The Grand Challenge Initiative - Cusp

A campaign of sounding rocket missions

to study the multi-scale physics

occurring in Earth's geomagnetic cusps

M. Conde, D. Rowland, K. Blix, J. Moen & the GCI Team

AGU 2018: SA31A-02

PennState ASC NASA JAXA NAROM UAF University of Alaska Fairbanks Clemson University

COSGC Colorado Space Grant Consortium The University of Iowa UiO : University of Oslo Dartmouth College

Background Image: Andøya Space Center/Trond Abrahamsen

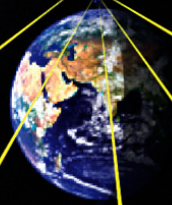
Grand Challenges in Heliophysics and Aeronomy

- 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.

Earth limb image adapted from https://www.universetoday.com/wp-content/uploads/2009/09/SED_wall_1920x1200.jpg

THE GRAND CHALLENGE INITIATIVE-CUSP

9 MISSIONS • 12 ROCKETS



MAGNETOSPHERE

POLAR CUSP

POLAR CUSP

MAGNETOSPHERE

AZURE*
Auroral Zone 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.

VISIONS-2*
Visualizing Ion Outflow via Neutral Atom Sensing-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.

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.

C-REX-2
Cusp-Region Experiment

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.

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.

JAXA SS-520-3
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.

CAPER-2
Cusp Alfven 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.

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

*TWO ROCKETS

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

Credit: Trond Abrahamsen, Andøya Space Center

NP-2018-4-195-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

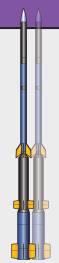
TRICE-2

MISSION: Twin Rockets to Investigate Cusp Electrodynamics-2

LAUNCH VEHICLES: Black Brant XII • 2 Rockets

LAUNCH SITE: Andøya, Norway

PRINCIPAL INVESTIGATOR: Craig Kletzing, University of Iowa, USA



2019 Spring

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: Andøya, Norway

PRINCIPAL INVESTIGATOR: James LaBelle, Dartmouth College, USA

January

G-CHASER

MISSION: University Student Experiments

LAUNCH VEHICLE: Terrier-Improved Malemute

LAUNCH SITE: Andøya, Norway

PRINCIPAL INVESTIGATOR: Chris Koehler, Colorado Space Grant Consortium

April

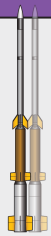
AZURE

MISSION: Auroral Zone Upwelling Rocket Experiment

LAUNCH VEHICLES: Black Brant XI • 2 Rockets

LAUNCH SITE: Andøya, Norway

PRINCIPAL INVESTIGATOR: Miguel Larsen, Clemson University, USA



2019 Fall

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: Andøya, Norway

PRINCIPAL INVESTIGATOR: Mark Conde, 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: Jøran Moen, University of Oslo, Norway

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.

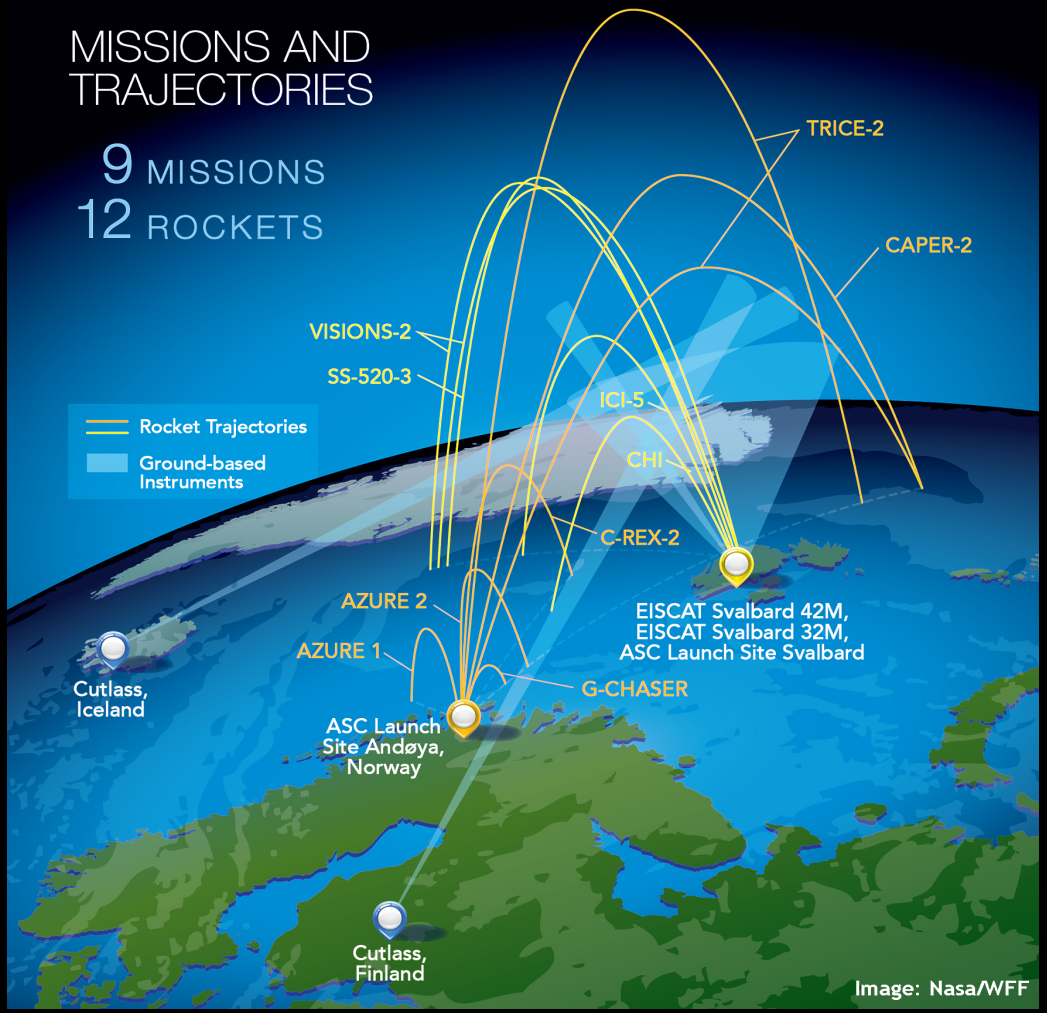
CHI: Measures neutral and plasma velocities in the cusp, to test current models of Joule heating and ion drag.

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

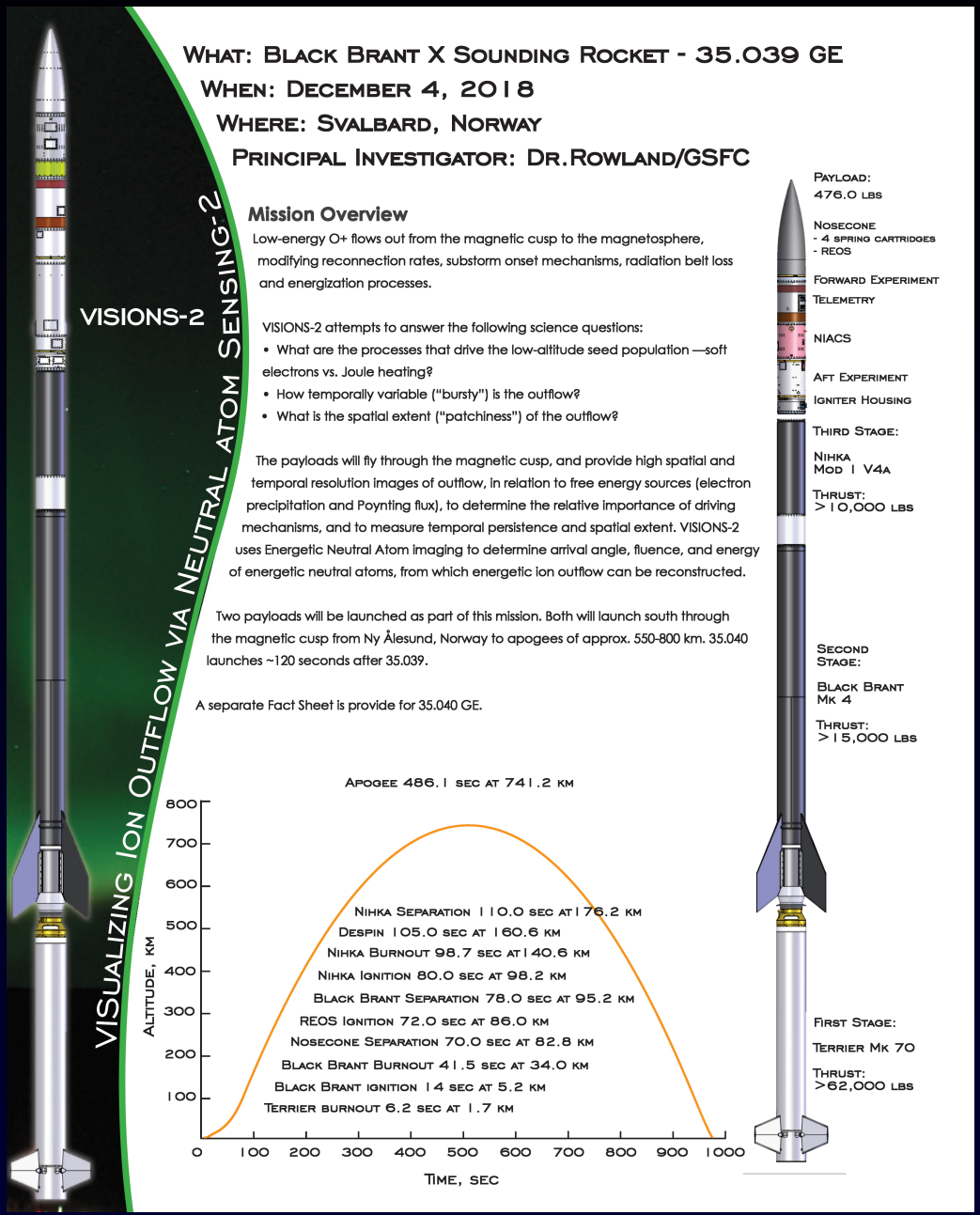
As of December 2018, both the VISIONS-2 and TRICE-2 missions have been completed successfully! Both missions used two rockets launched close together in time; images here are both composites, with the two launches overlaid in one image.

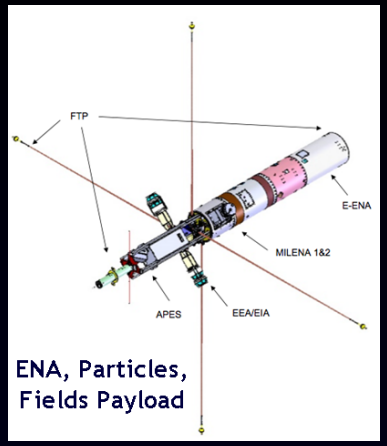
VISIONS-2: Ny-Alesund, December 7

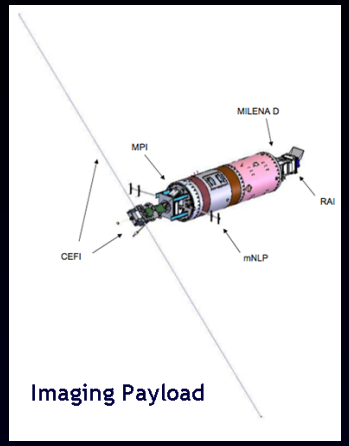
TRICE-2: Andoya, December 8

Images courtesy of NASA/Wallops Flight Facility

VISIONS-2

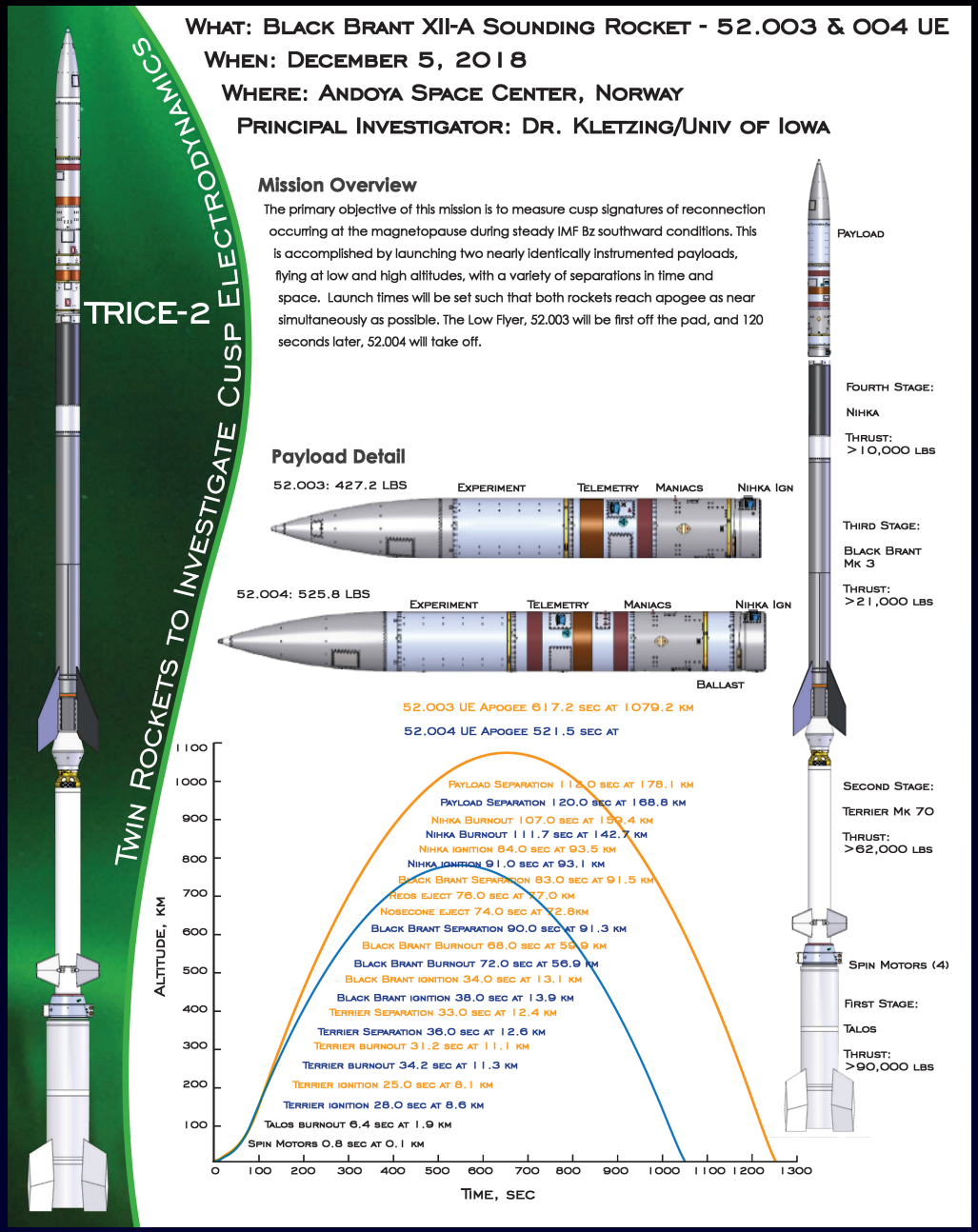


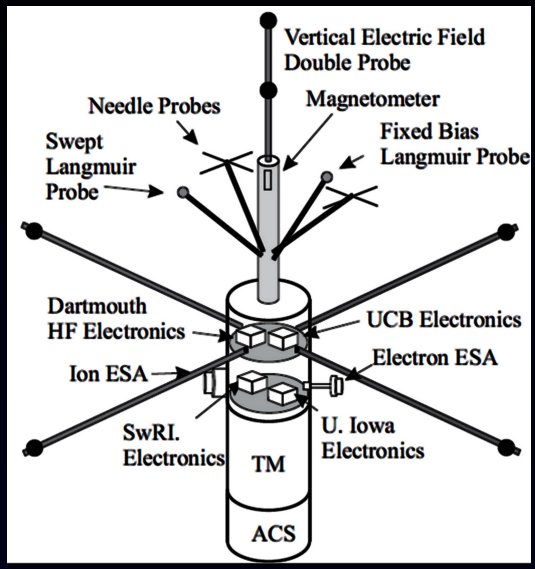




- ENAs 10-400 eV
- E-field (DC to 5 MHz)
- B-field
- Electrons 3 eV-30 keV
- Ions 1.5 eV-15 keV
- Thermal ions 0.1-10 eV
- Plasma density
- Electron temperature
- 4-channel visible camera (3914, 5577, 6300, 8446

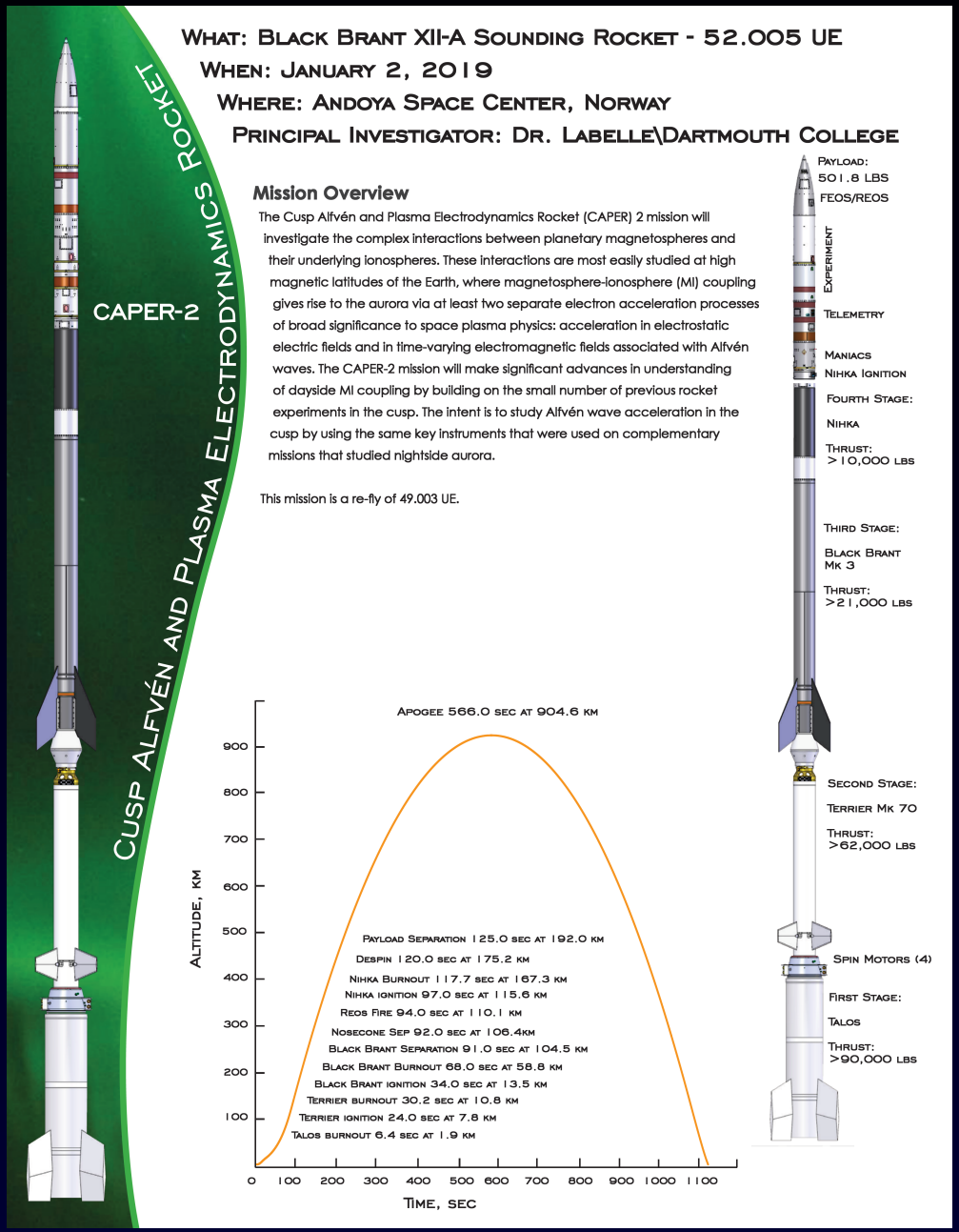
TRICE-2

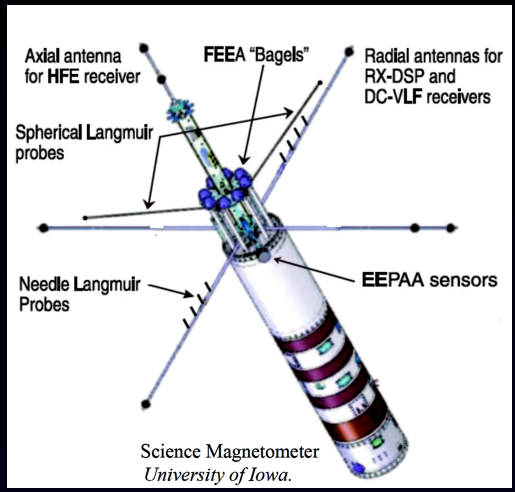




- Electron Energy and Pitch Angle Analyzers (EEPAA)
- Langmuir probes
- High frequency electric field receiver
- Ion ESA
- DC/ELF/VLF electric field receiver
- DC Magnetometer
- Langmuir probes

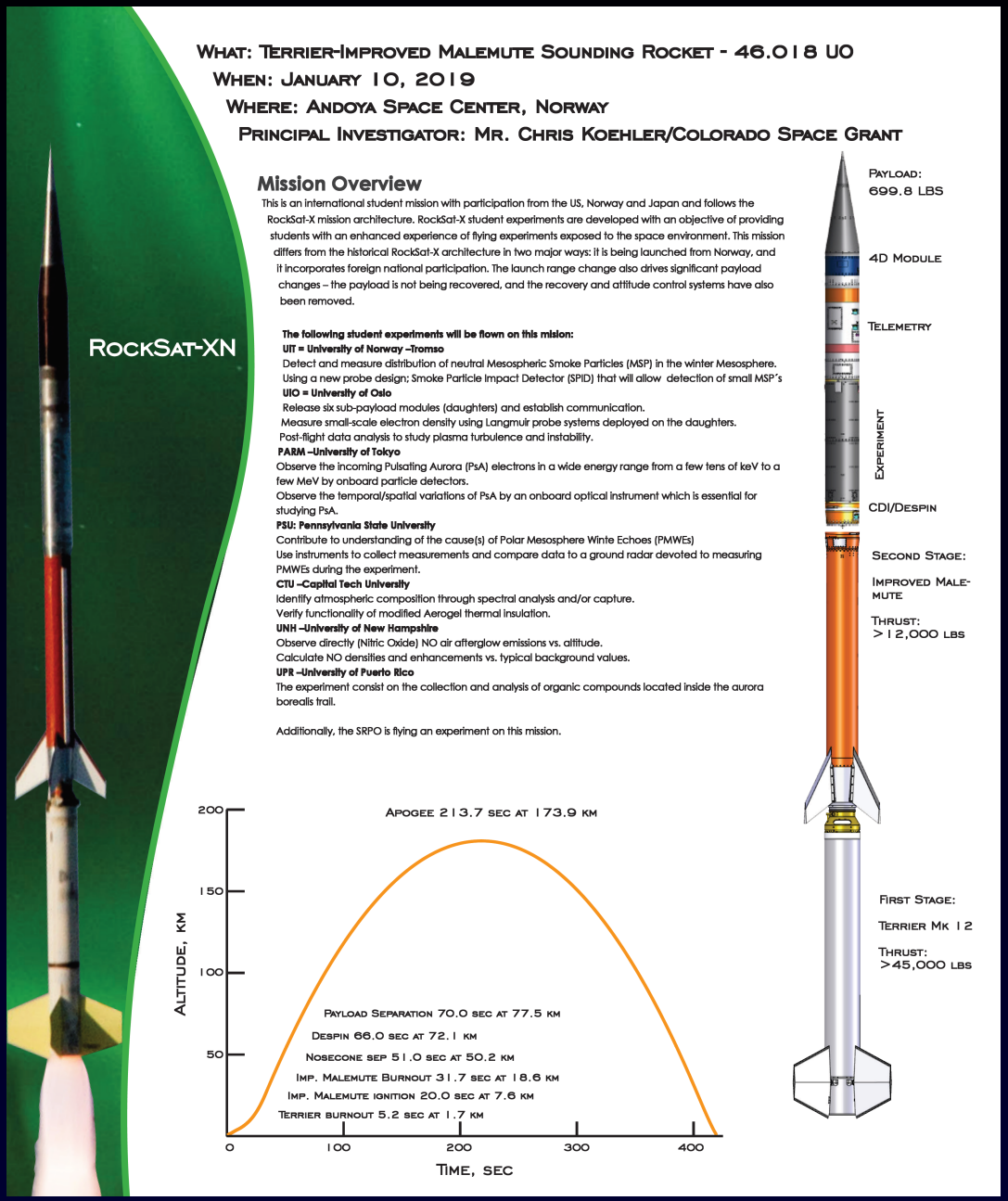
CAPER-2

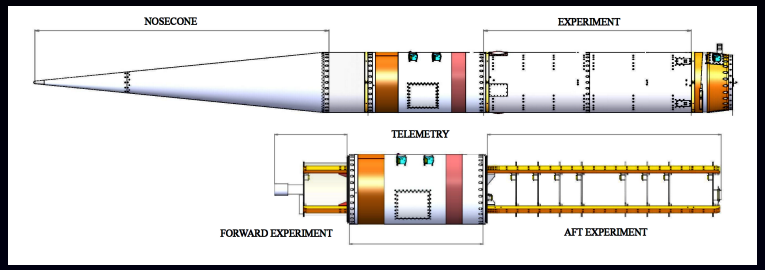




- DC/ELF/VLF electric field receiver
- High frequency electric field receiver
- Digital radio receiver/signal processor
- Electron Energy and Pitch Angle Analyzers (EEPAA)
- Fixed Energy Electron Analyzers (FEEA)
- Wave-Particle correlators
- Langmuir probes

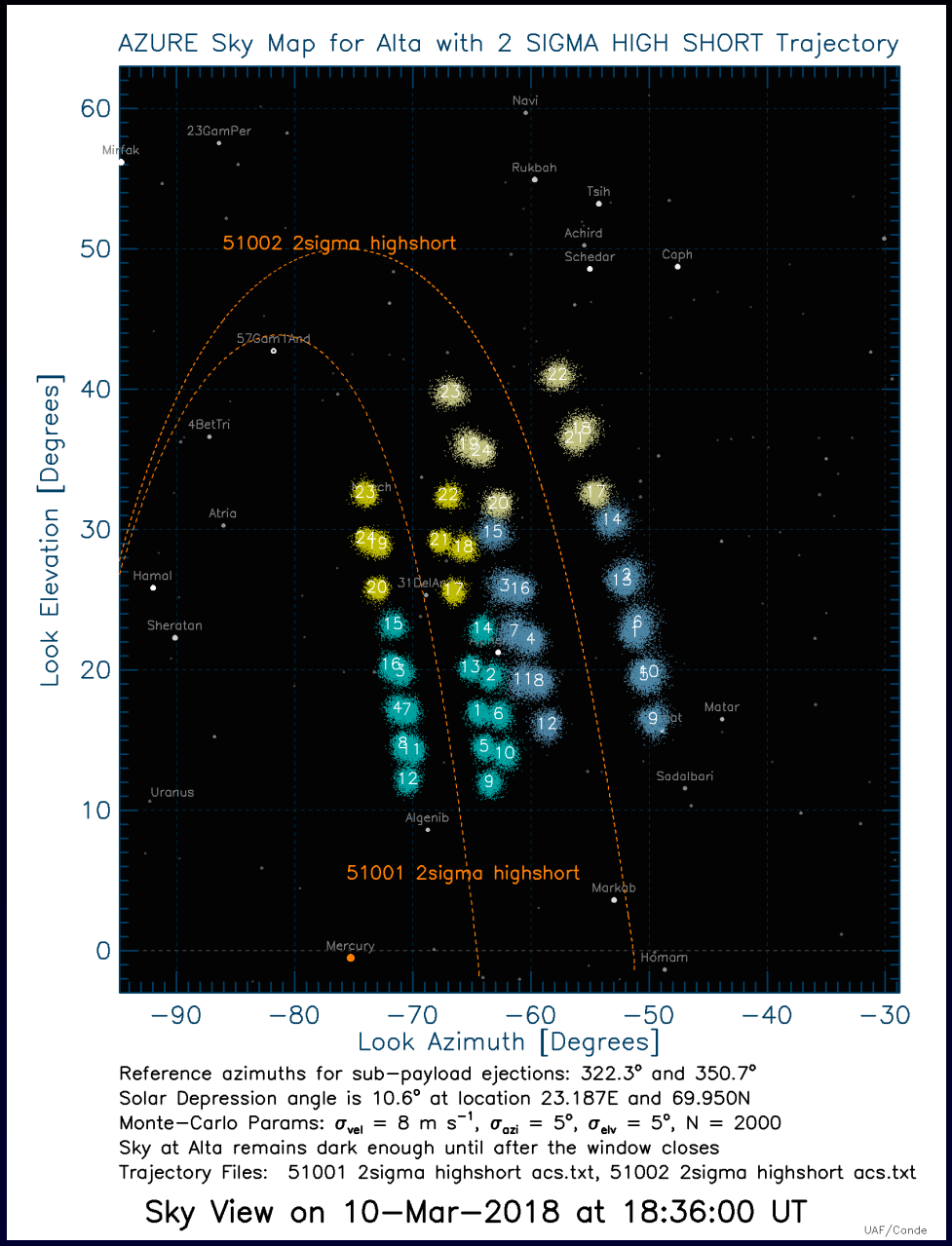
G-CHASER





- 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



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: σ_{vel} = 8 m s^{-1}, σ_{azi} = 5°, σ_{elv} = 5°, 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/Conde

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

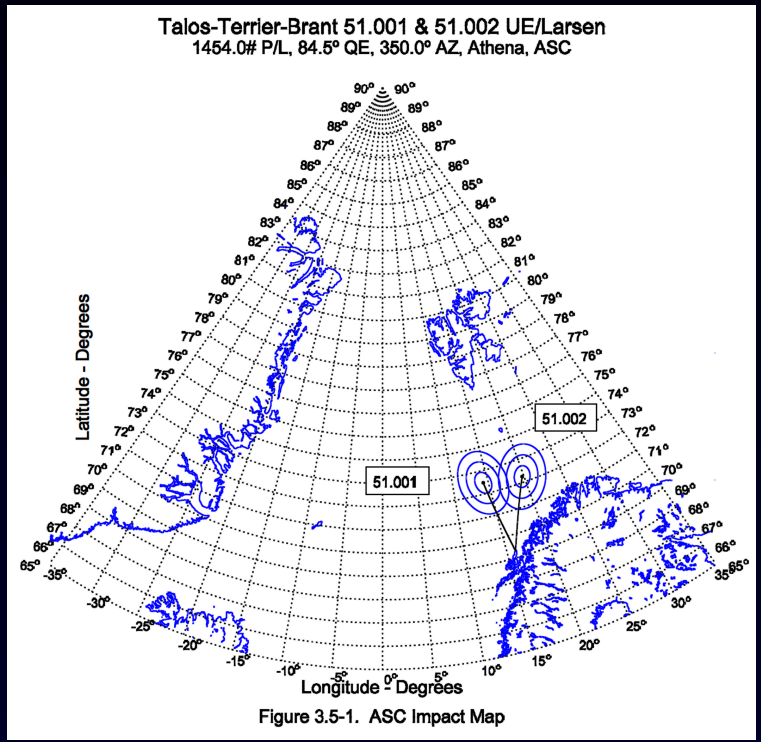
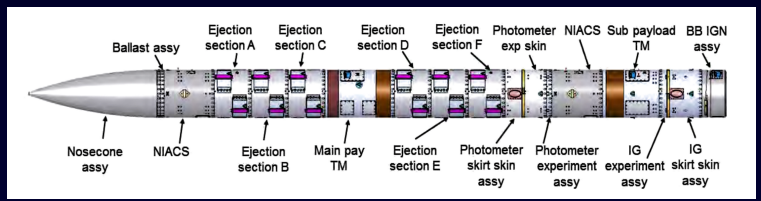
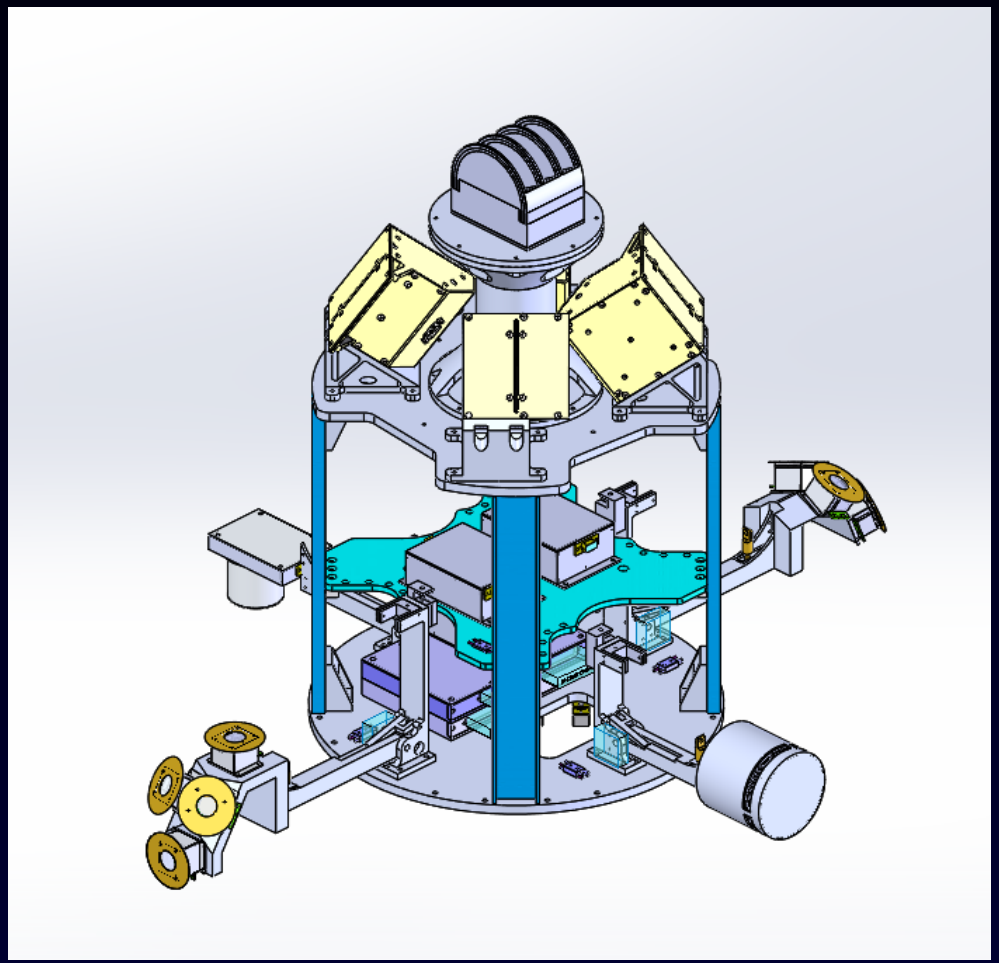


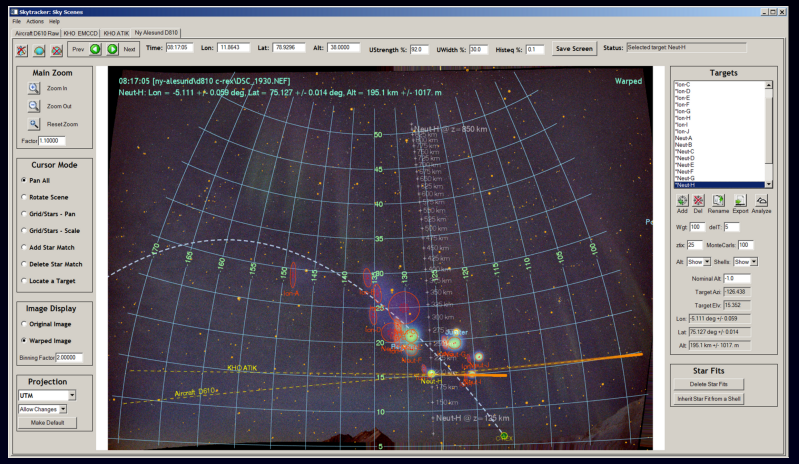
Figure 3.5-1. ASC Impact Map



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^+ clouds, by providing continuous fine-scale measurements at $\sim 2\,\mathrm{Hz}$.

EPLAS: The EPLAS measures the auroral electron phase space distribution over a nominal energy range of $20\,\mathrm{eV}$ to $15\ \mathrm{keV}$, 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 $300^\circ \times 5^\circ$.

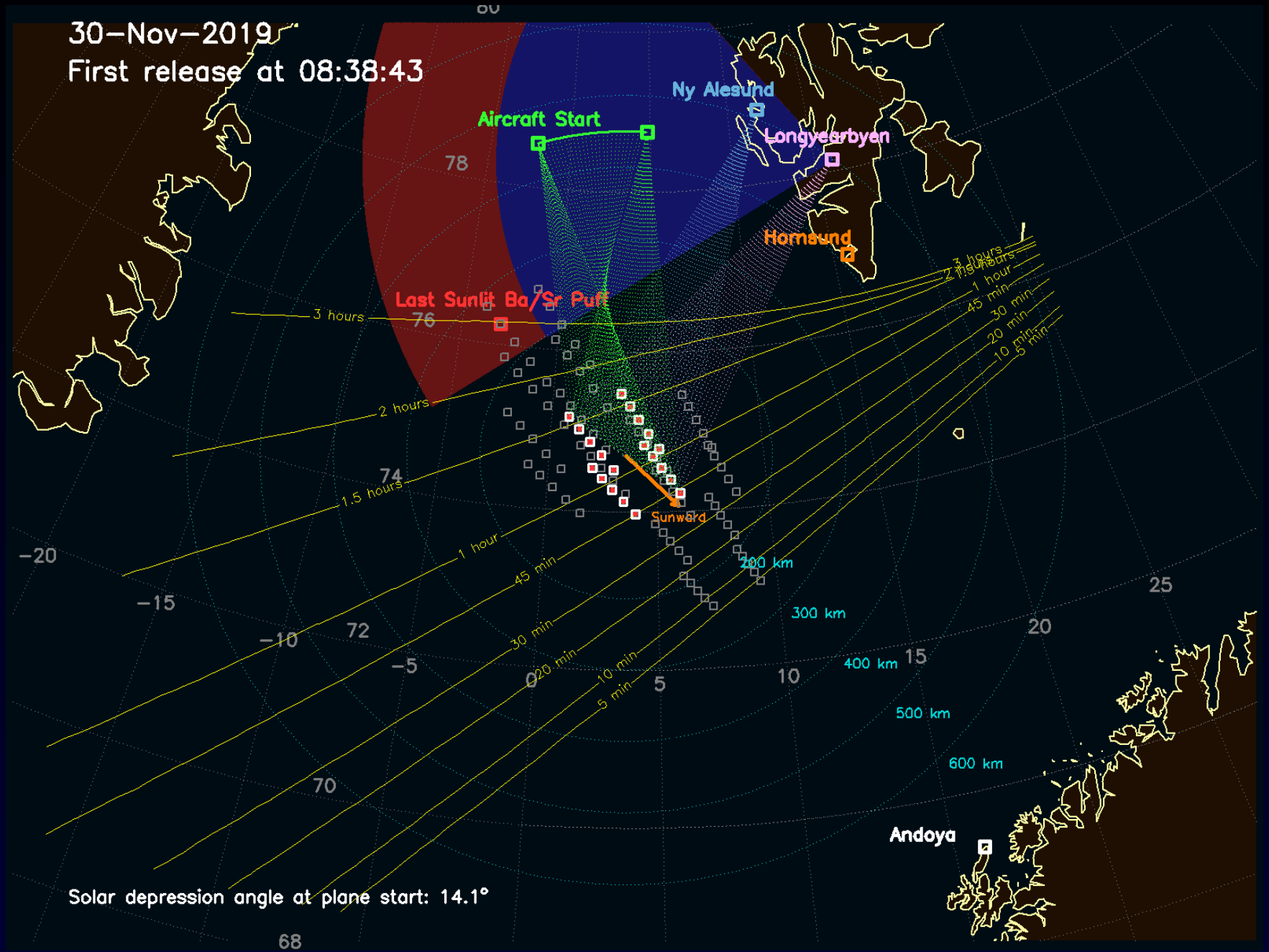
ERPA: The ERPA measures the thermal electron population (few tenths of an eV) as distinct from auroral precipitation measured by EPLAS. Operation is similar to a Faraday Cup with a swept retarding potential at its entrance for energy selection.

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?