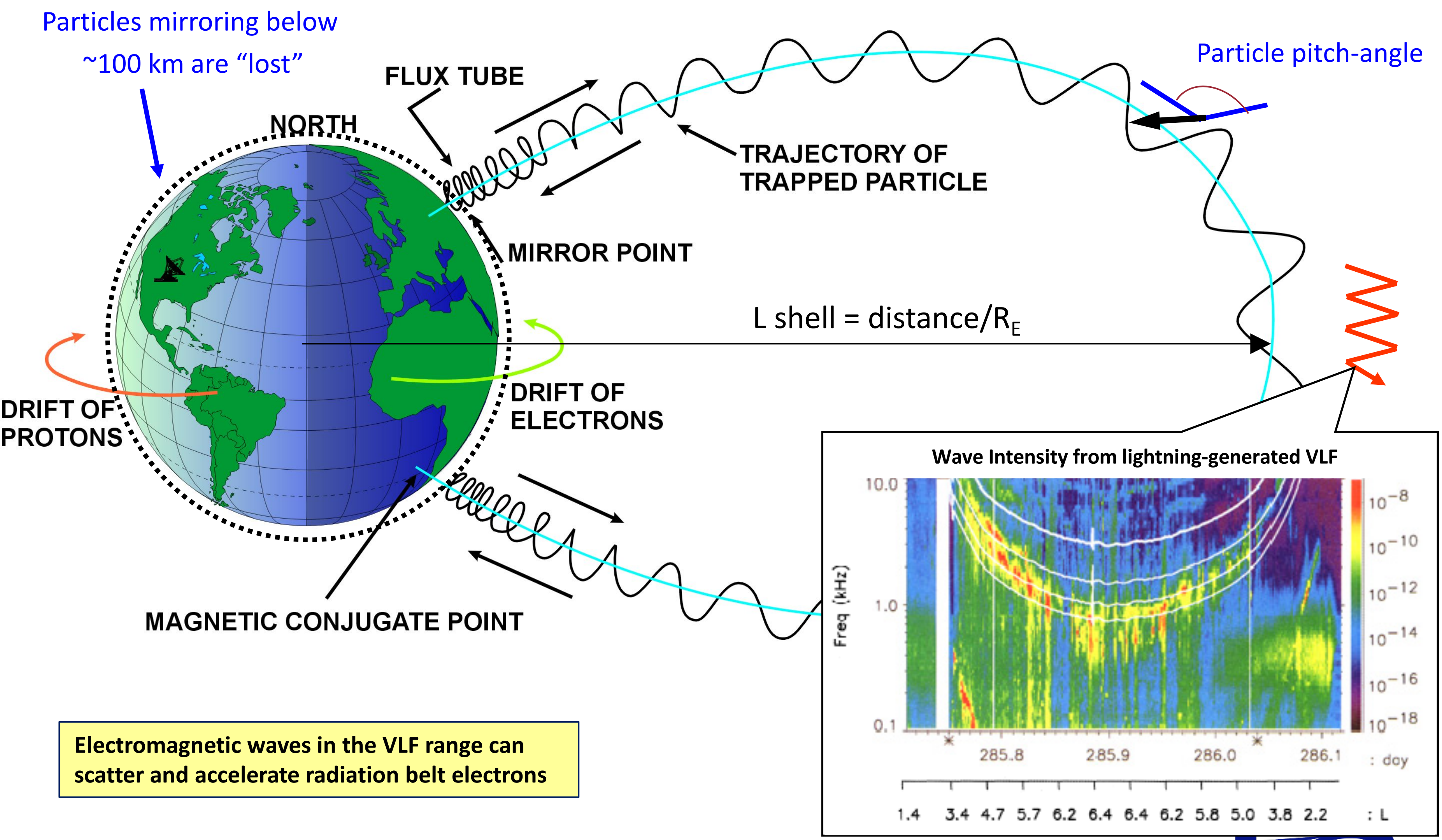
Radiometer



Photometer

Provider: AFRL/RQ

Wave-Particle Interactions

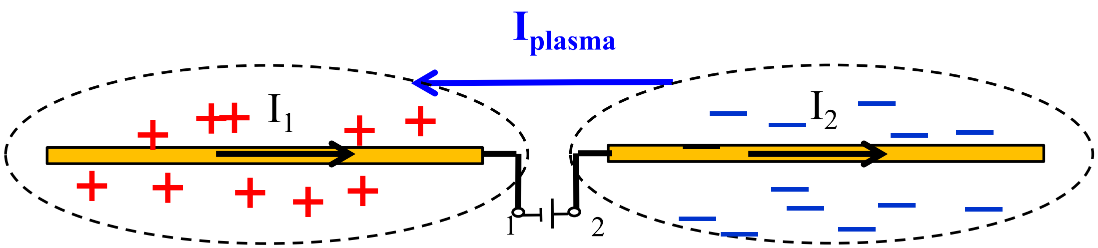


Electromagnetic waves in the VLF range can scatter and accelerate radiation belt electrons

Wave-Particle Interactions

Near Field: The basic physics of an antenna in a magnetoplasma are not well understood. **How much power is radiated beyond the sheath?**

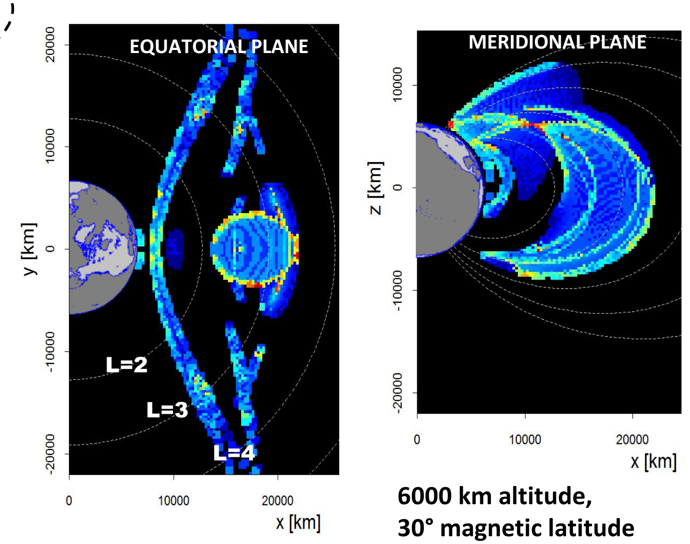
- Plasma sheaths and plasma heating effects
- Employ Nascap to determine bounds



$$\Delta V = V_2 - V_1$$

Far Field: 3D ray tracing

- Starting with a uniform spherical distribution leads to complex wave power distribution

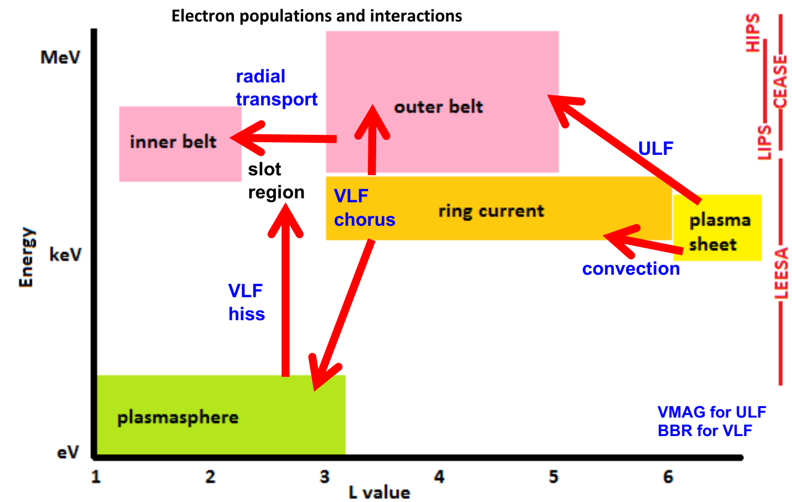


6000 km altitude, 30° magnetic latitude

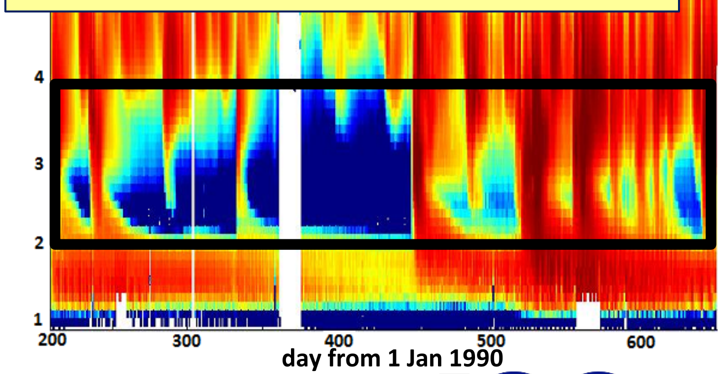
VPM will act as a far field sensor for DSX

Radiation Belt Dynamics

- Goal: Improve understanding of processes driving dynamics of the MEO environment
  - Natural wave particle interactions drive much of these dynamics, but we need more complete understanding
- DSX will contribute with:
  - Robust data on both the wave environment and the particle populations that drive and/or respond to it
    - Waves from ULF to VLF
    - Particles from plasmasphere to ring current to radiation belt populations
  - Participation in conjunction studies—both with other satellites and ground stations
- DSX mission is unique from others:
  - Orbit targets MEO and slot/plasmasphere-related processes
  - Higher inclination permits observations of off-equatorial waves



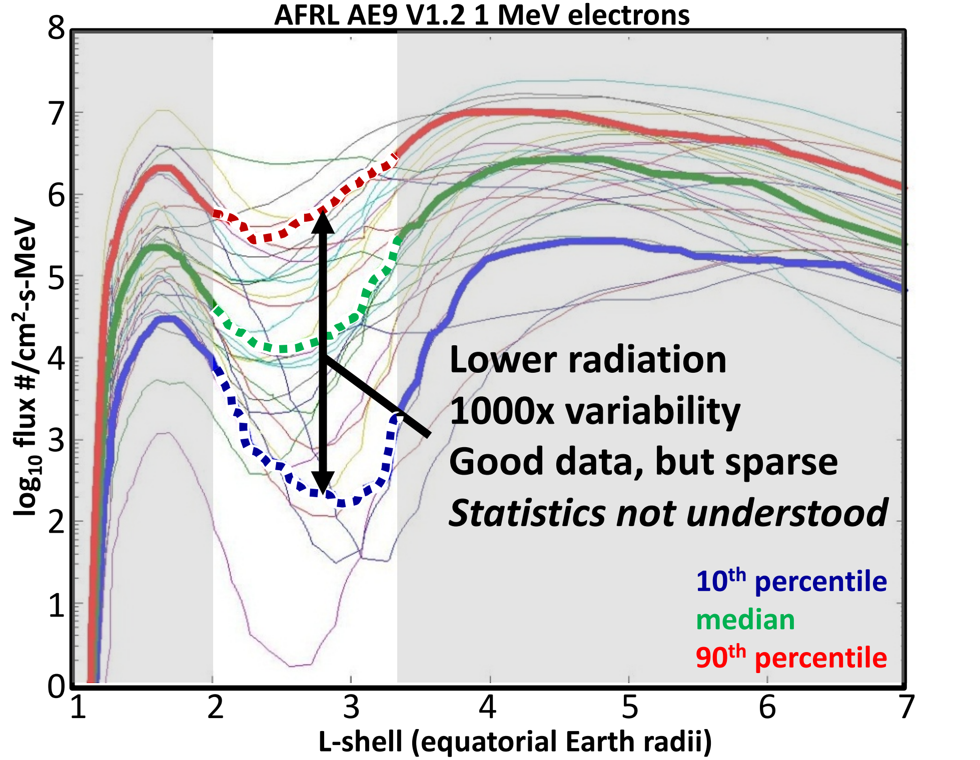
Better understanding of the fundamental processes governing the space radiation environment



Radiation Belt Mapping

- **Goal:** Characterize the *highly variable* MEO radiation environment
- **"Slot region?"**
  - AFRL CEASE on TacSat-4 (2012) observed elevated 5 MeV protons near L=2.5
  - NASA/AFRL CRRES (1990) observed transient filling of the slot region with electrons
- Targeted observations of the MEO environment in a variety of states is useful for:
  - Improve design climatology (AE9/AP9 ready to accept data)
  - Studies of "change of state" events in MEO

We cannot accurately specify a radiation environment!



- **MEO orbits can provide persistence, lower power requirements, and resilience through non-traditional orbits**

Mapping is critical for optimal design and planning of missions in this region

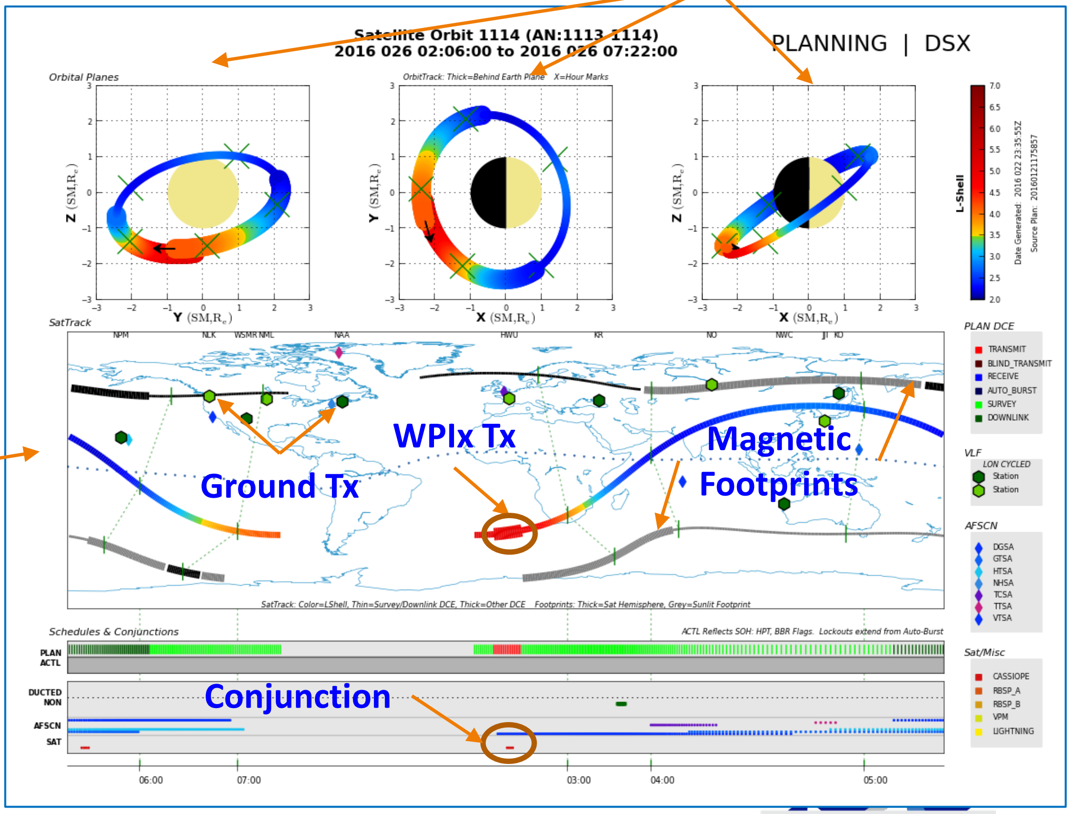
Mission Planning

- **Active Experiment:** Weekly science planning cadence incorporating late-breaking opportunities
  - Primary mission is study of VLF transmission, propagation, and interaction with trapped particles
  - Additionally examine the natural wave/particle environment

- WPIx transmissions: Rx conjunctions and "blind" near Equator

- Campaigns dedicated to magnetospheric waves, lightning, and ground transmitters

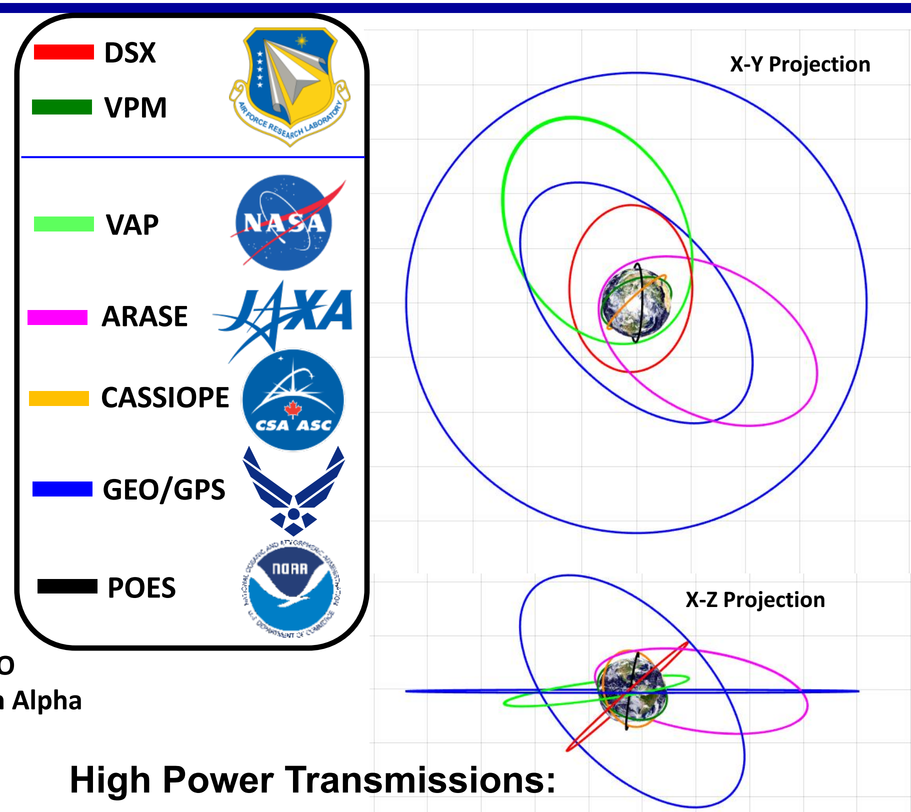
Thorough planning will increase value of active experiments

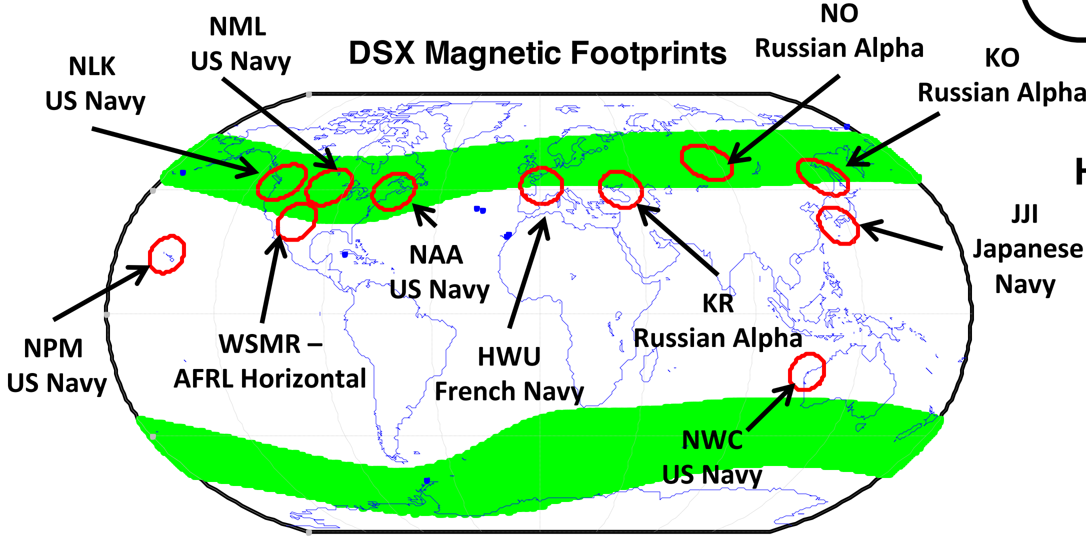


Conjunctions and Cooperation

We will utilize conjunctions with other assets for coordinated campaigns

- Detect transmitted waves and resulting particle effects
- Diagnose the environment during transmission
- Augment global coverage of particles and waves
- Assess ground VLF transmitter wave power
- Measure WSMR horizontal dipole experiment power
- Data will be cleared for release to collaborators





High Power Transmissions:

- Tx at the kV level at 2-50 kHz
- Up to 30 min per orbit occurring near the magnetic equator (|MLAT|<20° or L<3.5)
- Will coordinate with conjunction target teams with specifics

VPM Satellite

Mission

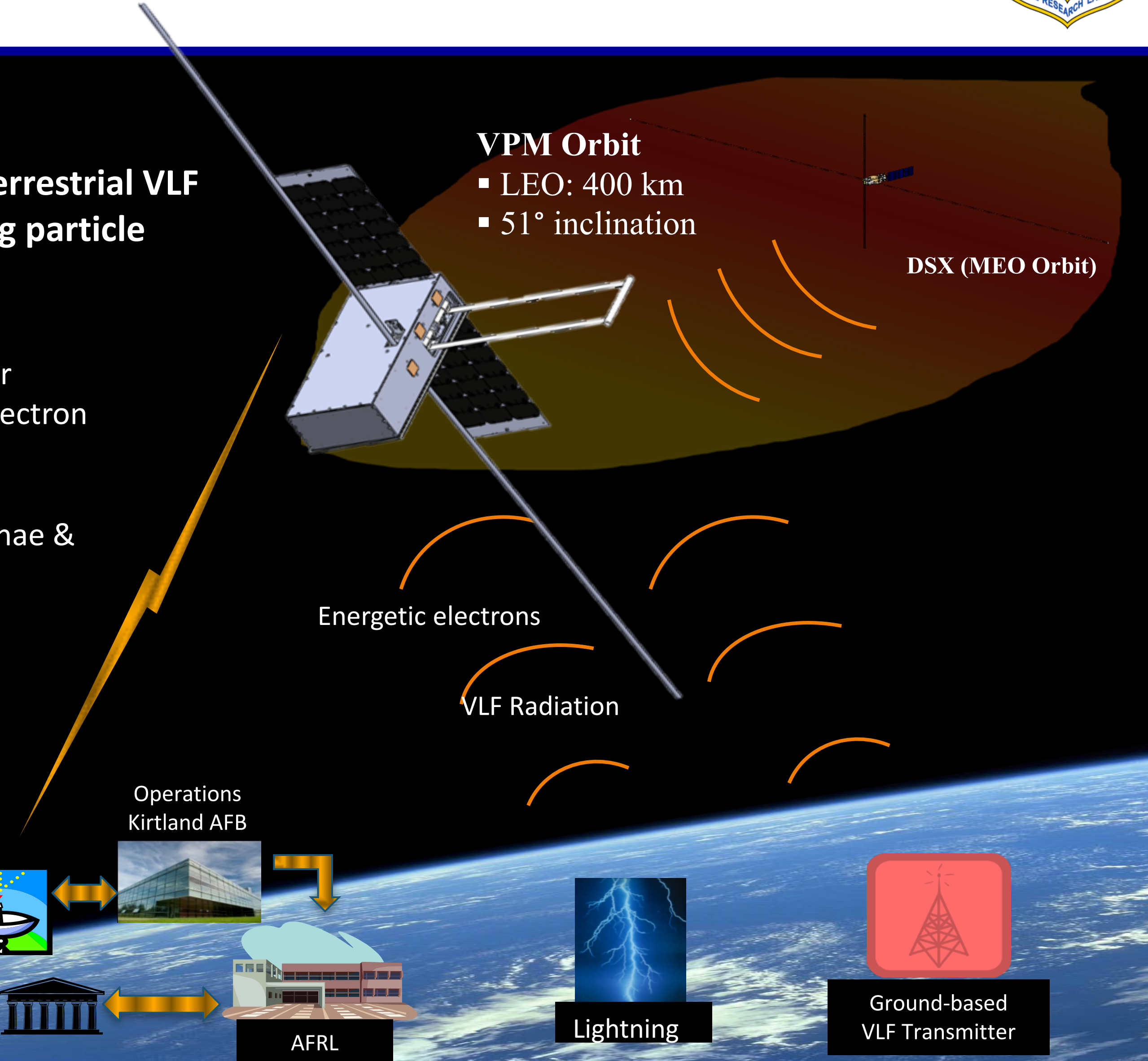
- **Quantify space and terrestrial VLF injection and resulting particle precipitation**

Payload

- Dual channel VLF receiver
- Loss cone and trapped electron spectrometers
- AC magnetic search coil
- Deployable E-field antennae & B-field boom

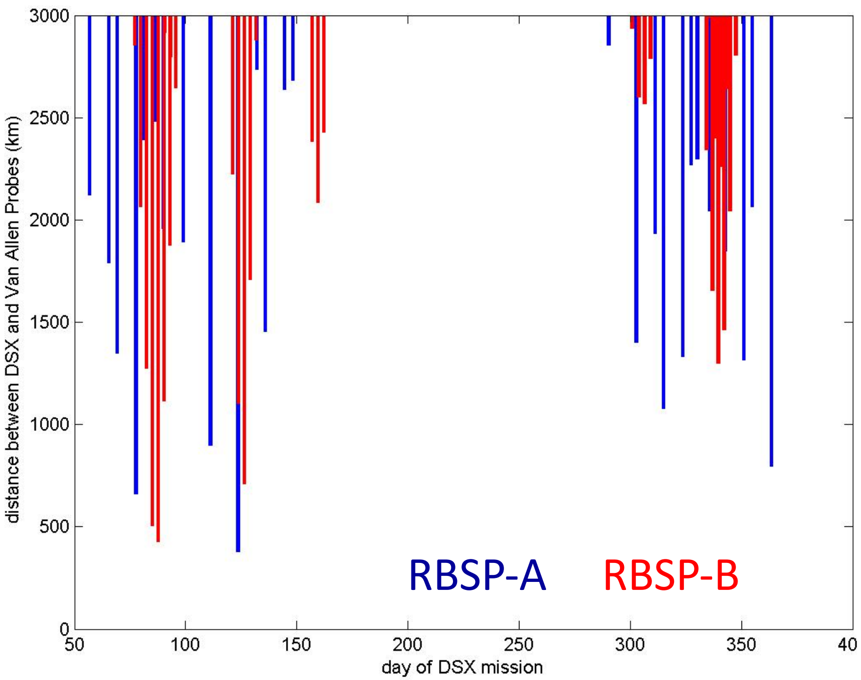
Spacecraft

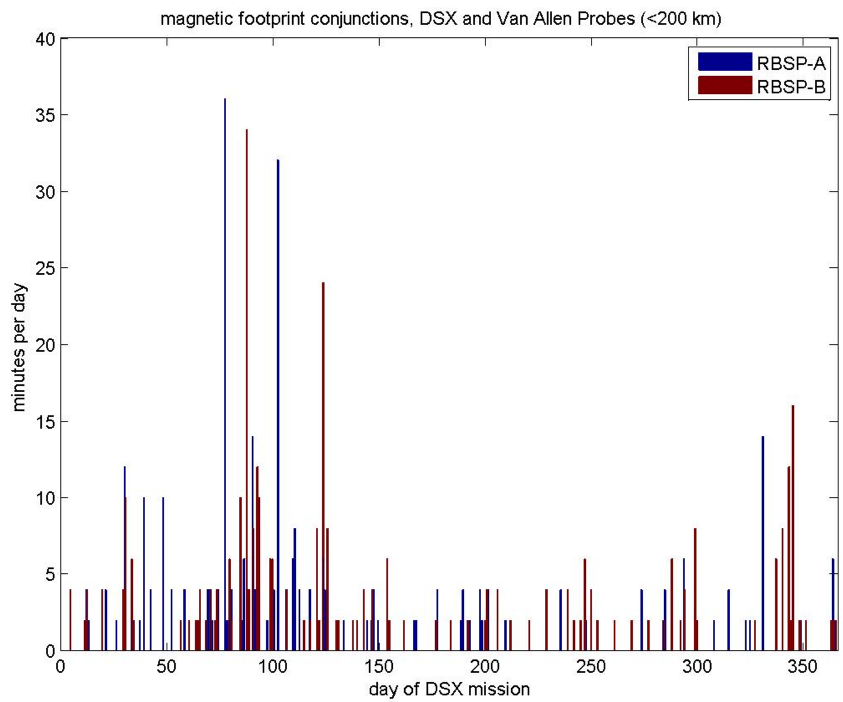
- 6U, 10kg, 20 W
- 1 year minimum mission



DSX-VAP Conjunctions

- Geographic conjunctions: ~7 within 1000 km during mission
- Magnetic conjunctions: ~13-21 days for A-B with footprints within 200 km for at least 5 minutes during mission

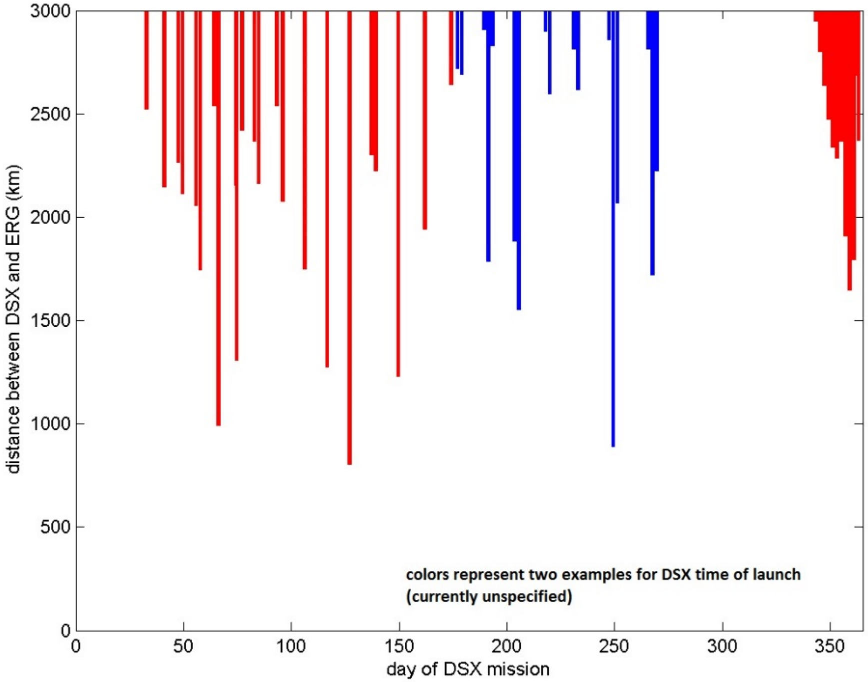


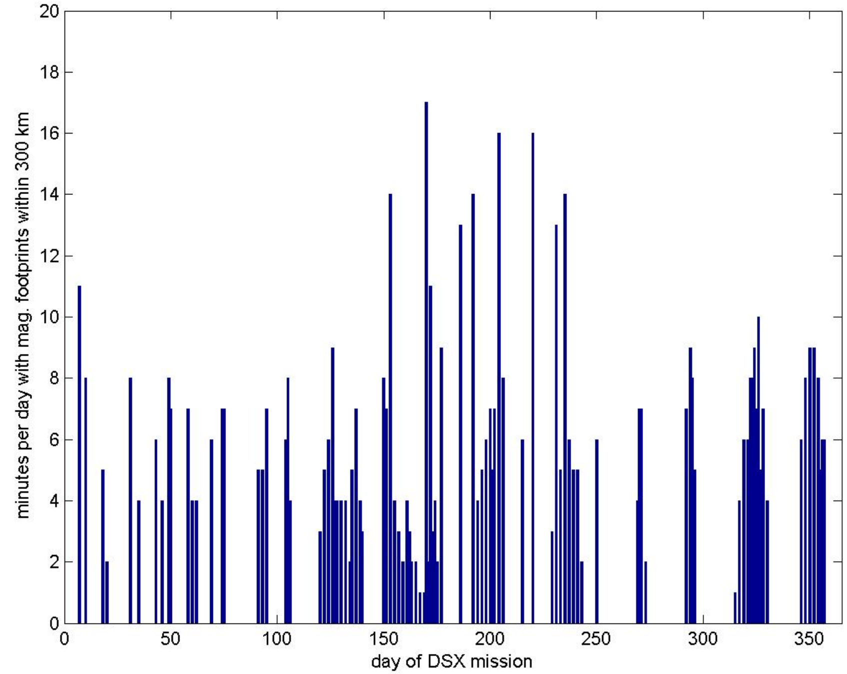


(illustrative—orientation of DSX orbit will not be known until launch)

DSX-ARASE Conjunctions

- Geographic conjunctions: ~7 within 1500 km during mission
- Magnetic conjunctions: ~33 days with footprints within 300 km for at least 5 minutes during mission





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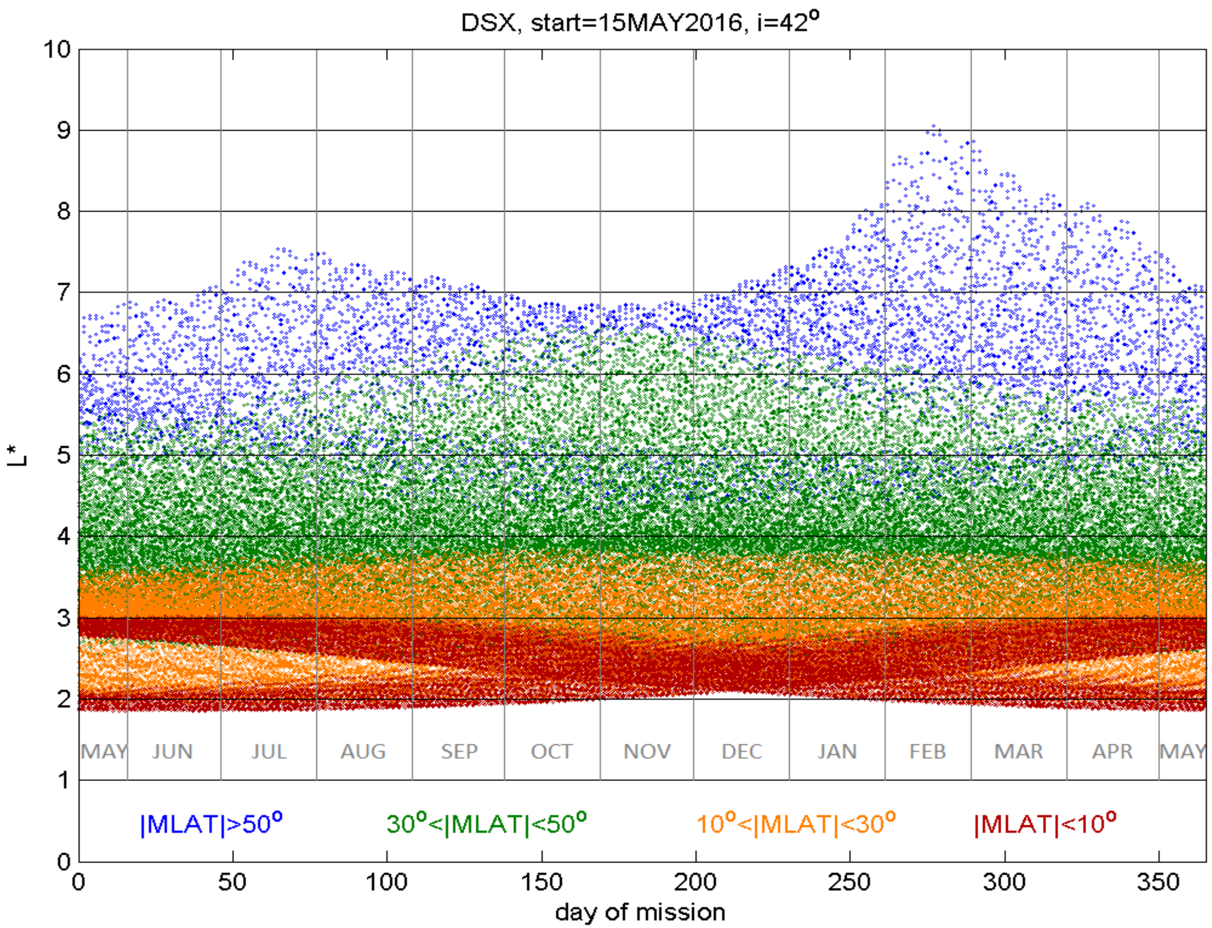
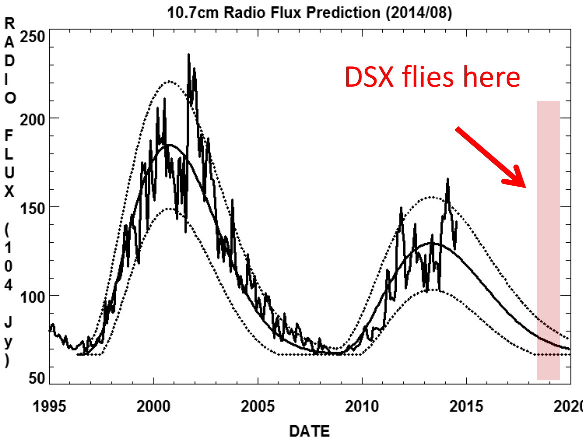
DSX spatiotemporal coverage



- Initial orbit has apogee and perigee near the equator
- Orbit precession period just over one year



Thank you!