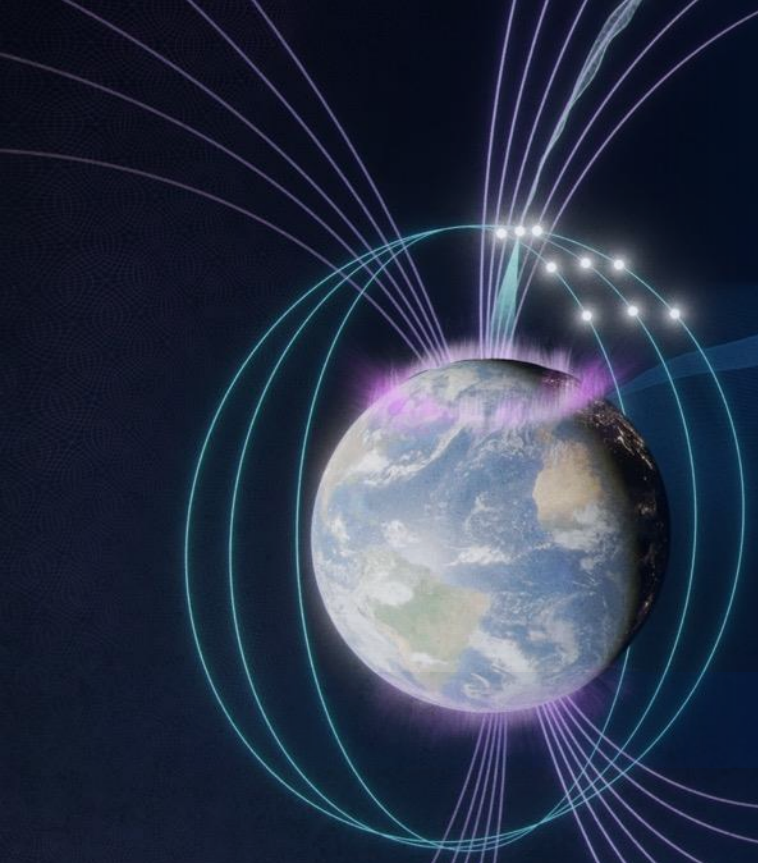

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CINEMA

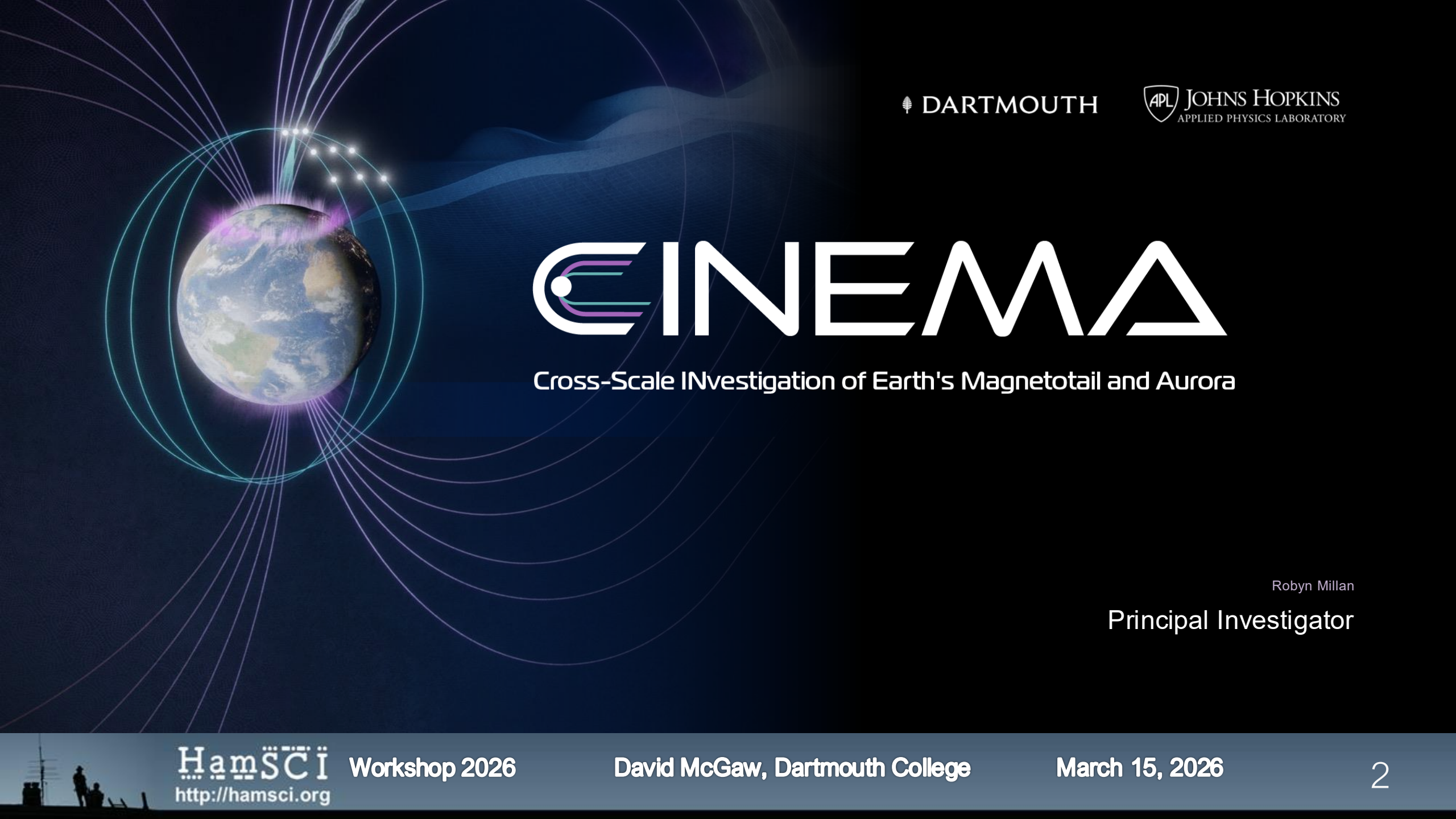
Cross-Scale INvestigation of Earth's Magnetotail and Aurora

MOVIE

Multi-platform Observations from Volunteers: Ionospheric Experiments

CINEMA Citizen Science Investigation

David McGaw, Robyn Millan, Michael Hartinger, Nathaniel Frissell, Kristina Collins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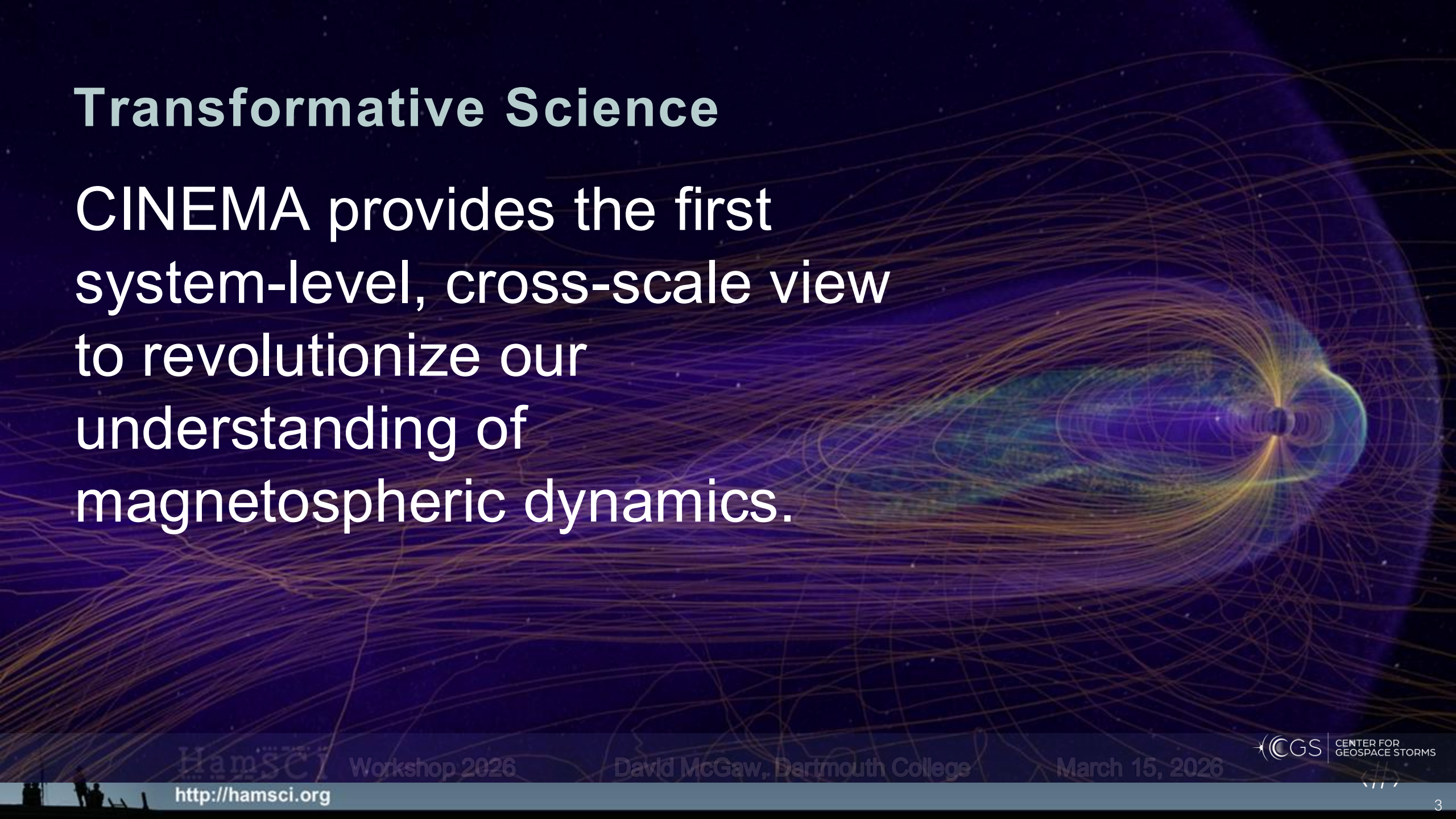
APPLIED PHYSICS LABORATORY
CINEMA
Cross-Scale INvestigation of Earth's Magnetotail and Aurora
Robyn Millan
Principal Investigator

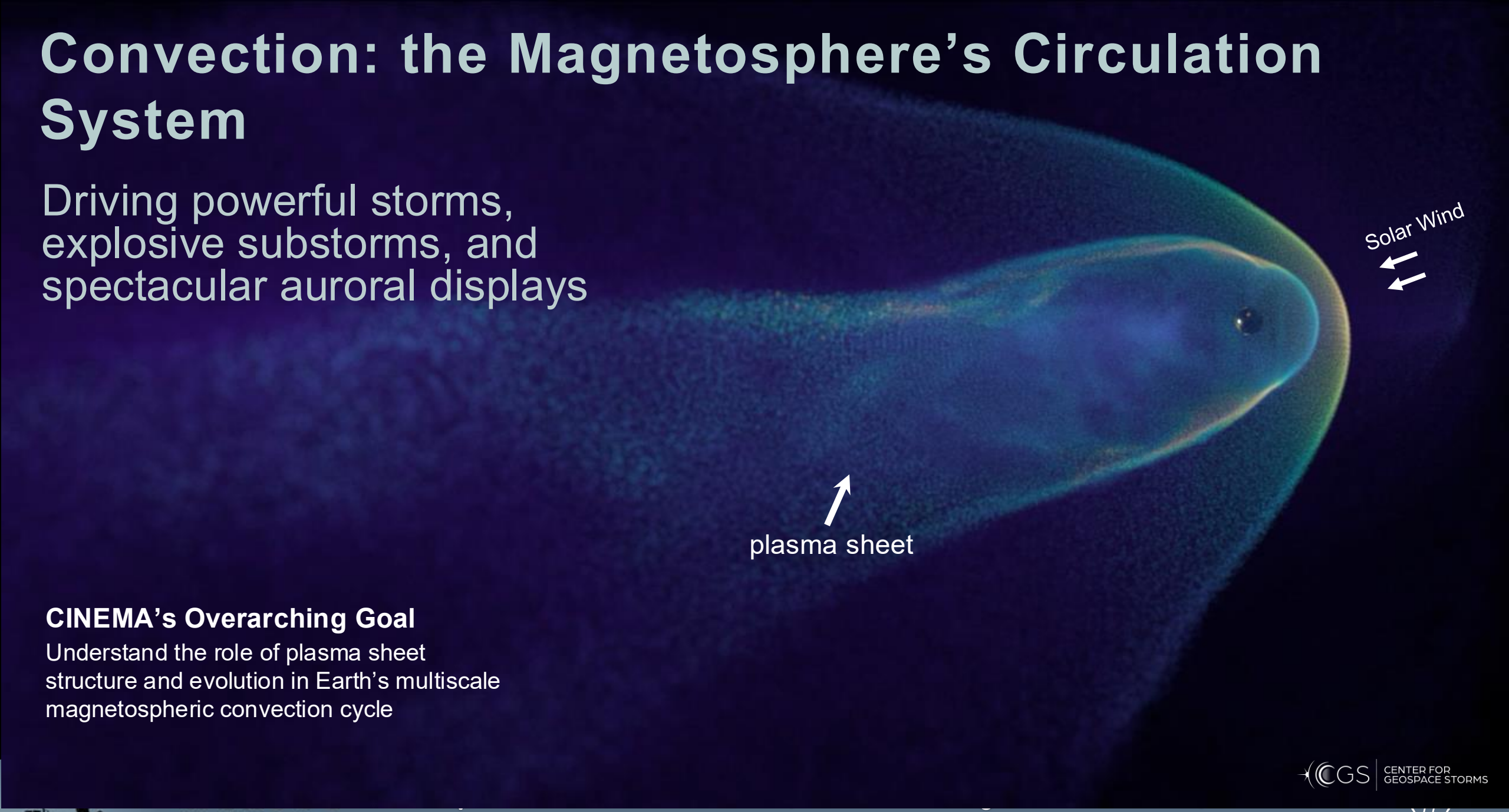
Transformative Science

CINEMA provides the first system-level, cross-scale view to revolutionize our understanding of magnetospheric dynamics.



Convection: the Magnetosphere's Circulation System

Driving powerful storms, explosive substorms, and spectacular auroral displays

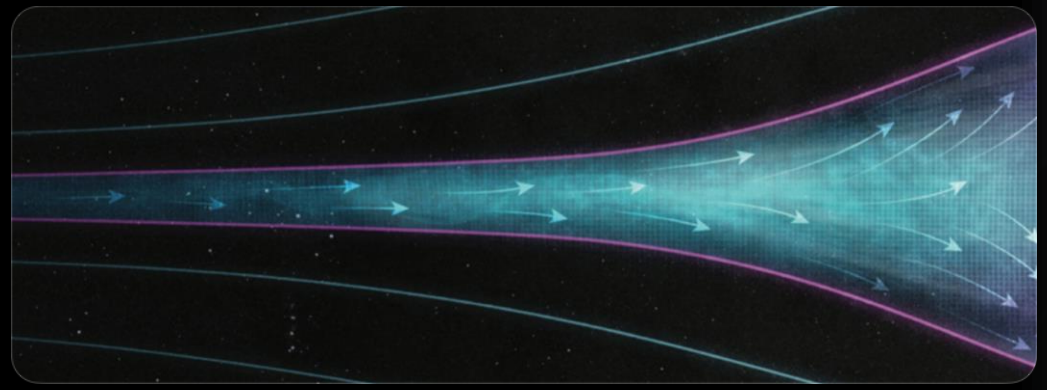


CINEMA's Overarching Goal

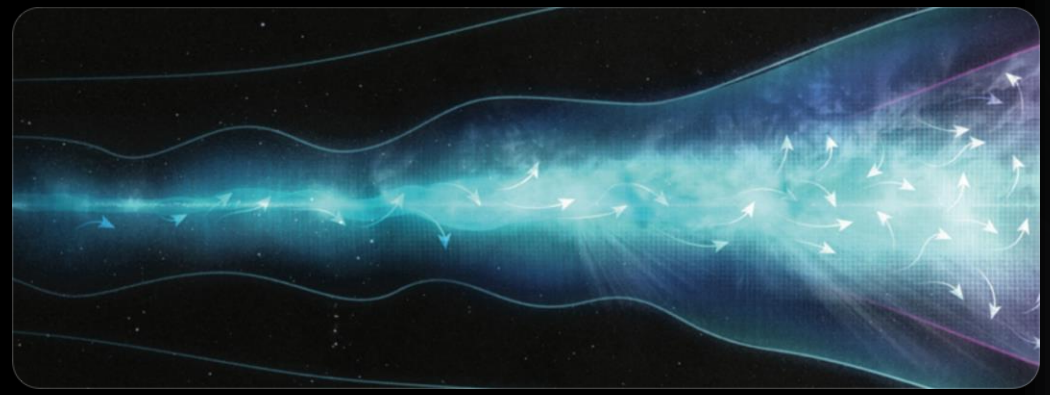
Understand the role of plasma sheet structure and evolution in Earth's multiscale magnetospheric convection cycle

CGS CENTER FOR GEOSPACE STORMS

The Mystery of Magnetotail Convection



How does the magnetotail maintain steady convection?



What determines when and how the magnetotail explosively releases its stored energy?

Magnetotail Convection Is Multiscale

It is not well understood how large-scale conditions control microscale processes, how the microscale processes impact the global dynamics, and how the interaction and feedback between the various scales operate.

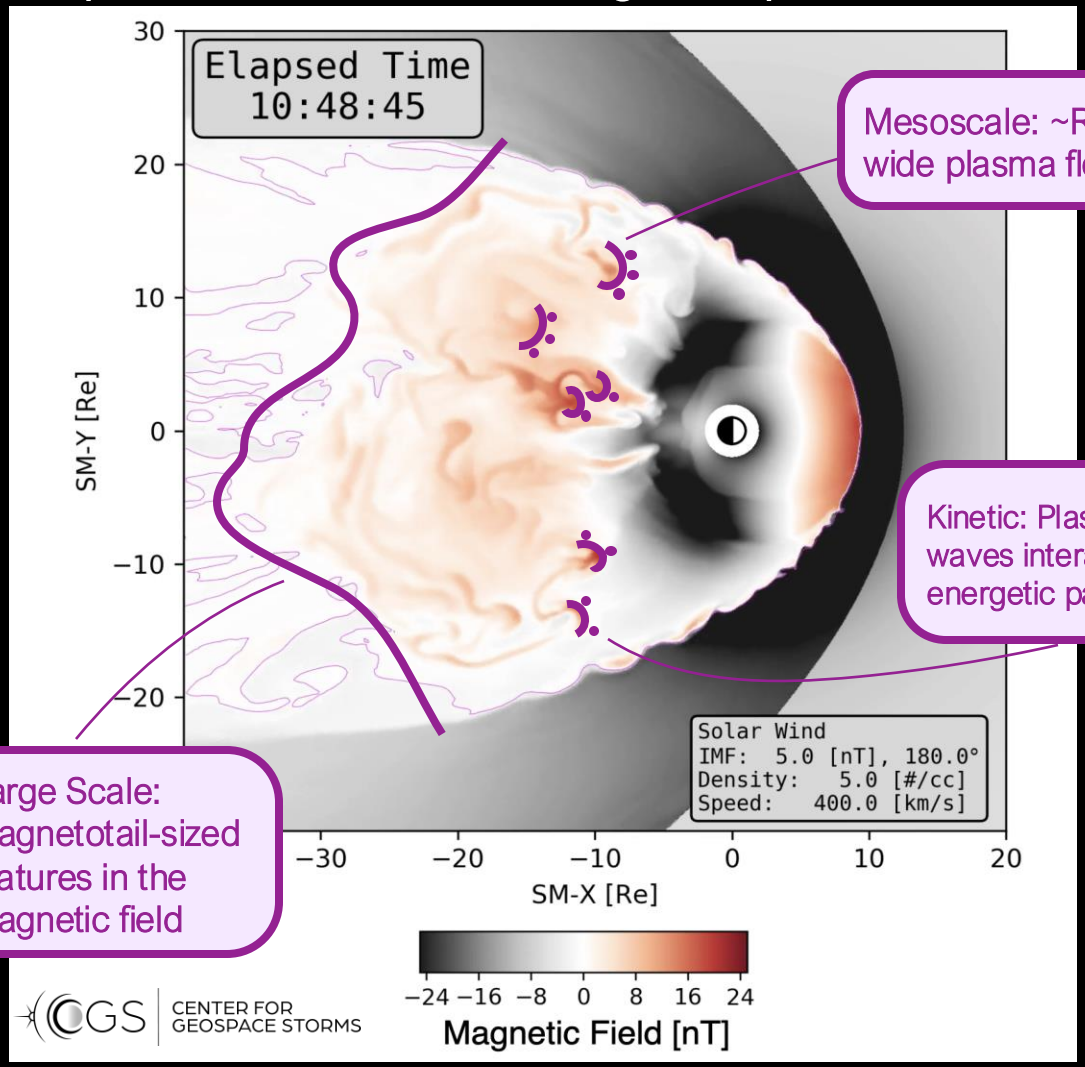
—2024 Decadal Survey

SO1: Large Scale
Determine the large-scale structure and evolution of the plasma sheet for different magnetotail convection regimes.

SO2: Mesoscale
Determine the link between mesoscale dynamics that manifest in the aurora and the structure of the plasma sheet.

SO3: Kinetic Scale
Determine the connection between particle precipitation attributed to kinetic wave effects and mesoscale dynamics.

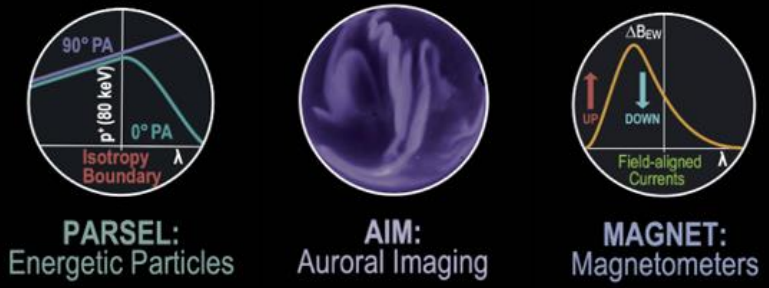
Equatorial View of the Magnetosphere



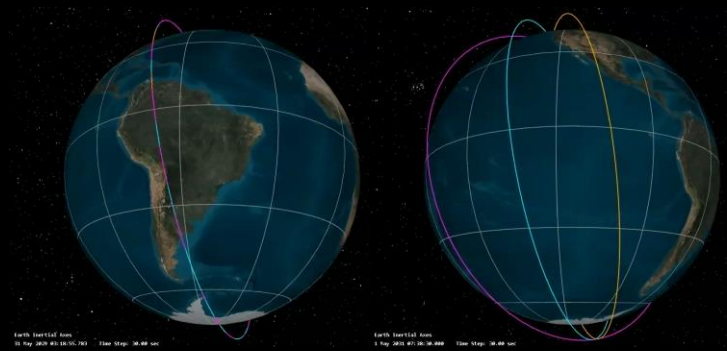

TECHNICAL AND
SCIENTIFIC INNOVATION

Three Powerful Design Strategies

Polar-orbiting satellites

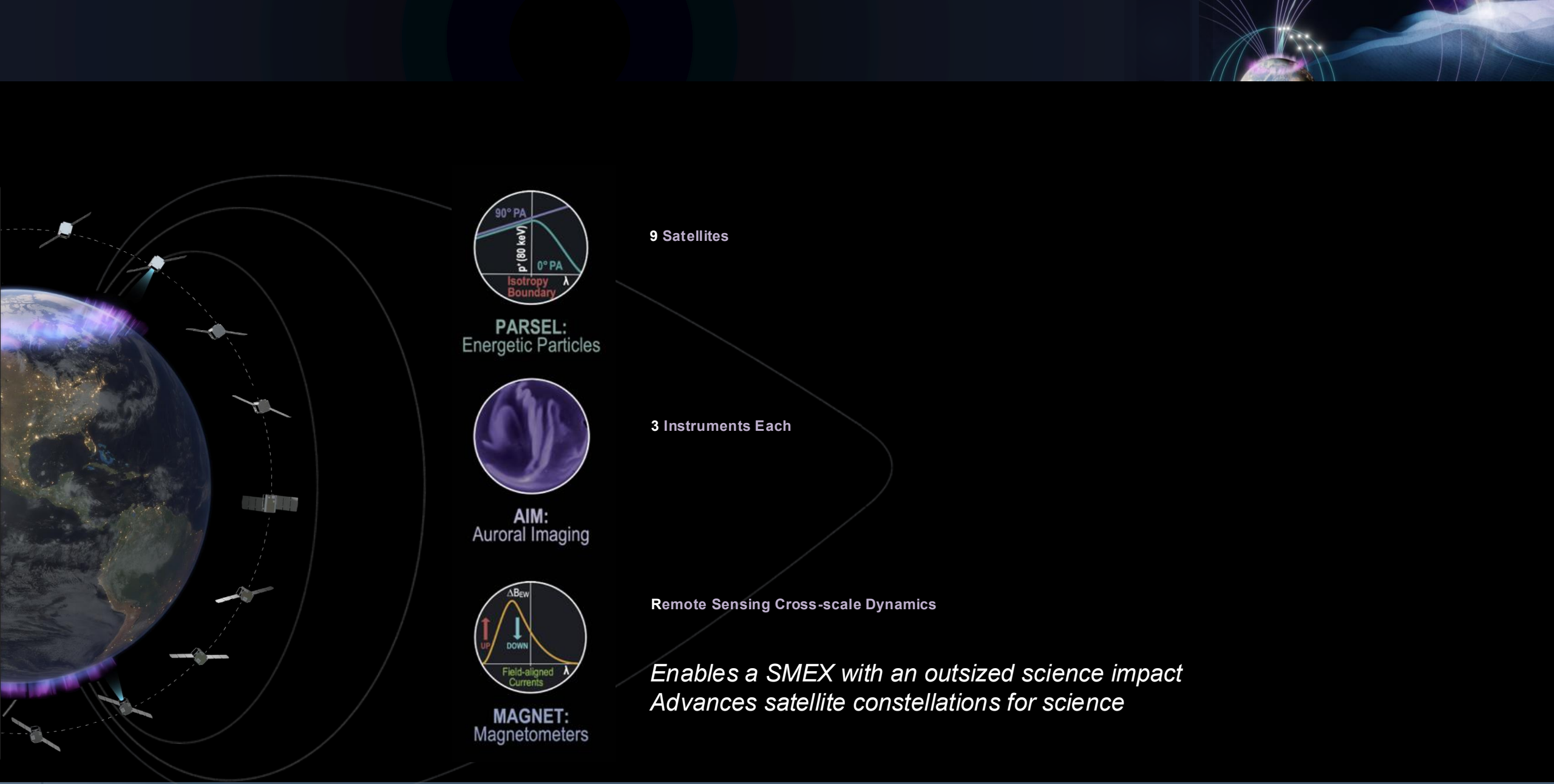


Remote sensing technique



Evolving satellite constellation

CINEMA tackles the mystery of magnetotail convection with three innovative design strategies.



9 Satellites

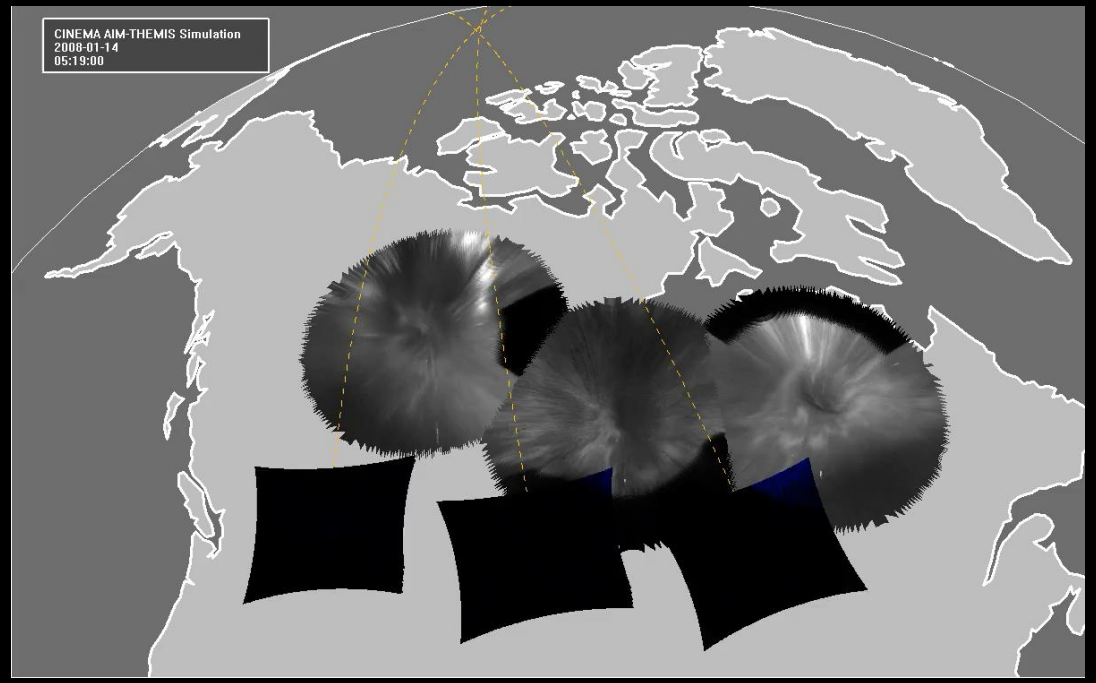
3 Instruments Each

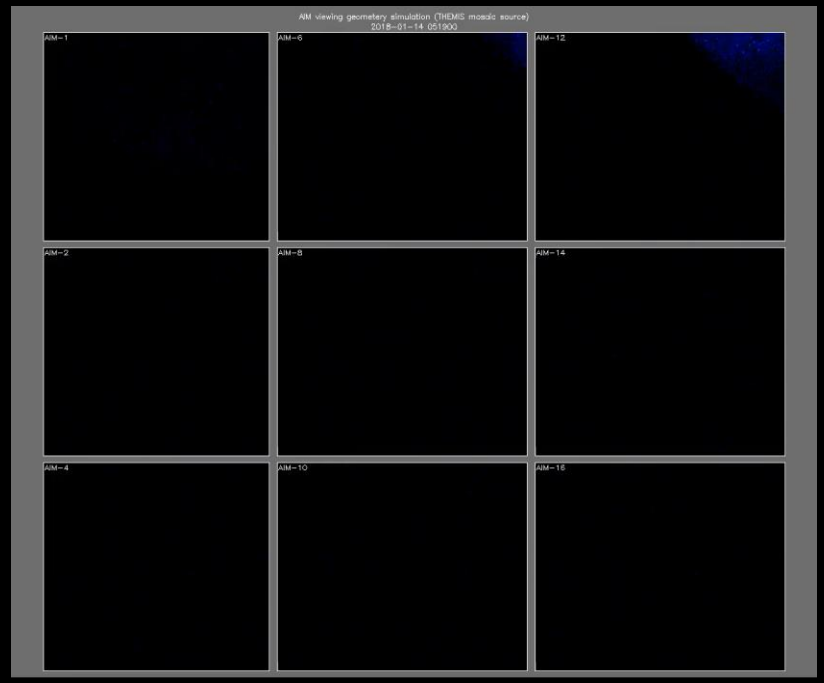
Remote Sensing Cross-scale Dynamics

Enables a SMEX with an outsized science impact
Advances satellite constellations for science

Remote Sensing: Imaging

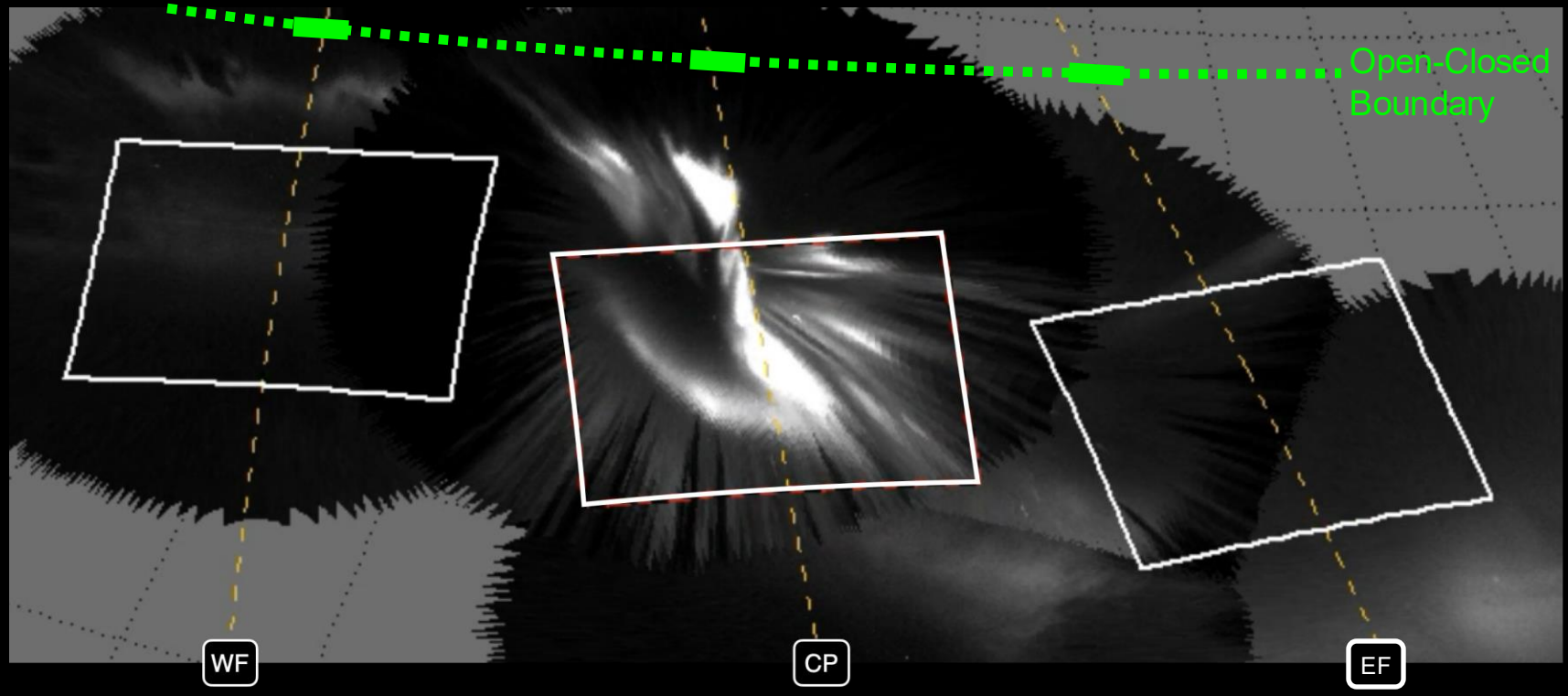
Auroral imaging is used identify substorm expansion and mesoscale convection events.



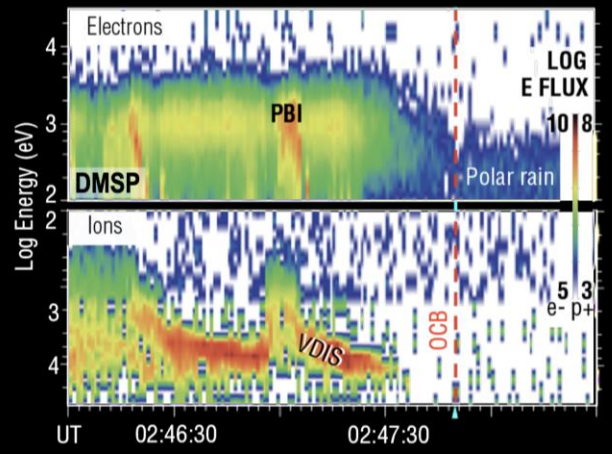


Remote Sensing Open-Closed Boundary

Energetic particles carry the signatures of key magnetospheric boundaries.



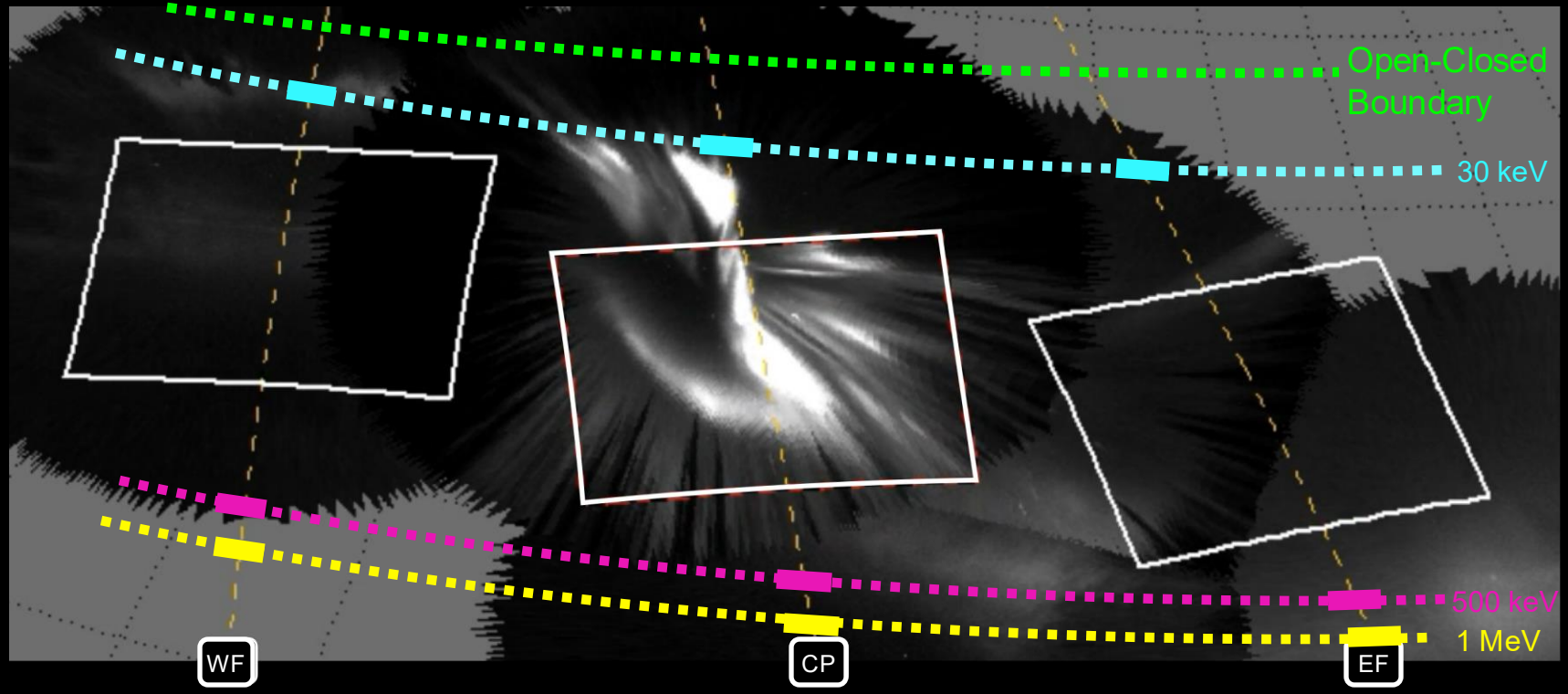
Open-Closed Boundary Reconnection Signatures



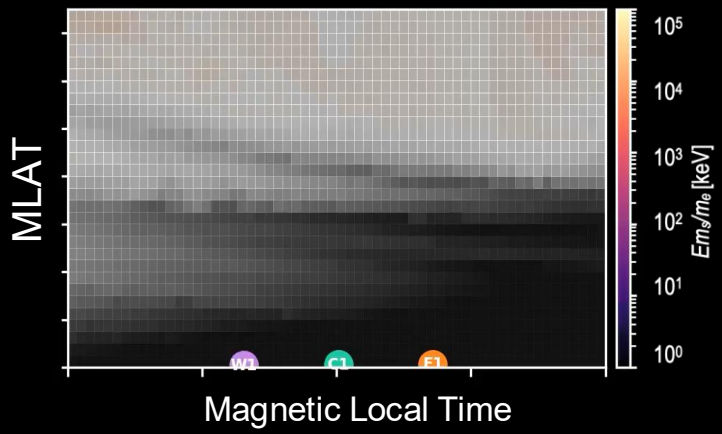
Pitch angle and energy-resolved:
electrons: 100 eV – 2 MeV
ions: 0.1–375 keV

Remote Sensing Magnetic Terrain

Magnetic terrain is imprinted on particle distributions.



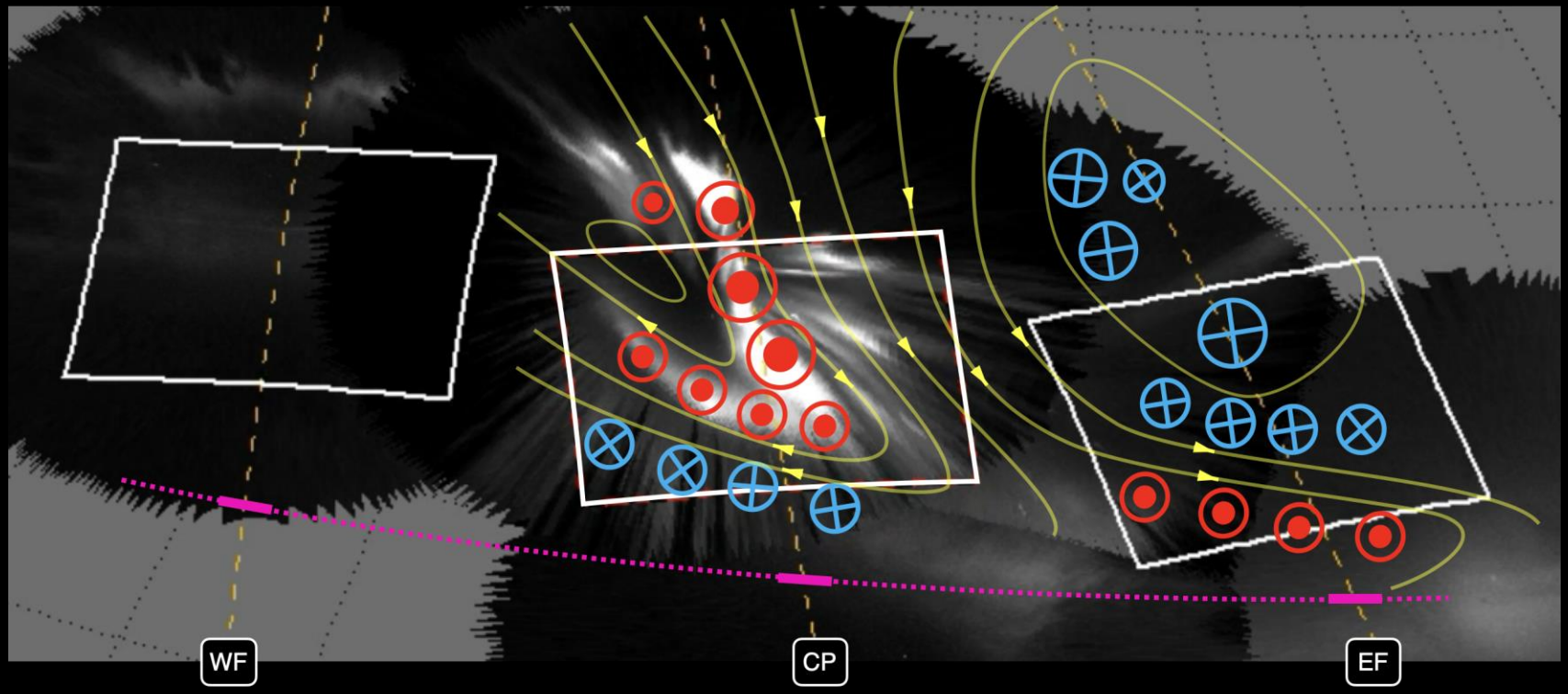
Isotropy Boundary Profile Resolves Magnetic Terrain

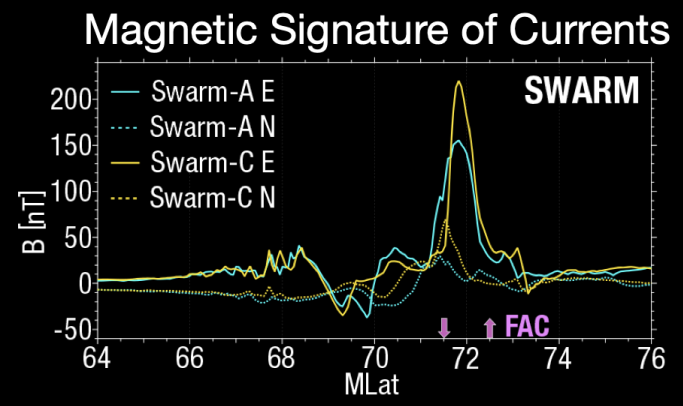


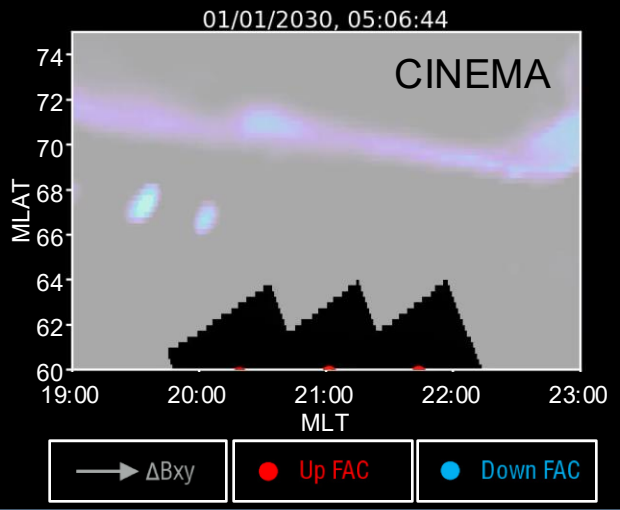
Pitch angle and energy-resolved:
electrons: 100 eV – 2 MeV
ions: 0.1–375 keV

Remote Sensing Electrical Currents

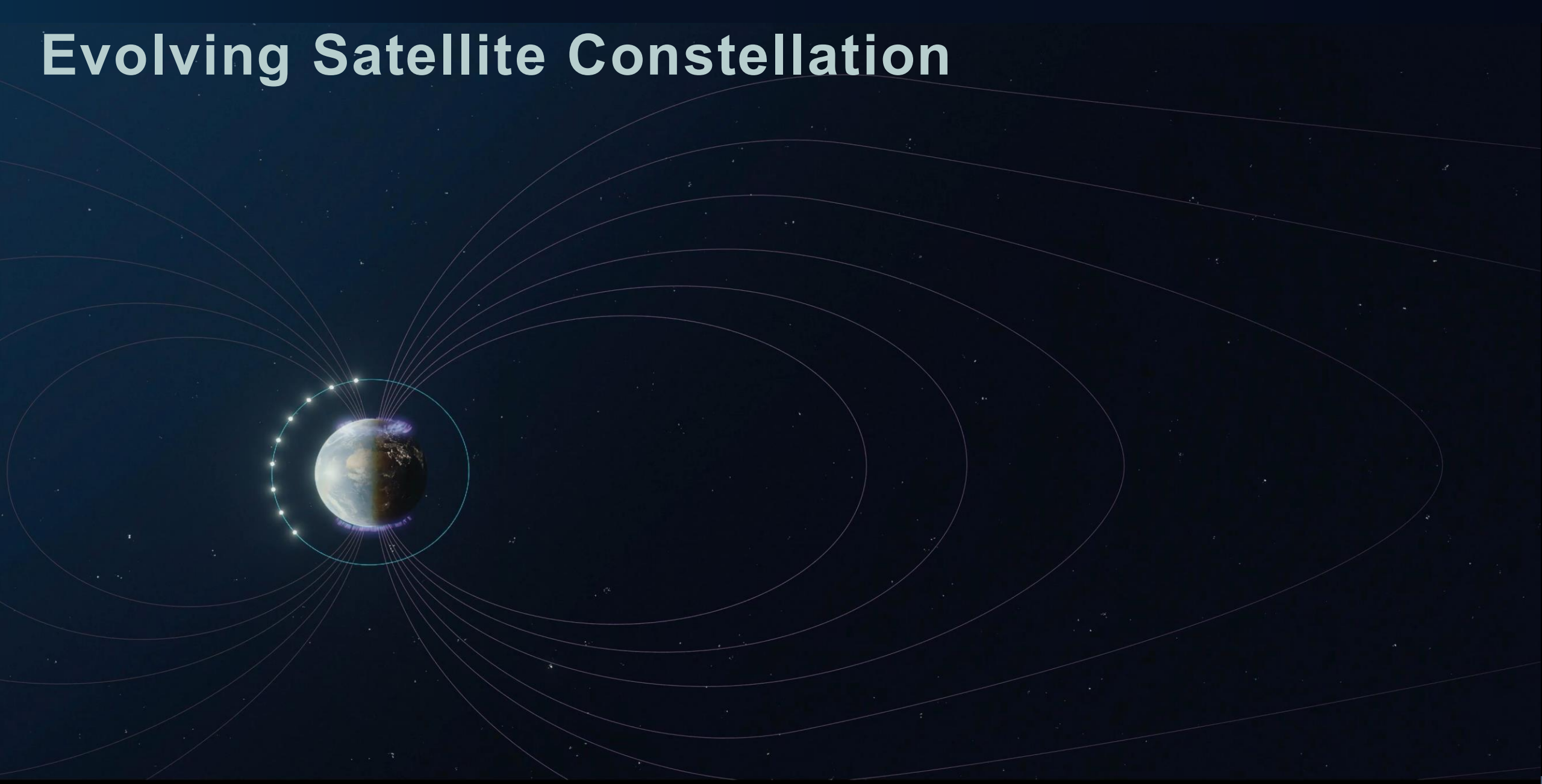
Magnetic field perturbations sense electric currents that flow between the magnetotail and ionosphere.







Evolving Satellite Constellation



CINEMA Team


welcome
CINEMA
site visit
welcome
CINEMA
Cross-Scale INvestigation of Earth's Magnetotail and Aurora
site visit

MOVIE

Multi-platform Observations from Volunteers: Ionospheric Experiments

Space Weather and Citizen Science

CINEMA's nine-CubeSat constellation and powerful instrument suite add a groundbreaking new capability to the HSO, enabling broad-reaching science, citizen science, and space weather science.

Space Weather Enhancement
Fills Key Observational Gaps

Citizen Science
Project (MOVIE)

The MOVIE Prequels: Part 1

MOVIE enables new discoveries by engaging a diverse community of volunteers

“Multi-platform Observations from Volunteers: Ionospheric Experiments” is CINEMA’s Citizen Science Project

MOVIE originates from four successful global citizen science activities with numerous publications

Beta test of the HARP project GUI with teen librarian program

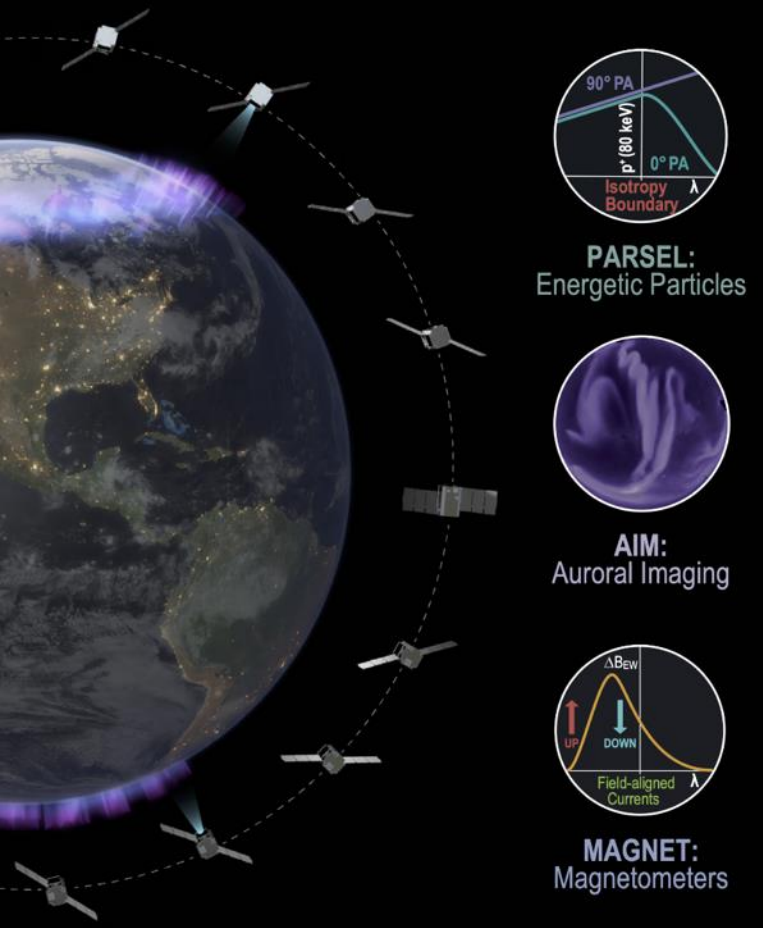
University of Scranton students and HamSCI leader Nathaniel Frissell

EZIE-Mag team getting ready to deliver units to schools throughout the country

Photo captured by Aurora chaser and MOVIE team member Vincent Ledvina, “The Aurora Guy”

The MOVIE Prequels: Part 2

We developed CINEMA-MOVIE to integrate these four projects with the CINEMA mission team to address compelling new science questions



PARSEL:
Energetic Particles

AIM:
Auroral Imaging

MAGNET:
Magnetometers

- The projects mentioned on the previous slide are all unified through studies of multi-scale auroral phenomena and ionospheric impacts, including impacts on radio waves and geomagnetic disturbance
- CINEMA will provide new data that support the science goals of all four of these citizen science projects and enable them to address new science questions

The MOVIE Cast

Michael Hartinger
MOVIE Overall Lead,
CINEMA Co-I,
Liaison to HARP

Robyn Millan
CINEMA PI,
MOVIE Lead
at Dartmouth

Kristina Collins
MOVIE Co-lead,
Liaison to HamSCI

Sasha Ukhorskiy
CINEMA
Project Scientist,
MOVIE Lead at APL

Leonardo Regoli
MAGNET,
Liaison to EZIE-Mag

Yen-Jung Wu
AIM, ML Expert,
MOVIE Lead at UCB

Vincent Ledvina
Liaison to
Aurora Chasers,
Consultant, Social Media

Anne Holland
MOVIE Evaluator

David McGaw
Ground-Based
Instrument
Development

Kelly Cantwell
Science Expert,
Tutorial/Educational
Material Reviewer

Jonathan Rizzo
VLF Receiver

Nathaniel Frissell
MOVIE Lead
at Scranton,
HamSCI and PSWS

James Harold
GUI Lead

MOVIE Goals

By providing multiple platforms for engagement, MOVIE empowers volunteers to make new discoveries in partnership with the CINEMA team

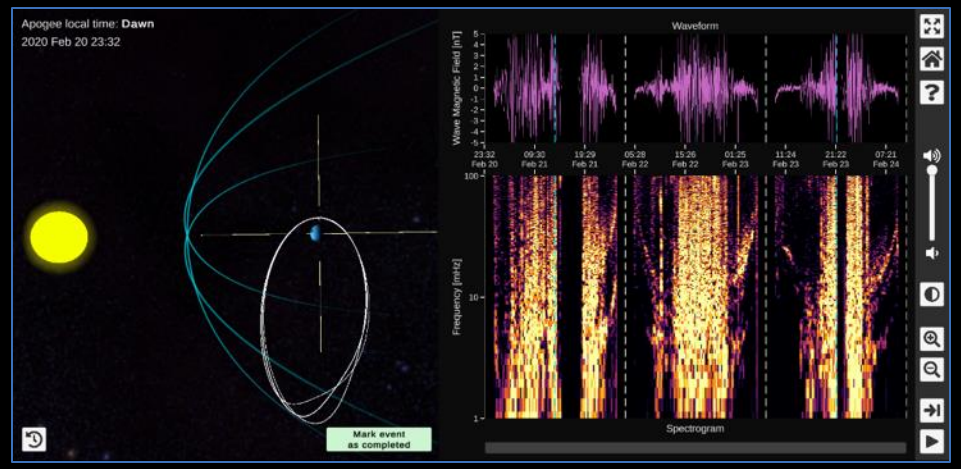
- Augment CINEMA science objectives through novel investigations of the relationships between plasma wave activity, multi-scale auroral dynamics, and space weather impacts
- Provide multiple pathways for volunteers with different skills, interests, and availability to contribute meaningfully to the CINEMA mission and have a positive experience

Photo captured by Christy Turner

MOVIE Components

MOVIE uses the proven approaches of crowd-sourced event finding and open-source instrumentation that have led to high-impact publications in other citizen science projects

- Crowd-sourced event finding (labeling) of CINEMA and ground-based dataset features to statistically study the causes and consequences of multi-scale aurora
- Observational campaigns supported by open-source instrument kits to study the causes and consequences of multi-scale aurora

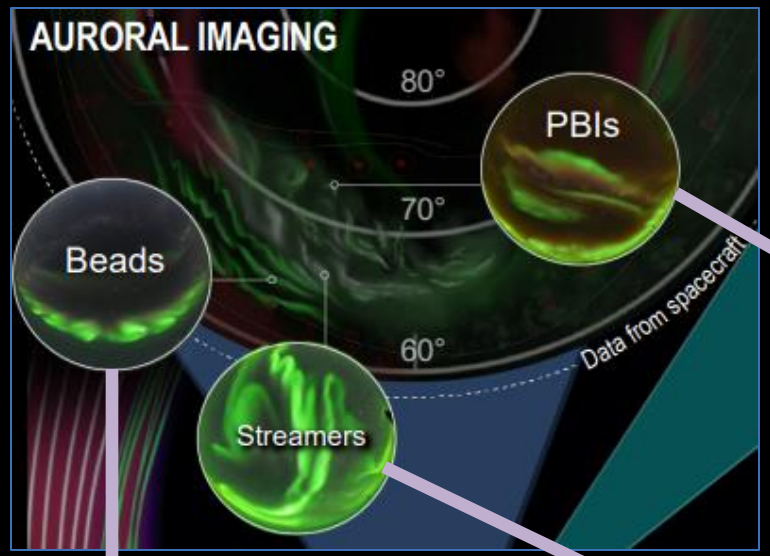


The Unity-based GUI developed for the HARP project

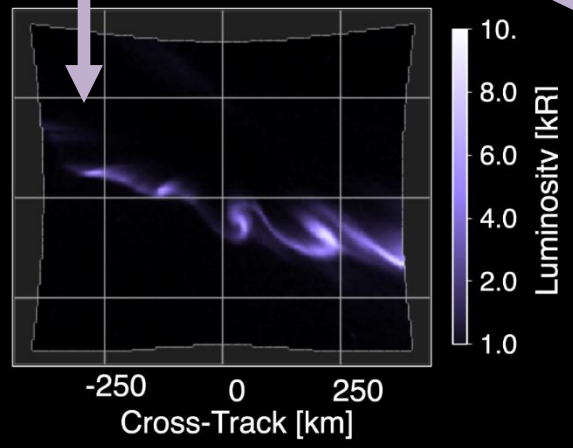
Scene 1 – Geomagnetic Disturbance Statistical Study

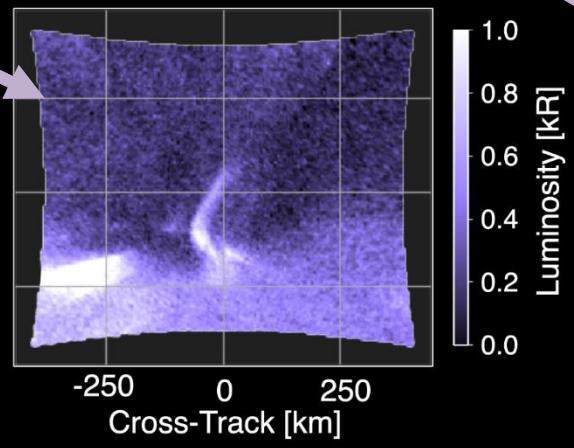
What factors control large-amplitude geomagnetic disturbances linked to mesoscale auroral features?

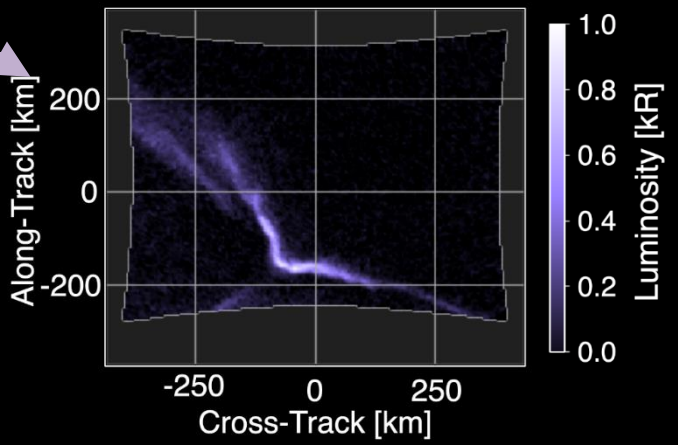
Motivation: space weather hazard, unresolved connections with magnetotail and aurora



- Volunteers label AIM images
- Use nearby ground-based magnetometers for dB/dt
- Context from MAGNET and PARSEL → connect to magnetotail



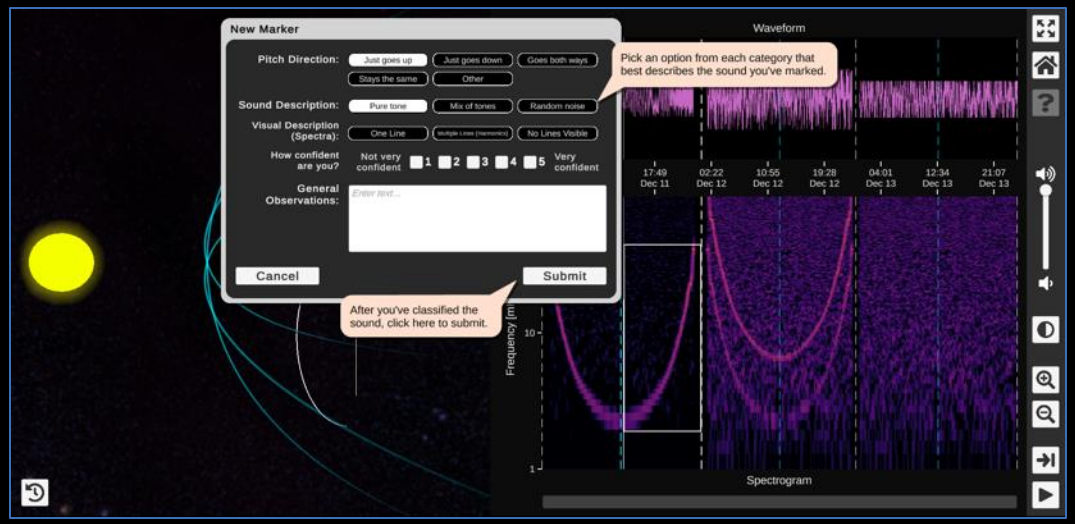




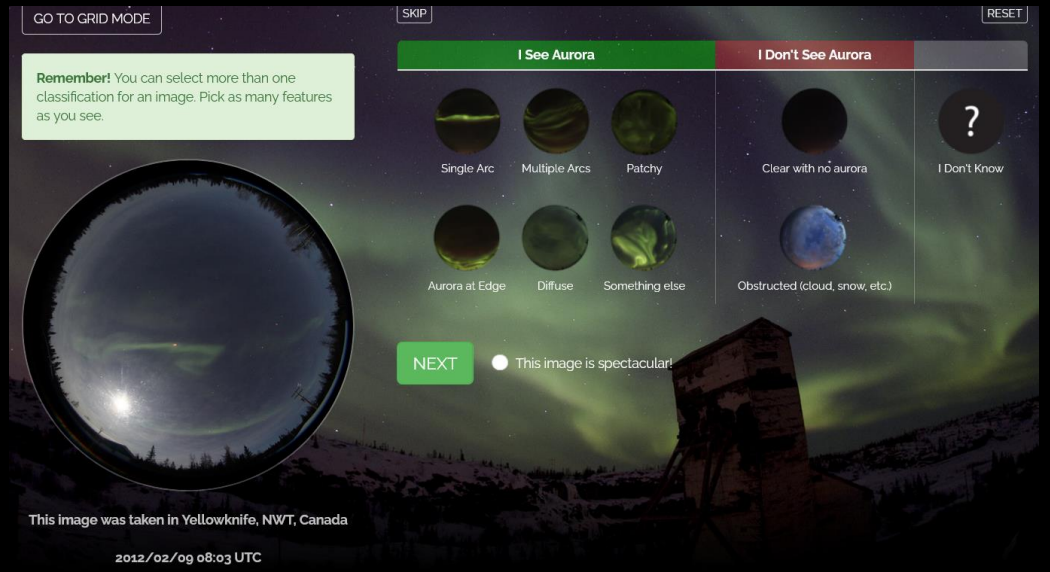
Scene 1 – Geomagnetic Disturbance Statistical Study

What factors control large-amplitude geomagnetic disturbances linked to mesoscale auroral features?
GUI and Tutorial Development

- Phase B feasibility study to identify the most appropriate GUI platform (Unity-based HARP, Zooniverse Aurora Zoo, Auroral Zone from Univ. of Calgary, etc.) and develop prototype with sample data from AIM
- Beta testing and tutorial development with volunteers in Phases B, C, and D
- Experience from past projects and already-established connections with several volunteer groups will facilitate the GUI development



HARP GUI tutorial screen. A walkthrough would also be provided for the MOVIE GUI



GUI from the Auroral Zone Project at Univ. of Calgary to identify different types of aurora in ground-based ASI

Scene 1 – Geomagnetic Disturbance Statistical Study

What factors control large-amplitude geomagnetic disturbances linked to mesoscale auroral features?

Data Collection and Expected Outcomes

- More than ~1000 volunteers expected based on statistics from HARP and Aurora Zoo → adequate to label all AIM images
- Auroras are further subdivided according to PARSEL and MAGNET data → connections with magnetotail processes
- Each category is sorted according to measured dB/dt from ground-based magnetometers as in Zou et al. (2022) to address the science question

Expected outcomes: Scientific publication, publication of labeled AIM images

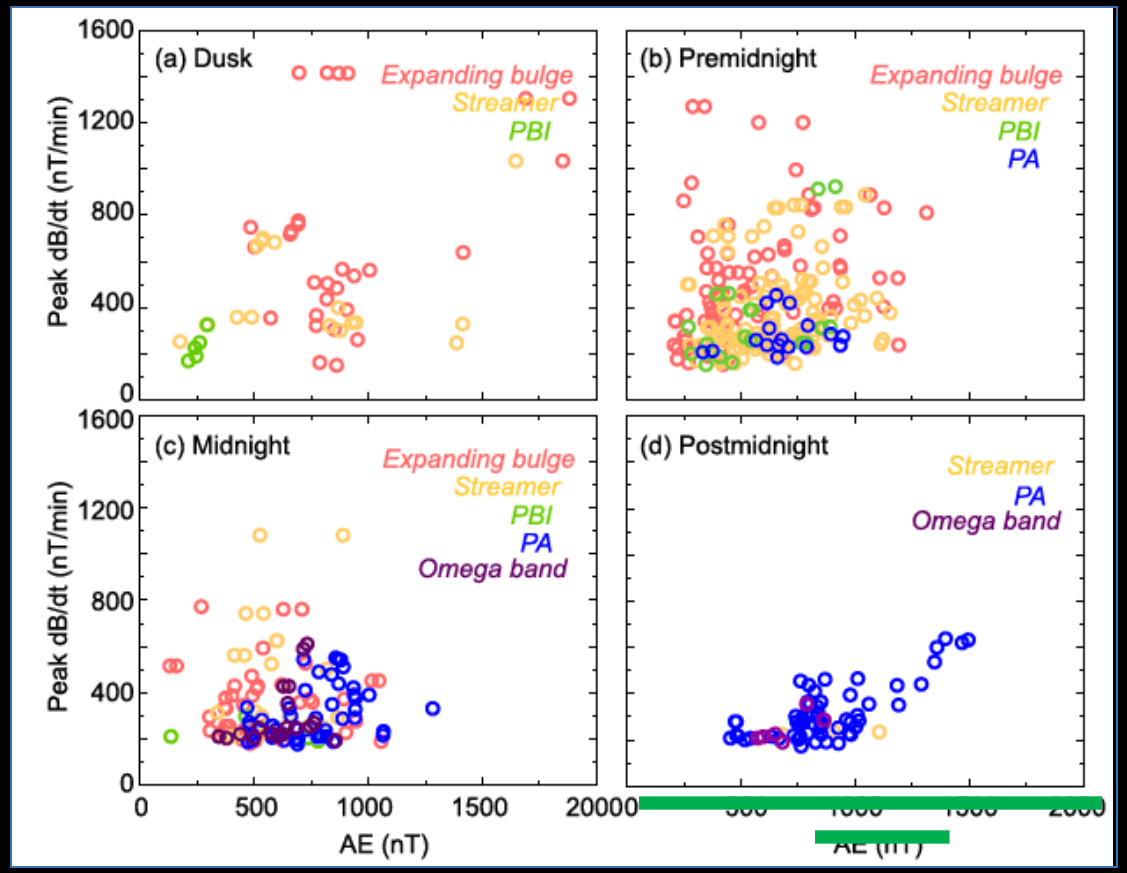


Figure 8 from Zou et al. (2022)

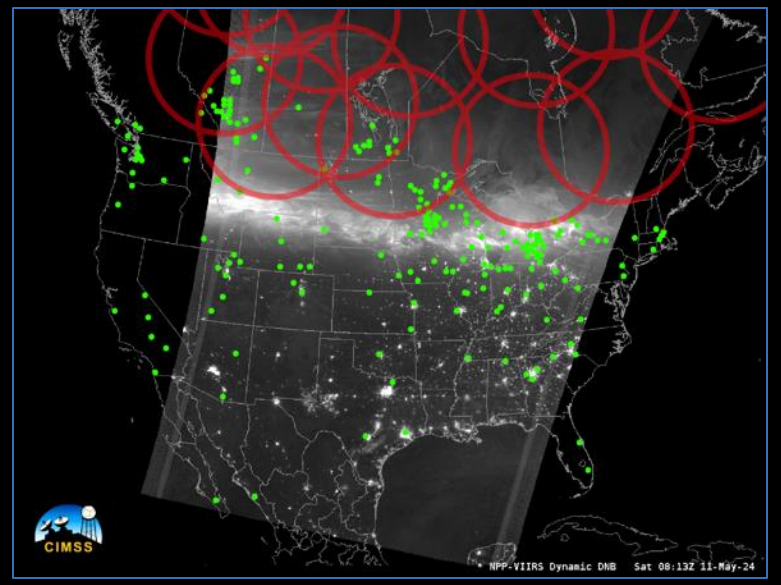
Distance to OCB

Scene 2 – Geomagnetic Disturbance Case Studies

What factors control large-amplitude geomagnetic disturbances linked to mesoscale auroral features?

Observational Campaigns During Geomagnetic Storms

- All sky imager (tuned to auroral dynamics) coverage gap at low latitudes → limited understanding during geomagnetic storms
- Observational campaigns with aurora chasers fill gaps
- Open-source instrument kits, including EZIE-Mag and PSWS, provide additional coverage for magnetometers and other instruments
- Expected outcomes: scientific publication, publication of aurora chaser images, open-source instrument kit documentation



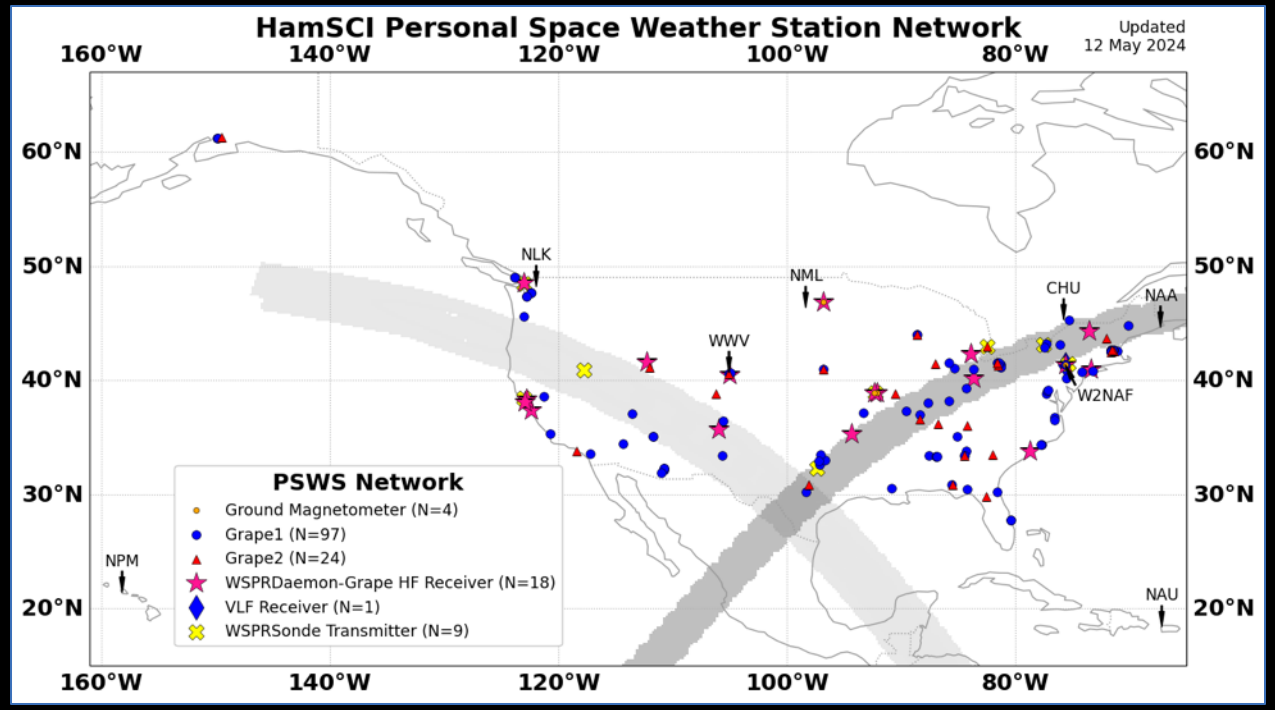
NOAA VIIRS images on 11 May 2024 with green dots indicating aurora chasers and red circles indicating existing ASI

Photo from EZIE-Mag workshop, Little Singer Community School in the Navajo Nation

Scenes 3 and 4 – Radio Wave Statistical Study and Case Studies

What factors control changes in radio wave propagation linked to mesoscale auroral features?
Statistical Study and Observational Campaigns

- Auroral precipitation leads to changes in the ionosphere that affect radio communications both locally and nonlocally
- Connections with mesoscale aurora have not been explored in depth: lack of coordinated investigations, lack of radio wave datasets with sufficient granularity
- Similar methodology to Scenes 1 and 2, except datasets used by HamSCI and the amateur radio community would be employed to identify radio wave impacts (blackouts, propagation enhancements) and determine correlations with different types of aurora using the labeled images
- Expected outcomes: scientific publication for statistical study and for case studies, publication of data collected by amateur radio community



The Personal Space Weather Station Network on 12 May 2024

Scene 5 – Empowering Volunteers to Define Questions

Volunteers in established communities such as HamSCI often define their own research questions MOVIE provides them with the tools and freedom to innovate with CINEMA data

- MOVIE supports volunteer engagement across multiple communities, from schools to expert radio operators; this includes regular communications between CINEMA and volunteers through multiple channels, participant costs to attend CINEMA meetings, tutorial materials to support volunteers of all levels, and participation in development of open-source instrumentation to meet their needs
- Possible outcomes include additional VLF, ASI, and other instrumentation at more locations to address investigations related to CINEMA; artificial intelligence/machine learning algorithms to identify features in aurora; and additional publications on other topics

University of Scranton students KC3UAW and KD2UHN with W2NAF at W3USR

HamSCI at the 2023 Dayton Hamvention

HARP teen librarian program beta testers (photo captured by Anne Holand)

Photo captured by Christy Turner

CINEMA/MOVIE: Ground-Based Remote Sensing

- Personal Space Weather Station (PSWS)
  - Many configurations that include HF, magnetometer, and more
  - VLF receiver
  - GNSS receiver
  - Riometer
  - Possible All Sky Imager integration
- EZIE-Mag
  - Designed to support magnetometer, but base platform/data acquisition system can support other instrumentation
  - Possible All Sky Imager integration
- MOVIE Phase B efforts will include a feasibility study for further instrument development, leveraging instrument development and integration that is already funded and underway

CINEMA/MOVIE: HF Studies

- F-layer Propagation
  - Doppler Shifts
    - Ionospheric Changes
    - Solar Flares
      - WWV, CHU
      - AM Broadcast
  - Time-of-Flight
    - Virtual Height
    - Back-Scatter
    - Long-Delayed Echoes
      - WWV/CHU
      - Signals of Opportunity: CODAR, Chirp Sounders
      - Enhanced Amateur Radio Beacons
  - Amplitude
    - Diurnal/Seasonal Variation
    - Solar Flares
      - WWV/CHU
      - AM Broadcast
      - Amateur Radio Beacons
      - Amateur Radio Contacts
- D-layer Absorption
  - Electron Precipitation
  - Solar Flares
    - Riometer: Stand-alone, SW Channel in PSWS
    - GPS TEC/Scintillation

Summary: Stay Tuned for the Main Feature!

We have the plot, a great cast, and the audience from the prequels
MOVIE is will enable new discoveries by engaging a diverse community of volunteers

- MOVIE leverages the expertise, tools, platforms, and volunteer communities of successful heliophysics citizen science projects: HamSCI, HARP, aurora chasers, and EZIE-Mag
- MOVIE integrates these four projects with the CINEMA mission team to address compelling new science questions on multi-scale auroral phenomena and ionospheric impacts, including impacts on radio waves and geomagnetic disturbance
- MOVIE uses the proven approaches of crowd-sourced event finding and open-source instrumentation
- By providing multiple platforms for engagement, MOVIE empowers volunteers to make new discoveries in partnership with the CINEMA team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