

# The Grand Challenge Initiative - Cusp

A campaign of sounding rocket missions  
to study the multi-scale physics  
occurring in Earth's geomagnetic cusps

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AGU 2018: SA31A-02

## Grand Challenges in Heliophysics and Aeronomy

- The Grand Challenge Initiative (GCI) is series of large-scale international collaborative programs that will use in-situ observations and remote sensing to address fundamental issues in space and Earth science.
- The GCI concept was developed by Andøya Space Center (ASC) and the University of Oslo.
- The first GCI project – “GCI Cusp” – is currently underway, with an objective to determine the multi-scale physics of heating and charged particle precipitation that occurs in the ionospheric footprints of Earth’s geomagnetic cusps
- The GCI Cusp campaign is based around of 9 sounding rocket missions that will launch a total of 12 individual rockets.
- Rocket missions will occur in conjunction with observations of the cusp from an aggregate of ground-based instruments, including incoherent and coherent backscatter radars, all-sky cameras, meridian scanning photometers, magnetometers, and other instruments, which will operate continuously throughout the launch windows.

# THE GRAND CHALLENGE INITIATIVE-CUSP



## THE SCIENCE OF THE CUSP:

The Grand Challenge Initiative - Cusp is an international collaboration to explore the polar cusp—where Earth's magnetic field lines bend down to meet the poles and particles from space can enter our atmosphere.

For more information, please visit:  
<http://www.grandchallenge.no>

9 MISSIONS • 12 ROCKETS

Visualizing Ion Outflow via Neutral Atom Sensing-2

**VISIONS-2\***

How do ions get 'boiled' off the atmosphere? VISIONS-2 observes how ionized oxygen—a comparatively heavy element—acquires enough energy to escape our atmosphere. The mission tracks the escape by visualizing the otherwise invisible atoms as they flow outwards.

Cusp-Region Experiment

**C-REX-2**

C-REX-2 measures winds and ion velocity at around 400 km in altitude in the cusp to track causes of increased density there. The mission differentiates between possible causes such as changes in wind, temperature, or ion velocity.

SS-520-3 **JAXA SS-520-3**

Atmospheric escape is a universal phenomenon occurring on Earth, Mars and other planets—but the mechanisms vary case by case. The SS-520-3 mission investigates the wave-particle interactions high in Earth's atmosphere that allow particles to heat up and escape.

MAGNETOSPHERE

**AZURE\***

*Auroral Zones Upwelling Rocket Experiment*

How do auroras impact the total amount of energy gained or lost by the atmosphere? AZURE measures ionospheric winds and circulation to better understand auroral effects.

**ICI-5**

*Investigation of Cusp Irregularities-5*

Turbulent hot patches of dense plasma exist inside the auroral region. ICI-5 seeks to understand the physical drivers of plasma turbulence, determine the size of the eddy structures, and explore how these plasma structures disturb radio signals.

**G-CHASER**

*G-CHASER*

G-CHASER is a collaboration between eight different student-led missions. It provides a unique opportunity for students to design, test, and ultimately fly their experiment from start to finish.

**TRICE-2\***

*Twin Rockets to Investigate Cusp Electrodynamics*

Researchers have observed step-like changes in ion energies near the pole. TRICE-2 distinguishes between two potential explanations: magnetic reconnection that turns on and off, like a light-switch, or steady magnetic reconnection occurring in varying locations.

**CHI**

*Cusp Heating Investigation*

CHI will measure the flow of plasmas and neutral gases in the cusp, testing current models of how they interact with one another and become heated and accelerated in the process.

**CAPER-2**

*Cusp Alfvén and Plasma Electrodynamics Rocket*

Auroras are created when fast-moving particles from the sun crash into Earth's atmosphere. CAPER-2 investigates how such particles can be accelerated via Alfvén waves—oscillating, low-frequency waves that provide particles with extra energy and send them speeding toward Earth.

MAGNETOSPHERE



\*TWO ROCKETS

NASA GSFC/WFF • Andoya Space Center • University of Oslo • JAXA • ISAS • Dartmouth College • University of Iowa • University of Alaska Fairbanks • Clemson University • University of Colorado

Credit: Trond Abrahamsen, Andoya Space Center

NP-2018-4-196-WFF

# Mission List

2018 Fall

**December**

**VISIONS-2**

MISSION: Visualizing Ion Outflow via Neutral atom Sensing-2

LAUNCH VEHICLES: Black Brant X + 2 Rockets

LAUNCH SITE: Ny-Ålesund, Svalbard

PRINCIPAL INVESTIGATOR: Doug Rowland, NASA Goddard Space Flight Center, USA



**December**

**TRICE-2**

MISSION: Twin Rockets to Investigate Cusp Electrodynamics-2

LAUNCH VEHICLES: Black Brant XII + 2 Rockets

LAUNCH SITE: Andoya, Norway

PRINCIPAL INVESTIGATOR: Craig Kletzing, University of Iowa, USA



**January**

**SS-520-3**

MISSION: Ion Outflow in the Cusp

LAUNCH VEHICLE: SS-520-3

LAUNCH SITE: Ny-Ålesund, Svalbard

PRINCIPAL INVESTIGATOR: Yoshifumi Saito, Japan Aerospace Exploration Agency



**January**


**CAPER-2**

MISSION: Cusp Alfvén and Plasma Electrodynamics Rocket-2

LAUNCH VEHICLE: Black Brant XII

LAUNCH SITE: Andoya, Norway

PRINCIPAL INVESTIGATOR: James LaBelle, Dartmouth College, USA



**January**


**G-CHASER**

MISSION: University Student Experiments

LAUNCH VEHICLE: Terrier-Improved Malemute

LAUNCH SITE: Andoya, Norway

PRINCIPAL INVESTIGATOR: Chris Koehler, Colorado Space Grant Consortium



**April**


**AZURE**

MISSION: Auroral Zone Upwelling Rocket Experiment

LAUNCH VEHICLES: Black Brant XI + 2 Rockets

LAUNCH SITE: Andoya, Norway

PRINCIPAL INVESTIGATOR: Miguel Larsen, Clemson University, USA



2019 Spring

**November/December**

**CHI**

MISSION: Cusp Heating Investigation

LAUNCH VEHICLE: Black Brant IX

LAUNCH SITE: Ny-Ålesund, Svalbard

PRINCIPAL INVESTIGATOR: Miguel Larsen, Clemson University, USA



**November/December**

**C-REX 2**

MISSION: Cusp-Region Experiment

LAUNCH VEHICLE: Black Brant XII

LAUNCH SITE: Andoya, Norway

PRINCIPAL INVESTIGATOR: Mark Conda, University of Alaska Fairbanks, USA



**December**

**ICI-5**

MISSION: 3D in situ Observations of Ionospheric Irregularities in the Cusp

LAUNCH VEHICLE: VS-30 - Improved Orion

LAUNCH SITE: Ny-Ålesund, Svalbard

PRINCIPAL INVESTIGATOR: Joran Moen, University of Oslo, Norway



2019 Fall



## Physical Problems Addressed by the GCI CUSP Missions

- VISIONS-2:** Addresses how ionized oxygen — a comparatively heavy element — can acquire enough energy to escape upward from Earth's atmosphere and into the magnetosphere.
- TRICE-2:** Will resolve whether changes seen in cusp-region ion energies are due to spatial or temporal modulation of magnetic reconnection.
- SS-520-3:** Will investigate the role played by wave-particle interactions in Earth's ionosphere in driving heating and atmospheric escape.
- CAPER-2:** Will investigate mechanisms by which Alfvén waves accelerate auroral precipitation in the cusp regions.



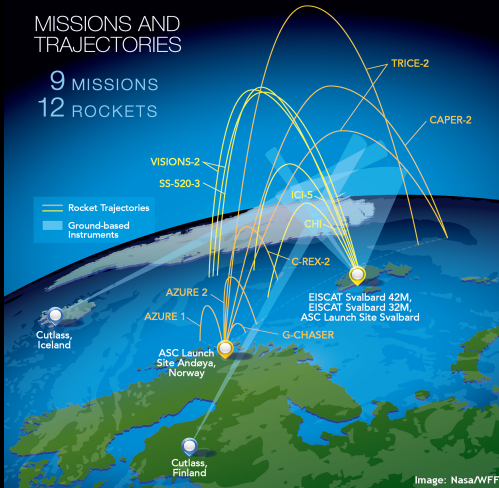
## Physical Problems Addressed by the GCI CUSP Missions – cont.

- G-CHASER:** Consists of eight student-led rocket instruments. The goal is to provide unique opportunities for students to design, test, and fly an experiment from start to finish.
- AZURE:** Examines the role of auroral forcing in driving hard-to-explain upwelling events that are observed to occur in Earth's thermosphere.
- CHI:** Measures neutral and plasma velocities in the cusp, to test current models of Joule heating and ion drag.
- C-REX-2:** Will examine the relative roles of neutral dynamics versus electrodynamics in supporting the poorly understood cusp region neutral density anomaly.
- ICI-5:** Seeks to understand the physical drivers of plasma turbulence, determine the size of the eddy structures, and explore how these plasma structures disturb radio signals.



## Trajectories and Launch Sites

Geomagnetic cusps occur on the dayside, at magnetic latitudes in the mid-to-high 70's.



- The only routinely operating sounding rocket ranges that can launch missions into the cusp region are those at Andoya in Norway and at Ny-Alesund on Svalbard.
- As shown here, the GCI initiative includes missions launched from both locations.
- Indeed, there may be an opportunity for synergy by launching C-REX-2 from Andoya at the same time CHI from Ny-Alesund.

## Breaking News – Four Rockets Successfully Launched Already

*As of December 2018, both the VISIONS-2 and TRICE-2 missions have been completed successfully!* Both missions used two rockets launched close together in time; images here are both composites, with the two launches overlaid in one image.



VISIONS-2: Ny-Alesund, December 7



TRICE-2: Andoya, December 8

# VISIONS-2

**WHAT: BLACK BRANT X SOUNDING ROCKET - 35.039 GE**

**WHEN: DECEMBER 4, 2018**

**WHERE: SVALBARD, NORWAY**

**PRINCIPAL INVESTIGATOR: DR. ROWLAND/GSFC**

## Mission Overview

Low-energy  $O^+$  flows out from the magnetic cusp to the magnetosphere, modifying reconnection rates, substorm onset mechanisms, radiation belt loss and energization processes.

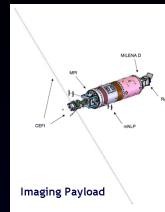
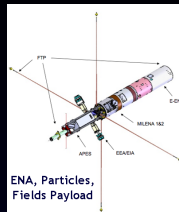
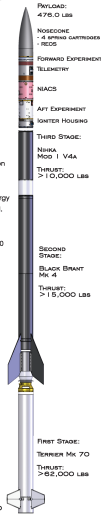
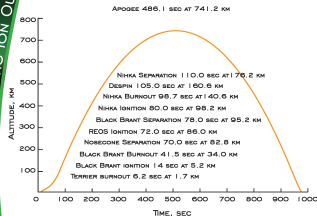
VISIONS-2 attempts to answer the following science questions:

- What are the processes that drive the low-altitude seed population — soft electrons vs. Joule heating?
- How temporally variable ("bustly") is the outflow?
- What is the spatial extent ("patchiness") of the outflow?

The payloads will fly through the magnetic cusp, and provide high spatial and temporal resolution images of outflow, in relation to free energy sources [electron precipitation and Poynting flux], to determine the relative importance of driving mechanisms, and to measure temporal persistence and spatial extent. VISIONS-2 uses Energetic Neutral Atom Imaging to determine arrival angle, fluence, and energy of energetic neutral atoms, from which energetic ion outflow can be reconstructed.

Two payloads will be launched as part of this mission. Both will launch south through the magnetic cusp from Ny Ålesund, Norway to apogees of approx. 550-800 km. 35.040 launches ~120 seconds after 35.039.

A separate Fact Sheet is provided for 35.040 GE.



- ENAs 10-400 eV
- E-field (DC to 5 MHz)
- B-field
- Electrons 3 eV-30 keV
- Ions 1.5 eV-15 keV
- Thermal ions 0.1-10 eV
- Plasma density
- Electron temperature
- 4-channel visible camera (3914, 5577, 6300, 8446)

# TRICE-2

WHAT: BLACK BRANT XI-A SOUNDING ROCKET - 52.003 & 004 UE

WHEN: DECEMBER 5, 2018

WHERE: ANDOYA SPACE CENTER, NORWAY

PRINCIPAL INVESTIGATOR: DR. KLETZING/UNIV OF IOWA

## Mission Overview

The primary objective of this mission is to measure cusp signatures of reconnection occurring at the magnetopause during steady IMF Bz southward conditions. This is accomplished by launching two nearly identically instrumented payloads, flying at low and high altitudes, with a variety of separations in time and space. Launch times will be set such that both rockets reach apogee as near simultaneously as possible. The Low Flyer, 52.003 will be first off the pad, and 120 seconds later, 52.004 will take off.

## Payload Detail

52.003: 427.2 LBS

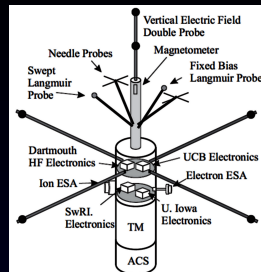
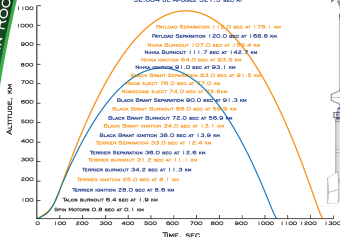
EXPERIMENT TELEMETRY MANACS NHKA ION

52.004: 525.0 LBS

EXPERIMENT TELEMETRY MANACS NHKA ION

52.003 UE APOGEE: 617.2 SEC AT 1 079.2 KM

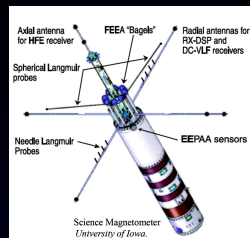
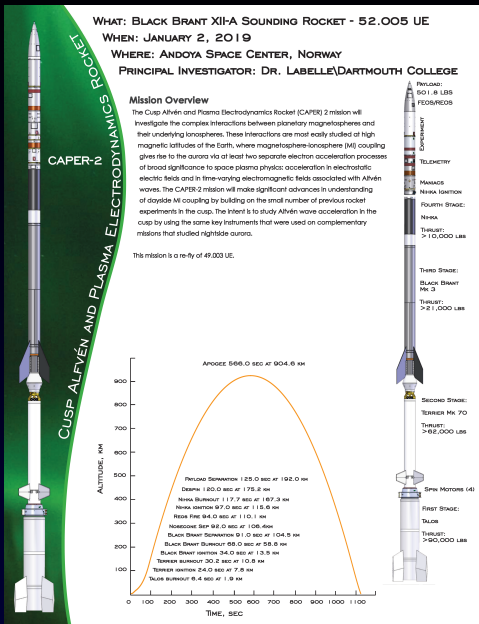
52.004 UE APOGEE: 521.5 SEC AT



- Electron Energy and Pitch Angle Analyzers (EEPAA)
- Langmuir probes
- High frequency electric field receiver
- Ion ESA
- DC/ELF/VLF electric field receiver
- DC Magnetometer
- Langmuir probes



## CAPER-2



- DC/ELF/VLF electric field receiver
- High frequency electric field receiver
- Digital radio receiver/signal processor
- Electron Energy and Pitch Angle Analyzers (EEPAA)
- Fixed Energy Electron Analyzers (FEEA)
- Wave-Particle correlators
- Langmuir probes

## G-CHASER

WHAT: TERRIER-IMPROVED MALEMUTE SOUNDING ROCKET - 46.018 UO

WHEN: JANUARY 10, 2019

WHERE: ANDOYA SPACE CENTER, NORWAY

PRINCIPAL INVESTIGATOR: MR. CHRIS KOEHLER/COLORADO SPACE GRANT

### Mission Overview

This is an international student mission with participation from the US, Norway and Japan and follows the RockSat-X mission architecture. RockSat-X student experiments are developed with an objective of providing students with an enhanced experience of flying experiments exposed to the space environment. This mission differs from the historical RockSat-X architecture in two major ways: it is being launched from Norway, and it incorporates foreign national participation. The launch range change also drives significant payload changes - the payload is not being recovered, and the recovery and attitude control systems have also been removed.

#### The following student experiments will be flown on this mission:

US - University of Norway -Svenes

Detect and measure distribution of neutral Mesospheric Smoke Particles (MSF) to the winter Mesosphere. Using a new probe design: Smoke Particle Impact Detector (SPID) that will allow detection of small MSF's.

USO - University of Ohio

Release (radio-payload) modules (daughters) and establish communication.

Measure small-scale electron density using Langmuir probe systems deployed on the daughters.

Post flight data analysis to study plasma turbulence and instability.

FMM - University of Idaho

Observe the incoming Pulsating Aurora (PNA) electrons in a wide energy range from a few tens of keV to a few MeV by onboard particle detection.

Observe the temporal/spatial variations of PNA by an onboard optical instrument which is essential for studying PNA.

PSU - Pennsylvania State University

Contribute to understanding of the cause(s) of Polar Mesosphere Winter Echoes (PMWEs). Use instruments to collect measurements and compare data to a ground radar devoted to measuring PMWEs during the experiment.

CSU - Capital Tech University

Identify atmospheric composition through spectral analysis and/or capture.

Verify functionality of modified Aerogel thermal insulation.

UMN - University of New Hampshire

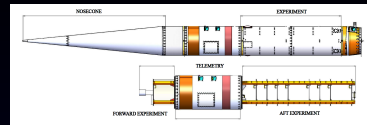
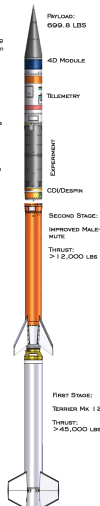
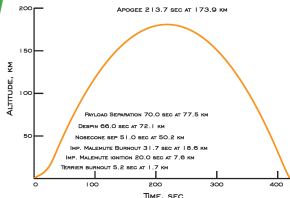
Observe directly (NIR-C) Ozone (NO) at otherglow emissions vs. altitude.

Calculate NO densities and enhancements vs. typical background values.

UPN - University of Puerto Rico

The experiment consist on the collection and analysis of organic compounds located inside the aurora borealis trail.

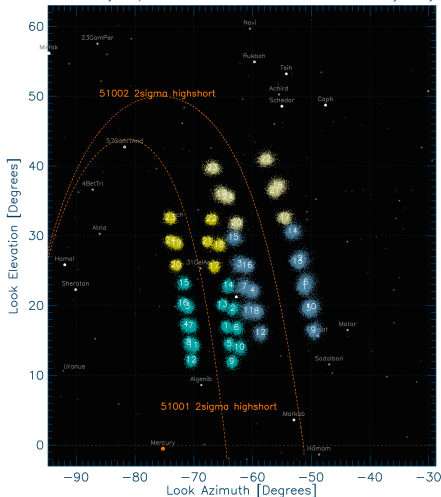
Additionally, the SPPO is flying an experiment on this mission.



- 5 Experiment Sections
- 2 dedicated to United States Student Teams
- 2 dedicated to Norway Student Teams
- 1 dedicated to an International Student Team (Penn State)
- Each section may be divided into two (10 total decks)
- Additionally, experiment under Nosecone and 4-D module

# AZURE

AZURE Sky Map for Alta with 2 SIGMA HIGH SHORT Trajectory

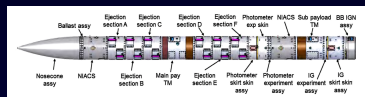
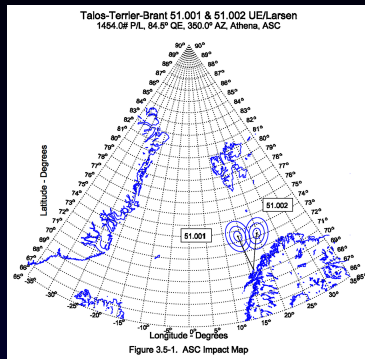


Reference azimuths for sub-payload ejections: 322.3° and 350.7°  
 Solar Depression angle is 10.6° at location 23.187E and 69.950N  
 Monte-Carlo Params:  $\sigma_{vel} = 8 \text{ m s}^{-1}$ ,  $\sigma_{az} = 5^\circ$ ,  $\sigma_{elv} = 5^\circ$ ,  $N = 2000$   
 Sky at Alta remains dark enough until after the window closes  
 Trajectory Files: 51001 2sigma highshort acs.txt, 51002 2sigma highshort acs.txt

Sky View on 10-Mar-2018 at 18:36:00 UT

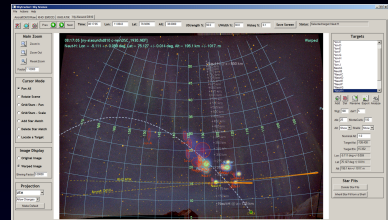
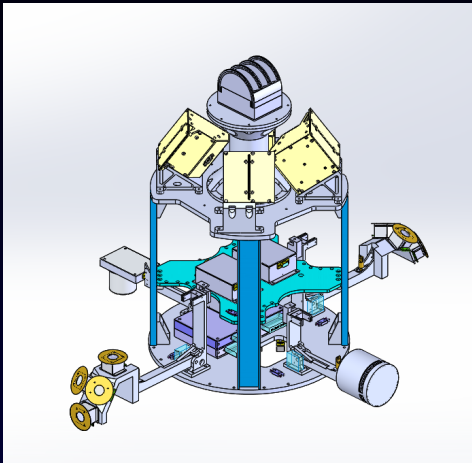
UAF/Conda

AZURE will use two rockets to release 48 wind tracer clouds, to study the relationship between neutral divergence and vertical wind.



## C-REX-2

- The C-REX-2 mission will use a combination of chemical release tracer clouds and in-situ payload instrumentation to study the neutral density anomaly that occurs in Earth's cusp-region thermosphere.



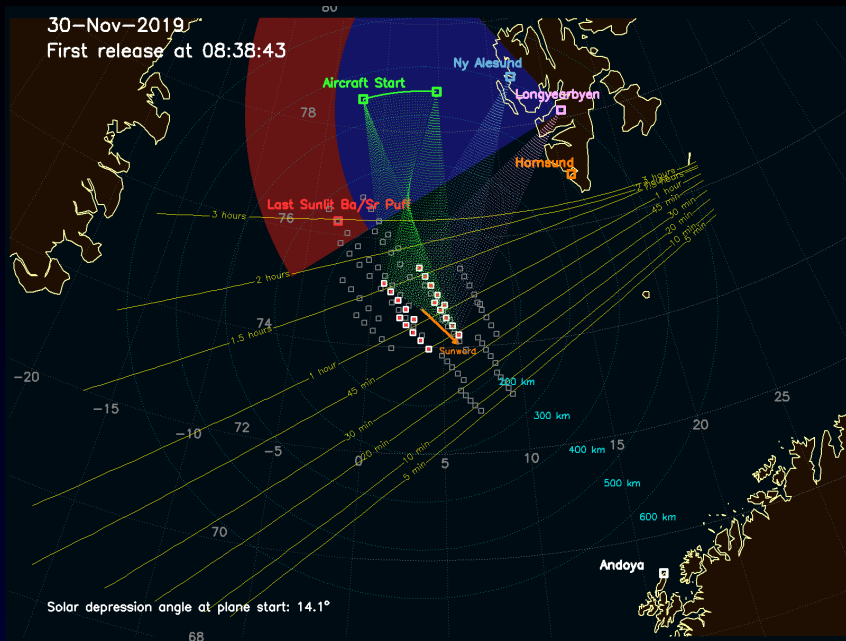
### Science Question: Cusp Density Anomaly

What are the relative roles of neutral dynamics versus electrodynamics in establishing and supporting the persistent region of enhanced neutral mass density that is observed to occur at around 400 km altitude in the geomagnetic cusp regions?

## C-REX-2 Instrumented Measurements

- MPI:** The Miniature Plasma Imager will yield measurements of the 3-component plasma drift velocity along the trajectory of the main payload. It will complement the ion drift measurements from the Ba<sup>+</sup> clouds, by providing continuous fine-scale measurements at  $\sim 2\text{Hz}$ .
- EPLAS:** The EPLAS measures the auroral electron phase space distribution over a nominal energy range of 20eV to 15 keV, divided into 42 steps with 17% energy resolution. The instrument incorporates 30 discrete angular bins (for pitch angle determination), with total field of view of approximately  $300^\circ \times 5^\circ$ .
- ERPA:** The ERPA measures the thermal electron population (few tenths of an eV) as distinct from auroral precipitation measured by EPLAS. Operation is similar to a Faraday Cup with a swept retarding potential at its entrance for energy selection.
- PIPs:** The main payload will carry six PIP instruments, providing measurements of the thermal ion distribution bulk moments of density and temperature, given constraining information from the MPI and the ERPA on plasma flow and electron temperature.
- TIGTOF:** Will be used to study the composition of the ionospheric thermal ions.
- MAG:** A science-grade magnetometer will be used to infer field-aligned currents.

# Overview Map of the C-REX-2 Experiment





# Questions?

