# Active Experiments with the DSX Mission: Science Campaigns and Collaborations

AFRL HERITAGE | 1917–2017

100 YEARS OF U.S. AIR FORCE SCIENCE & TECHNOLOGY

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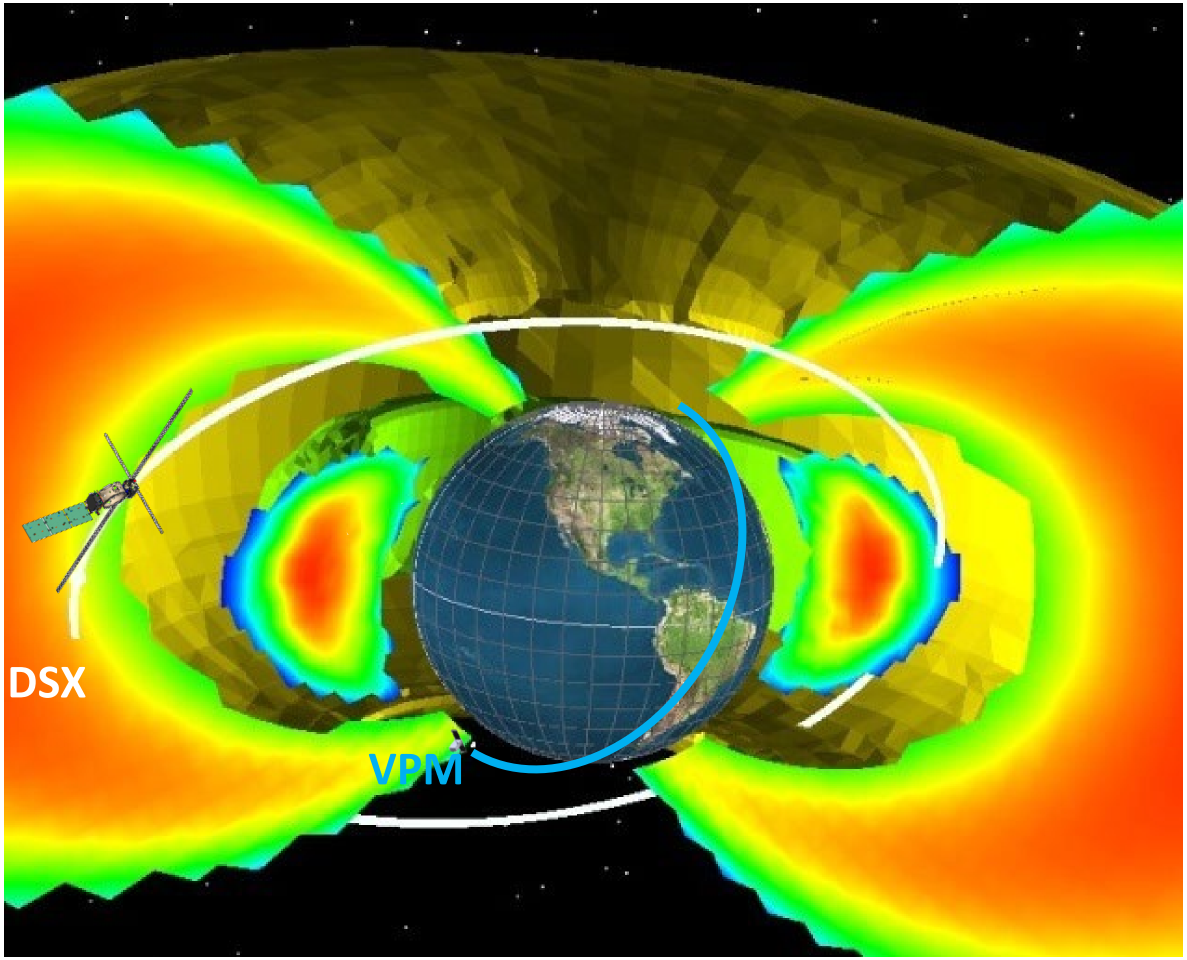
*Integrity ★ Service ★ Excellence*

# DSX Overview

- Planned launch in 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

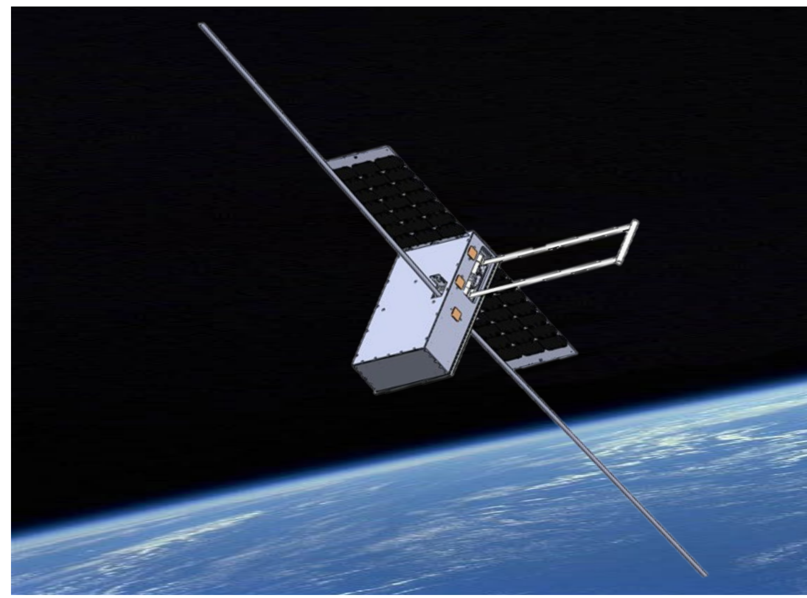
## The DSX Mission (2018 aboard SpaceX Falcon Heavy)

- Active study of wave-particle interactions with in-situ high power VLF transmitter
- Comprehensive study of MEO space environment

## The VPM Mission (2018 launch into LEO)

- 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)

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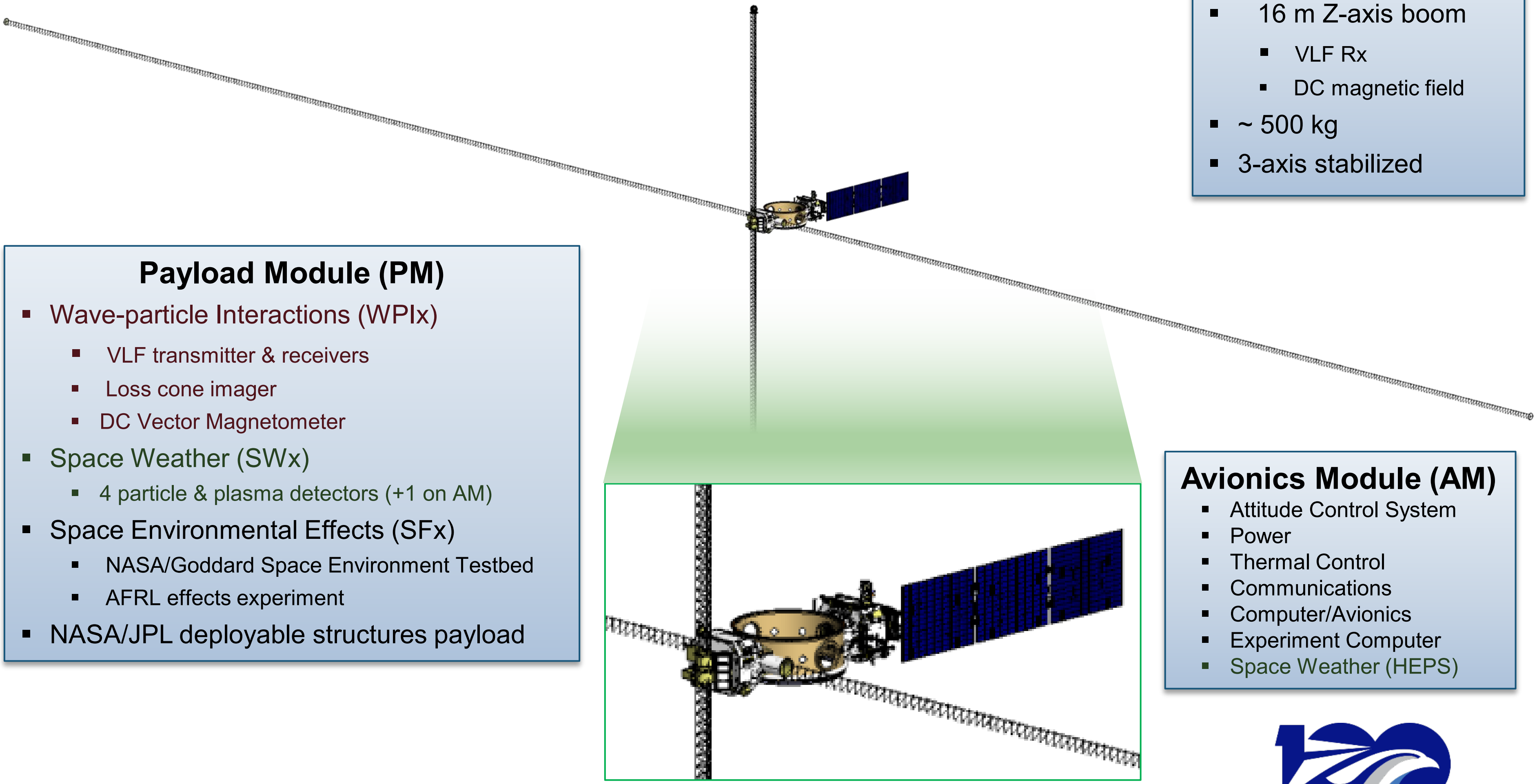
# DSX Spacecraft

**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)
  - 4 particle & plasma detectors (+1 on AM)
- 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)

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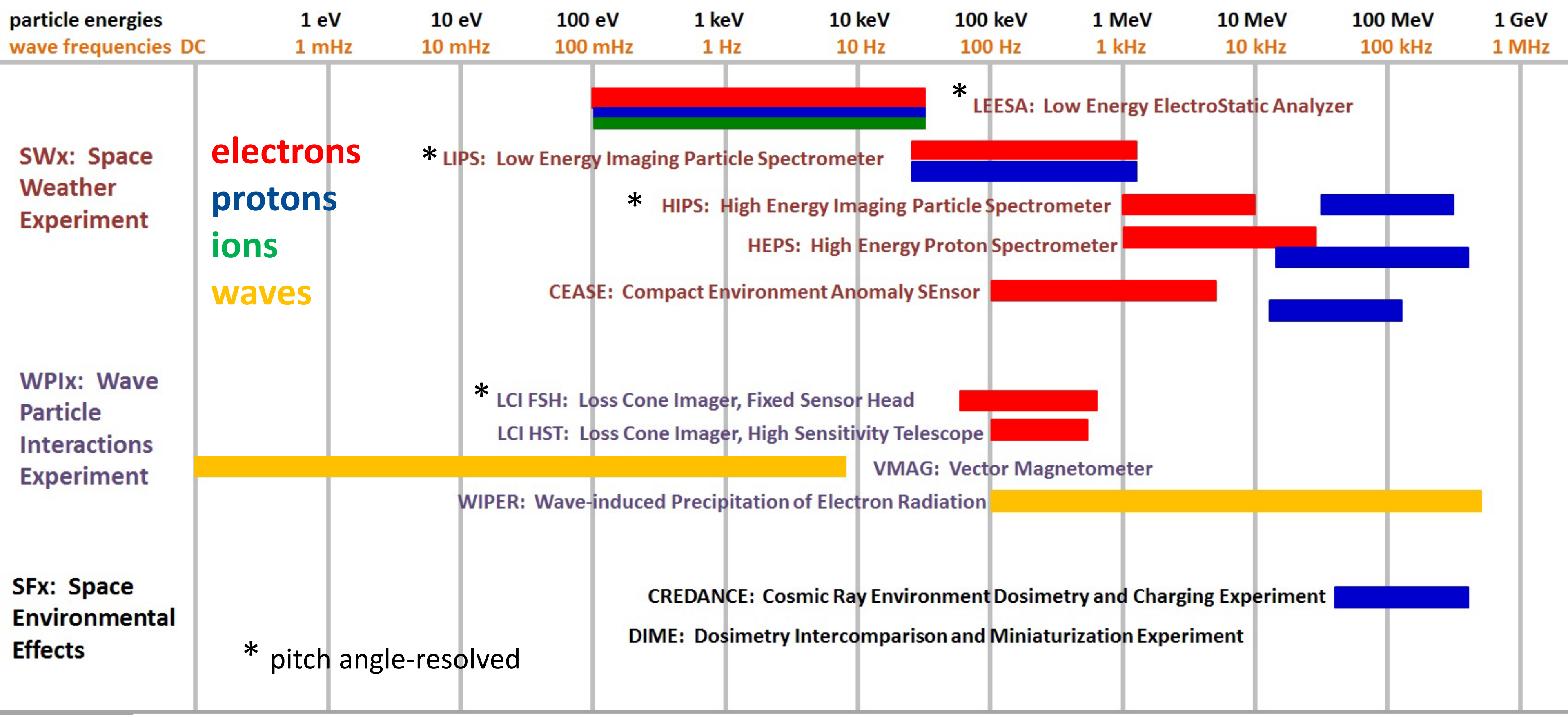
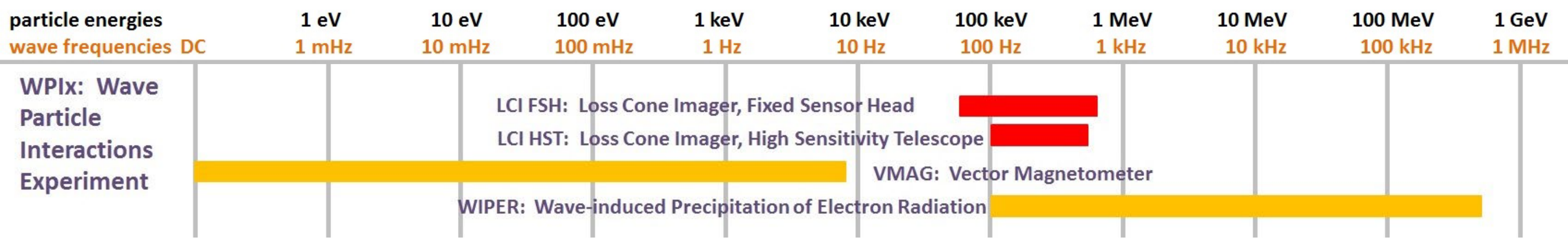
# DSX Science Payloads

- WPIx will transmit and measure waves and precipitating particles to understand VLF direct injection performance and diagnose effects
- SWx will measure distributions of protons and electrons to map the MEO environment and diagnose the environment for WPIx experiments
- SFx will advance our understanding of on-orbit degradation and directly measure changes due to MEO radiation environment



# WPIx Science Payloads

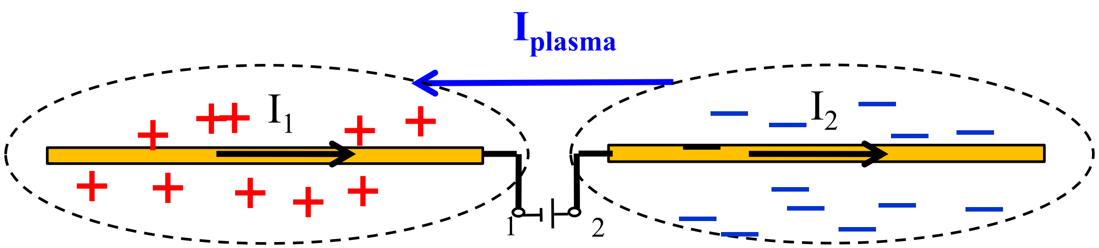



- **Transmitter (TNT):** UMass Lowell, SWRI, Lockheed-Martin
  - 3 – 50 kHz at up to 5 kV (9 kV at end of life)
  - 50 – 750 kHz at 1W (local electron density)
- **Receiver (BBR/SRx):** Stanford, Lockheed-Martin, NASA/Goddard
  - 3 **B** components (TASC), 2 **E** components (dipole antennas)
  - Frequency range: 100 Hz – 50 kHz
- **Vector Magnetometer (VMAG):** UCLA, UMich
  - 0 – 8 Hz three-axis measurement, ±0.1 nT accuracy
- **Loss Cone Imager (LCI):** Boston University, AFRL
  - High Sensitivity Telescope (HST): FOV 6.5° (centered on LC); 100 – 500 keV $e^-$
  - Fixed Sensor Heads (FSH): 3 angular zones, 180°x10°; 50 – 700 keV $e^-$

# 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?**

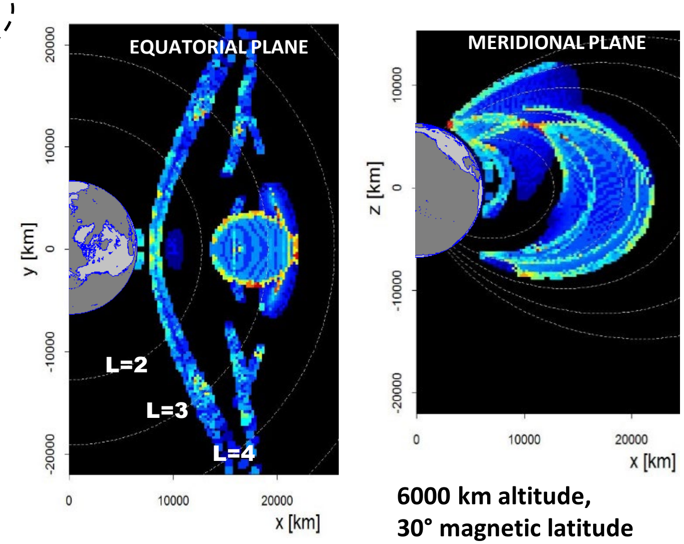
- Plasma sheaths and plasma heating effects
- Employ Nascap to determine bounds




$$\Delta V = V_2 - V_1$$

**Far Field:** 3D ray tracing

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

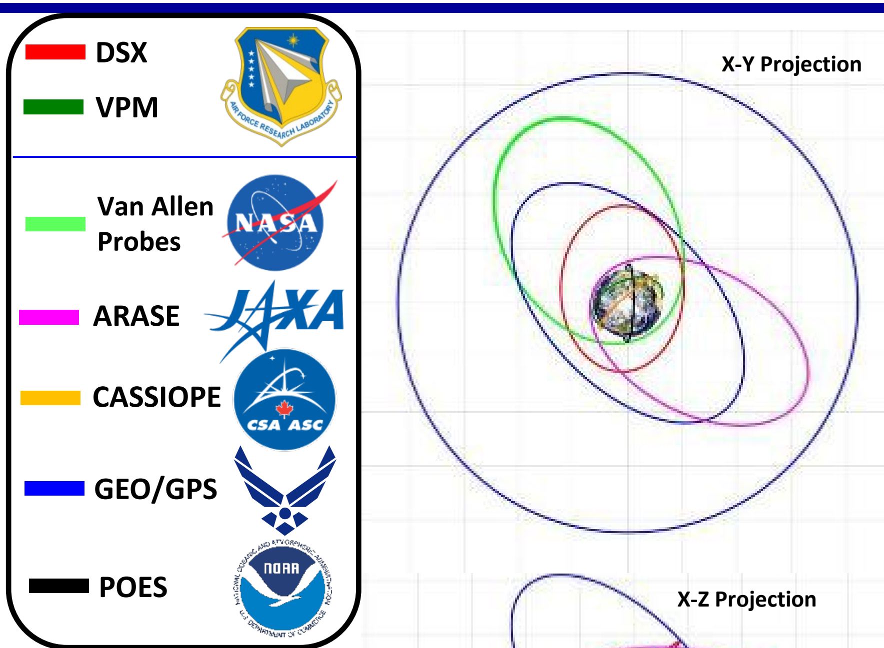


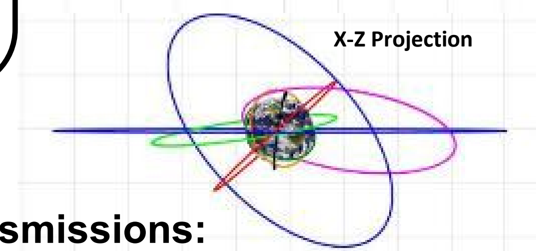

**6000 km altitude, 30° magnetic latitude**

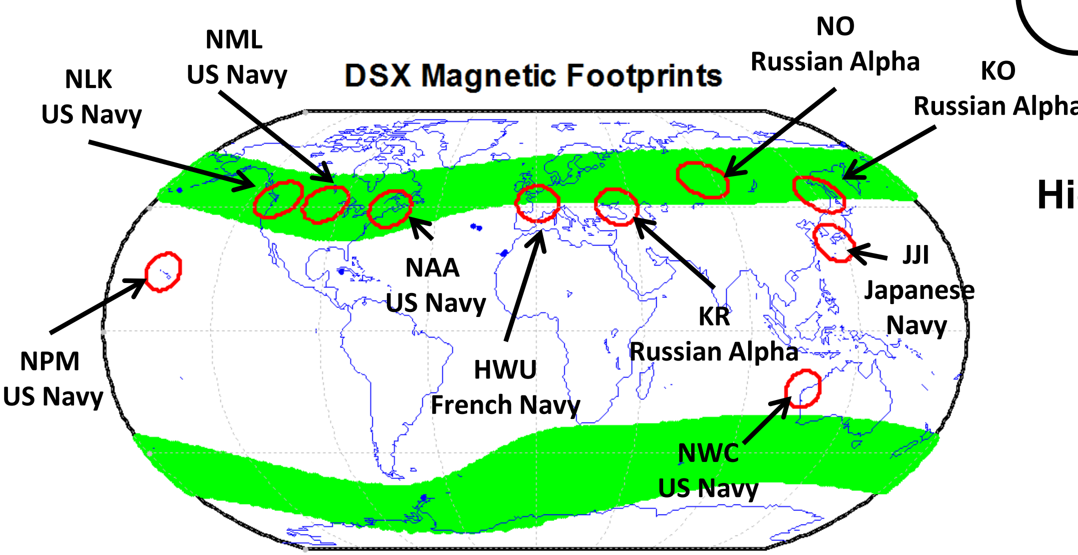
# Conjunctions and Cooperation

**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 kW 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



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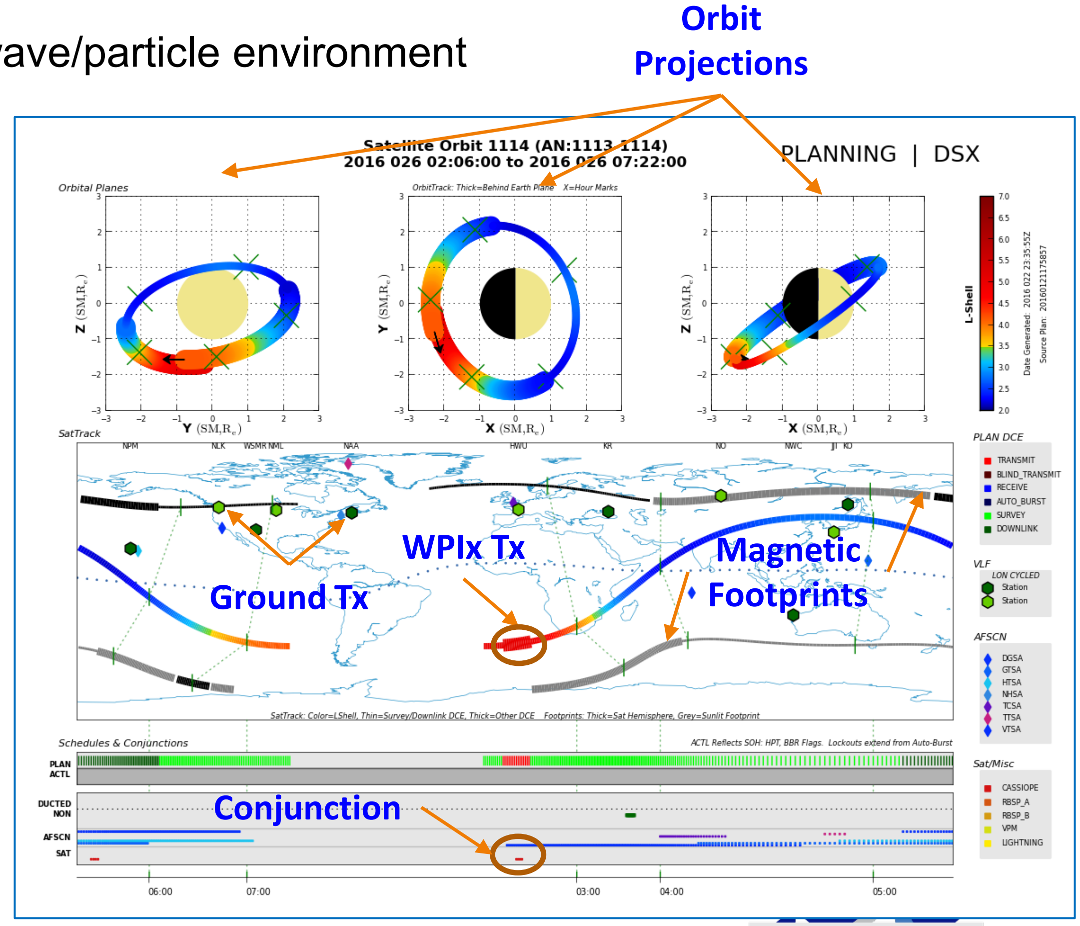
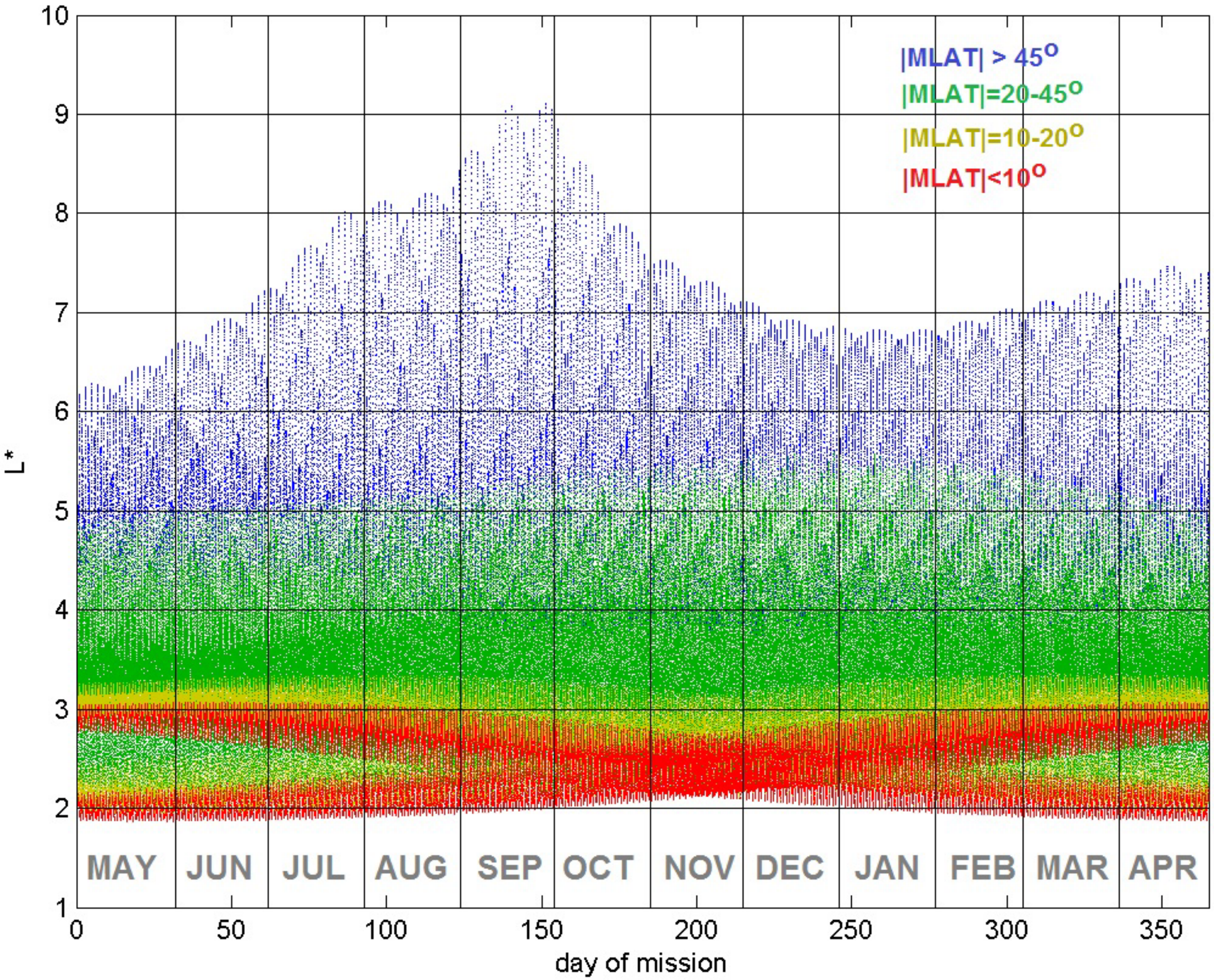
# Mission Planning

- **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

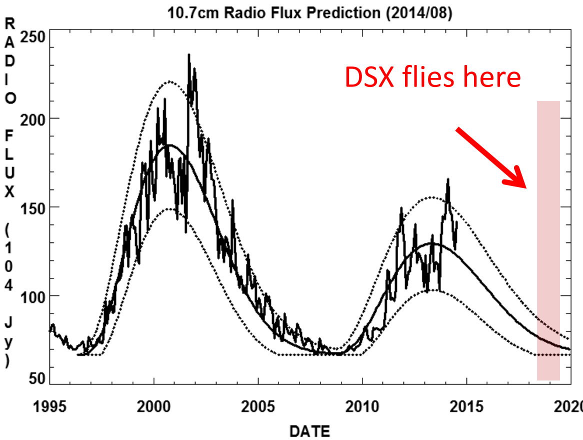
- WPIx transmissions: Tx conjunctions and "blind" near equator
- Campaigns dedicated to magnetospheric waves, lightning, and ground transmitters
- Science planning cycle works one week at a time, two weeks in advance



# DSX spatiotemporal coverage

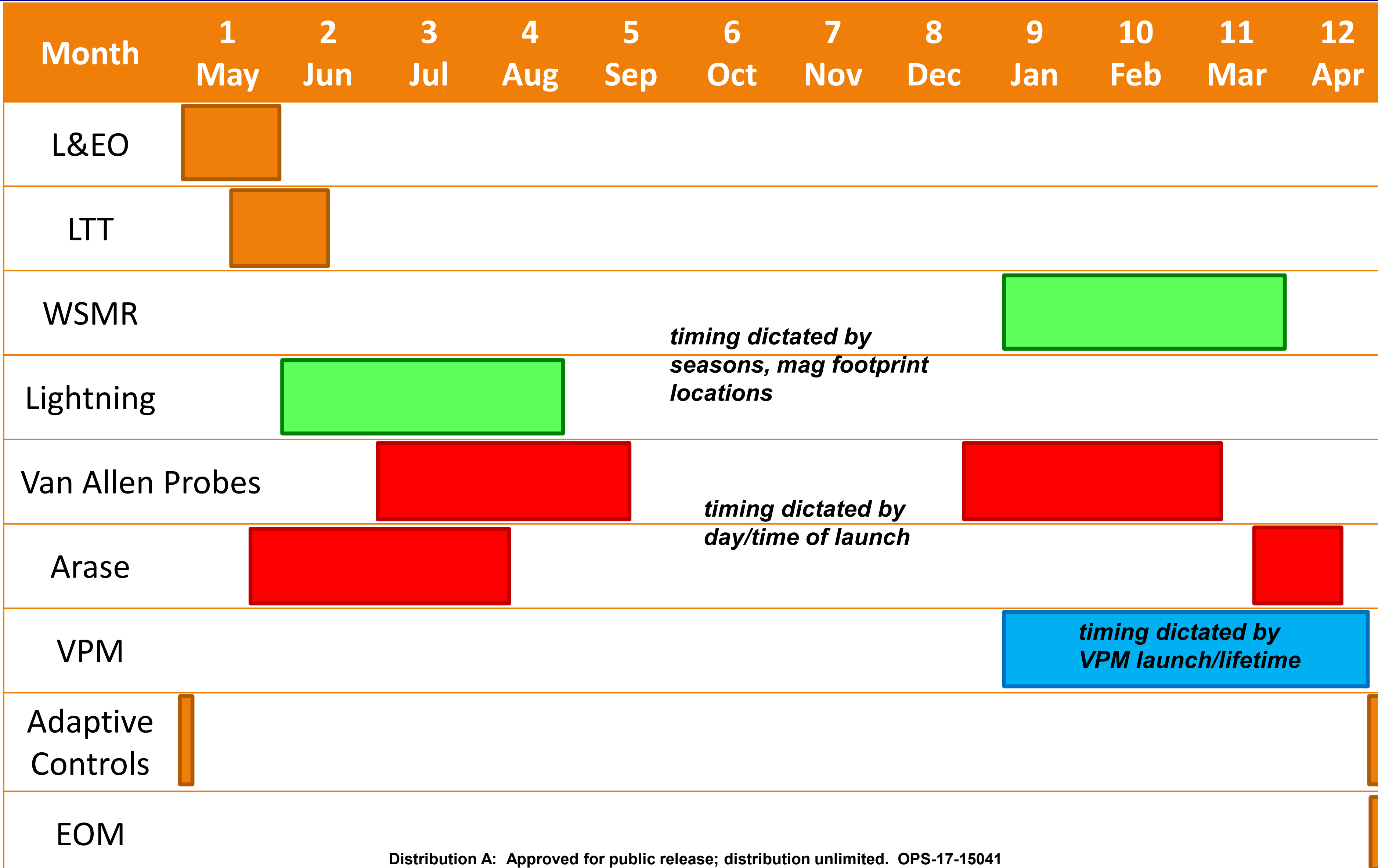



- Initial orbit crosses equatorial plane near perigee and apogee
- Orbit precession period just over one year



# DSX notional science campaigns

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

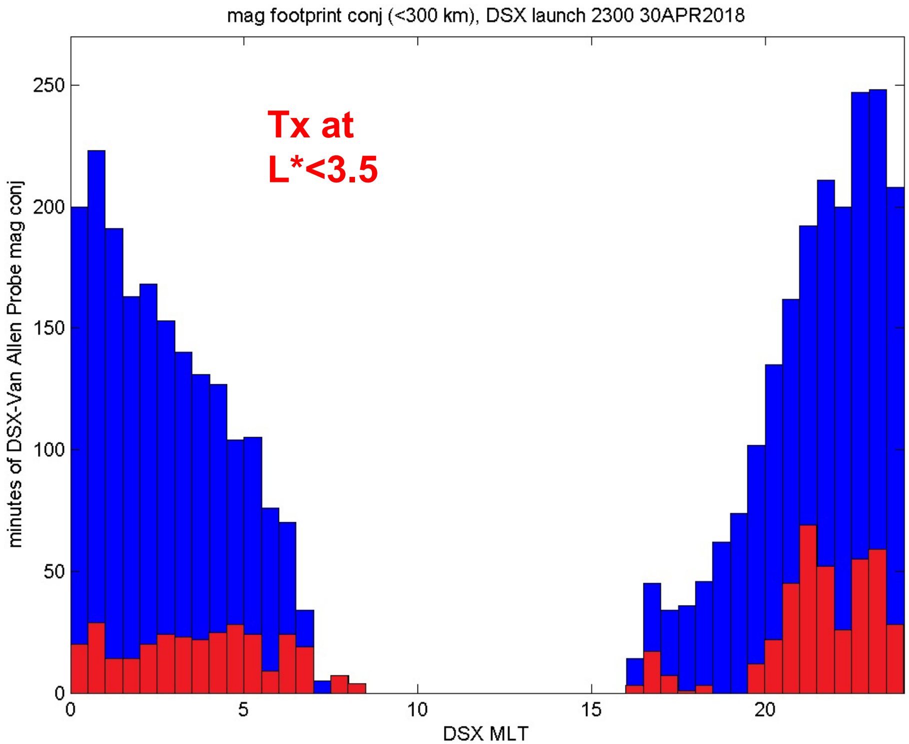


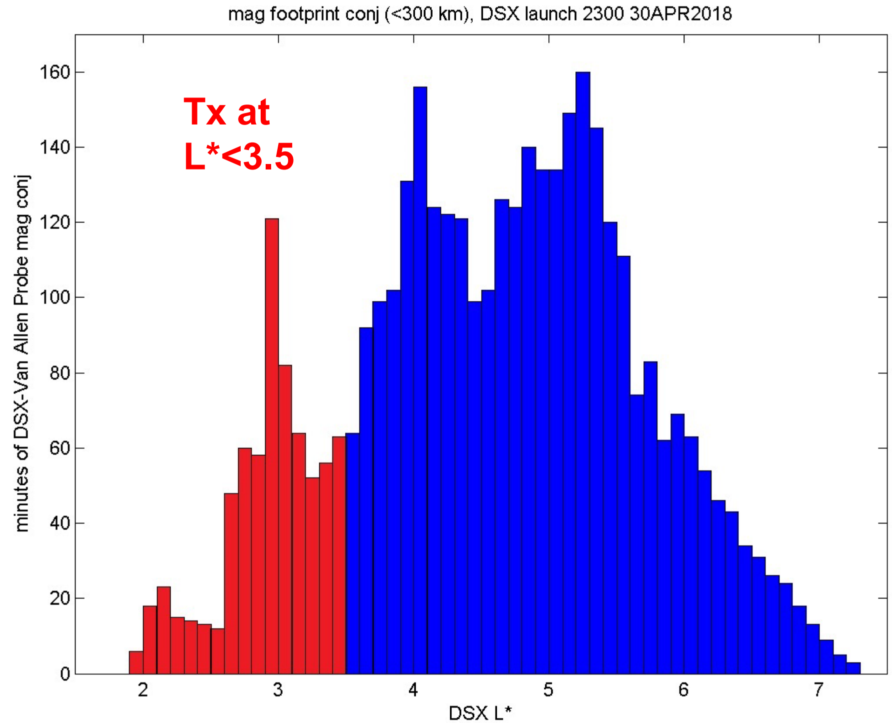
# Collaborations

- Coordinating missions should expect two week advance notice on planned transmissions
  - Subject to change at the last minute
  - Input on planning can be submitted to DSX science team
- Data sharing
  - SWx (particle) data, VMAG, LCI, BBR and TNT wave data, and DSX orbit/ephemeris are already approved for release to collaborators
  - We expect to “push” data to collaborators (one way or another)
- Rules of the road in development
  - Any results for publication/presentation will need to go through AFRL clearance

# DSX-Van Allen Tx Conjunctions

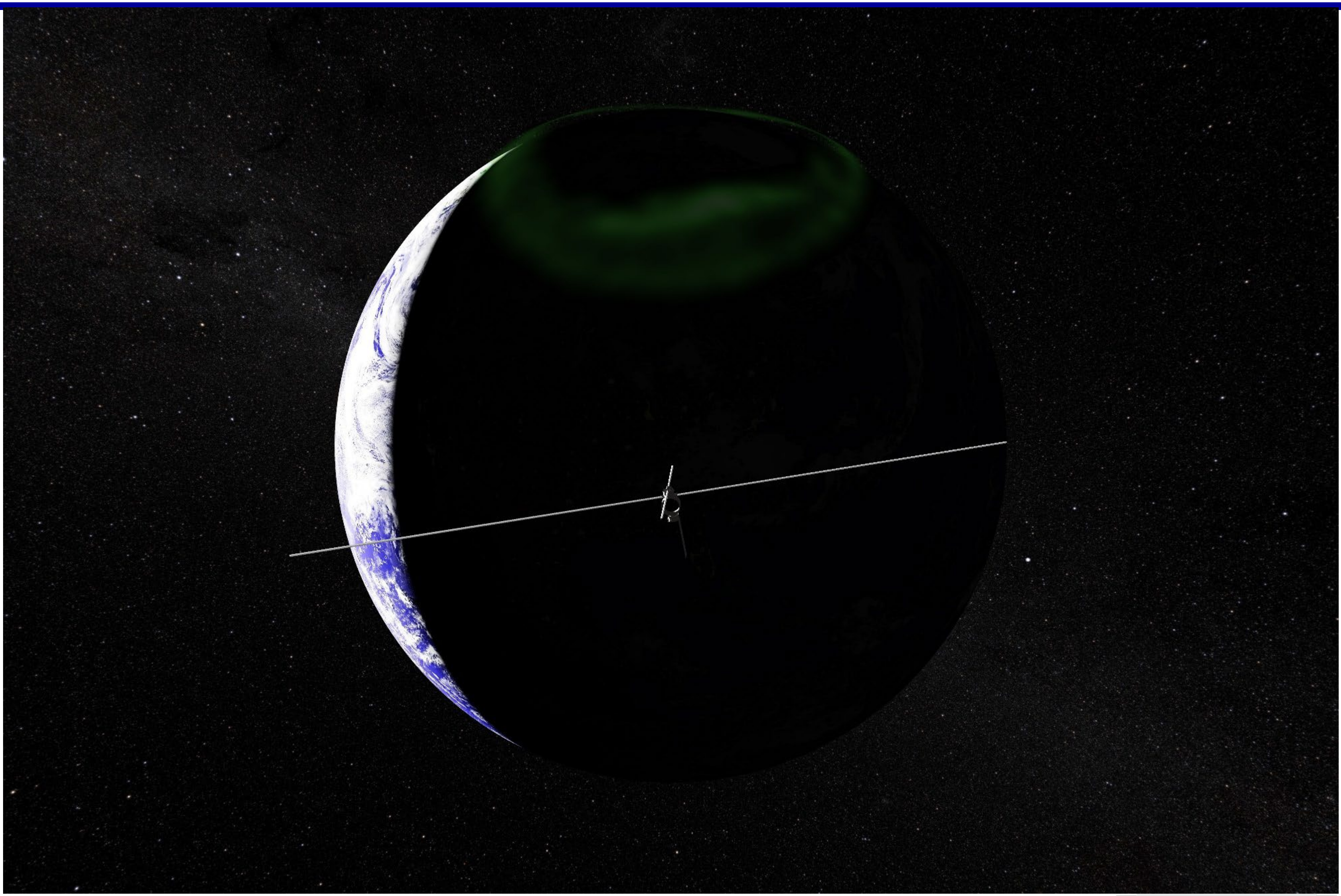
- L* and MLT distribution of magnetic footprint conjunctions, sample launch time for DSX, one year mission
- All magnetic conjunctions in blue, those potentially during high power transmissions in red




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

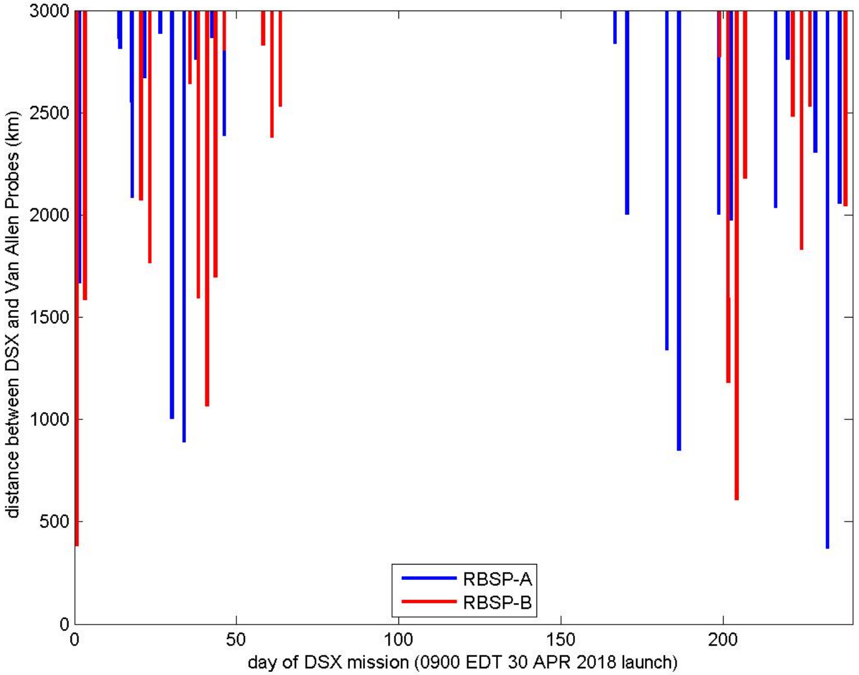
# Thank you!

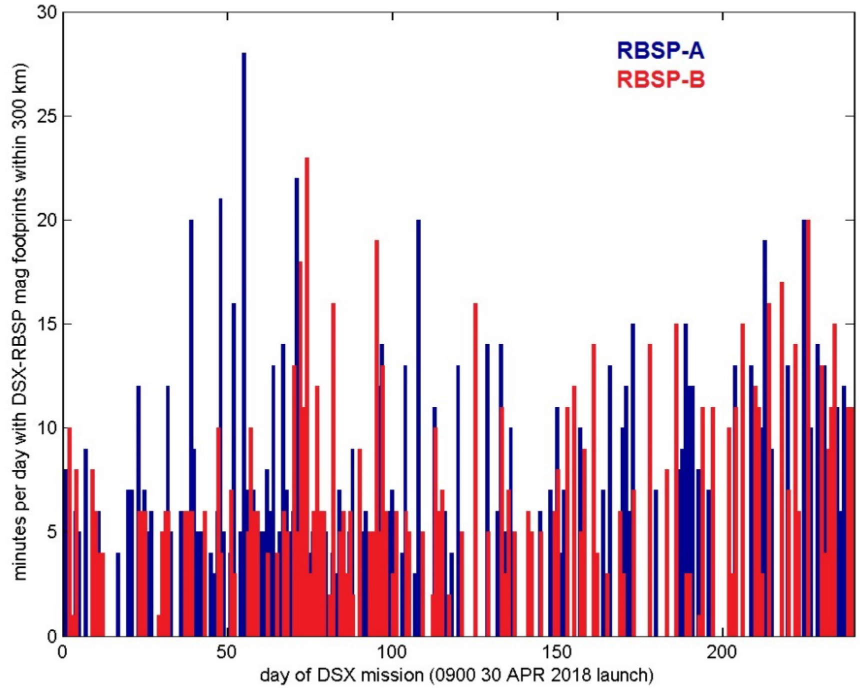


# Backups

# DSX-Van Allen Conjunctions

- Geographic conjunctions: ~15 within 2000 km through Dec 2018 (11-20)
- Magnetic conjunctions: ~307 for A+B with footprints within 300 km, through Dec 2018 (201-381)
  - Same, during first 4 months: ~168 (82-279)

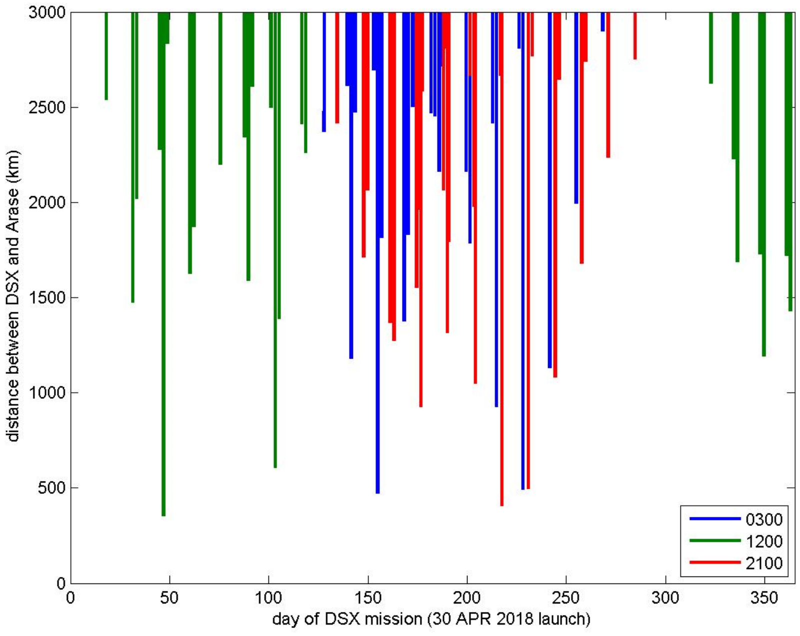


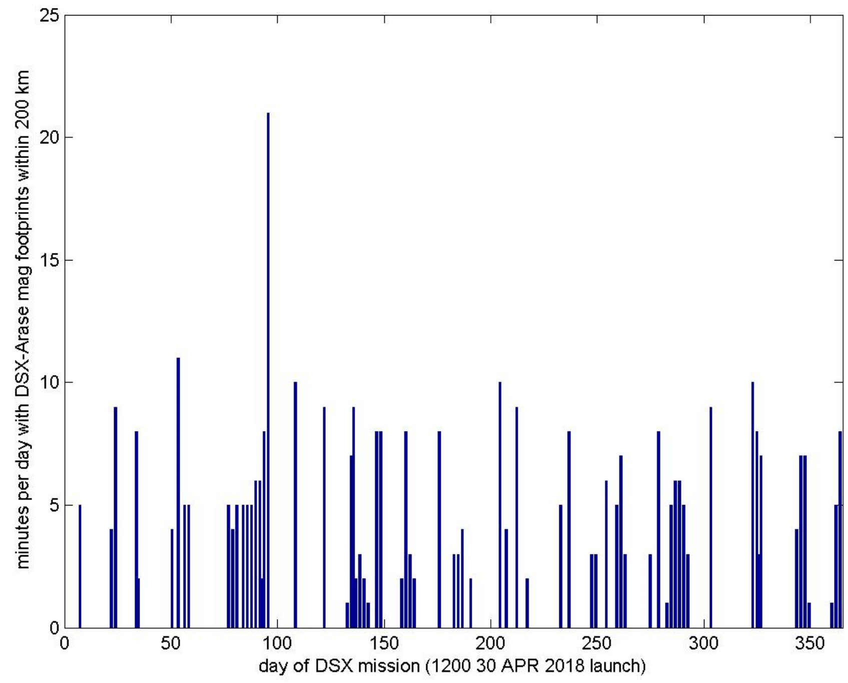




*(illustrative—orientation of DSX orbit will not be known until launch)*

# DSX-Arase Conjunctions

- Geographic conjunctions: ~7 within 1500 km during mission (2-21)
- Magnetic conjunctions: ~116 with footprints within 200 km (60-190)
  - Same, but with L*<3.5 (high power Tx): ~33 (25-44)

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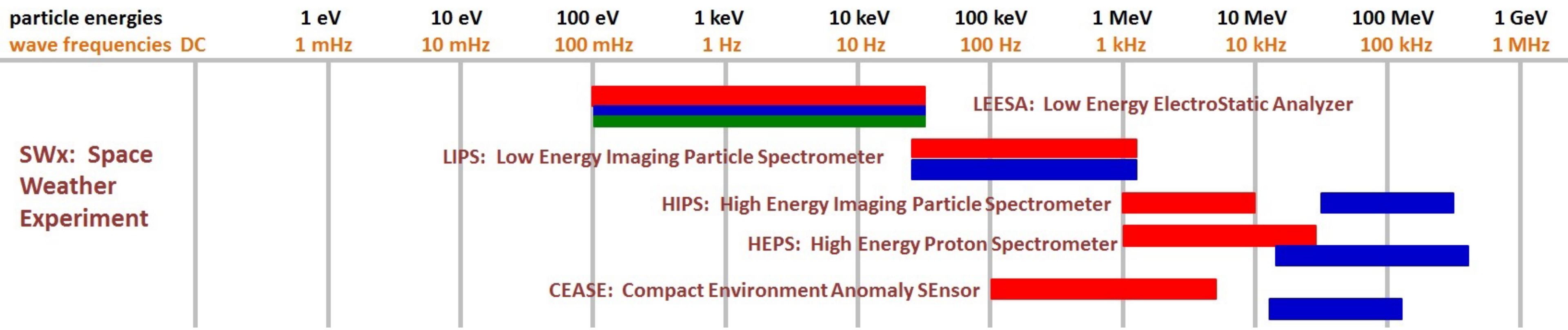
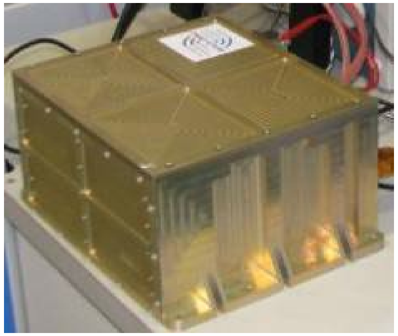
# SWx Science Payloads

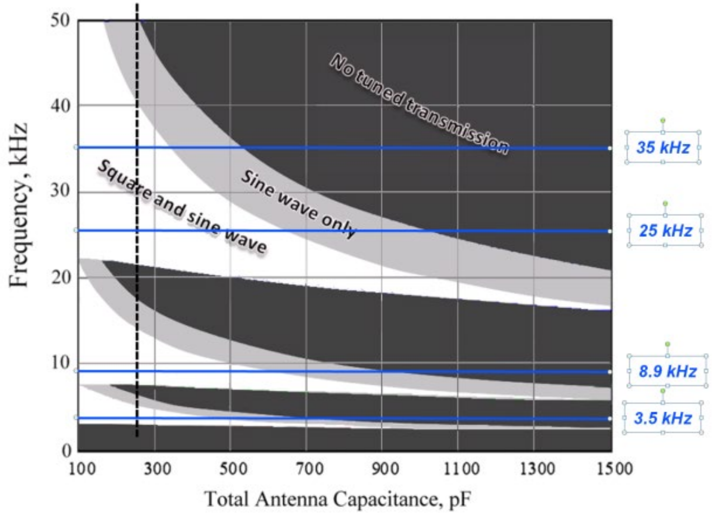



- **Low Energy ElectroStatic Analyzer (LEESA):** AFRL/RVB
  - 5 angular zones, total FOV 120°x12°; 30 eV—50 keV $e^-$, ions
- **Compact Environmental Anomaly Sensor (CEASE):** AFRL/RVB
  - Telescope: FOV 60°; dosimeters: FOV 90°; 100 keV—6.5 MeV $e^-$; 20—100 MeV $p^+$
- **Low-energy Imaging Particle Spectrometer (LIPS):** PSI, AFRL
  - 8 angular zones, FOV 79°x8°; 30 keV—2 MeV $e^-$, $p^+$
- **High-energy Imaging Particle Spectrometer (HIPS):** PSI, AFRL
  - 8 angular zones, FOV 90°x12.5°; 1—10 MeV $e^-$, 30—300 MeV $p^+$
- **High Energy Proton Spectrometer (HEPS):** ATC, Amptek, AFRL
  - 1 look direction, FOV 24° ($p^+$) 40° ($e^-$); 20—440 MeV $p^+$

# TNT—Transmitter, Narrowband Rx, and Tuners

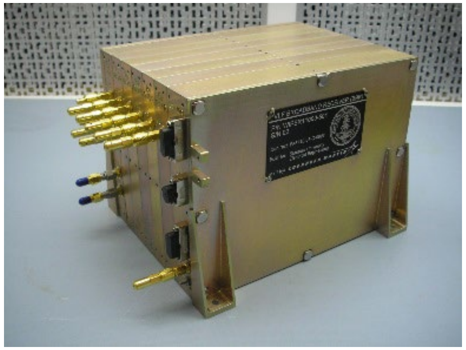
- Comprised of 80 m dipole antenna, cabling, and control and tuning units for VLF transmitter and narrowband VLF receiver
- Transmits 3-50 kHz tuned signals
  - Up to ~5 kV during high-power transmissions
  - Low-power "sounding" operations at 50-750 kHz
- Tuners capable of adaptively maximizing antenna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

BU

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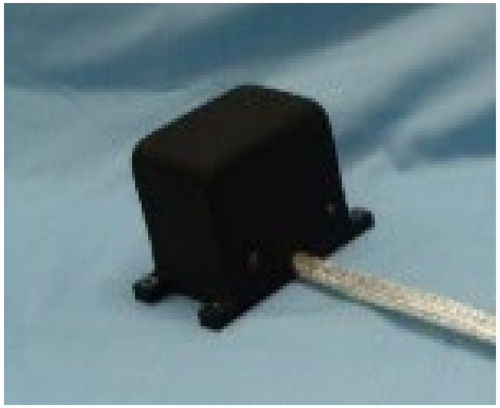
# VMAG—Vector Magnetometer

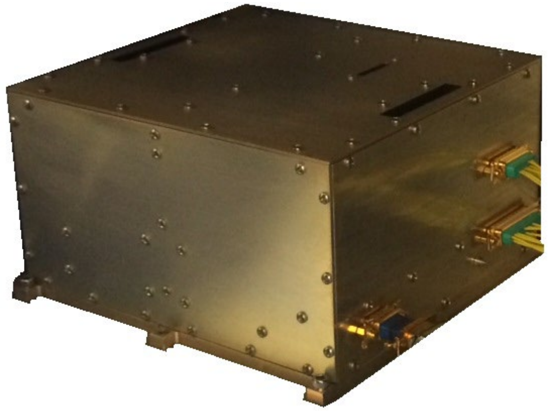
- **Comprised of boom-mounted fluxgate sensor head, cable assembly, and electronics unit**
- **Measures ULF and DC Magnetic field**
  - **0 – 8 Hz three-axis measurement at ±0.1 nT accuracy**
  - **±1° field direction accuracy**

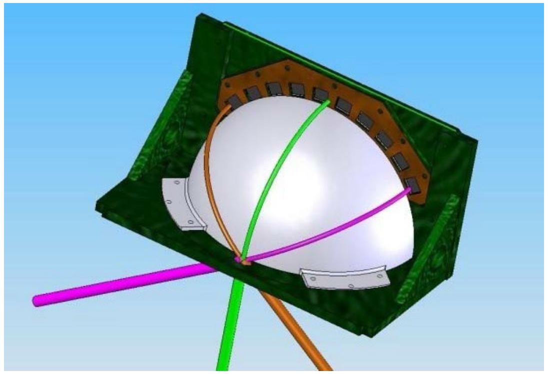


UCLA

# LEESA—Low Energy Electrostatic Analyzer

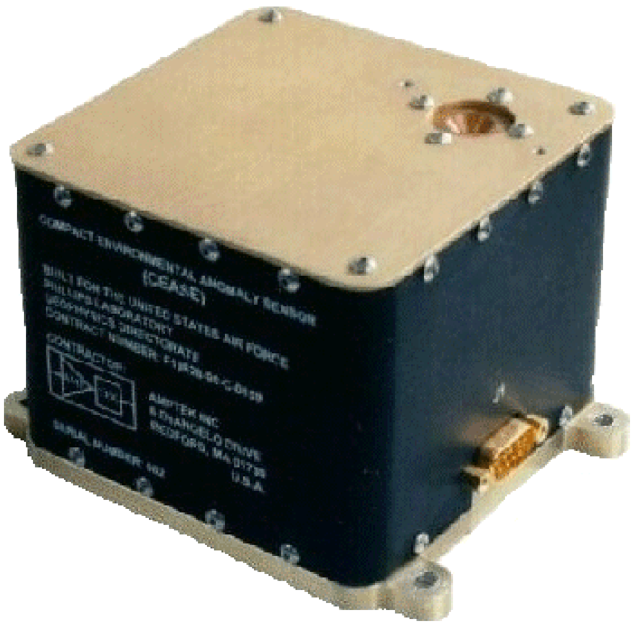
- Comprised of two pairs of concentric quarter spherical electrostatic analyzers, with voltage differences cycled to select particle energies
- Measures electron/ion fluxes for ~20 eV to 50 keV energies
  - 80 energies sampled per sweep from 256 choices of energy
  - Low energy limit in practice will 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





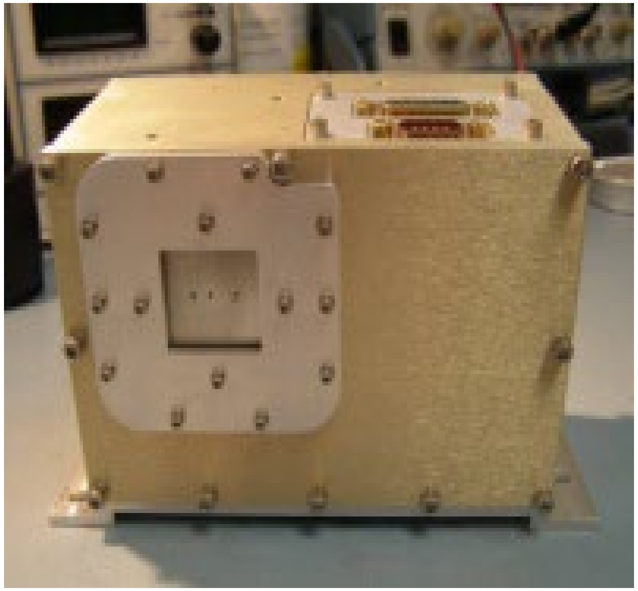
# CEASE—Compact Environment Anomaly SEnsor

- 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



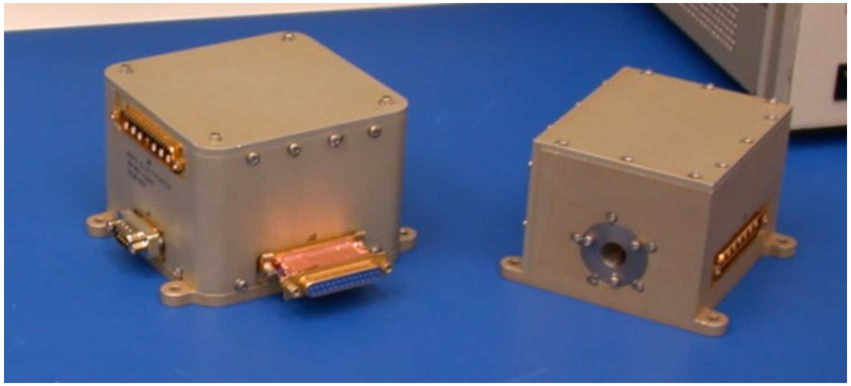
# HIPS—High Energy Imaging Particle Spectrometer

- **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**

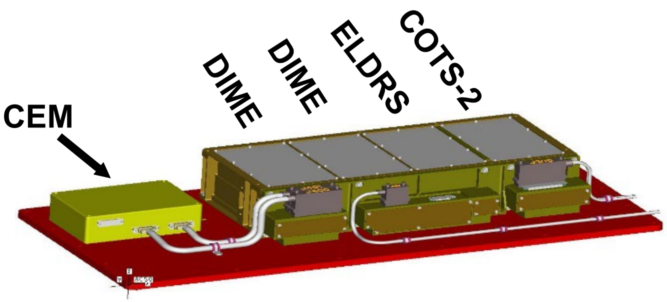
PSI

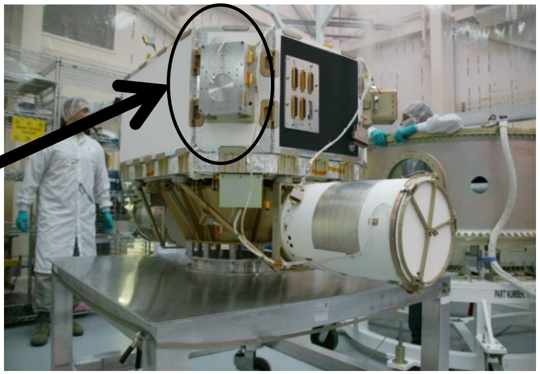
# HEPS—High Energy Particle Sensor

- 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



SET on DSX

**SET advances our understanding of on-orbit degradation**

## 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

Radiometer

Photometer

## 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

Provider: AFRL/RQ

# DSX-Van Allen Conjunctions

- Geographic conjunctions: ~15 within 2000 km through Dec 2018 (11-20)
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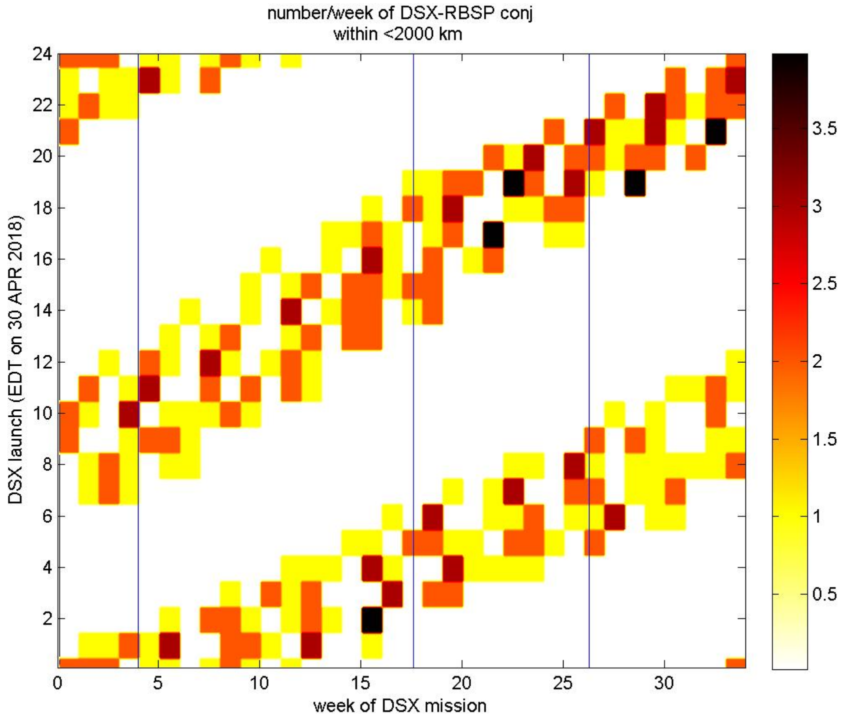
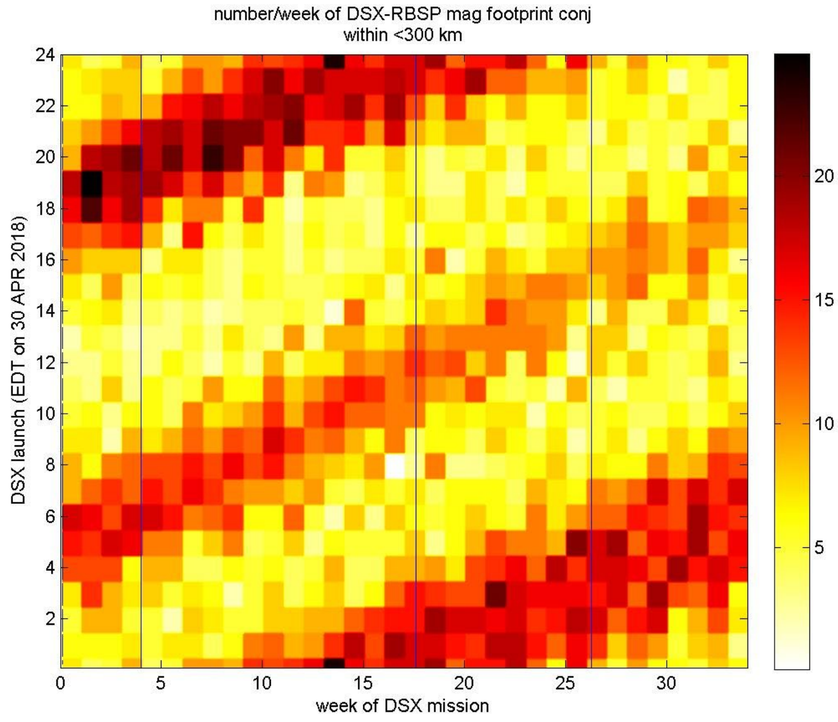
  - Same, during first 4 months: ~168 (82-279)

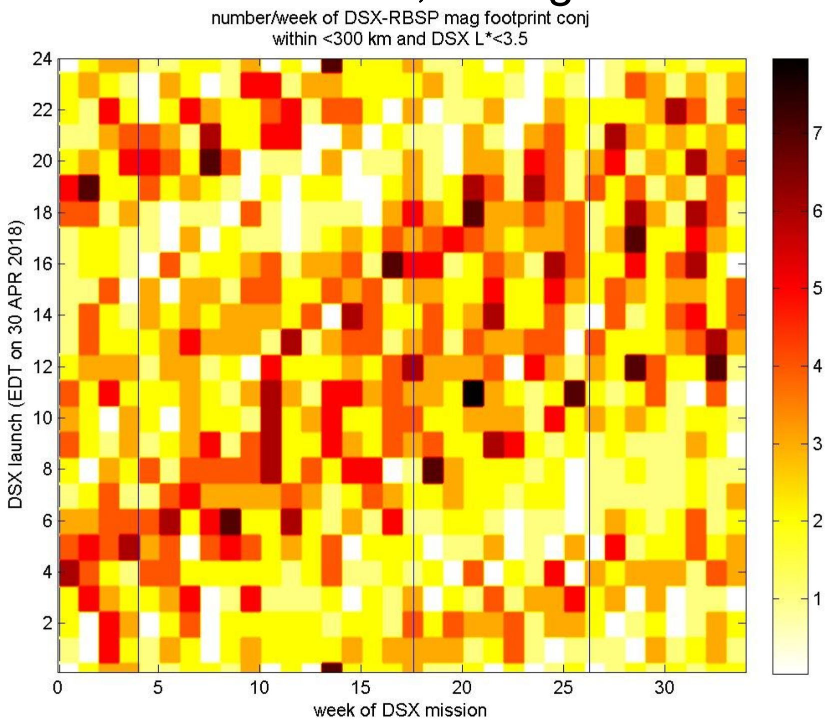


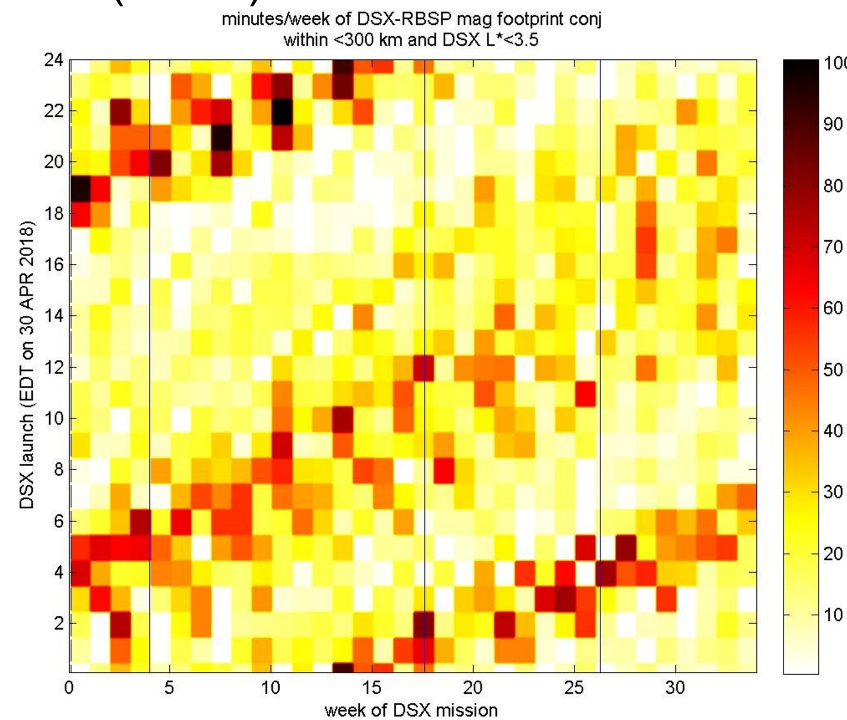




*(orientation of DSX orbit will not be known until launch)*

# DSX-Van Allen Tx Conjunctions

- Magnetic conjunctions at locations appropriate for high power transmissions (L*<3.5): ~82 for A+B with footprints within 300 km, through Dec 2018 (56-100)
  - Same, during first 4 months: ~45 (29-61)

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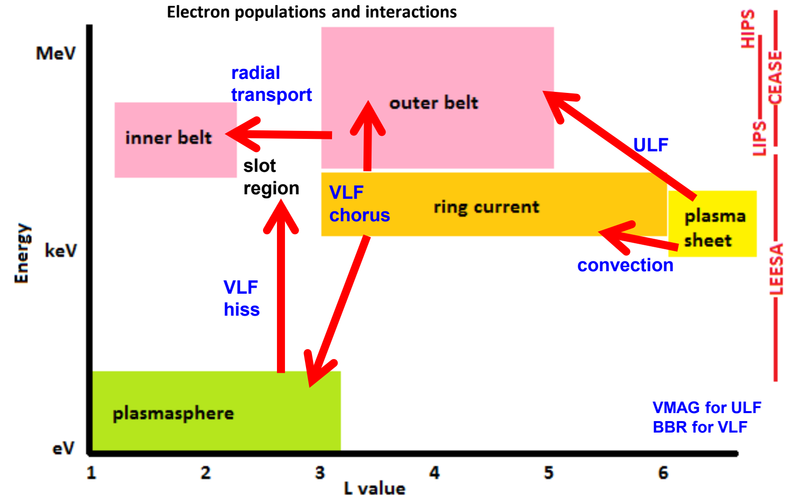
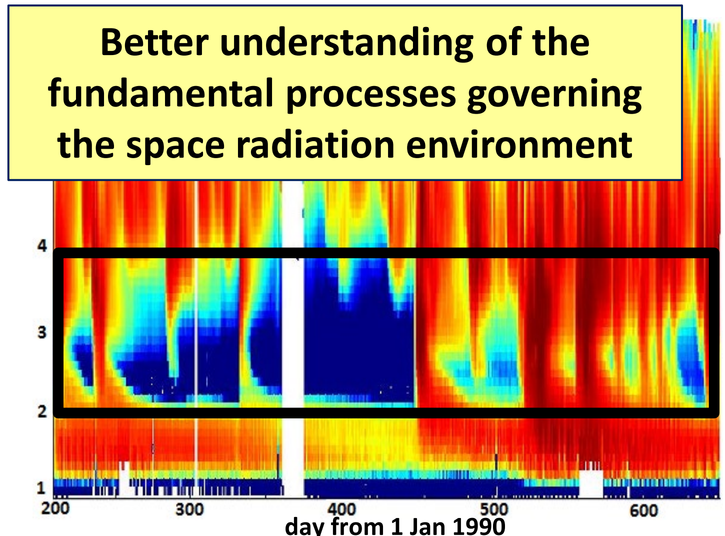
# Radiation Belt Dynamics

- **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**



# 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!**