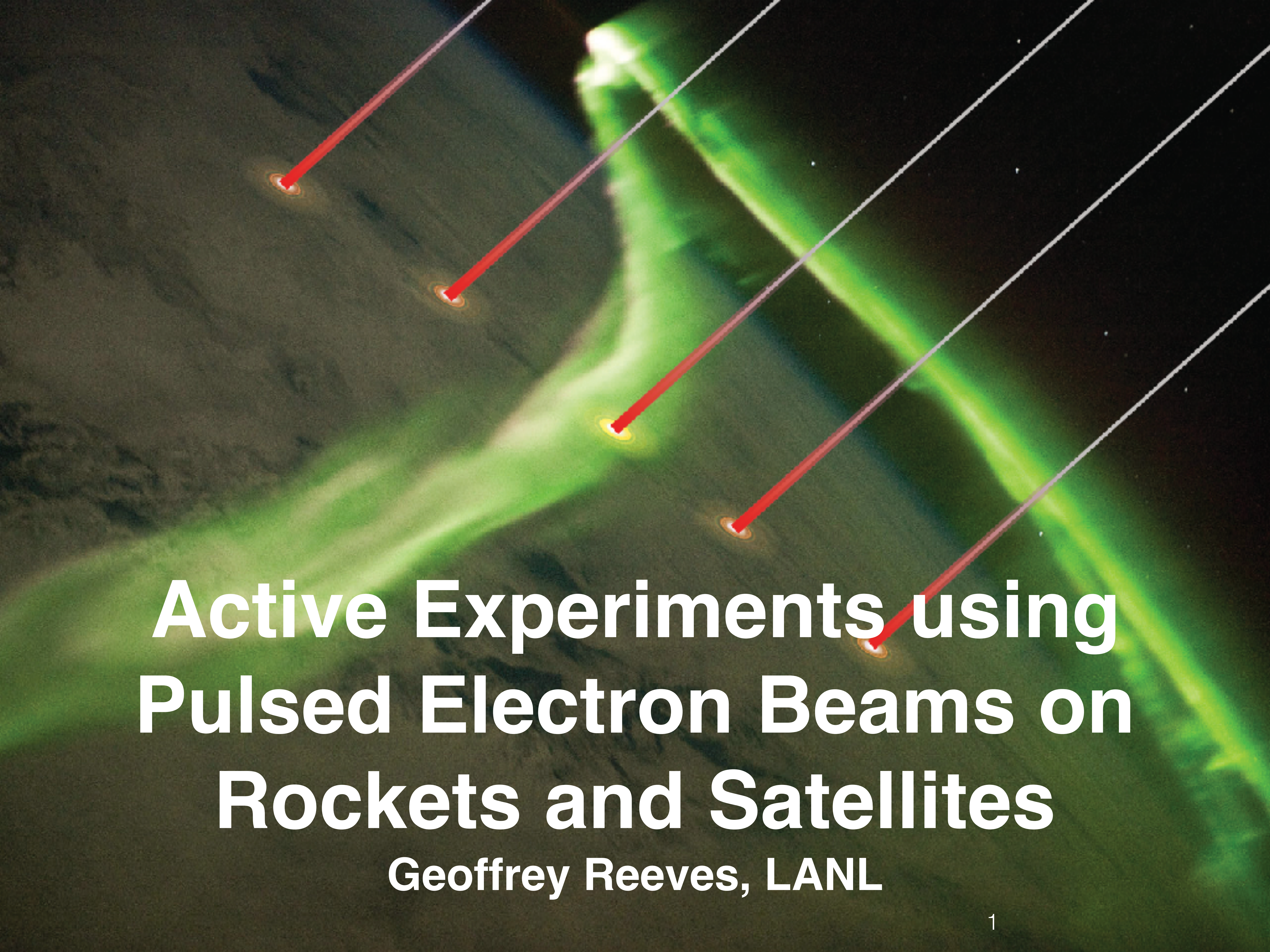


Active Experiments using Pulsed Electron Beams on Rockets and Satellites

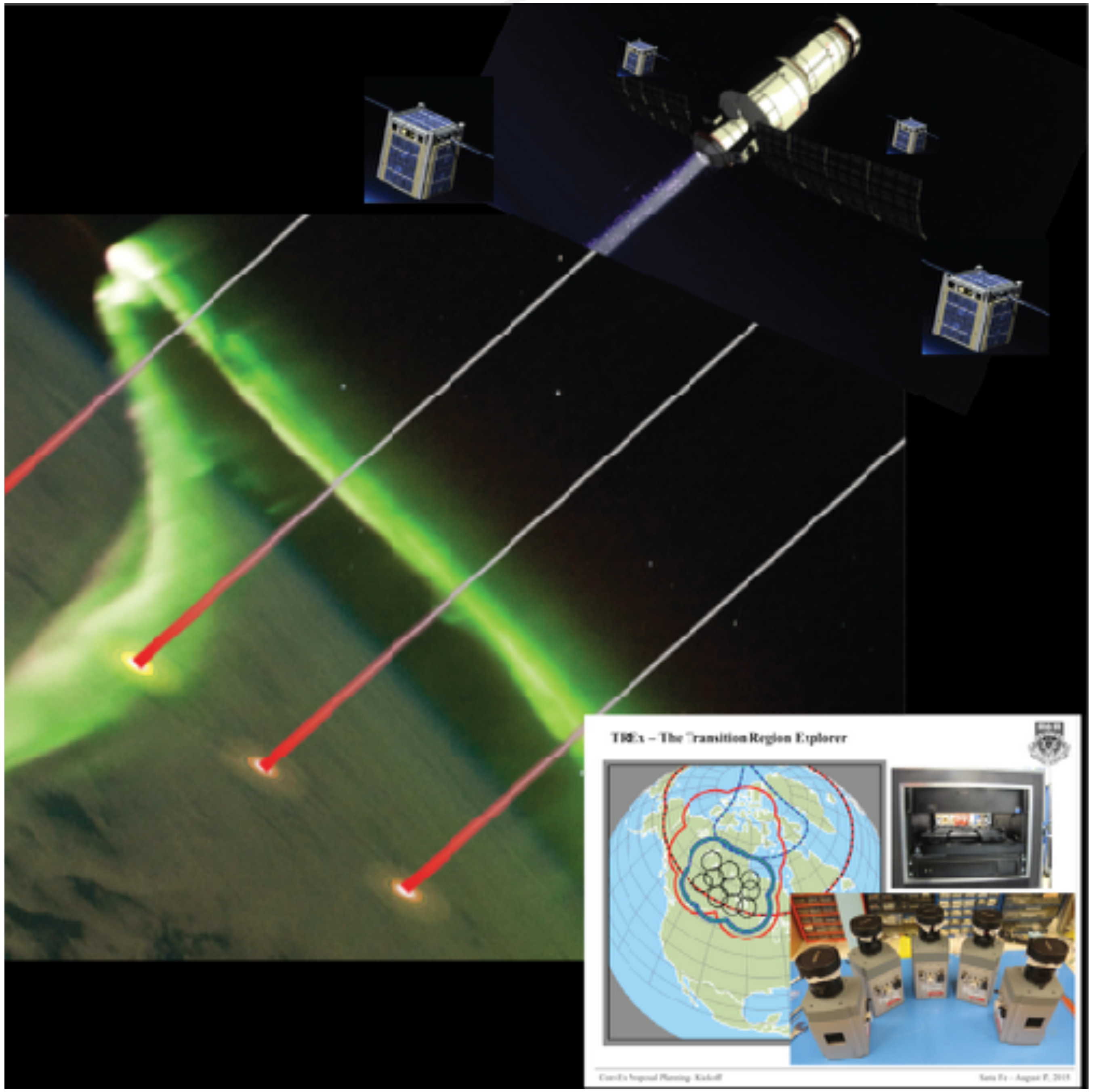
Geoffrey Reeves, LANL

Beams have been used, successfully, for many active space experiments

- **Spacecraft Charging**: e.g. Mullen et al., 1986; Sasaki et al., 1986; 1988; Banks et al., 1990
- **Beam-Plasma Interaction Physics**: e.g. Gendrin, 1974; Cambou et al., 1978; Cambou et al., 1980
- **Magnetic Bounce and Drift Physics**: e.g. Hendrickson et al., 1975; Winckler et al., 1975; Hendrickson et al., 1976
- **VLF Wave Generation**: e.g. Monson et al., 1976; Dechambre et al., 1980; Obayashi et al., 1982; Farrell et al., 1988; Reeves et al., 1988; Reeves et al., 1990a; Reeves et al., 1990b
- **National Security Applications**: e.g. the BEAR Rocket

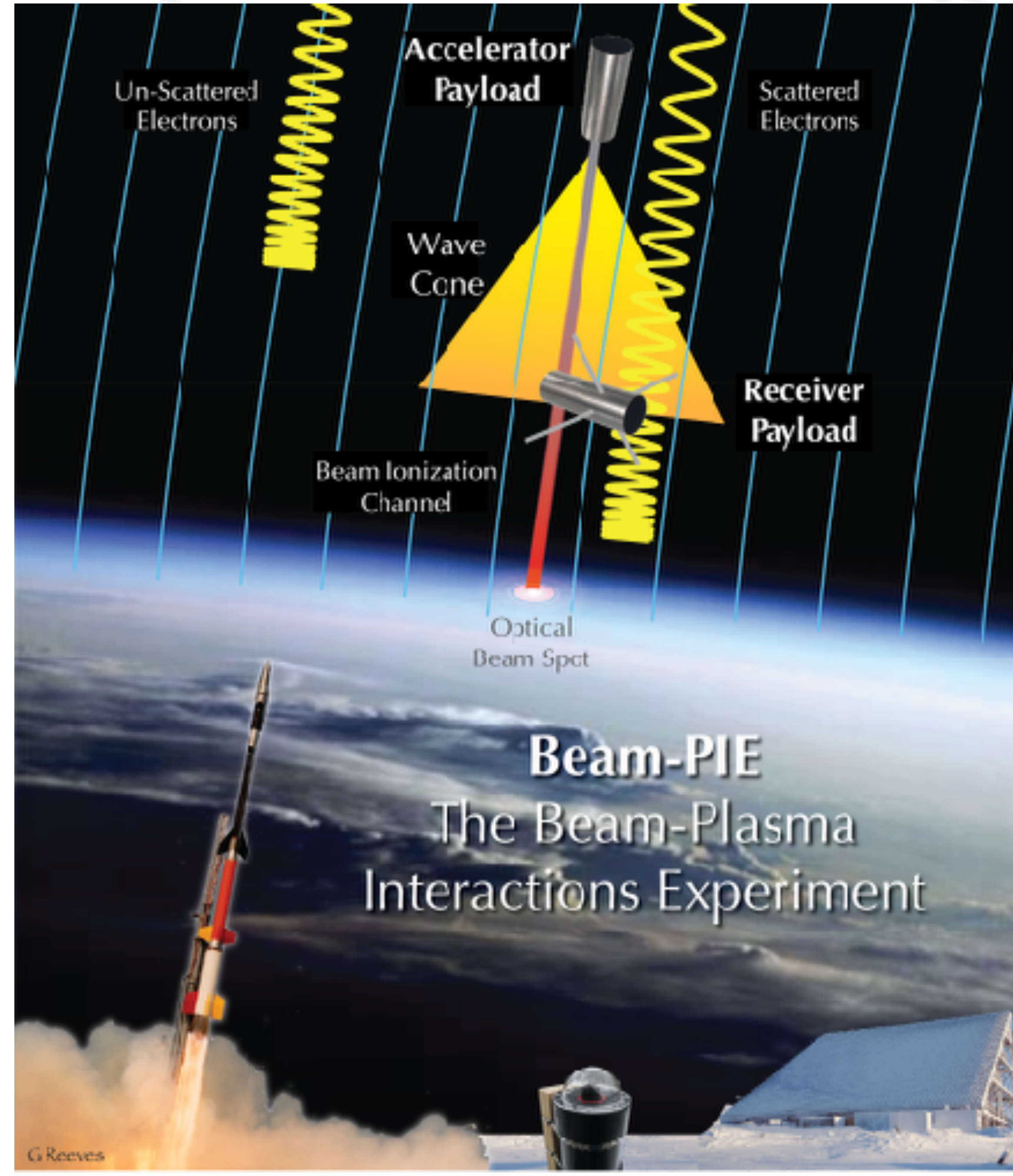
CONNEX

Magnetosphere-Ionosphere Connections Explorer



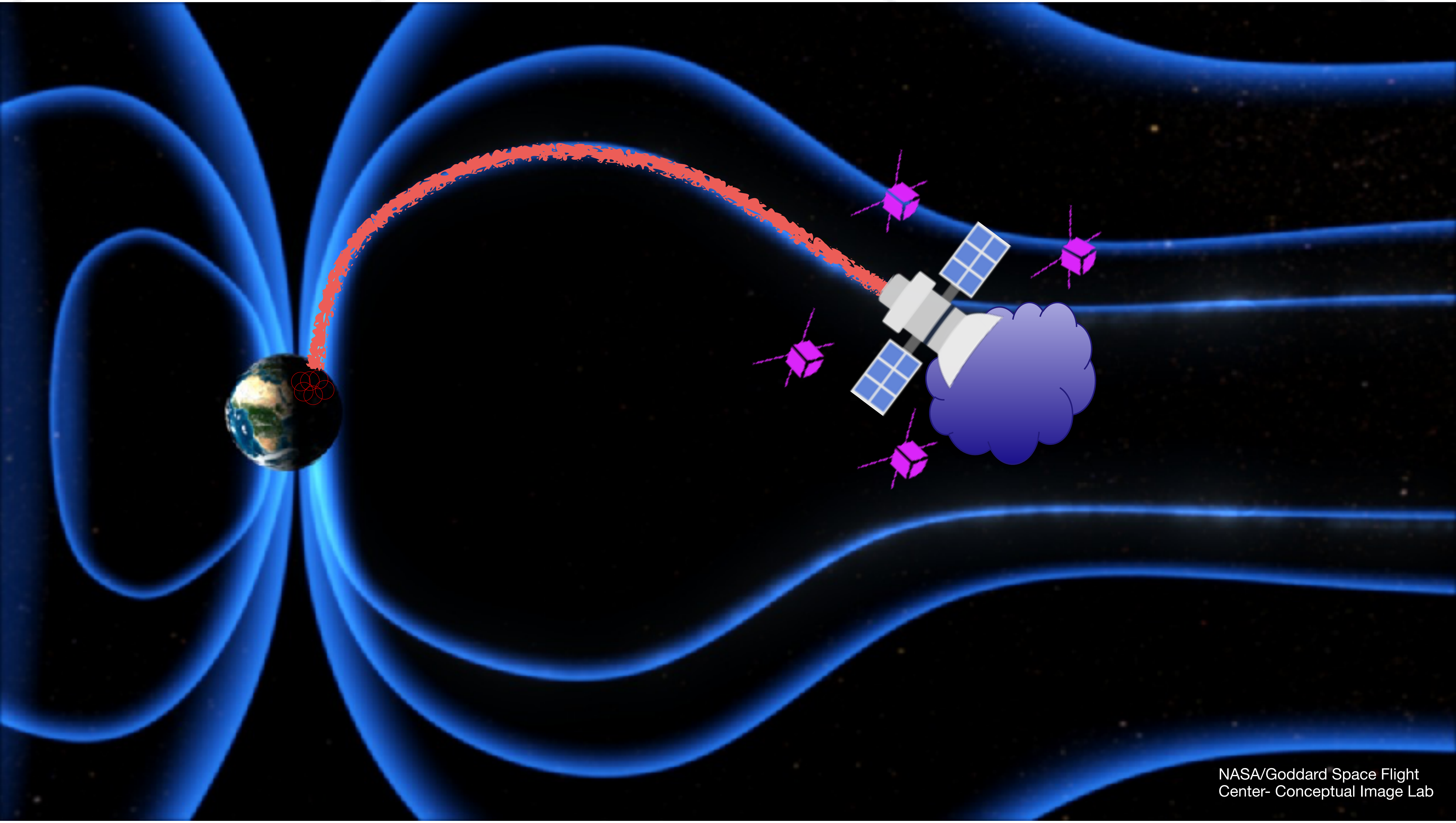
Beam PIE

Beam-Plasma Interactions Experiment

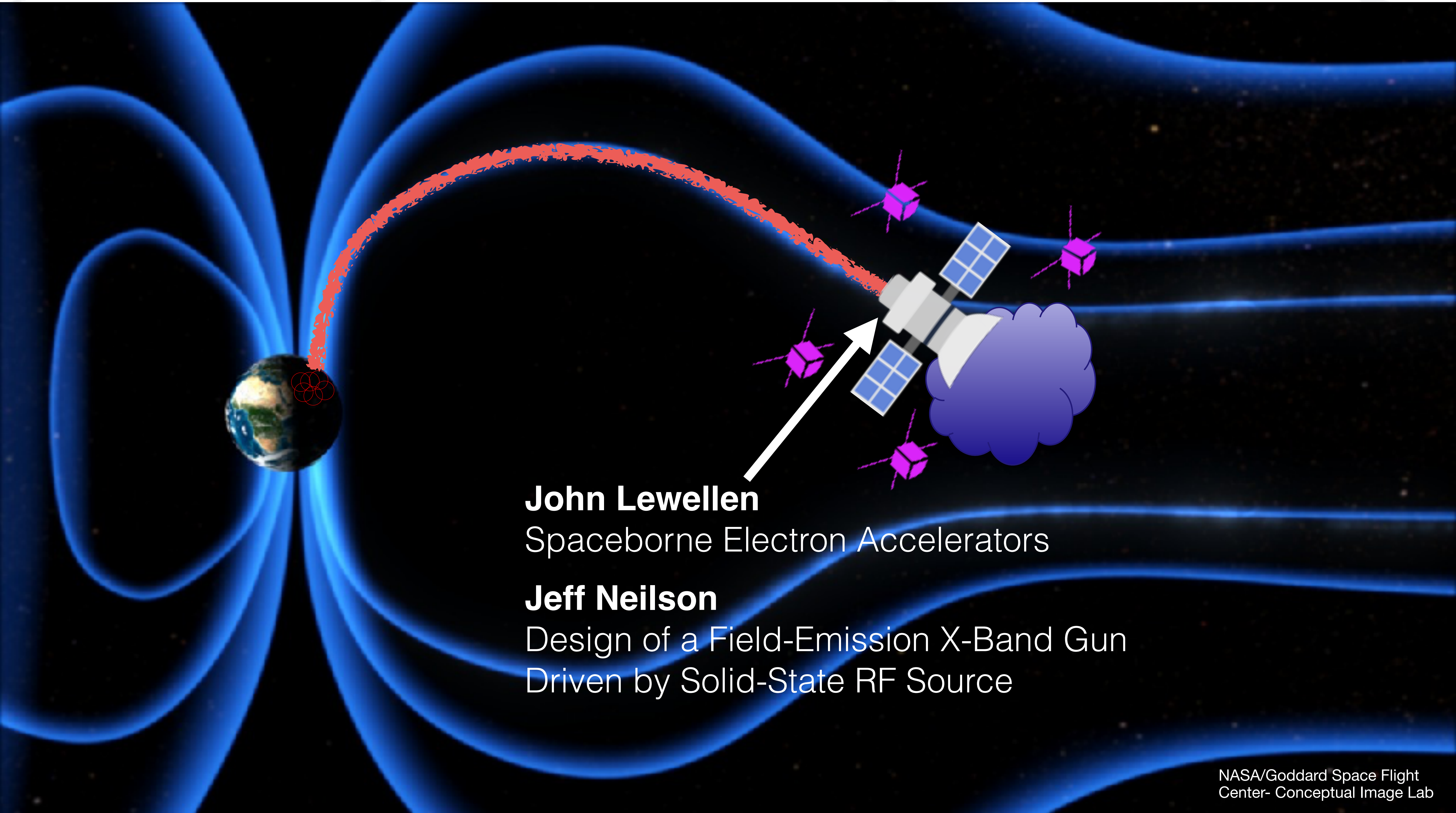


CONNEX

Magnetosphere-Ionosphere Connections Explorer



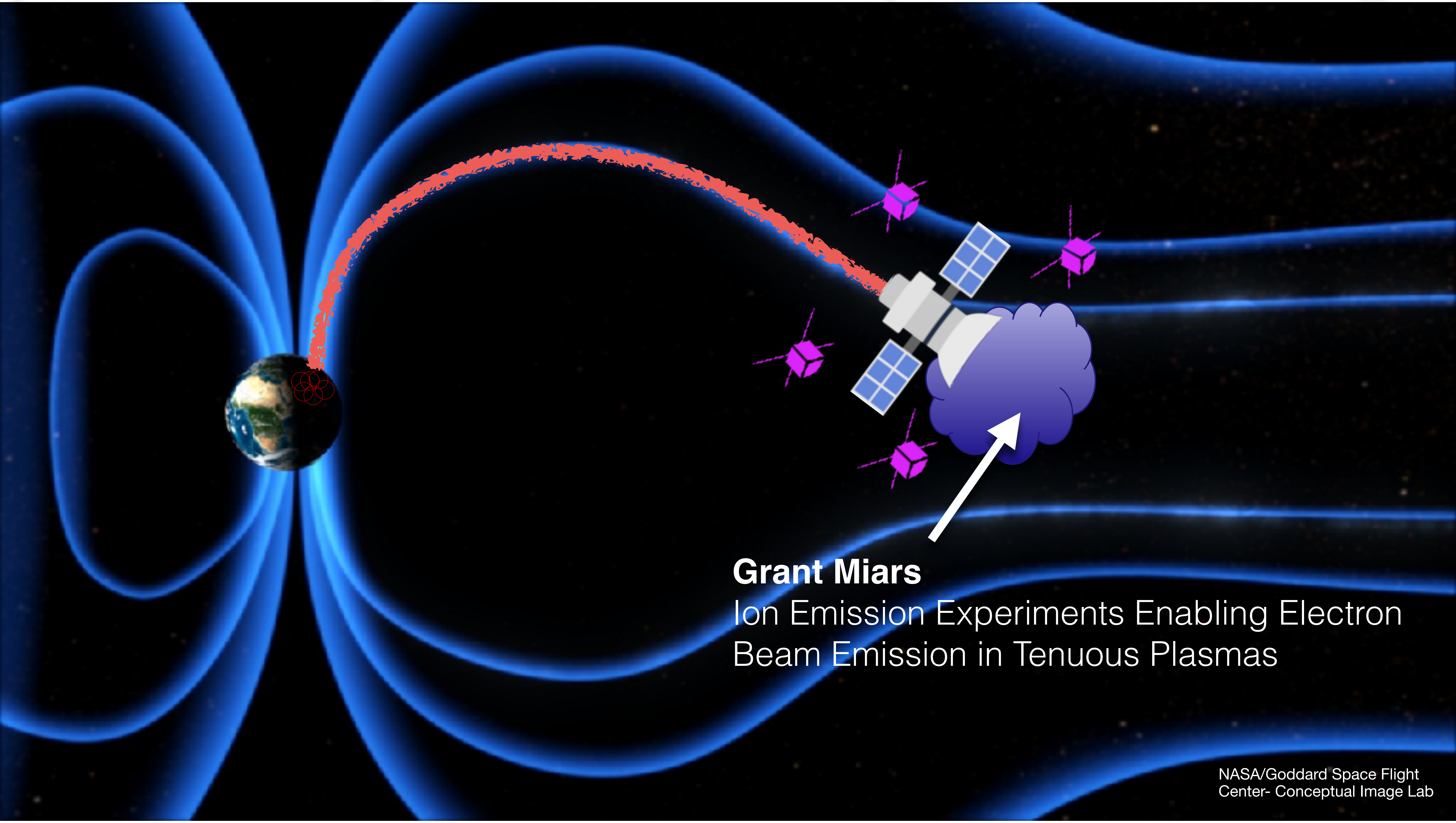
Relativistic Electron Accelerator Technologies



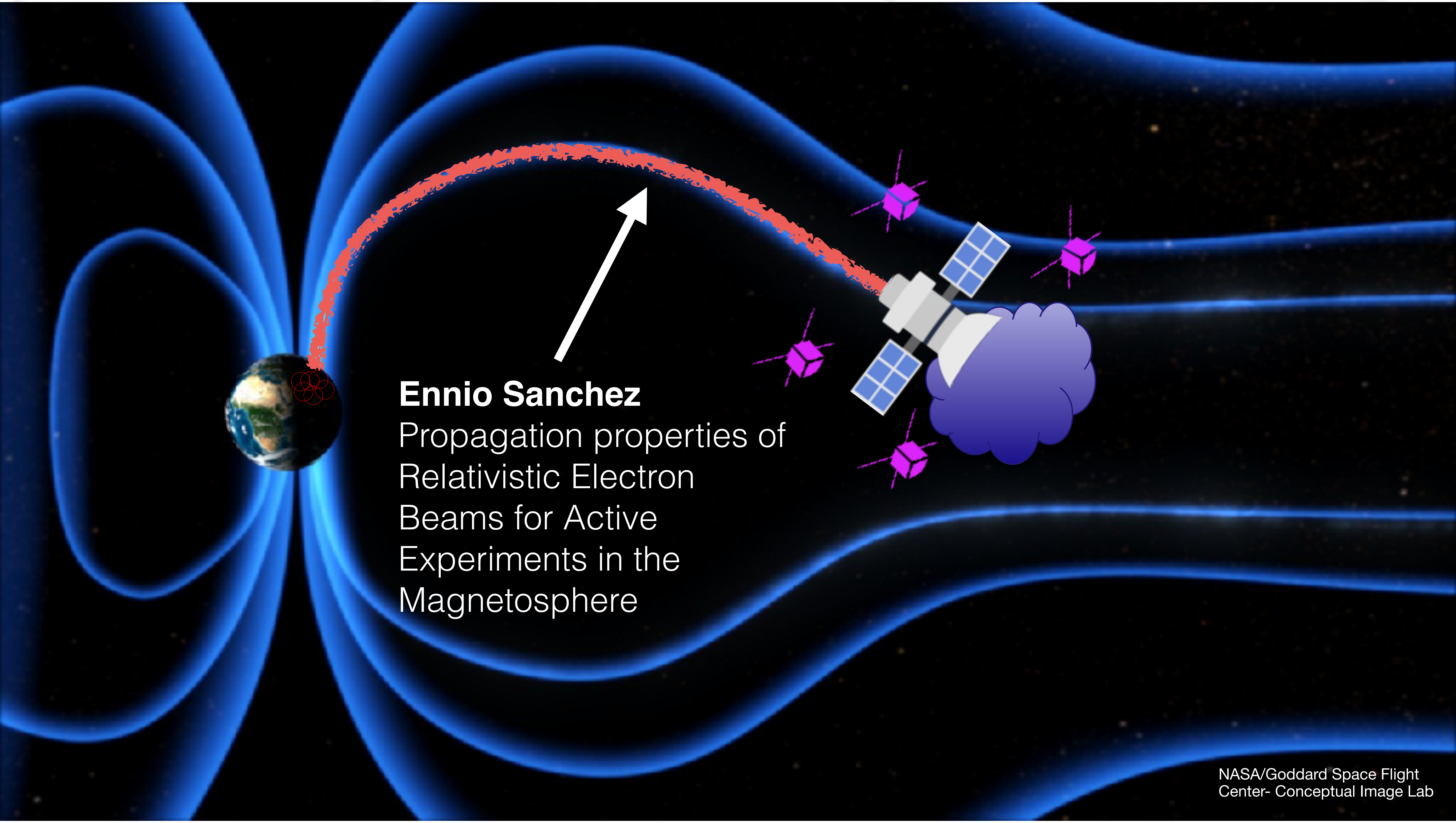
John Lewellen
Spaceborne Electron Accelerators

Jeff Neilson
Design of a Field-Emission X-Band Gun
Driven by Solid-State RF Source

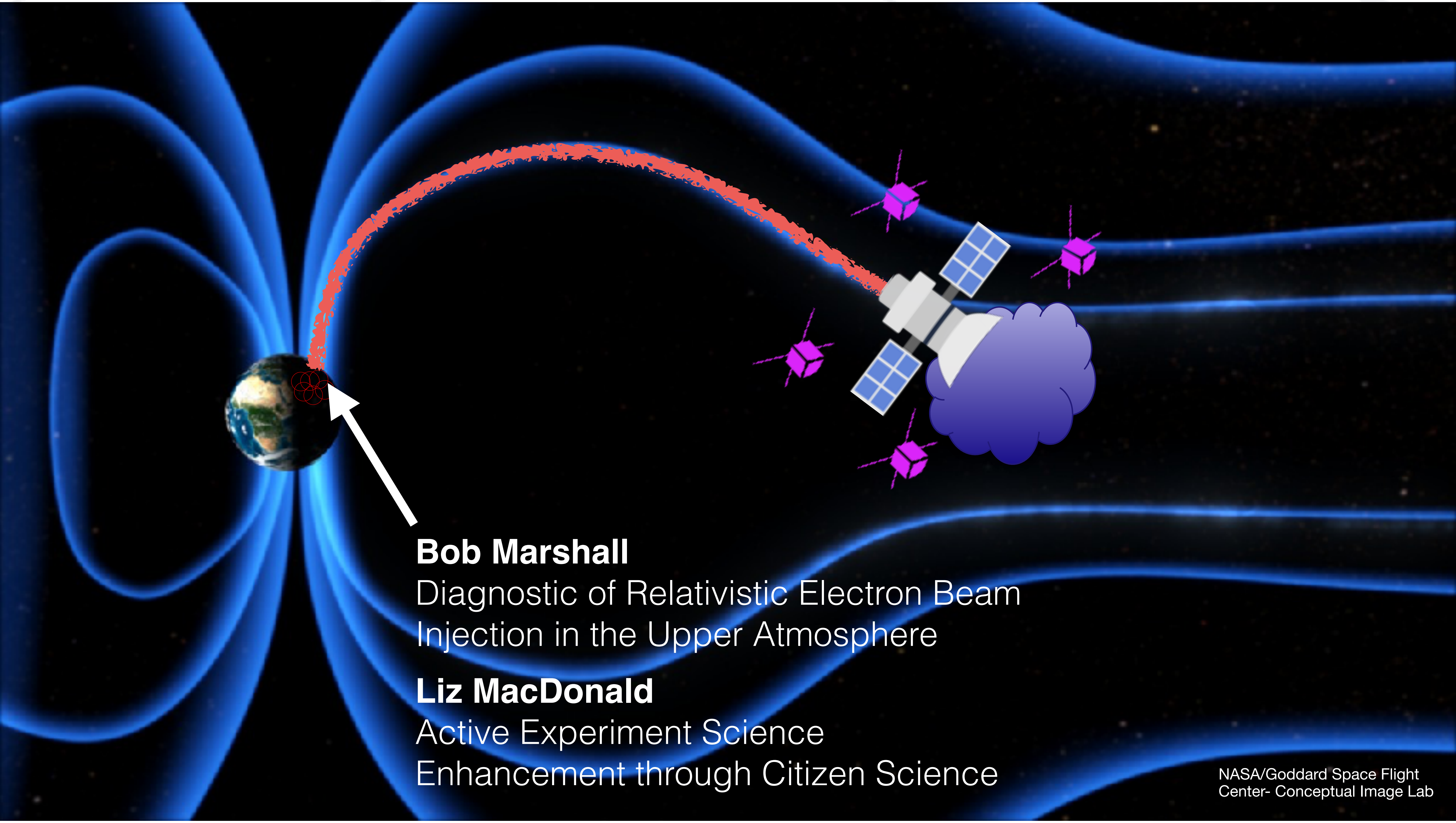
Spacecraft Charging Mitigation



Beam Propagation & Beam Stability



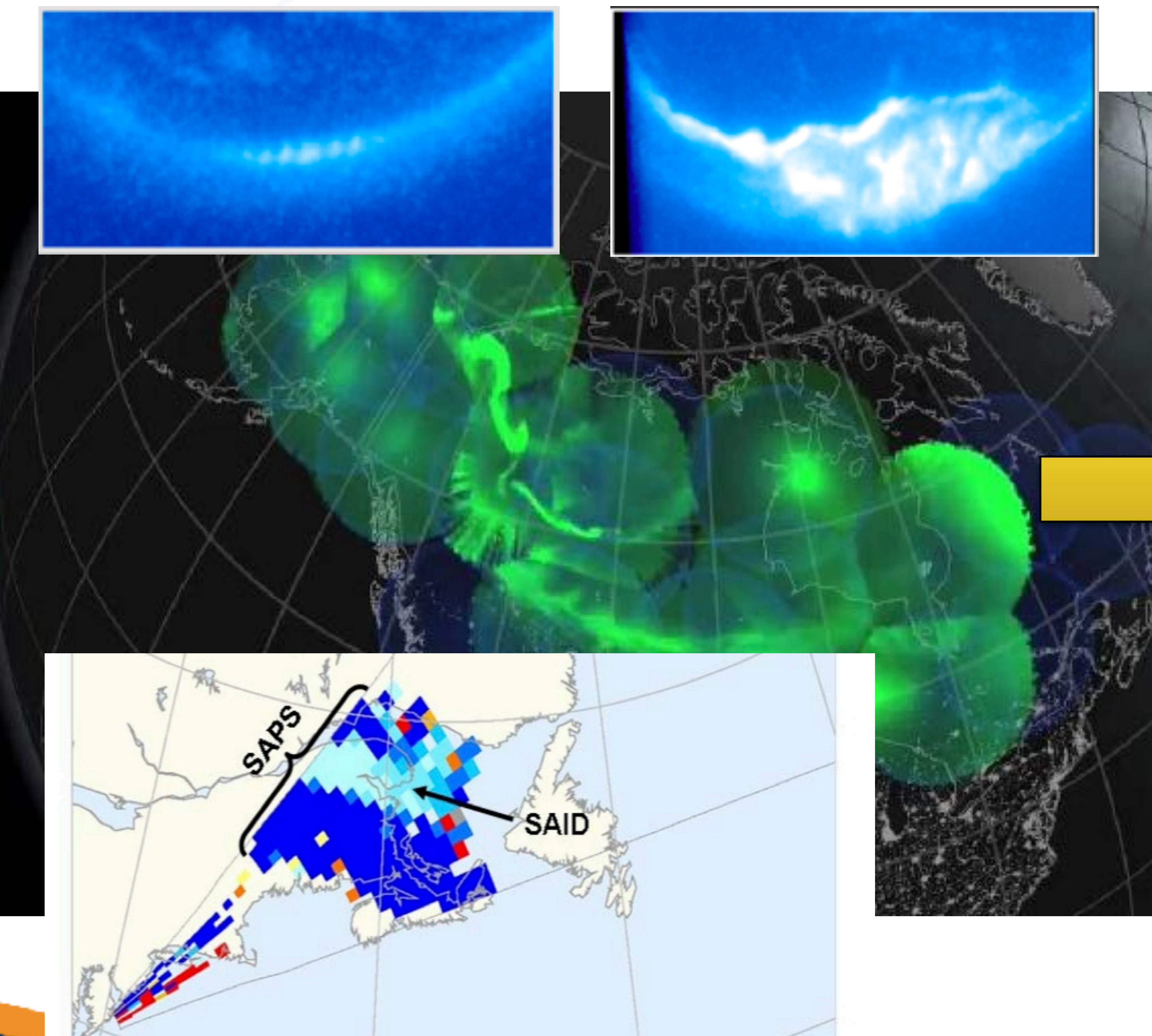
Beam Detection & Footpoint Identification



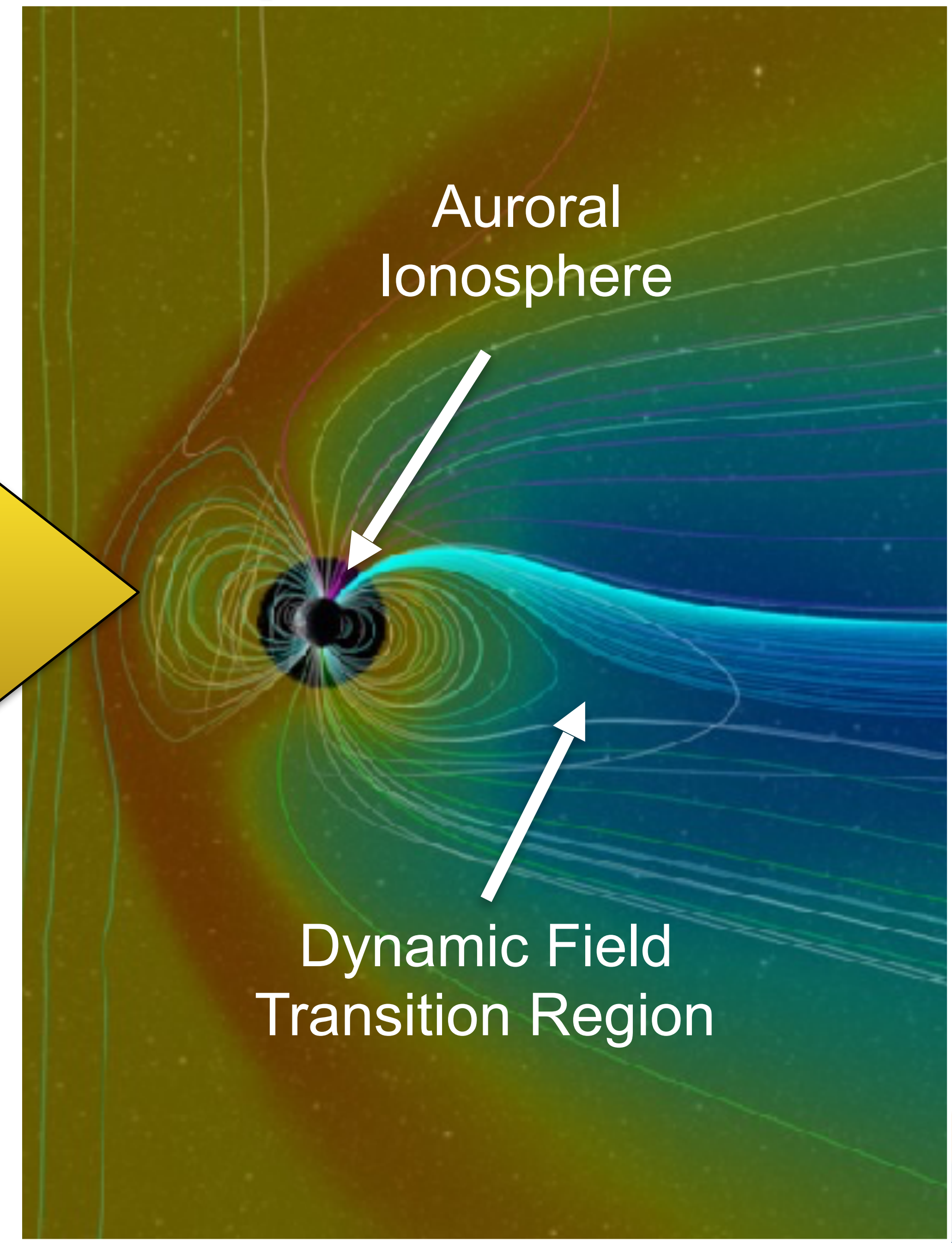
The ultimate objective of CONNEX is not to operate an electron beam

CONNEX will enable resolution of important, long-standing problems in understanding magnetosphere-ionosphere coupling

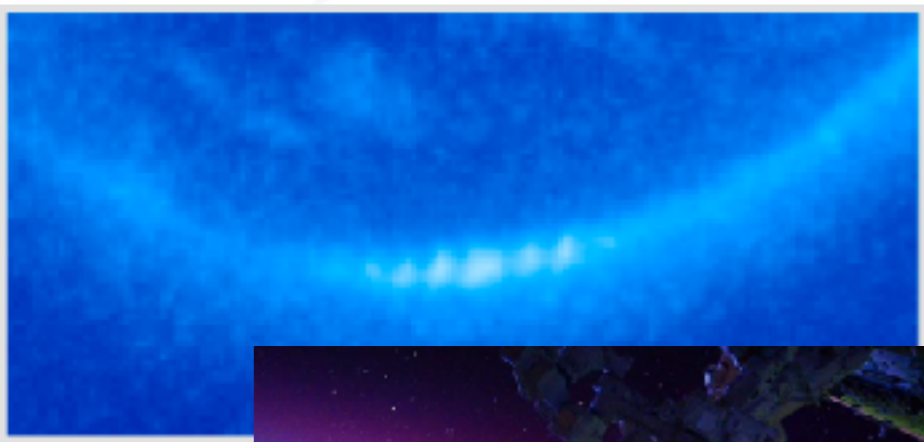
What are the magnetospheric processes and conditions that drive various types auroral & ionospheric activity

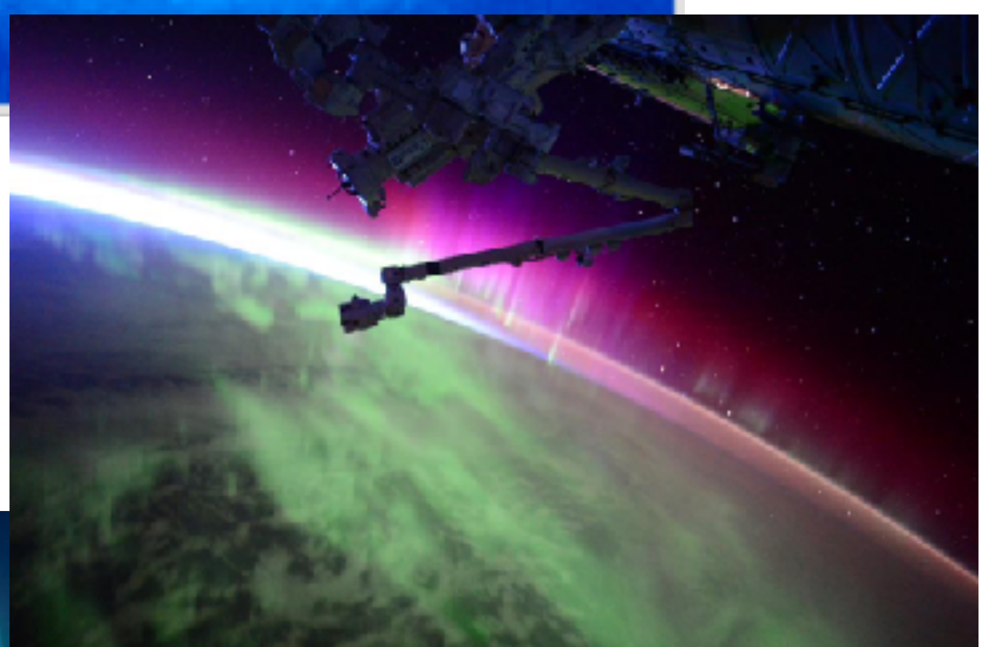


Two-Dimensional Image of Sub Auroral Ion Drifts (SAID) within the Sub Auroral Polarization Stream (SAPS).



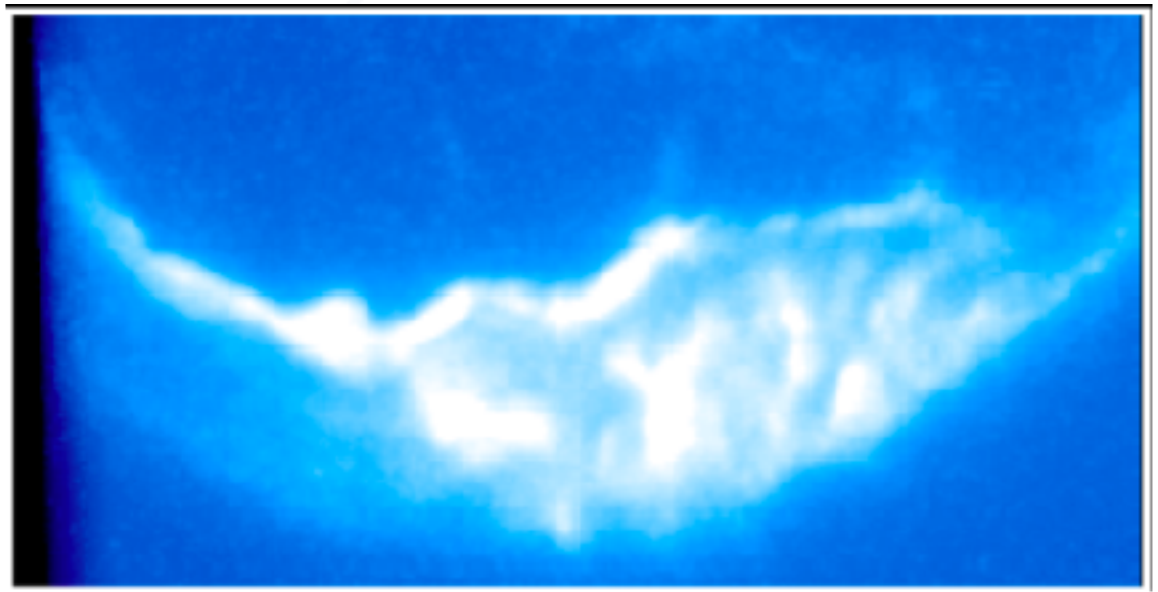
“Quiet” & “Normal” Conditions

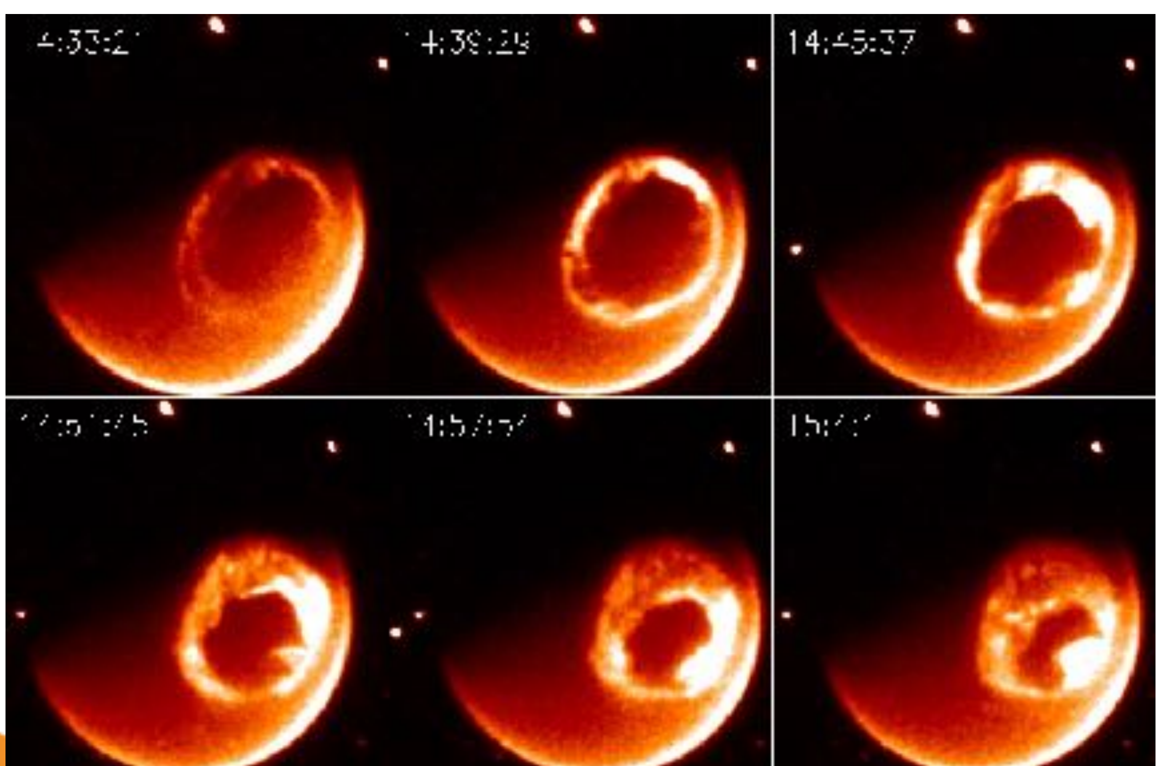




- Quiet time Auroral Arcs
- Growth Phase Arcs
- Onset Arc
- Auroral Beading
- Proton Arcs
- Poleward expansion & Westward traveling surge
- Rays & Folding
- ETC!

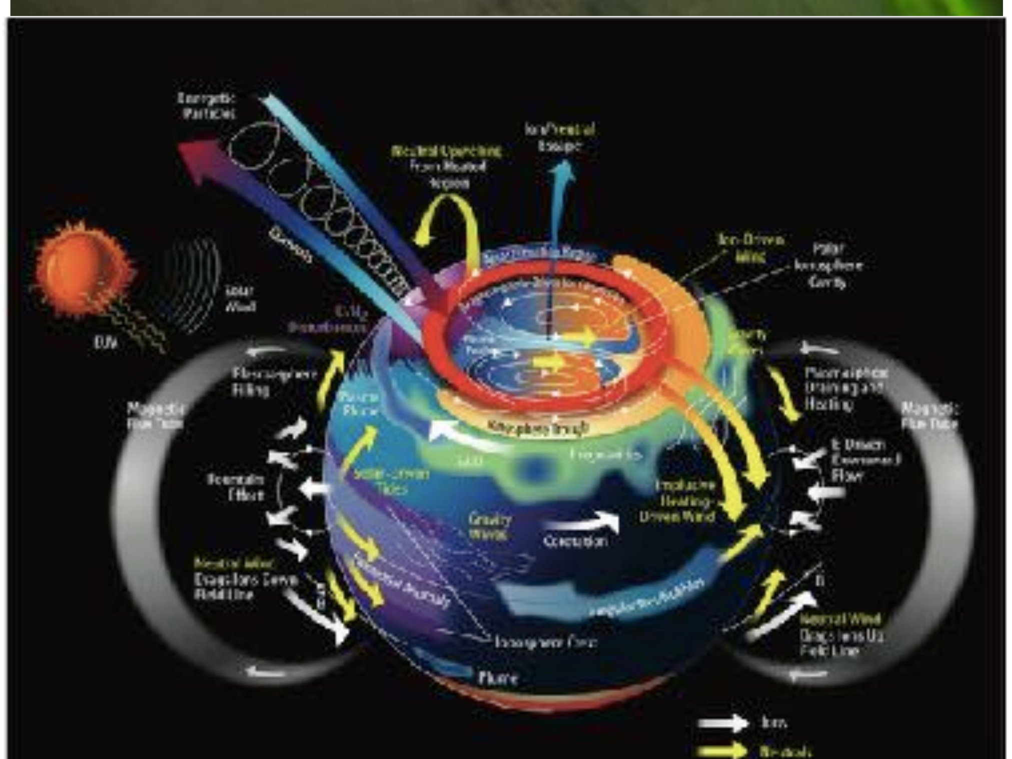
Active and Storm Conditions

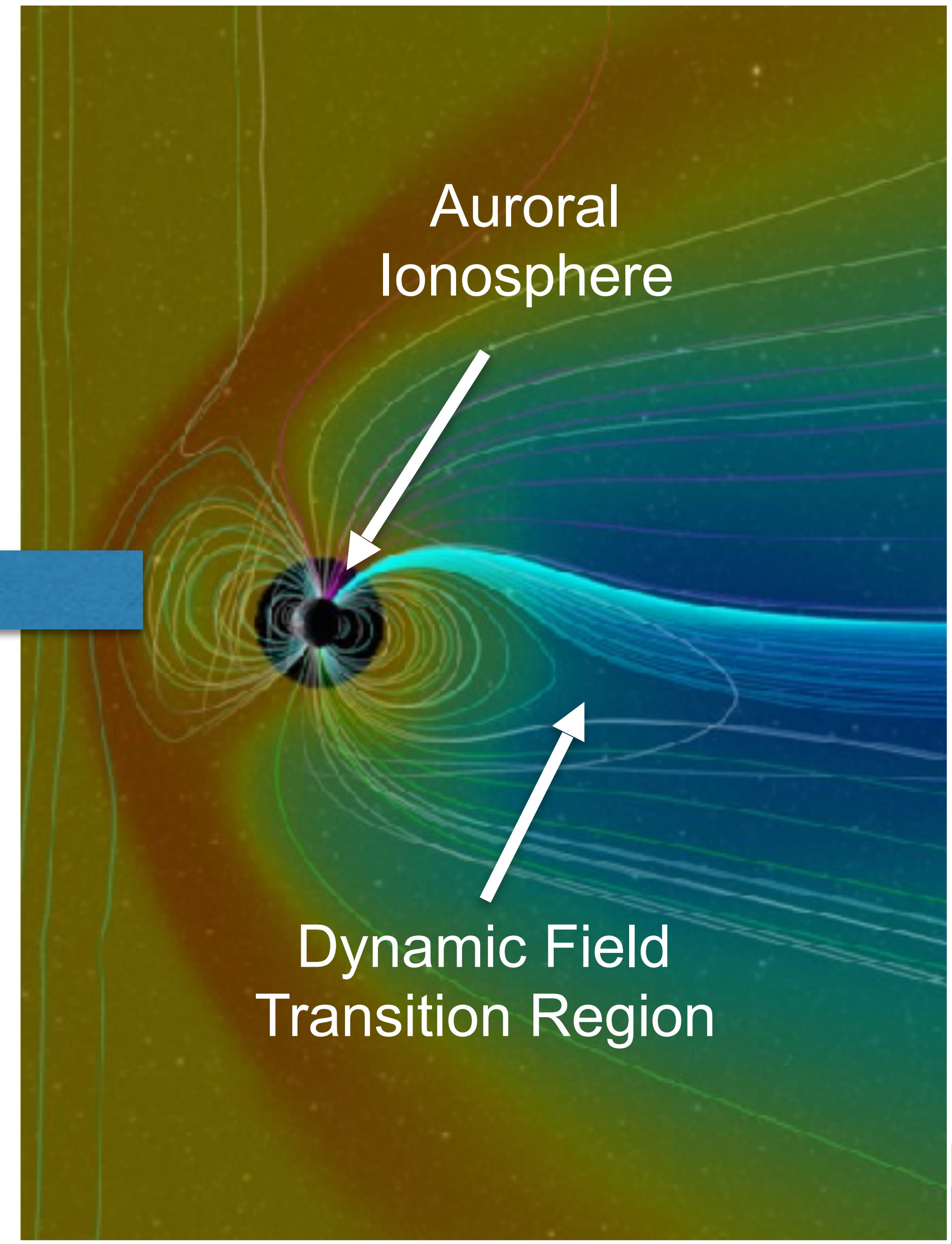




- Storm-time Double Oval
- PBIs, Streamers
- Re-activation of the equatorward arc system
- Omega Bands
- Giant Pulsations
- Torches Structures
- ETC!

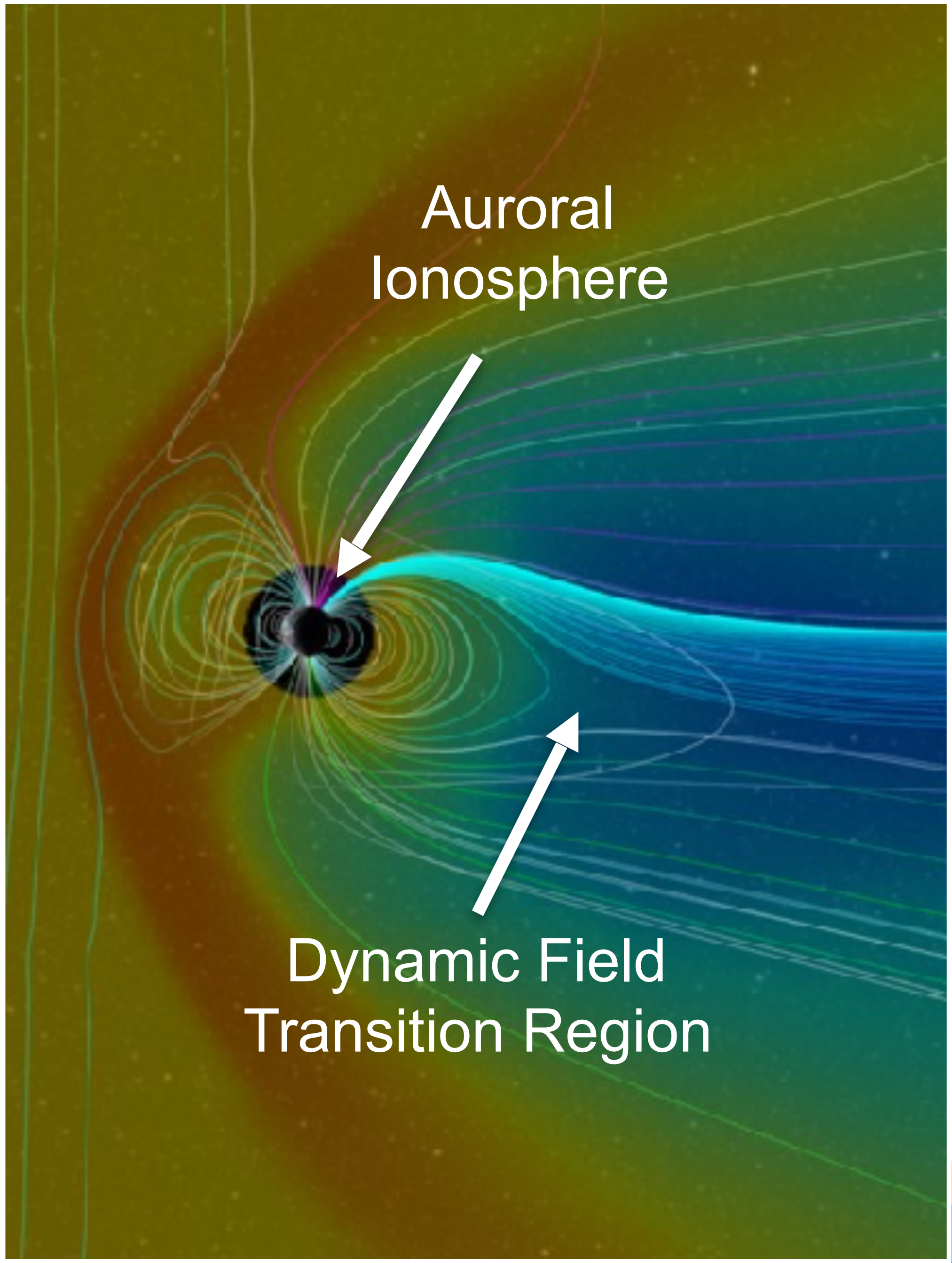
What are the ionospheric signatures of magnetospheric regions and processes?



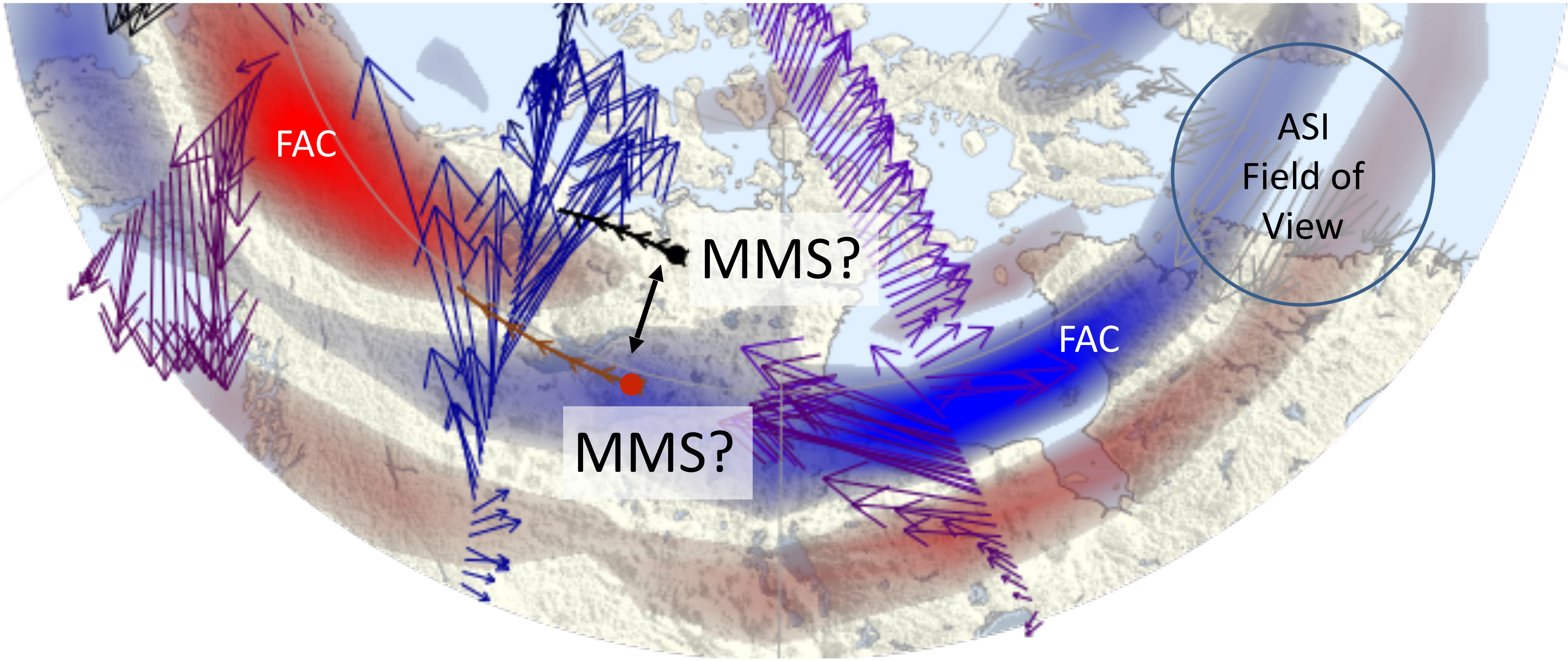


What are the ionospheric signatures of magnetospheric regions and processes?

- Electron & Ion plasma sheets
- Substorm injection, dipolarization fronts, BBFs
- Sawtooth Events
- SAPS and SAID
- Ring current pressure peak
- Plasmapause
- Isotropic Boundary
- PSBL
- Open/Closed Boundary



Why do we need to know the magnetic connection?



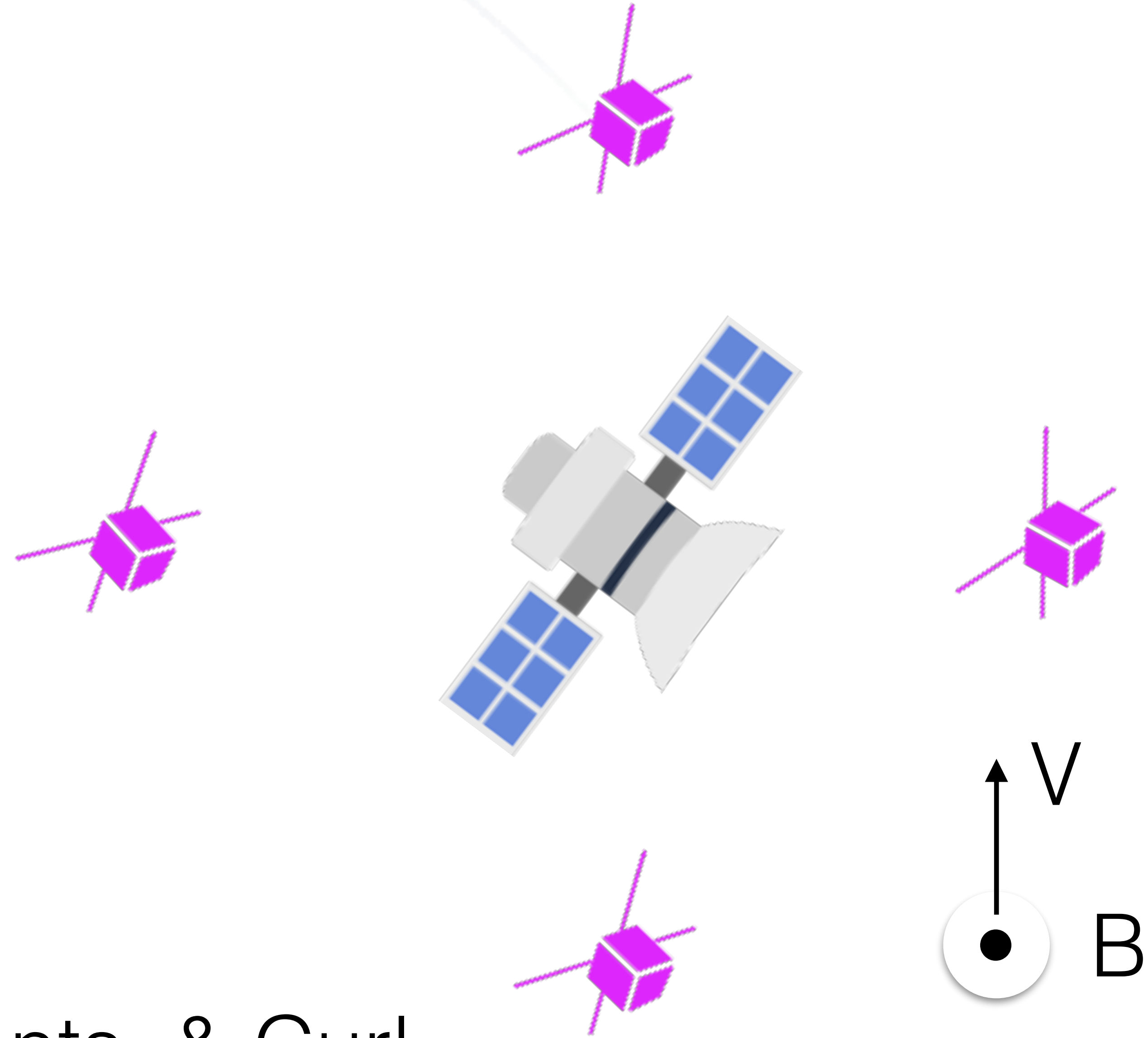
In this example, field models map MMS to red or black points – or anywhere in between. That's a HUGE difference, with no way to tell which is correct.

No way to link in situ measurements to aurora -> ***and no way to know what creates the aurora***.

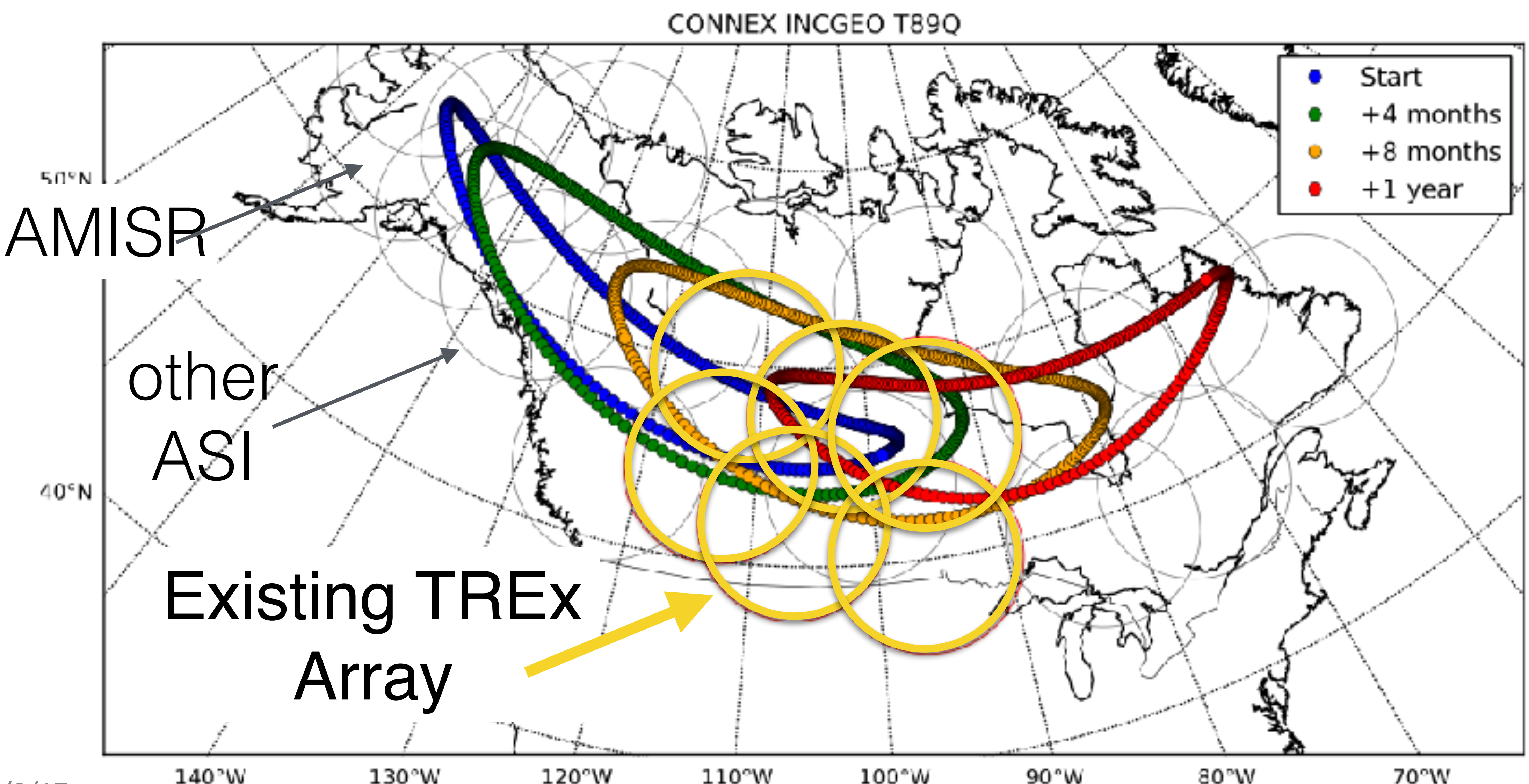
Furthermore the picture is **dynamic** and changes on time scales of minutes

Measurements of magnetospheric boundaries, processes, & conditions

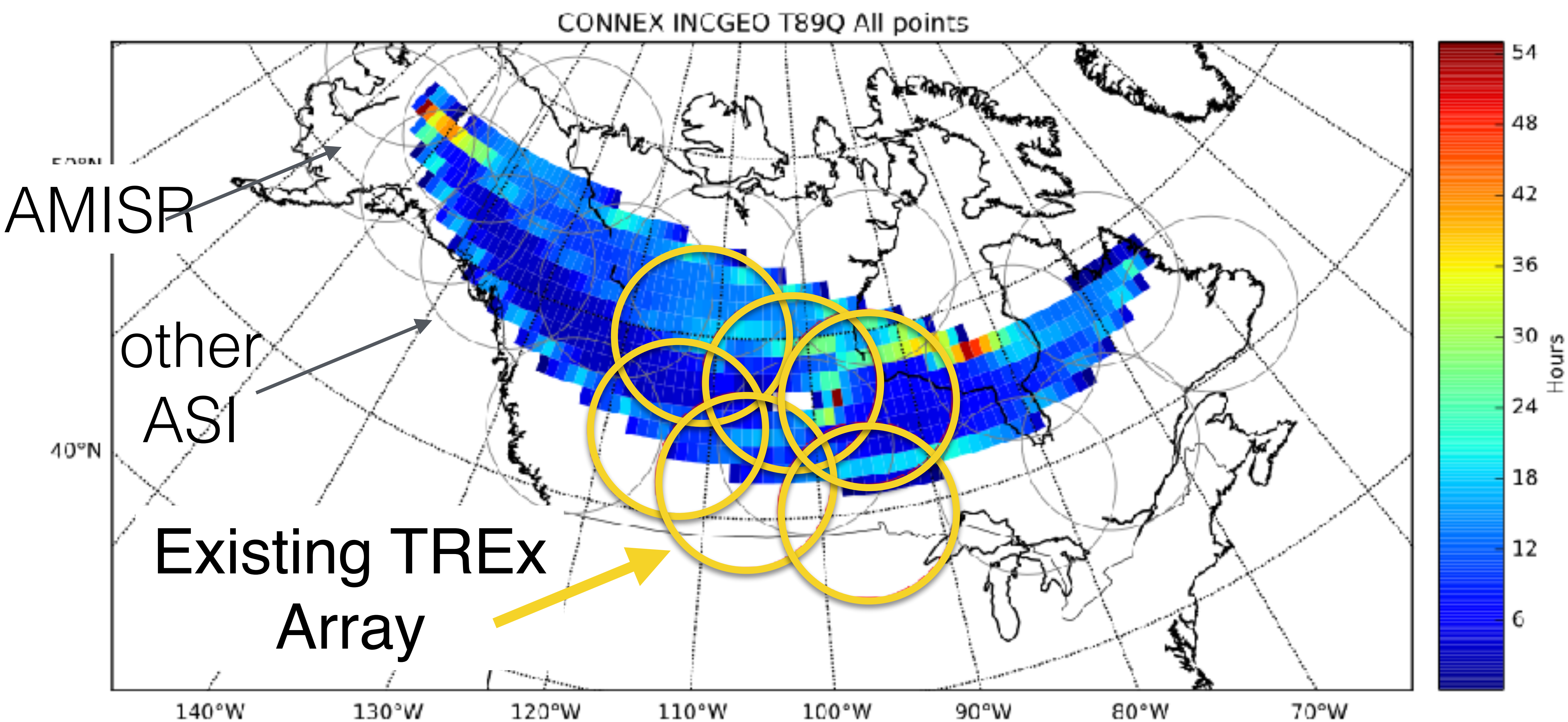
- **Slightly Elliptical GEO**
  e.g. ~ 5 x 8 Re
  - Plasma fluxes
  - Moments
    - temperature
    - density
    - pressure
  - Plasma Gradients
  - Magnetic fields, Gradients, & Curl
  - Electric Fields and Flow Velocities



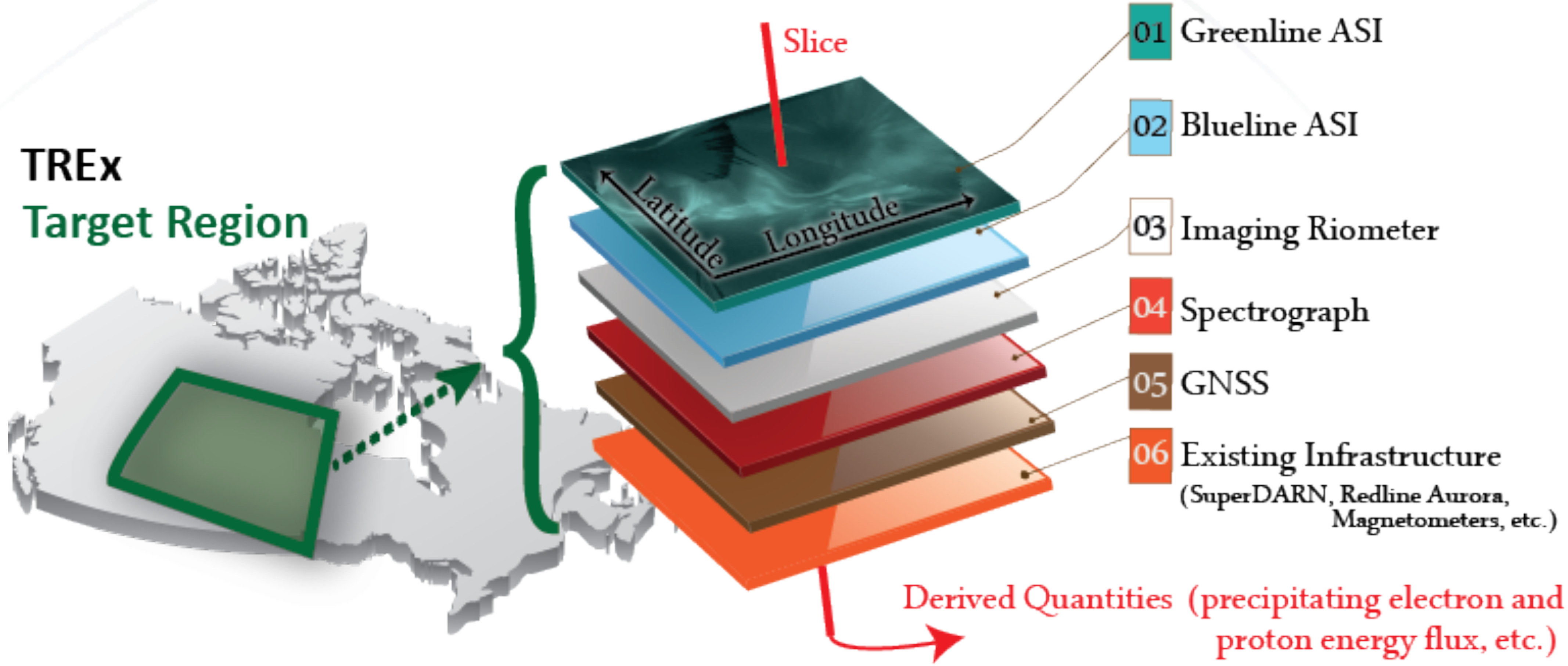
- 5 x 8 RE 24 hour orbital period keeps the entire orbit in the auroral / transition region 24 x 7 x 365
- Max/Min Latitude set by apogee/perigee (we can optimize the orbit)
- The entire footpoint loop can be precessed East-West
- Winter -> Canada Optical | Summer -> Alaska Radar

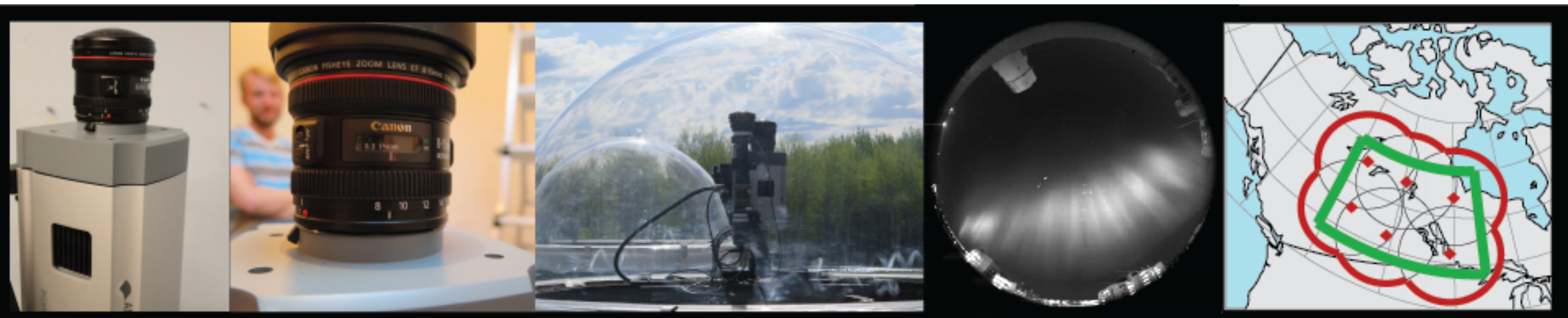


- One year of foot points shown below
- Up to 50 hrs in a 1°x1° bin
- Thousands of hours over any single ASI field of view
- East - West drift of the footpoint is fuel-cheap



TREx


TREx
Target Region
Slice
Latitude
Longitude
01 Greenline ASI
02 Blueline ASI
03 Imaging Riometer
04 Spectrograph
05 GNSS
06 Existing Infrastructure
(SuperDARN, Redline Aurora, Magnetometers, etc.)
Derived Quantities (precipitating electron and proton energy flux, etc.)



Beam π

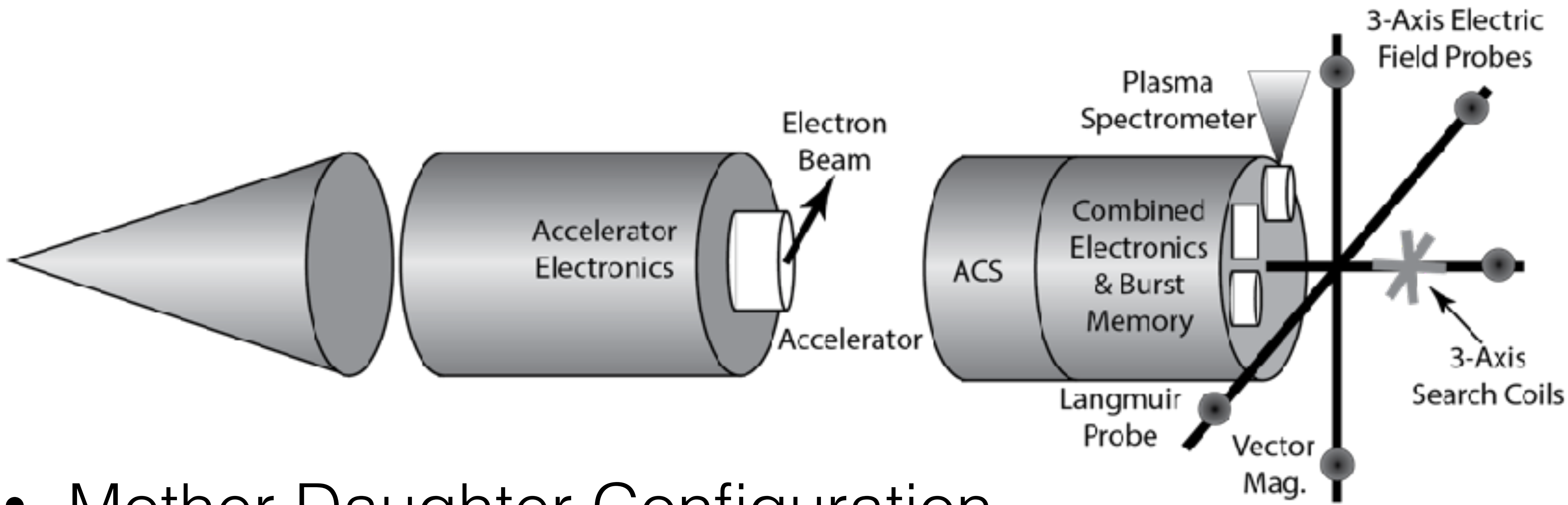
Beam Plasma Interactions Experiment

LCAS Proposal

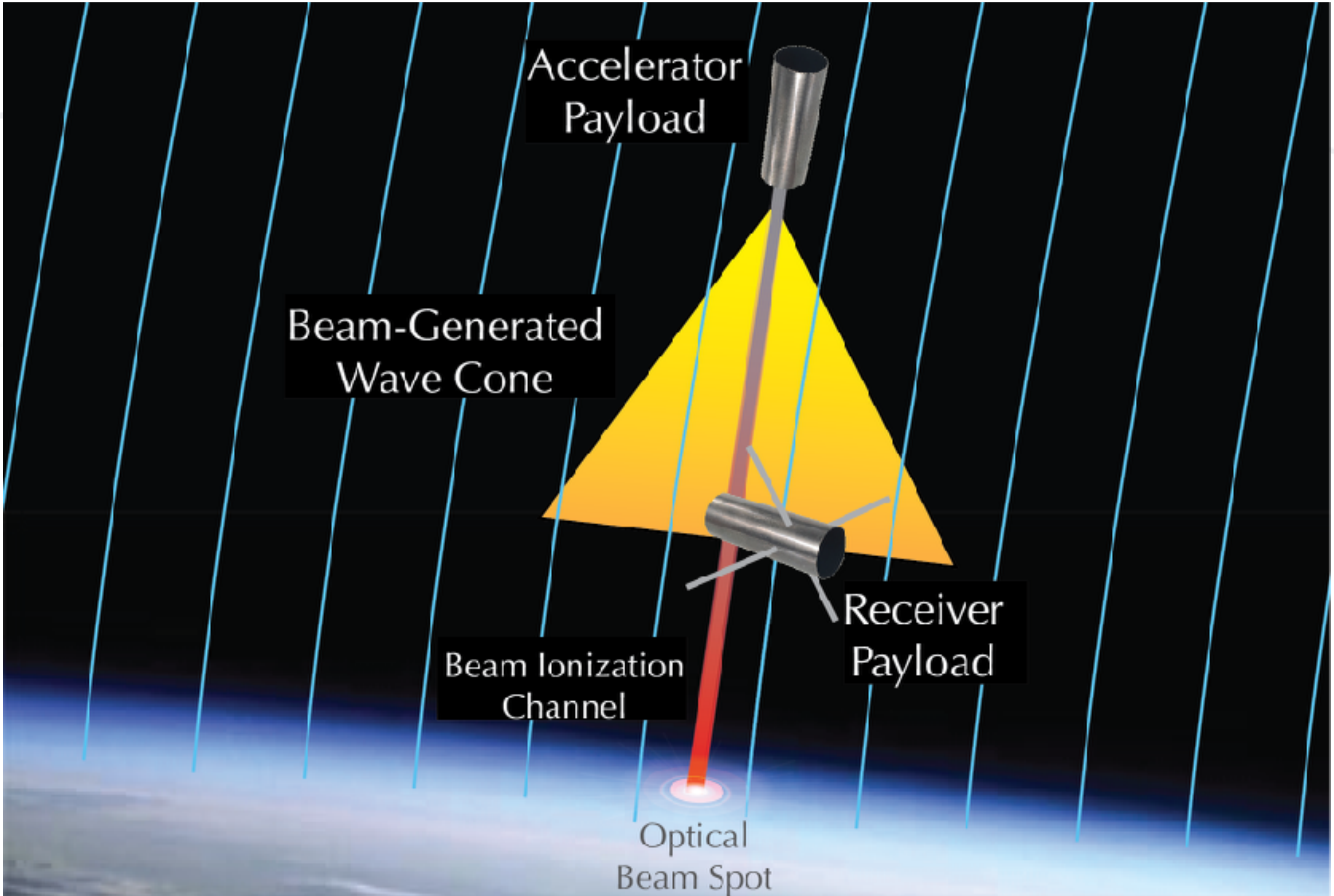
Beam PIE

The Beam Plasma Interactions Experiment

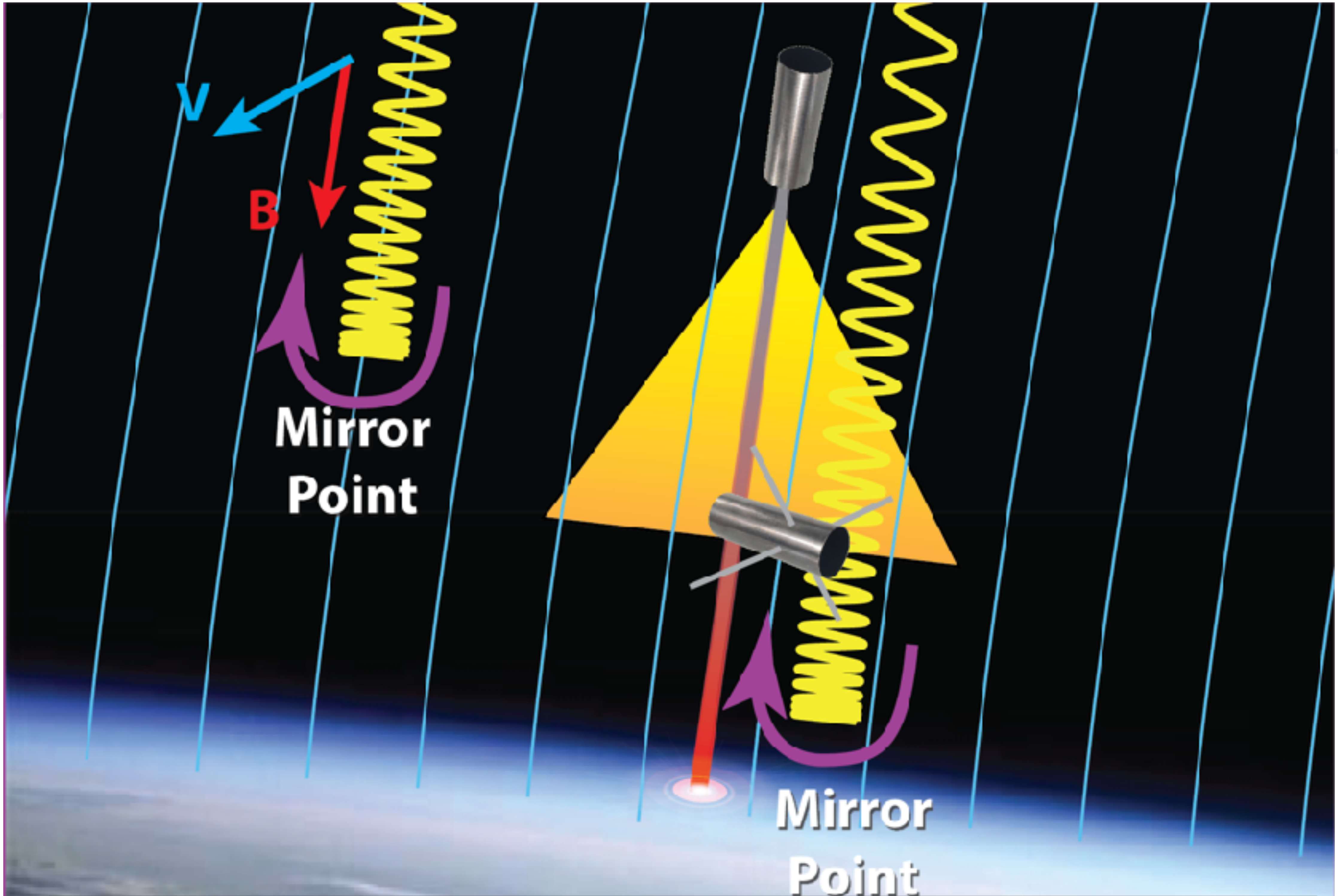
- Quantitatively test theories of how energetic electron beams couple to plasmas to stimulate whistler mode radiation
- Discover and characterize how energetic electron beams couple to plasmas to stimulate propagating X-mode radiation
- Measure and quantify the resonant wave-particle scattering of ambient ionospheric electrons by X-mode electromagnetic waves
- Demonstrate advanced linear electron accelerator technologies for CONNEX and other future space experiments



- Mother-Daughter Configuration
- Accelerator payload with a 0-60 keV pulsed beam
- Receiver payload with fields, waves, plasma spectrometer, Langmuir probe & attitude control
- Launch from Poker to ~450 km in dark skies but Quiet conditions



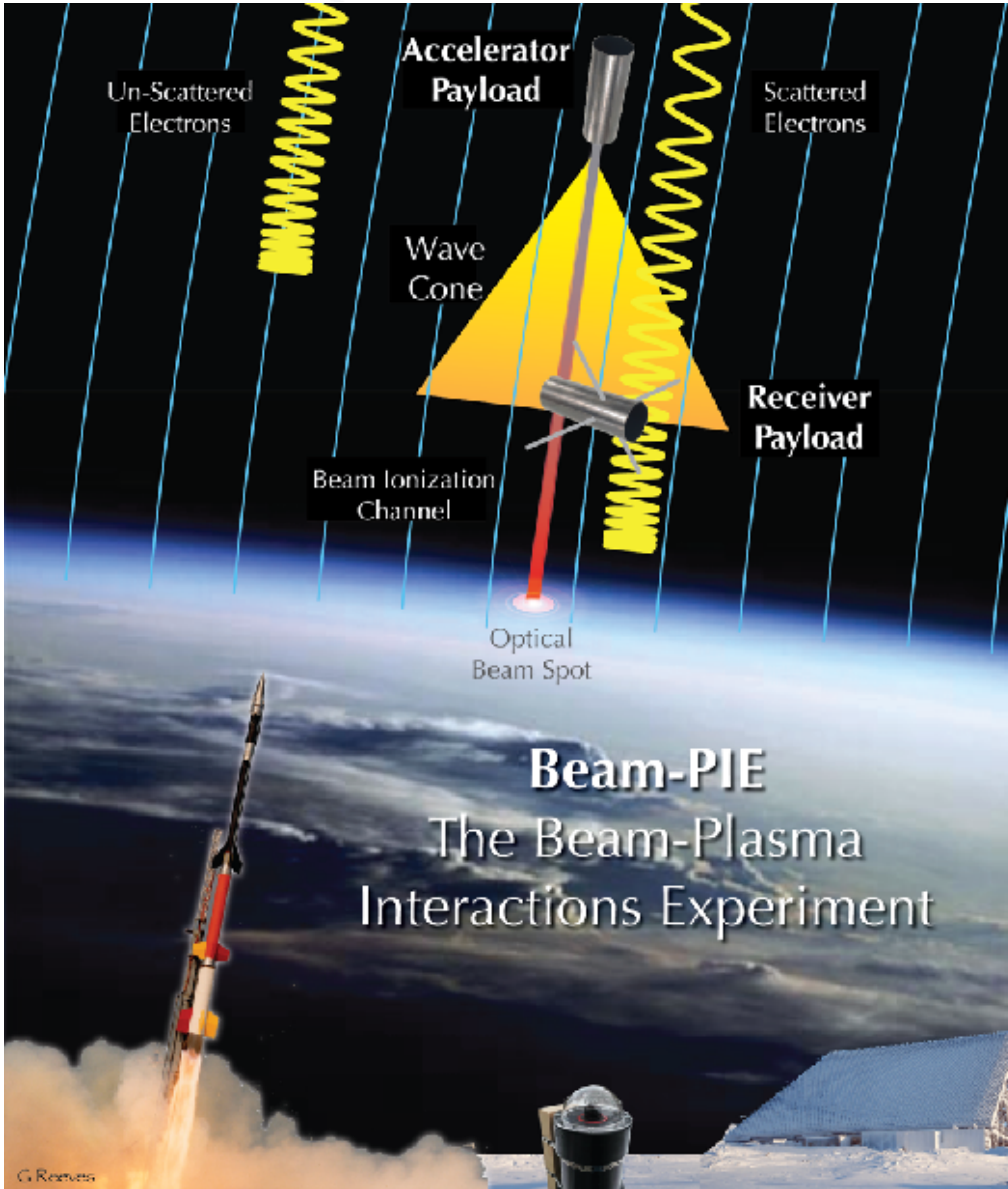
- Generate whistler and X-mode waves using various pulsed electron beam patterns
- Detect and characterize the waves at the receiver payload

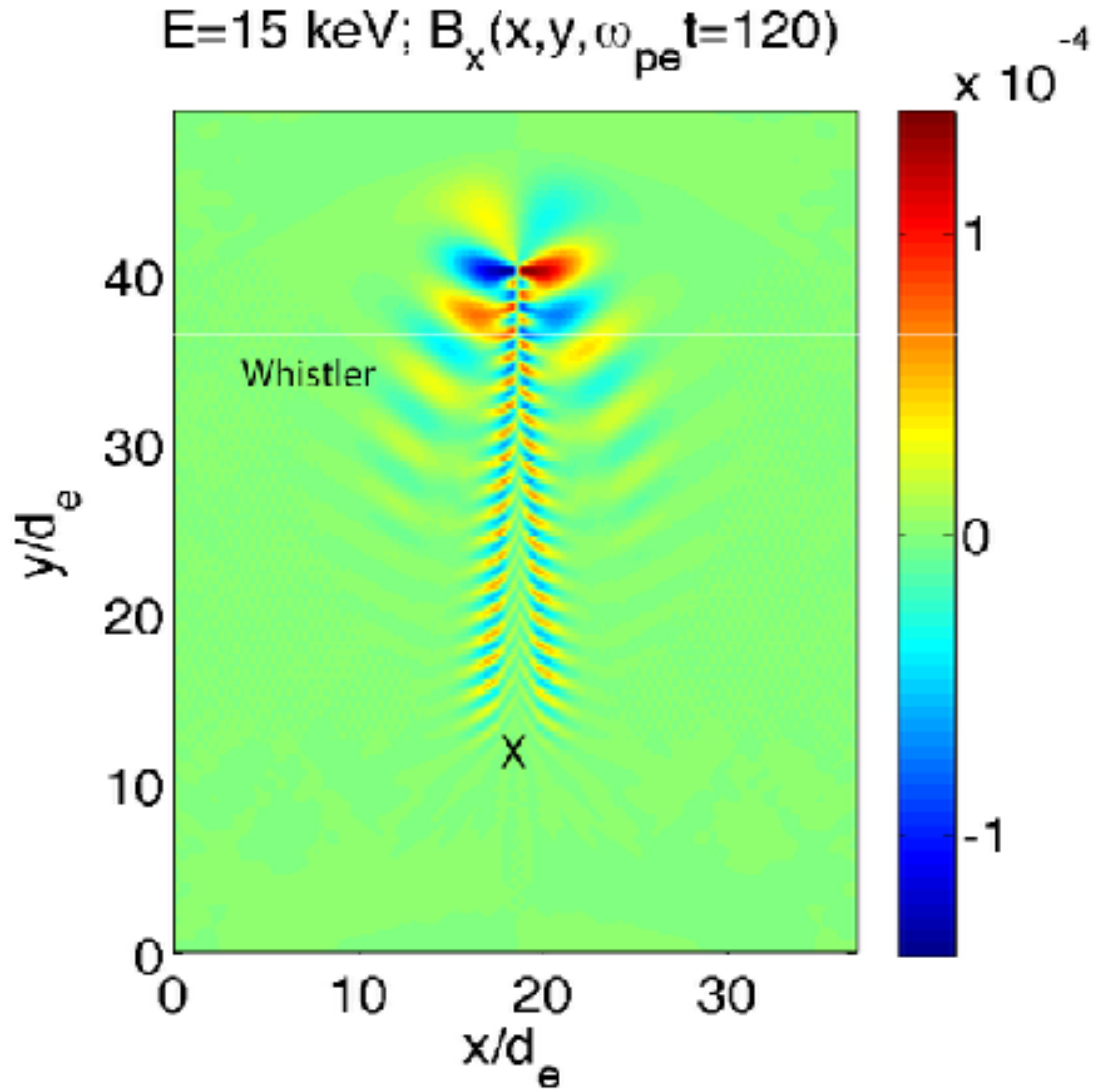


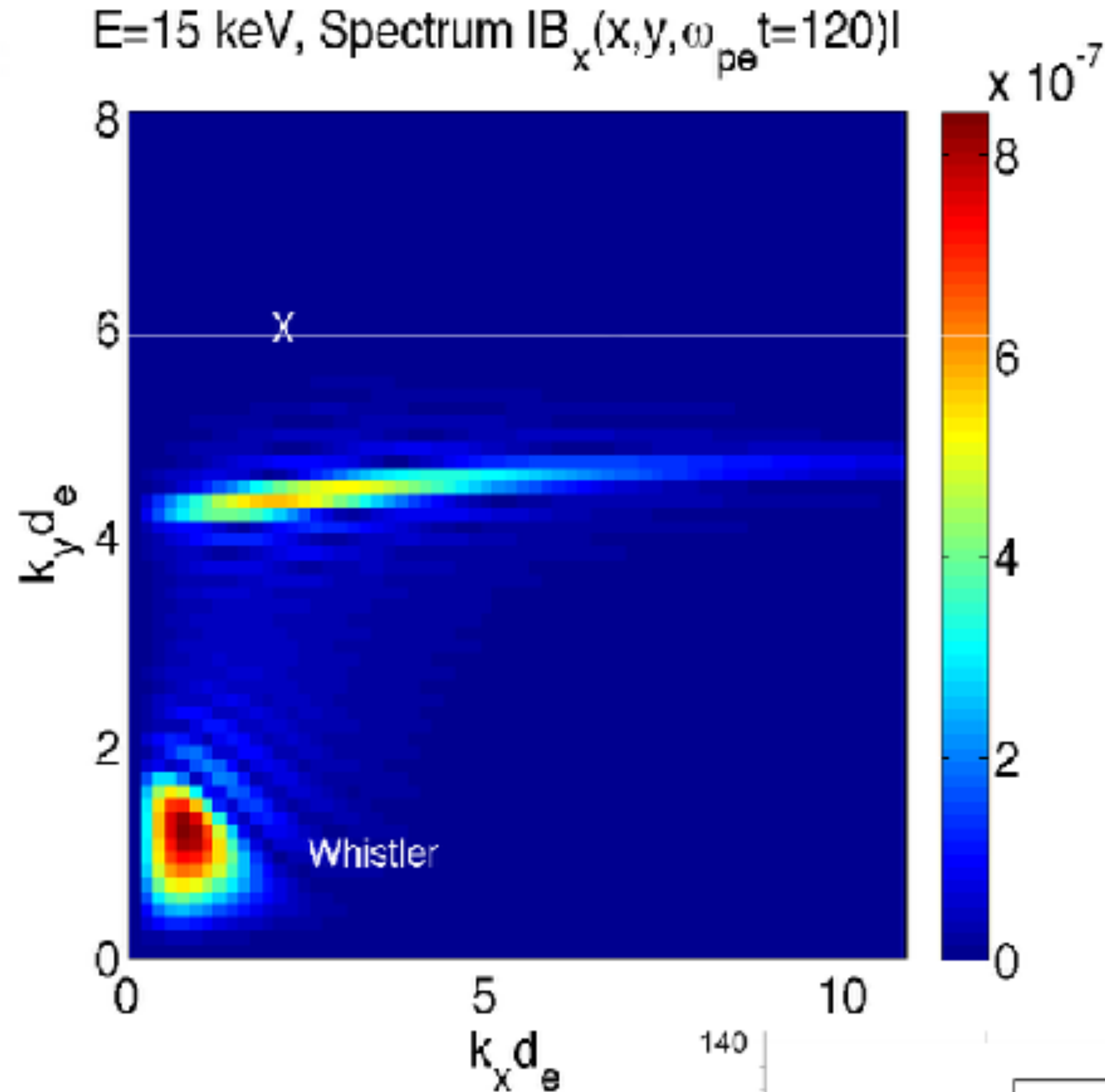
- Measure the ambient electron pitch angle distribution near the bounce loss cone
- Look for an increase in upward-going electrons when the beam is generating waves

Collaborative Ground Instrumentation
(as available)

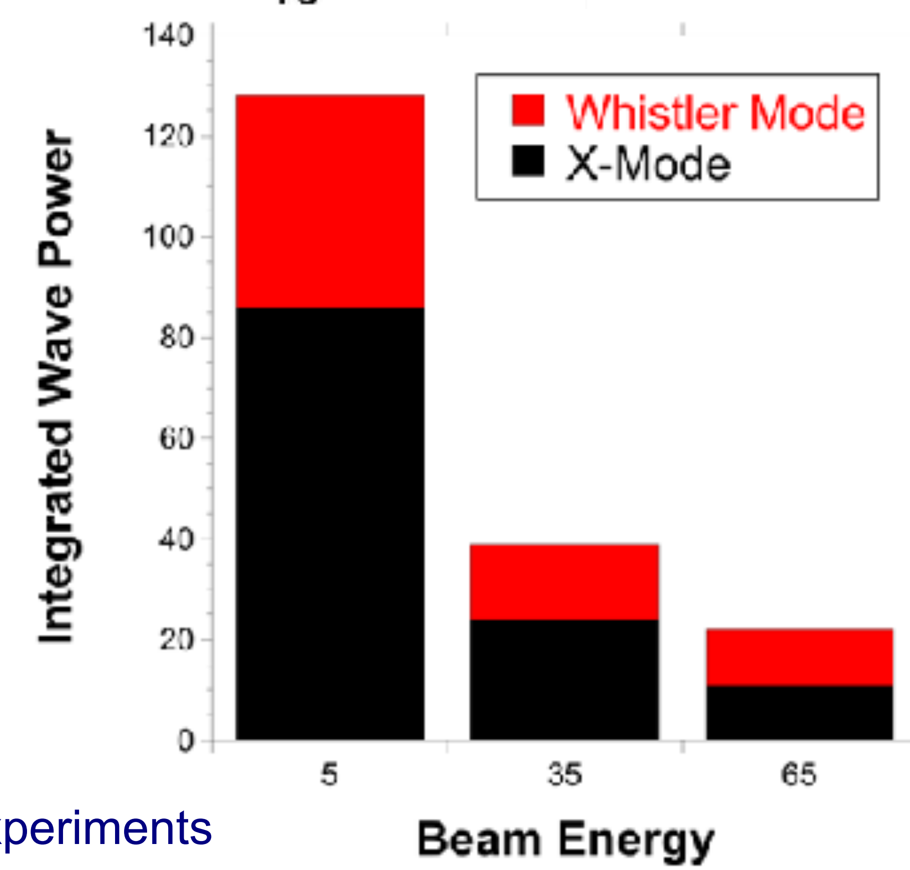
- Purpose:
  - To remotely sense whistler and X-mode waves
  - Beam propagation
  - Demonstrate detectability
- Wave Receivers
- AMISR radar
- Optical Detectors
- Riometers





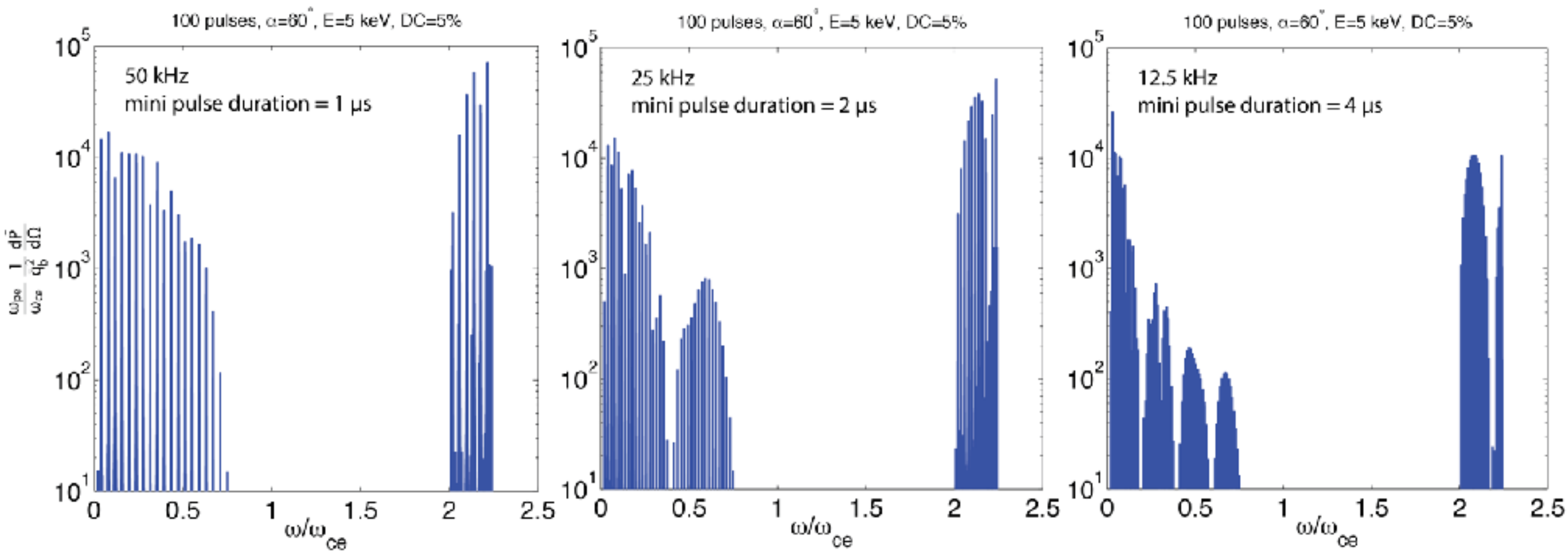


- Both whistler and X-mode waves will be generated (at different frequencies)
- Chart (wave power at 50 kHz, 5% duty cycle) shows X-mode actually dominates

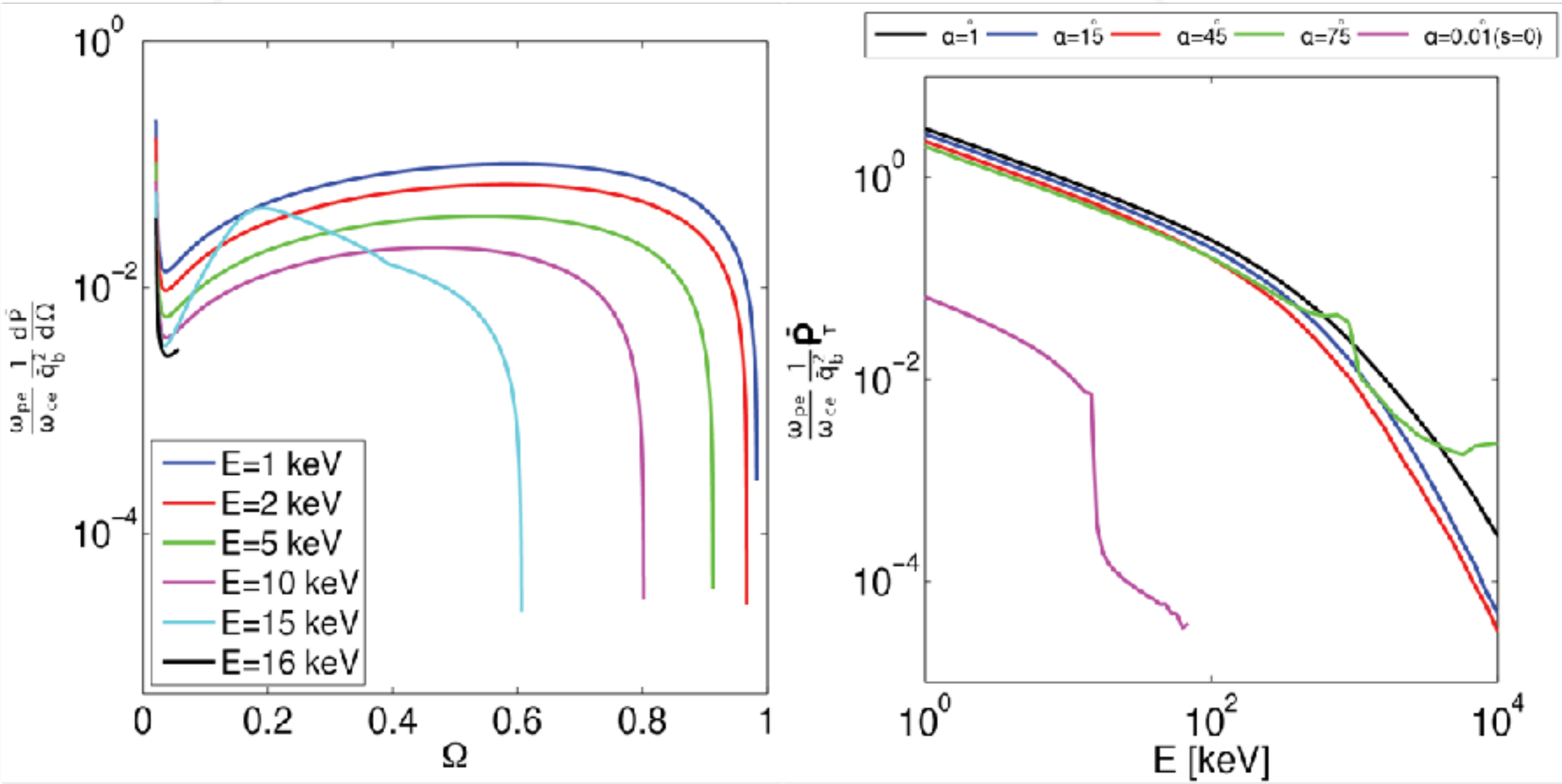


Predicted whistler and X-mode wave power as a function of modulation frequency.

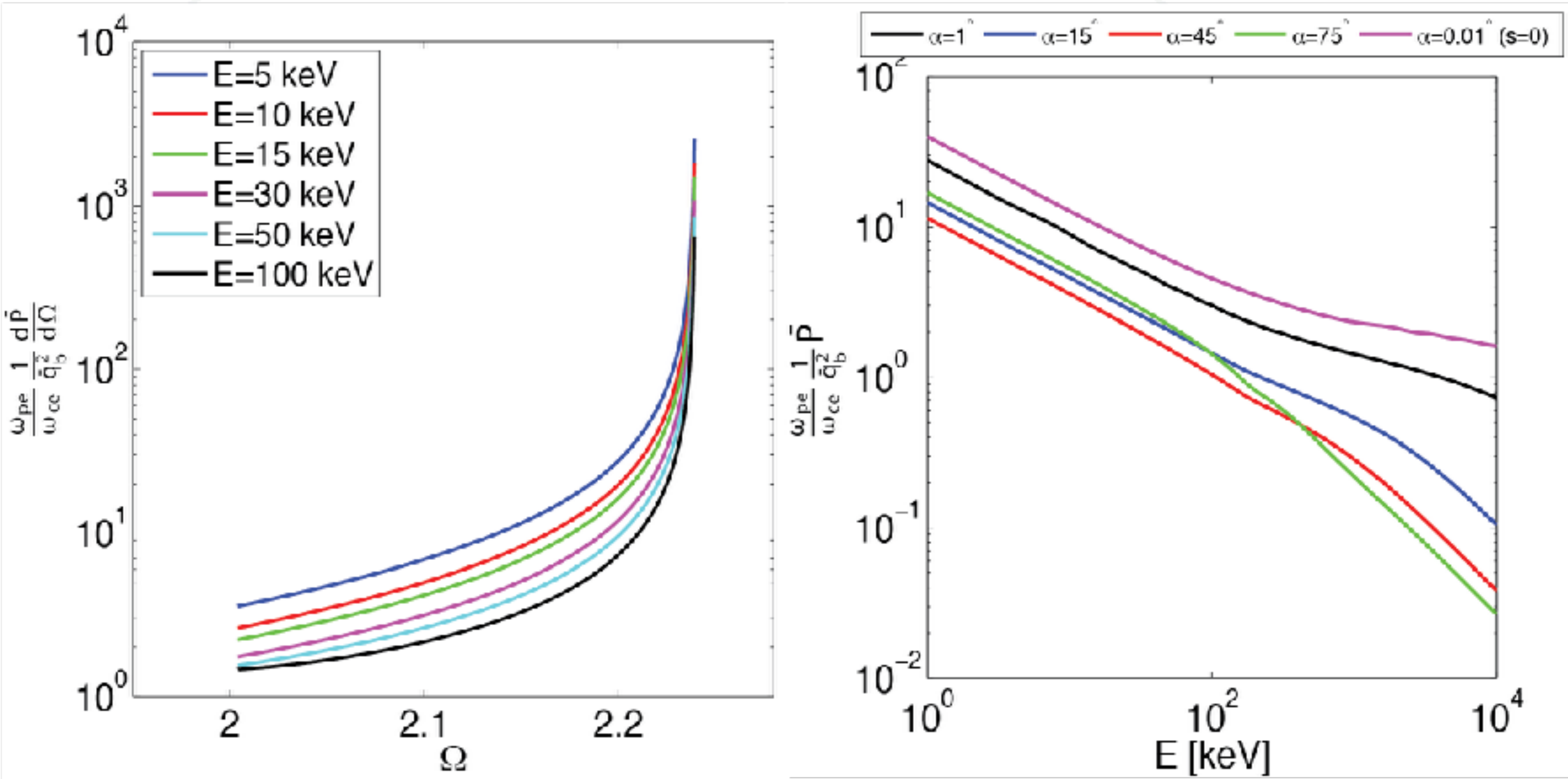
- All plots are for a 5 keV - 5% duty cycle beam.
- Note the relative wave powers and discrete harmonic structure



Whistler mode wave power is a function of beam energy and pitch angle

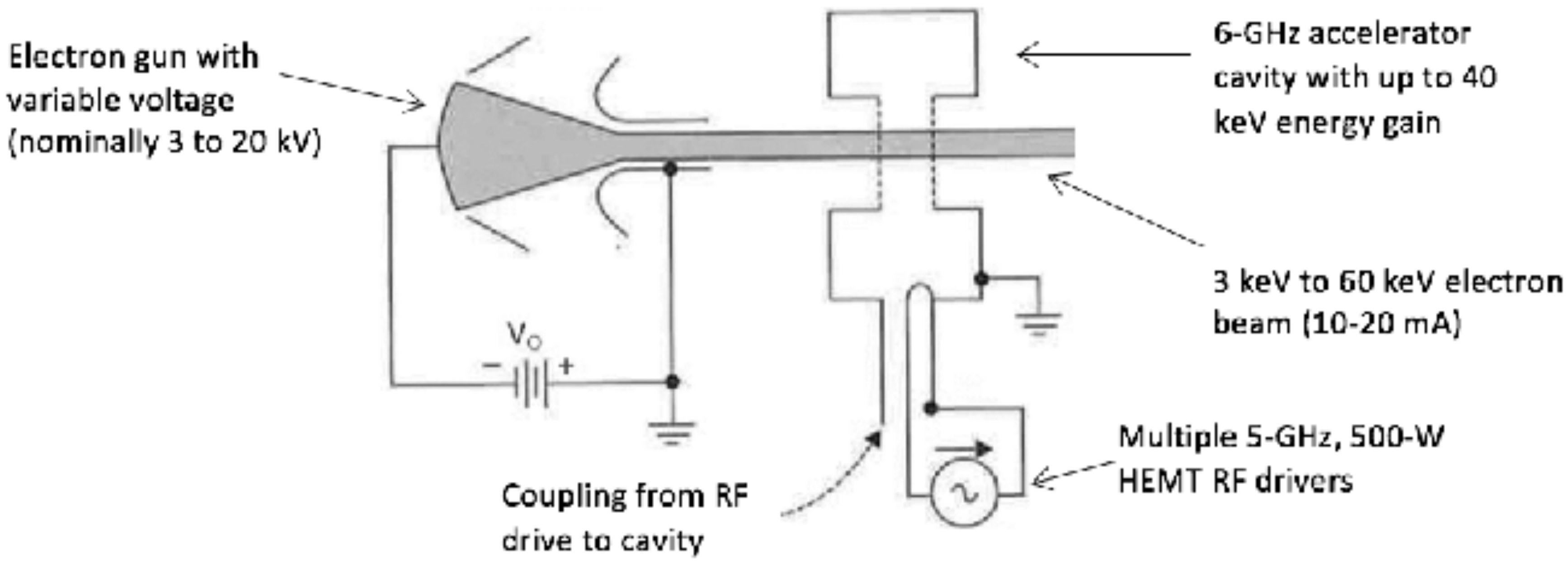


X-mode wave generation by electron beams has not previously been studied



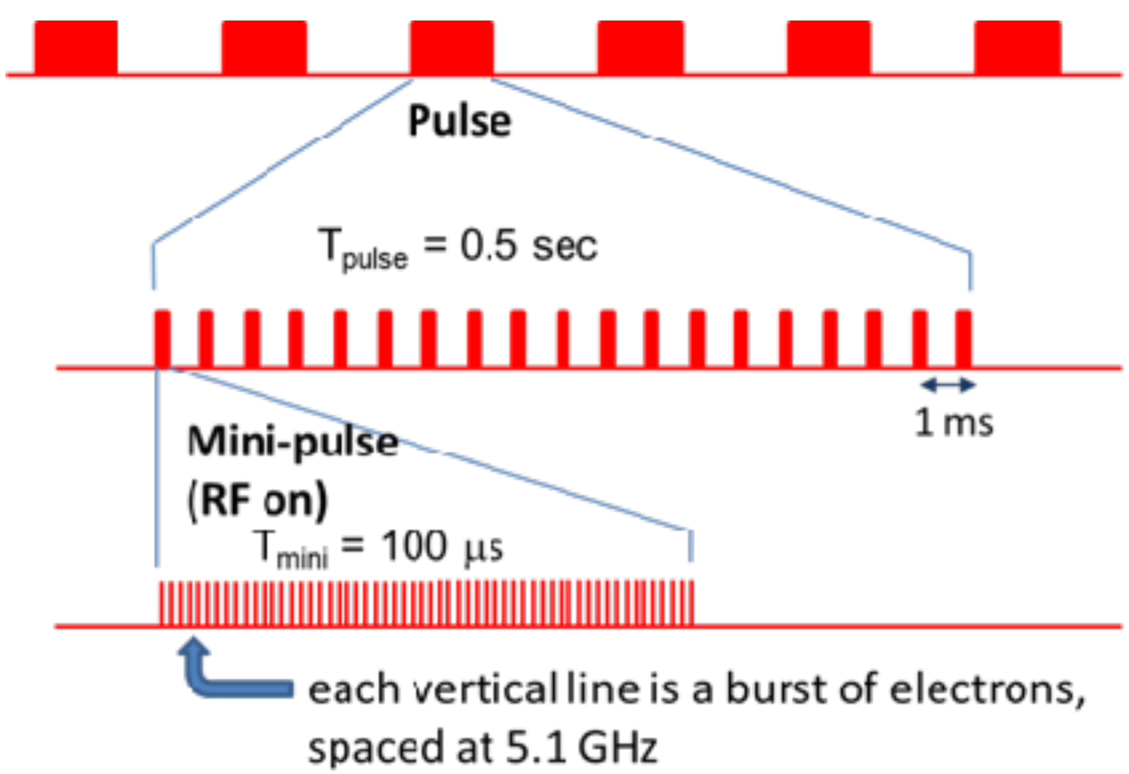
upper hybrid frequency $\omega_{uh} = 2.3\ \omega_{ce}$

Beam Operations

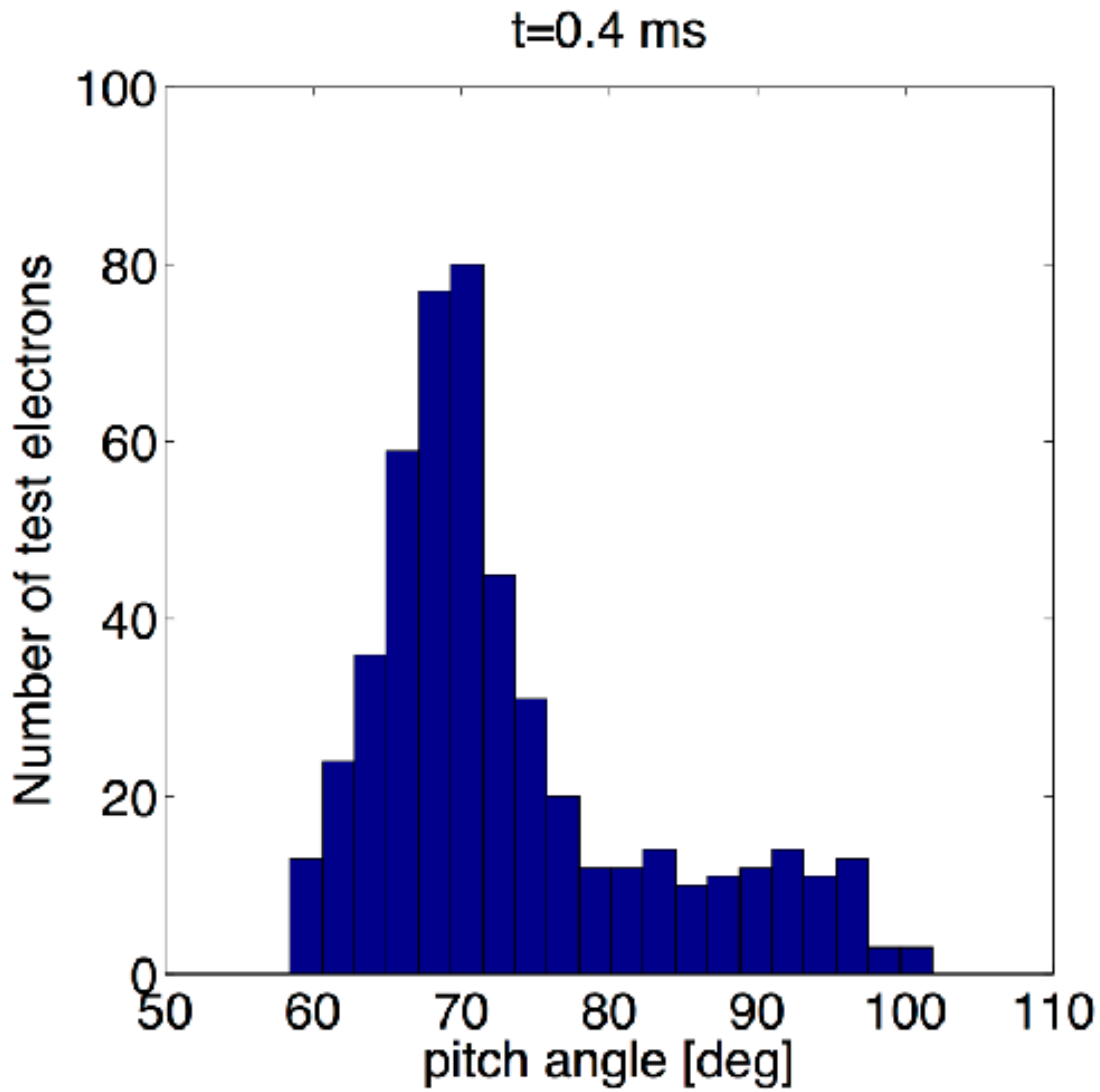


Beam Firing	Beam Energy	Modulation Frequency	Mini Pulse	Duty Cycle
1	5 keV	50 kHz	1 µs	5%
2	20 keV	50 kHz	1 µs	5%
3	40 keV	50 kHz	1 µs	5%
4	60 keV	50 kHz	1 µs	5%
5	5 keV	10 kHz	2 µs	2%
6	5 keV	25 kHz	2 µs	5%
7	5 keV	35 kHz	2 µs	7%
8	5 keV	5 kHz	10 µs	5%
9	20 keV	5 kHz	10 µs	5%
10	40 keV	5 kHz	10 µs	5%
11	60 keV	5 kHz	10 µs	5%

Almost Infinitely Configurable



Wave-Induced Particle Scattering



The final pitch angle distribution of test electrons with energy 39 keV and initial pitch angle 69° evolving in the field of an X-mode wave with $\omega = 2.1\ \omega_{ce}$ for 0.4 ms.

Beam PIE Team

LANL

- Geoff Reeves
- Phil Fernandez
- Bruce Carlsten
- John Lewellen
- Mike Holloway
- Dinh Nguen
- Gian Luca DelZano
- Joe Borovsky

GSFC

- Rob Pfaff
- Bill Farrell
- Doug Rowland
- Marilia Samara

Calgary

- Emma Spanswick
- Eric Donovan

SRI

- Ennio Sanchez

Thank You