O^+ at the Dayside Magnetopause and in the Outer Magnetosphere

Stephen A. Fuselier

Southwest Research Institute

University of Texas at San Antonio

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This presentation is being recorded

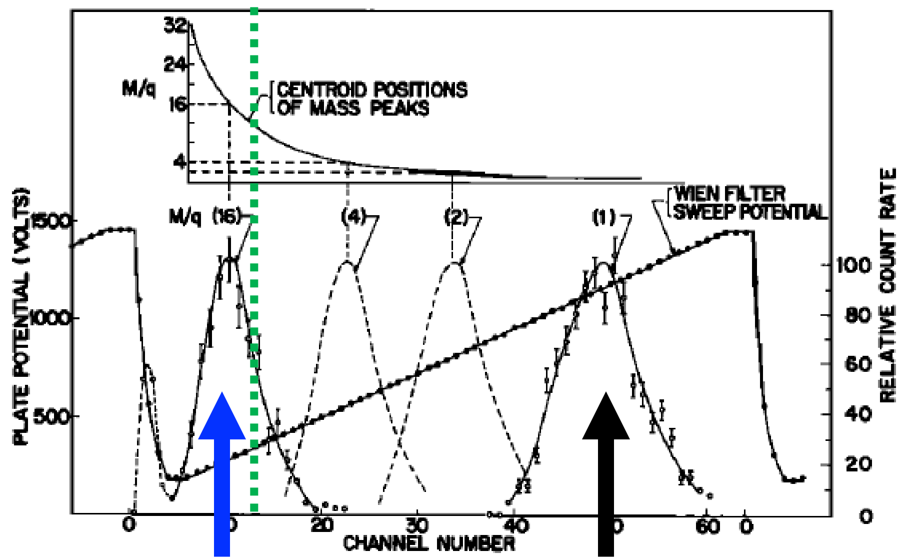
Agenda

- O^+ in the Magnetosphere
  - Discovery
    - 1972 Observations (Shelley et al., 1972)
  - Sources and Populations
    - The High Latitude Ionosphere
      - The Cusp, The Auroral Oval, Nightside Auroral Oval, Polar Cap
    - Populations: “Ring Current” and “Warm Plasma Cloak”
  - Transport to the Dayside Magnetopause
    - Convection: The ring current and the warm plasma cloak
  - Sinks on the Dayside
    - Dayside Magnetic Reconnection
  - The “Special Case” for Northward IMF
- Conclusions, Questions, and Future Work

Discovery of O^+

- Observations from a polar orbiting spacecraft
  - 800 km, near-sun synchronous orbit
  - Swept Wien velocity filter followed by an ESA and a CEM
    - 0.7 – 12 keV
  - Geomagnetic storm December 16-18 1971

The discovery of O^+ in the magnetosphere was a surprise!



O^+ (M/Q=16)

H^+ (M/Q=1)

Shelley, Johnson, and Sharp, JGR, 1972

ASTEX 1 (Launched 17 Oct 1971)

Earlier version of the mass spectrometer flew on OV1-18 (Launched 18 Mar 1969) but it had a maximum mass range of m/q=8 (green dashed line)

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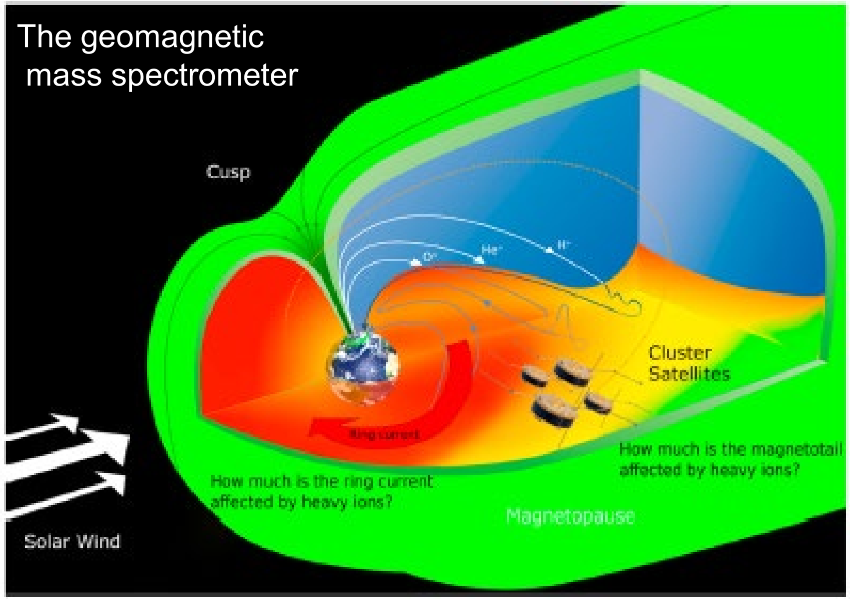
O^+ in the Dayside Magnetosphere: Sources

- The high latitude ionosphere is the source of all(?) of the O^+ observed in the dayside magnetosphere
  - Which part of the high latitude ionosphere?
    - Potential sources: Cusp, Auroral Oval, Nightside Auroral Oval, Polar Cap
  - Dominant sources depend on magnetospheric convection
    - Convection depends on the strength and orientation of the Interplanetary Magnetic Field
      - Example: Southward IMF



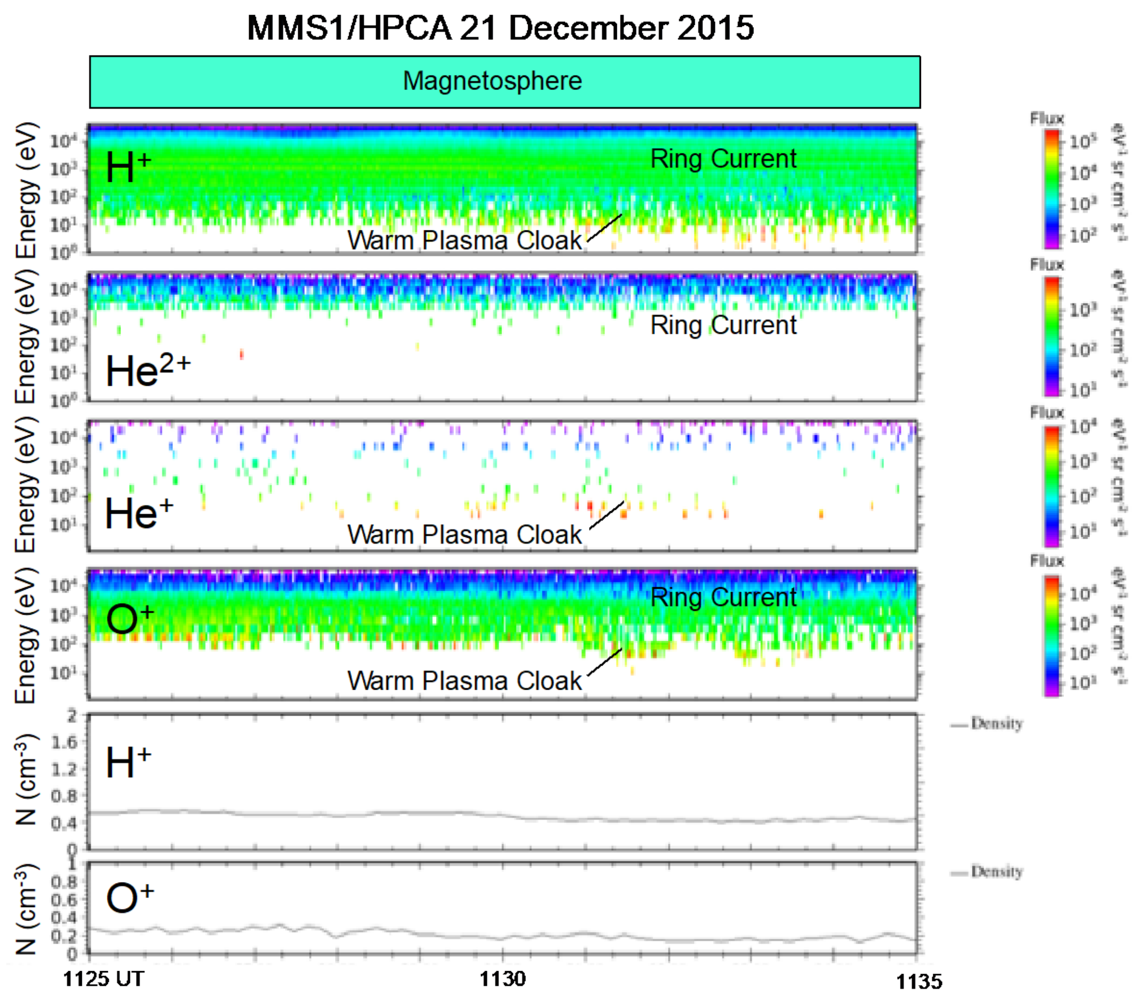
Kronberg et al., JGR 2017

O^+ in the Dayside Magnetosphere: Populations

- Two basic Populations
  - Ring Current ("hot") and Warm Plasma Cloak ("cold")
- Composition, Energy Distinguish These Two Populations
  - Ring Current – Substantial Solar Wind Source
  - Warm Plasma Cloak – "Pure" Ionospheric Source
- If the Overall Composition is Different, Does That Mean the Ionospheric Components Come from Different Source Locations?
  - Or is the energization/convection history of the two populations different? Or both?

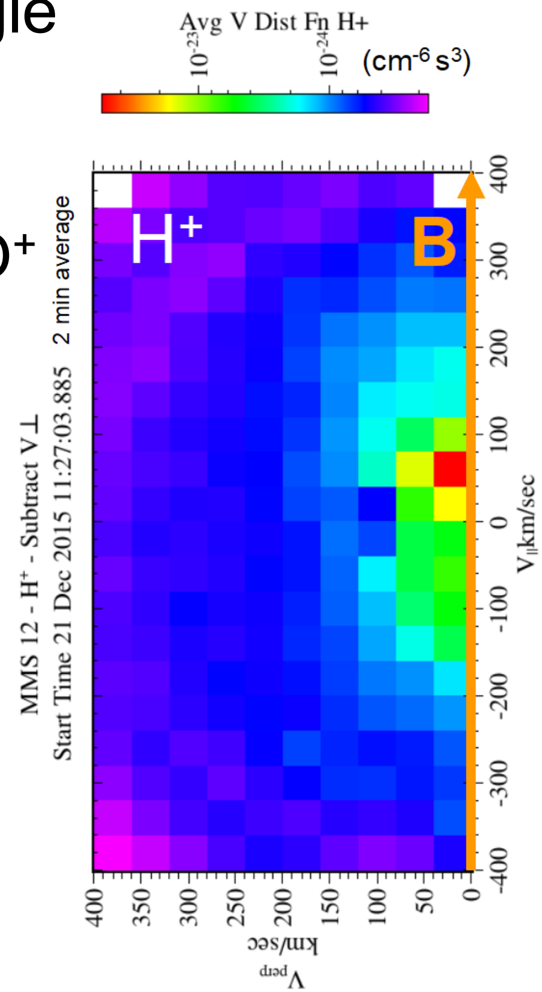
Example: Ring Current and Warm Plasma Cloak in the Magnetosphere

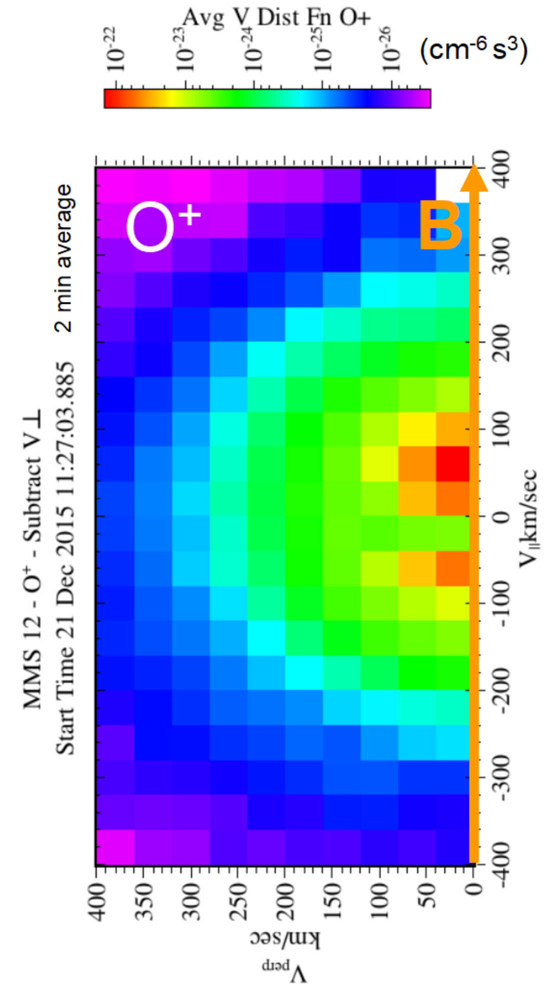
- Energy-Time Spectrograms and Densities: 10 min in the outer magnetosphere (noon ~8.4 – 9.3 R_E)
  - After a geomagnetic storm
  - Ring Current He^{2+} >5 keV
  - H^+ Warm Plasma Cloak <0.2 keV
- No He^{2+}, Very Little He^+ in the Warm Plasma Cloak
  - “Pure” high-latitude ionospheric source
- H^+ and O^+ Warm Plasma Cloak at Different Energies
  - O^+ Ring Current and Warm Plasma Cloak Energies Overlap



Distribution Functions: Difference Between Temperature and Speed

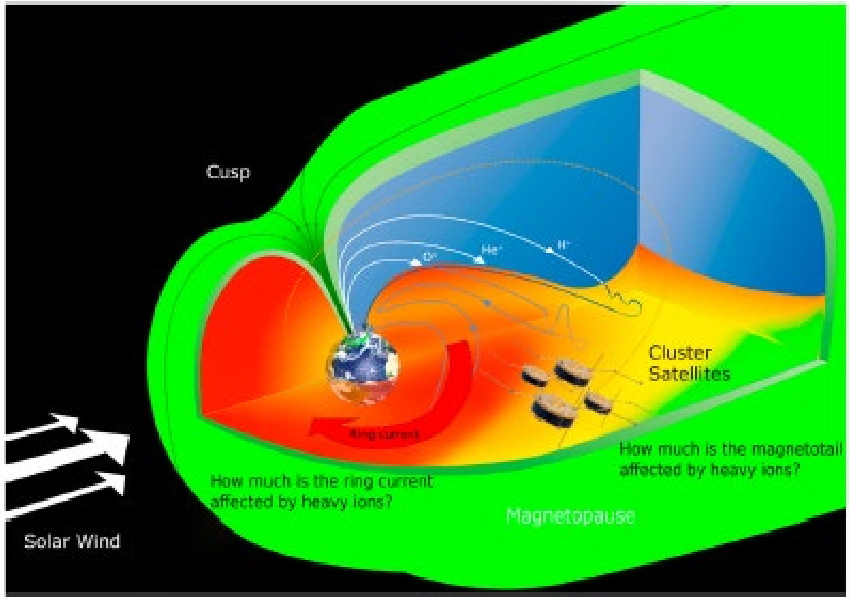
- Zoomed in 2-D pitch angle distributions
- Warm Plasma Cloak: Counter-streaming H^+, O^+ at the <u>same velocity</u>
  - 100 km/s parallel to B
    - 50 eV for H^+, 840 eV for O^+
- $T_{perp} > T_{par}$
- No energy distinction between cloak and ring current





Side-Stepping an Issue…..

- What are the Ultimate Sources of the Ring Current and Warm Plasma Cloak
  - For southward IMF: Both populations go into the tail
    - Competition between the Cusp and the nightside auroral oval
    - See recent papers by Kistler and associates (Arase, MMS)
      - Definitive work
  - For our Purposes Here
    - Assume that O^+ enters the nightside for southward IMF

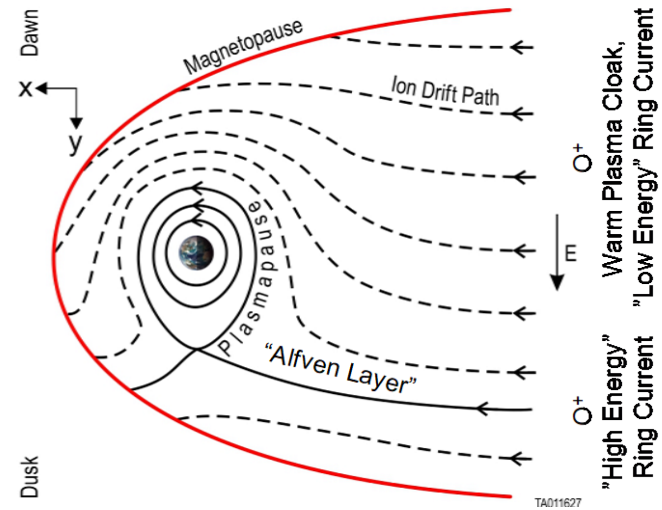


Kronberg et al., JGR 2017

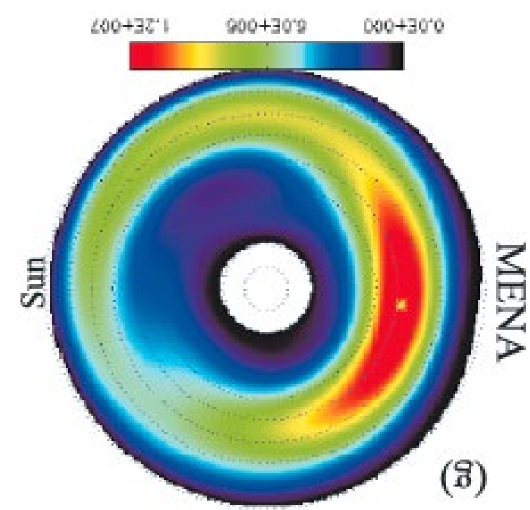
The "special case" for northward IMF will be discussed later

How Does the Ring Current/Warm Plasma Cloak get to the Dayside?

- Answer: Convection
- "Injection" of plasma from the tail
  - Plasma will drift
    - Dawnward, low energy plasma
    - Duskward, high energy plasma
  - Should not cross the "Alfven Layer"
- Energetic Neutral Atom (ENA) observations reveal this drift
  - 5-12 keV ion fluxes derived from ENAs observations during a moderate storm



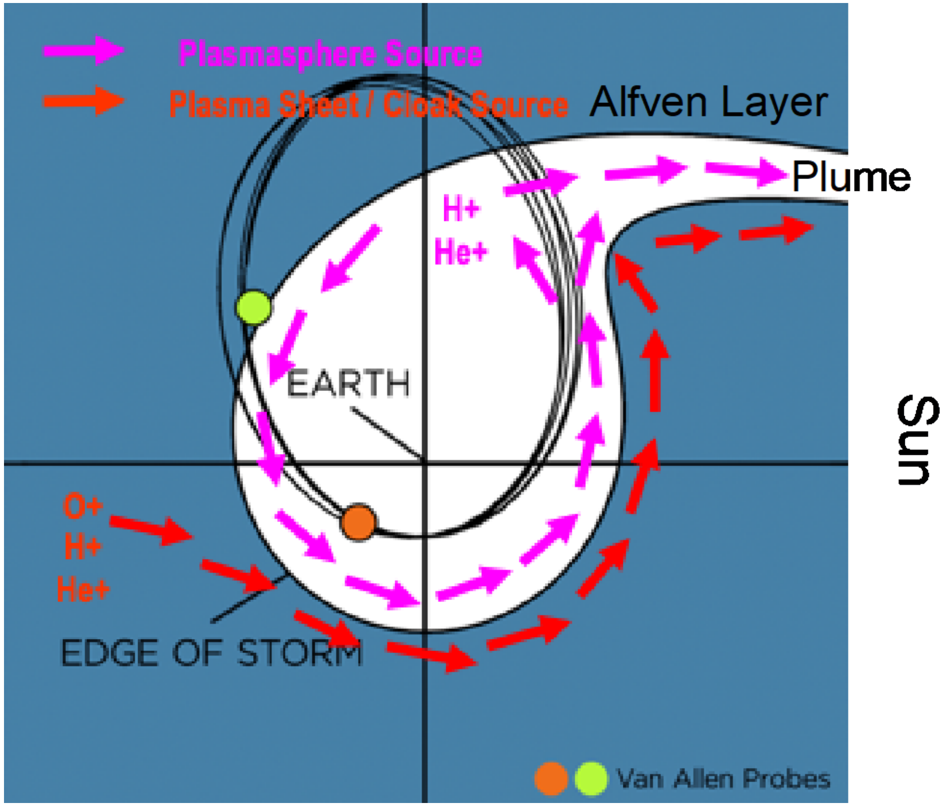
View of equatorial plane from the North



Perez et al., JGR, 2004

Convection and the Plasmaspheric Plume

- Results from LANL/MPA and VAP/HOPE observations
  - Ion composition is different
    - Plume – H^+ and He^+
    - Ring Current, Warm Plasma Cloak – O^+, H^+, He^+, (and He^{2+})

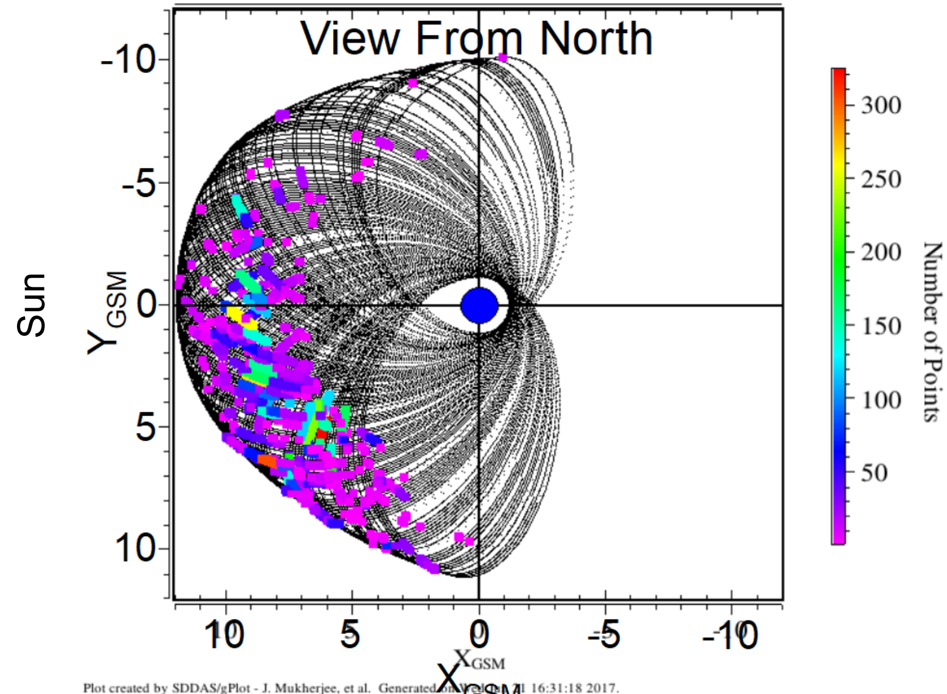


Denton et al. Sept 2018 Los Alamos Workshop

Note: This picture extends out to ~6.6 R_E (geosynchronous)

Convection in the Outer Magnetosphere: Is it "the Same"?

- MMS Statistical survey (Sep 2015 – Mar 2016)
  - warm plasma cloak within 1.5 hours of a magnetopause crossing
- Little evidence of an "Alfven layer"
  - Not the same as tracing the ion convection from the tail to the dayside



Fuselier et al., JGR, 2017

What does convection look like in the outer magnetosphere?

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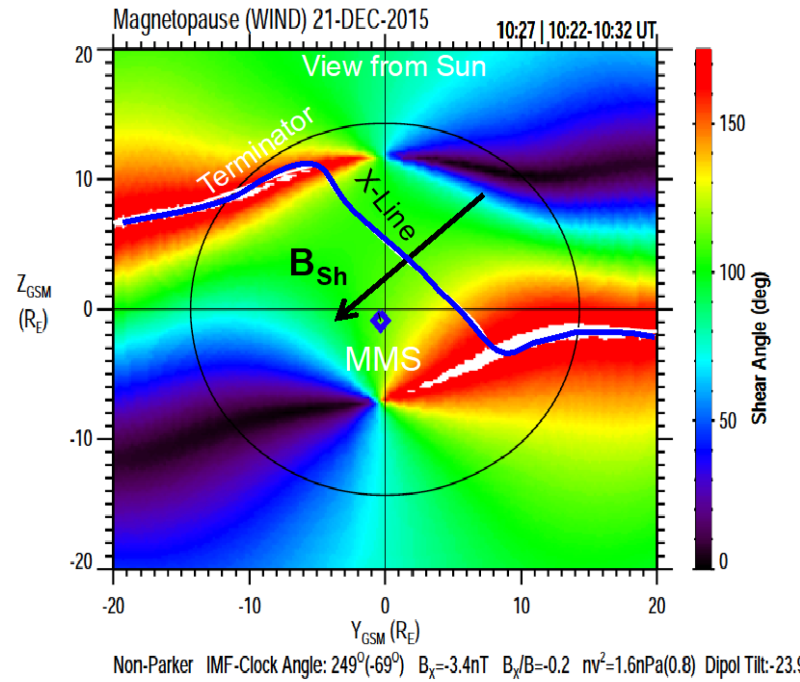
Sinks of Magnetospheric O^+

- Charge Exchange – largely ignored here!
  - An important sink for O^+ convecting from the nightside (Kistler et al., 1989)
- Ionosphere – Interesting new developments from our rocket Experiment in the cusp (TRICE-2, launched Dec 2018)
  - Rhyan Sawyer, my student, had a talk at AGU
- Magnetic Reconnection at the Dayside Magnetopause

Dayside Magnetic Reconnection (For Southward IMF)

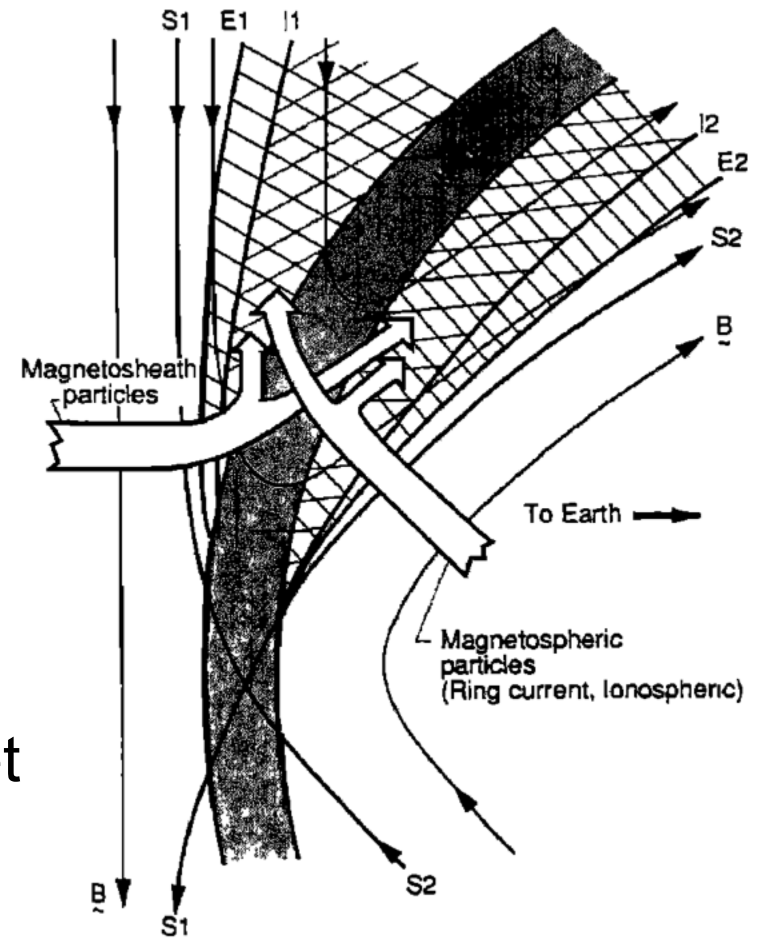
- My view of magnetic reconnection (shared by others)
  - Always occurring somewhere on the magnetopause
  - Southward IMF – long reconnection line or lines across the entire dayside
  - Magnetopause is "open" everywhere all the time (for southward IMF)
- If O^+ convects to the magnetopause, then it will be affected by reconnection



"Maximum Magnetic Shear" model of the reconnection X-line for $-B_Z$, $-B_Y$

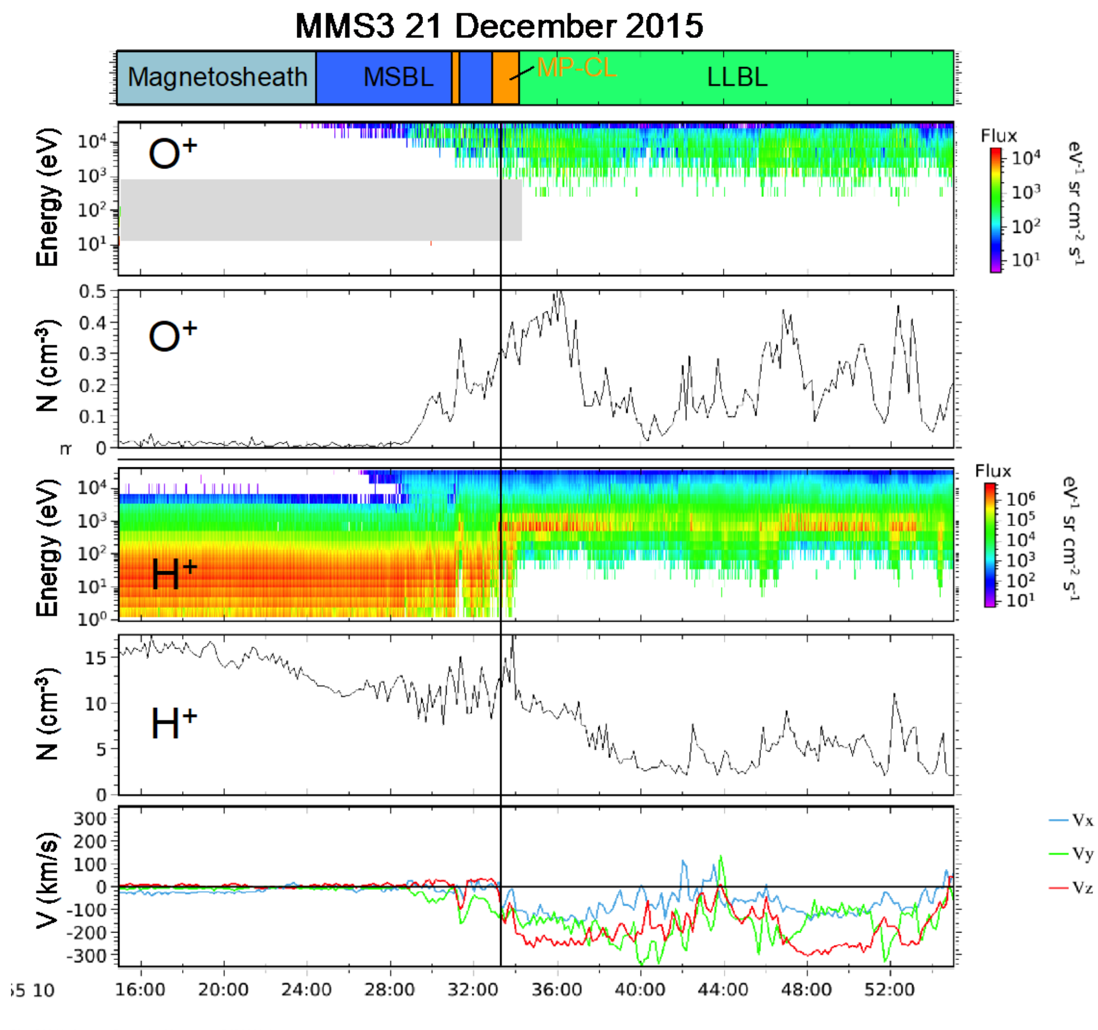
What Reconnection Does to Plasma at the Magnetopause

- Gosling et al., 1990
  - (Cover of GRL)
  - Ions either transmit through or reflect off the magnetopause
  - Plasma on both sides of the magnetopause participates
- Reflection Coefficient
  - ~50% (as best as we can tell)
  - Independent of mass (Delano et al., 2019)



Geomagnetic Storm 20-21 Dec 2015: High O^+ Content Magnetosphere

- One of the larger geomagnetic storms in 2015
- Solar wind density >50 cm^{-3} 1 day earlier
- Very high O^+ densities
  - Warm plasma cloak + ring current
- O^+, higher energy H^+ in the MSBL
  - Open field lines due to reconnection
  - Accelerated flows in the boundary layer – also evidence of reconnection



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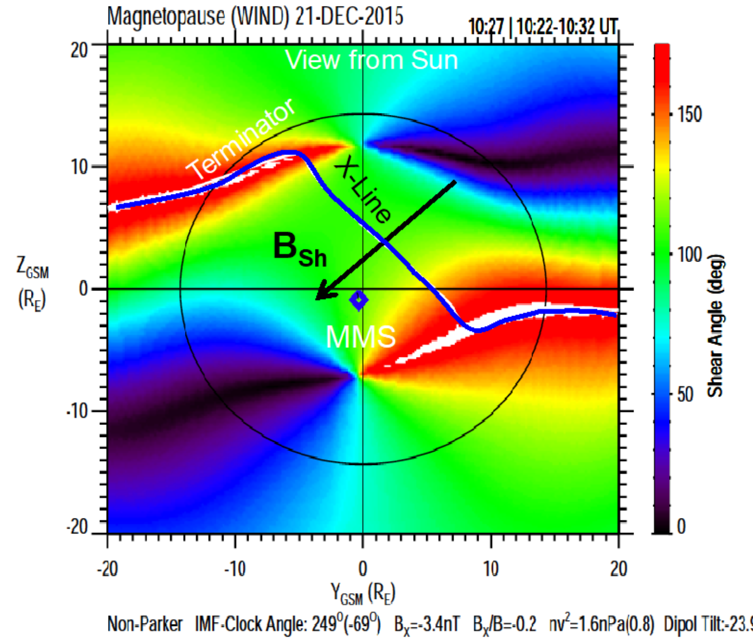
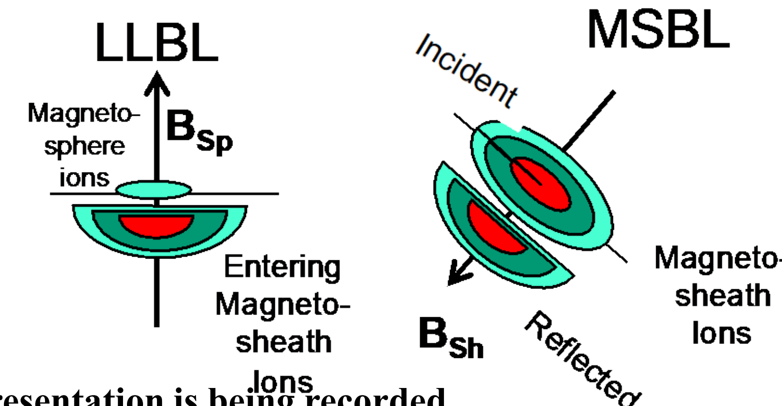
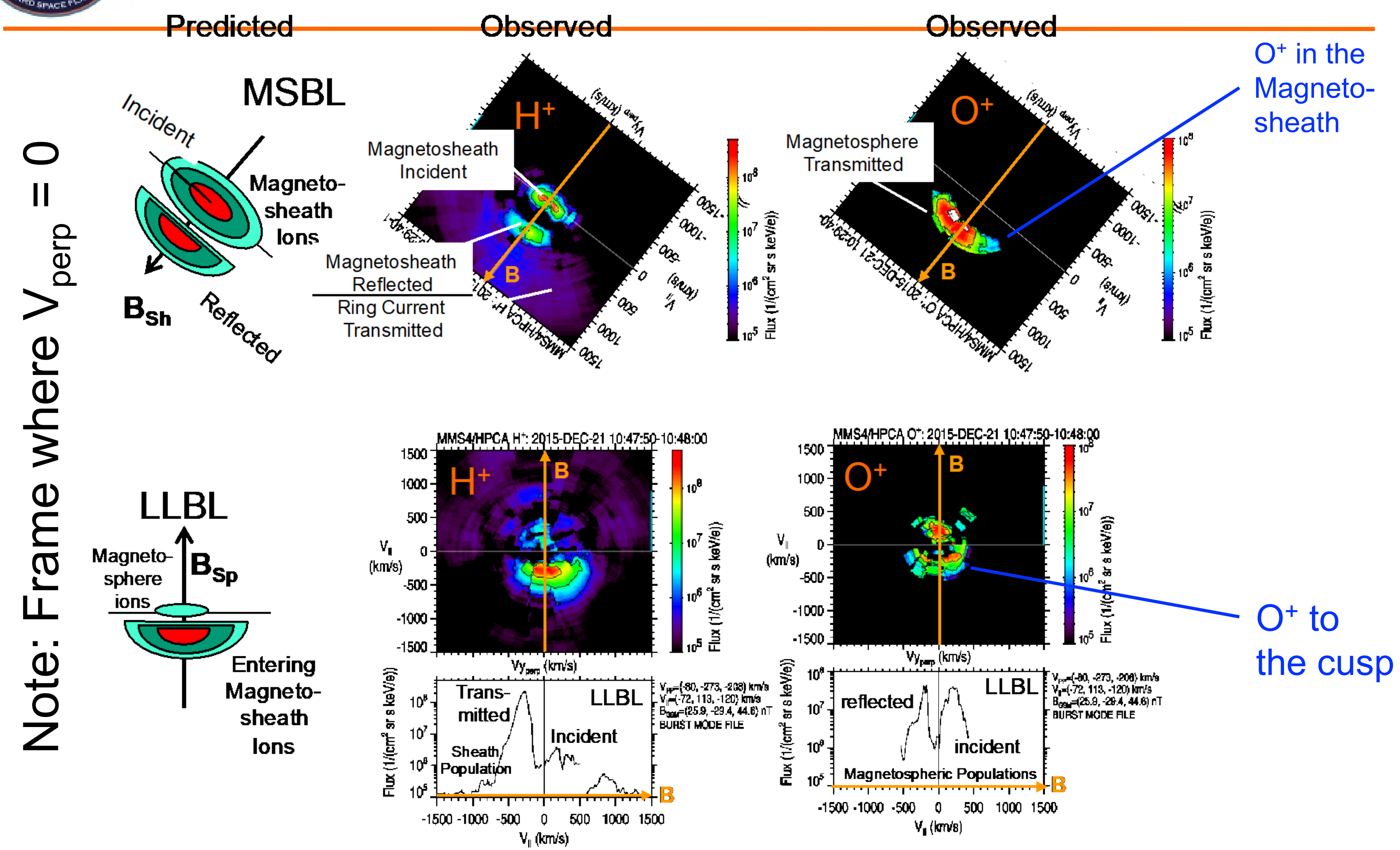
Reconnection at the Magnetopause: Predictions from the Model

- MMS Spacecraft at the subsolar point
- Reconnection X-line "far from the spacecraft"
  - North of the spacecraft
- Specific predictions from reconnection





Ion Distributions Predicted by Reconnection Are Observed



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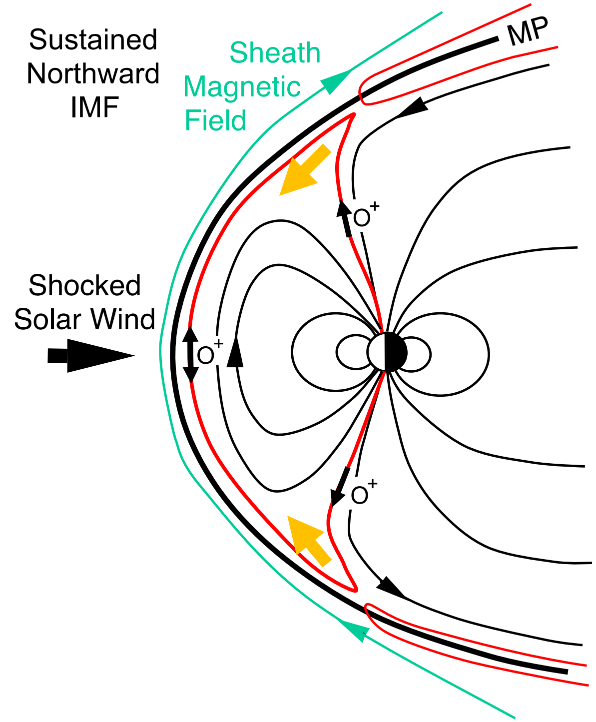
The “Special Case” for Northward IMF: Mass-Loading the LLBL

- Similar to mass loading in the magnetotail
- Sustained B_Z north:
  - <u>Dual-lobe</u> reconnection injects O^+ directly into dayside LLBL
  - Closed field line, filled with ionospheric and solar wind plasma
    - Convects very slowly to the tail

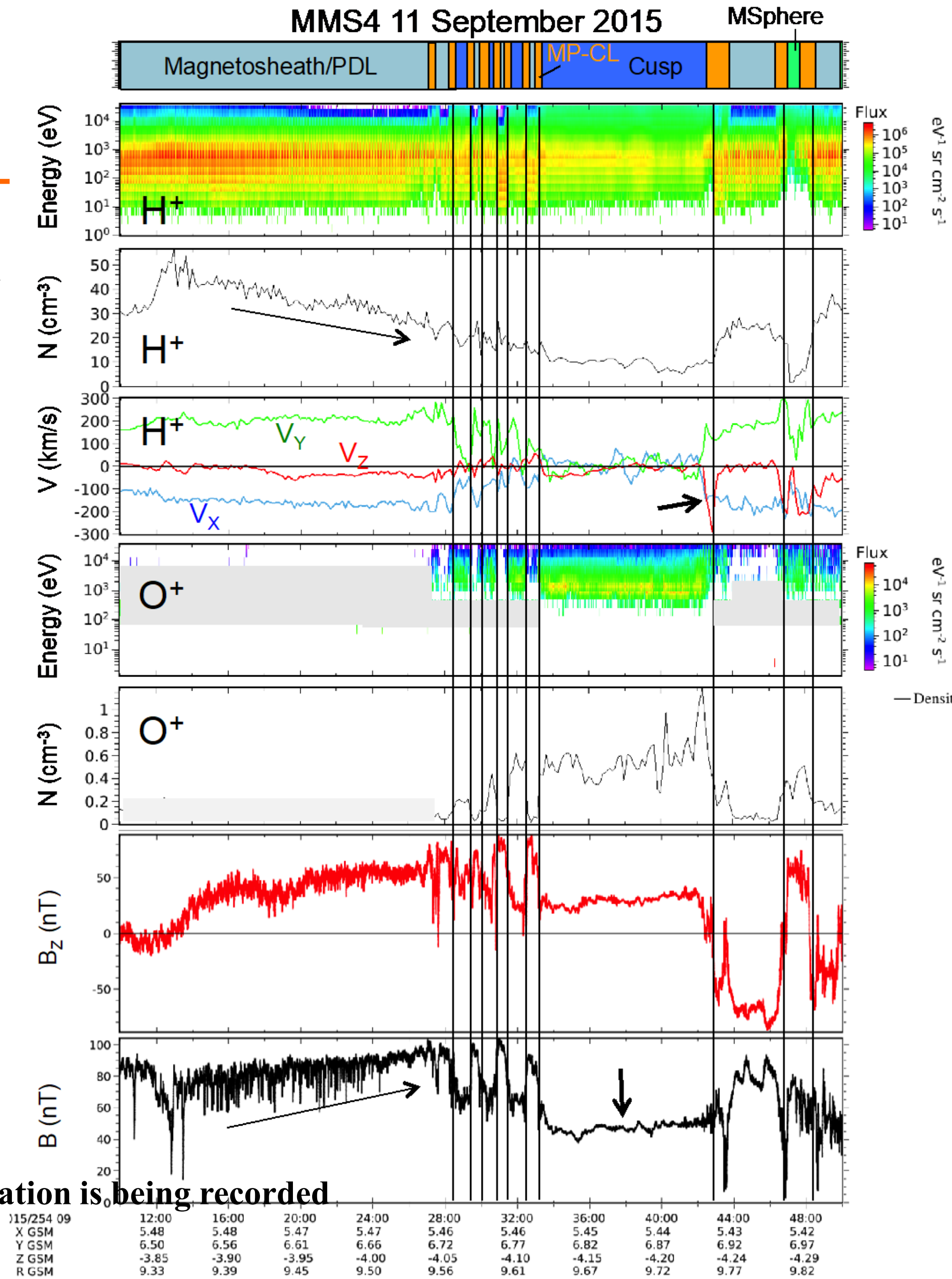


Fuselier et al., 1989; 2019

All that is needed is sustained (~10-20 min) B_Z north

Example: Mass Loading LLBL

- B_Z North for 24 min
  - Plasma Depletion Layer prior to first MP encounter
- Depressed field inside MP
  - "Magnetospheric Cusp" (Nykyri et al., 2018)
- High shear MP crossing at 0943 UT
  - Accel flows = evidence of reconnection
- Very high O^+ densities in the LLBL/Cusp only



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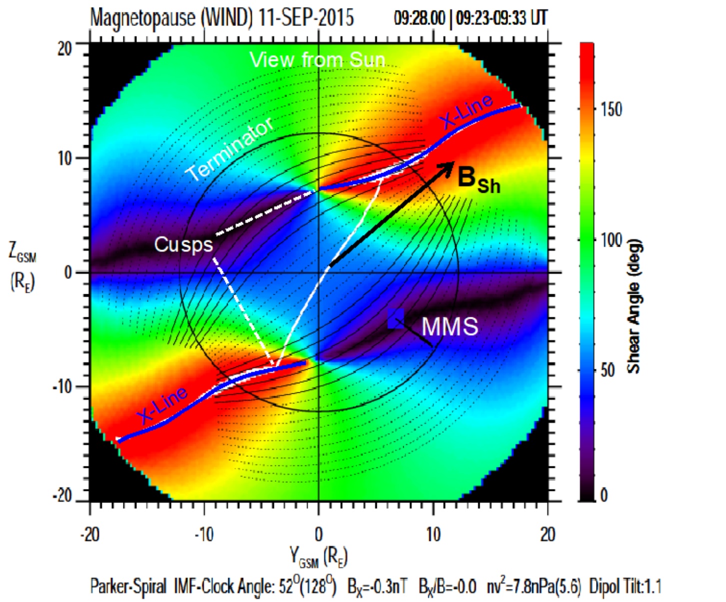
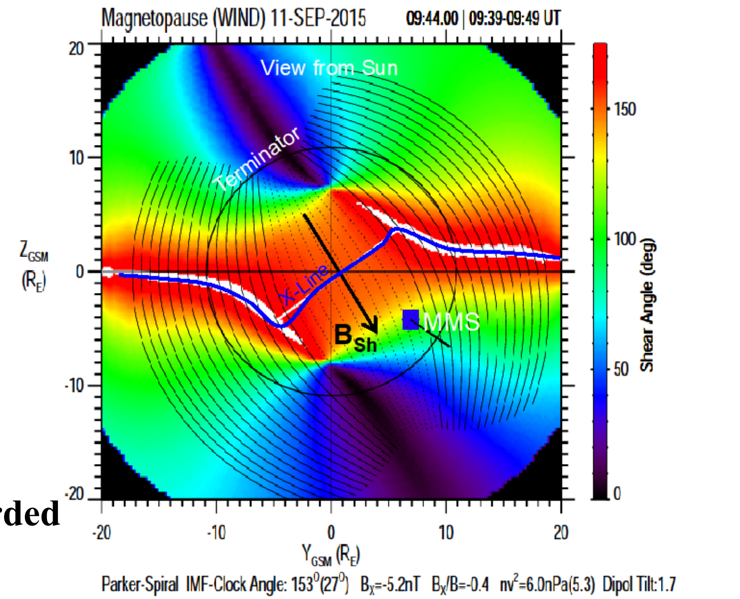
Reconnection Locations for Northward and Southward IMF Intervals

- Northward IMF interval
  - High latitude reconnection poleward of both cusps
  - MMS at a very low-shear magnetopause, but observes signatures of reconnection
- Southward IMF interval
  - Low-latitude reconnection, including component reconnection
  - Spacecraft is still “far” from the reconnection X-line
  - Also observes signatures of reconnection





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Conclusions

- O^+ in the Dayside Magnetosphere
  - Originates from the High Latitude Ionosphere
  - Two populations: Ring Current, Warm Plasma Cloak
- Sustained B_Z south injects O^+ into the tail
  - Convects to the dayside: variety of sinks
  - Magnetic reconnection
    - ~50% to the magnetosheath, ~50% to cusps and down tail
- Sustained B_Z north injects O^+ from the ionosphere directly into the LLBL
  - <u>Mass-loads the LLBL</u>

Questions and Future Work

- Ionospheric Component of the Ring Current and Warm Plasma Cloak
  - Appear to be two different populations
  - Are they from two different sources or the same source and just processed differently? Or both?
- Ignored the O^+ in the Plasmasphere/plume
  - In the plasmaspheric plume the He^+ density > O^+ density
- How does Dayside Outer Magnetosphere Convection work?
  - How does the (large) temperature difference between the warm plasma cloak and ring current come into play?
  - Does the warm plasma cloak and plume mix at $R>6.6\ R_E$?
- No truly large O^+ population observed in the MMS era
  - What would that population do to convection, reconnection, and …?

Backup

1971-089A

- ASTEX 1 (Norad 05560) is still in orbit
  - Launch 17 Oct 1971

at much lower levels. Comparable heavy-ion fluxes were also observed during at least two magnetic storms in 1969 by an earlier version of

the spectrometer on polar-orbiting OV1-18. The mass sweep on the OV1-18 spectrometer did not cover the entire mass 16 peak, and so the data were less definitive than those shown here. The earlier data had not previously been reported, pending verification by the improved spectrom-

Orbiting Vehicle

From Wikipedia, the free encyclopedia

Not to be confused with orbital vehicle, Orbiter Vehicle, or Orbiter.
"SATAR" redirects here. For other uses, see Satar (disambiguation).
For other uses, see Orbital vehicle (disambiguation).

Orbiting Vehicle or **OV**, originally designated **SATAR** (SATellite - Atmospheric Research[1]), was a series of American satellites operated by the US Air Force, launched between 1965 and 1971. Forty seven satellites were built, of which forty three were launched and thirty seven reached orbit. With the exception of the OV3 series, and OV4-3, they were launched as secondary payloads, using excess space on other missions.

Five separate series of OV satellites were launched. The first satellites were OV1, which were carried on suborbital Atlas missile tests, and subsequently placed themselves into orbit by means of an Altair-2 kick motor. OV2 satellites were built using parts left over following the cancellation of the Advanced Research Environmental Test Satellite. Three OV2 spacecraft flew on Titan IIIC test flights. The OV3 satellites were the only ones in the series to be launched on dedicated rockets. Six were launched on Scout-B rockets between 1966 and 1967. OV4 satellites were launched as part of a test flight for the Manned Orbiting Laboratory (MOL), with two satellites conducting a communications experiment whilst a third, OV4-3, was the primary payload, a Boilerplate mockup of the MOL space station. Two further OV4 satellites, duplicates of the first two, were built but not launched. OV5 satellites were launched as part of the ERS project, as secondary payloads on Titan IIIC rockets.

Typically, OV satellites carried scientific and/or technological experiments.

Launch reentry

OV1-18		1969 025B	18 Mar 1969	27 Aug 1972	Ionospheric studies

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