TRACERS: Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites

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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
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: 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

Does Spatial/Temporal dominance depend on Solar Wind conditions?
Science Objective 2: For temporally varying reconnection, determine how the reconnection rate evolves.

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

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

TRACERS 1 (or 2) Cusp Ion Energy-Latitude Dispersion

- Ion Injections

- $E_{sc}$

- UT GeoMag Lat

- Energy (eV)

- Ion Density $\times 10^9$ cm$^{-3}$ s eV

- 11:04:30 10000

- 05:00 1000

- 05:30 100

- 06:00 10

- 07:00 1

- 07:30 0.1

May 19, 2020 Princeton TRACERS Seminar - April 2, 2021
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

**Spatial**
- FAST/ESA 25-Aug-1998
- Trattner et al., 2002

**Ions**
- Geomag Lat UT
- 72.5 00:42:45
- 73.0 00:43:00
- 73.5 00:43:15
- H^+ Energy (keV/e)
- 10^5 to 10^7

**Electrons (eV/Particle)**
- Burch & Hu, 2002
- 0 to 100


**Temporal**
- FAST/ESA 25-Aug-1998
- Trattner et al., 2002

**Ions**
- Geomag Lat UT
- 72.5 00:42:45
- 73.0 00:43:00
- 73.5 00:43:15
- H^+ Energy (keV/e)
- 10^5 to 10^7

**E-Field (mV/m)**
- Northward Component
- Eastward Component
- Accelerated Electrons

**ΔB (nT)**
- Northward Component
- Eastward Component

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

May 19, 2020
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

Launched from Andoya, Norway
8 December, 2018
Launched from Andoya, Norway

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.
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

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**Region of Interest (ROI):**
- Enter ROI at 85° Magnetic latitude
- may still be in ground contact
- Higher Rate Science Data Capture
- Cusp Crossing ROI Event (CCRE)
- sun on arrays

**BOR + Forward**
- Ground Station Contact (AOS)
- downlink data (contact pass) up to twice/day/satellite
- upload commands (7 day plan updated every 3 days)

**Back-Orbit:**
- Hold to next ROI or1 trim slew/day
  - Exit ROI at 60° MLat
  - Low Rate h/k Data (MAG acquires cal. data)
  - sun on arrays
  - MTC slew 1.3° (avg) to new LABF once/day

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**BOR: hold to next ROI:**
- satellite settled
- exit eclipse
- Low Rate h/k Data (MAG cal. data)

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**BOR: hold to next ROI:**
- enter eclipse; on batteries
- Complete trim slew
- satellite settling
- Low Rate h/k Data (MAG cal. data)
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!