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Title: CONNEX: Concept to Connect Magnetospheric Physical Processes to Ionospheric Phenomena

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Proposal Socialization

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CONNEX: Concept to Connect Magnetospheric Physical Processes to Ionospheric Phenomena

Active Experiments in Space Workshop
11 September 2017
Santa Fe, NM

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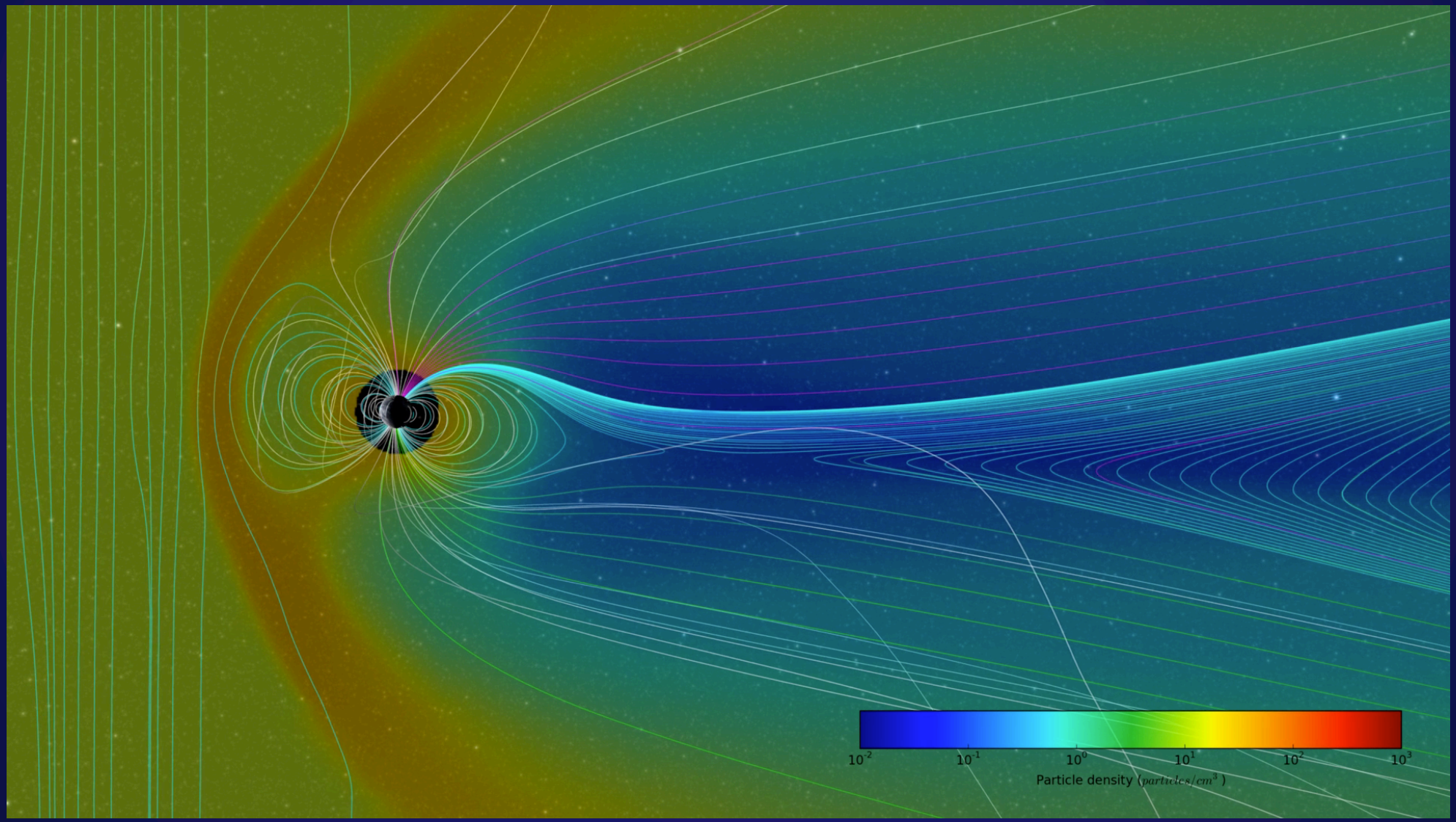
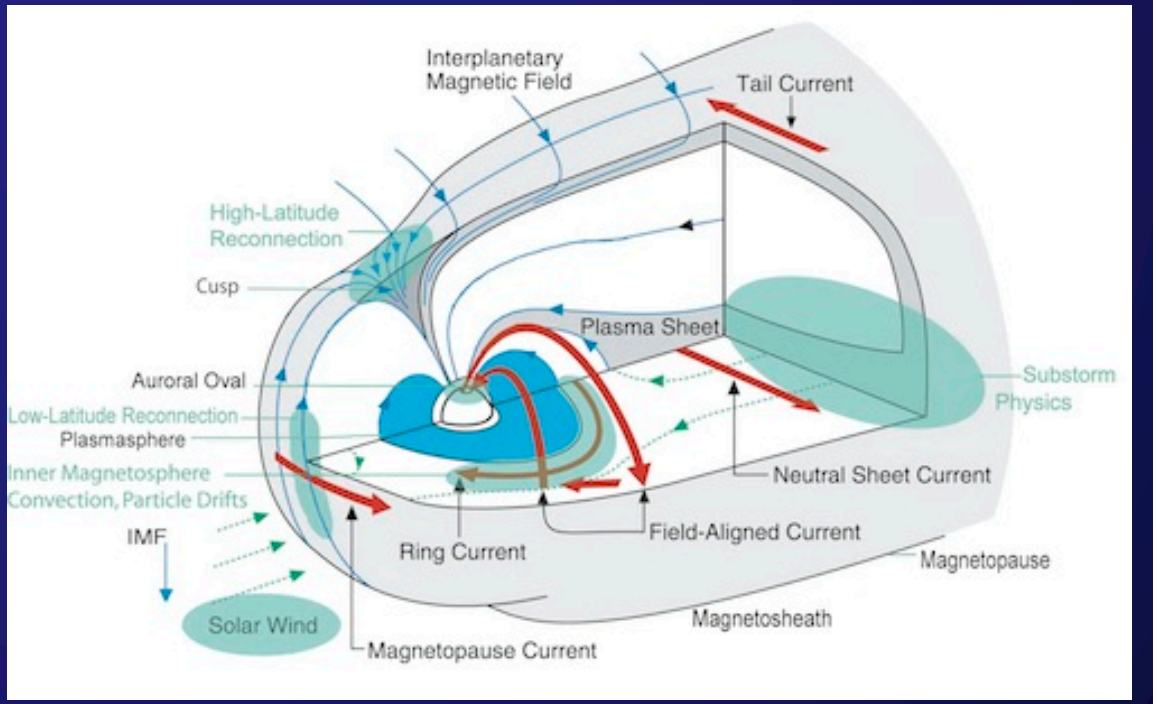
[1] Los Alamos National Laboratory; [2] NASA Goddard; [3] Space Science Institute; [4] Planetary Science Institute; [5] SRI International; [6] U. New Hampshire; [7] U. Michigan; [8] U. Calgary; [9] U. Colorado; [10] SLAC

The Earth's dynamic magnetic field connects two branches of space physics

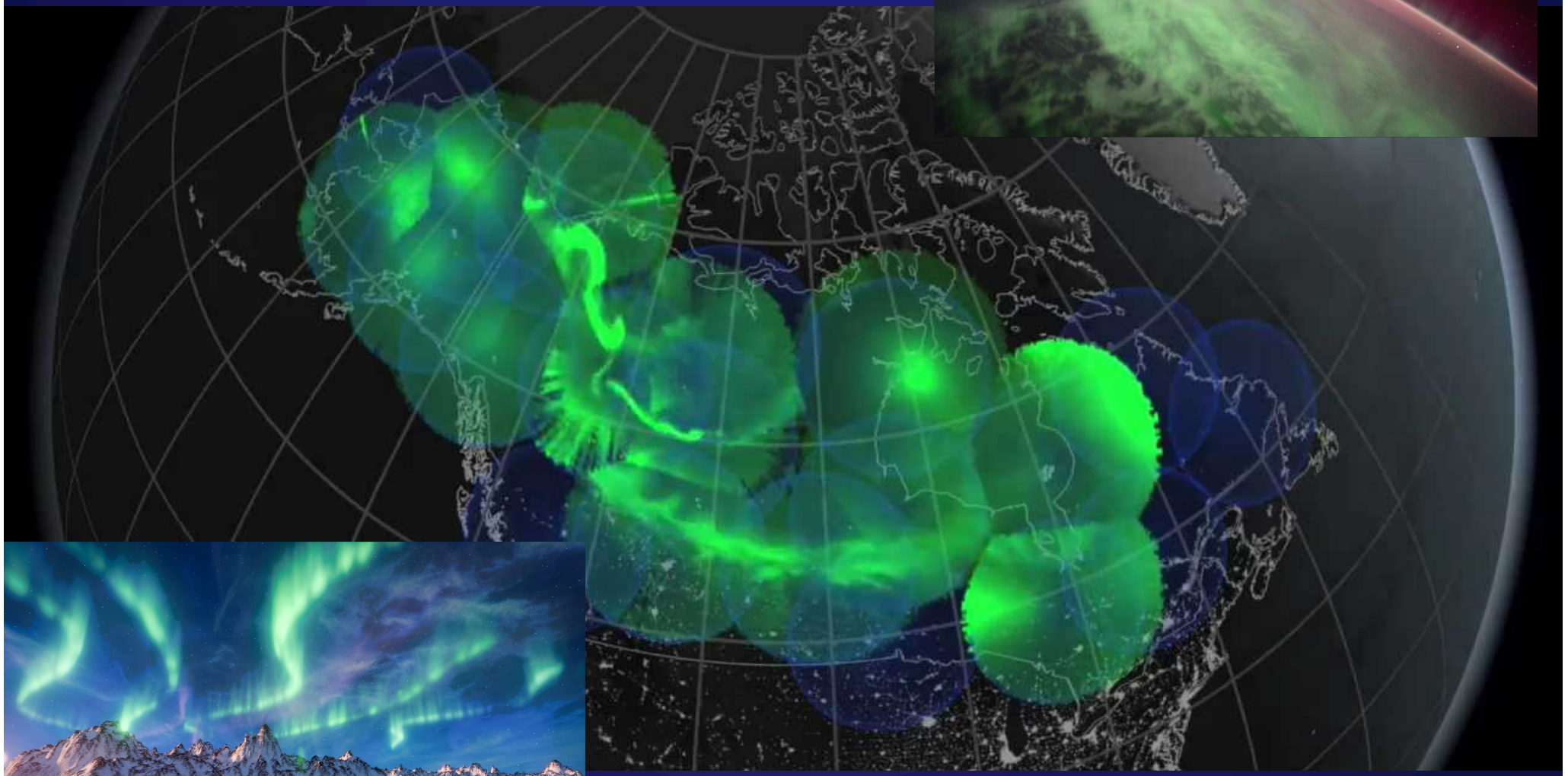


The magnetospheric community has a well developed understanding of specific magnetospheric regions, boundaries, and events.

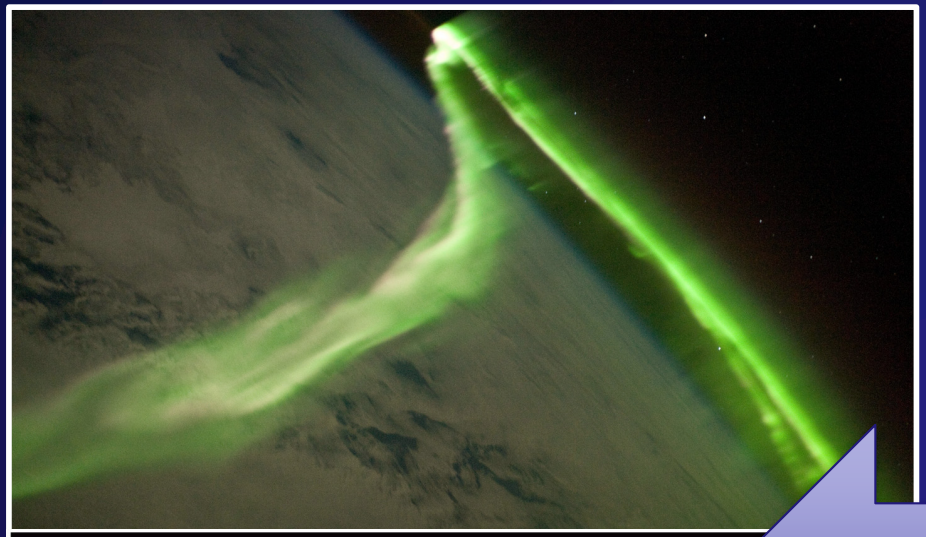
- Plasmasphere
- Electron & Ion plasma sheets
- Substorm injection boundary / dipolarization front
- Ring current pressure peak
- SAPS
- BBFs
- Isotropic Boundary
- PSBL
- Open/Closed Boundary

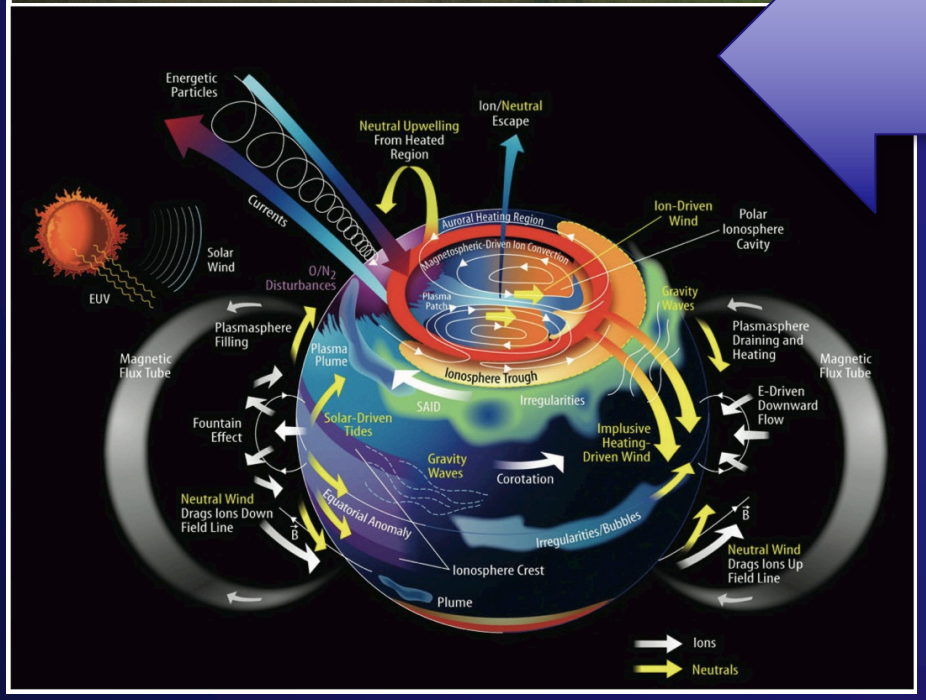


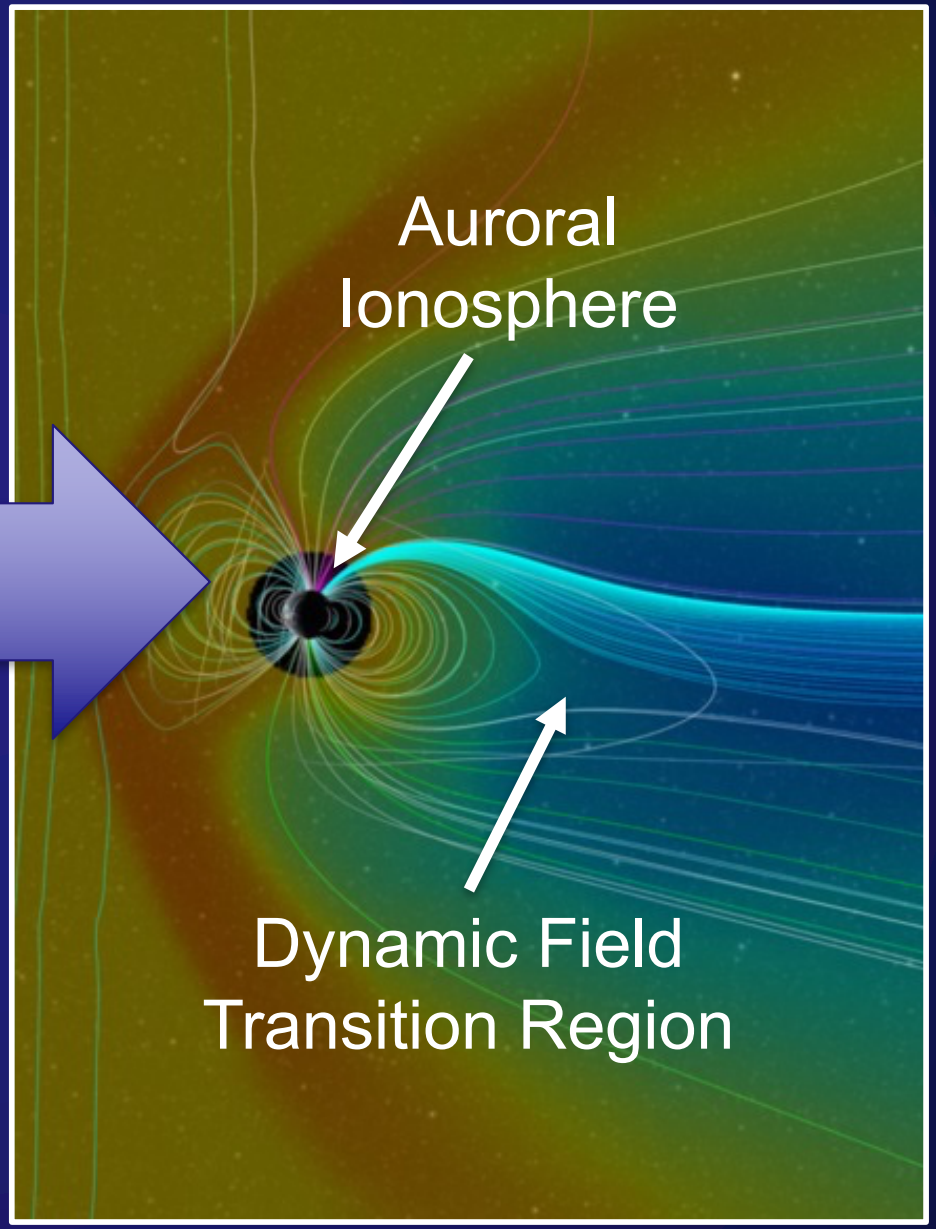
The Ionospheric community has a well developed understanding of current systems, convection, auroral signatures, and temporal evolution.



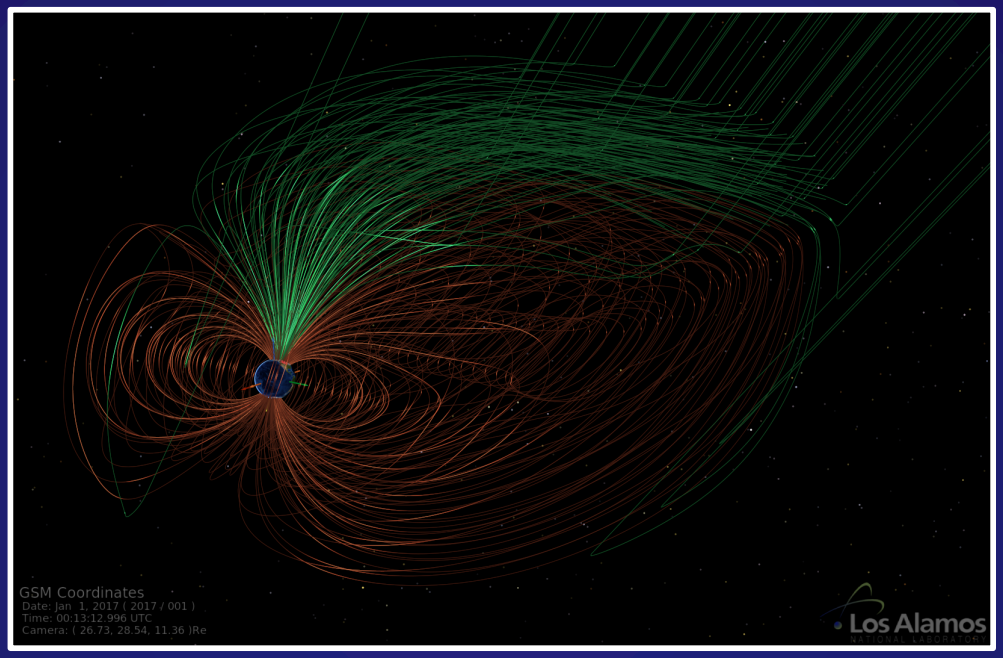
Context: What magnetospheric processes and conditions produce particular auroral and ionospheric signatures?







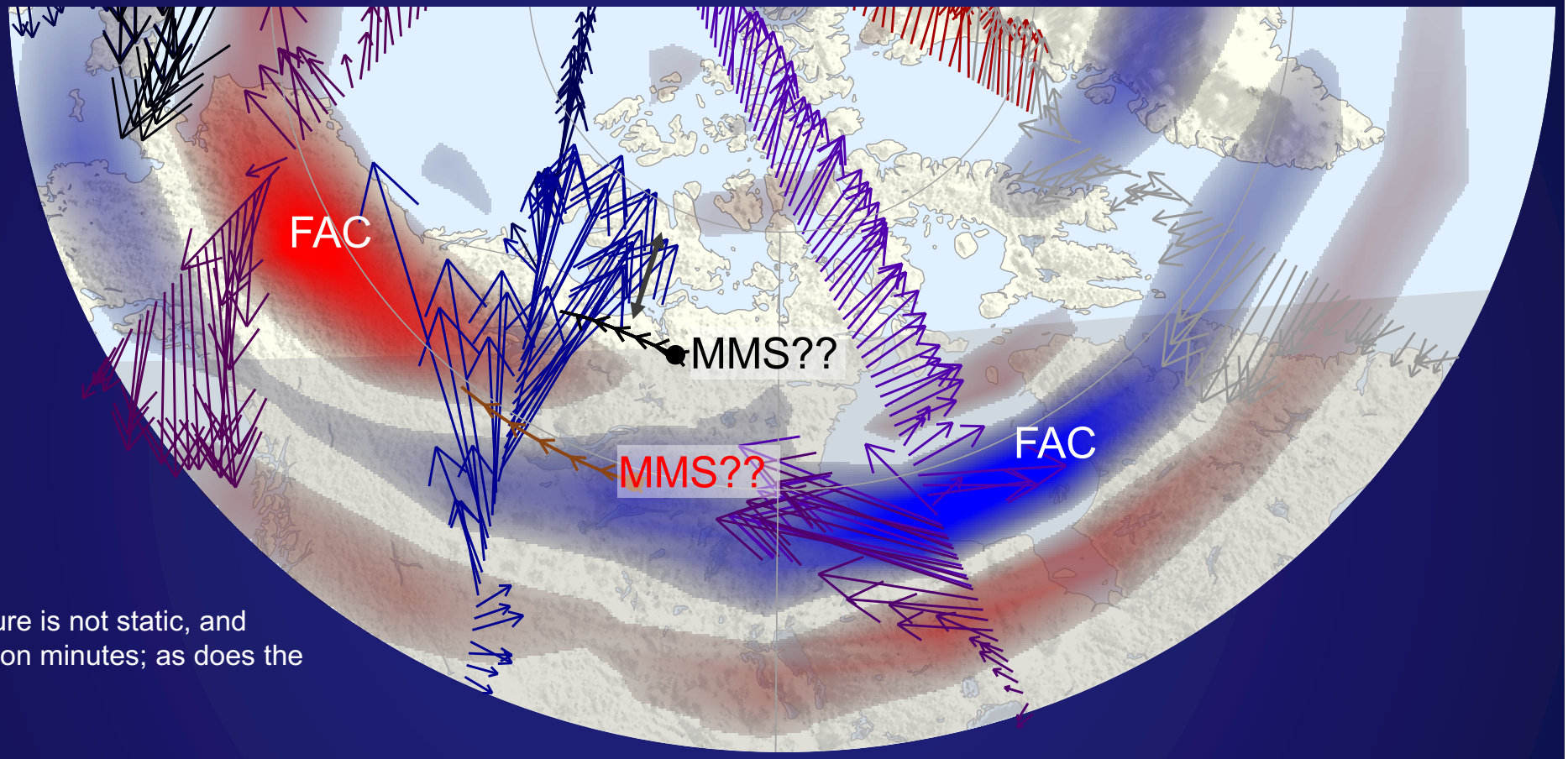
Many researchers have developed magnetic mapping techniques to estimate time-dependent connectivity between magnetospheric regions and their ionospheric foot points.



- Empirical field models (like TS04 shown here) are only good “on average.” But are likely never quite right for any individual event.
- Event-fitted models (tuning a few parameters with data for a specific event) do better, but mapping is still largely constrained by the functional forms used in the model.
- MHD models still lack some key inner magnetospheric physics (ring currents, FACs, substorm current systems).
- Direct mappings have been done (e.g. pulsating aurora, plasma distribution matching), but are rare and are typically done during uninteresting times.

- Currently, mapping success is limited to quiet times and many ambiguities remain.

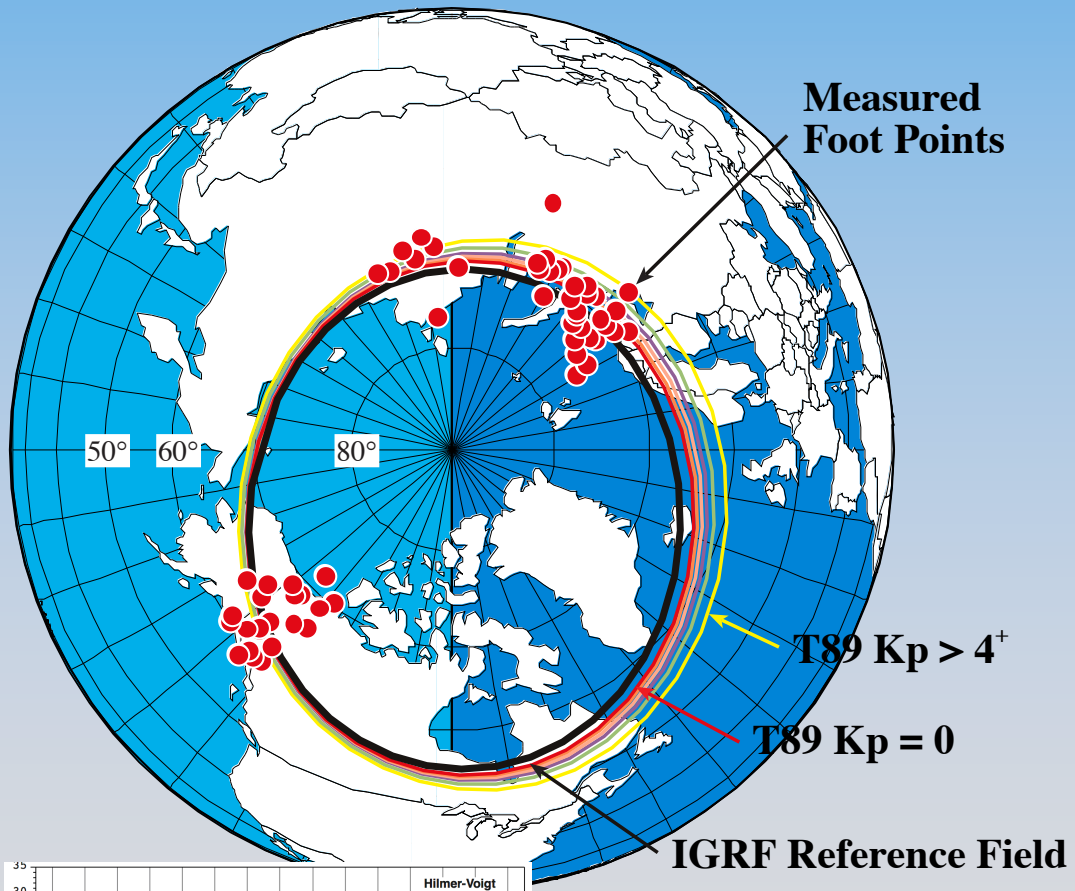
Example: Field model mappings from MMS, in the transition region, to the ionosphere results in ambiguous interpretations.

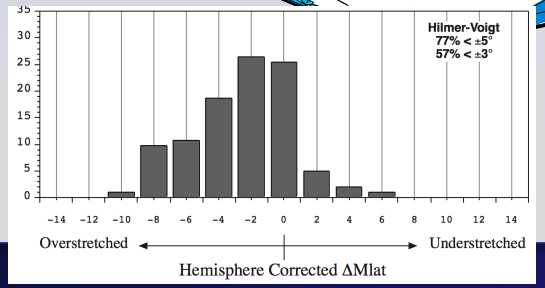


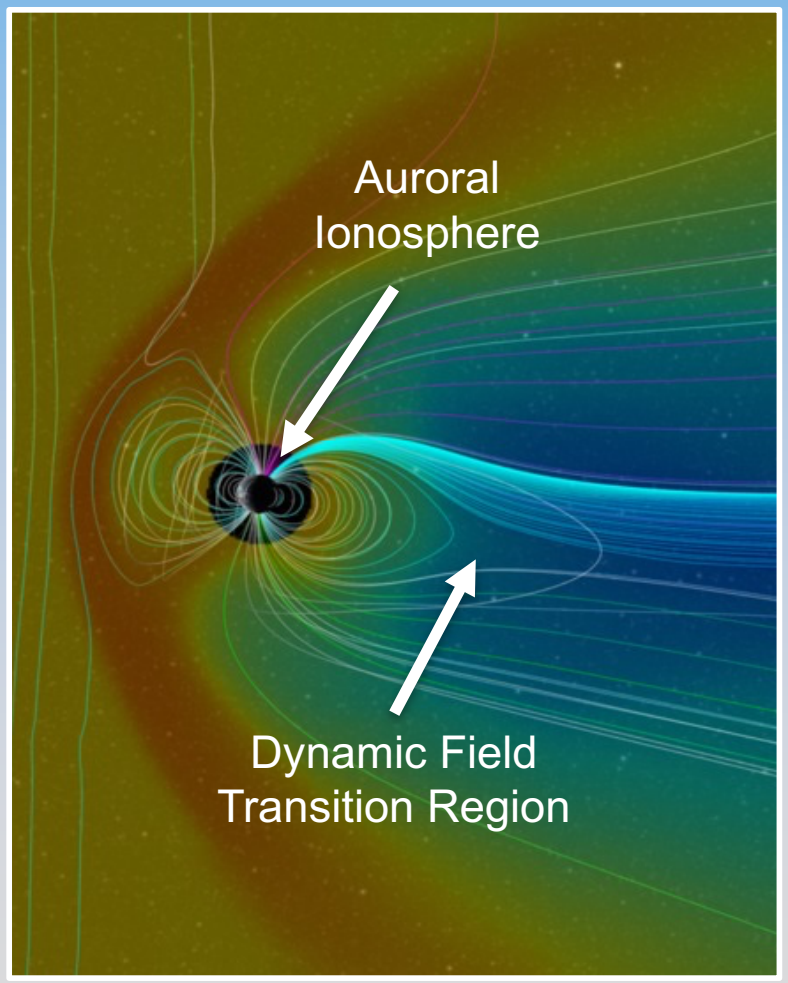
This picture is not static, and changes on minutes; as does the mapping

In this example, MMS is at 10 RE, the transition region. 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***.

Example: The foot-point of GEO was estimated by matching particle spectra from LANL GEO to DMSP. The range of estimated foot-points is not consistent with the range of magnetic mappings for reasonable parameters of T89.







The CONNEX team seeks to generate an unambiguous connection between the magnetosphere and ionosphere through an active mapping technique.

- **Eliminate reliance on magnetic field models**
- **Continuously maintain mapping knowledge throughout the dynamical evolution the coupled system**
- **Co-design ground and space segments enable real-time "sounding" of magnetic connection**

Provide answers to open questions:

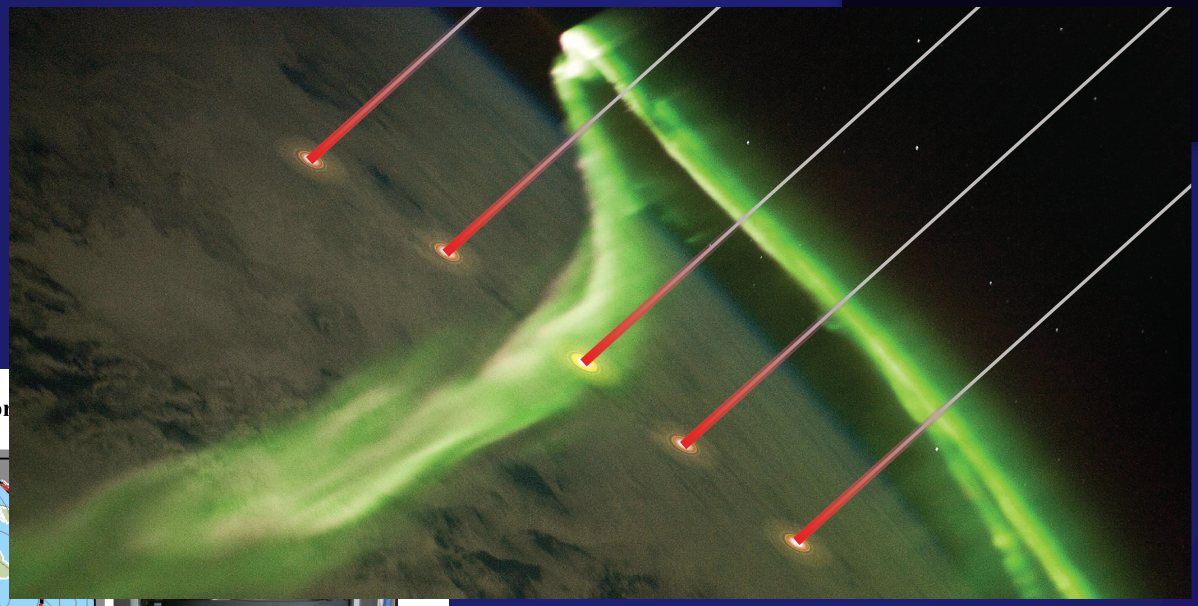
What creates the aurora?

- How are the auroral ionosphere and night-side magnetosphere connected through its time-varying magnetic field?
- What magnetospheric processes and conditions produce particular auroral and ionospheric signatures?
- What are the ionospheric signatures of specific magnetospheric regions, boundaries, and events?

CONNEX

Space Segment:

- *In situ* measurements provide magnetospheric context
- Electron accelerator regularly “paints” the field line to provide ***precise*** mapping

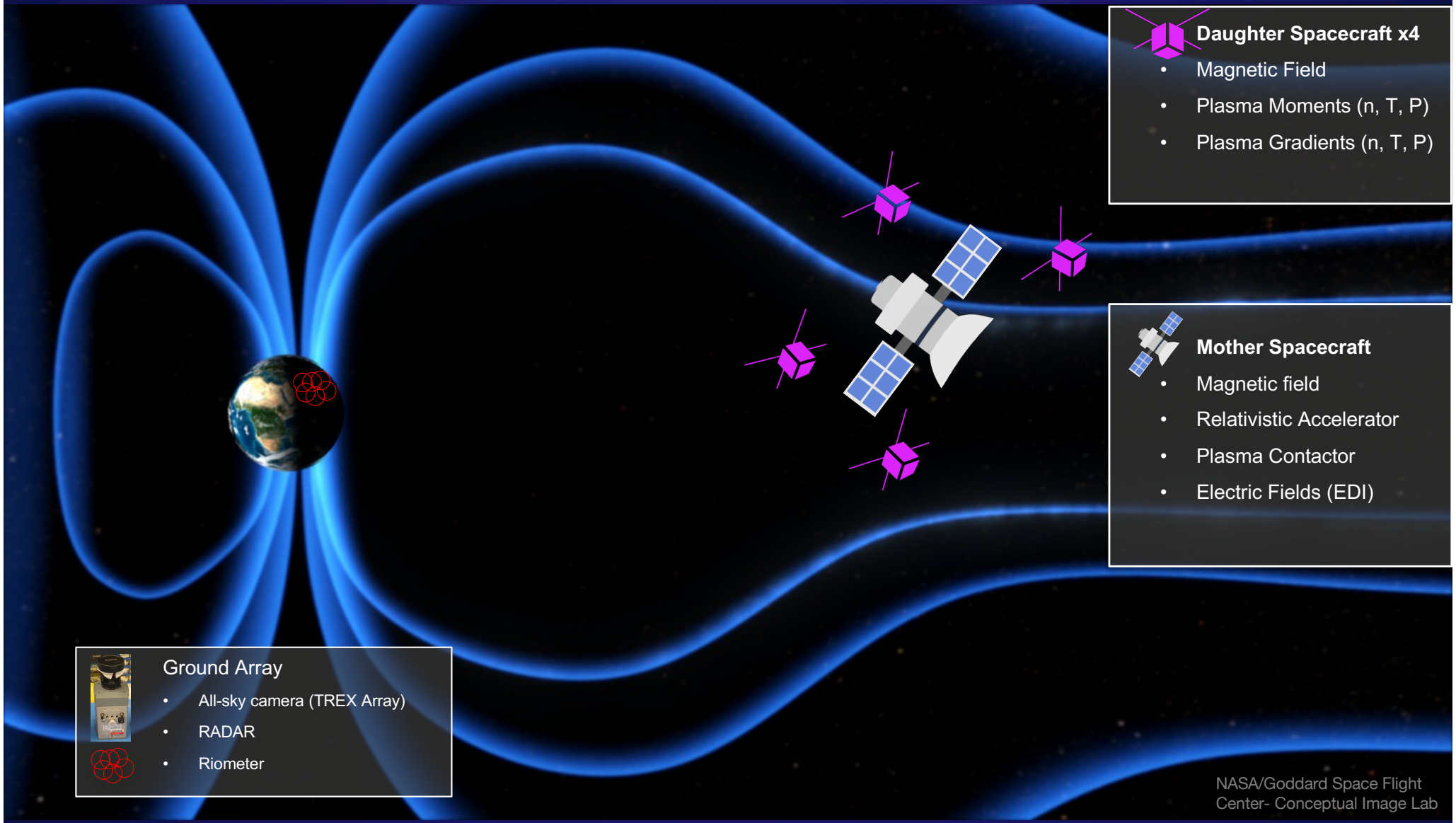


TREx – The Transition Region Explor

Ground Segment:

- Observe deposited beam spot in ionospheric context
- Enable Daytime/Nighttime Science

1. Record Magnetospheric and Ionospheric Context



Daughter Spacecraft x4

- Magnetic Field
- Plasma Moments (n, T, P)
- Plasma Gradients (n, T, P)

Mother Spacecraft

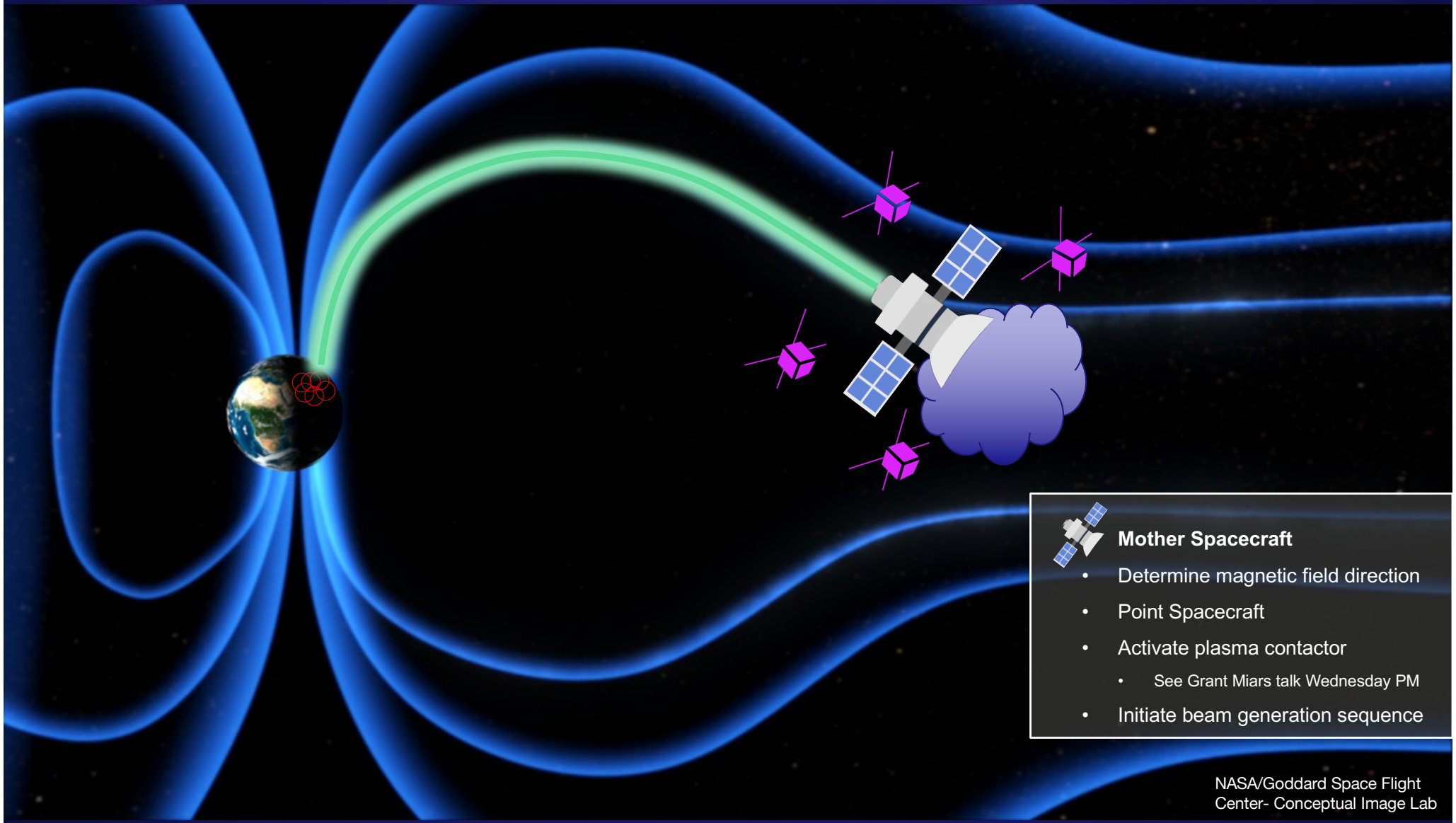
- Magnetic field
- Relativistic Accelerator
- Plasma Contactor
- Electric Fields (EDI)

Ground Array

- All-sky camera (TREX Array)
- RADAR
- Riometer

NASA/Goddard Space Flight Center- Conceptual Image Lab

2. A mapping sequence is triggered through a timed command plan or scientist in the loop activation



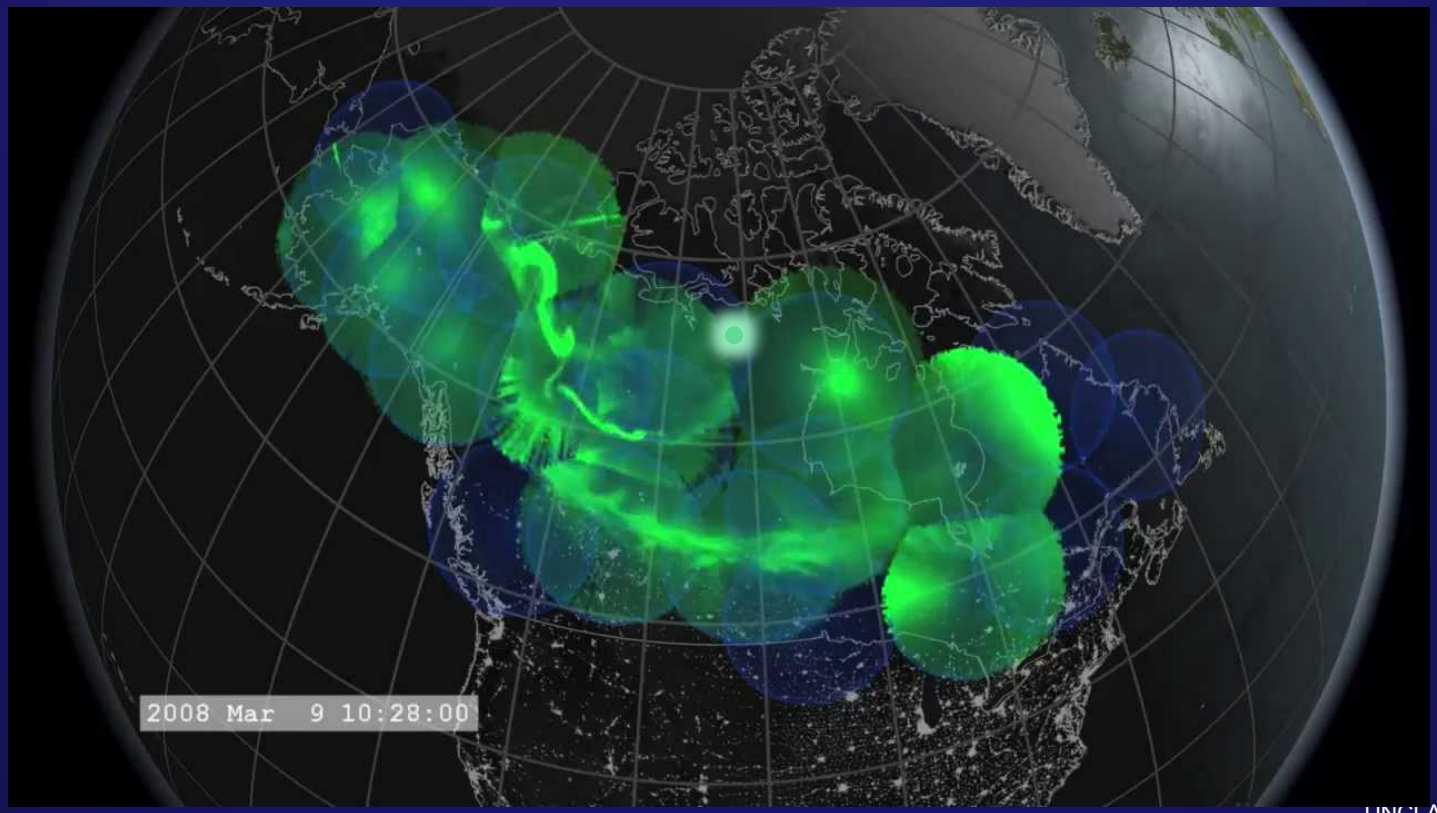
Mother Spacecraft

- Determine magnetic field direction
- Point Spacecraft
- Activate plasma contactor
  - See Grant Miars talk Wednesday PM
- Initiate beam generation sequence

NASA/Goddard Space Flight Center- Conceptual Image Lab

3. A beam burst arrives at ionosphere at regular intervals providing real-time assessments of spacecraft location in ionospheric coordinates.

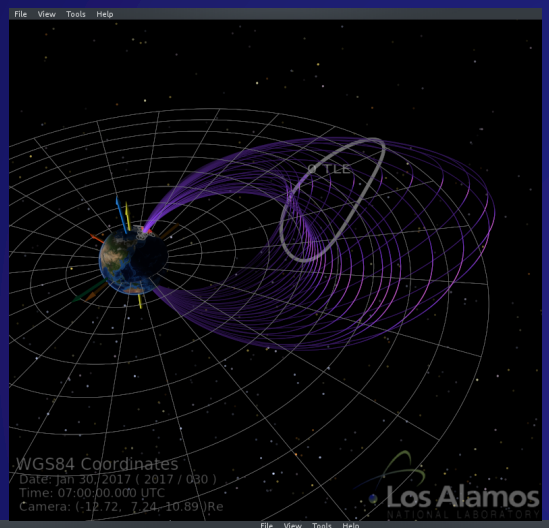
- **Beam traverses magnetic field line**
  - Stability calculations discussed in Sanchez talk Thursday AM
  - Deposition and detection discussed in Marshall talk next
- **Beam deposits energy creating light**
- **Beam is detected by all-sky cameras in auroral context**
- **Investigating RADAR possibilities incoherent scatter, SuperDARN**

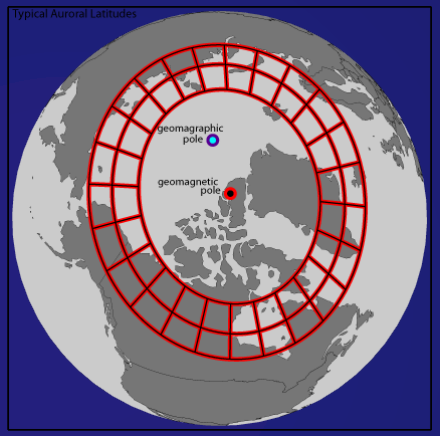


Identify orbit which dwells over TREx* for maximum conjunction with areas of ionospheric activity

Mission Orbit: 5 x 8 Re “Inclined Geosynchronous”

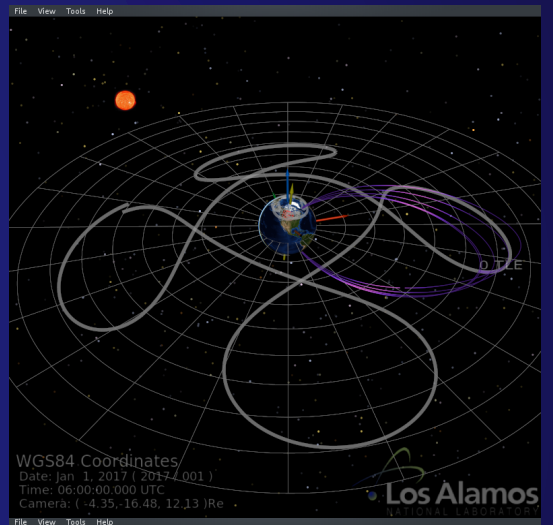
- Provides “Magnetic Ground Track” over Central Canada and TREx
- Orbit Selection Trade Underway

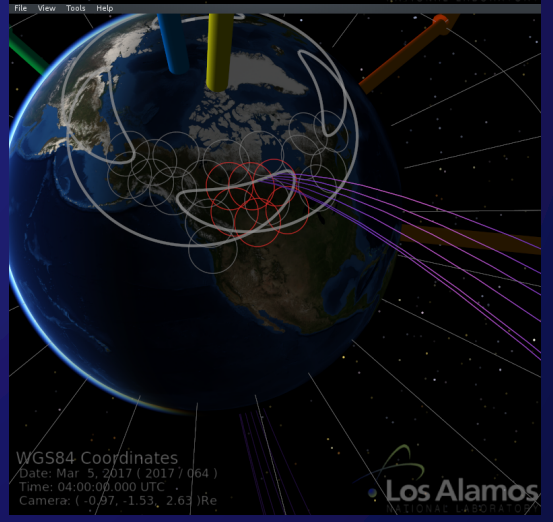




Four-Petal Elliptical Orbit

(One of many alternates studied)

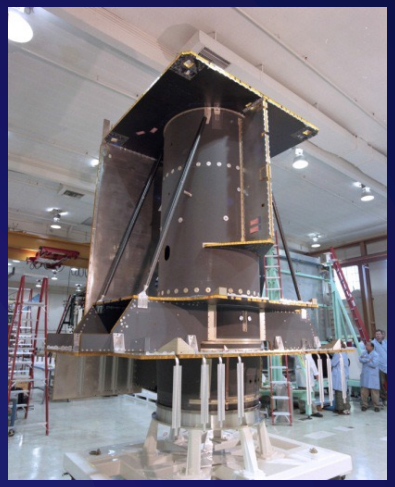




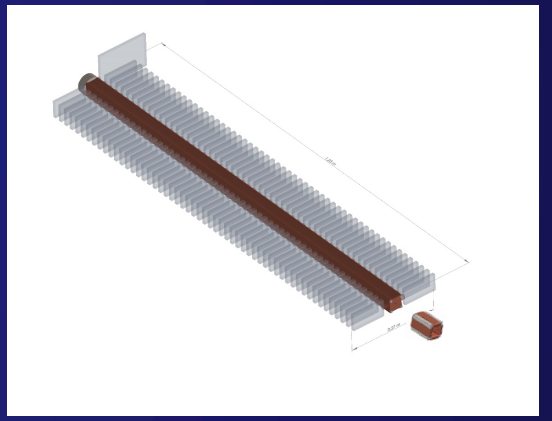
* TREx=Transition Region Explorer

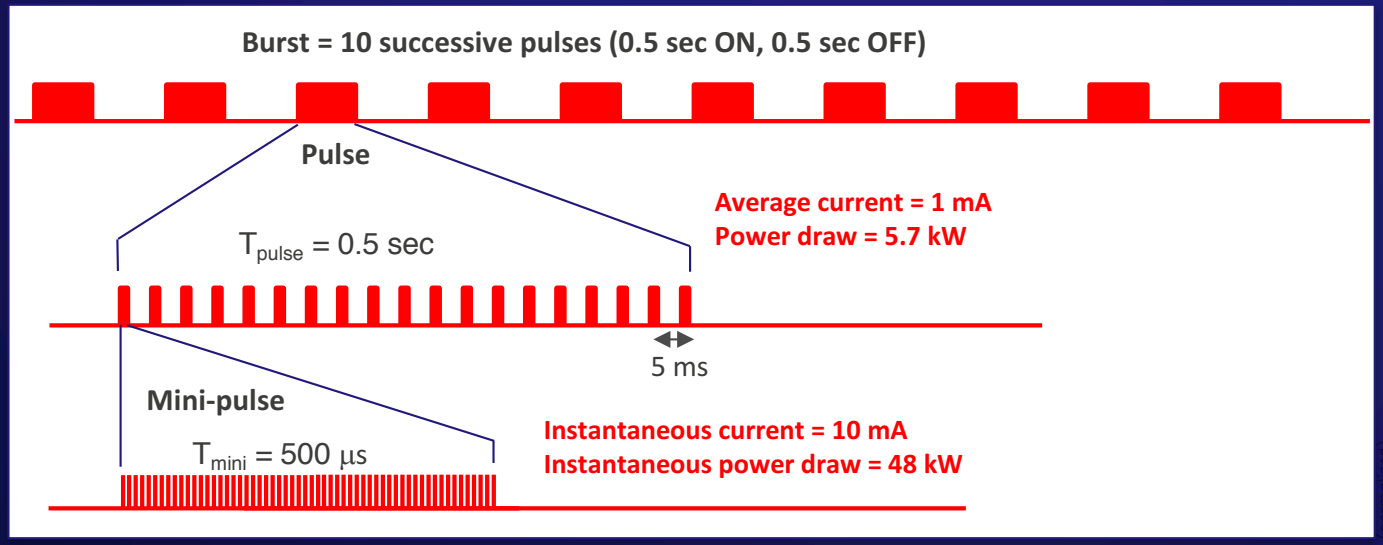
TREx FOV is RED circles

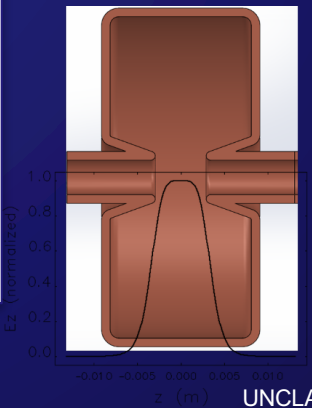
One kilowatt, relativistic beam beam generates signal detectable throughout the evolution of auroral activity



- **Configurable burst (pulse sequence) for maximum S/N**
- **Beam burst every five minutes, indefinitely**
- **Architecture is not power limited - thermal limits dominate**
- **Accelerator details discussed later this week:**
  - Lewellen talk on accelerator prototype Tuesday PM
  - Neilson talk on electron source Wednesday AM

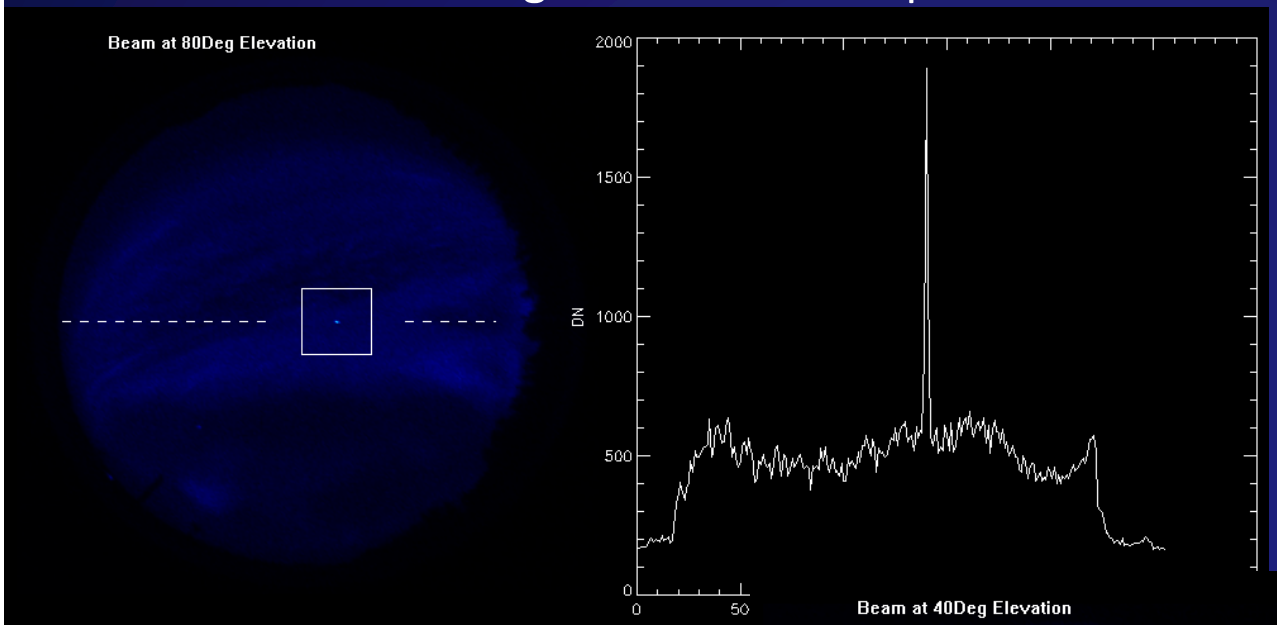


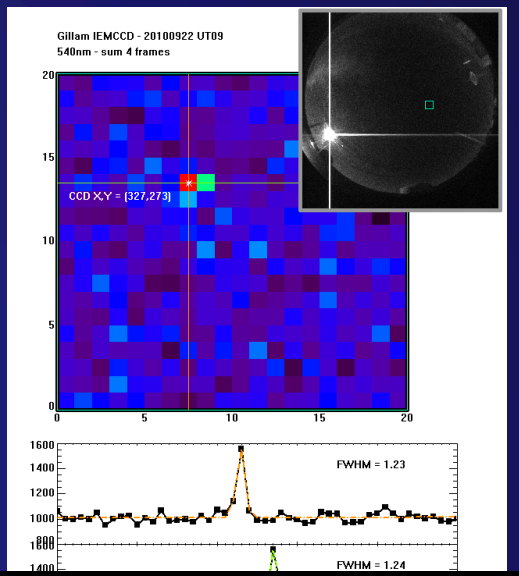




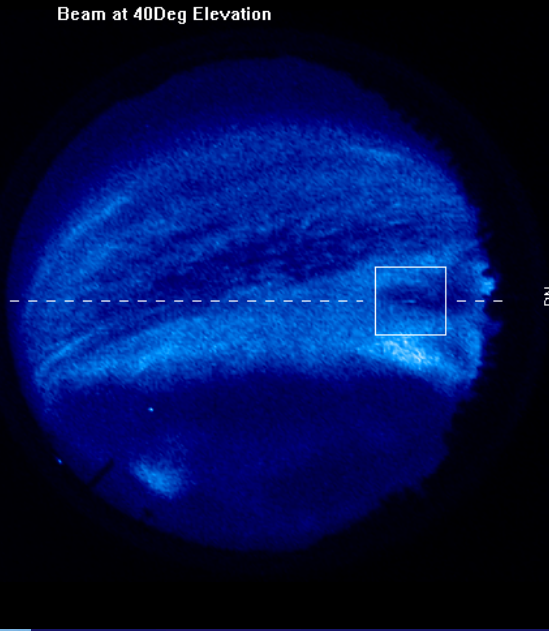
Simulations show high-confidence signal detection with Transition Region Explorer all-sky cameras against recorded background

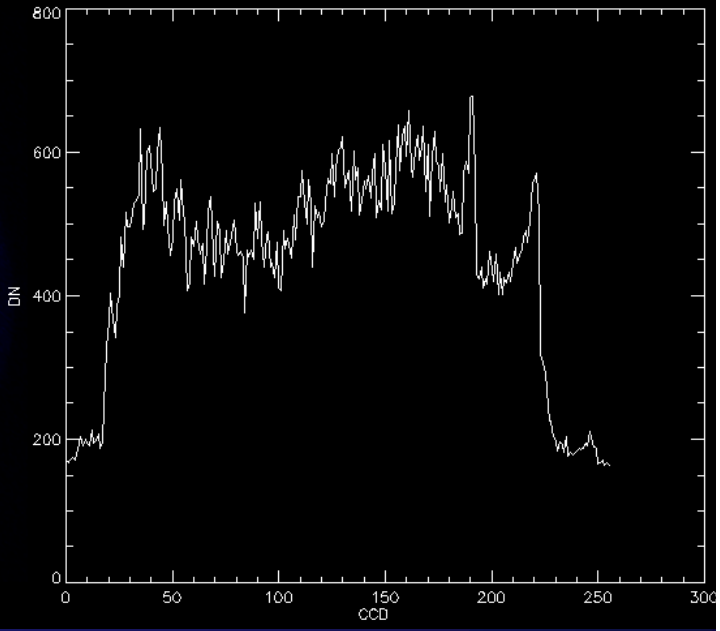
Note : these 4278 images are from the April 5th 2010 storm





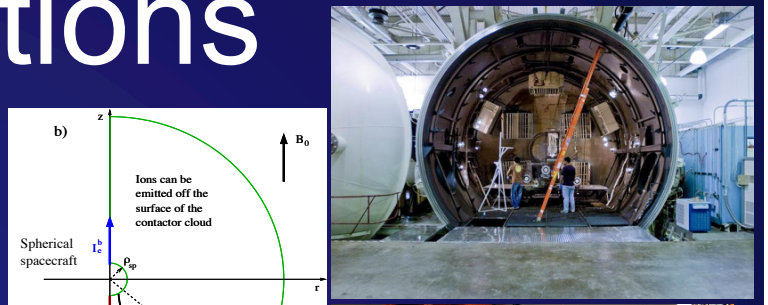
TREx – The Transition Region Explorer

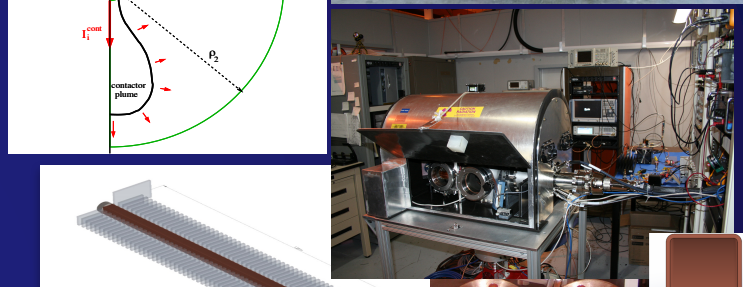


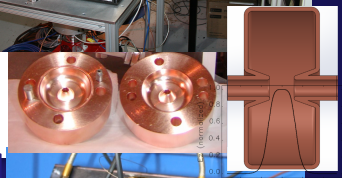


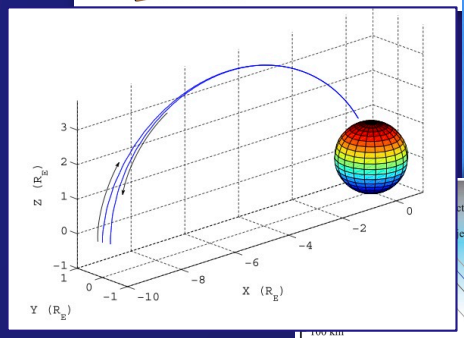
Challenges and mitigations

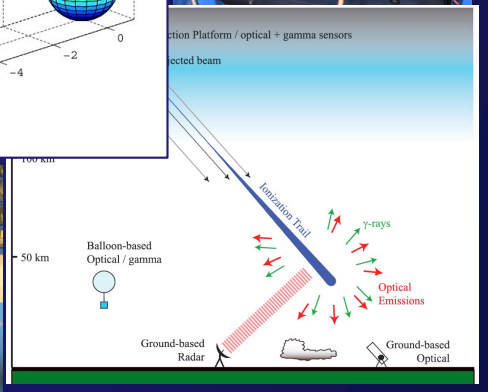
- Address spacecraft charging
  - cPIC simulation of charging environment
  - Model of plasma contactor performance
  - Experimentally validating simulation
- Operate an MeV accelerator in space
  - Leverage extensive RF accelerator expertise
  - Experimentally validate new accelerator architecture for space
- Beam propagation
  - Extensive modeling of beam propagation
- Beam detection
  - Extensive modeling of beam deposition, signal generation, and detection









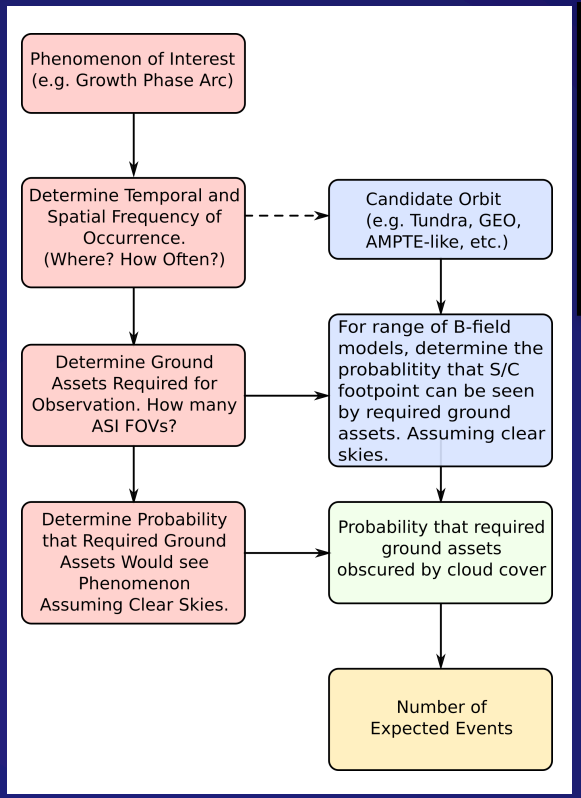


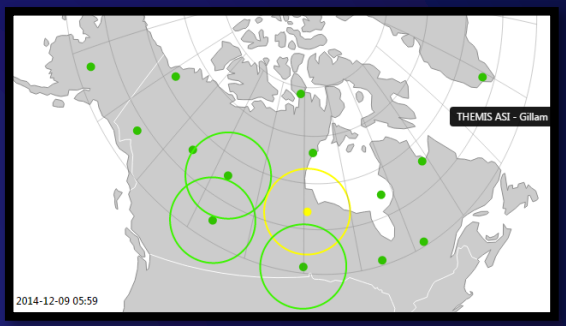
Challenges successfully mitigated through grants and internal investments.

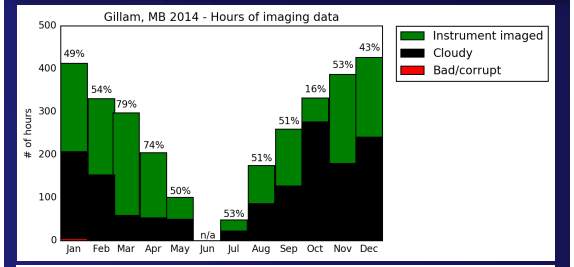
Mission Simulator for CONOPS Optimization

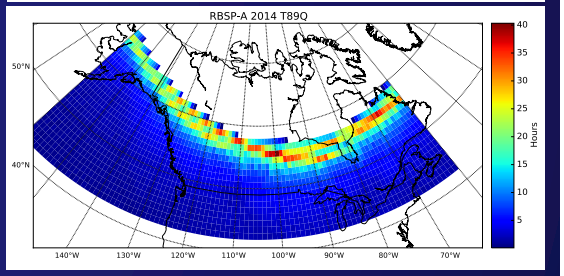
- Evaluate statistics of science targets
- Address clouds and orbits
- Optimize ground station location
- Explore multiple magnetic field models
- Explore auroral statistics

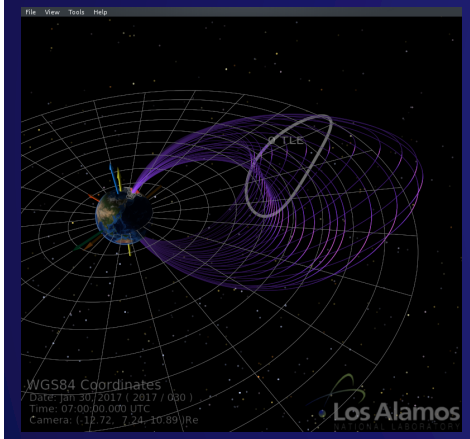
- Determine number of expected events

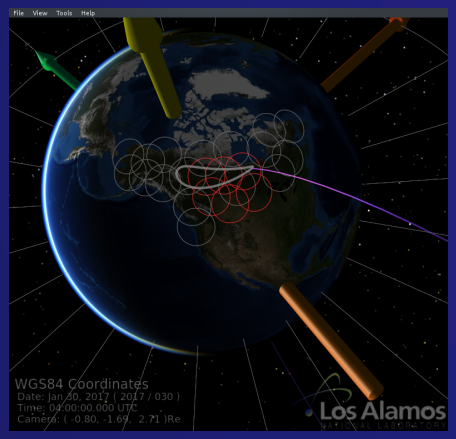


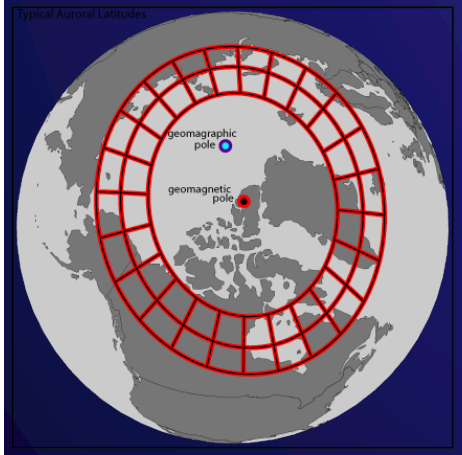


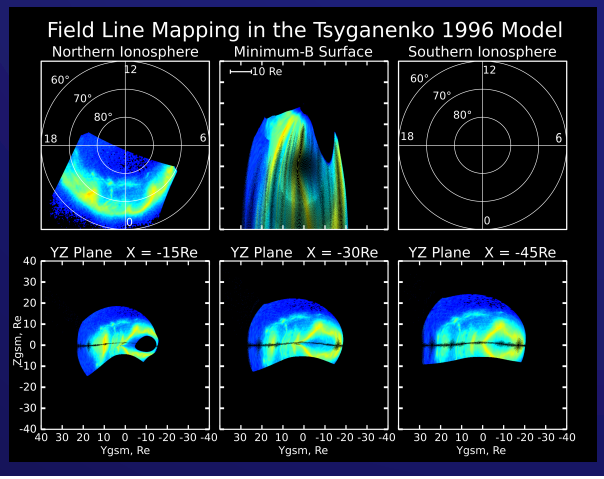


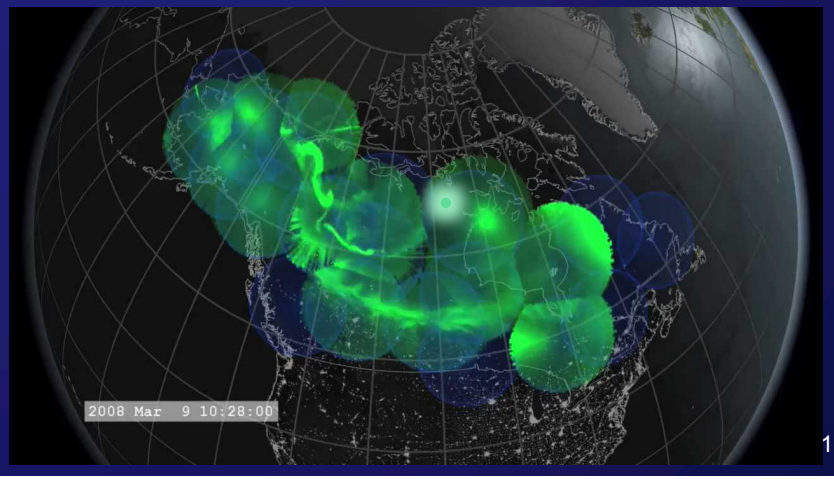




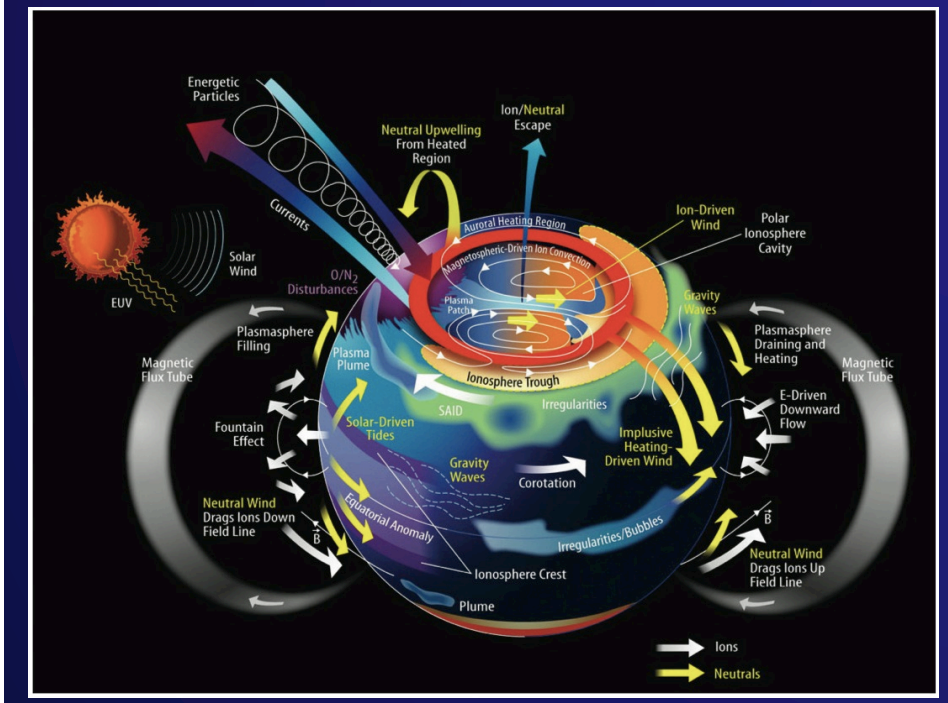


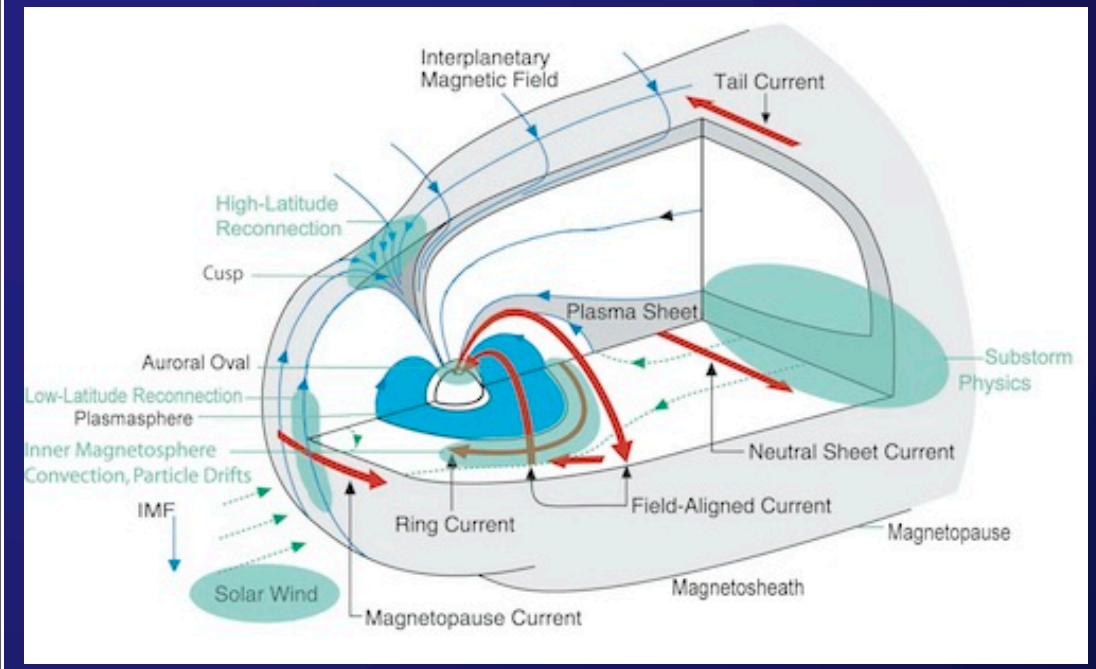






CONNEX will deliver unambiguous observations of magnetospheric processes in ionospheric coordinates AND ionospheric processes in magnetospheric coordinates





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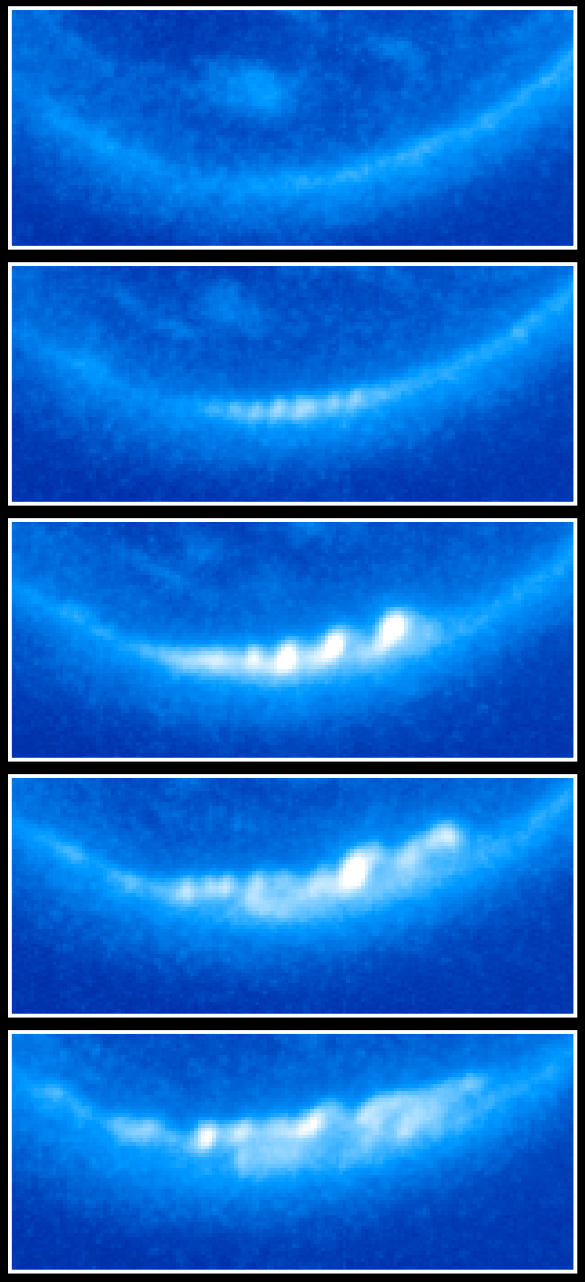
[1] Los Alamos National Laboratory; [2] NASA Goddard; [3] Space Science Institute; [4] Planetary Science Institute; [5] SRI International; [6] U. New Hampshire; [7] U. Michigan; [8] U. Calgary; [9] U. Colorado; [10] SLAC

Cloud Statistics and Expected Number of Events

M. G. Henderson, LANL
A. Boyd, NMC

July 5, 2017

IMAGE/WIC November 21, 2002



Growth phase arc deep in closed field line region (far equatorward of open−closed boundary.) Begins to brighten at onset location.

Spatially periodic intens−−ifications develop on growth phase arc.

Growth of inner magnetospheric instability.

Poleward distortion and growth of periodic forms.

Continued poleward expansion. Forms begin to distort into an east−west alignment at their poleward edge.

Distortions have developed into an east−−west aligned arc system at the poleward edge of the expanding bulge.

Midtail X−line forming.

Growth Phase Arc

- Growth phase arc is present for ~30-60min prior to onsets.
- It is much wider in MLT than the onset region.
- Perhaps ~4hours in MLT or ~1/3 of the nightside sectors.

Growth Phase Arc Occurrence Frequency

- Periodic substorms occur approximately every 2-4 hours on average.
- But we don't see periodic substorms all the time.
- Assume ~4 substorms per day.
- Growth phase arc exists ~2-4 hours per day.
- Visible for 1-2 hours per day on nightside (our orbit will be on dayside ½ the time.)
- ~5-10% of each (~12h) night.
- This would be much higher if we just want arcs of any sort.

Statistical Location of Onset

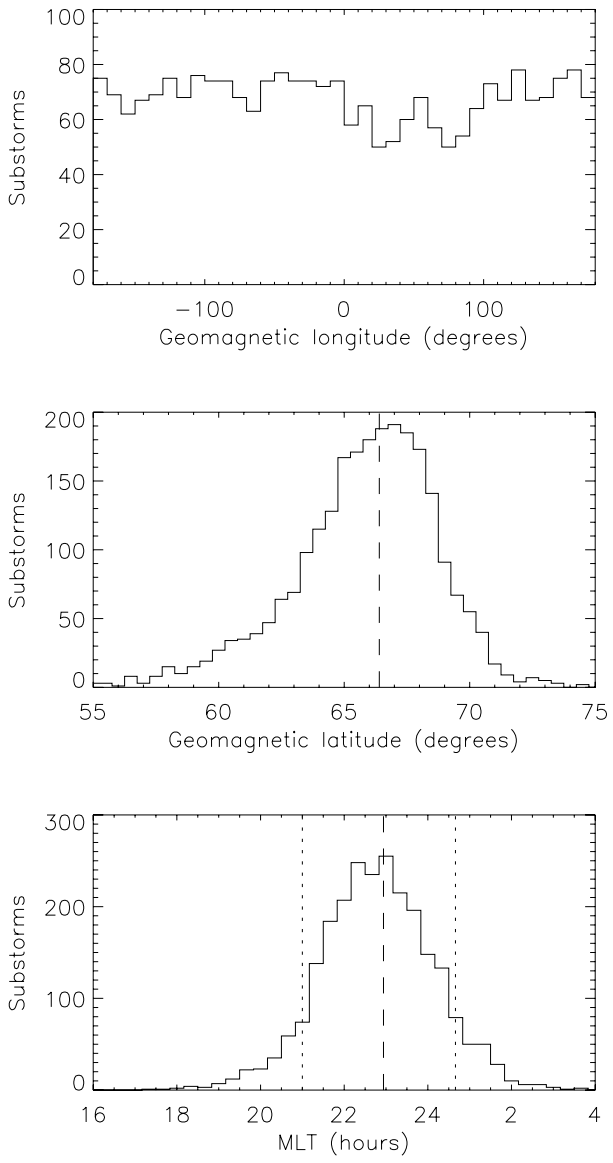
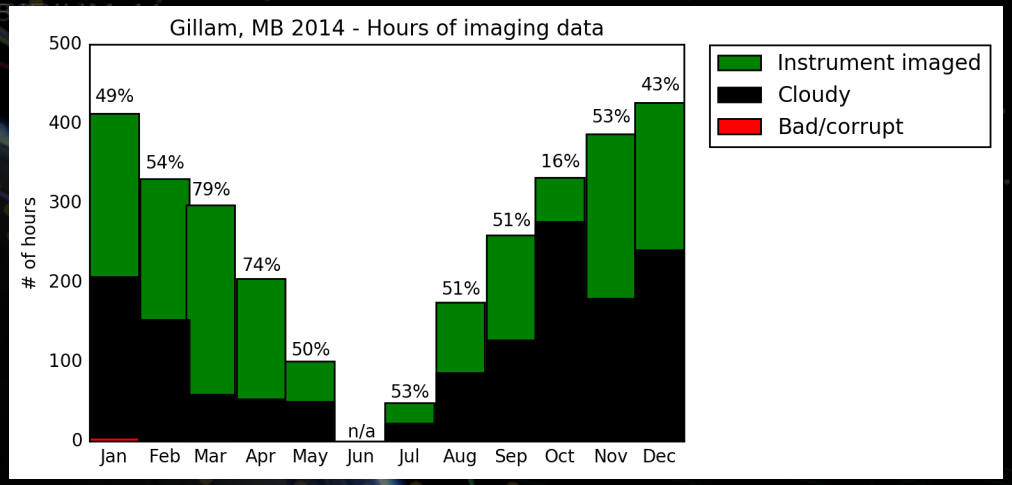
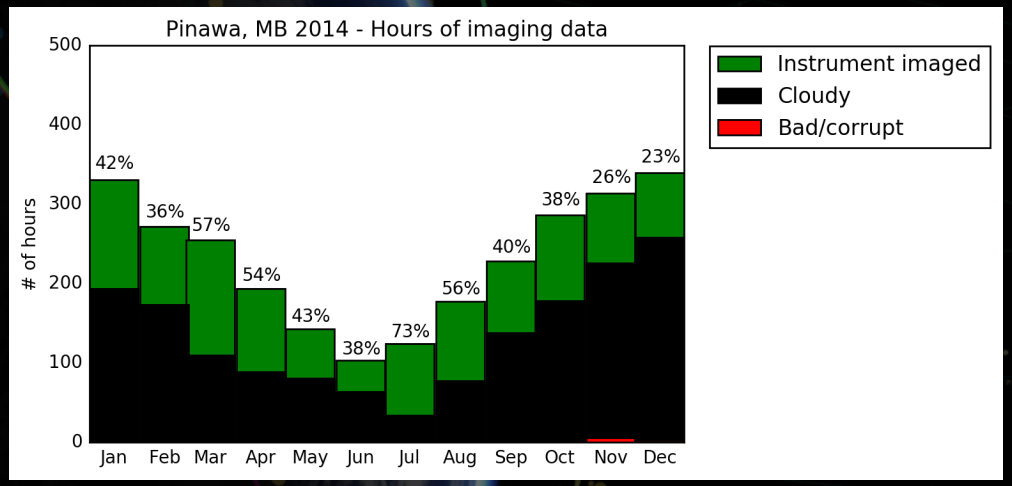


Figure 2. Histograms of the distribution of substorm onsets in geomagnetic longitude (top), latitude (middle), and local time (bottom). The median values are marked in the two bottom panels. The last panel also shows the range in local time with more than 80% of observed substorms (10% on each side). Frey et al., 2004

- Statistical location of onsets in the IMAGE-FUV auroral dataset.
- Onset latitude is an excellent proxy for statistical latitude of growth phase arc.
- Almost all onsets between 60° and 70°.
- T-REX is in the right latitude to see most of them.
- Assume ~90%

Cloudiness Over T-REX Stations

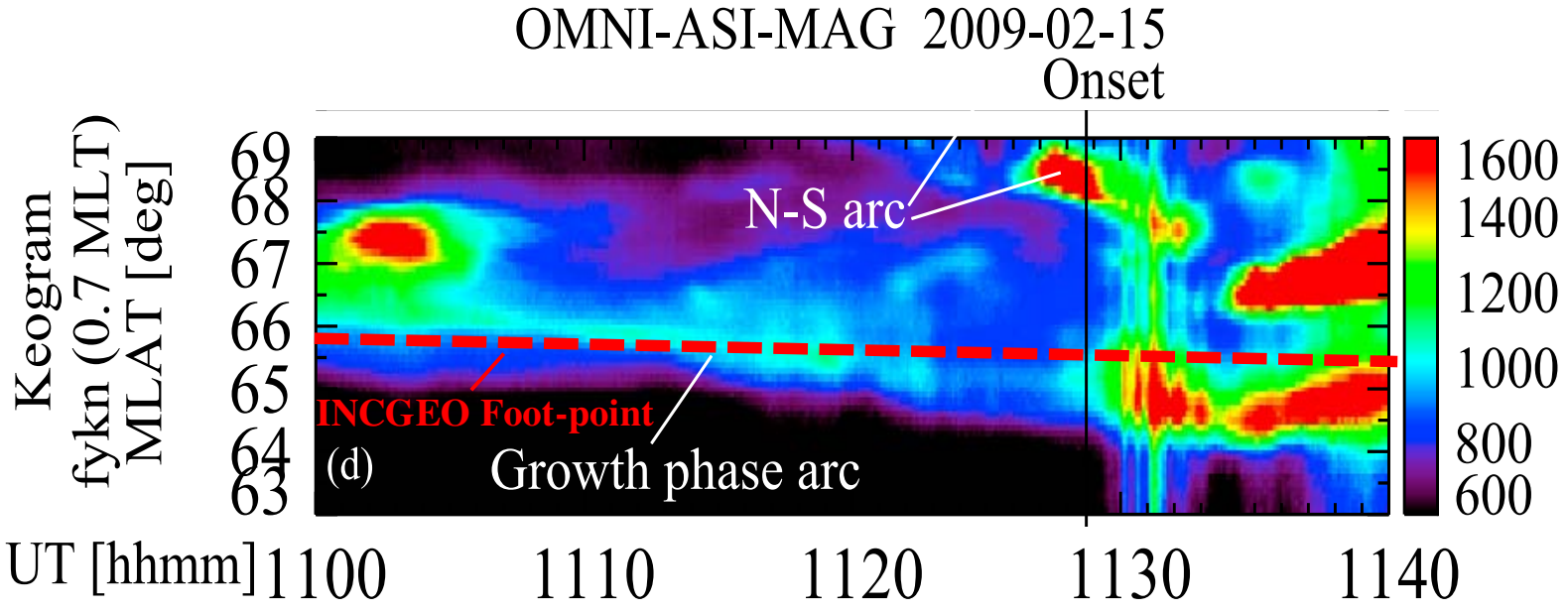




E. Spanswick

- Cloud cover stats over two of the T-REX stations: Gillam and Pinawa.
- Over Gillam, ~1500hrs of cloud-free viewing for 2014.
- Assume that GP arcs exist for 5-10% of time and that 1/3 of them overlap T-REX array in MLT and 90% in latitude.
- We should capture ~1500/3 * .05 * .9
- 23-45 good growth phase arcs per year.

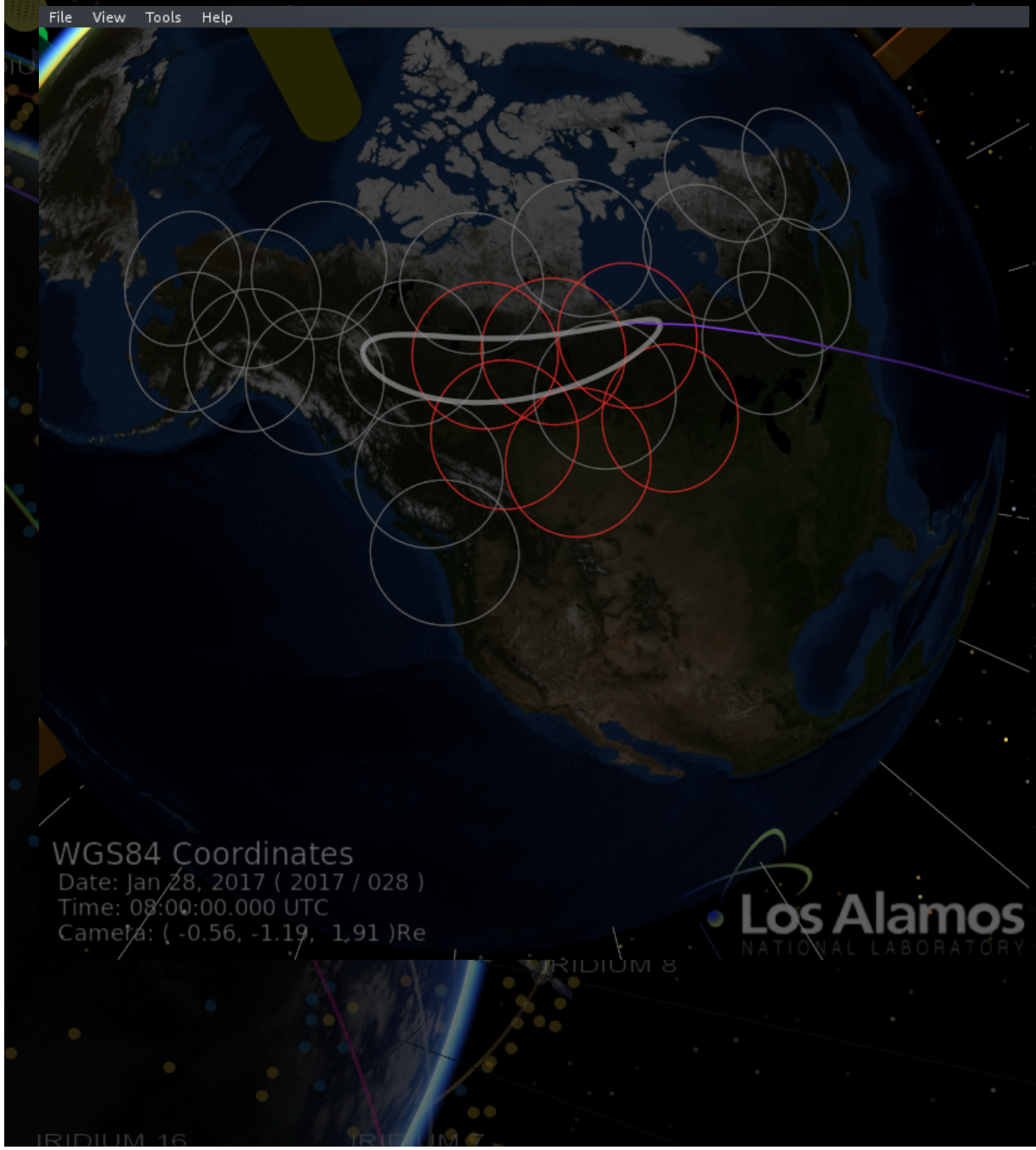
Latitudinal Motion of Growth Phase Arc and Inclined GEO Orbit



Adapted from Nishimura et al., [2010]

- Keogram from Fort Yukon showing Inclined GEO S/C footpoint.
- Growth phase arc moves equatorward ~3°/hour on average (Coumans et al. [2007].)
- Orbit could potentially be tuned to increase/decrease (nominal) rate of crossing.

Inclined GEO orbit



- Inclined GEO orbit is over the THEMIS ASIs basically full time when its dark.
- So, we should be able to do 23-45 clear mappings per year with GP arcs present.
- How many crossings?? From Coumans et al. [2007], GP arc moves ~3°/hr.
- Inclined GEO crossing at ~66° MLAT would see ~15-20% move across the footpoint.
- ~4-10 crossings of a pre-substorm GP arc per year. (8-20 for 2-year mission.)
- Moonlight degradation may reduce high quality crossings by a factor of ~3/2.
- ~5-13 very high quality crossings for a 2-year mission.