Radial dependence of near-Earth space plasmas (5 to 26 R_E)

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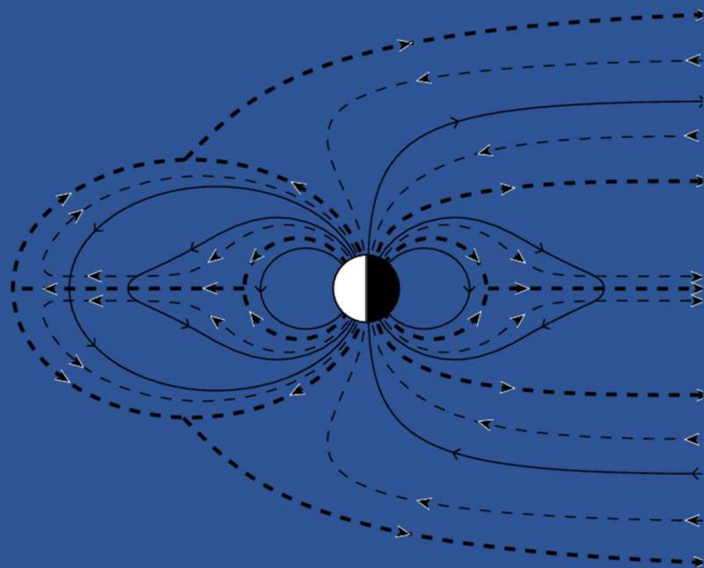
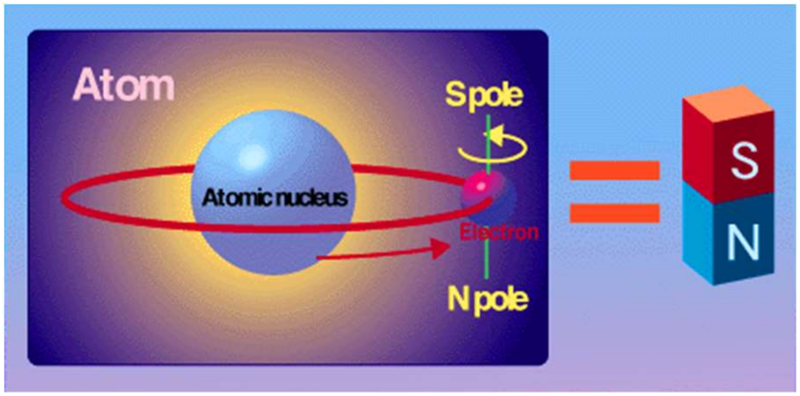
Image source: Science Photo Library

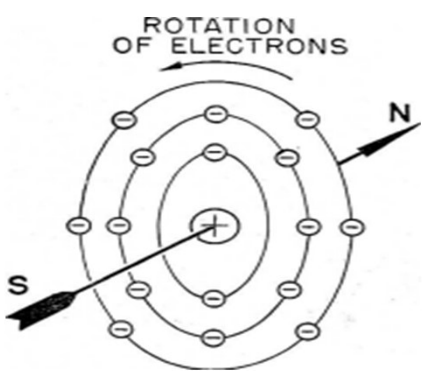
Outline

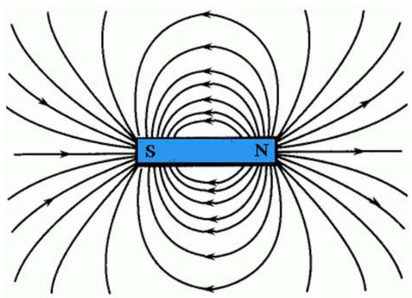
- Dynamics of magnetized spheres
  - Micro to macro scale
  - Trapped particle motion
    - Single particle motion
    - Field-aligned motion
- Magnetospheres and ionospheres
  - The sun, Earth, and other bodies within our solar system
  - Magnetosphere-ionosphere coupling
    - The aurora and it’s relation to oxygen
- Oxygen escaping Earth’s atmosphere into it’s magnetosphere
  - Ion transport mechanisms *(this is what I study)*
  - Satellites in the ionosphere and near-Earth space
    - Van Allen Probes (RBSP)
    - “Space weather” implications

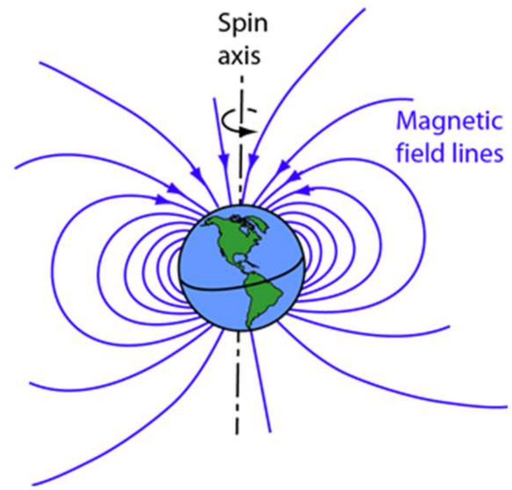


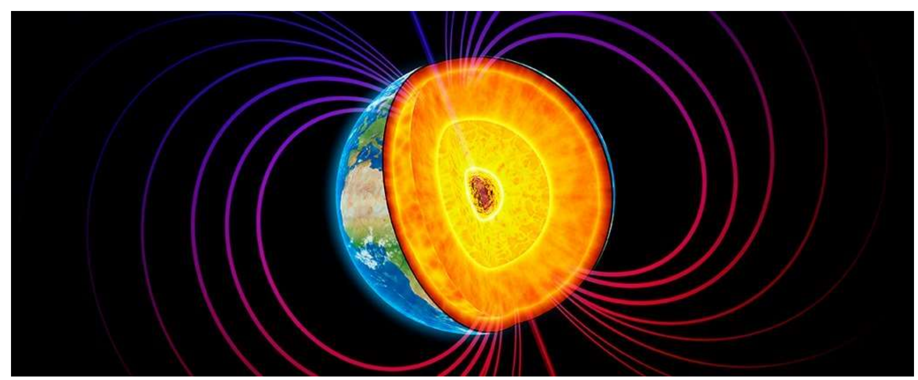
Micro to macro sized magnetized spheres











Single particle motion

Lorentz-force law:

$$\boldsymbol{F_L} = q[\boldsymbol{E} + (\boldsymbol{v} \times \boldsymbol{B})]$$

Example: In uniform magnetic field and absence of electric field, a charged particle moves in a circle. Assume that ***B*** is along ***z*** axis and write ***x*** and ***y*** velocity terms (v_{x} , v_{y})

Assumptions: ($B = B_z$)
($E = 0$)

$$m\dot{v}_x = q v_y \boldsymbol{B} \qquad m\dot{v}_y = -q v_x \boldsymbol{B}$$

Momentum change:

$$m\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}\boldsymbol{t}} = q[\boldsymbol{E} + (\boldsymbol{v} \times \boldsymbol{B})] + \boldsymbol{F_g}$$

Substitute and generalize for j = x , y : $\ddot{v}_j = -(q\boldsymbol{B}/m)^2 v_j = -\omega^2 v_j$

This could be also generalized to: $\ddot{x}_j = -(q\boldsymbol{B}/m)^2 x_j = -\omega^2 x_j$

Angular frequency:

$$\boldsymbol{\omega} = \frac{|\boldsymbol{q}|\boldsymbol{B}}{\boldsymbol{m}}$$

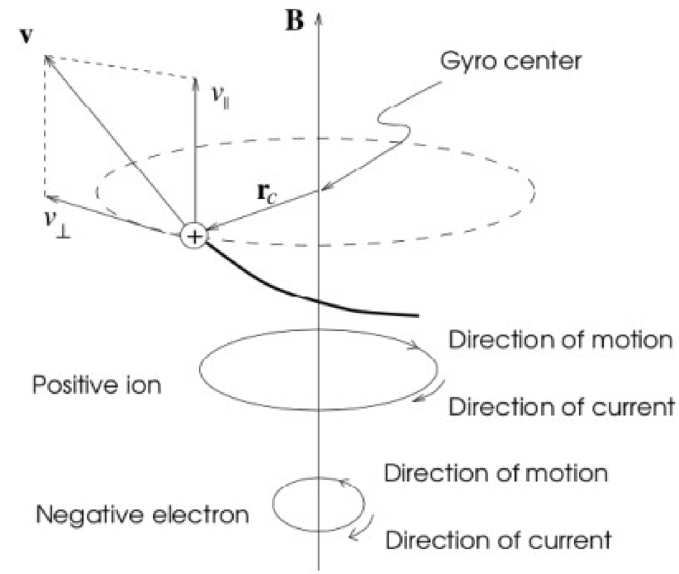
- Charged particle motion in magnetic fields
- Ideal MHD
  - Ignores relativistic effects

Trapped particle motion

- *Gyromotion:* charged particles gyrate around center with circular motion perpendicular to the magnetic field ($\boldsymbol{B}$)
  - Parallel velocity is constant ($v_{\parallel}$)

- *Pitch angle*: the angular trajectory a charged particle is deflected at along B ($\boldsymbol{\alpha}$)
  - 0°/180°: particle motion is *field-aligned* with $\boldsymbol{B}$
  - 90°: particle motion is a corkscrew along $\boldsymbol{B}$
  - For my studies;
    - *Parallel flow*: 0°< $\boldsymbol{\alpha}$ < 30° → field-aligned
    - *Perpendicular flow*: 80°< $\boldsymbol{\alpha}$ < 100° → gyromotion
    - *Antiparallel flow*: 150°< $\boldsymbol{\alpha}$ < 180° → field-aligned

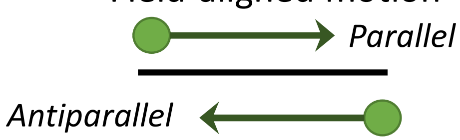
Gyromotion



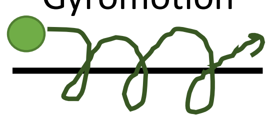
Cyclotron frequency: $\boldsymbol{\omega} = \dfrac{|q|\boldsymbol{B}}{m}$ $\qquad tan\,\boldsymbol{\alpha} = \dfrac{v_{\perp}}{v_{\parallel}}$

Cyclotron radius: $\boldsymbol{r_c} = \dfrac{v_{\perp}}{\boldsymbol{\omega}} = \dfrac{mv_{\perp}}{|q|\boldsymbol{B}}$

Field-aligned motion

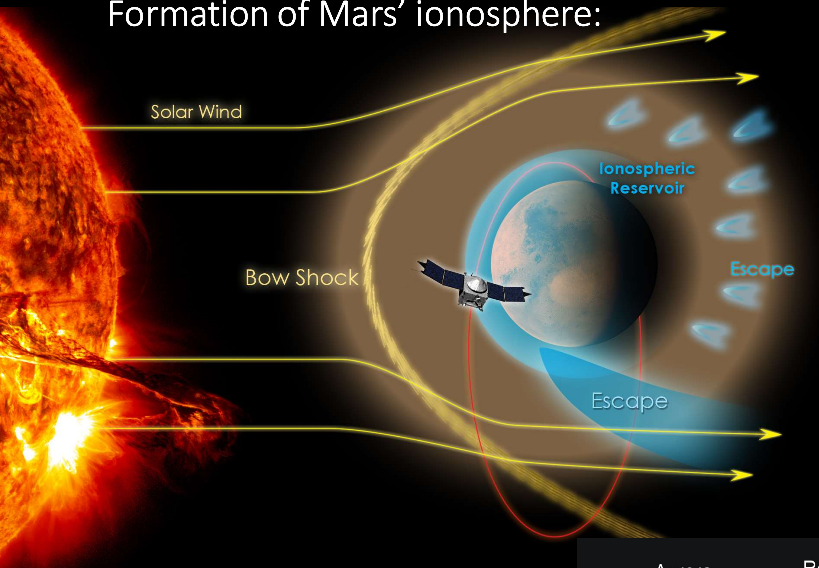


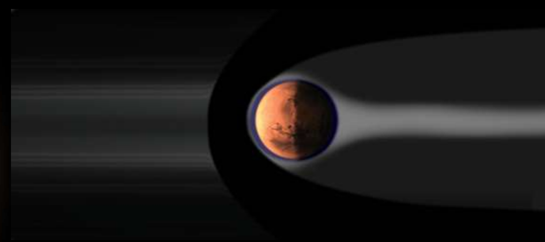
Gyromotion



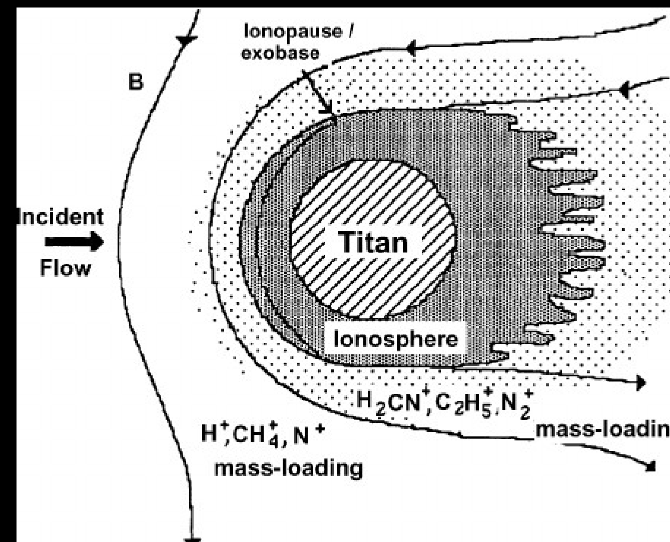
Ionospheres

Formation of Mars' ionosphere:

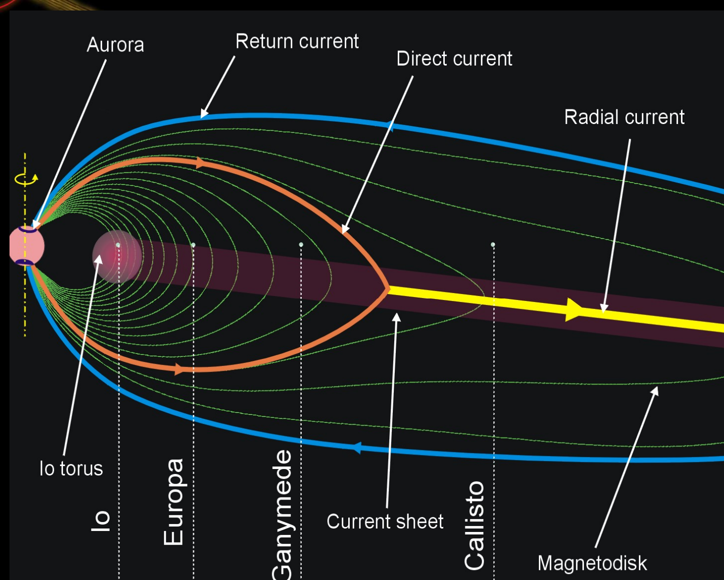




Formation of Titan's ionosphere:

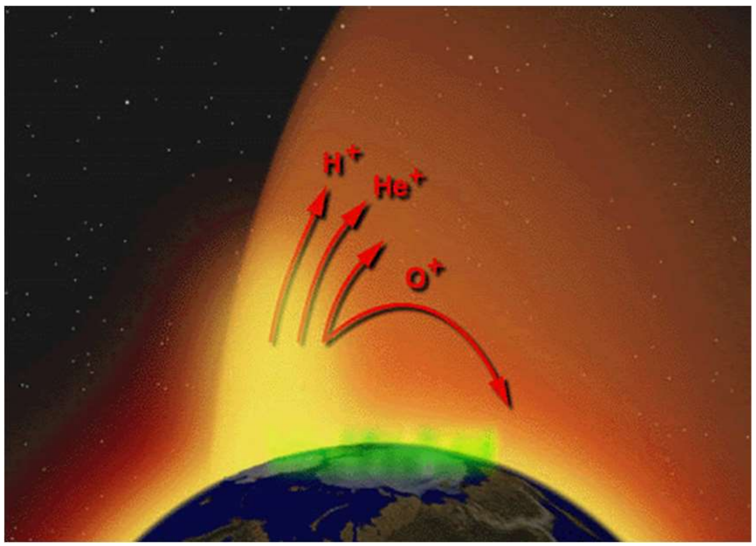


Formation of Ganymede's ionosphere:

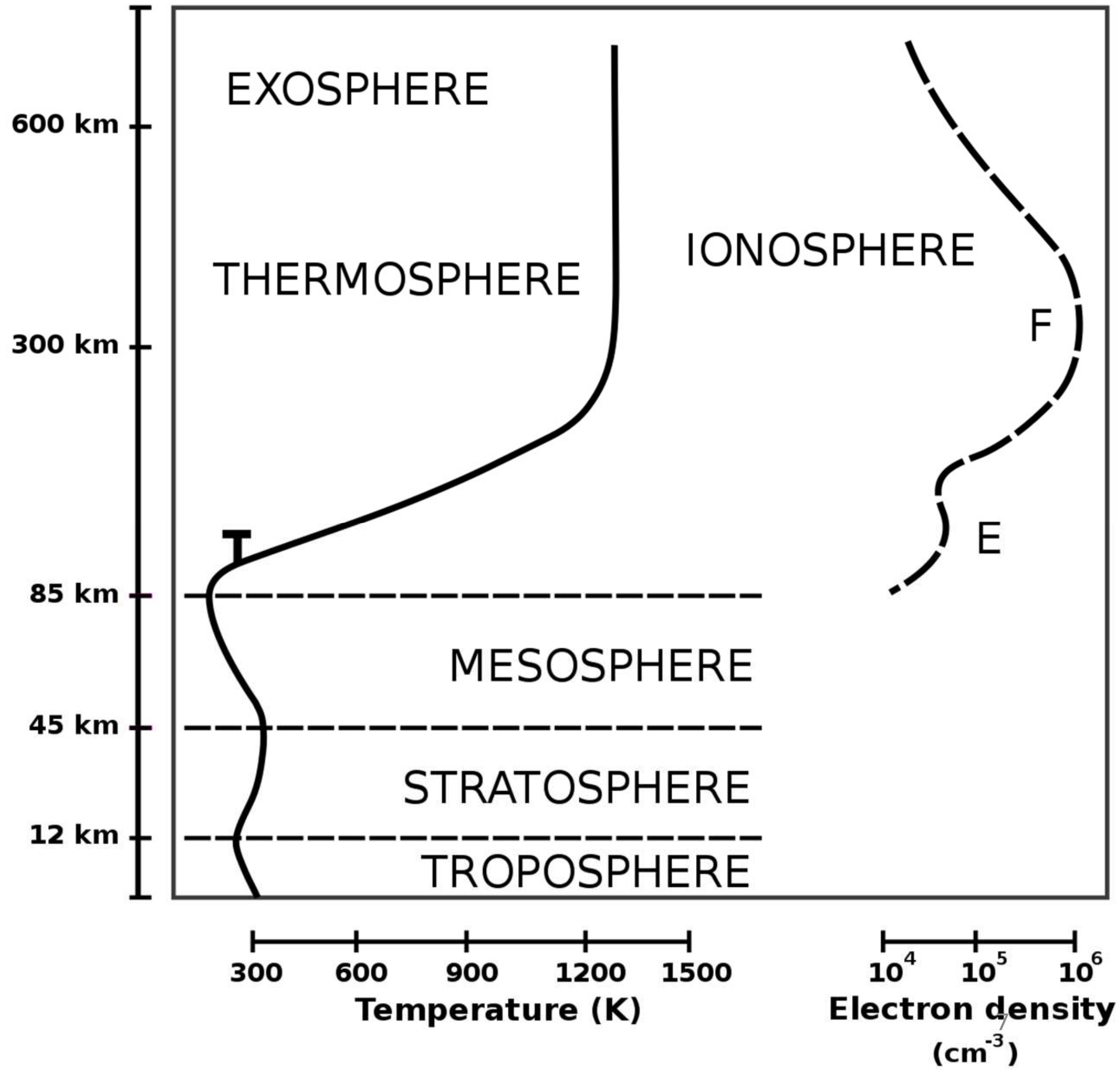


Earth's ionosphere

Ionospheric outflow

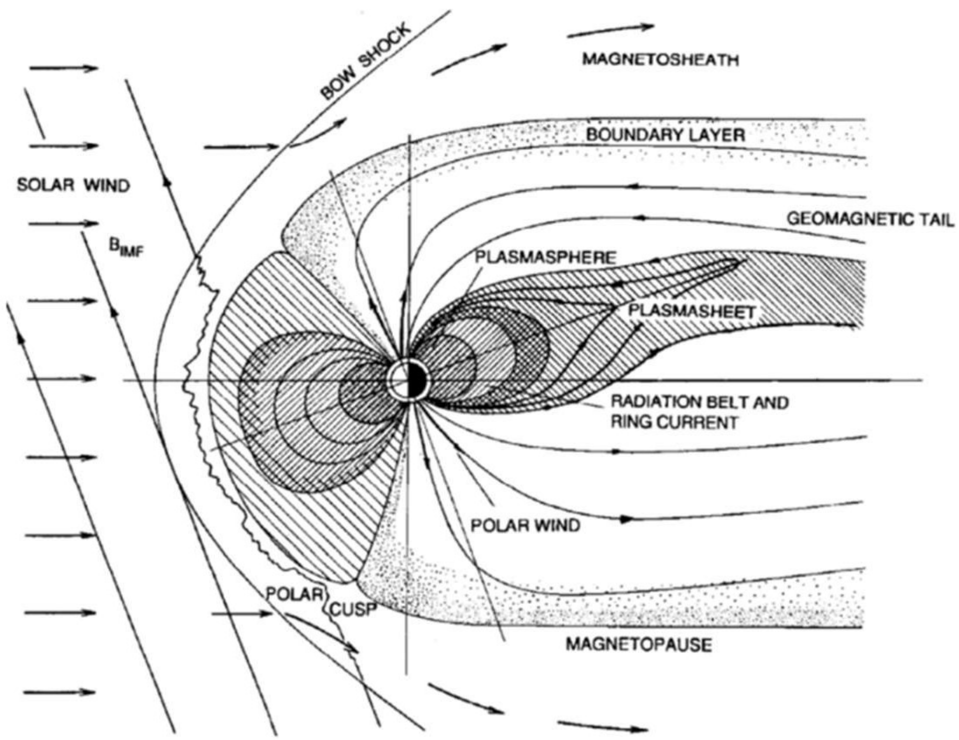


Regions of the atmosphere

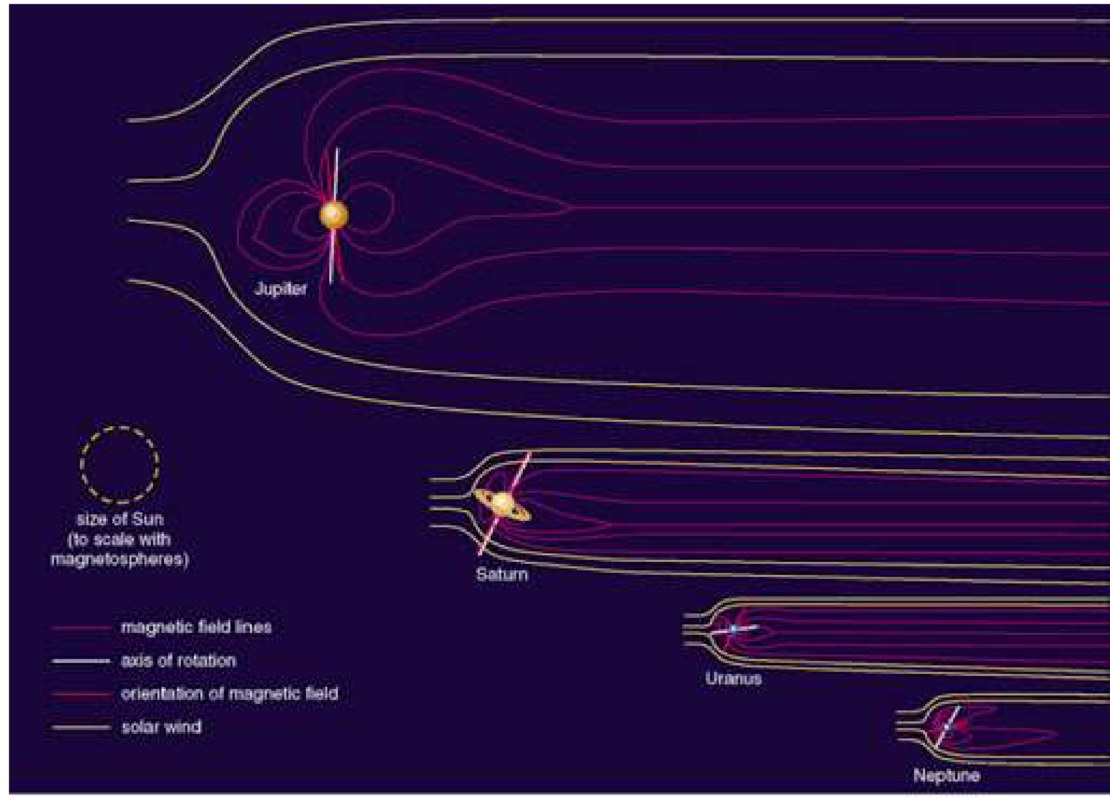


Magnetospheres

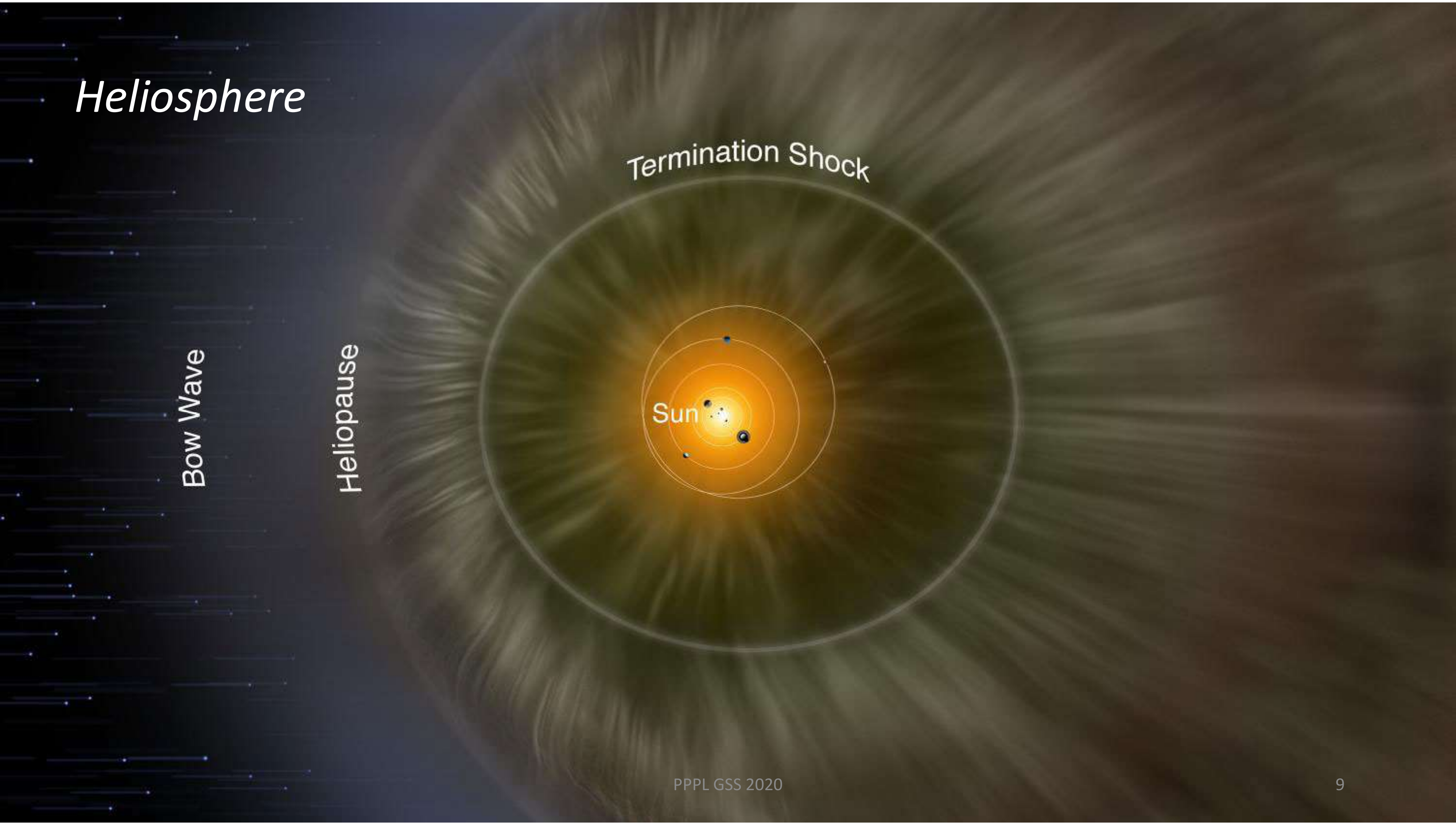
Formation of Earth's magnetosphere:

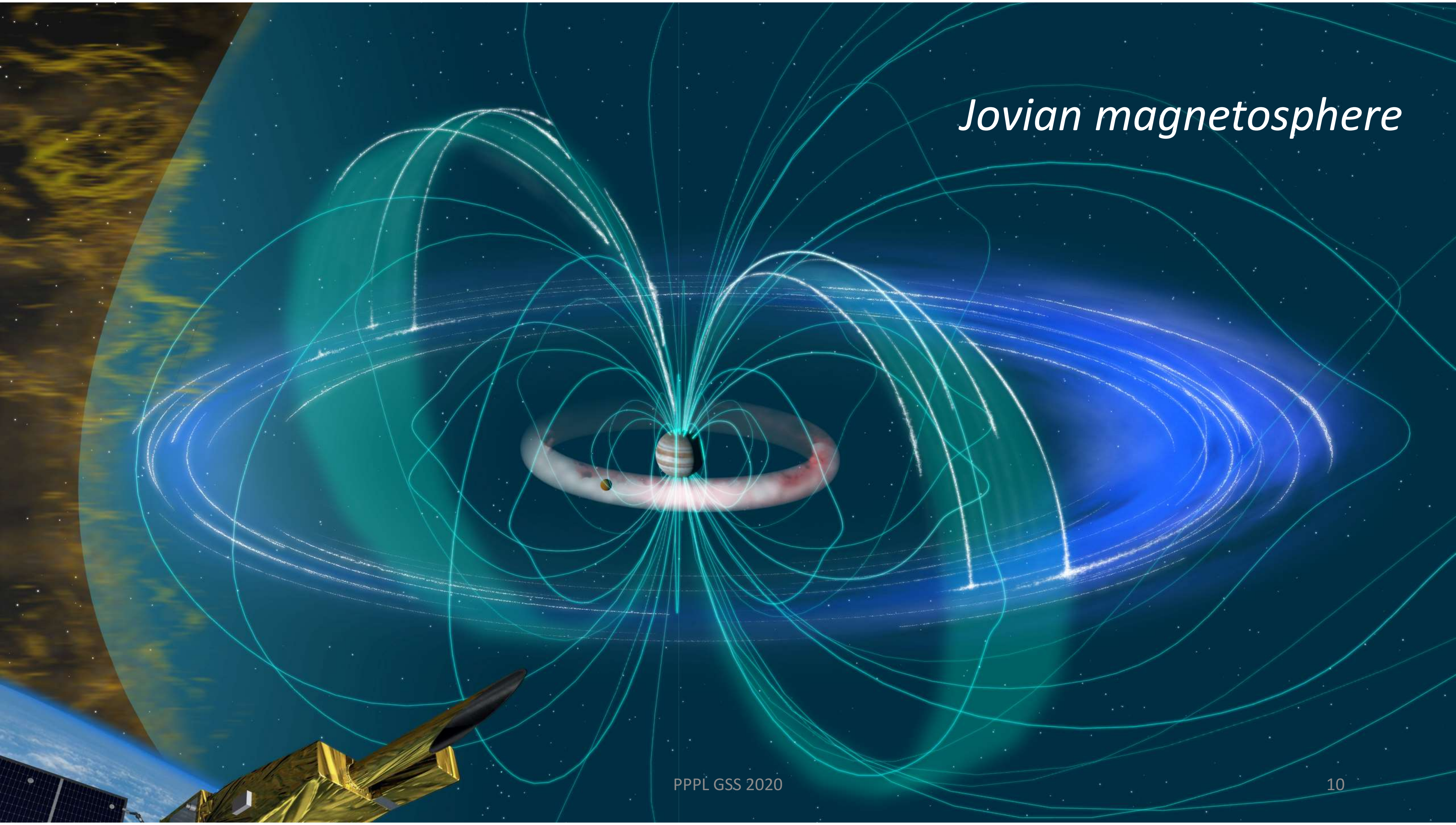


Outer planets' magnetospheres:



Heliosphere

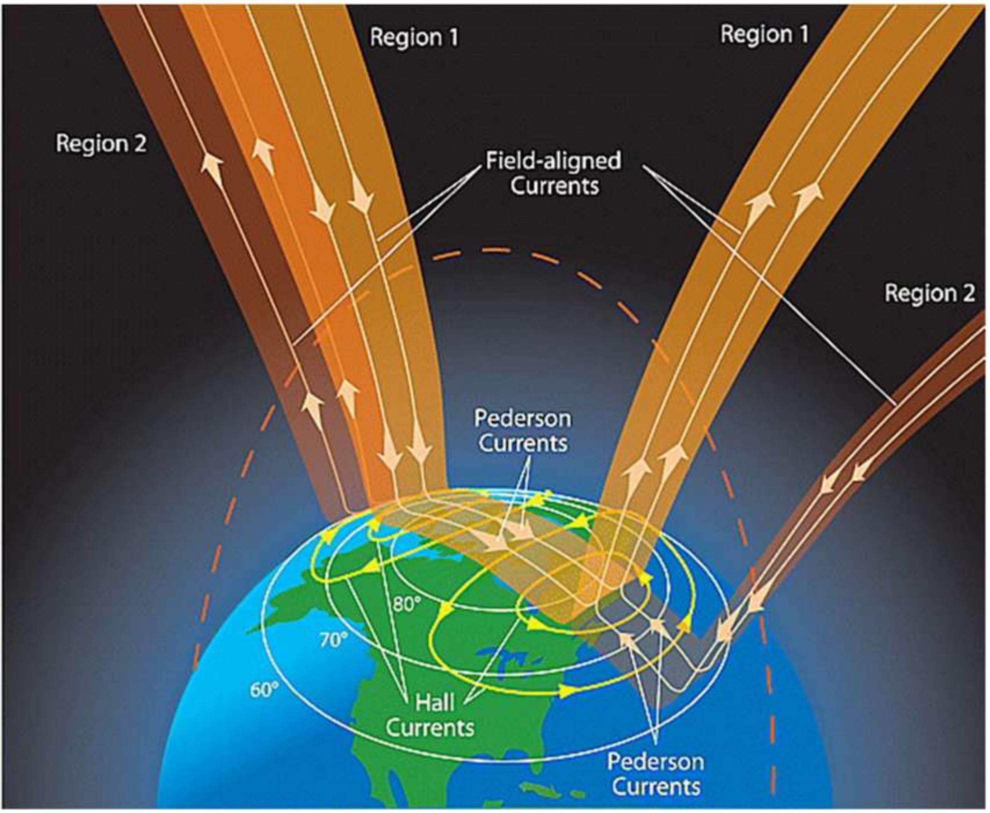



Jovian magnetosphere

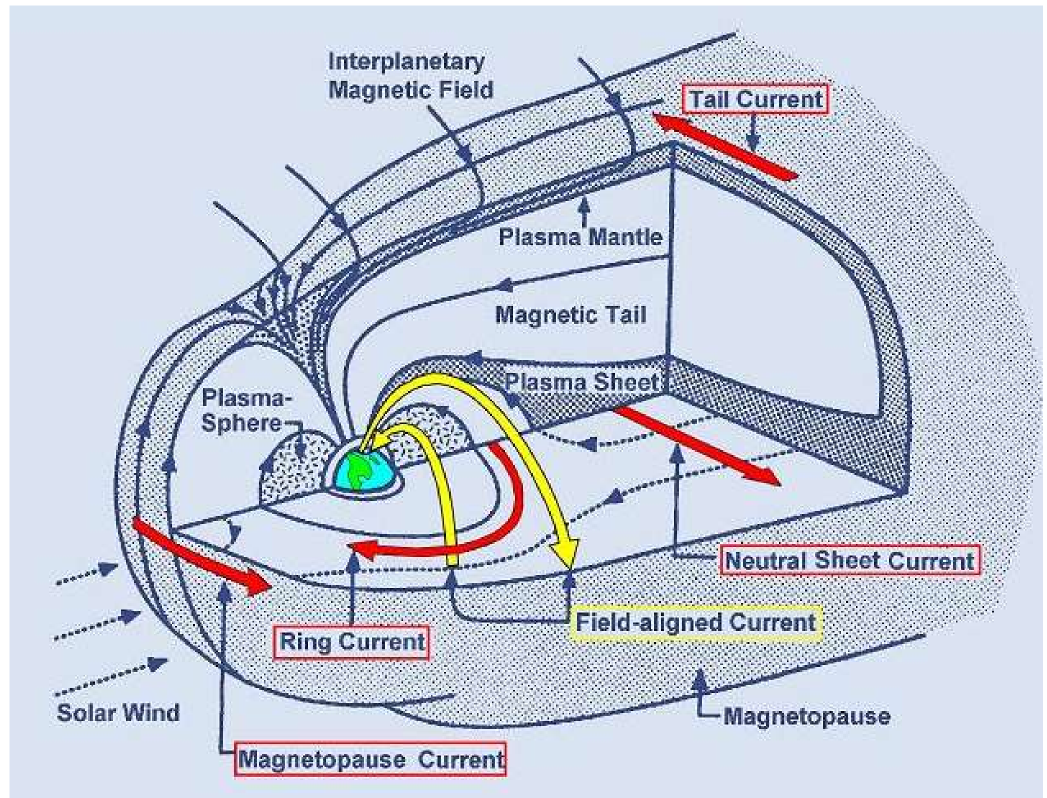
This is a real image

Magnetosphere-Ionosphere Coupling

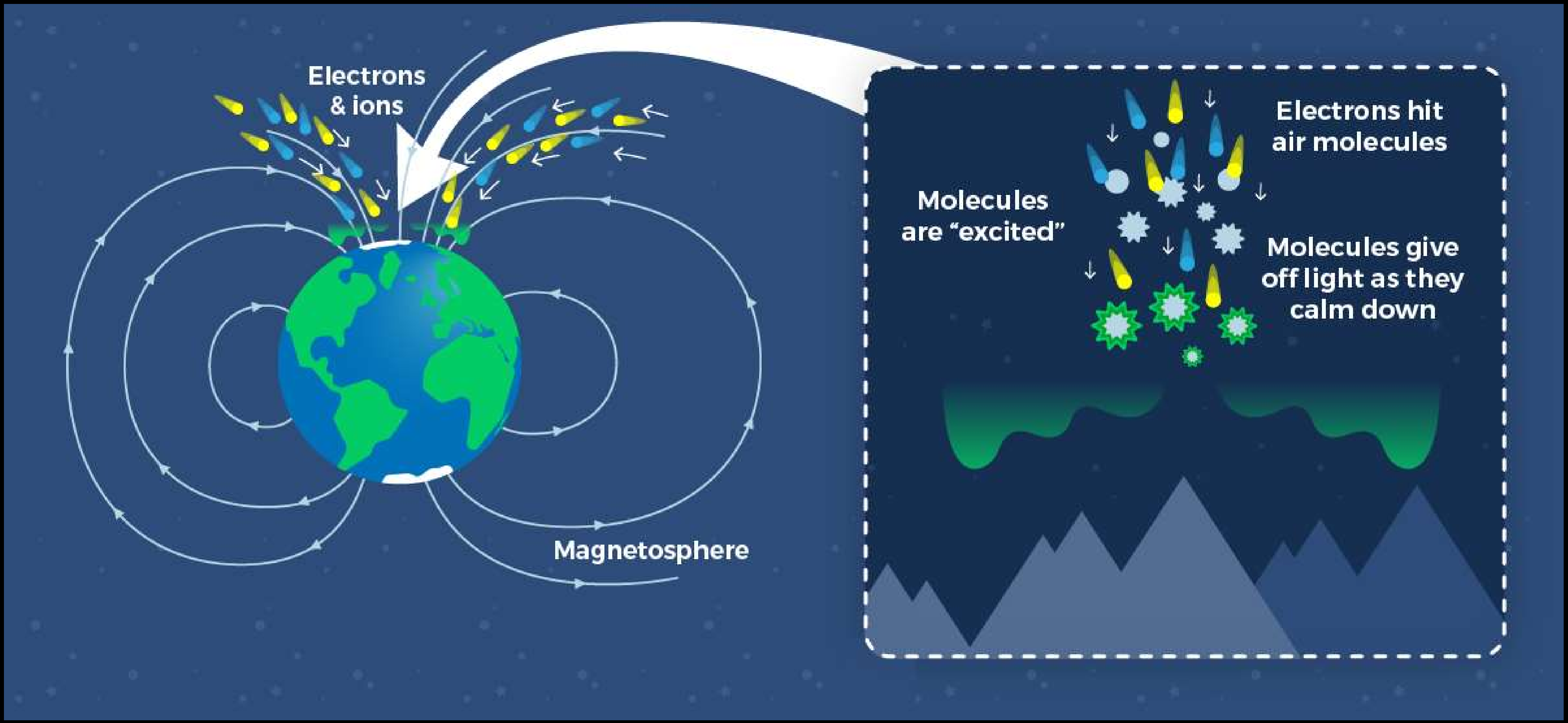
Formation of field-aligned currents in near-Earth space:



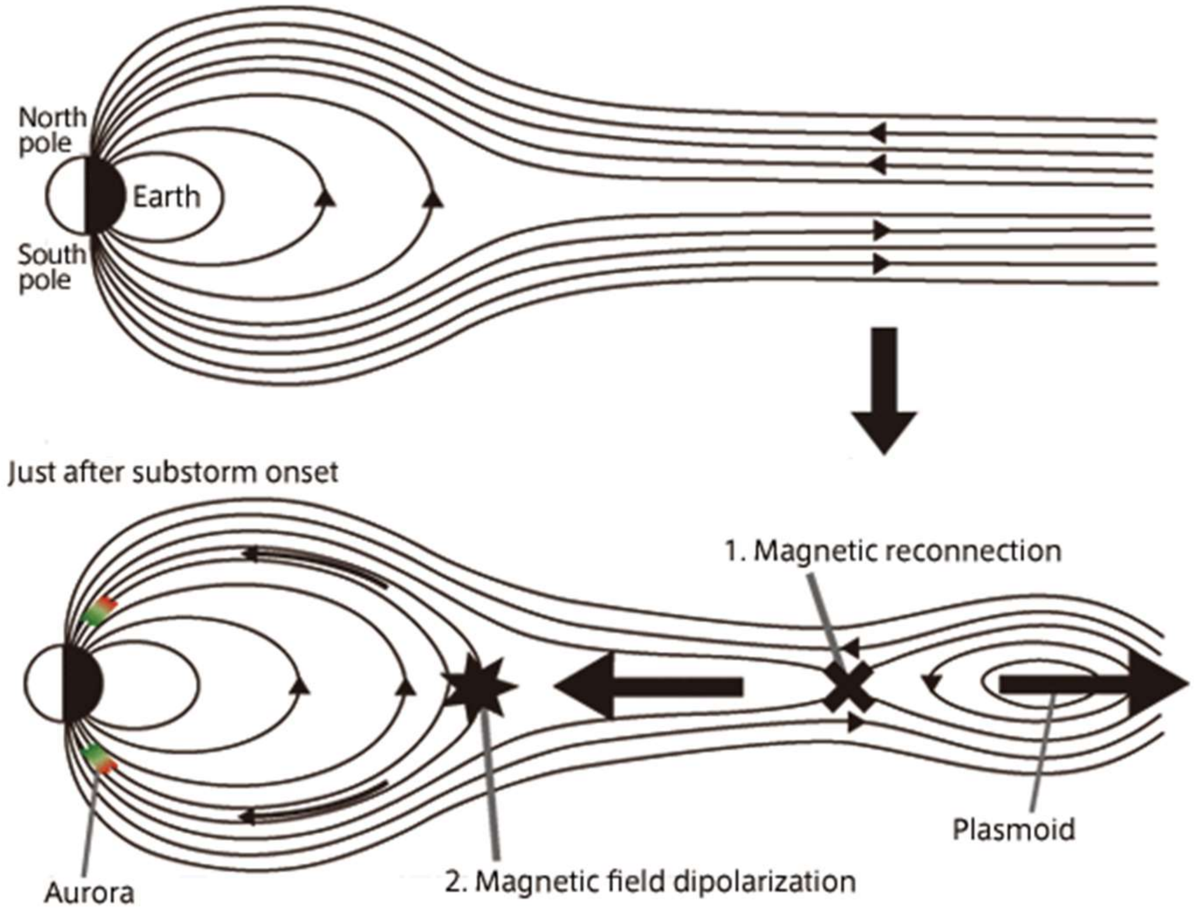
Regions of Earth's magnetosphere:



Formation of Aurorae



Magnetic dipolarization substorms



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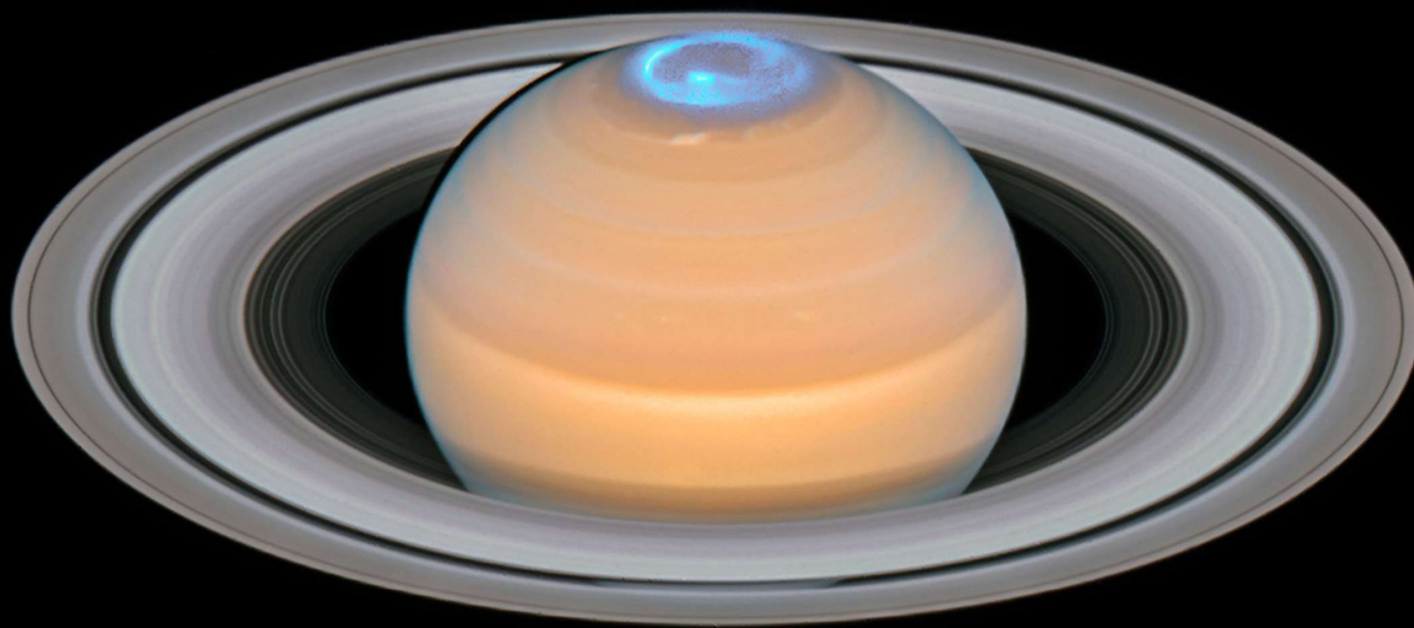
Saturn's Aurora



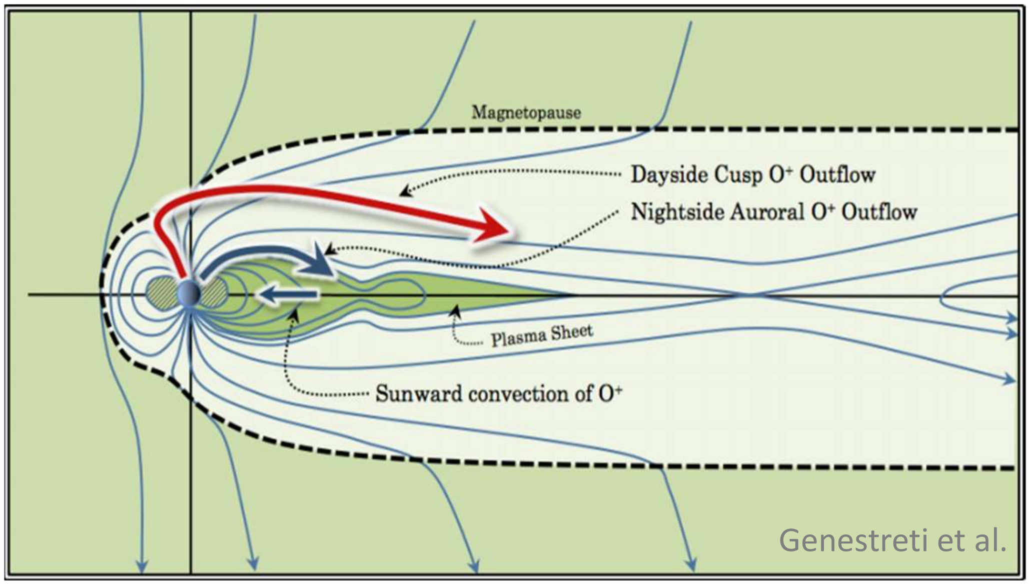
Hubble Space Telescope

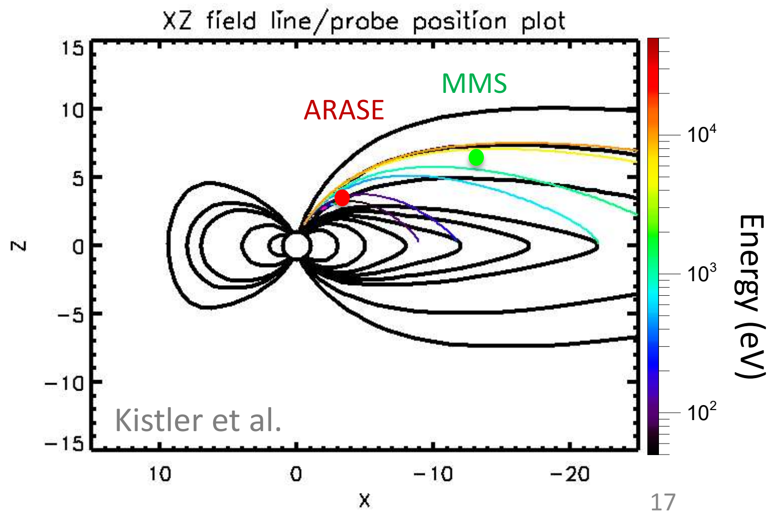
ESA/Hubble, NASA,
A. Simon (GSFC) &OPAL Team,
J. DePasquale (STScI) & L. Lamy (Obs. Paris)

Ion transport mechanisms

- Ionospheric O^+ outflow enters the magnetosphere from either the dayside cusp or nightside auroral regions of very near-Earth space

- O^+ sourced from the nightside aurora has direct access to the plasma sheet and exhibits characteristic temporal energy dispersions
  - Often injected into plasma sheet following magnetic dipolarizations



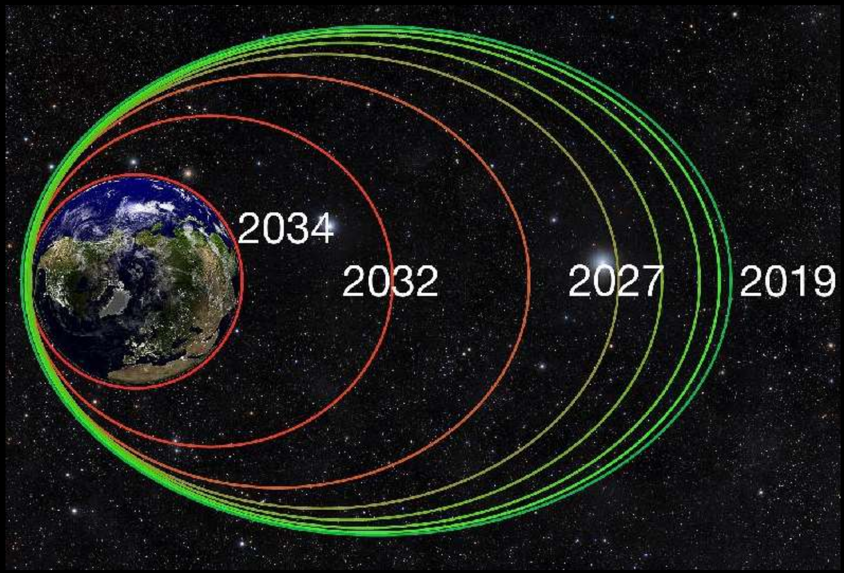


Van Allen Probes (RBSP-A & RBSP-B)

- The 2 spacecraft were used to study the Van Allen radiation belts that encompass our planet
  - Ran out of fuel - will deorbit in 2034
  - No one expected them to last longer than 2 years because of the horribly violent environment they lived in

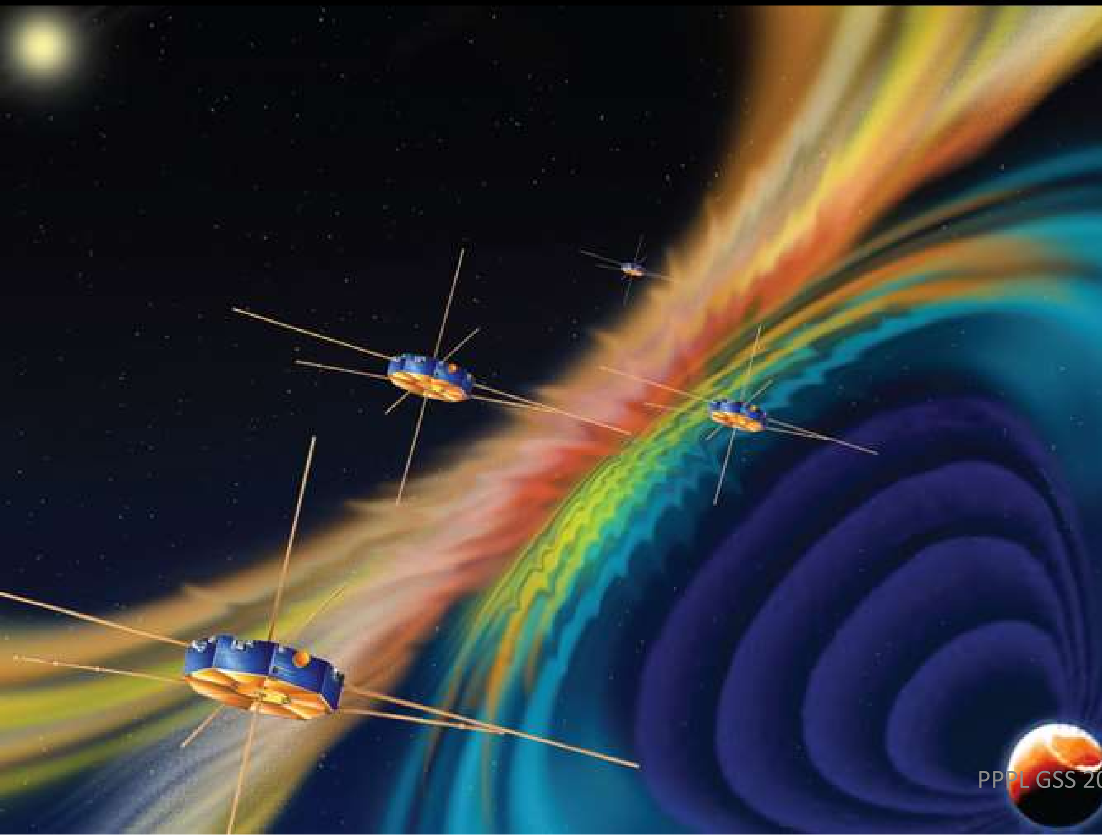
- NASA Goddard, Solar Dynamics Observatory (SDO), and The Johns Hopkins University Applied Physics Lab (APL) operate RBSP instruments
  - Often injected into plasma sheet following magnetic dipolarizations

Van Allen Probe B was shut-off 07/19/2019 and *Van Allen Probe A* was deactivated 10/18/2019 after operating for 7 years



Magnetosphere Multiscale Mission (MMS)

- MMS consists of 4 identical spacecraft
  - Studies how the Earth and Sun’s magnetic fields connect and disconnect
    - Magnetic reconnection events transfer massive amounts of energy and momentum
  - First mission to allow for small-scale, 3D structure of extremely dynamic systems (*microphysics*)
    - Renown for high spatial and temporal resolution instruments
- Spacecraft were launched 03/13/2015 and are estimated to remain operational until 2040
  - 3 phase mission to study *space weather*



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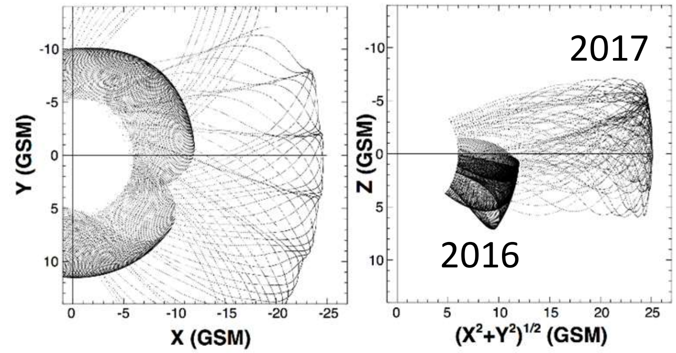
Statistical study of MMS & RBSP

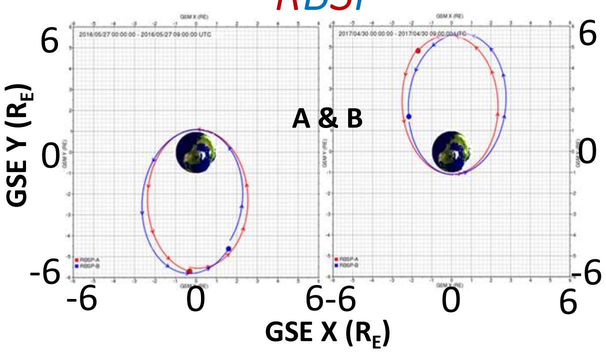
Phase 1b & 2



Data sets: MMS 2016 & 2017, RBSP 2016-2017 tail seasons

- **For each data set:**
  1. **Identify O^+ dispersions (characteristic of nightside auroral source)**
  2. **Record maximum and minimum energies of dispersion**
  3. **Record flow direction (uni or bi-directional by pitch angle α)**
  4. **Note if there was a dispersionless ion injection observed by LANL geosynchronous satellites**
  5. **Identify if injection followed dipolarization by checking for increase in Bz**
- **Sort through data sets for highest quality events ("Greatest Hits")**

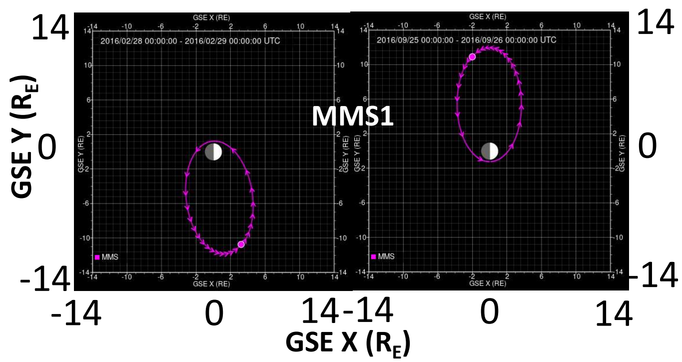
RBSP



05/27/2016 to 04/30/2017

- Apogee 6 R_E

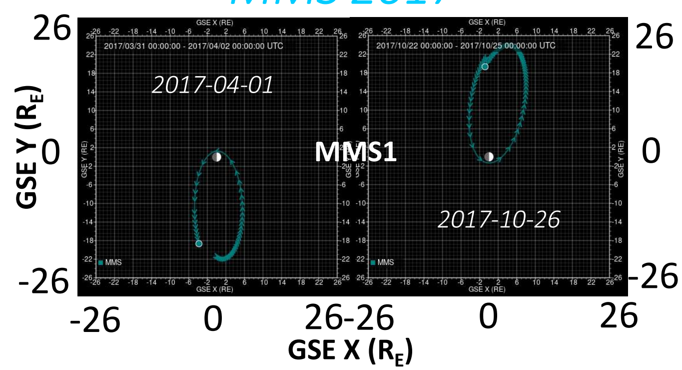
MMS 2016



03/01/2016 to 09/25/2016

- Apogee 13 R_E

MMS 2017



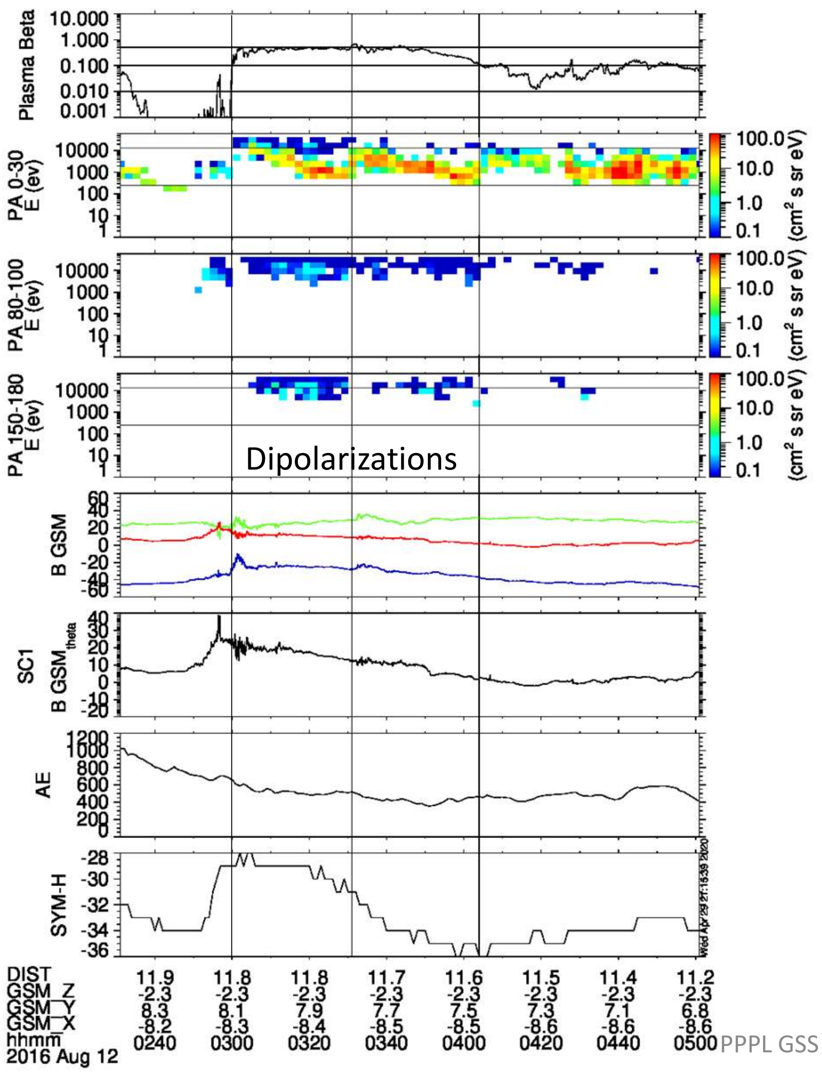
04/01/2017 to 10/26/2017

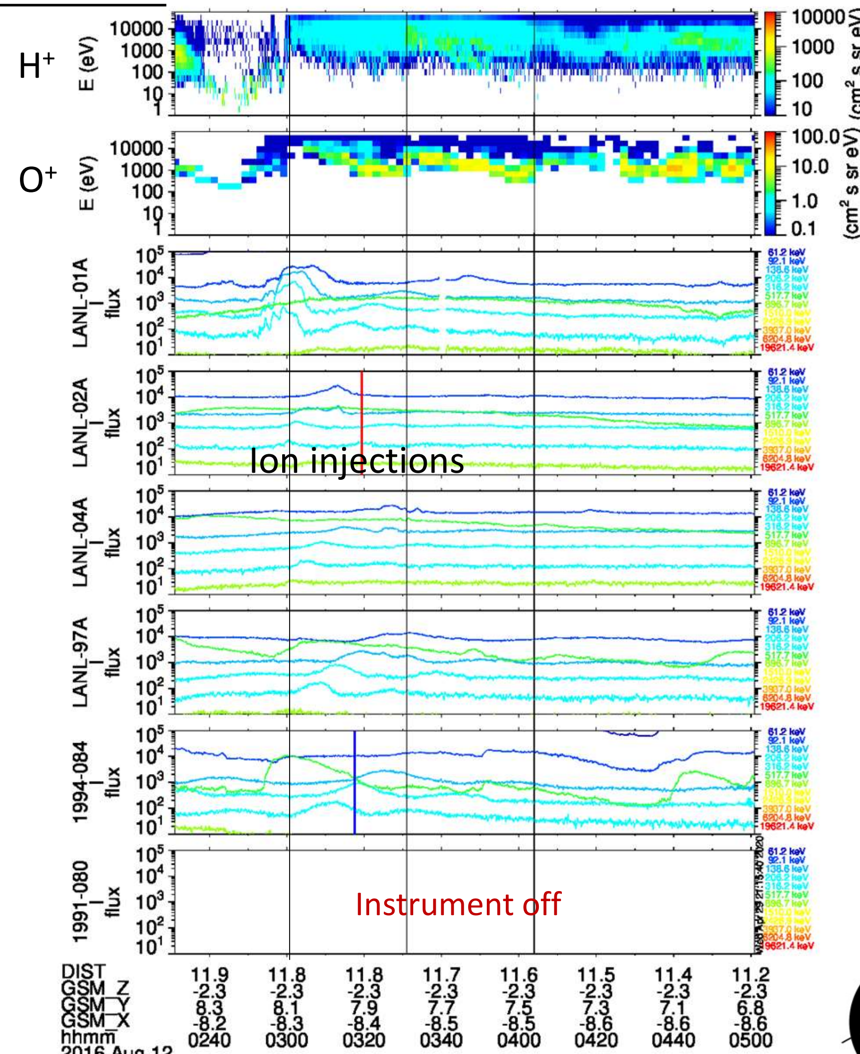
- Apogee 26 R_E

Hedlund/Kistler/Mouikis

Sample MMS Event

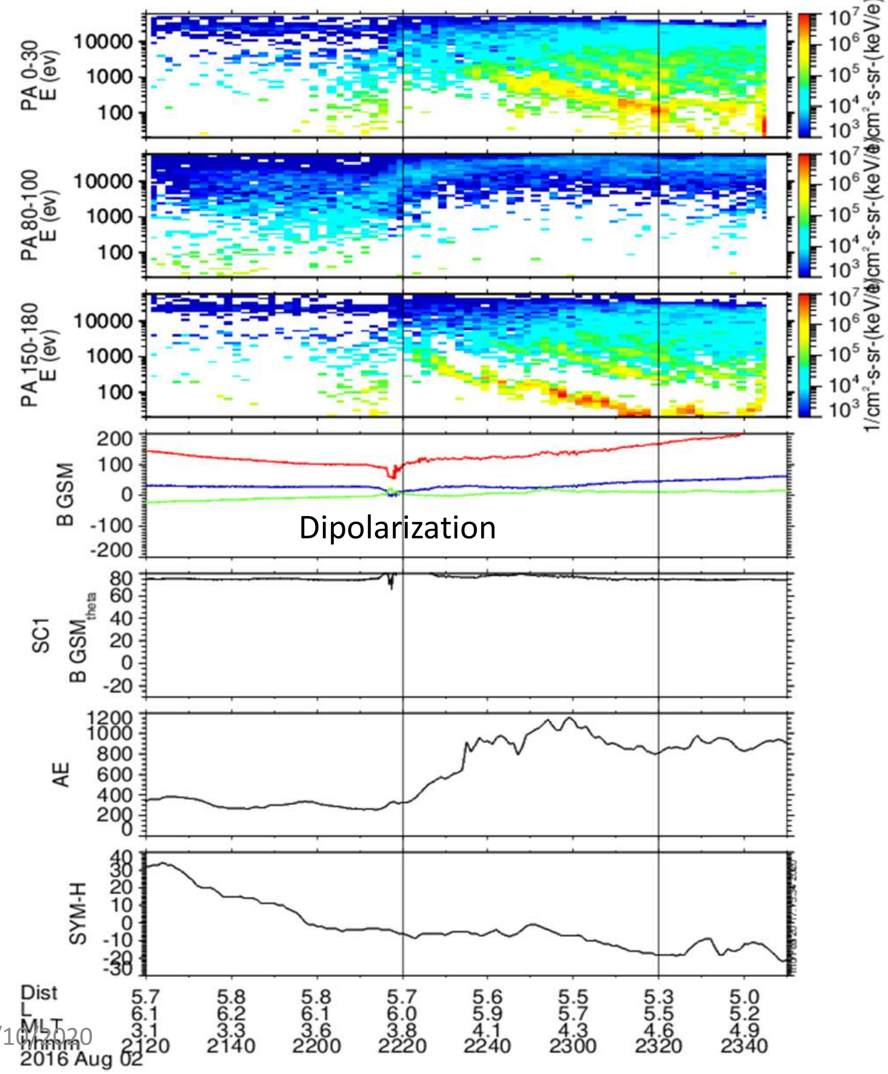
08-12-2016

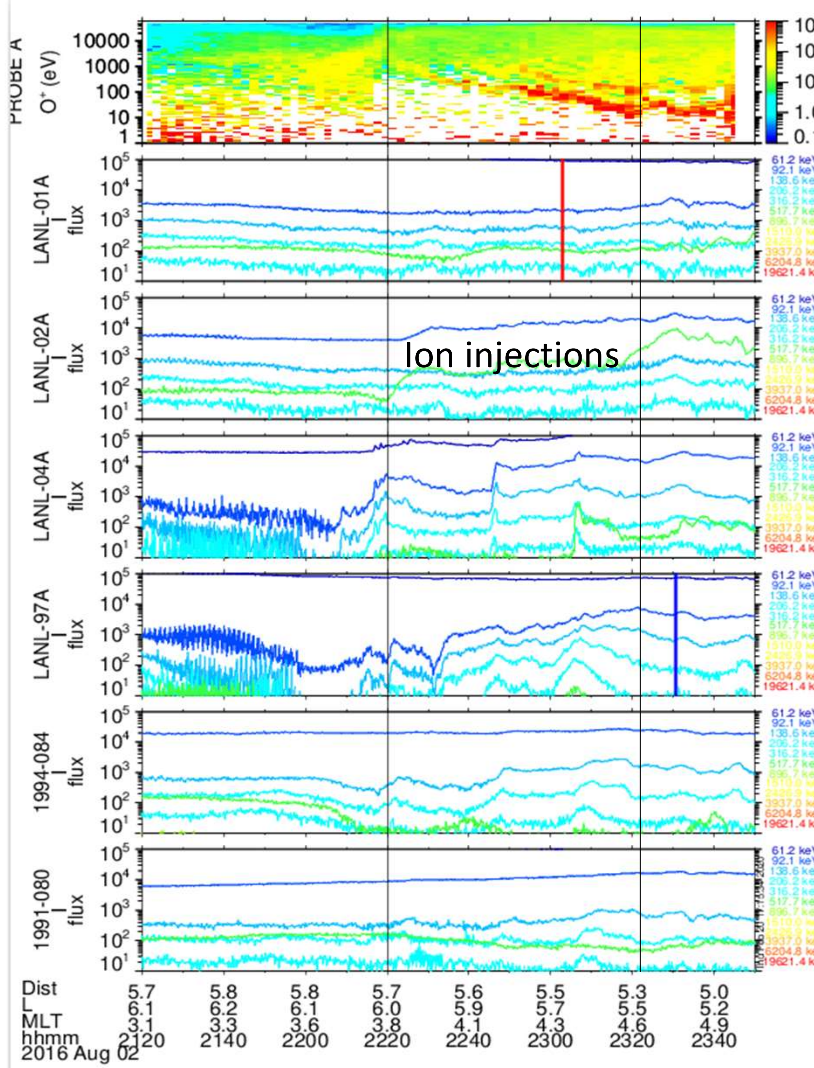




Sample RBSP Event

08-02-2016





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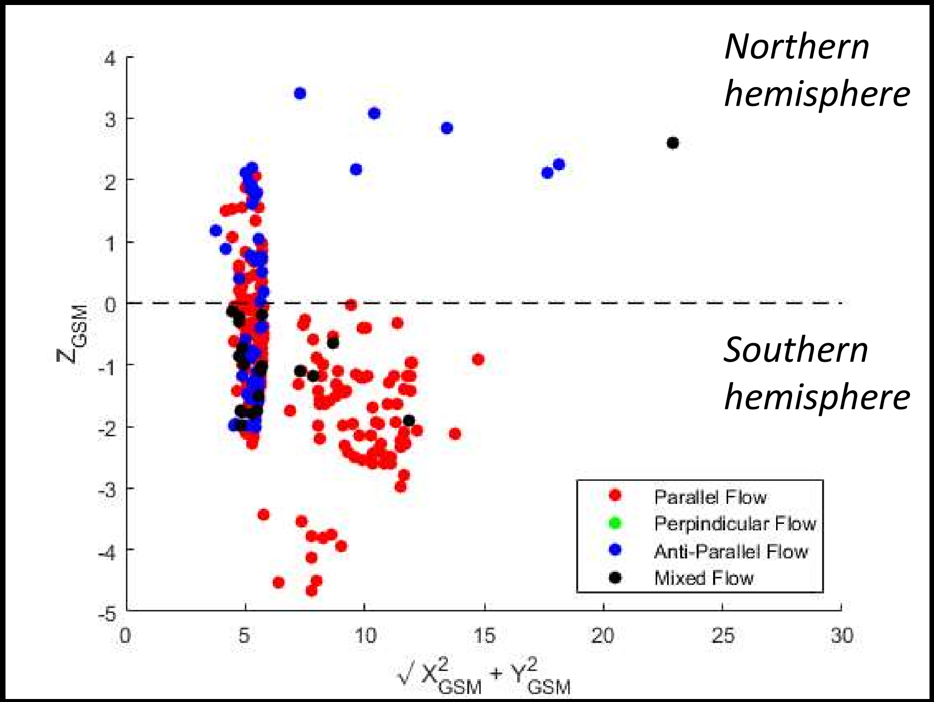
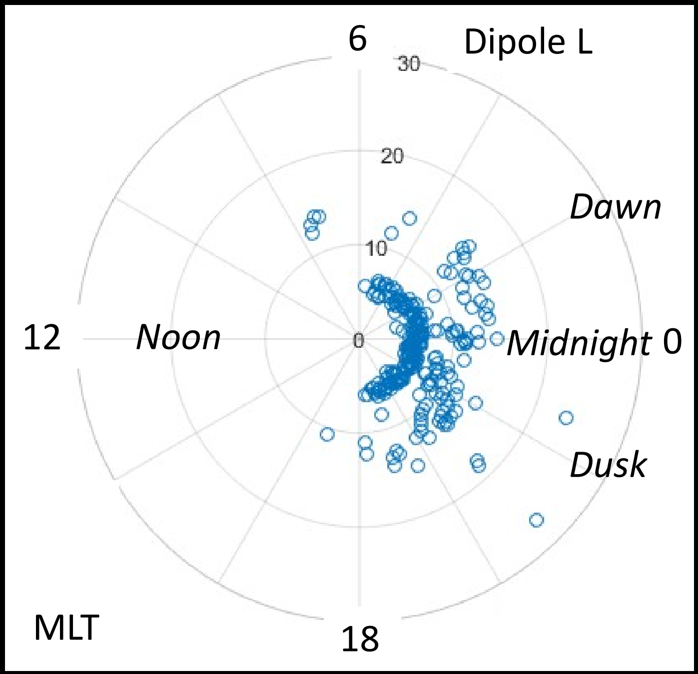
Preliminary Results

Flow Direction of O^+ Dispersions

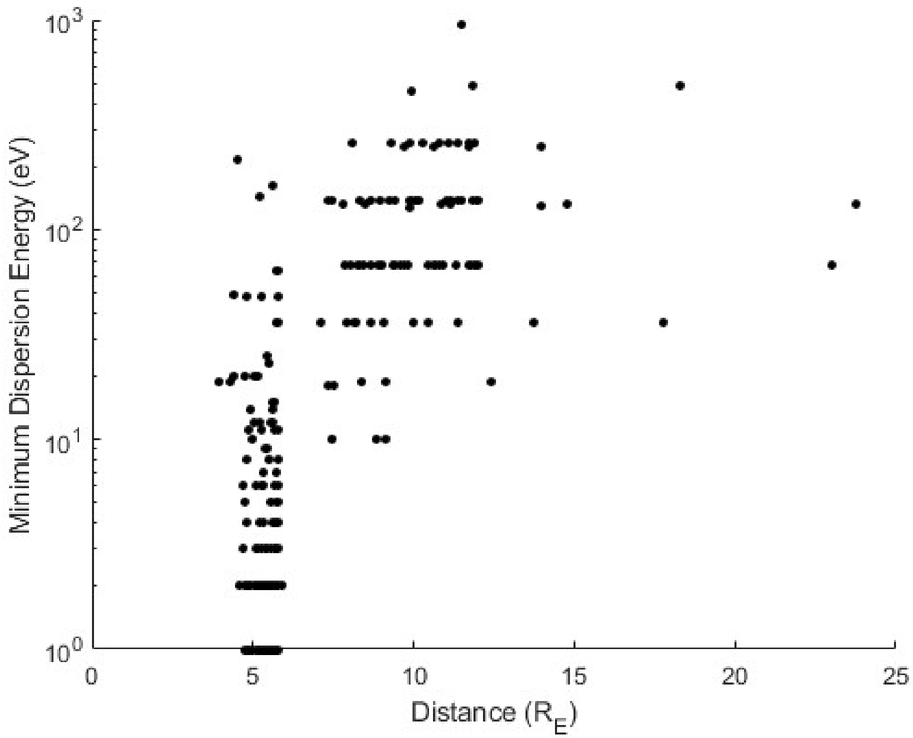


Location of O^+ Dispersions

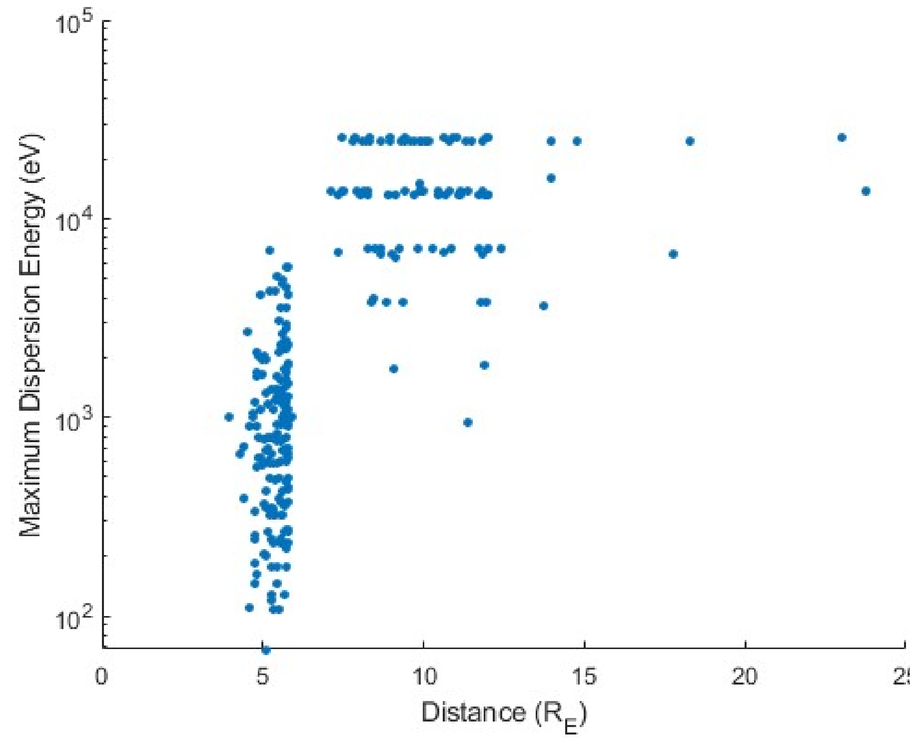


Preliminary Results

Min E of O^+ vs. Radial Distance



Max E of O^+ vs. Radial Distance



Preliminary Results

General statistics of O^+ dispersions

Data set	Total no. events	"Greatest Hits"	% with LANL	% with dipolarizations
RBSP	181	**N/A**	49.73% (total)	52.05% (total)
MMS 2016	261	80	31.25%	81.25%
MMS 2017	57	14	50%	64.29%

Averages of O^+ dispersions

Data set	R_E	Dipole L	Max E (*keV*)	Min E (*eV*)
RBSP	5.4	5.921	1.22	9.02
MMS 2016	9.9	11.38	15.0	127
MMS 2017	14.0	14.57	16.1	129

Conclusions from initial statistics:

- The number of dispersed O^+ injections into near-Earth plasma sheet decrease with radial distance
  - Most events are occurring at $<15R_E$
- Locationally, we see a dusk-ward skewing of O^+ energy dispersions
- The minimum/maximum energy of O^+ dispersions agree with a model of a nightside aurora source
  - Model considers convection combined with parallel motion

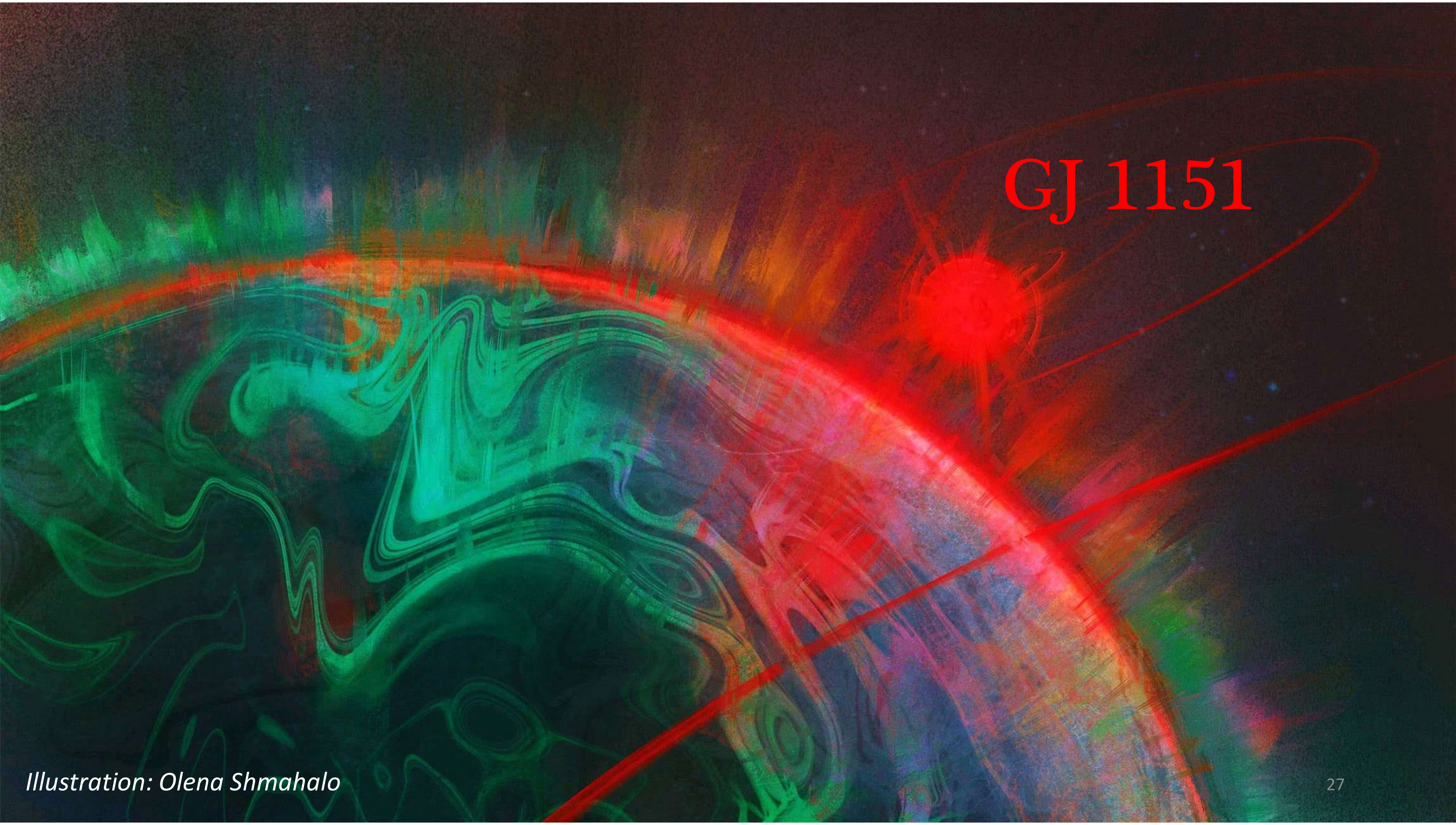


Illustration: Olena Shmahalo

Personnel & Acknowledgements

- Marissa is an analytical chemist by training
  - Started studying space physics in 2018 as a Boulder Solar Alliance REU Intern at HAO (NCAR)
- NASA: Living With a Star (**LWS**) Focus Science Team (**FST**) #3- Ion Transport
  - FST #3: Magnetosphere-Ionosphere Processes Responsible for Rapid Geomagnetic Changes

Lynn Kistler

Yours truly

Chris Mouikis

Kevin Pham

Bill Lotko

Thank you for listening!
Any questions?

Extras

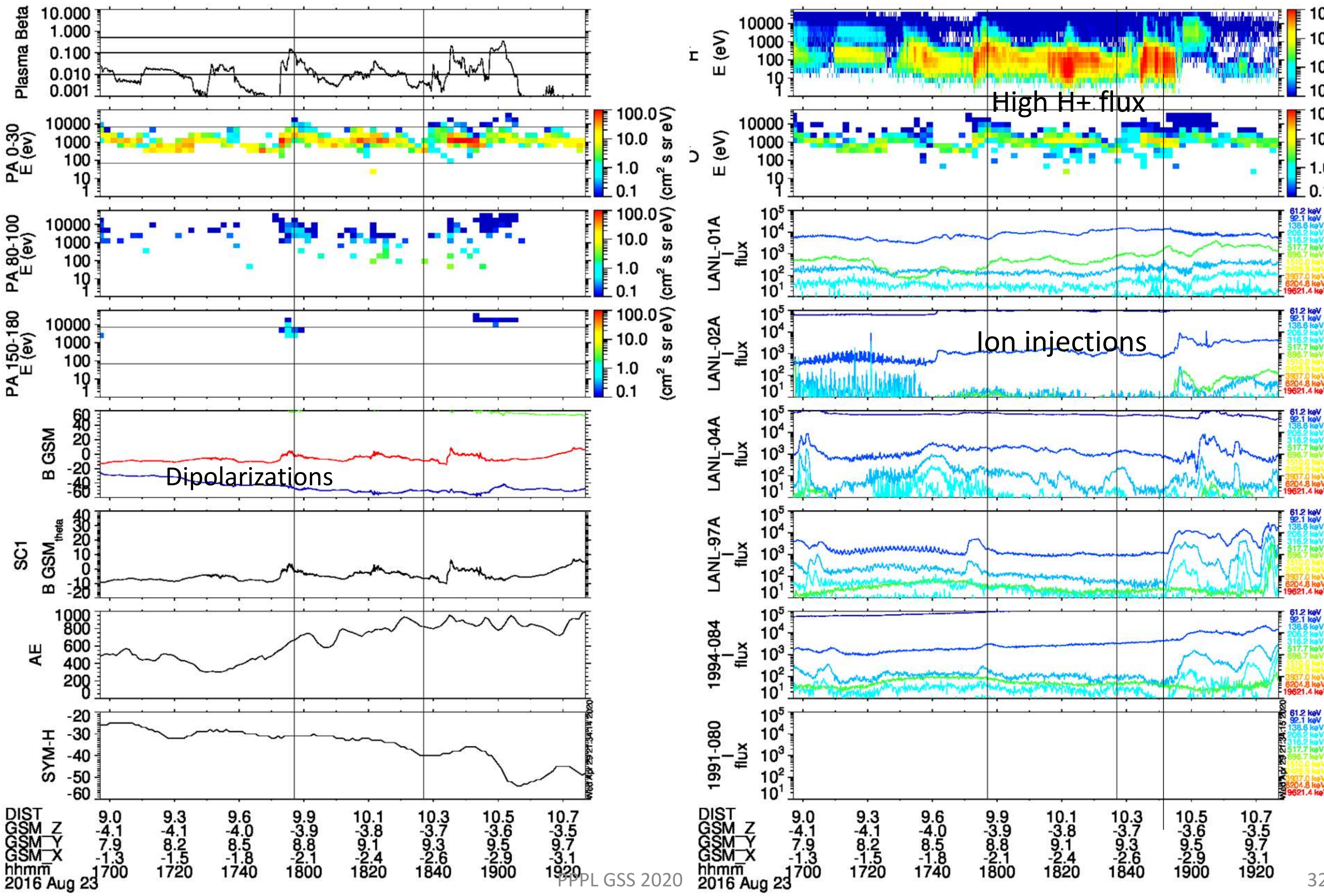
Perceived Impact

- **Determine solar wind parameters, magnetospheric conditions, and ionospheric properties that affect the rate of change of the geomagnetic field in the coupled solar wind – magnetosphere – ionosphere system**
- **Establish a predictive capability for geomagnetically induced current (GIC) events**
  - **Can disrupt telecommunications and electrical grid systems**
  - **Hazardous for humans aboard ISS**

ISS

Hedlund/Kistler
/Mouikis

08-23-2016



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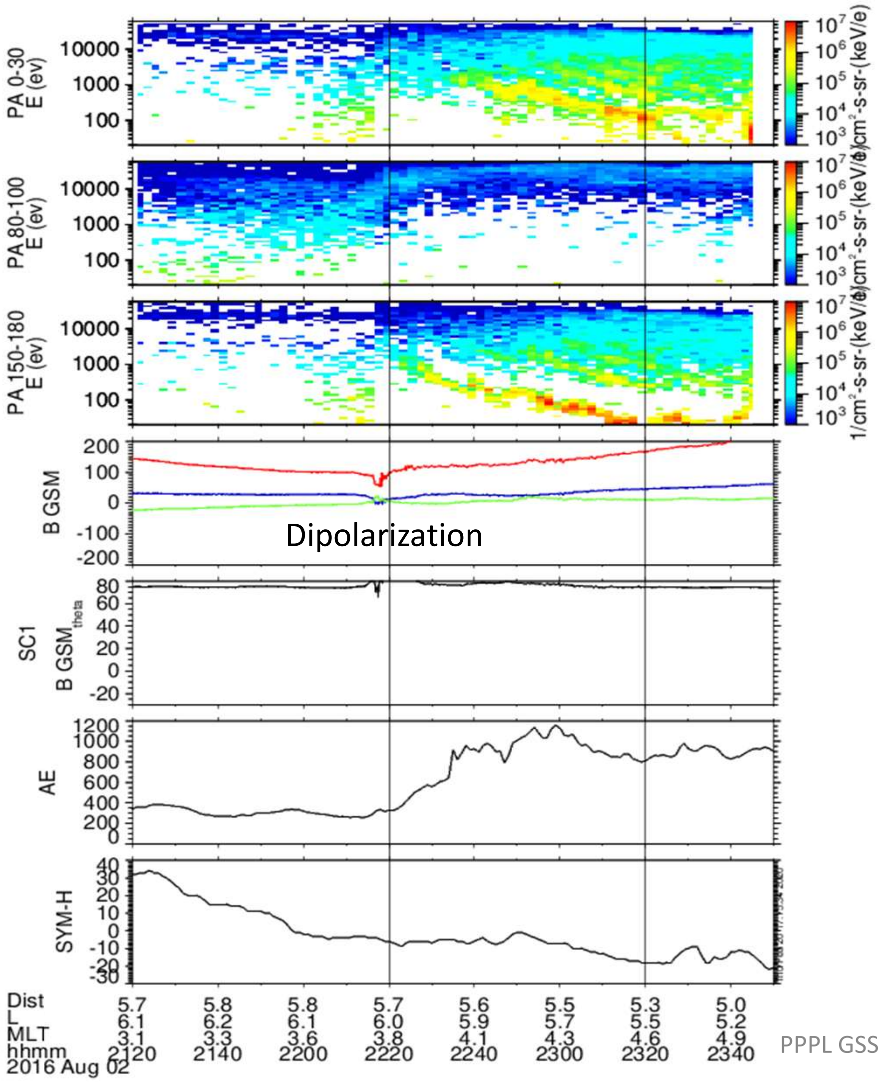
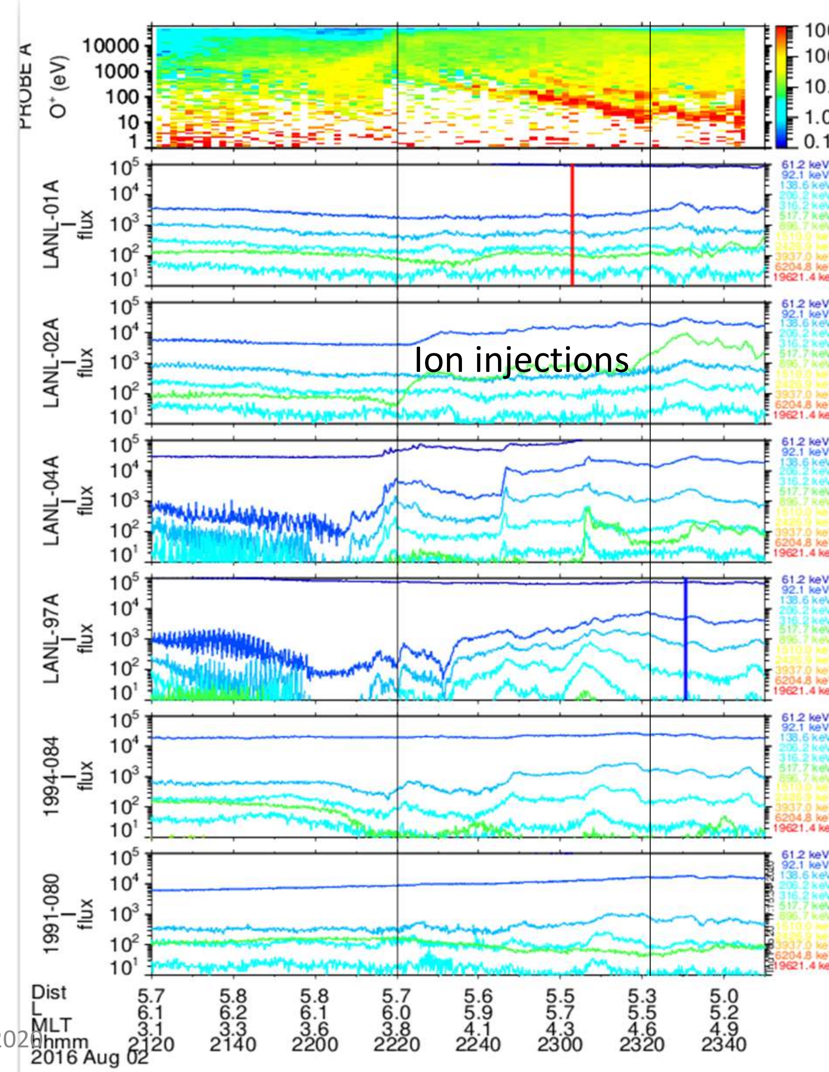
Sample RBSP O^+ Dispersion

08-02-2016





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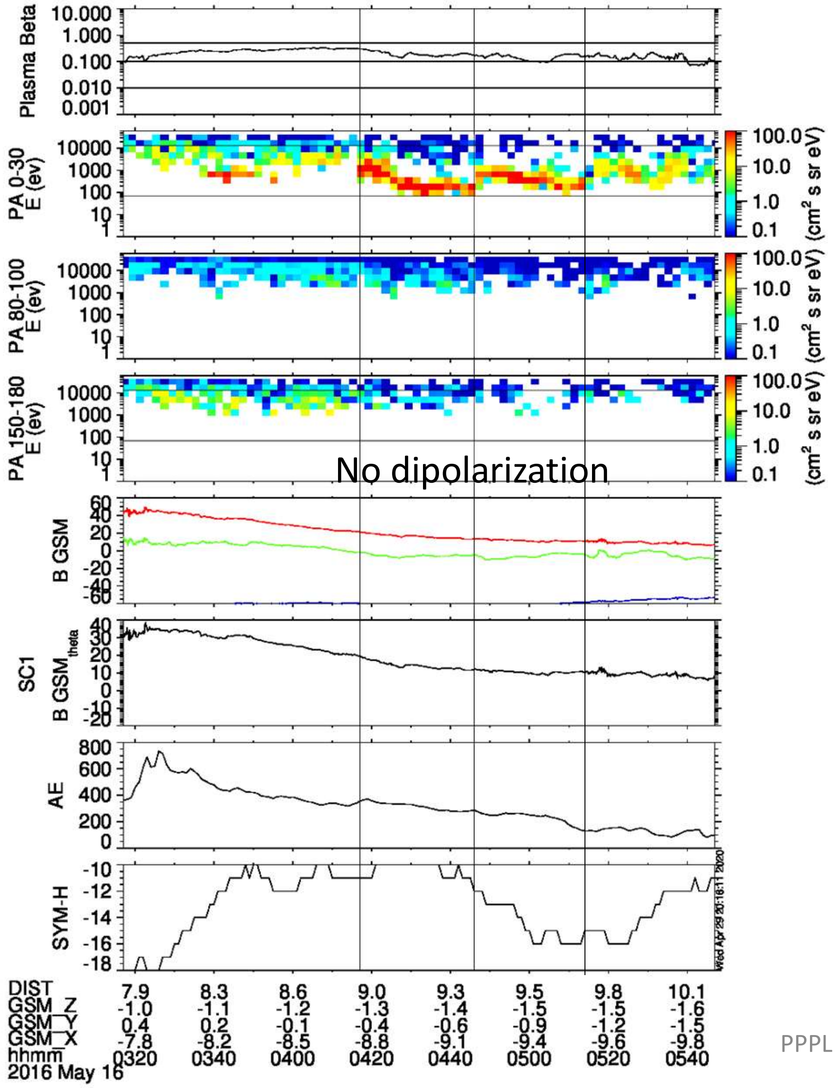
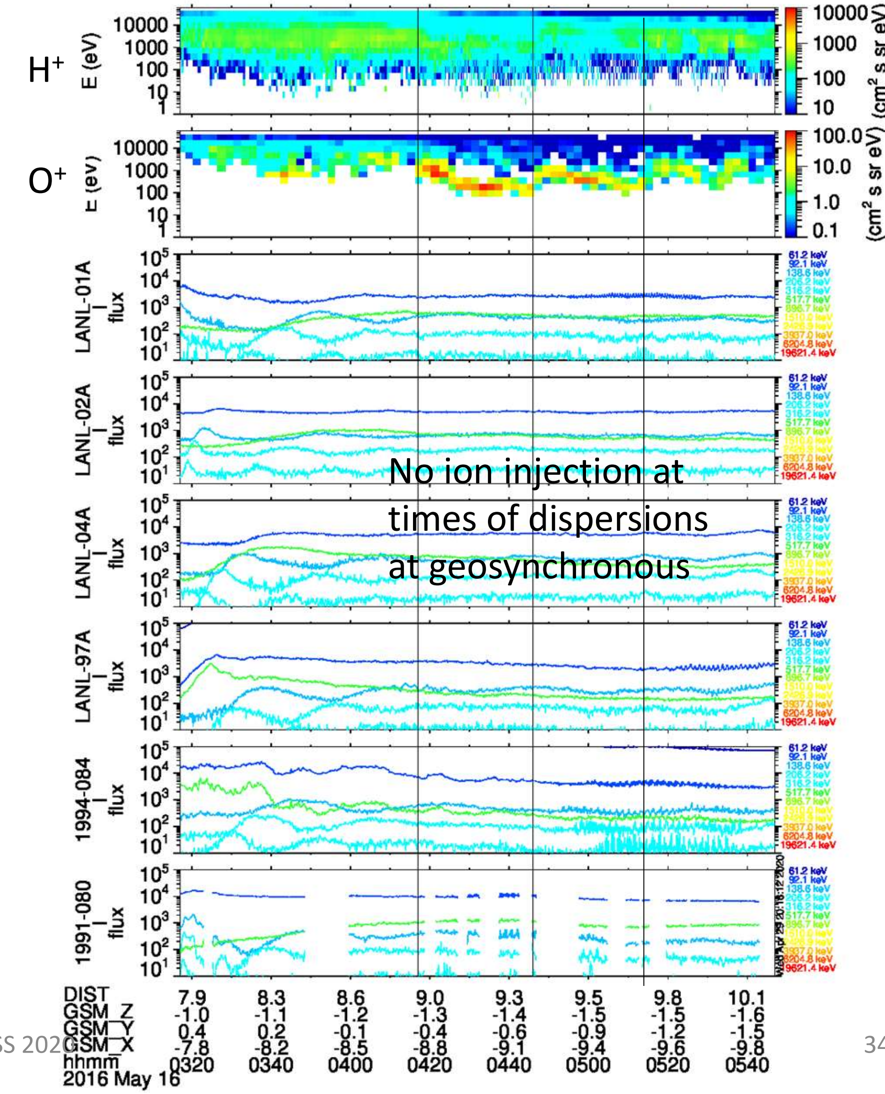
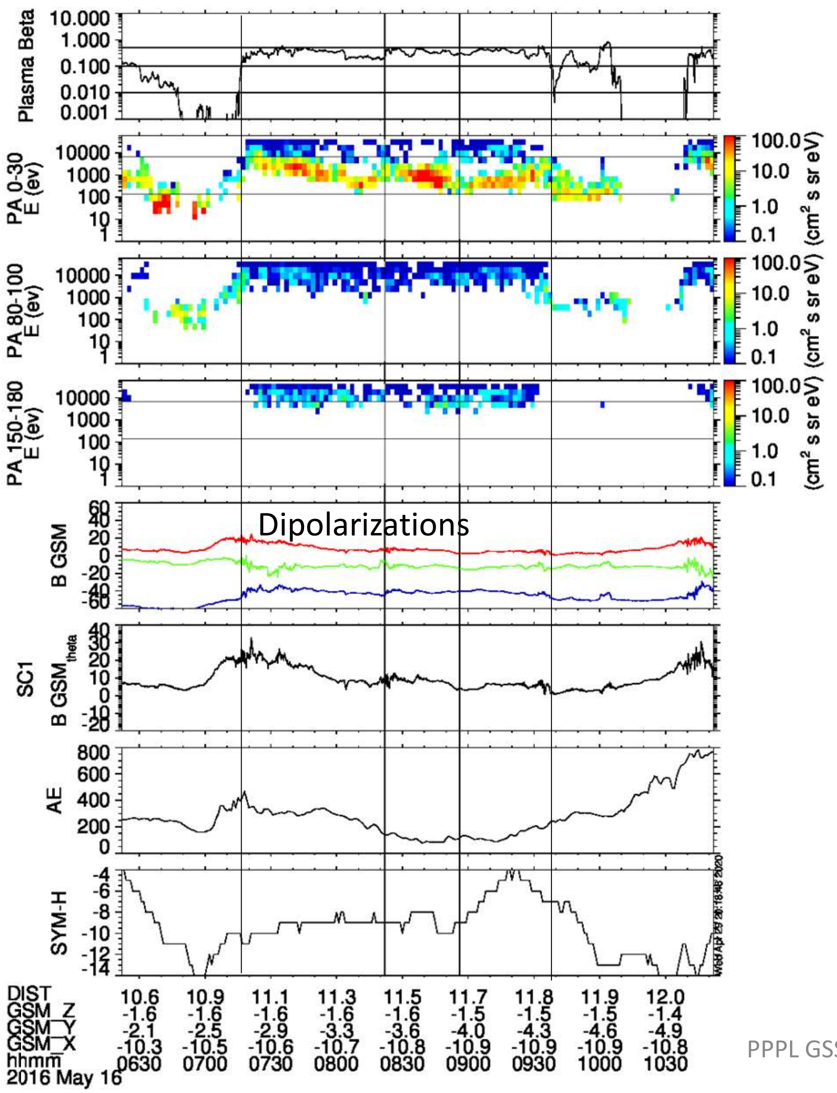
Sample MMS Multi-Dispersed Event

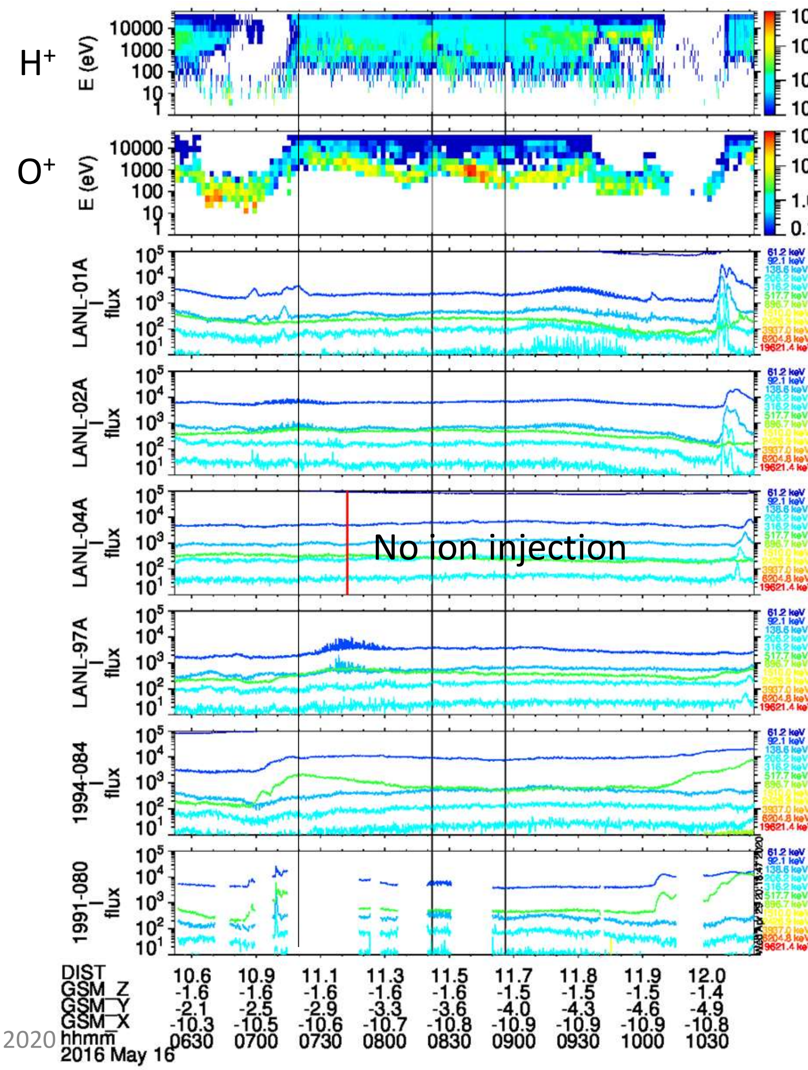
05-16-2016





05-16-2016





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Sample MMS O^+ Dispersion

08-12-2016