# TRACERS: Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites

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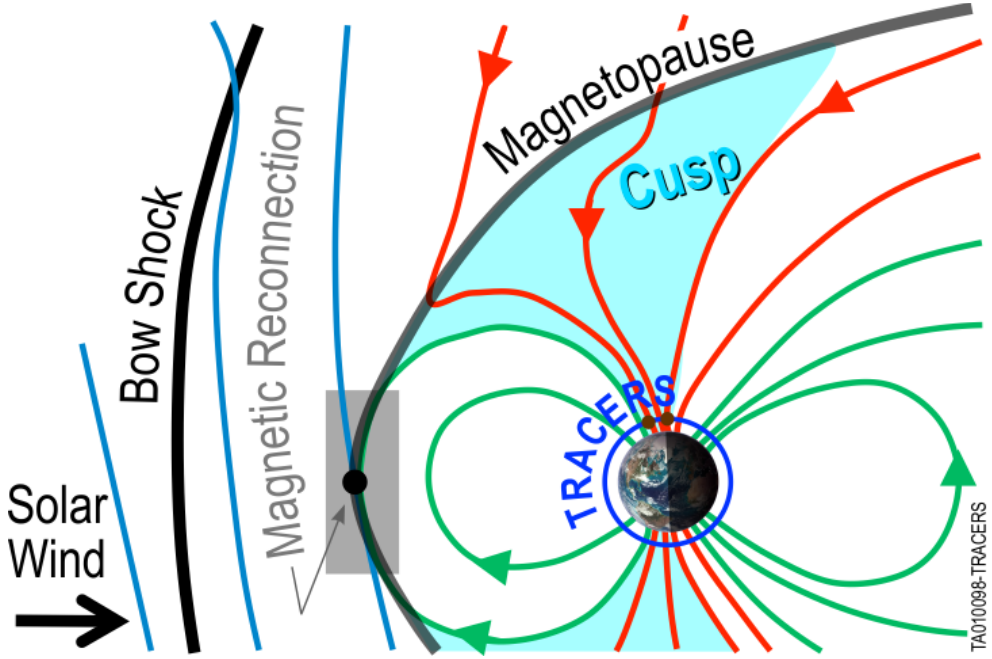
TRACERS Seminar

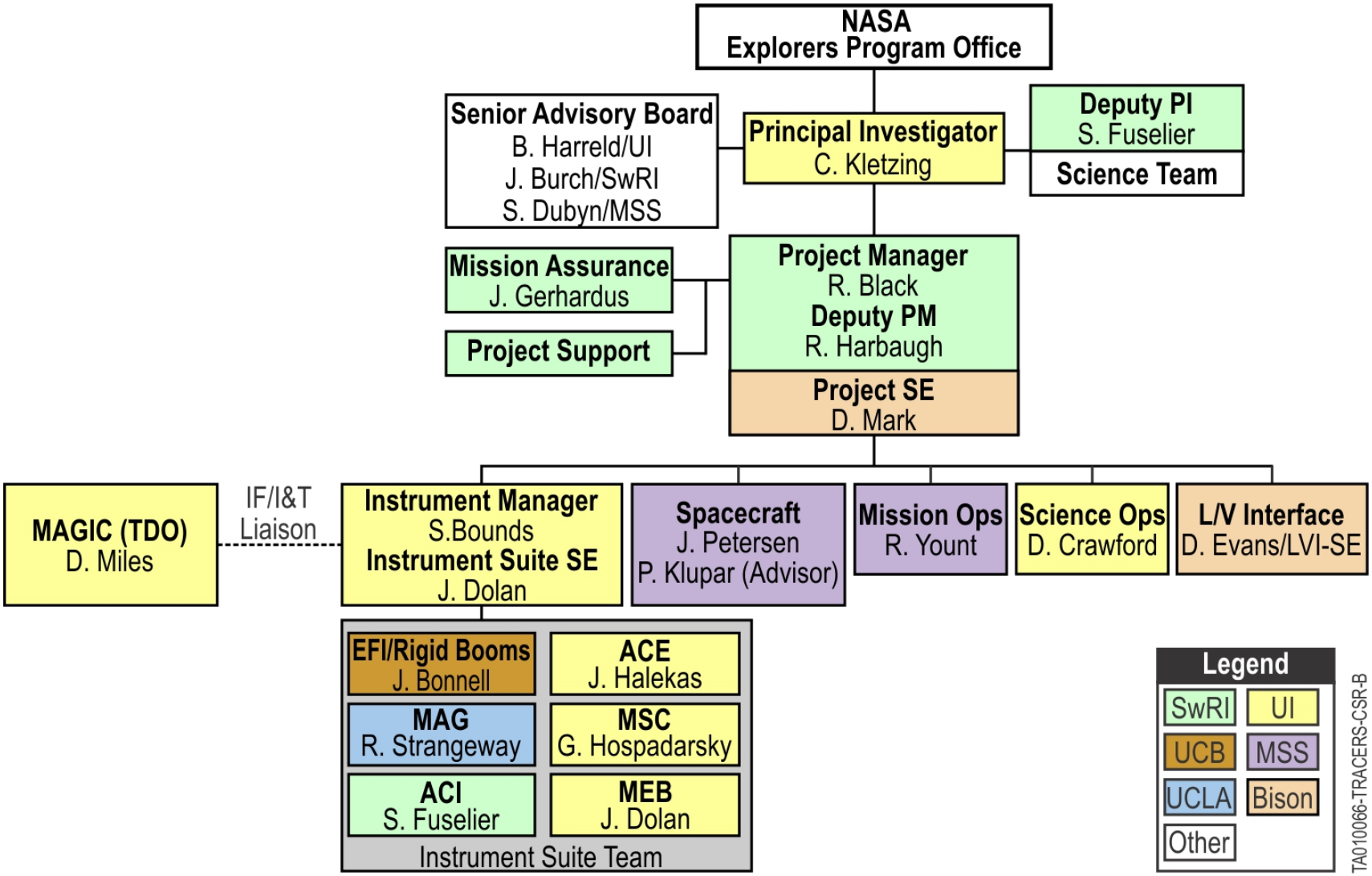
# TRACERS Mission Overview

- Two satellites in the same ~500 km, sun synchronous circular orbit
- Separated by 10-120 seconds as they pass through the cusp
- Extensive orbit studies using historical DMSP cusp location show that TRACERS will encounter the cusp ~3250 times in 1 year




- Minor satellite spin axis slew once per day aligns satellites to magnetic field when in the cusp "region of interest" that achieves proper field alignment for majority of orbits

# TRACERS Org Chart



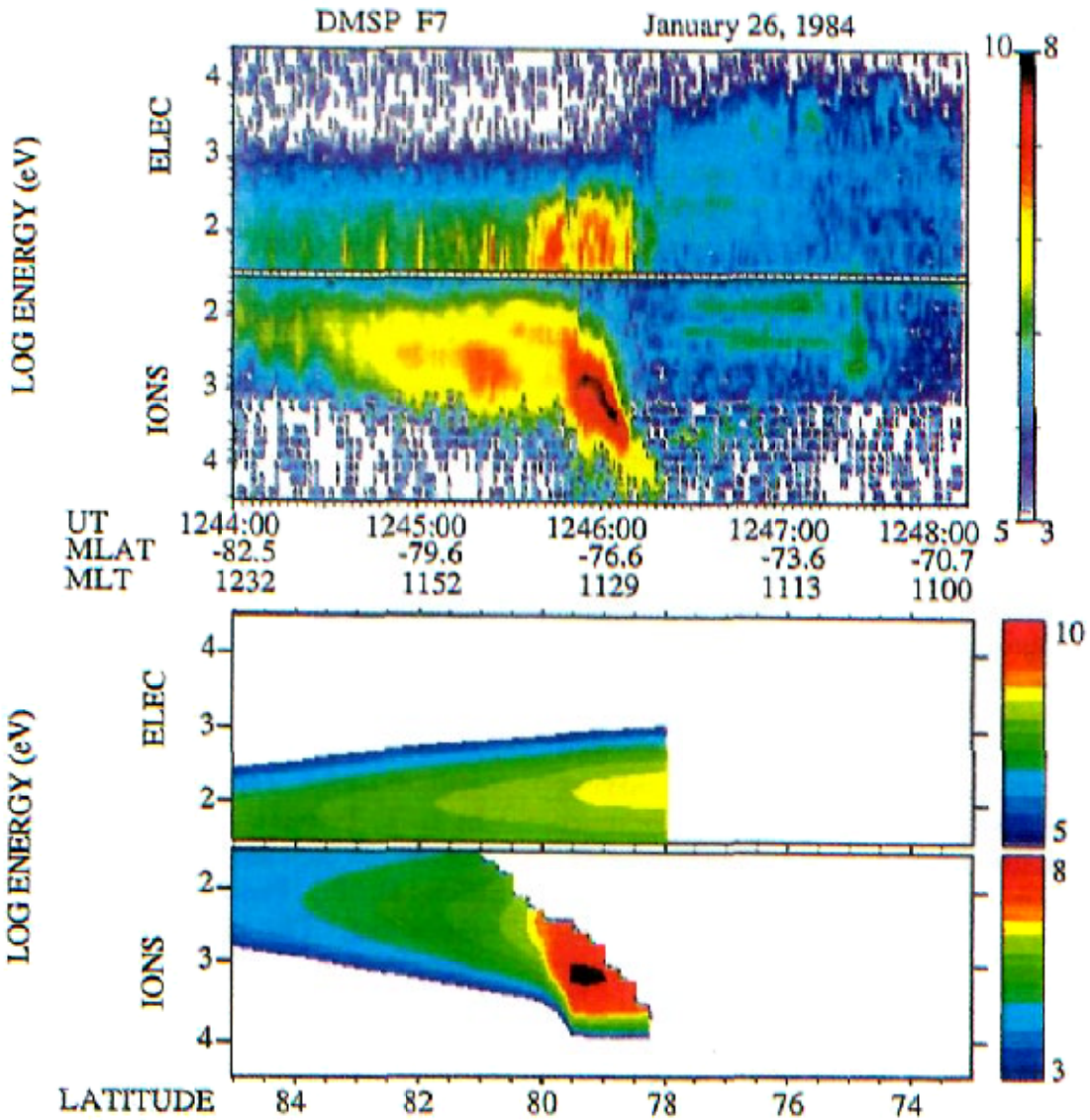
# Science Objectives

- **TRACERS Overarching Science Goal:**

  Connecting the Cusp to the Magnetosphere – Discovering how spatial or temporal variations in magnetopause reconnection drive cusp dynamics
- This is a major unresolved question in magnetospheric physics that has been unanswered for more than 2 decades
- Three science objectives flow from this goal

# Early Motivation

- Observations by polar orbiting spacecraft such as DMSP showed energy-time dispersion of ions
- A simple model of ion injection coupled with poleward convection explains the dispersion (Onager et al., 19930



# Science Objective 1

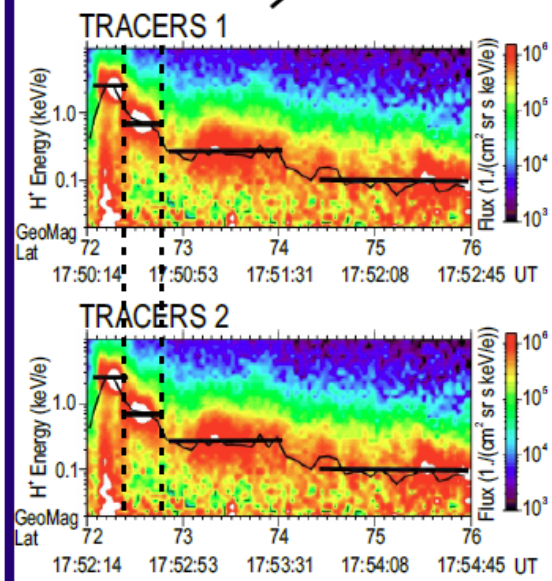
**Science Objective 1:** Determine whether magnetopause reconnection is primarily spatially or temporally variable for a range of solar wind conditions.

**3250 Cusp Crossings, 1600 in the first 6 months**

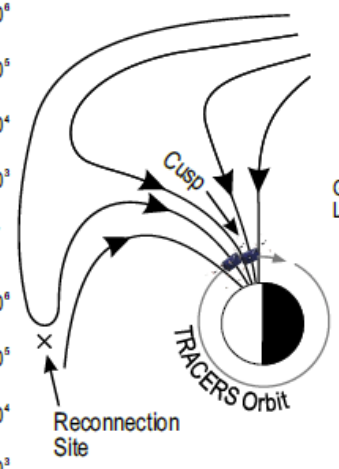
Spatial 50% (?)

Temporal 50% (?)

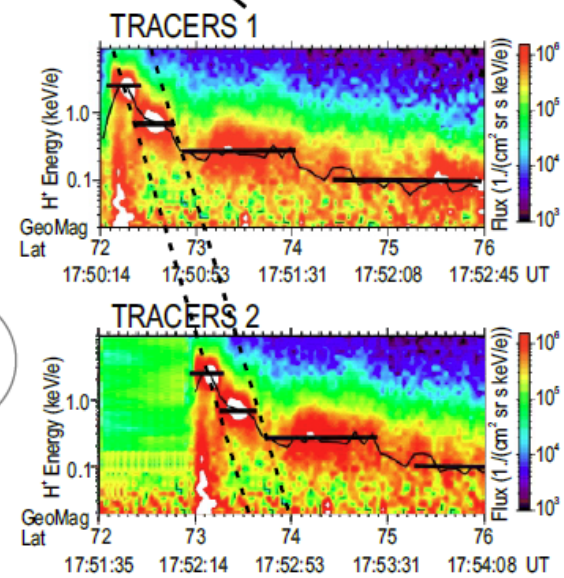
## Spatial




**Cusp ion steps show No Latitude Displacement**




## Temporal




**Cusp ion steps show Latitude Displacement**

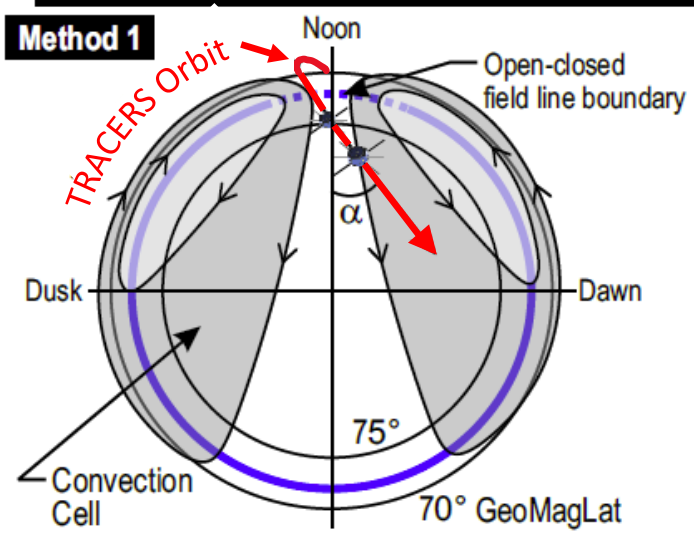
**Does Spatial/Temporal dominance depend on Solar Wind conditions?**

# Science Objective 2

**Science Objective 2:** For temporally varying reconnection, determine how the reconnection rate evolves.

**Temporal events from Science Objective 1 (Reconnection Rate Measured 2 Ways)**

**Method 1**




**Is $V_N$ Different for TRACERS 1 & TRACERS 2?**

$V_C$ at merging gap= $V_{SC} + V_N + V_M$

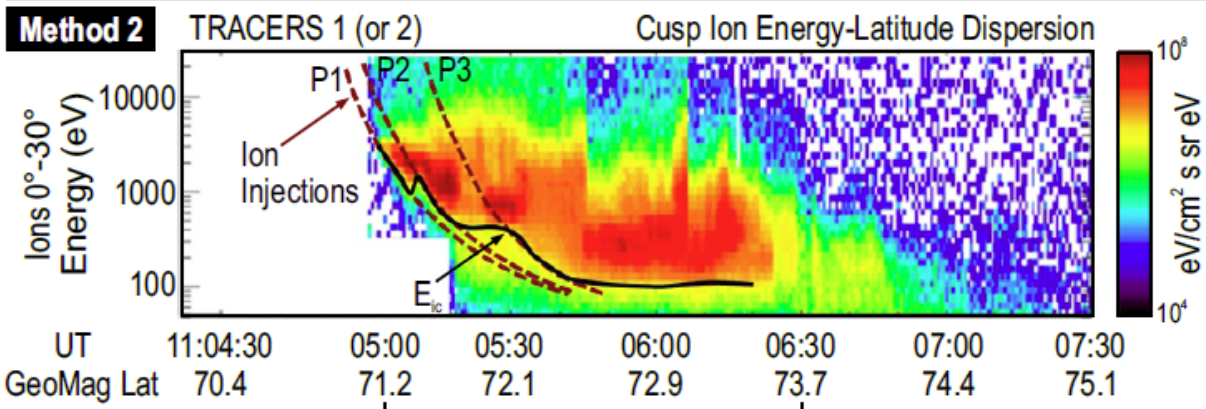
$V_{SC}$ = Spacecraft speed

$V_N$ = Reconnection inflow

$V_M$ = Motion of open/closed field line boundary from electrons on 2 spacecraft

$\alpha$ = Angle between normal to merging gap and $V_{SC}$ from electric field

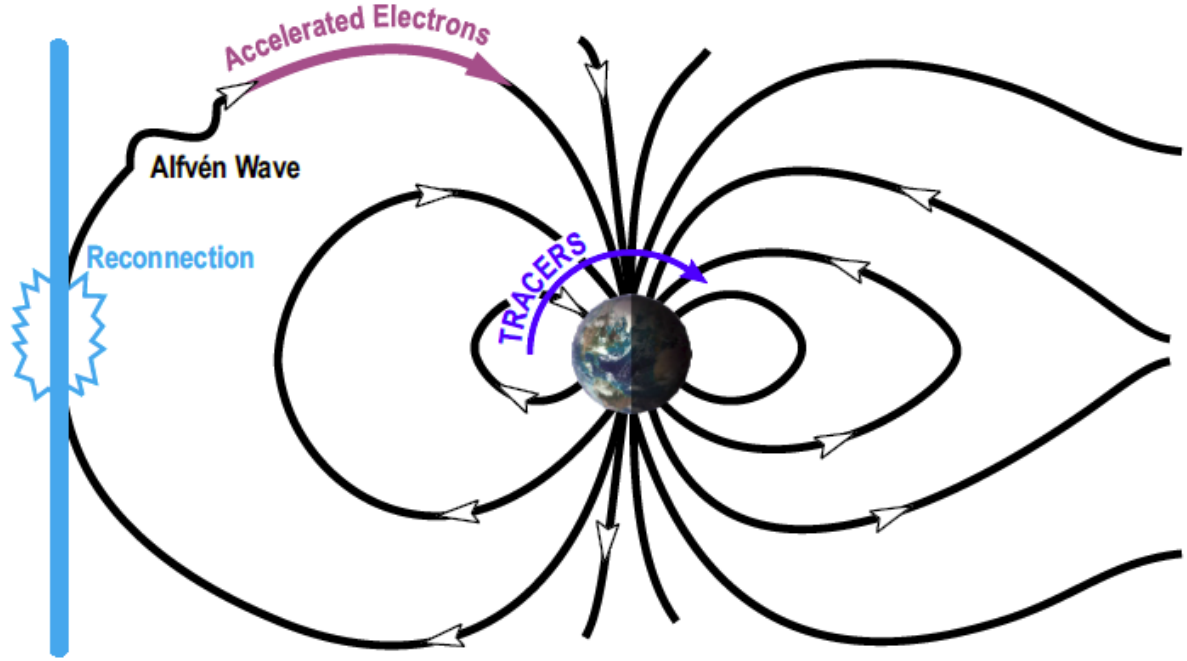
**Method 2**



# Science Objective 3

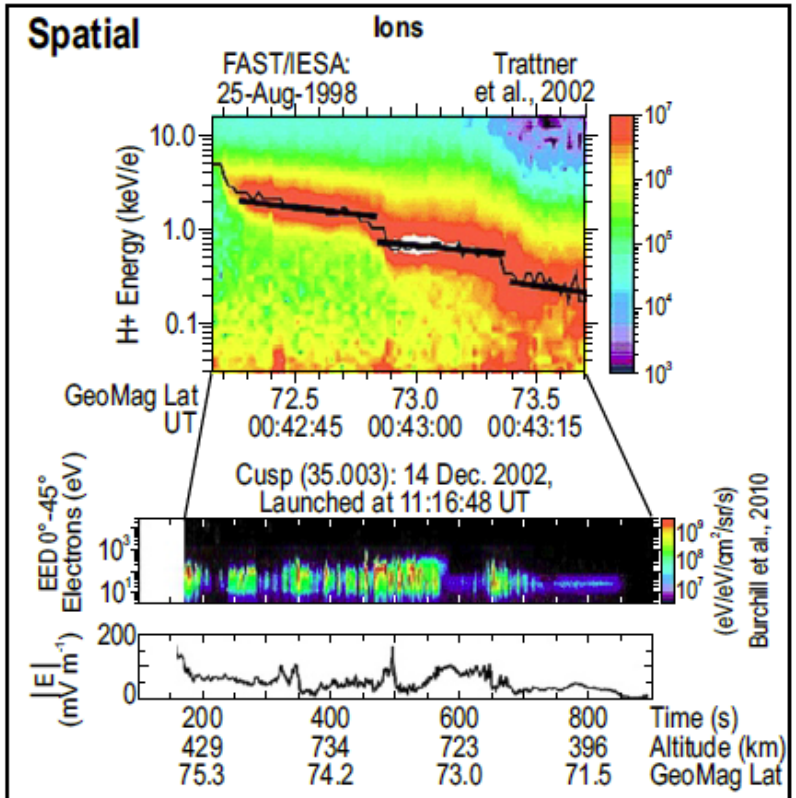
**Science Objective 3:** Determine to what extent dynamic structures in the cusp are associated with temporal versus spatial reconnection.

**3250 Cusp Crossings, 1600 in the first 6 months**

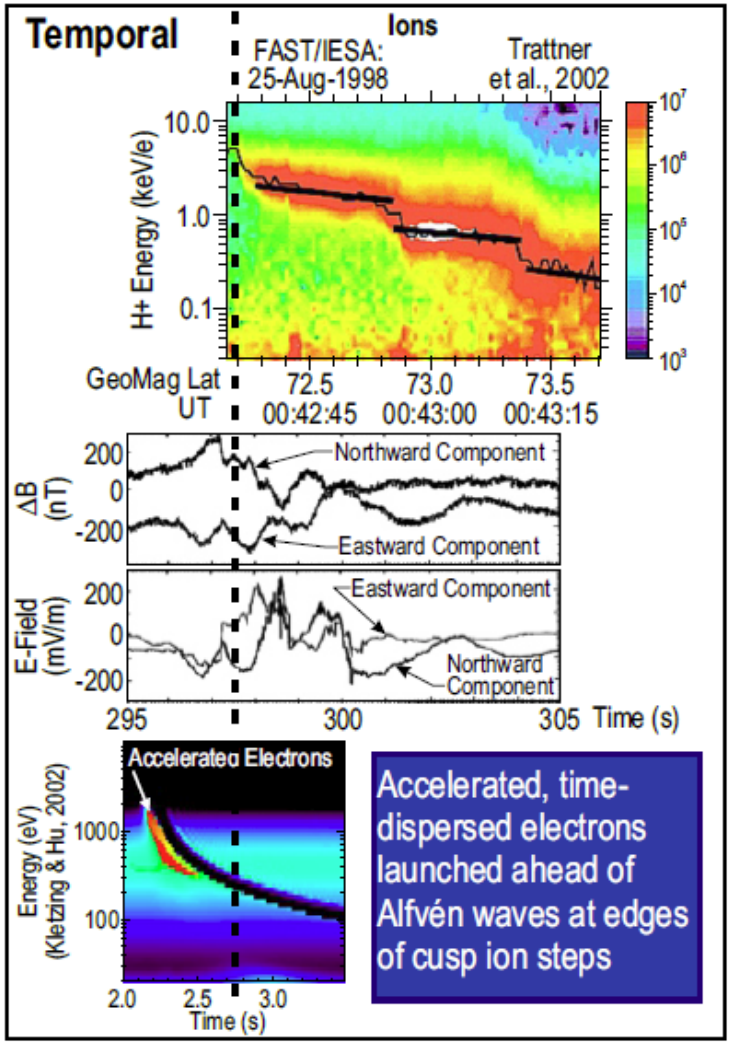


# Science Objective 3 (cont'd)

## TRACERS Signatures




No accelerated, time-dispersed electrons. No Alfvén waves. Possible current structures and other wave modes at cusp ion step edges.




Accelerated, time-dispersed electrons launched ahead of Alfvén waves at edges of cusp ion steps

# Why Now?

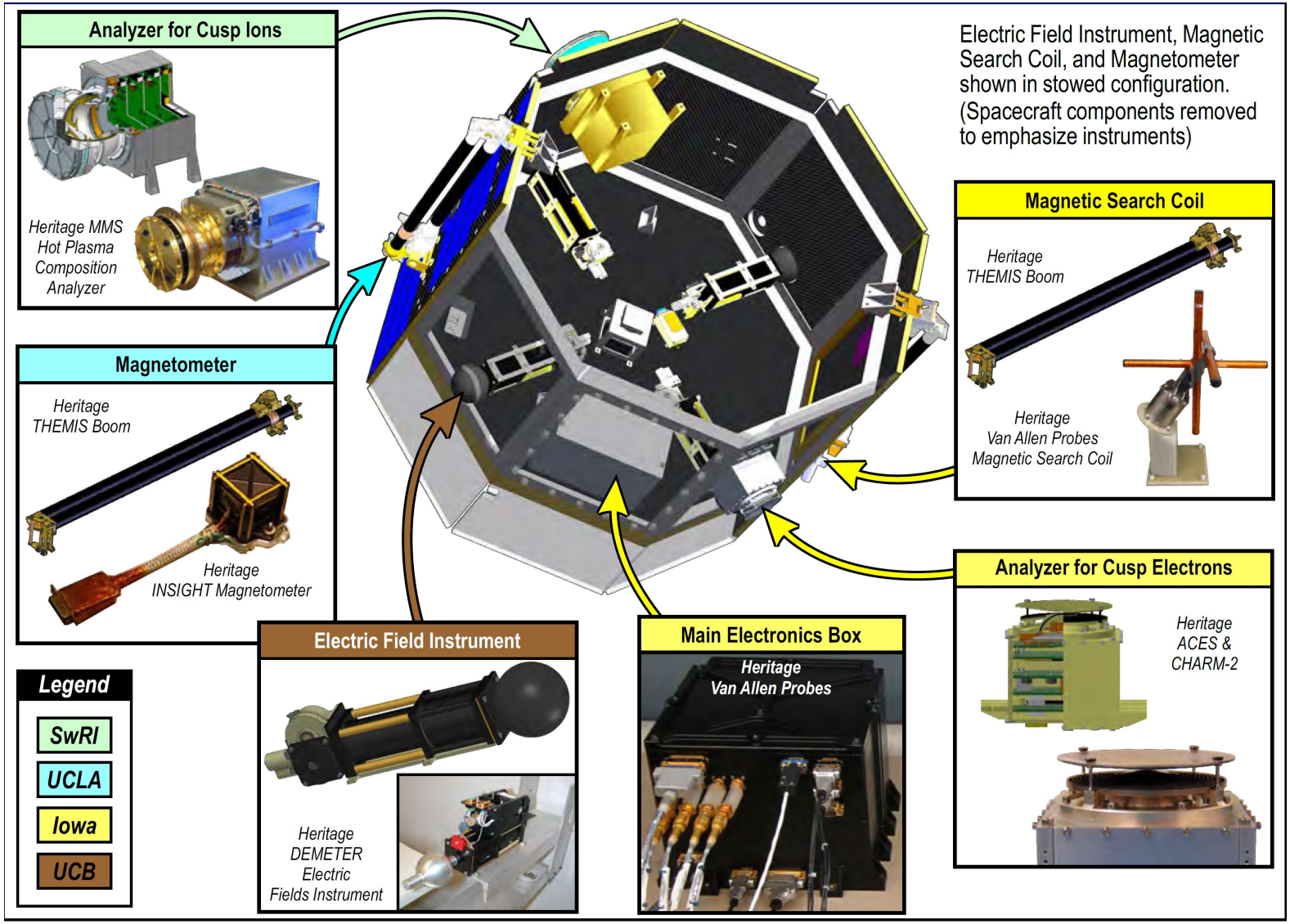
- The magnetospheric community is focused on reconnection spurred on by the MMS science of the micro-physics of reconnection
- Given this focus, now is the time to answer the complementary questions about the larger scale aspects of temporal vs. spatial variability of reconnection
- Simulation tools are now sophisticated enough to provide strong global context to the TRACERS local measurements

# TRACERS Highlights

- Once daily spin-axis re-orientation aligns instruments with nominal field, simplifying implementation and operations
- Satellite design is compatible across wide range of launch vehicles depending on propellant system option decision, providing NASA with launch flexibility
- Innovative ride-share launch approach reduces cost while providing an important new model for future SMEX programs
- Robust theory and simulation enables strong science closure
- TRICE-2 rocket mission demonstrates team's capabilities:
  - TRACERS has the right instruments matched to our science
  - Highly experienced team well-versed with each other and works well together
- PI's demonstrated record (VA Probes/EMFISIS) delivering high fidelity usable data access to the broad scientific community

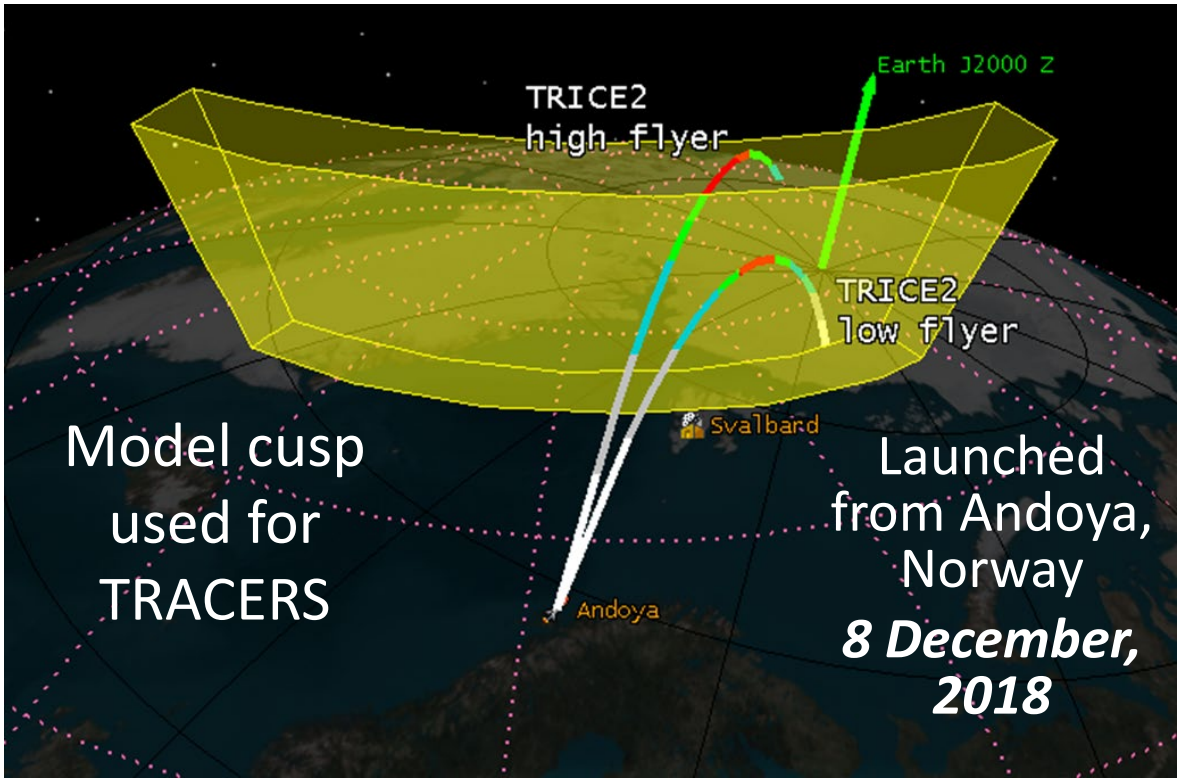
# TRACERS Instruments

*shown inside Millennium Space Systems S/C bus*



# TRACERS Heritage & Validation of Measurements

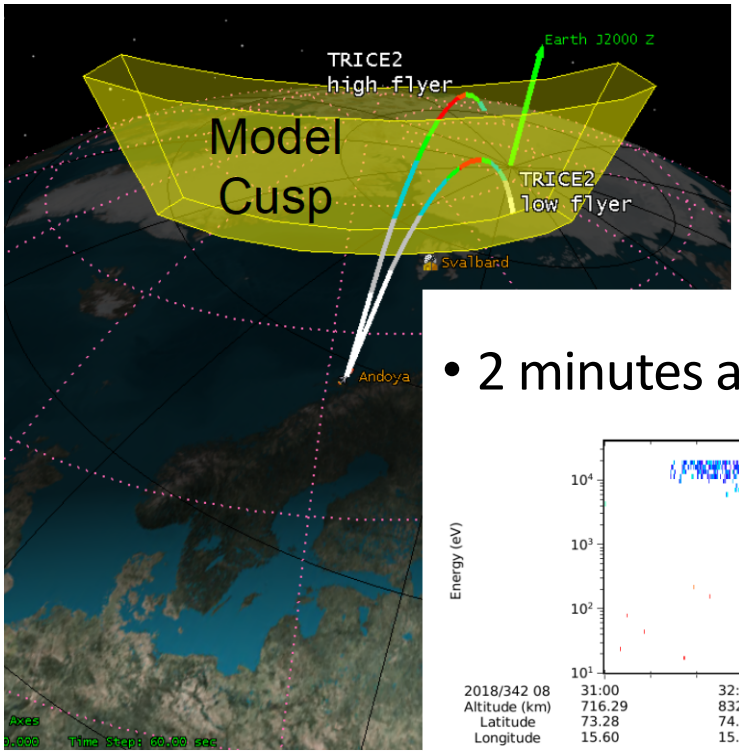
*Successful TRICE-2 Rockets*



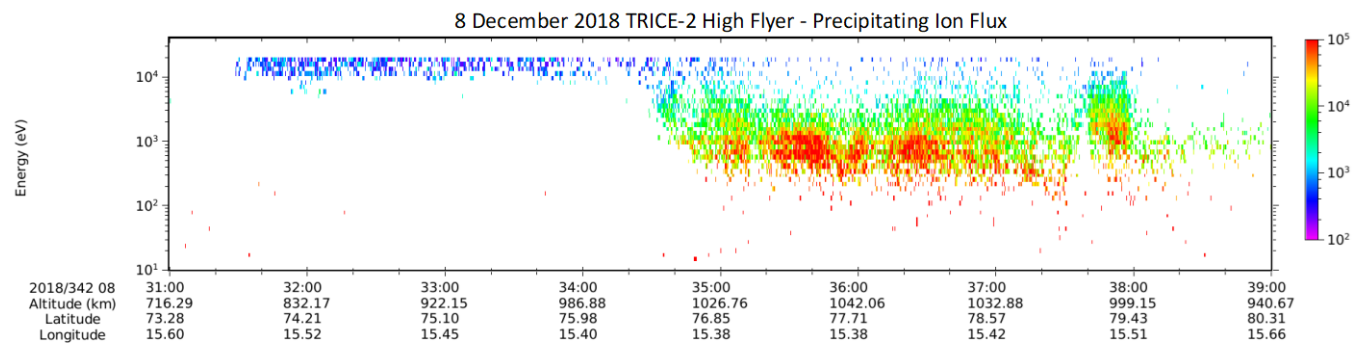

- Successfully Targeted the Cusp – ***Validates TRACERS mission ConOps & Science Observing Plan modelling***
- 2 minutes apart: ***Analog & proof of TRACERS temporal spacing***
- ***TRICE-2 is the genesis of TRACERS concept and teaming***

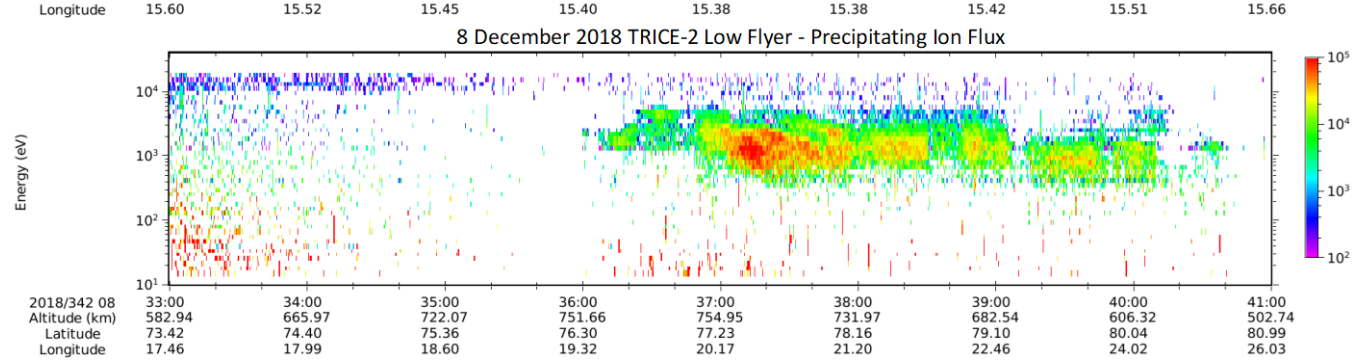
# TRACERS Heritage & ACI

## *Successful TRICE-2 Rockets Ion Instrument*




- Successfully targeted the cusp – ***confirms TRACERS mission ConOps & science observing plan modelling***
- TRACERS ACI Proof-of-Concept: ***TRICE-2 ion instruments prove exact team build of 2 ACI units on short schedule to cusp measurement ranges/specs***
- 2 minutes apart: ***Validates TRACERS temporal spacing***



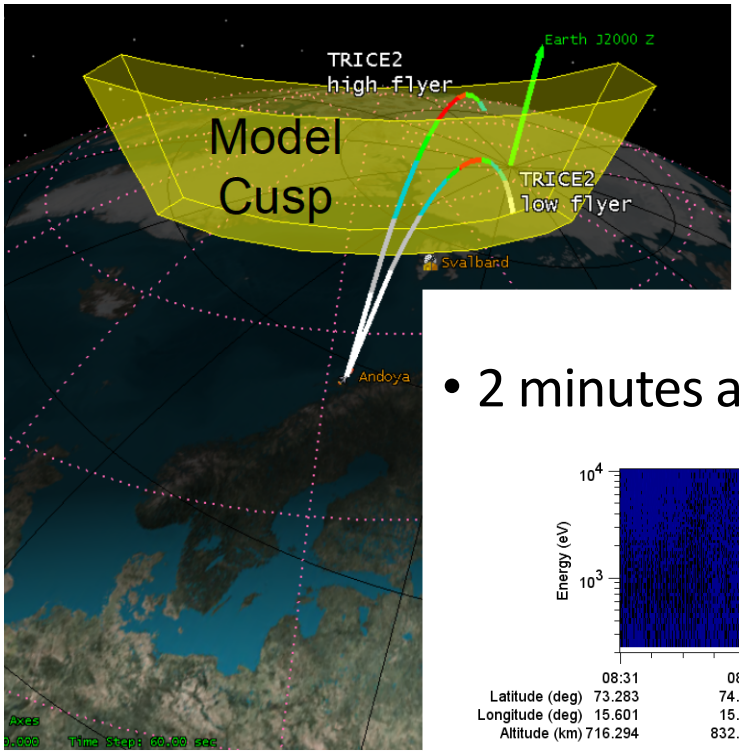




Launched from Andoya, Norway

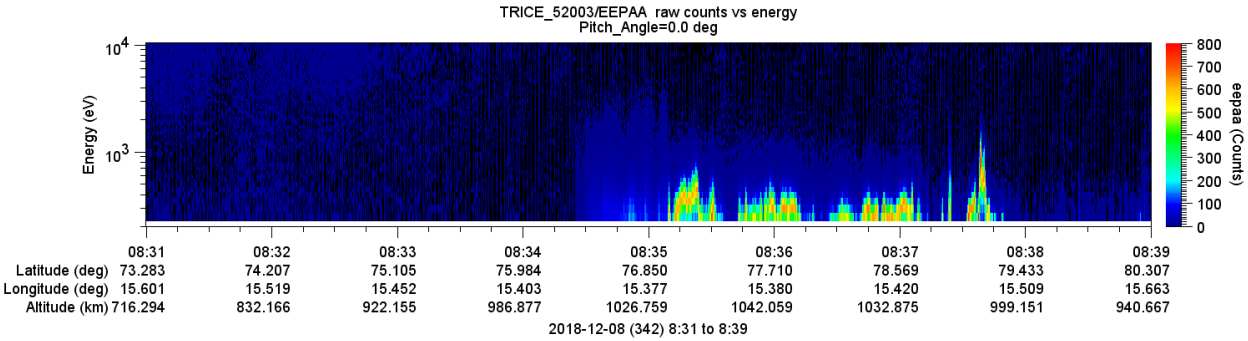
***8 December, 2018***

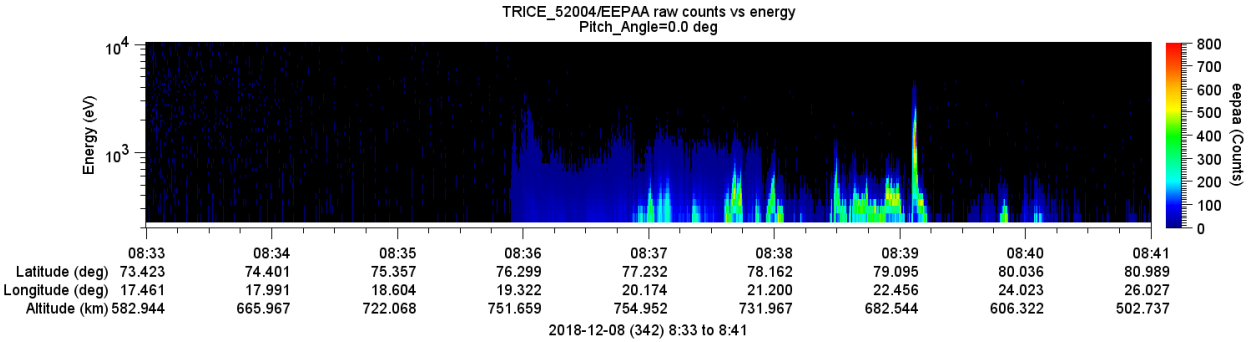
# TRACERS Heritage & ACE

## *Successful TRICE-2 Rockets Electron Instrument*




- Successfully targeted the cusp – ***confirms TRACERS mission ConOps & science observing plan modelling***
- TRACERS ACE Proof-of-Concept: ***TRICE-2 electron instruments prove exact team build of 2 ACE units on short schedule to cusp measurement ranges/specs***
- 2 minutes apart: ***Validation of TRACERS temporal spacing***

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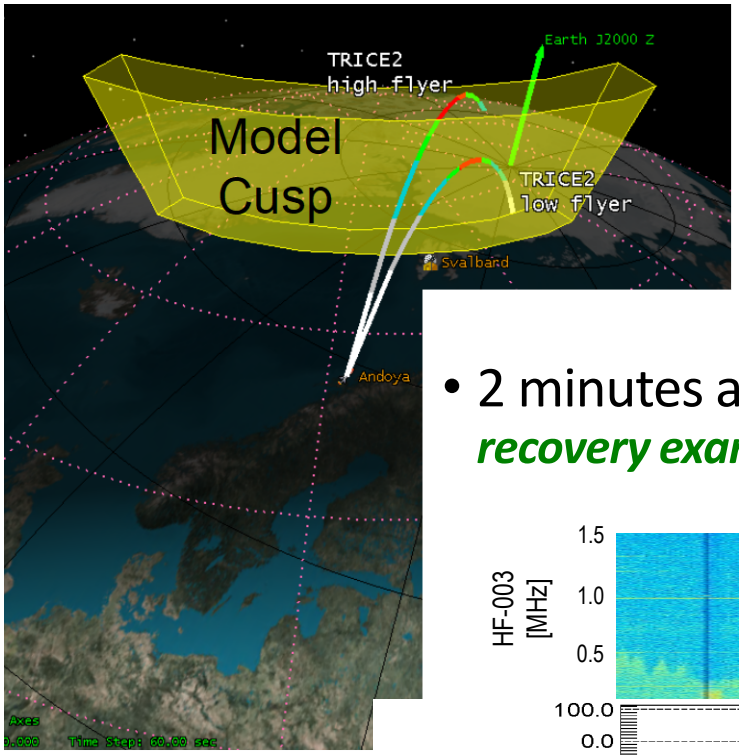
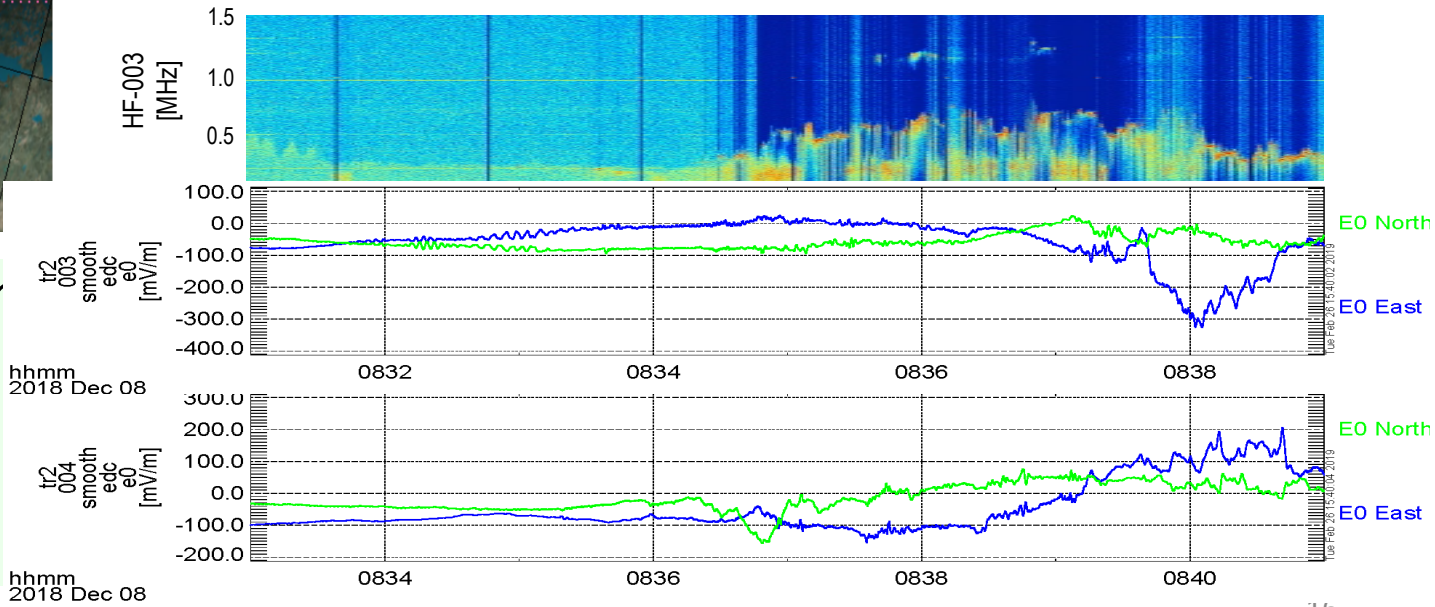
***8 December, 2018***

# TRACERS Heritage & EFI

## *Successful TRICE-2 Rockets Electric Fields Instrument*




- Successfully targeted the cusp – ***confirms TRACERS mission ConOps & science observing plan modelling***
- TRACERS EFI Proof-of-Concept: ***TRICE-2 E-field Instruments prove exact team build of 2 EFI suites on short schedule to cusp needed measurement ranges/specs***
- 2 minutes apart: ***DC convection field and HF spectra ($n_e$) recovery example validates TRACERS specs.***



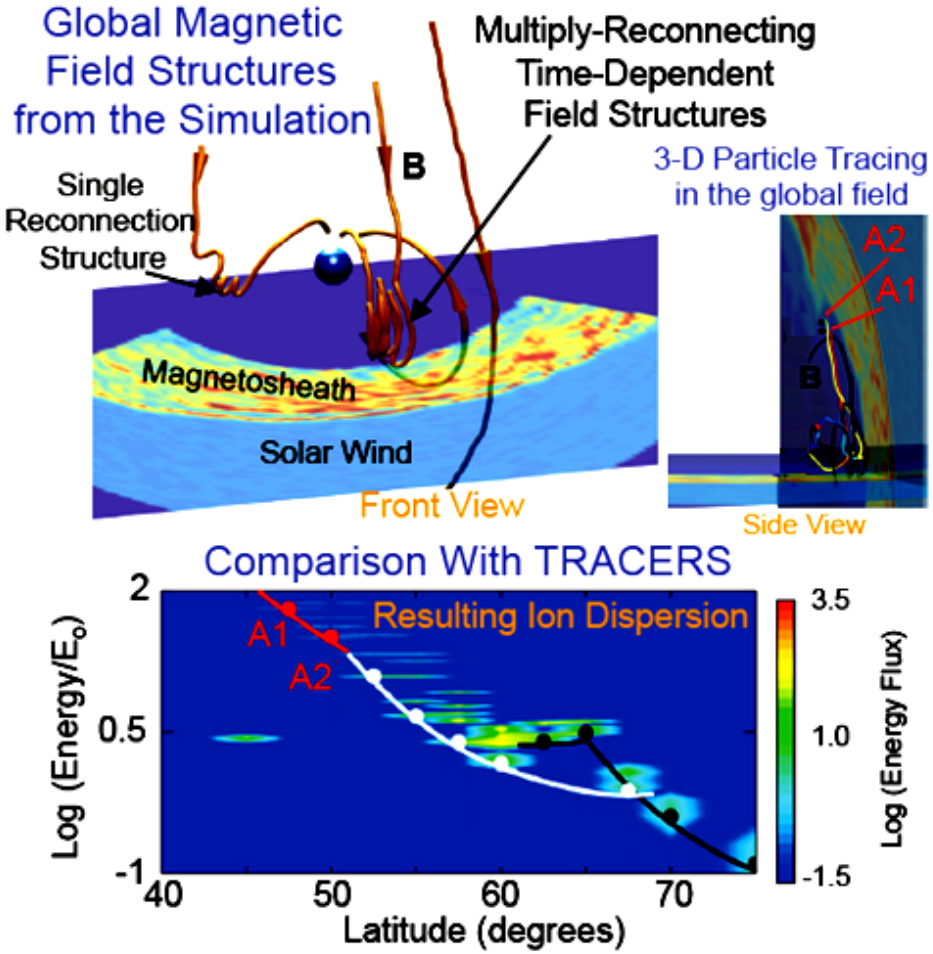

Launched from Andoya, Norway

***8 December, 2018***

# Instruments: Simulations

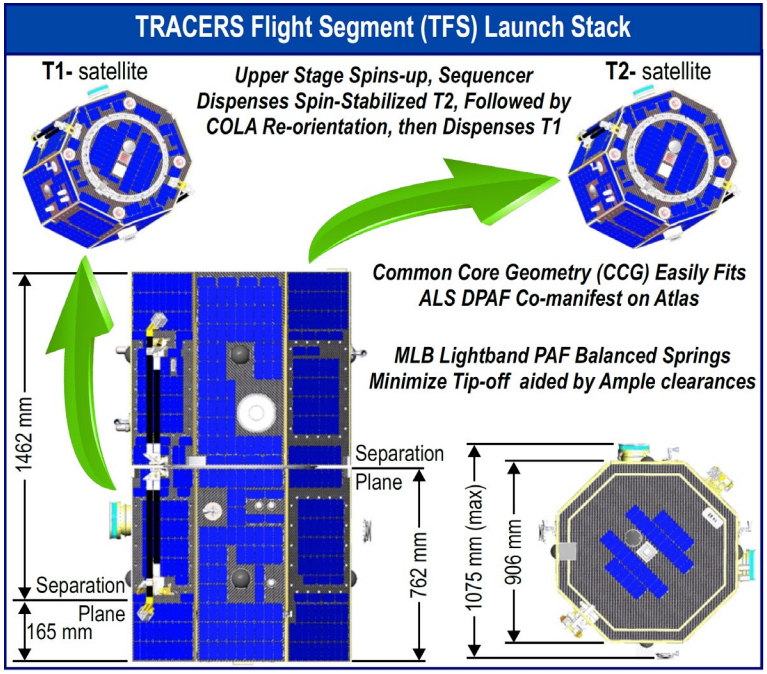
*Plasma Simulations: Y. Lin, Auburn*

- Global hybrid simulations provide context for the TRACERS observations
- Field line tracing allows direct comparison with TRACERS particle measurements

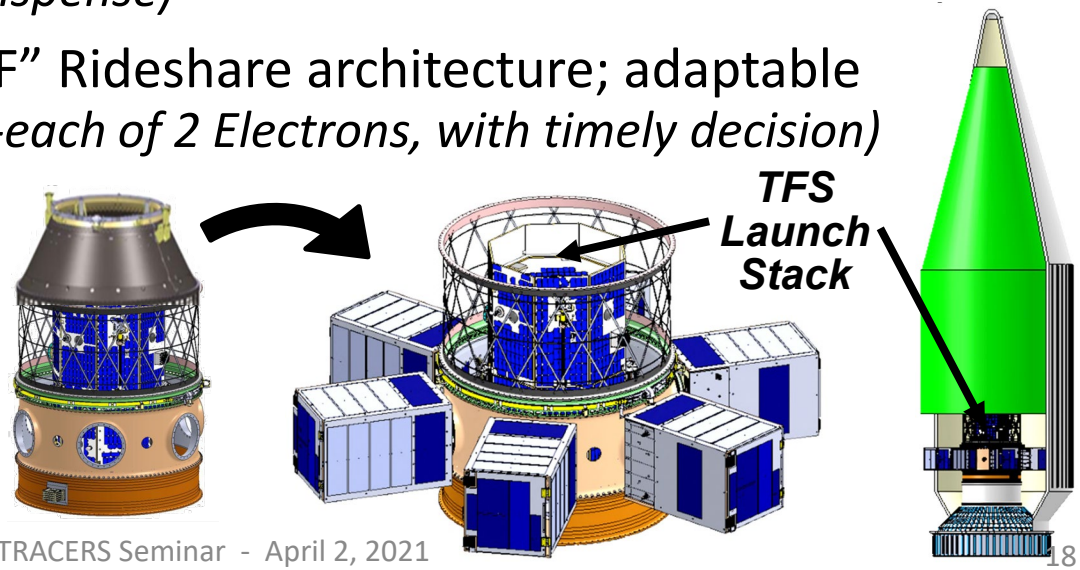


# Launch Compatibility

- TRACERS Flight Segment (TFS) Launch "Stack": Self-protect and Do No Harm (DNH) approach for Rideshare
- 400 kg *(Agreed-to Limit, both T1 & T2 satellites, wet, NTE)* into 500 km SSO; *(optimal science @ 10:30 LTDN baseline)*
- Launch: receiver on, switch to internal *(~T-10m)* power; instruments off
- 2-10 rpm L/V rotation; spin-stabilized dispense into safe mode *(T2 dispense-reorient-then-T1 dispense)*

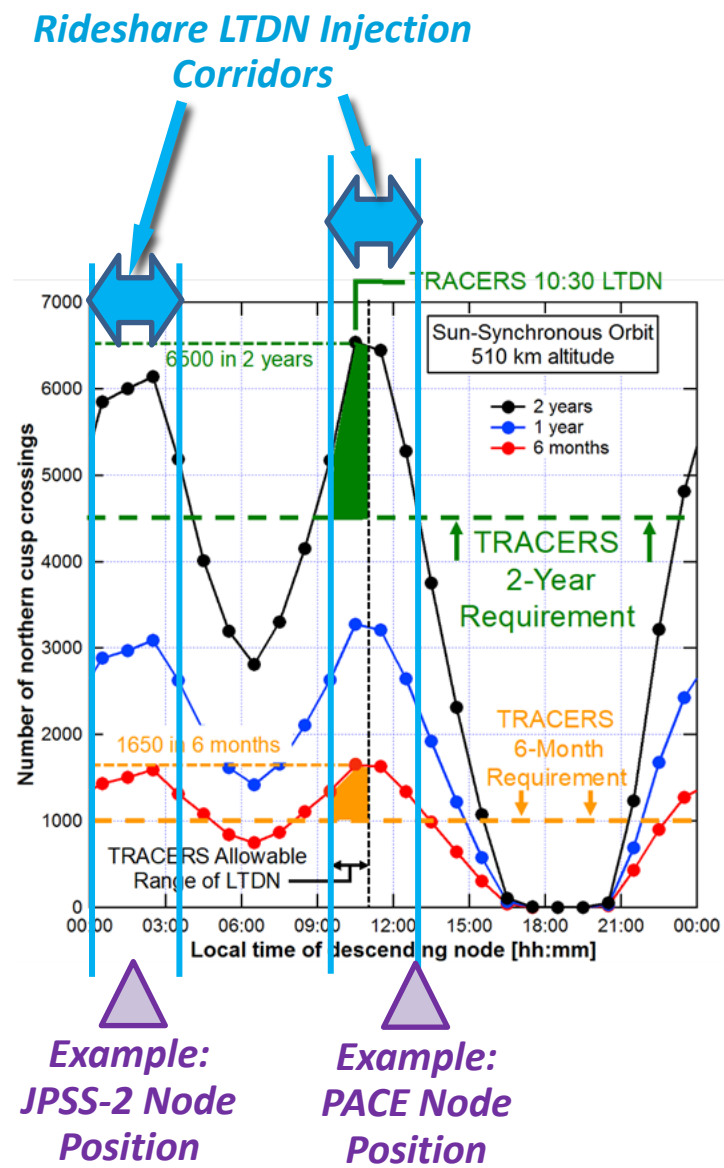



- Deliberate "inside ESPA/DPAF" Rideshare architecture; adaptable to small ELV *(Firefly or one-on-each of 2 Electrons, with timely decision)*
- PDR-fidelity ICD formed in Phase A *(in ΔCSR Appendix)*
- Lightband PAF unchanged across adaptations *(preserves satellite I/F)*



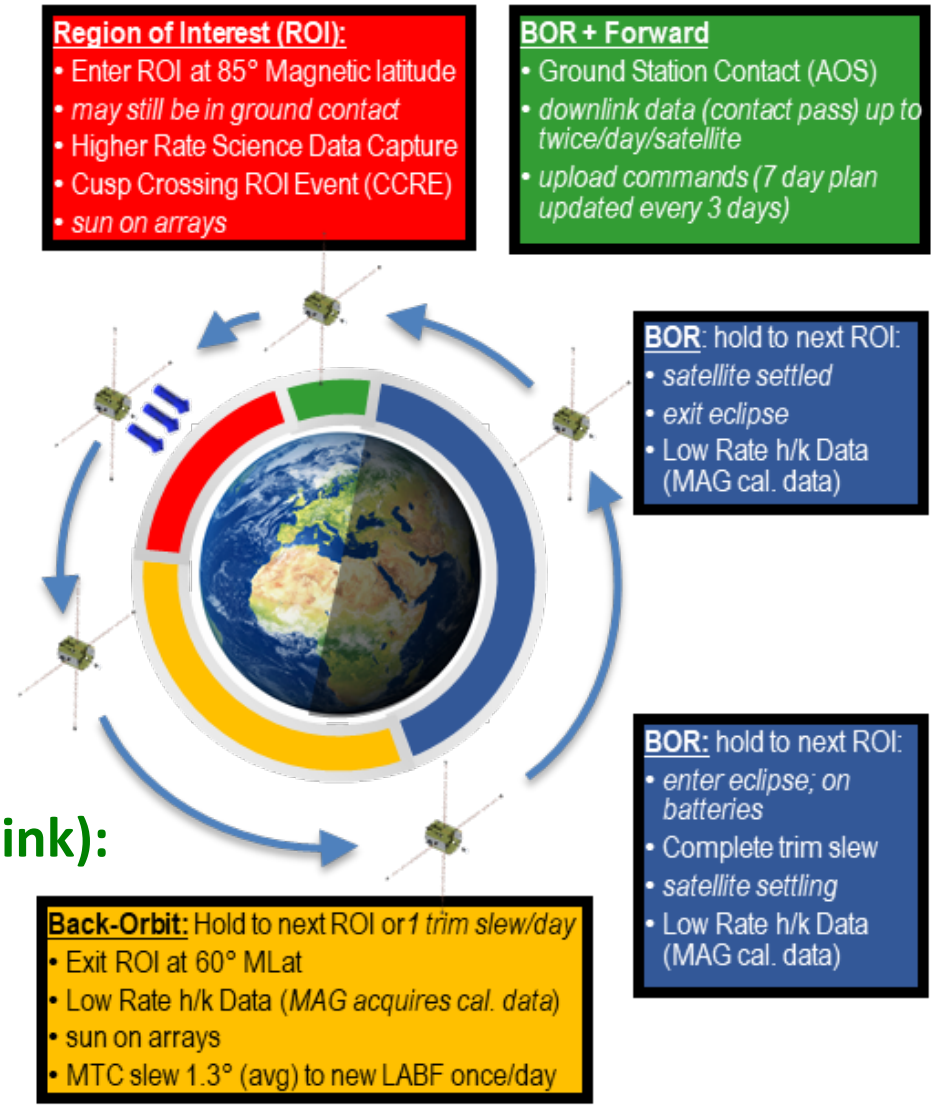
# Cusp Accumulation Science Efficiency

- **Two LTDN Efficiency Maxima**
  - 10:30 Highest; 02:00 is close-2nd
  - Science Cusp accumulation rate varies ~5% between 500-750 km SSO range
  - COLA better lower
  - Passive EOM orbit debris/demise envelope altitude ~<605 km
- **Propulsion up-size option streamlines launch service**
  - Original CSR capacity to induce LTDN drift
  - Widens injected SSO altitude, LTDN acceptance corridor
  - ConOps: Direct-inject the main Rideshare partner; dispense TRACERS after; no further L/V actions (standard upper stage profile)
  - Accumulates TRACERS 6 mo. threshold science "along the way"
  - Option decision: <3 mo. after Bridge start



# Mission ConOps: *Typical "Orbit in the Life" Scenario (OILS)*

- **Science Region of Interest (ROI):**
  - ~7 min/orbit during cusp transit (60-85° geomagnetic latitude)
- **Back Orbit (BOR):**
  - Once/day: Align spin-axis to LABF (B-field inertial attitude); Avg. slew ~1.3°
  - Slew-settle occurs <50 min
  - Only H/K + filtered cal. data in BOR (mostly EFI/MAG background)
- **Eclipse:**
  - Occurs every orbit predominantly in BOR
  - 35.2 min. peak duration (37% of $T_{orbit}$)
  - Post-shadow equilibration (booms) minimal *(configuration & prior experience)*
- **Communications/Forward (Downlink):**
  - Contact nominally occurs in BOR
  - System designed to operate during downlink *(occasionally can span into ROI)*
  - 7-day forward stored-command sequence uploaded, during regular contact, every 3 days



# TRACERS Resilience

- Science closure:
  - Threshold quickly achieved (6 mos.)
  - Full mission of robust cusp event statistics in one year.
- Mission Ops
  - Phase A resulted in simplified ops and low complexity
- Fault tolerant architecture – What if an instrument fails?
  - Preserves majority of science
  - Example: Loss of 1 ACI – Threshold mission still achieved
  - Example: 1 Boom deploy failure – satellite stable, slight "wobble" w/increased MAG/EFI noise; Baseline mission achieved

# Public Engagement

- Space weather is the best rubric for engaging the public with the TRACERS science
  - Society uses a wide range of space assets, so understanding how energy couples to the magnetosphere is an easy sell
- TRACERS directly measures electrons responsible for cusp aurora. The aurora is interesting and in the vernacular of the public; many (*particularly across the mid-to-west*) have seen it or plan travel around potential viewings
- Hands-on engagement is a smaller cross-section, but allows a more in-depth demonstration of the physics of the mission. We are thinking about inexpensive magnetic field experiment kits to distribute to students

# TRACERS Science Summary

- TRACERS answers long-standing questions about reconnection that are fundamental to understanding the coupling of the Earth-Sun system
- TRACERS data set provides a wealth of Multi-satellite cusp region measurements to make large-step advancement from prior single point cusp studies
- Our strong theory team integrates statistically significant rich set of cusp crossing measurements to ensure closure of the science objectives

# That’s all folks!