The Demonstration and Science Experiments (DSX) mission: Nearly two years of active experiments in the radiation belts

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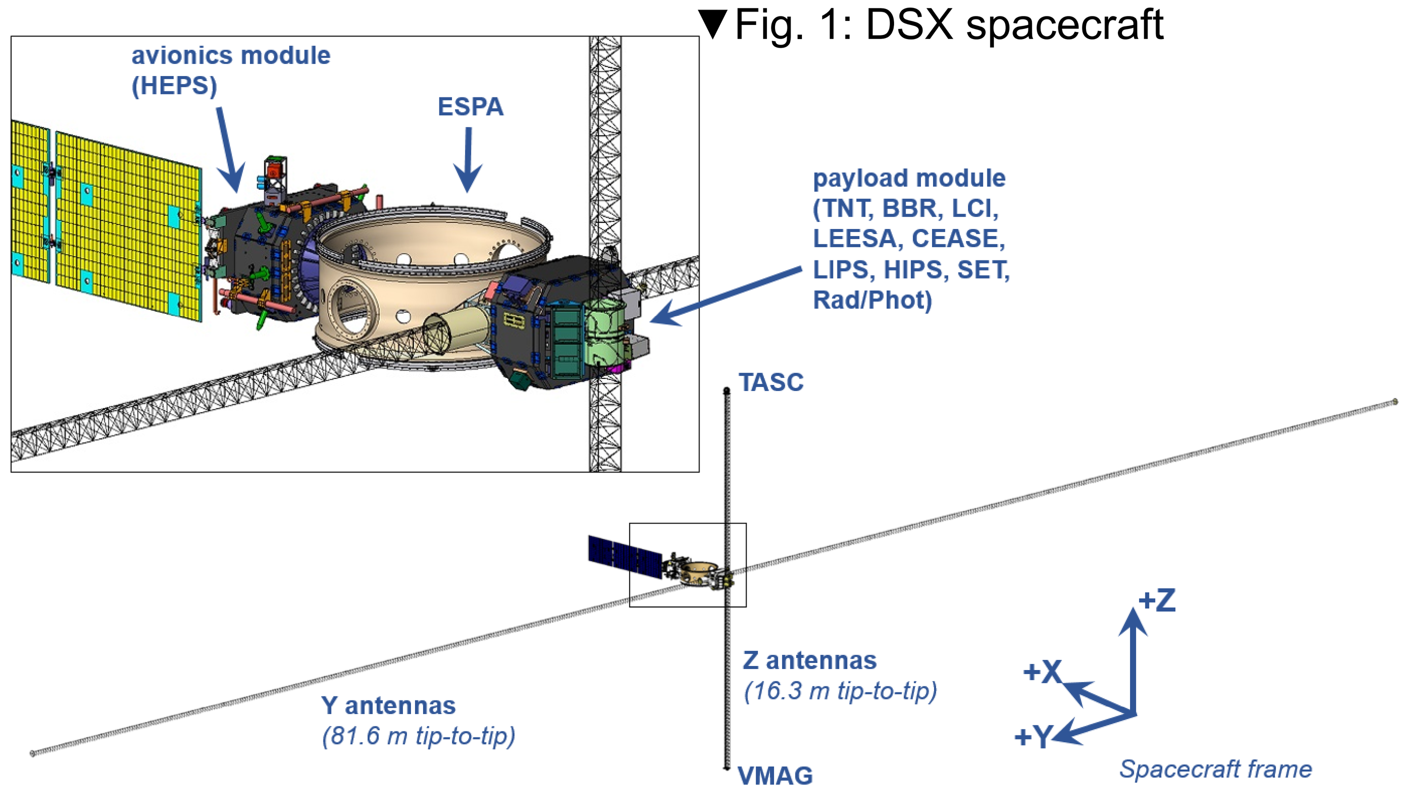
Abstract: The Air Force Research Laboratory's Demonstration and Science Experiments (DSX) mission investigated wave-particle interactions and the particle and space environment in Medium Earth Orbit (MEO) from June 2019 to May 2021. Its Wave-Particle Interactions Experiment (WPIx) conducted over 1,300 active high power VLF transmissions in the radiation belts providing observations of antenna performance and signal propagation from a controlled source in magnetospheric plasma. This included hundreds of transmissions while in magnetic conjunction with other satellites. The Loss Cone Imager (LCI) and Space Weather Experiment (SWx) suite observed electron and proton populations over a wide energy range. The Space Environmental Effects Experiment (SFx) investigated effects of the MEO environment on electronics and materials. The Adaptive Controls Experiment (ACE) demonstrated technology for on-board identification and control of large structure vibrational modes.

▼Fig. 1: DSX spacecraft



DSX Mission

DSX operated in a 6000 x 12000 km, 42 incl. orbit, 5.3 hr period from launch 25 June 2019 to passivation 31 May 2021. Experiment suite objectives:

- Wave Particle Interactions (WPIx)—transmit and measure waves and precipitating particles to understand VLF direct injection performance and diagnose effects. These active experiments explored antenna performance, plasma heating, and VLF propagation including observation of return signals to DSX.
- Space Weather (SWx)—measure distributions of protons and electrons to map the MEO environment and diagnose the environment for WPIx experiments.
- Space Effects (SFx)—advance our understanding of on-orbit degradation and directly measure changes due to MEO radiation environment. Included NASA's Space Environment Testbed (SET).
- Adaptive Controls Experiment (ACE)—demonstrated identification and control of large structure vibrational modes using the spacecraft attitude determination and control subsystem (Davis and Sinclair, 2020). In addition, the NASA/JPL Phaeton Mast Dynamics Central Assembly accelerometer measured DSX structural vibrations.

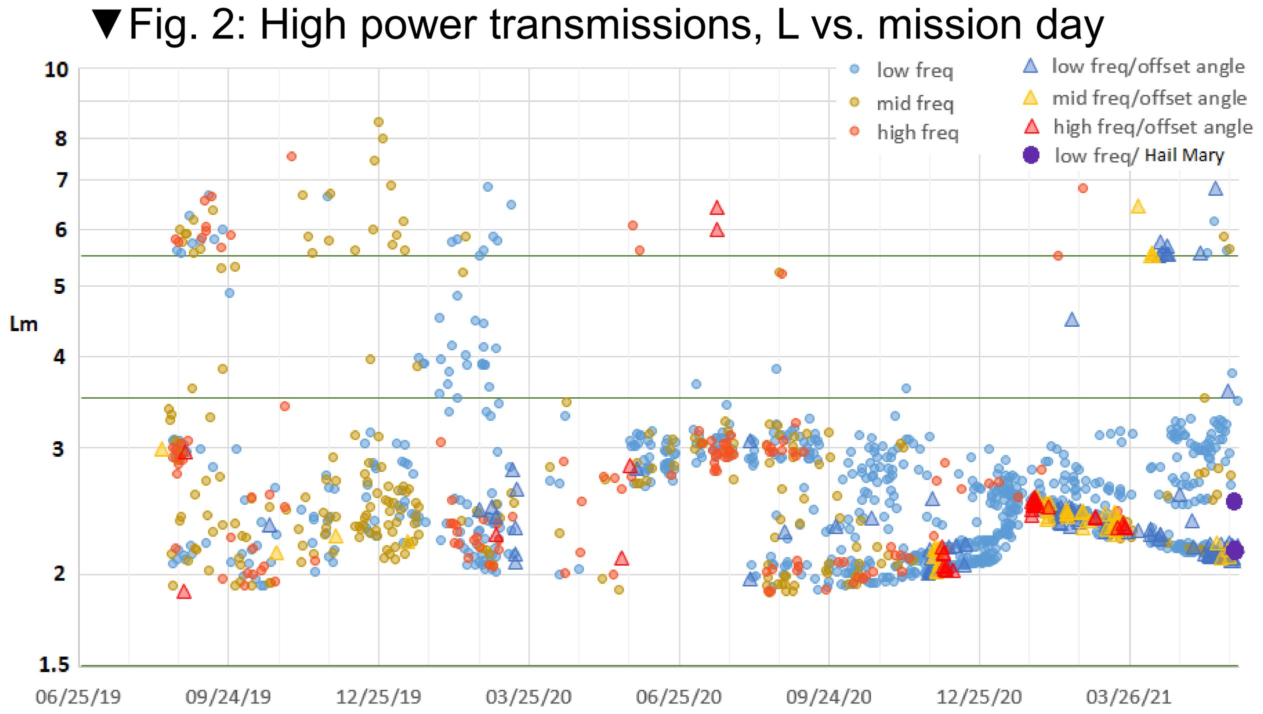
DSX Data Availability

- As DSX data complete quality control and calibration they will be available at NASA's Space Physics Data Facility.
- A detailed catalog of DSX transmit/receive DCEs has been released as a supplement to Johnston et al. (2022).
- Bibliography of DSX publications at https://www.vdl.afrl.af.mil/programs/ae9ap9/dsx_publications.php

DSX Wave Instruments

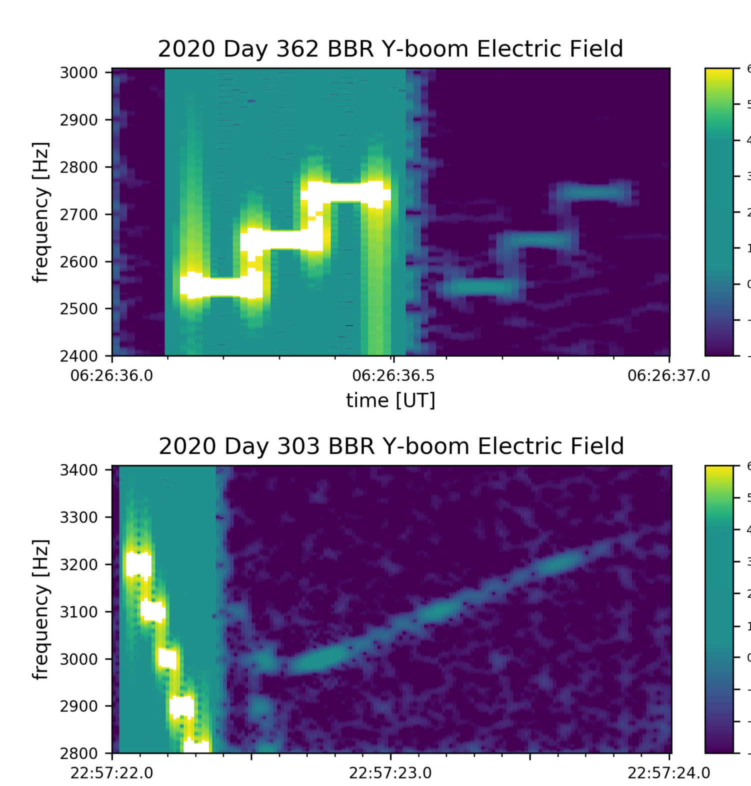
- Tuner Control Unit (TCU), NarrowBand Receiver (NBR), and Transmitter Amplifier and Tuner Unit (TATU), these collectively called TNT. The two TATU transmitters could operate at ~1 kW combined at 3-50 kHz for high power transmissions or <1 W at 50-750 kHz for relaxation sounding mode. NBR receiver covered 3-750 kHz. TNT used the 81 m Y-boom antennae for transmissions.
- Tuned transmissions were at low (1.4-8.5 kHz), medium (6.6-23.4 kHz), or high (10.6-39.4 kHz) frequency while fixed frequency transmissions were at chosen frequencies in the 2.8-28 kHz range.
- Tri-Axial Search Coil (TASC) magnetometer measured vector magnetic field at 0.1-50 kHz.
- BroadBand Receiver (BBR) processed signals from the Z-boom antenna, the Y-boom antenna via TNT, and TASC.
- Vector Magnetometer (VMAG) measured the vector magnetic field from 100-10^4 nT over 0-10 Hz.

▼Fig. 2: High power transmissions, L vs. mission day



DSX Experiments

- Science activities were planned as data collection events (DCEs) with distinct instrument settings and spacecraft attitude modes.
- High power VLF transmission DCEs typically occurred near the magnetic equator (hence L~2-3) with 5-40 min duration. Some were conducted at other locations—including DCEs in magnetic conjunction with other missions.
- Spacecraft attitude was 3-axis stabilized, generally with Y-antenna perpendicular to the magnetic field for transmissions and otherwise +Y axis pointing sunward for power collection.



▲Fig. 3: BBR spectrograms of 2 DCEs showing DSX transmitted pulses and return signals. Y-antenna E-field signal is color mapped; white shows saturated signals during pulse transmission. Top: a 3-step pulse transmission on 27 Dec 2020 followed by detection of "boomerang echoes", signals received back to DSX following remote reflection. Bottom: a 5-step pulse transmission on 29 Oct 2020 followed by typical boomerang echoes near 22:57:22.5 UT, then a triggered emission of rising frequency at 22:57:22.7-23.8 UT.

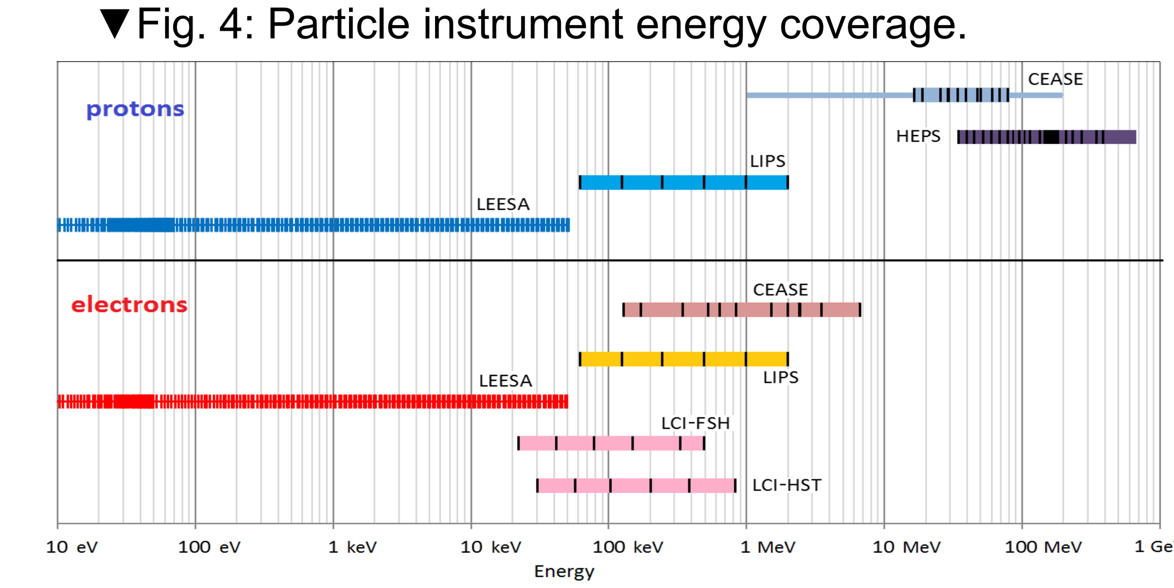
DSX Wave Experiment Results

- 1338 high-power transmissions were completed (Fig. 2) including 315 in magnetic conjunction with other missions including VPM (VLF Propagation Mapper), Arase, Van Allen Probes A, FIREBIRD-4, CASSIOPE, POES/METOP, and a BARREL balloon flight in early 2020.
- Passive wave collection occurred otherwise, including 159 receive DCEs in magnetic conjunction with ground transmitters.
- Experimental results for antenna impedances and radiated power have been compared to cold-plasma EM wave propagation models (Tu et al., 2022; Song et al., 2022). Return signals following transmissions exhibit a range of features, e.g. normal boomerangs or triggered emissions (Fig. 3).
- DSX VLF signals were observed by Arase (McCollough et al., 2022).
- Passive observations of quasi-periodic VLF emissions have revealed novel features (Farrell et al., 2022).

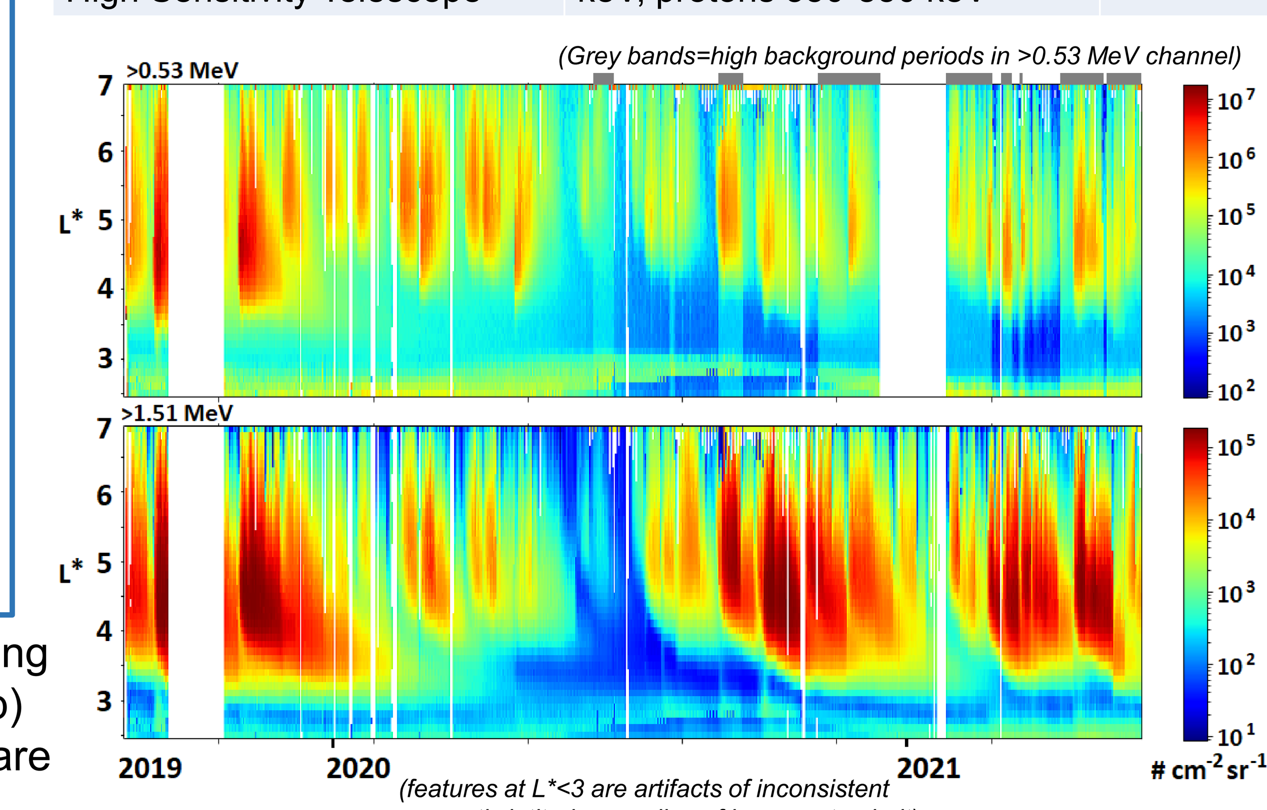
DSX Particle instruments

SWx payloads plus LCI (part of WPIx) observed particles from electron/ion plasma to relativistic electrons/protons (Fig. 4).

▼Fig. 4: Particle instrument energy coverage.



Instrument	Description	Data
CEASE = Compact Environmental Anomaly Sensor	telescope + 2 dosimeters, electrons >0.13 to >3.5 MeV, protons >16 to >79 MeV	552 days
LEESA = Low Energy ElectroStatic Analyzer	programmable ESA, 5 pixels, electrons + ions ~30 eV-30 keV	424 days
LIPS = Low energy Imaging Particle Spectrometer	8 scintillator pixels, electrons + protons 60 keV to >2 MeV	559 days
HEPS = High Energy Particle Sensor	Telescope, protons 20-440 MeV	408 days
LCI-FSH = Loss Cone Imager-Fixed Sensor Head	3 pixelated telescopes, 6 pixels each, electrons 30-550 keV	<387 days
LCI-HST = Loss Cone Imager-High Sensitivity Telescope	Telescope, electrons 30-850 keV, protons 350-850 keV	<54 days



►Fig. 5: CEASE electron flux data vs. time and L* during DSX mission for >0.53 MeV (telescope channel 04, top) and >1.51 MeV (dosimeter channel 07, bottom). Data are averaged in bins of 1 day and 0.1 in L*.

Published DSX results

Johnston et al. (2022), *JGR-Sp. Phys.*, 2022JA030771, in press (with DCE catalog supplement)
Farrell et al. (2022), *JGR-Sp. Phys.*, 127:e2022JA030327
Tu et al. (2022), *JGR-Sp. Phys.*, 2022JA030564, in press
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