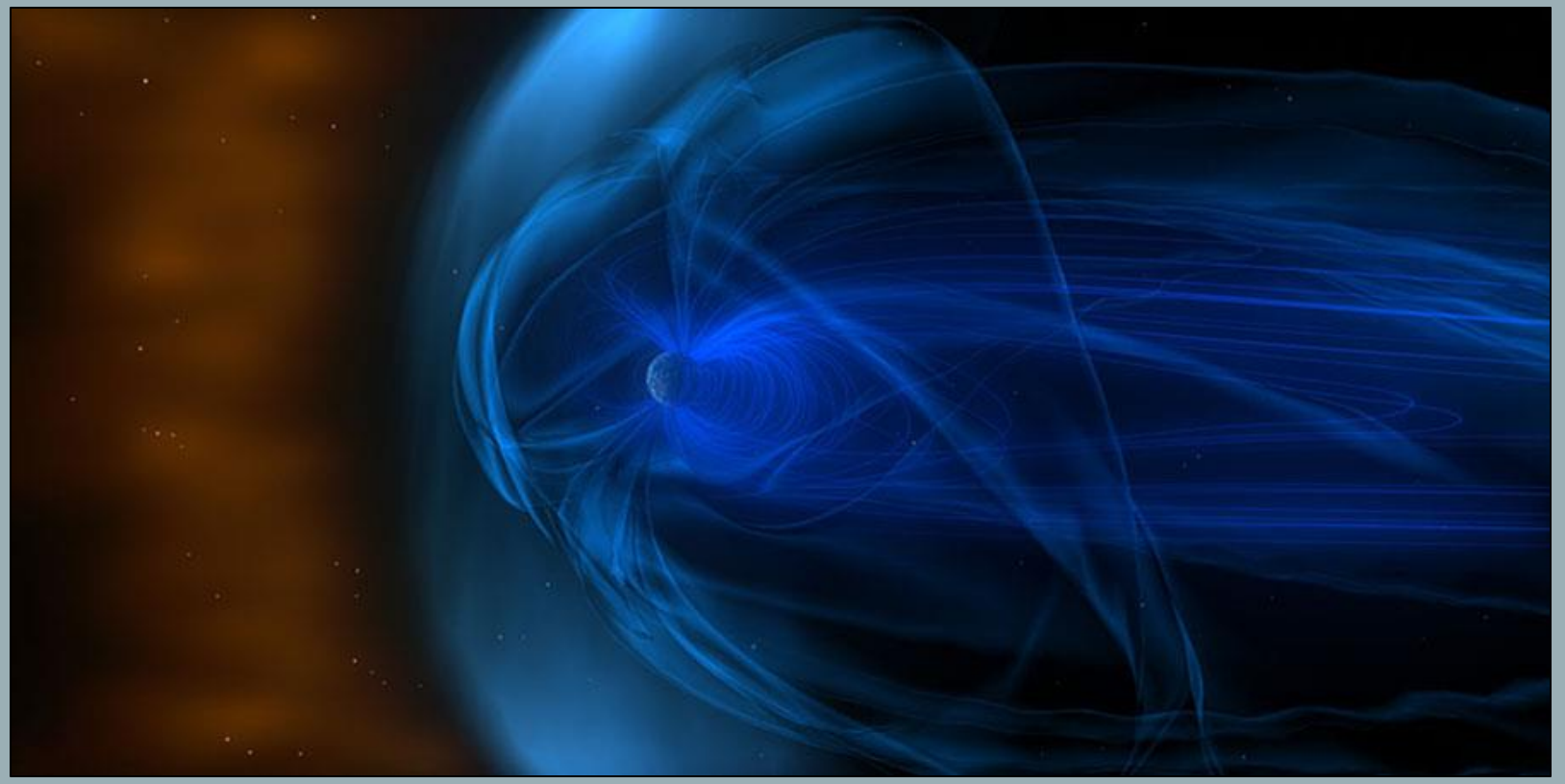
HELIO OVERVIEW II: GEOSPACE PLASMA ENVIRONMENT

Lauren Blum – lauren.blum@lasp.colorado.edu



A BIT ABOUT MYSELF:

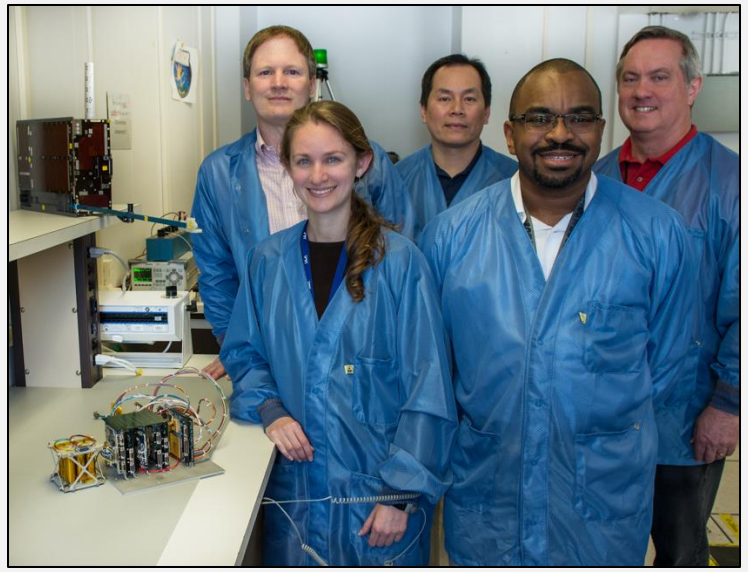
Dr. Lauren Blum, Assistant Professor

(she/her)

Laboratory for Atmospheric and Space Physics,

Astrophysics and Planetary Science Department

- Born/raised in NYC
- Physics major in undergrad, then worked at Los Alamos National Laboratory
- PhD, Aerospace Engineering Sciences, CU Boulder, 2014
- Postdoc, Space Sciences Lab, UC Berkeley 2014-2016
- Research Scientist, NASA Goddard Space Flight Center, 2016-2020
- Assistant Professor, APS & LASP, CU Boulder, 2020-present
- Research: Planetary magnetospheres, energetic particle dynamics in Earth's radiation belts; charged particle instrumentation and SmallSat design



GTOSat CubeSat prototype, NASA Goddard

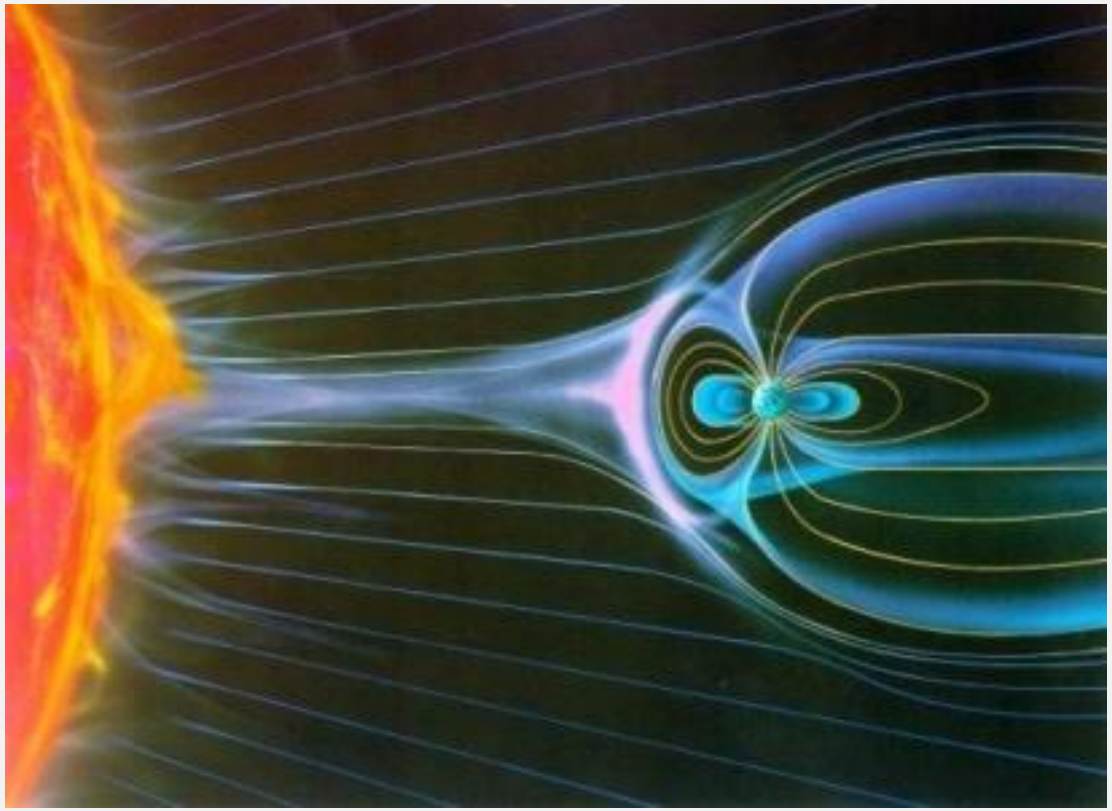
Balloon campaign in Sodankla Finland

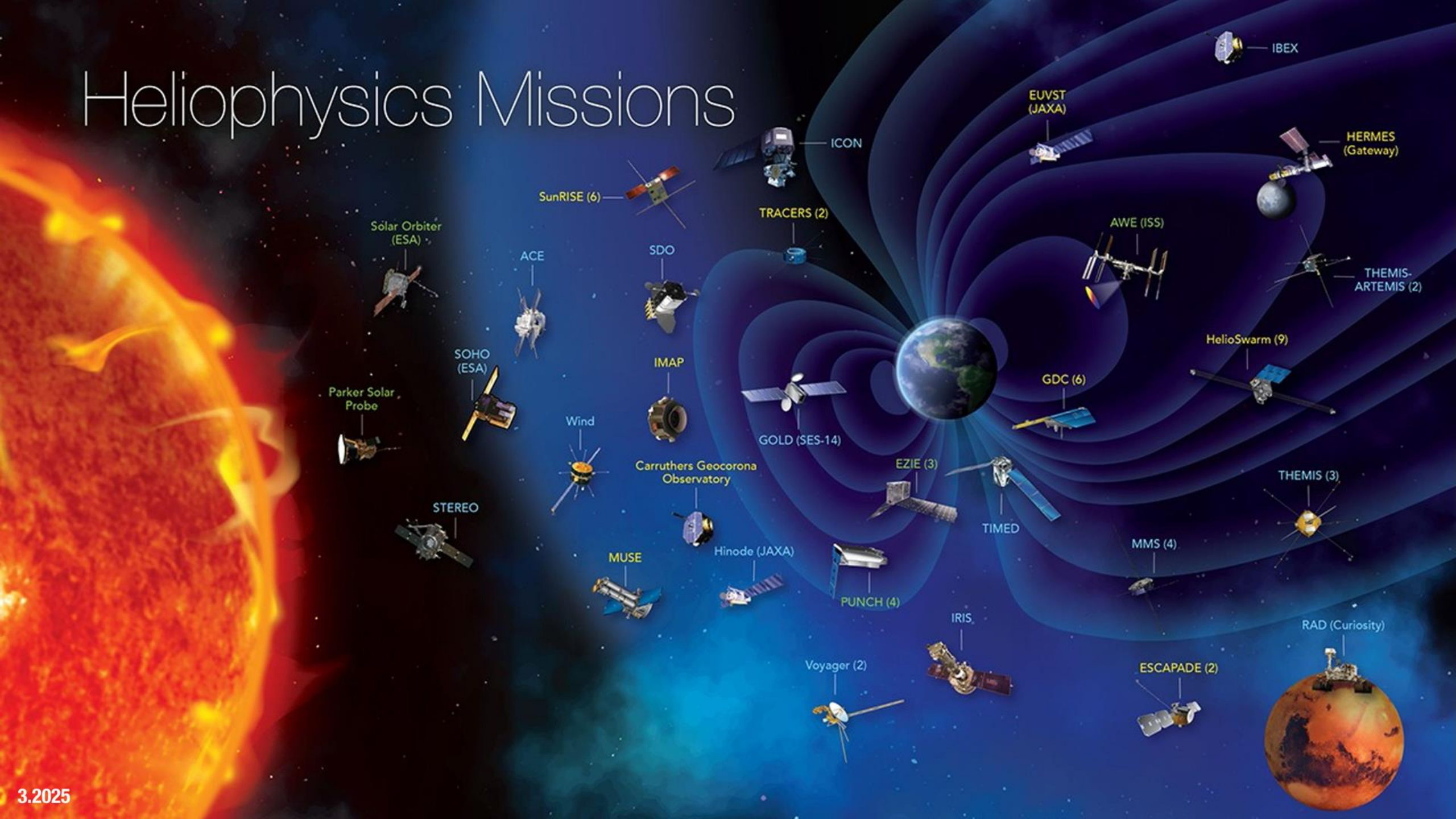
MAGNETOSPHERES

- What are they?
- What do they look like?
- How do they behave?

- How do we know any of this?

(something we should ask ourselves all the time, about any information presented to us!)




Heliophysics Missions
IBEX
EUVST (JAXA)
HERMES (Gateway)
ICON
SunRISE (6)
TRACERS (2)
AWE (ISS)
Solar Orbiter (ESA)
ACE
SDO
THEMIS-ARTEMIS (2)
SOHO (ESA)
IMAP
HelioSwarm (9)
Parker Solar Probe
GDC (6)
Wind
GOLD (SES-14)
Carruthers Geocorona Observatory
EZIE (3)
THEMIS (3)
STEREO
TIMED
MMS (4)
MUSE
Hinode (JAXA)
PUNCH (4)
IRIS
RAD (Curiosity)
Voyager (2)
ESCAPADE (2)
3.2025

A FEW NOTES:

- Please interrupt at any point with questions, comments, additions from your own research or experience
- My hope is you'll learn as much (more?) from each other as you do from me

Also: Let's consider common questions or misconceptions throughout this talk… please speak up if you think of some!

QUICK POLL

What is the primary topic of your research/research interests:

A) Solar/solar wind

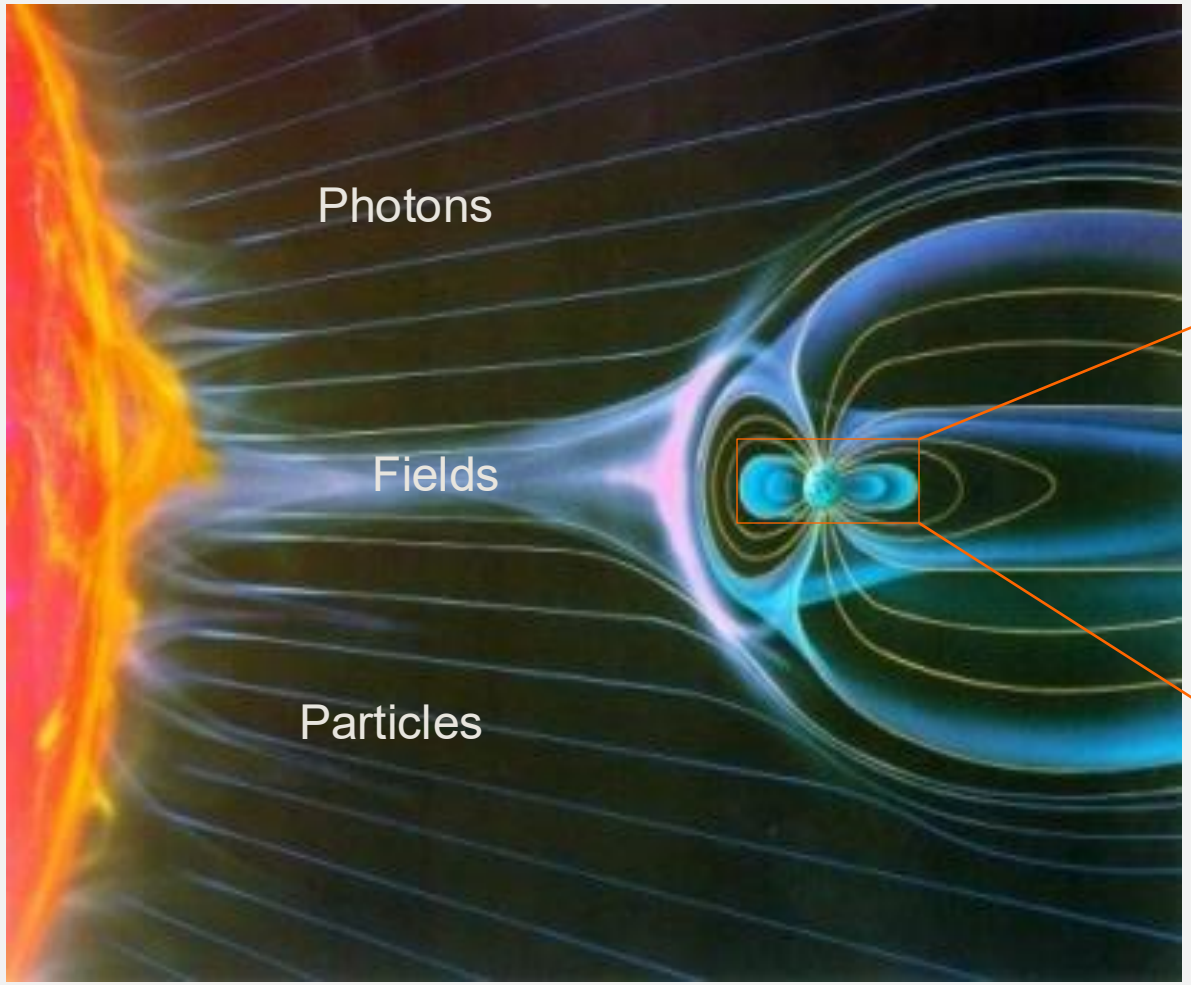
B) Earth's magnetosphere

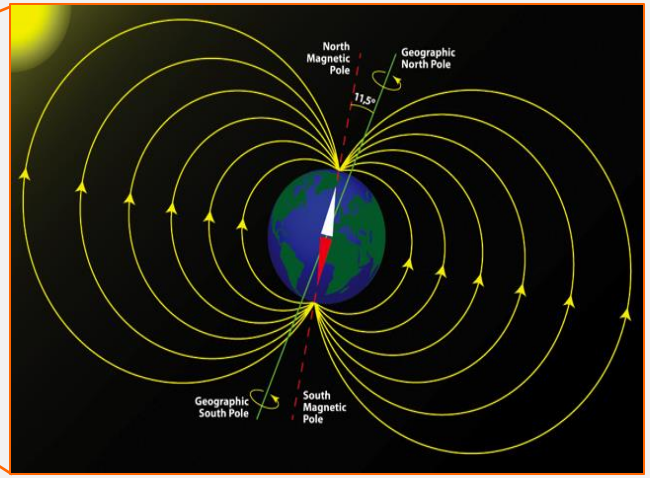
C) Earth's ionosphere/atmosphere

D) Other planetary systems

E) Other/not sure

WHAT IS A MAGNETOSPHERE?





The volume of space from which the solar wind is excluded by a planet's magnetic field, formed by the interaction of a flowing plasma with a magnetized body

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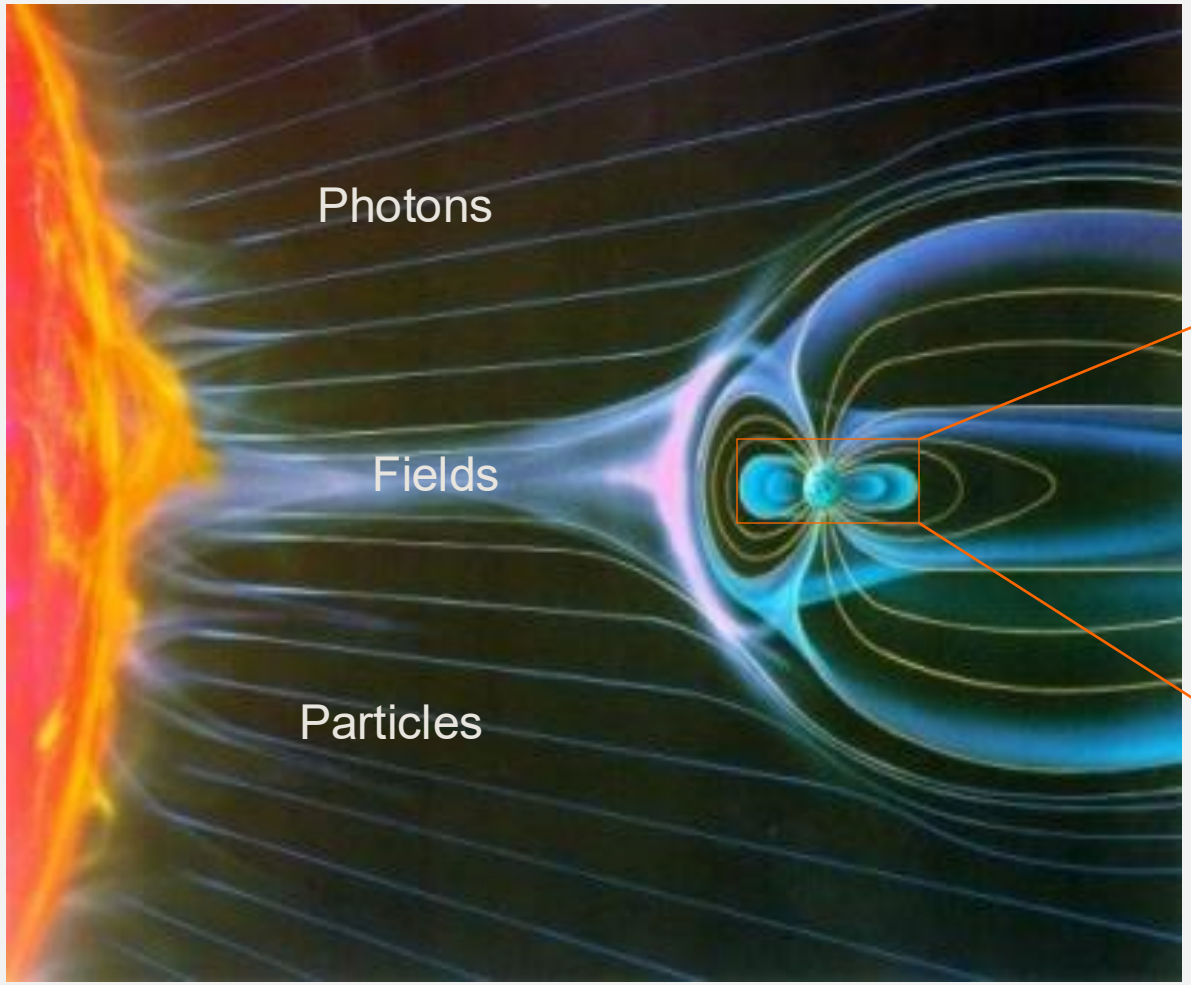
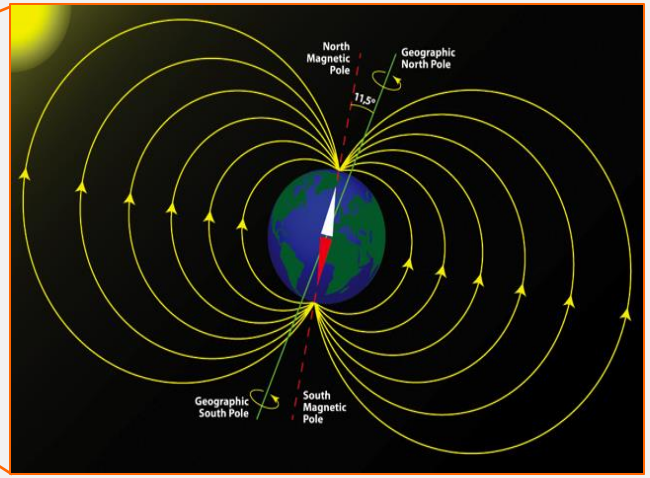
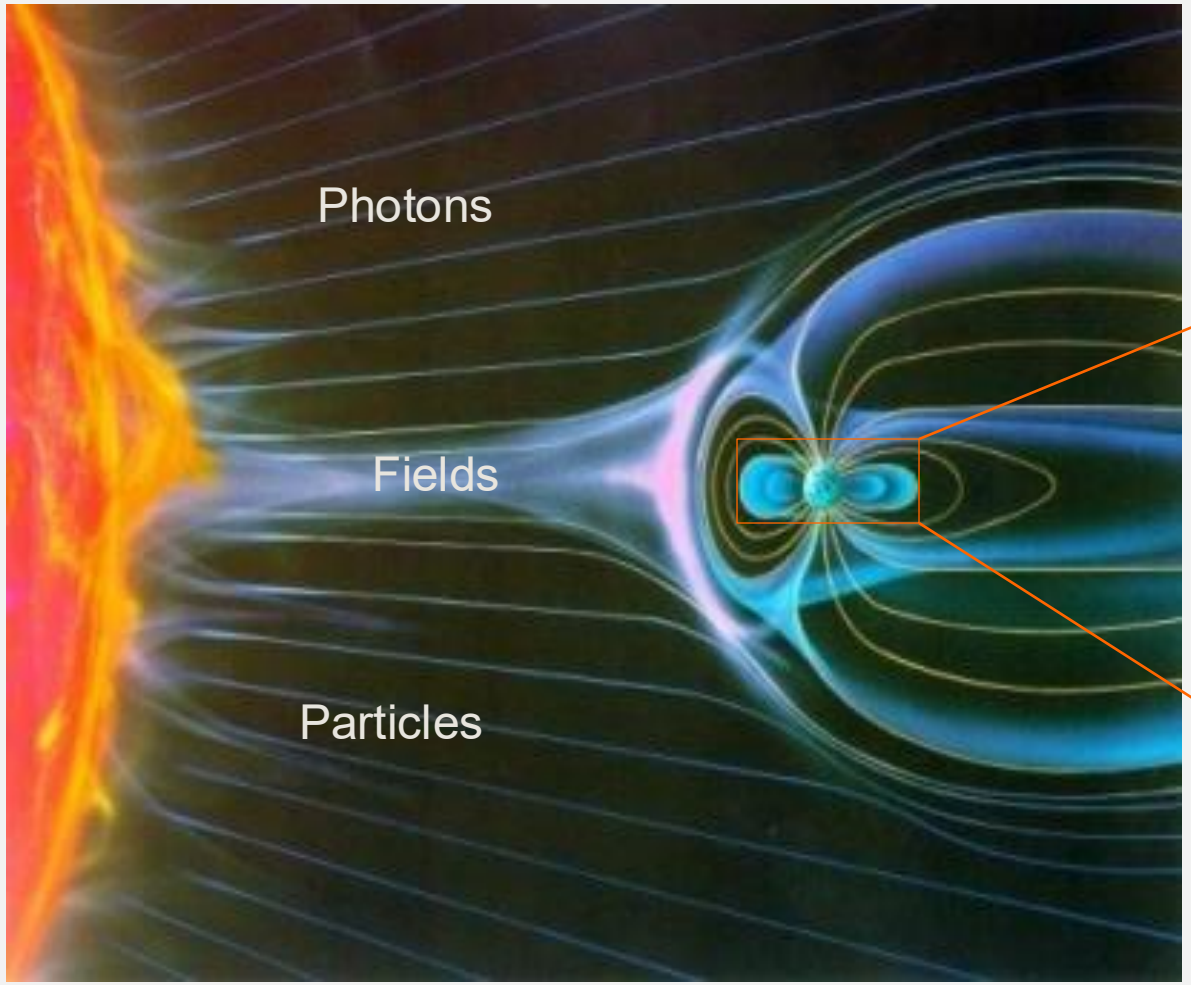


Any caveats/modifications we should make to this definition?



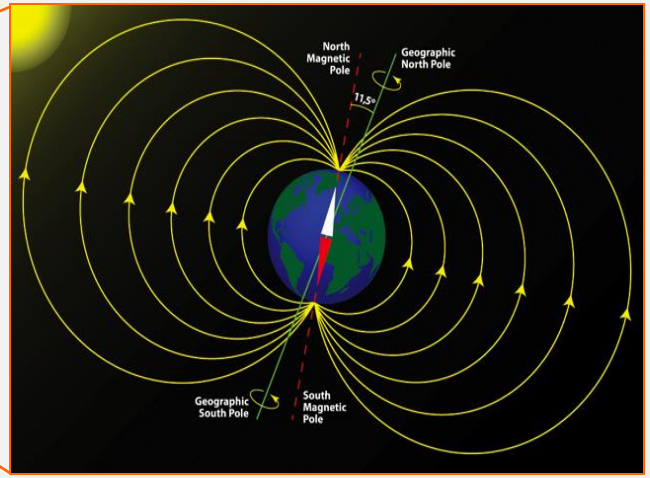
The volume of space from which the solar wind is excluded by a planet's magnetic field, formed by the interaction of a flowing plasma with a magnetized body

EARTH'S MAGNETOSPHERE



The inner field:

- Originates in a dynamo process inside the Earth's core
- Close to the surface described by as a dipole or a multipole
- Variable in magnitude and direction: polarity reversals approximately all 500 000 years.



The outer field:

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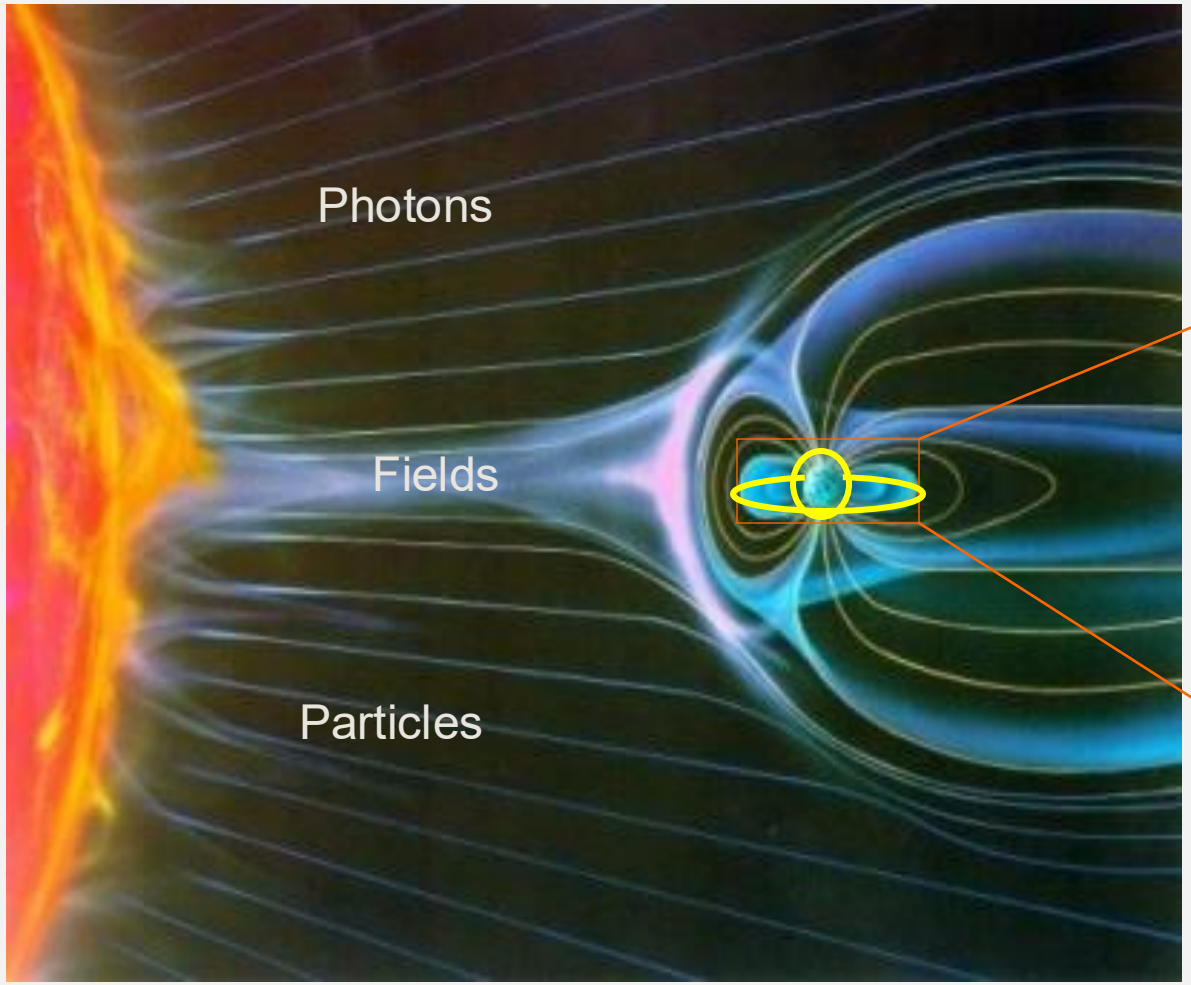

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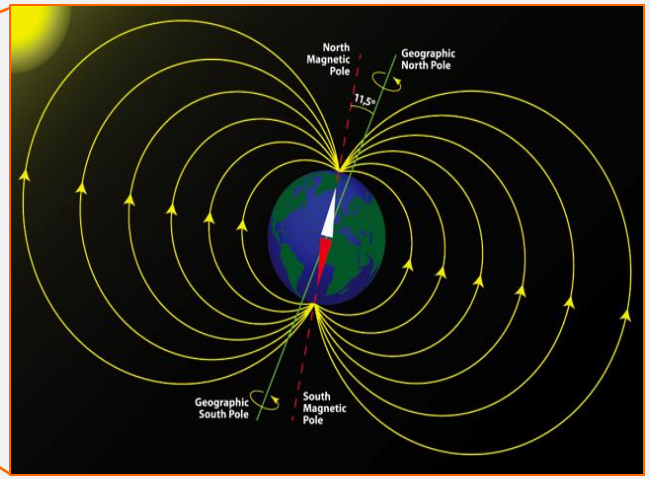

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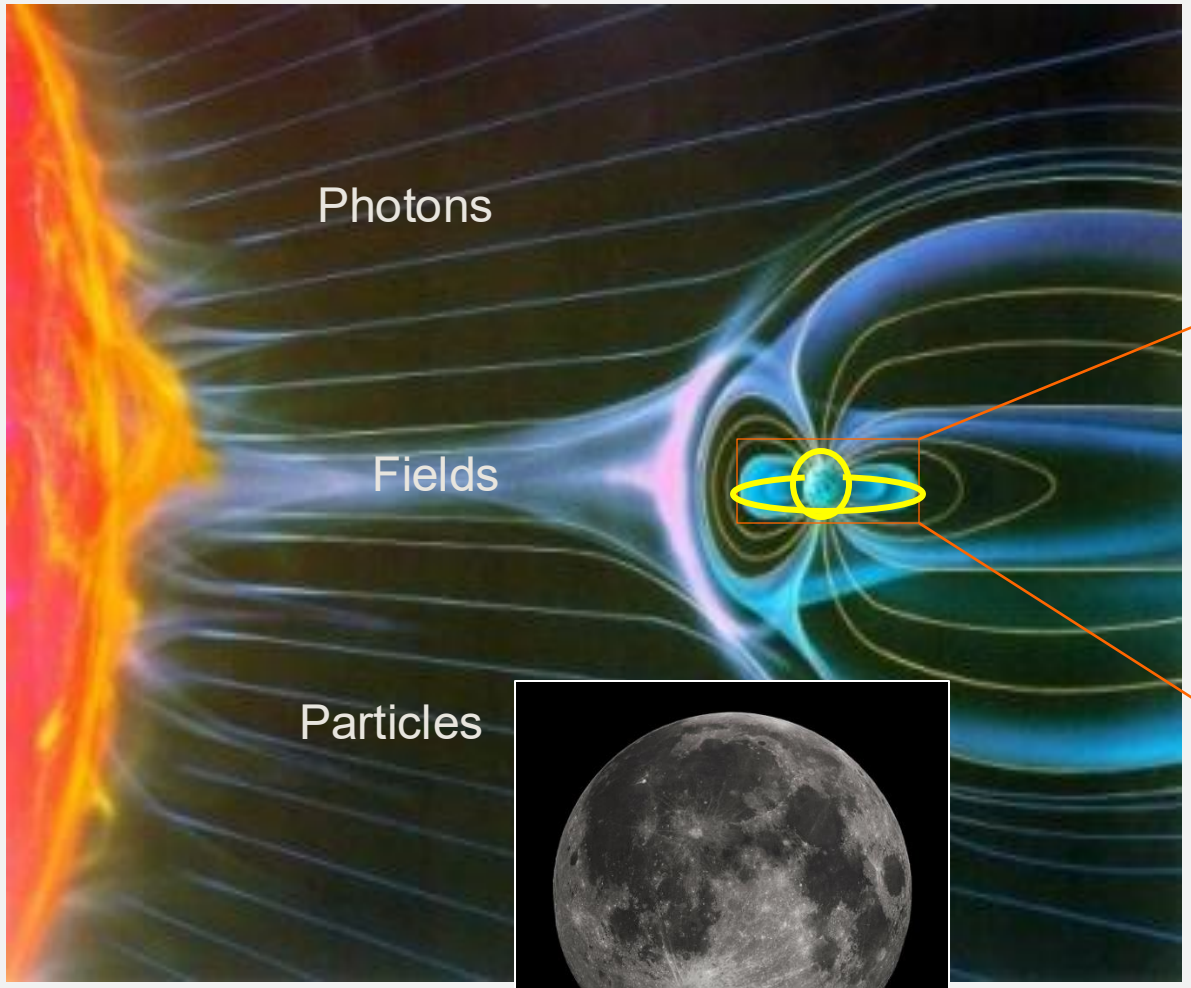

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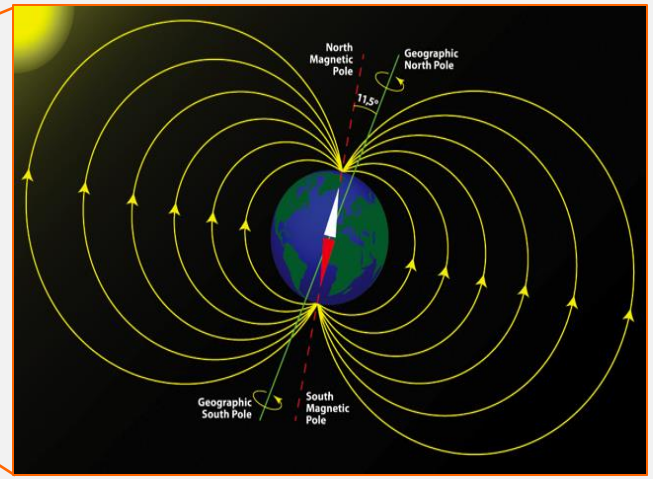

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Where is the moon in this picture? (and why am I asking?)

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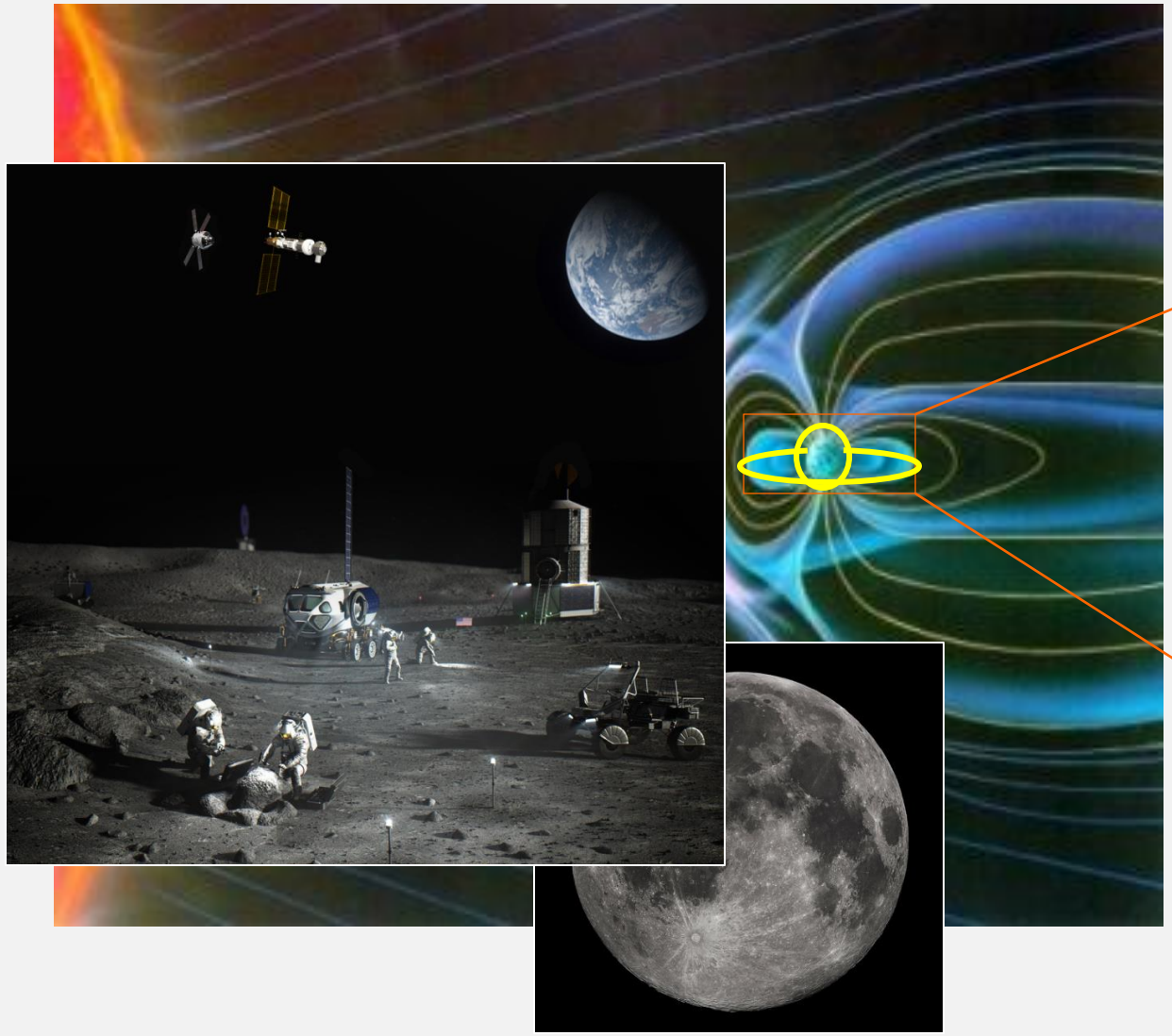

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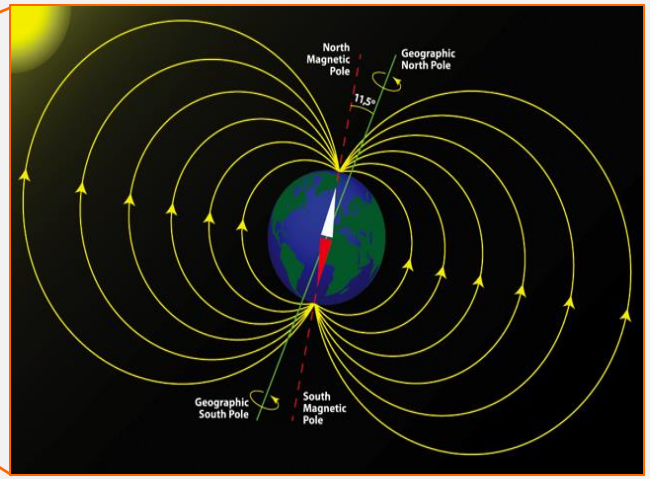

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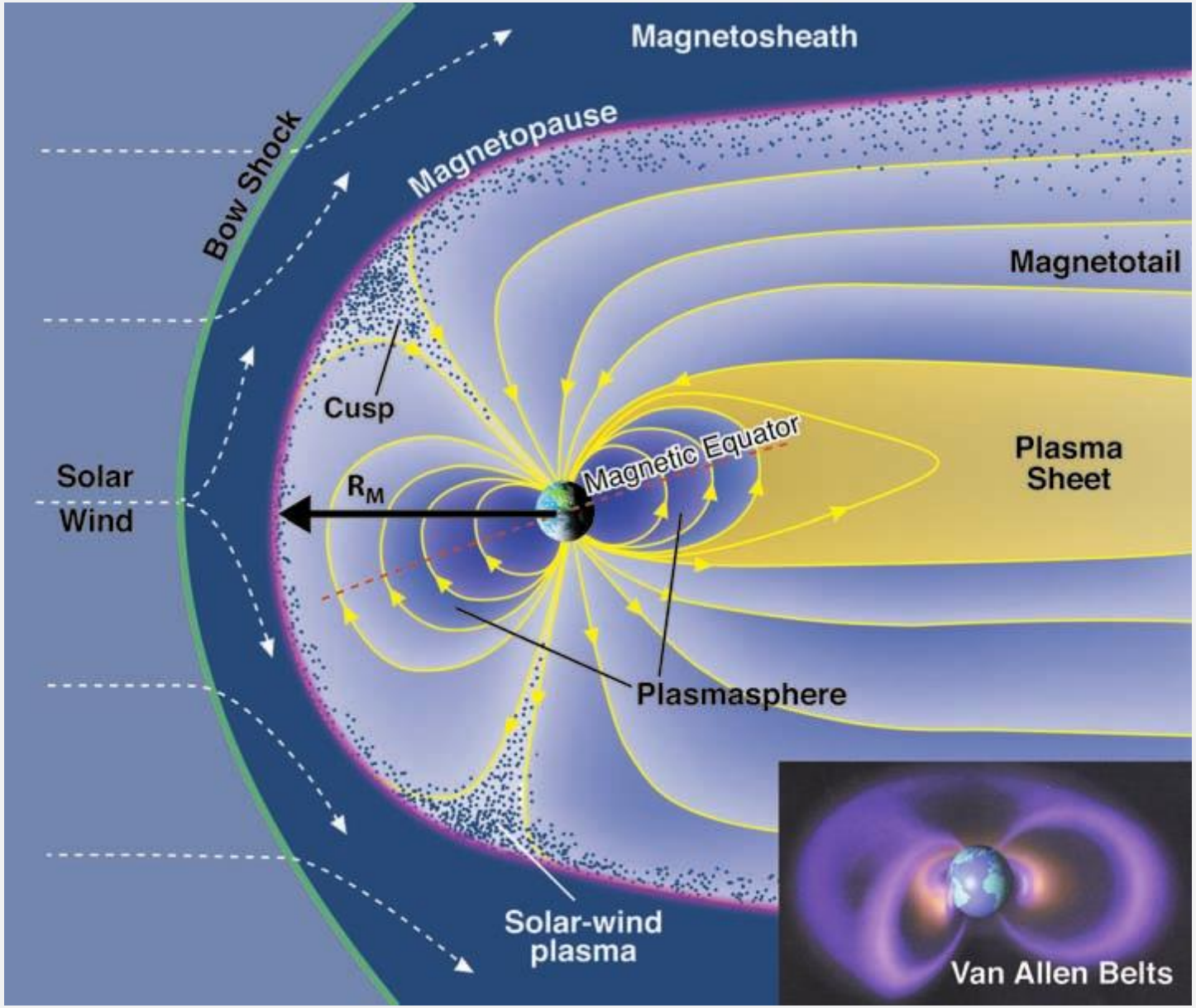
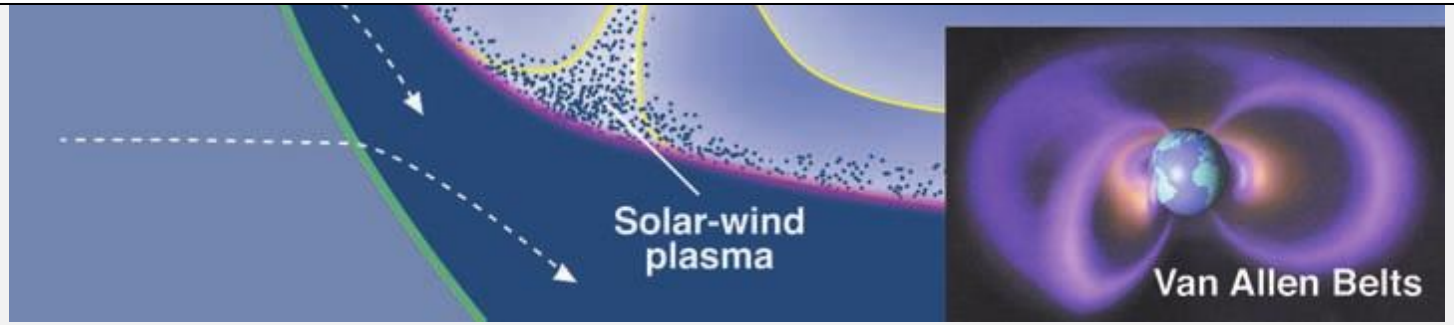


EARTH'S MAGNETOSPHERE

Lockwood (2022) Frontiers "The Joined-up Magnetosphere'



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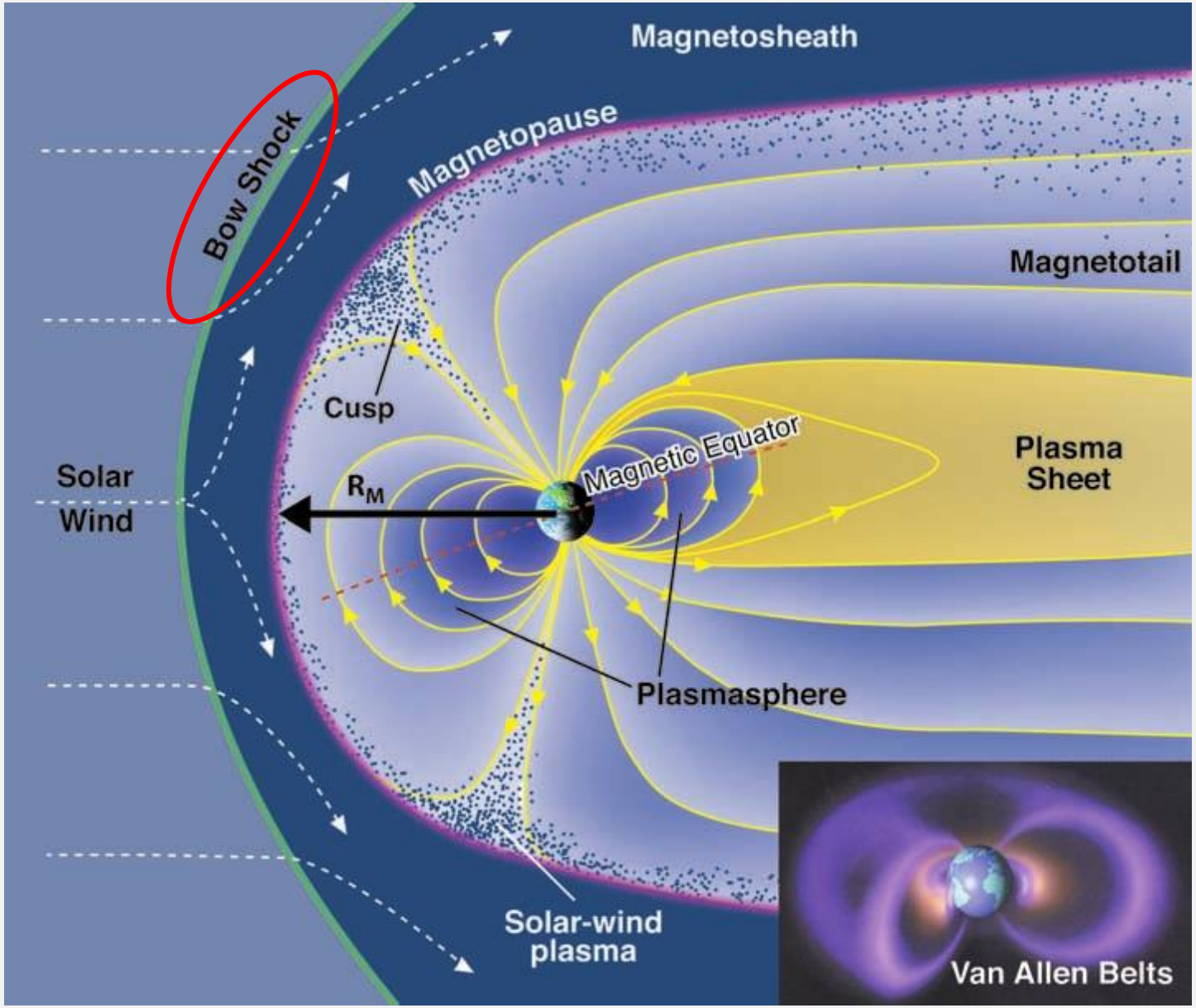
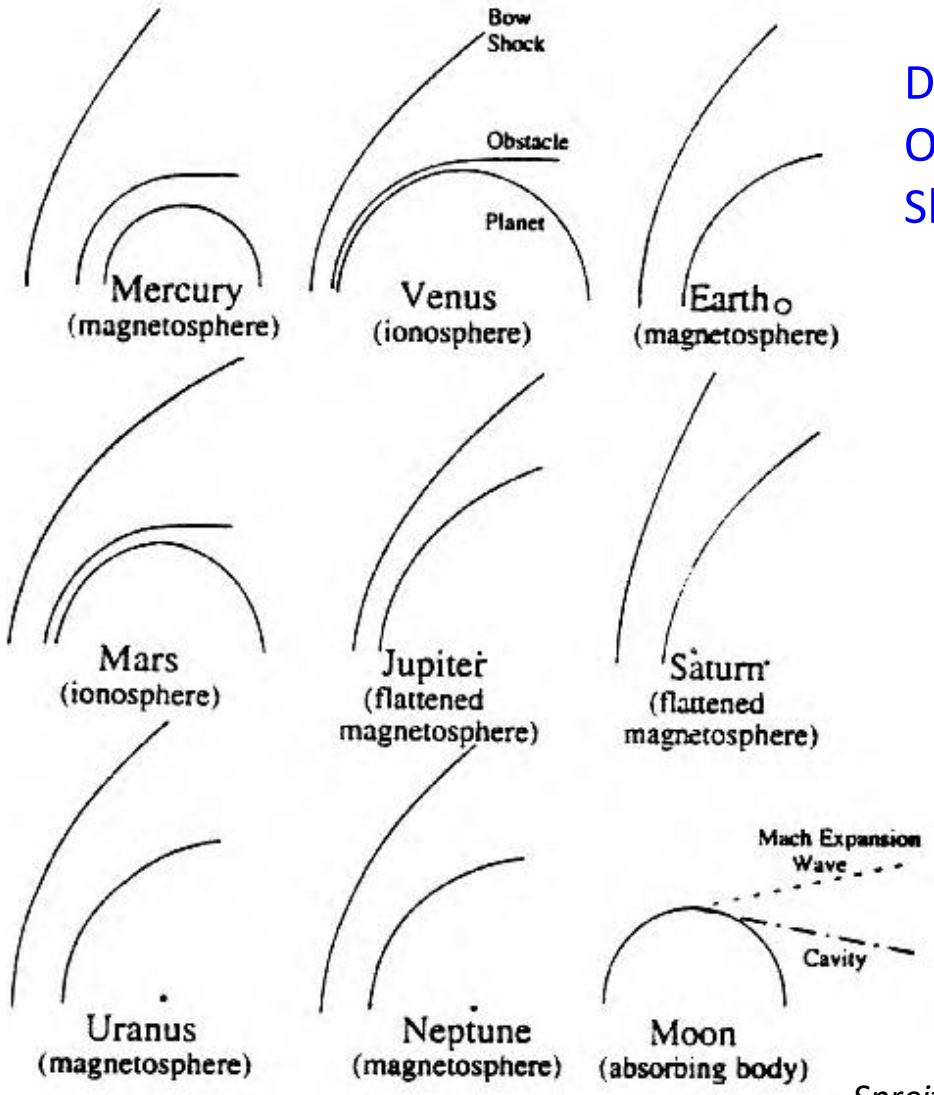


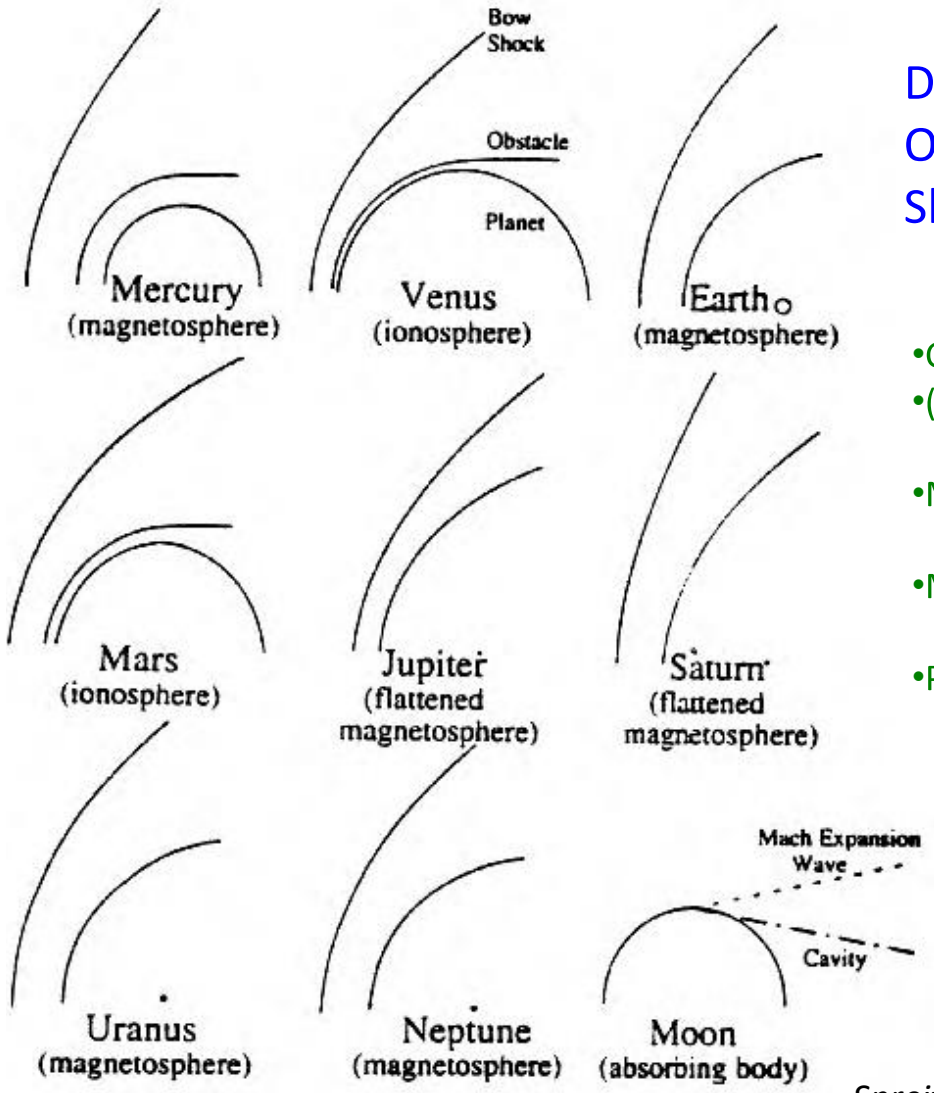
BOW SHOCK - COLLISIONLESS SHOCKS IN PLASMAS



Distance of Shock from Obstacle and Shape of Shock depends on....?

Spreiter'&'Stahara'

BOW SHOCK - COLLISIONLESS SHOCKS IN PLASMAS

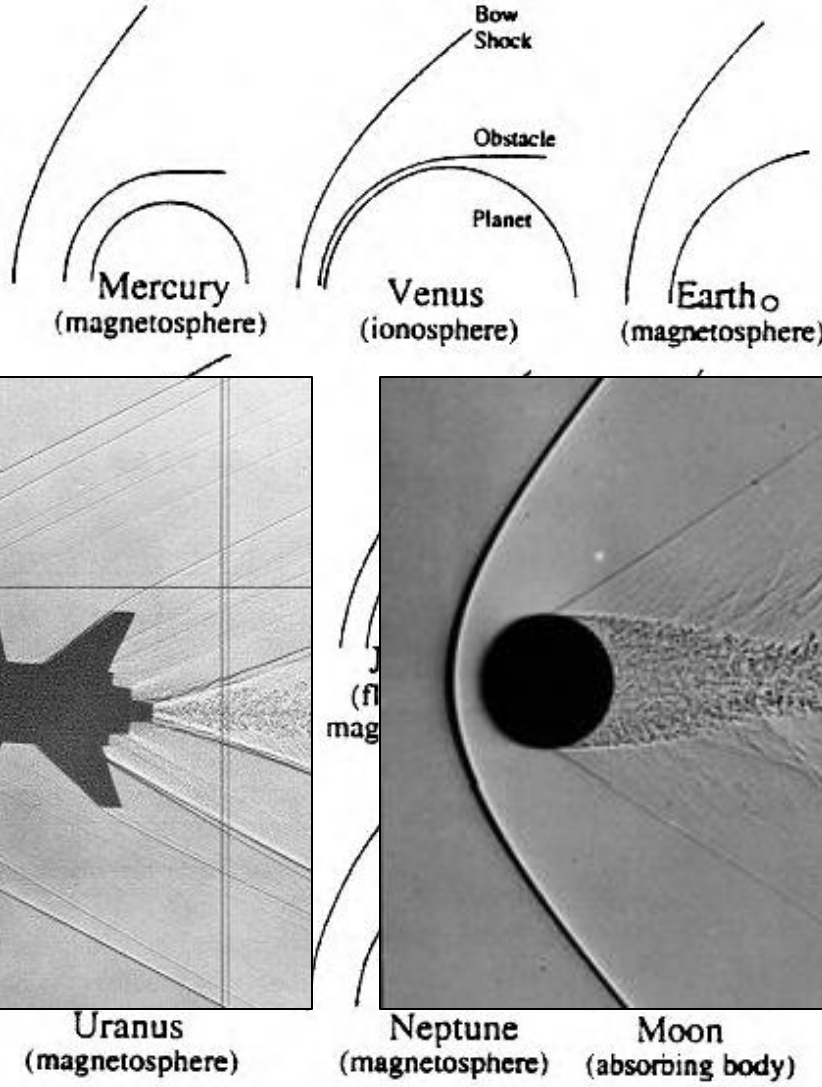


Distance of Shock from Obstacle and Shape of Shock depends on....?

- Conductance of body
- (e.g. Moon vs. Mars)
- Magnetic field of planet
- Mach number of solar wind
- Presence of escaping atmosphere

Spreiter'&'Stahara'

BOW SHOCK - COLLISIONLESS SHOCKS IN PLASMAS



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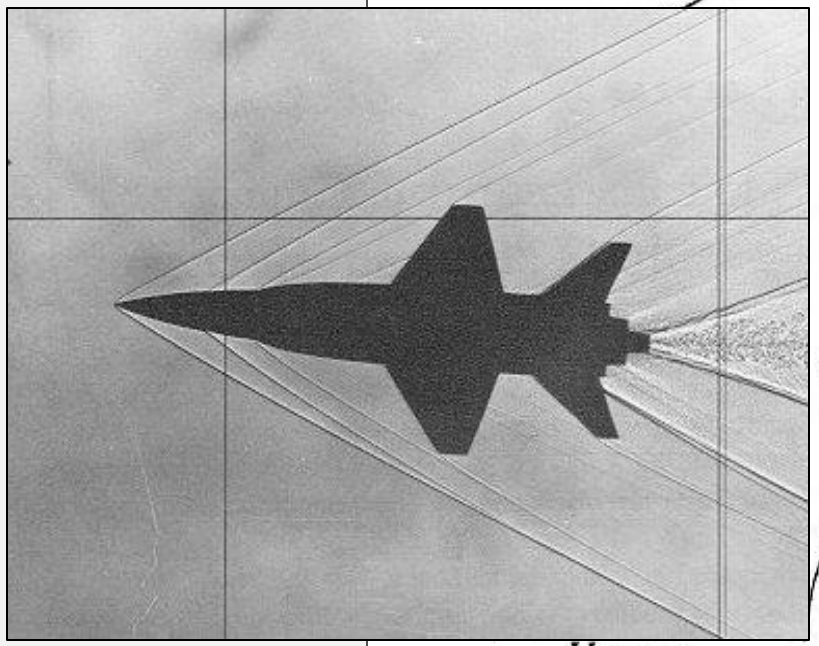
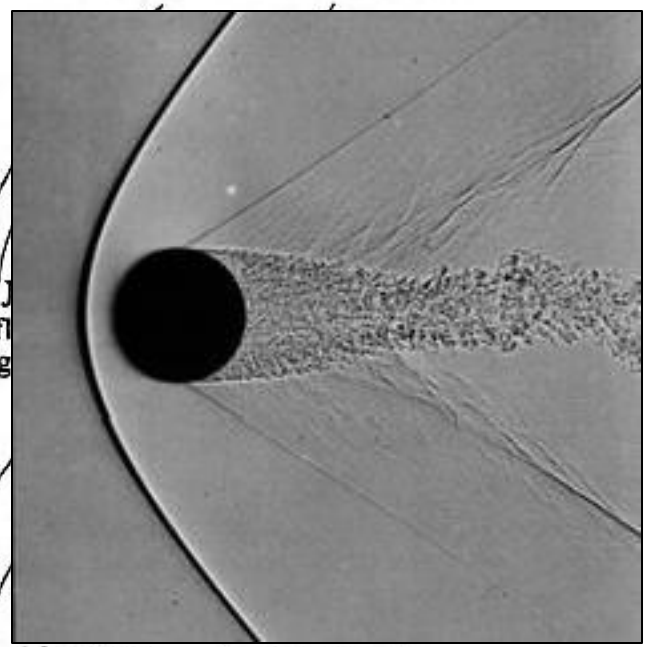
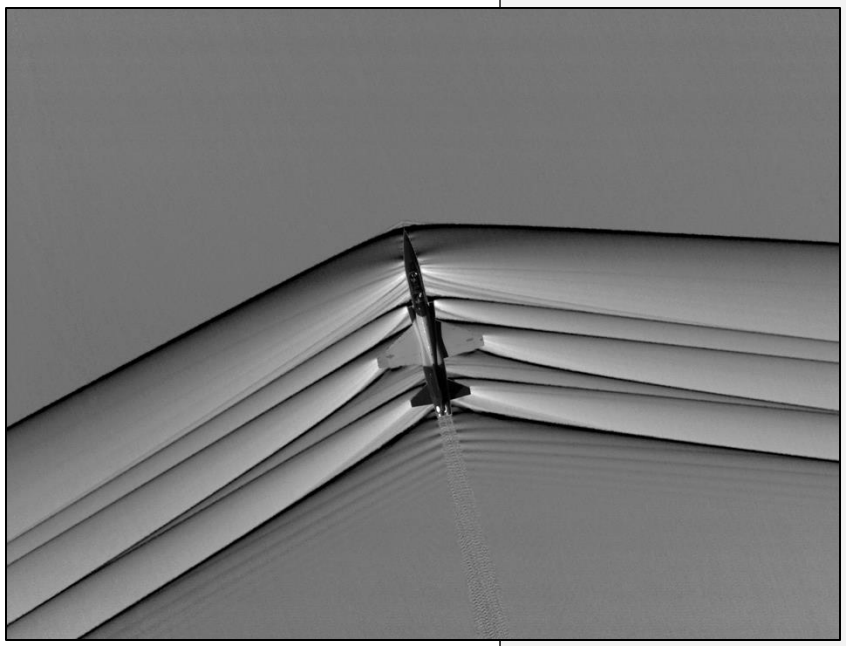




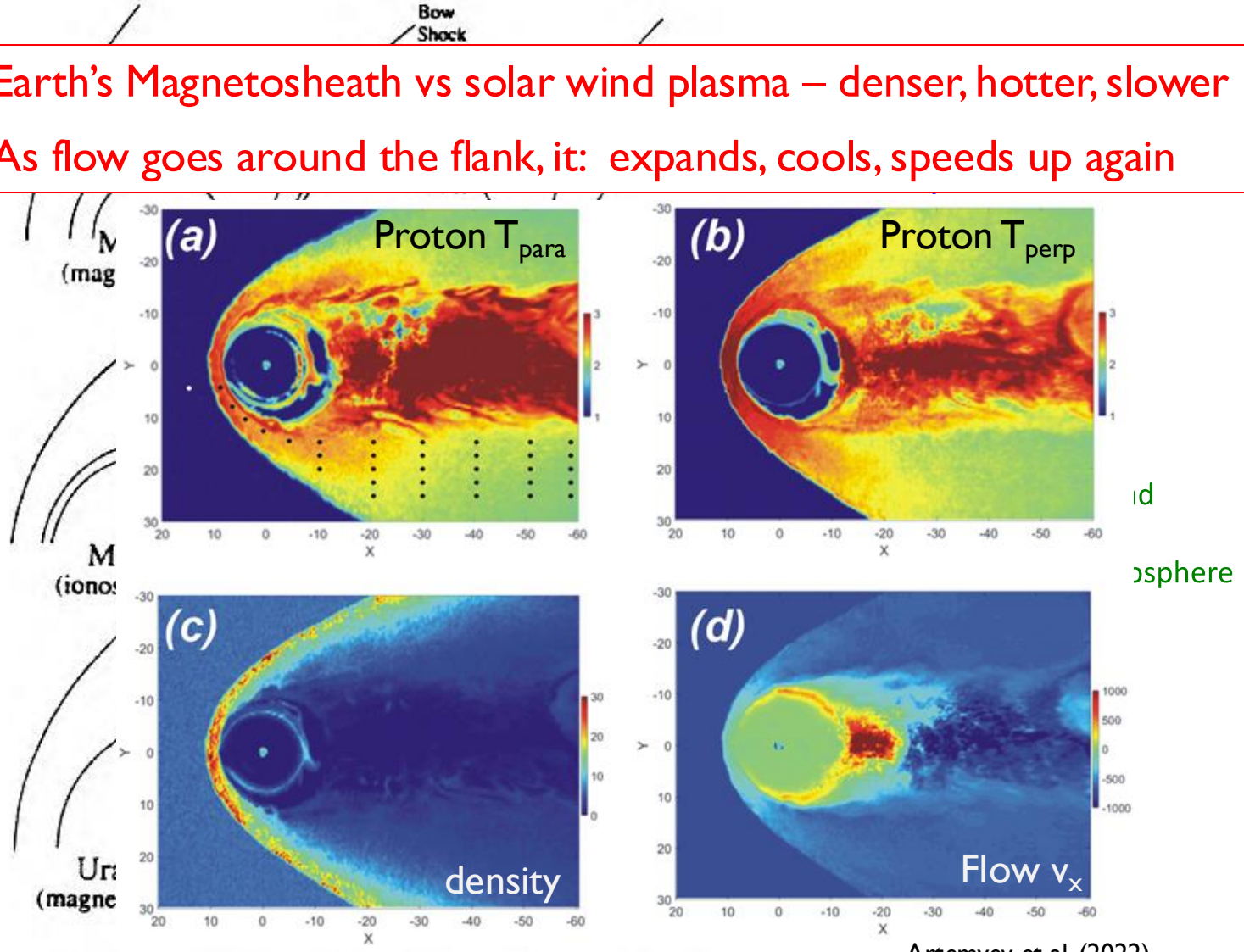


Spreiter'&'Stahara'

BOW SHOCK - COLLISIONLESS SHOCKS IN PLASMAS

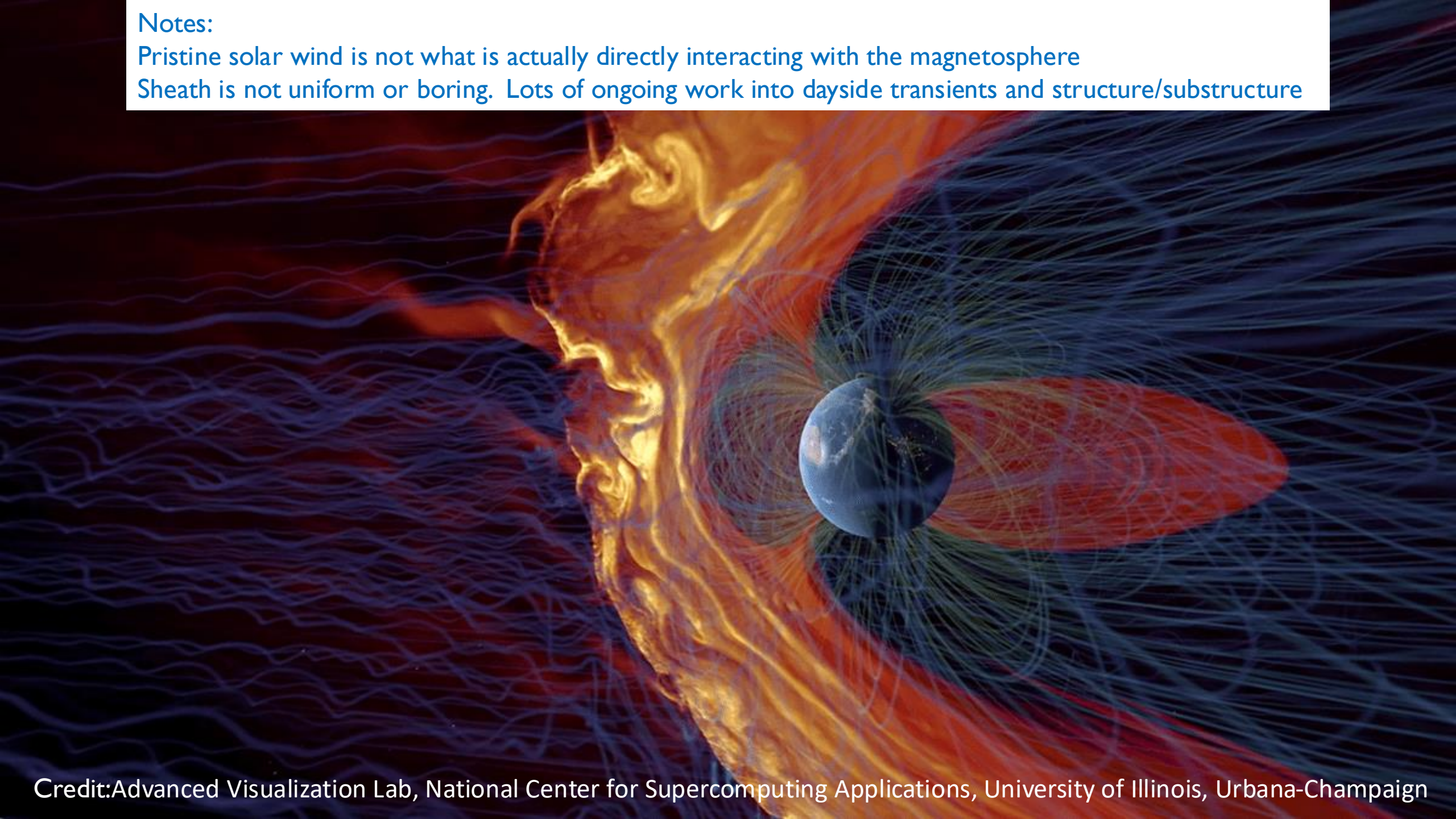
Earth's Magnetosheath vs solar wind plasma – denser, hotter, slower

As flow goes around the flank, it: expands, cools, speeds up again



Artemyev et al. (2022)

Notes:
Pristine solar wind is not what is actually directly interacting with the magnetosphere
Sheath is not uniform or boring. Lots of ongoing work into dayside transients and structure/substructure



Credit:Advanced Visualization Lab, National Center for Supercomputing Applications, University of Illinois, Urbana-Champaign

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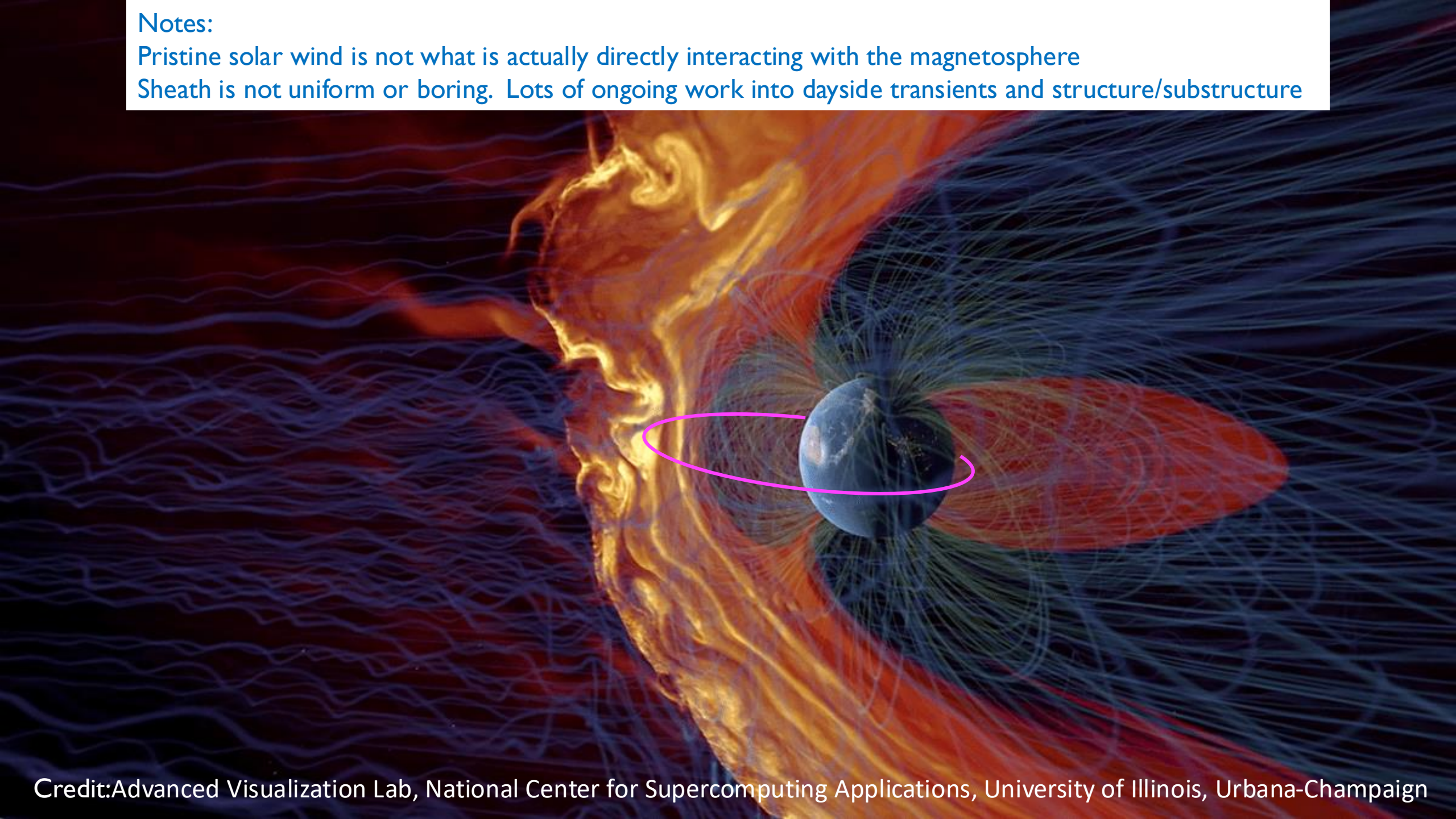

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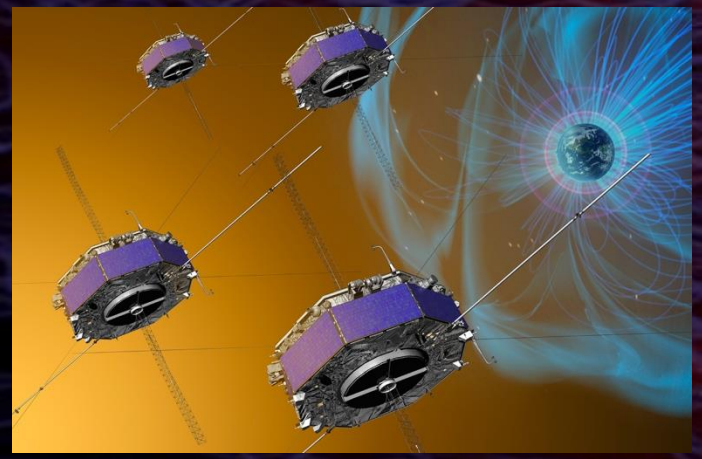
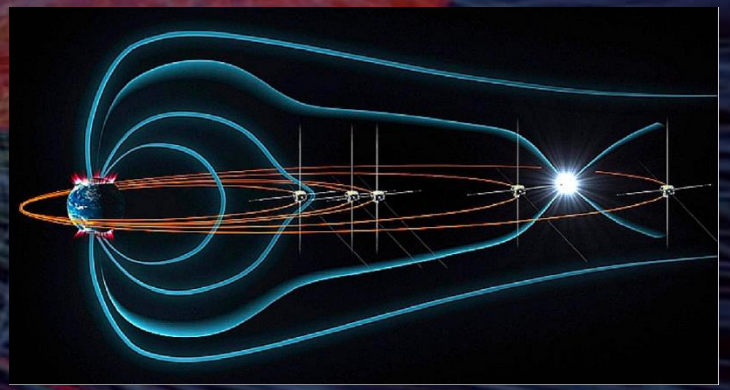


NASA's Magnetospheric Multiscale Mission (MMS)



NASA's THEMIS mission

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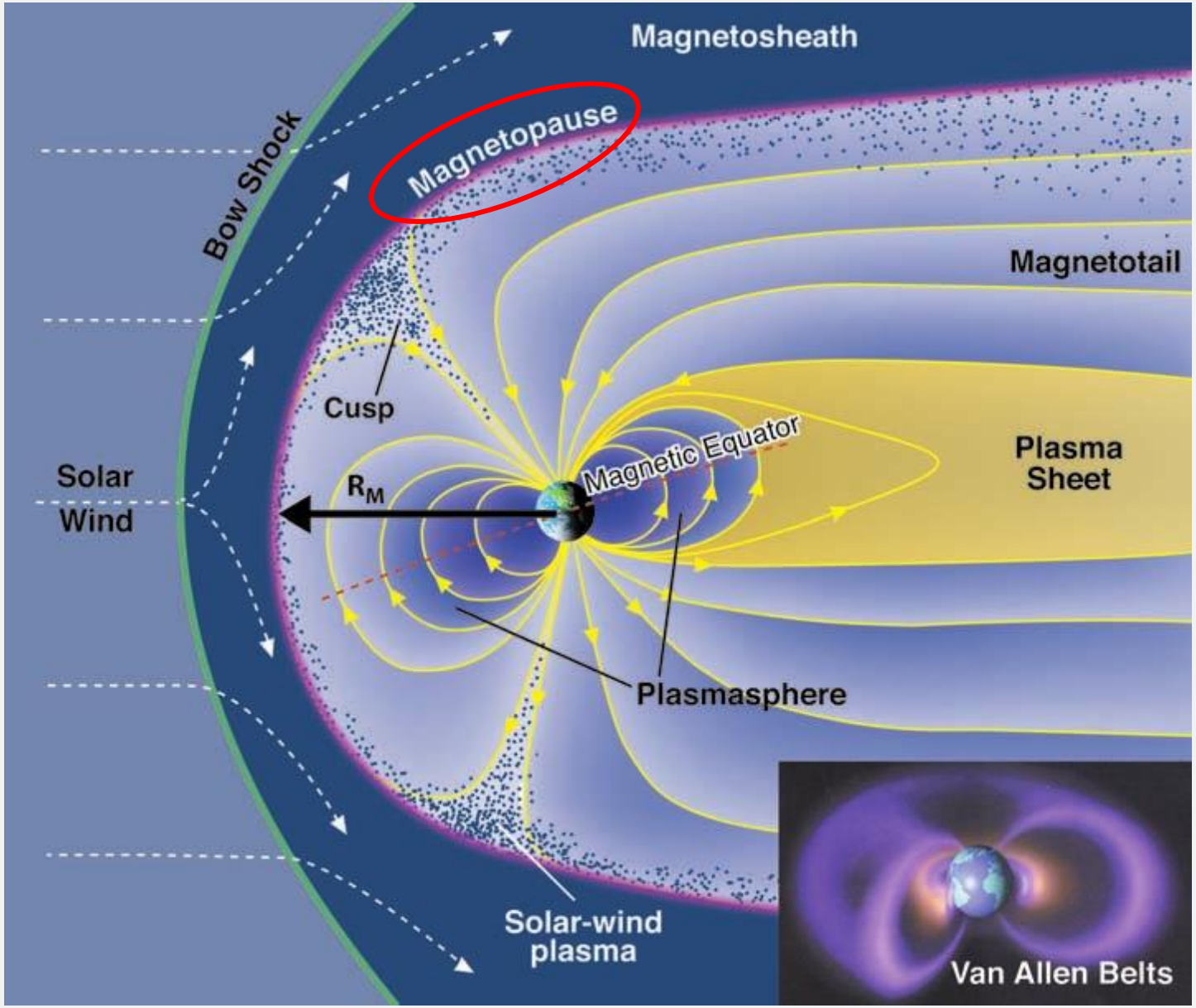
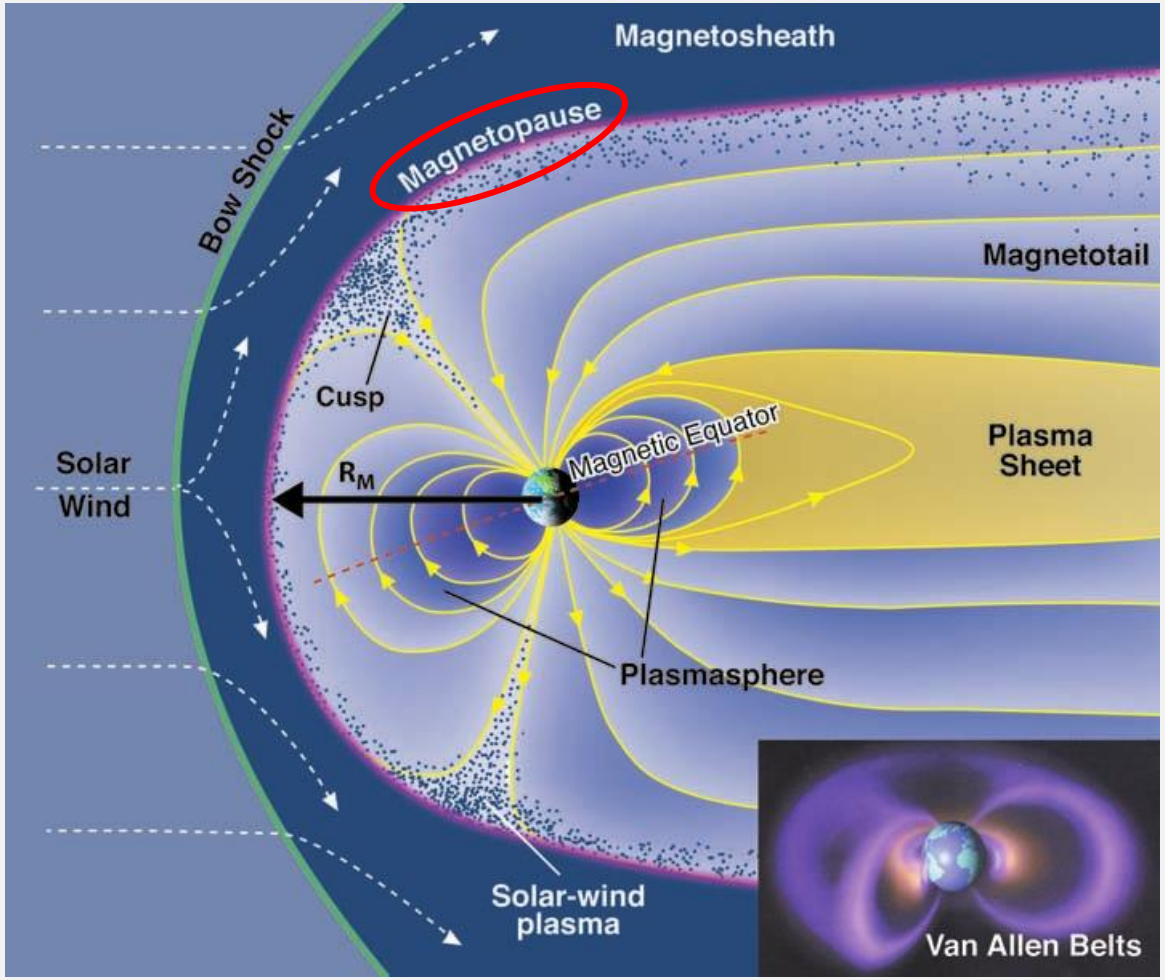
EARTH'S MAGNETOSPHERE



MAGNETOPAUSE



Total pressure P:

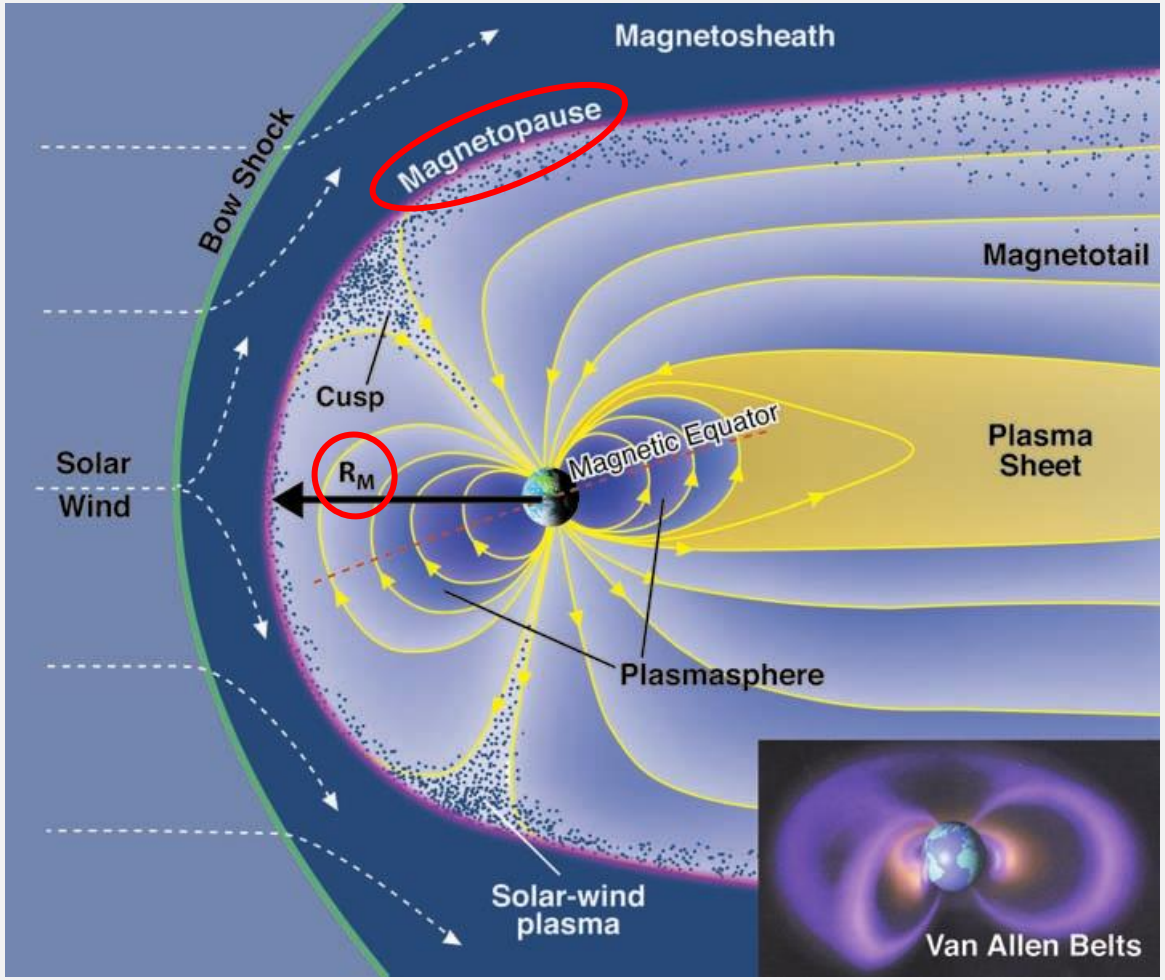
$$P = \rho u^2 + p + B^2/2\mu_o$$

Dynamic pressure

Thermal pressure

Magnetic pressure

MAGNETOPAUSE



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Dynamic pressure

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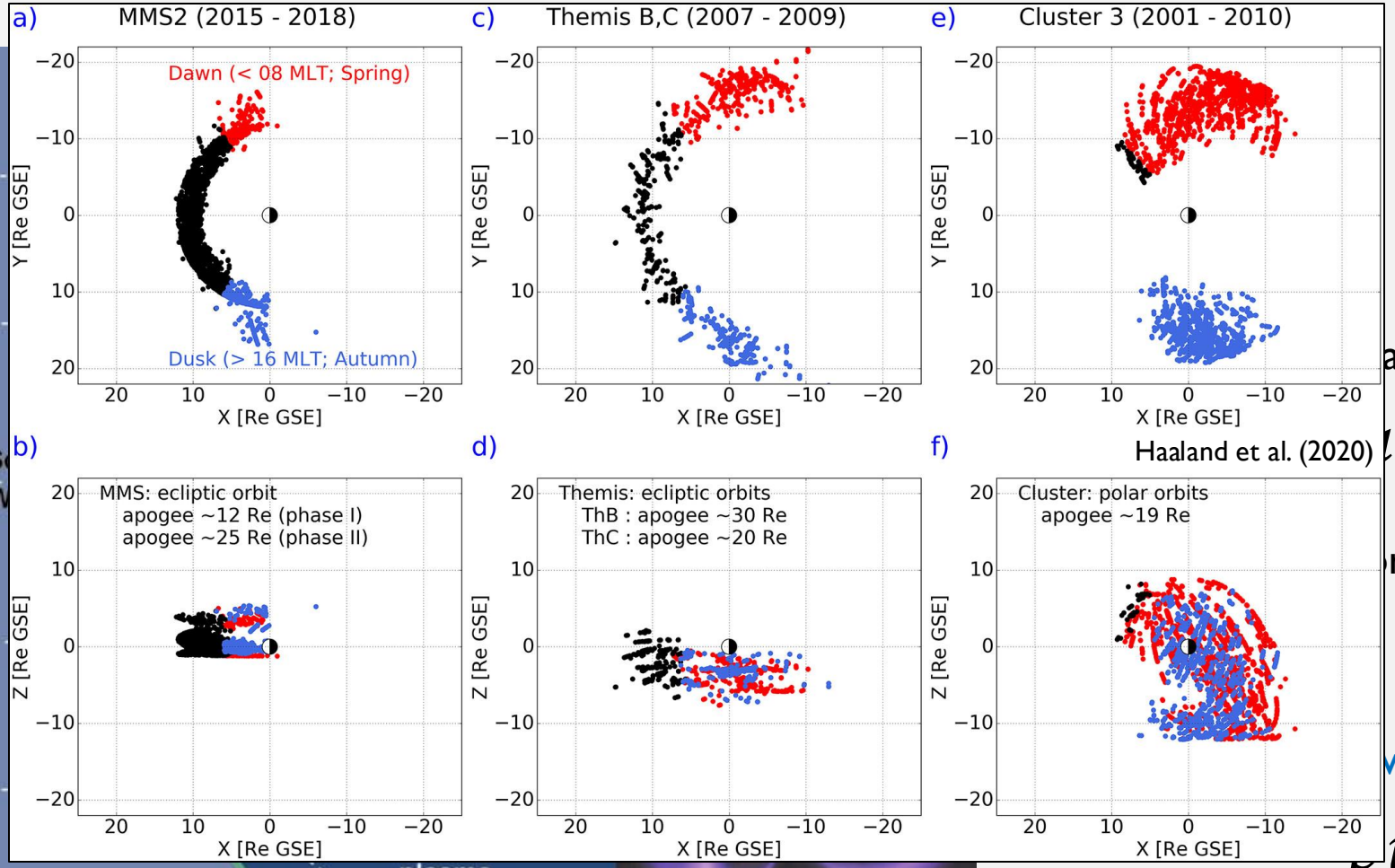
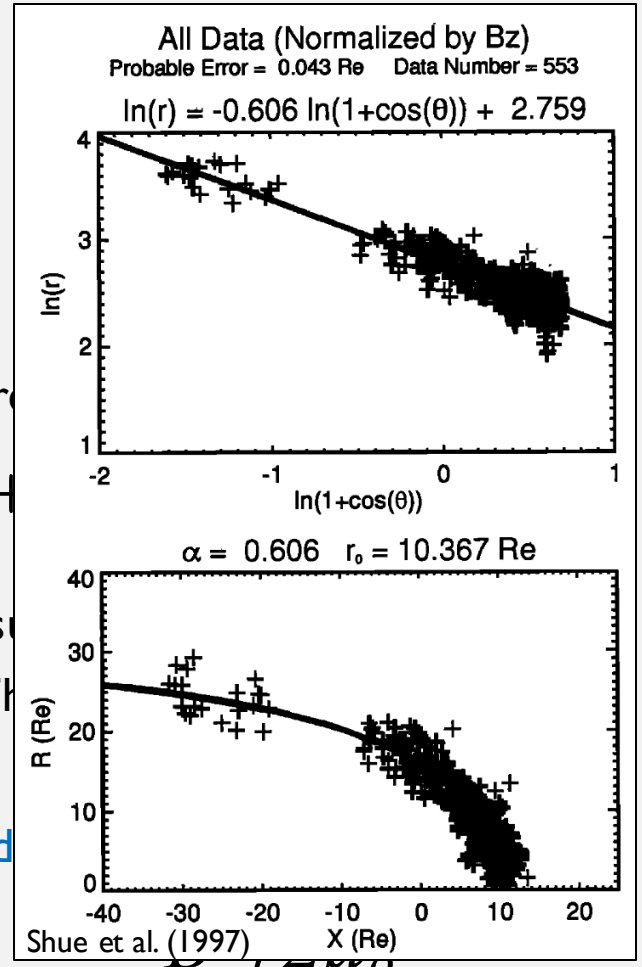
Solar wind: Earth's Magnetosphere:

$$\rho u^2 \sim B^2/2\mu_o$$

How do we know this?

MAGNETOPAUSE



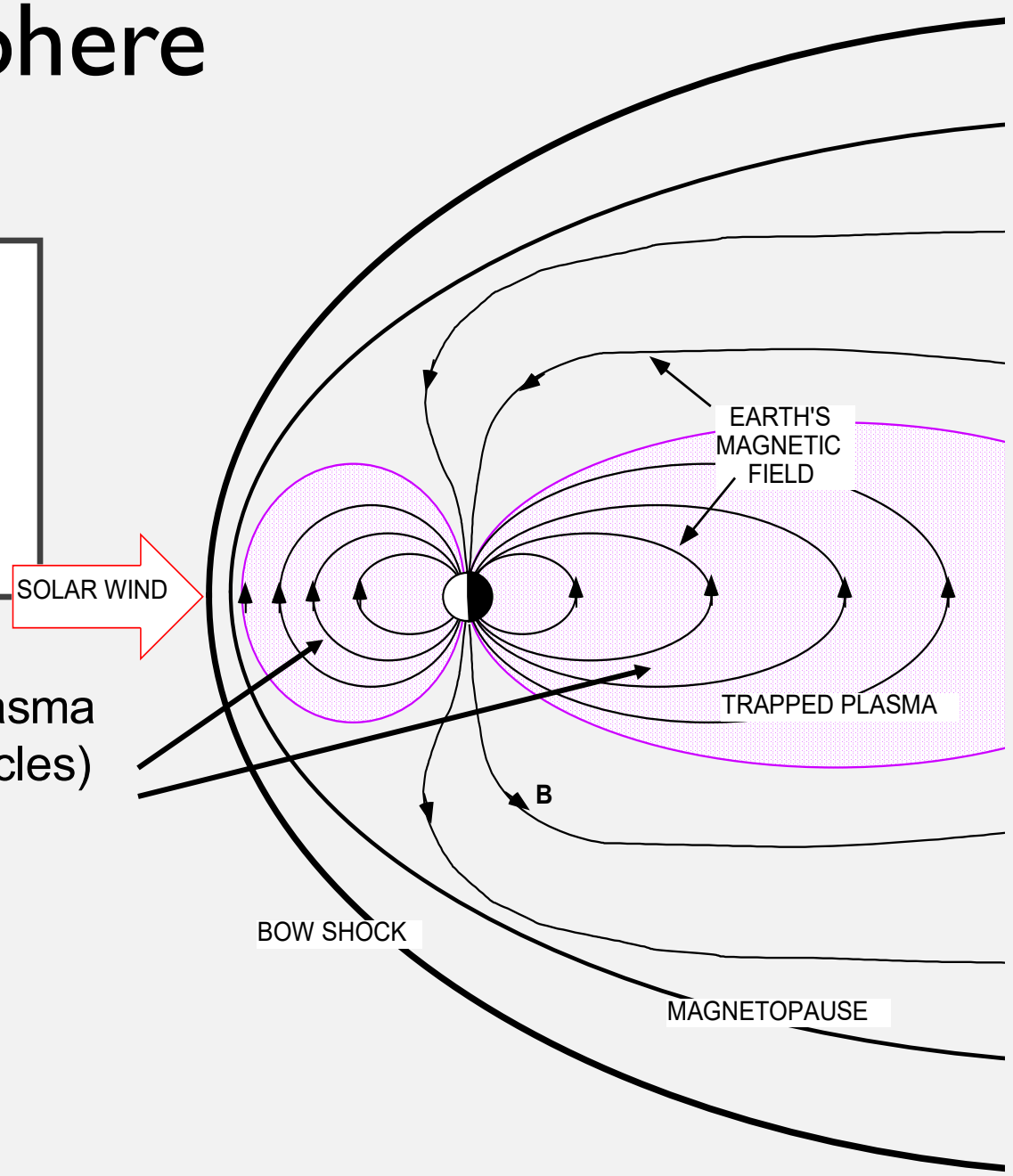


How do we know this?

Earth's Magnetosphere

THE BUBBLE ISN'T EMPTY

Charged particles (plasma and high-energy particles) are trapped in the magnetosphere



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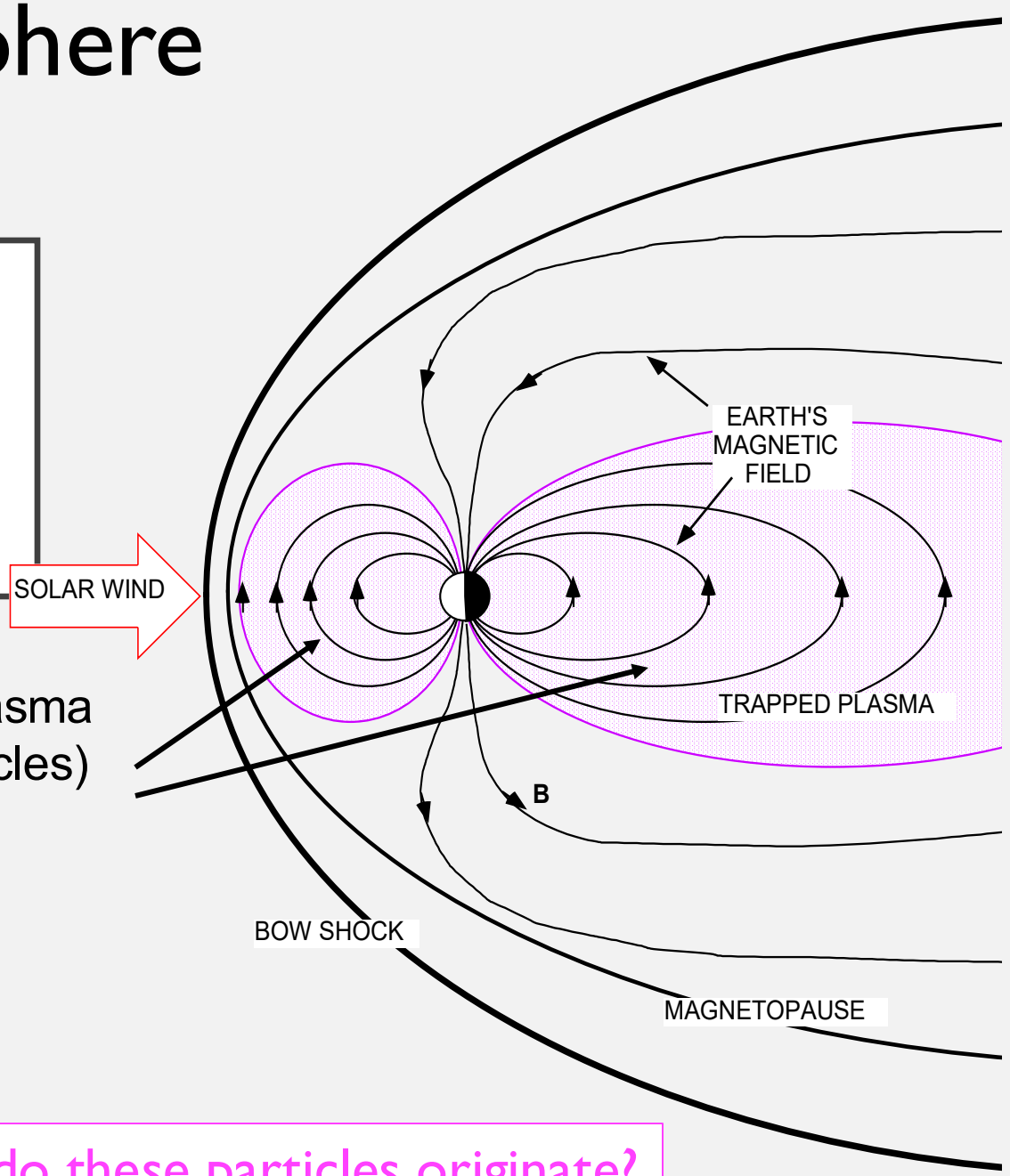


Charged particles (plasma and high-energy particles) are trapped in the magnetosphere

Where do these particles originate?

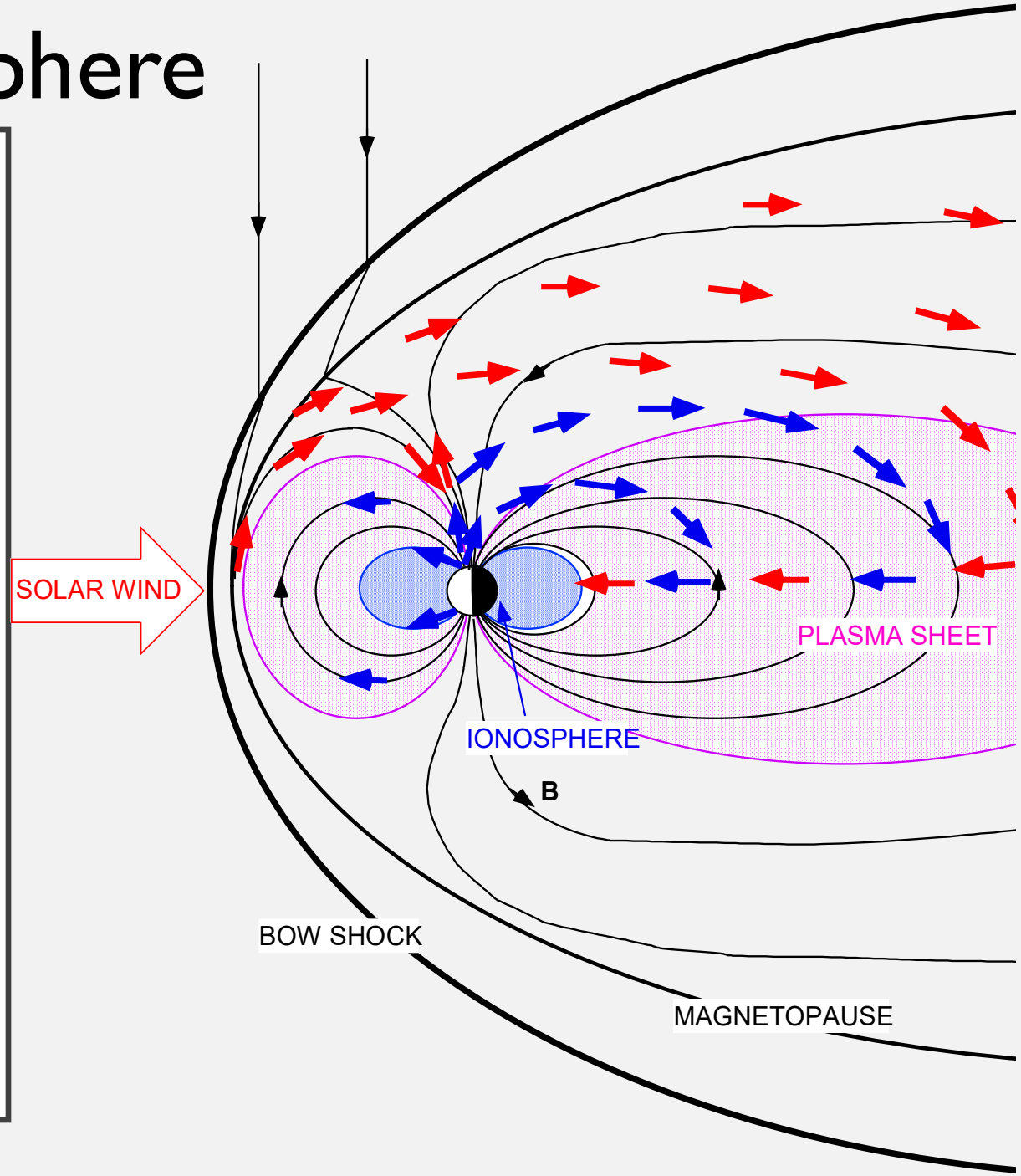
Earth's Magnetosphere

PARTICLE SOURCES:

THE EARTH'S UPPER ATMOSPHERE (RELATIVE IMPORTANCE IS ACTIVELY DEBATED.)

AND

THE SOLAR WIND (HOW? IS ACTIVELY DEBATED.)



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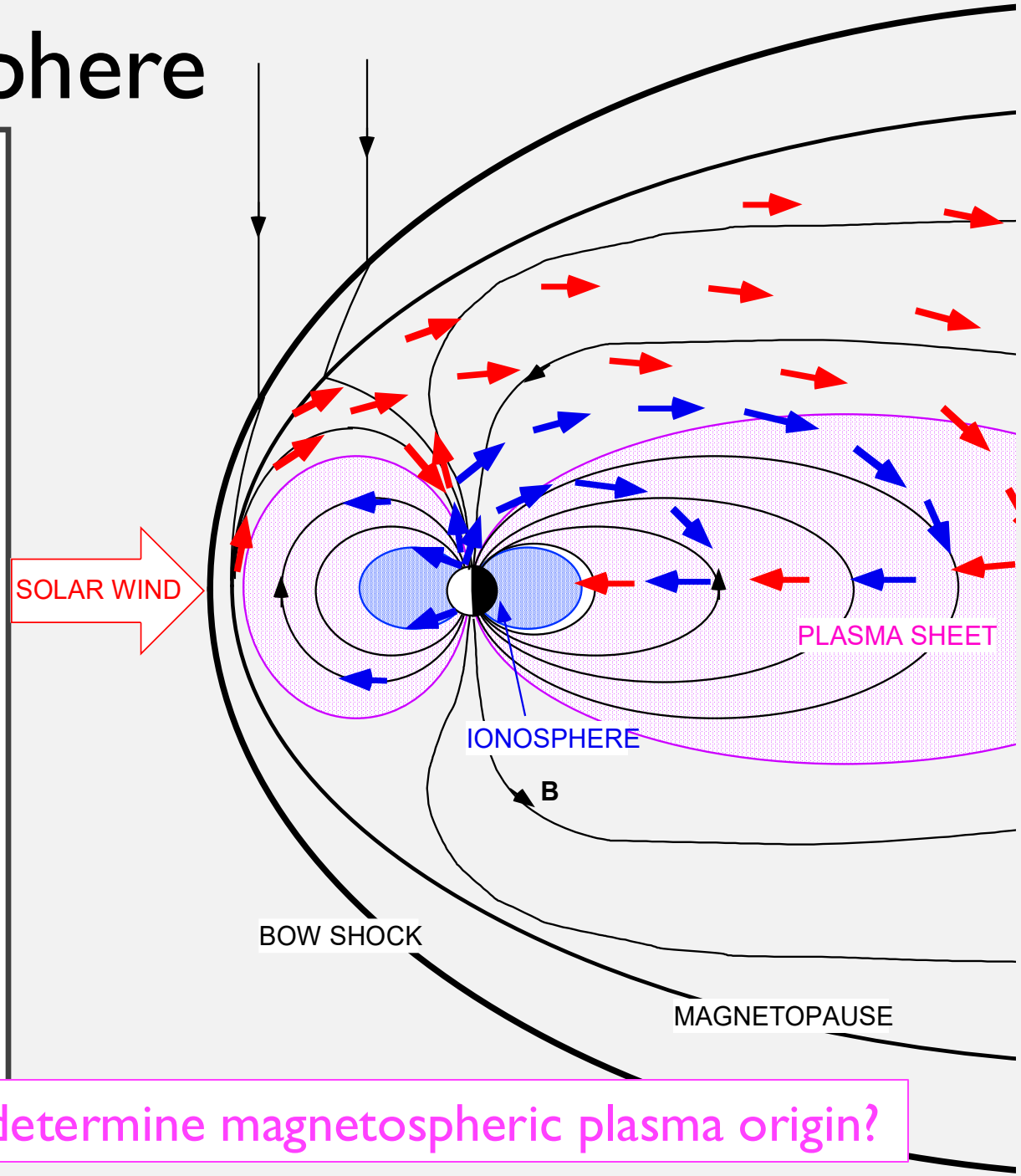
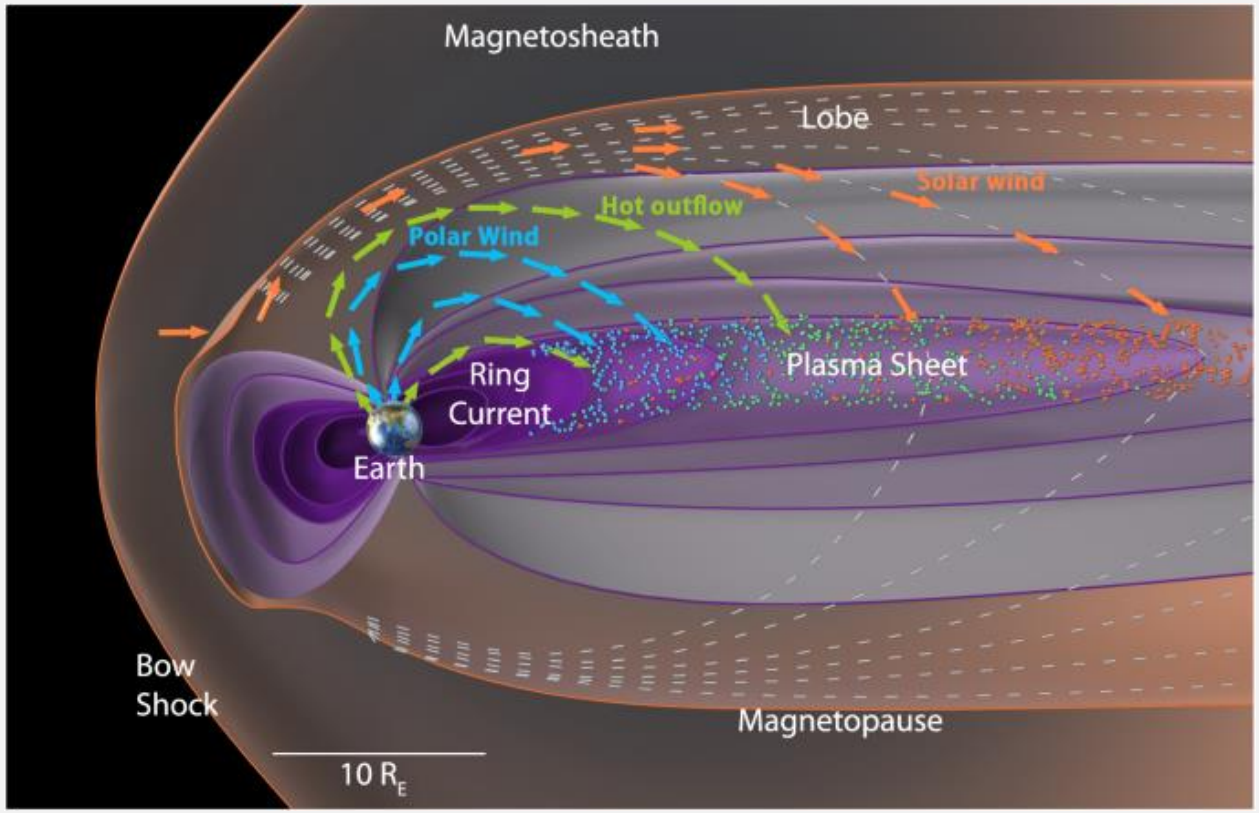
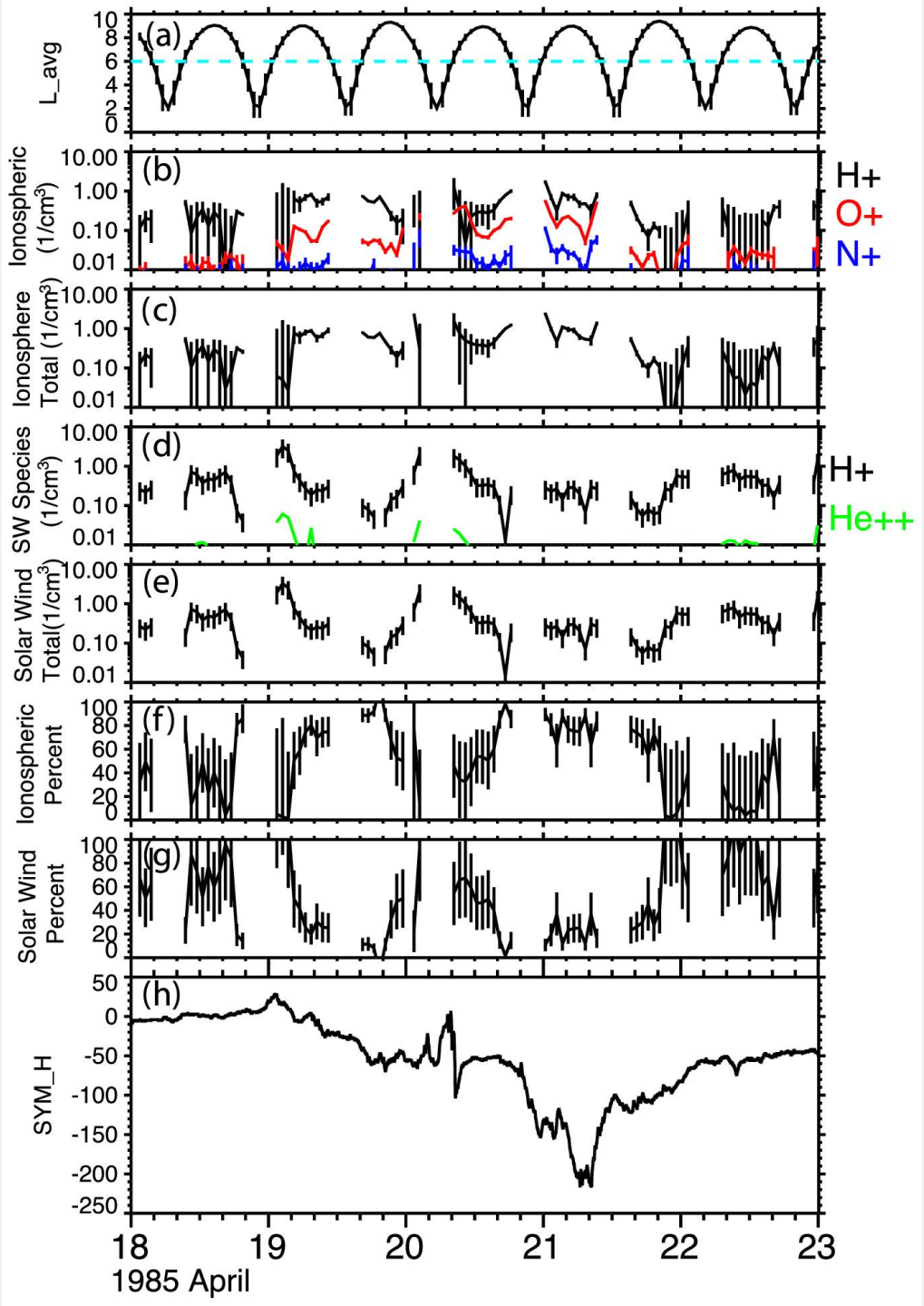


How do we determine magnetospheric plasma origin?

HOW DO WE KNOW THIS?



Kistler et al. (2023, 2020)



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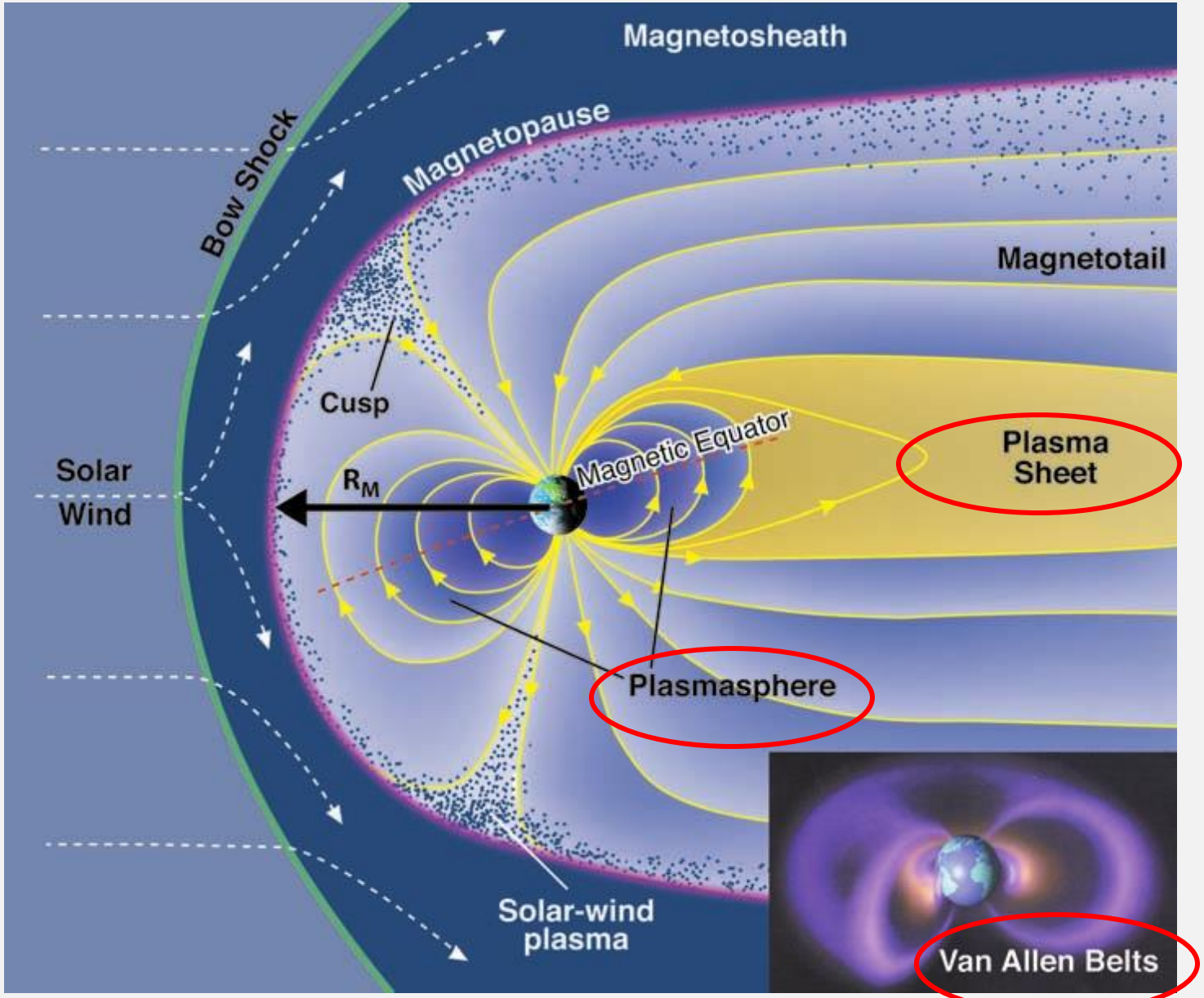
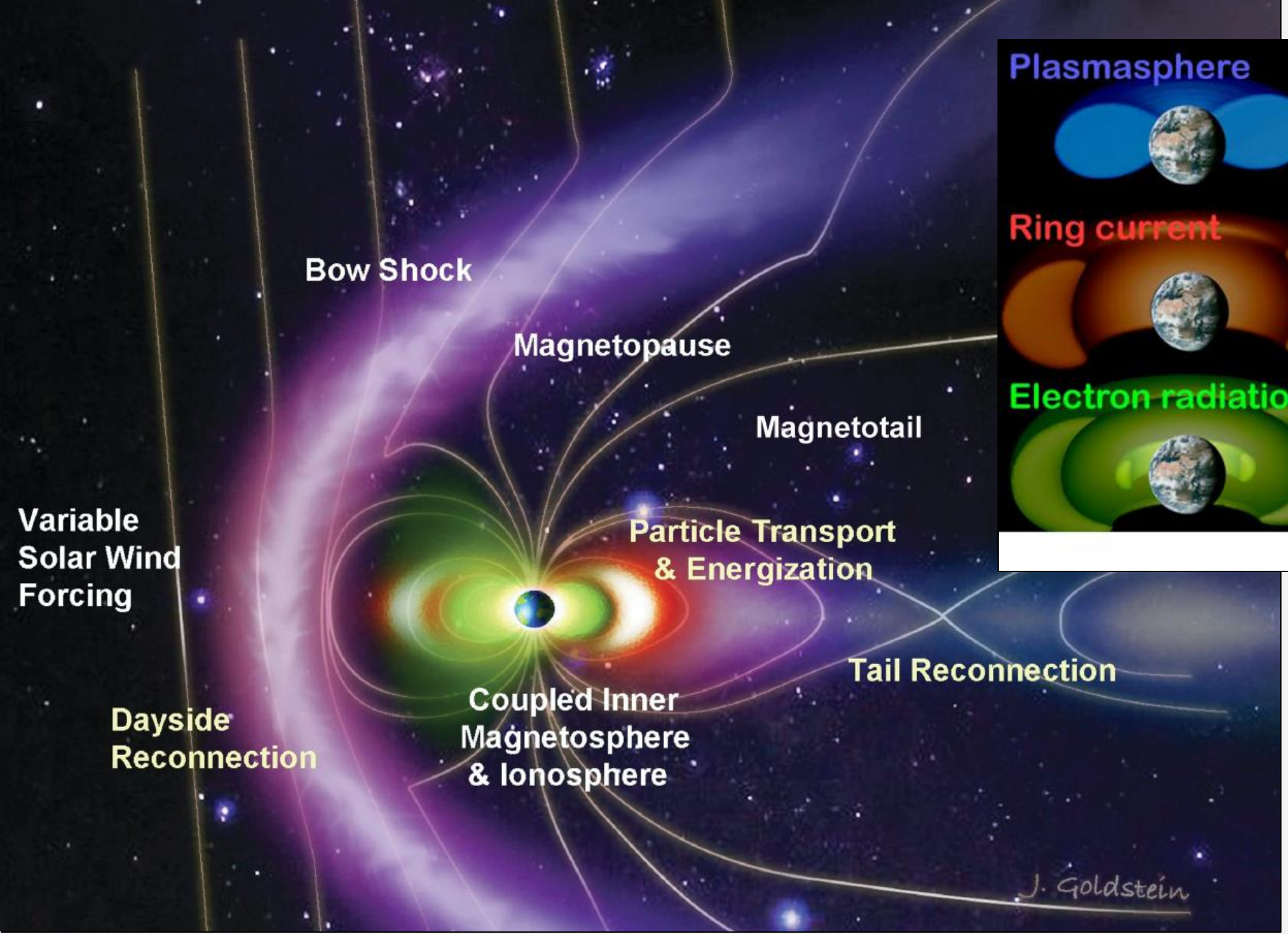
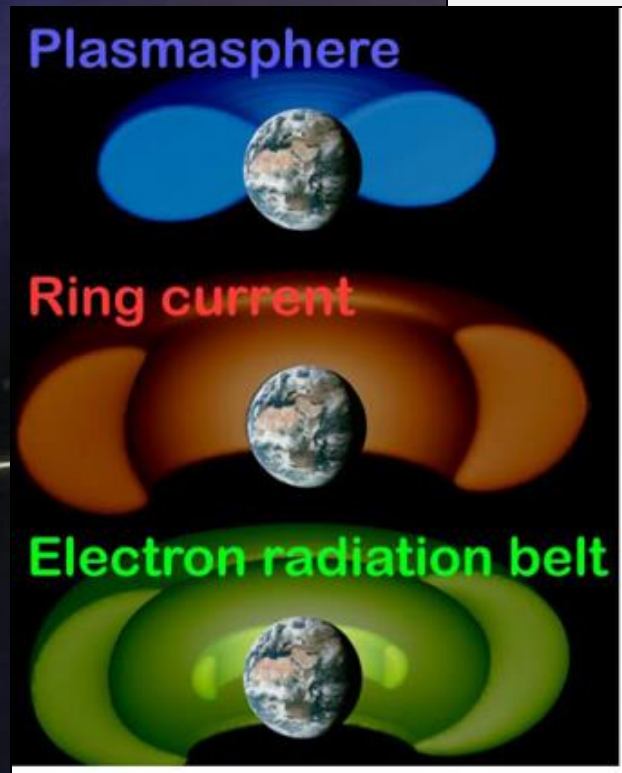




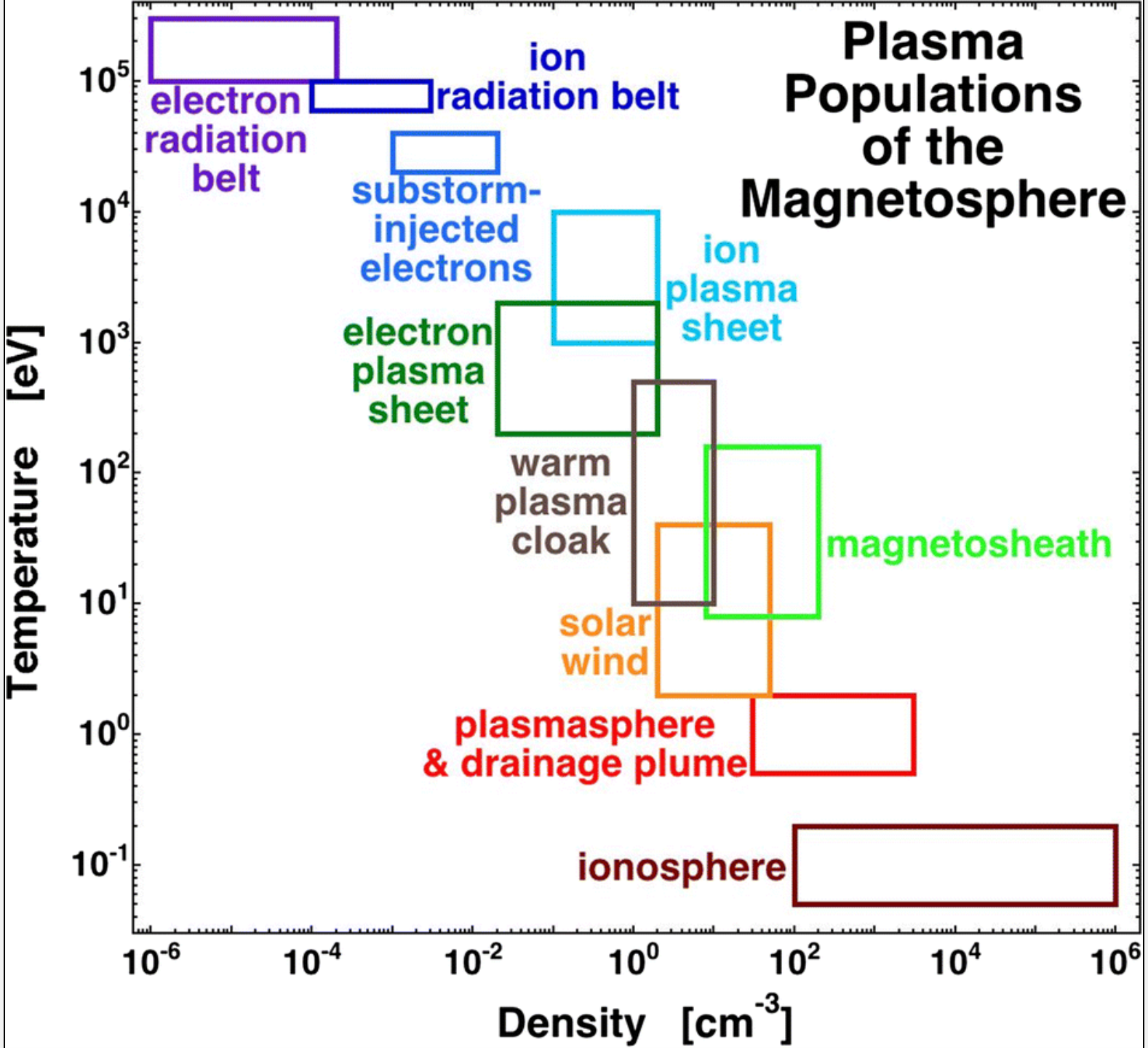


Energy: a few eV

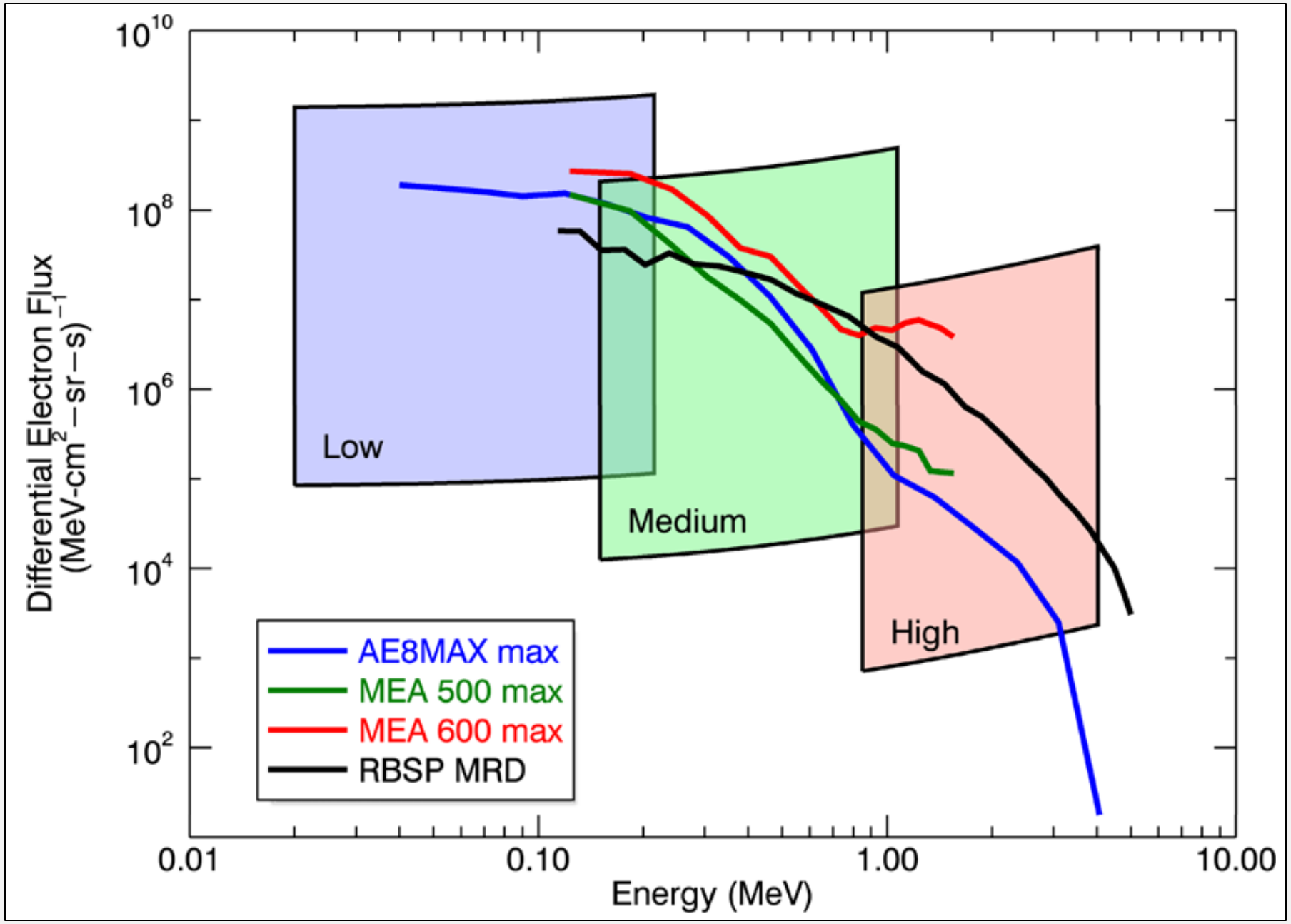
Energy: 10-100 keV

Energy: ~1MeV

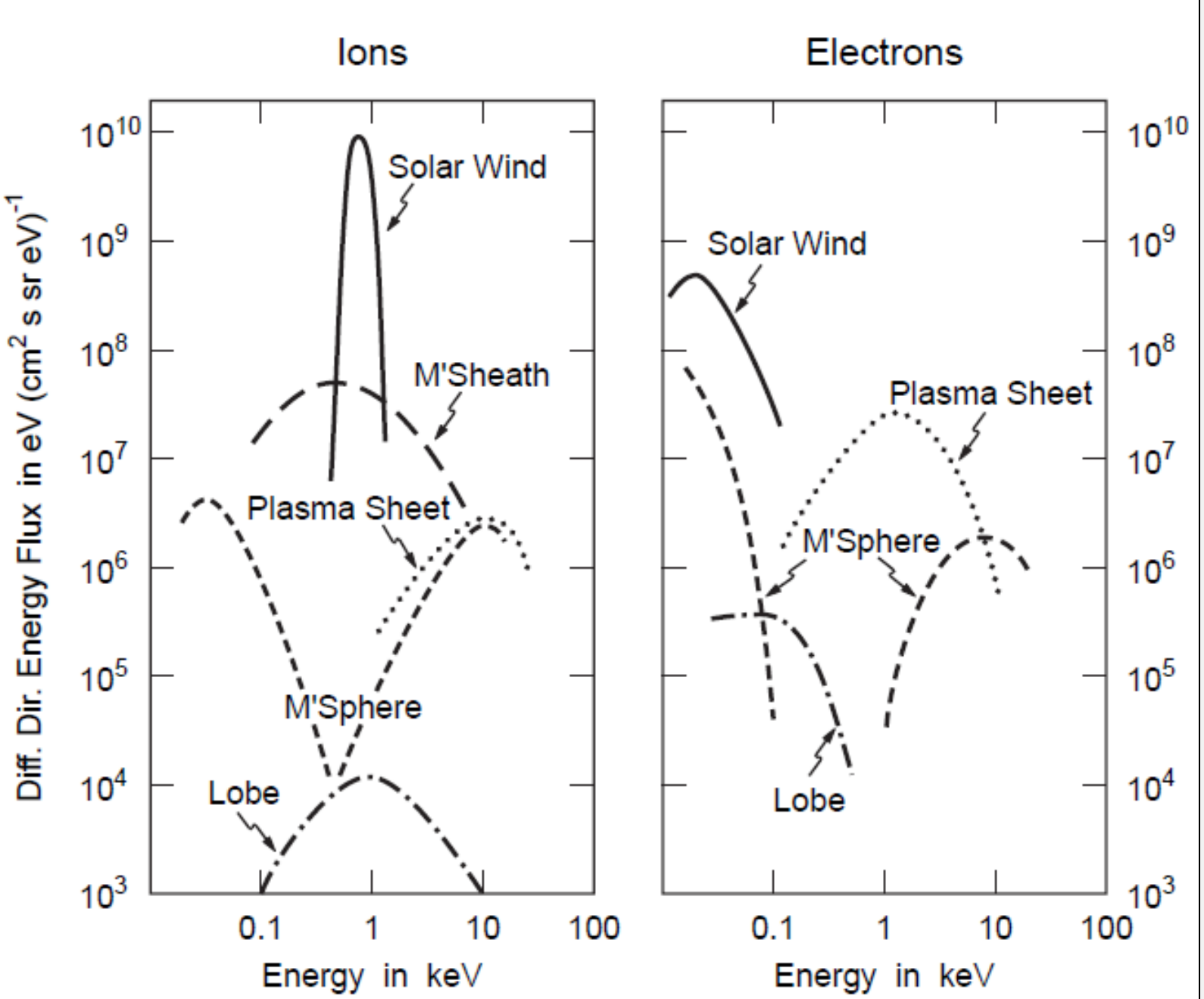
[Ebihara and Miyoshi, 2011]



Borovsky and Valdivia (2018)

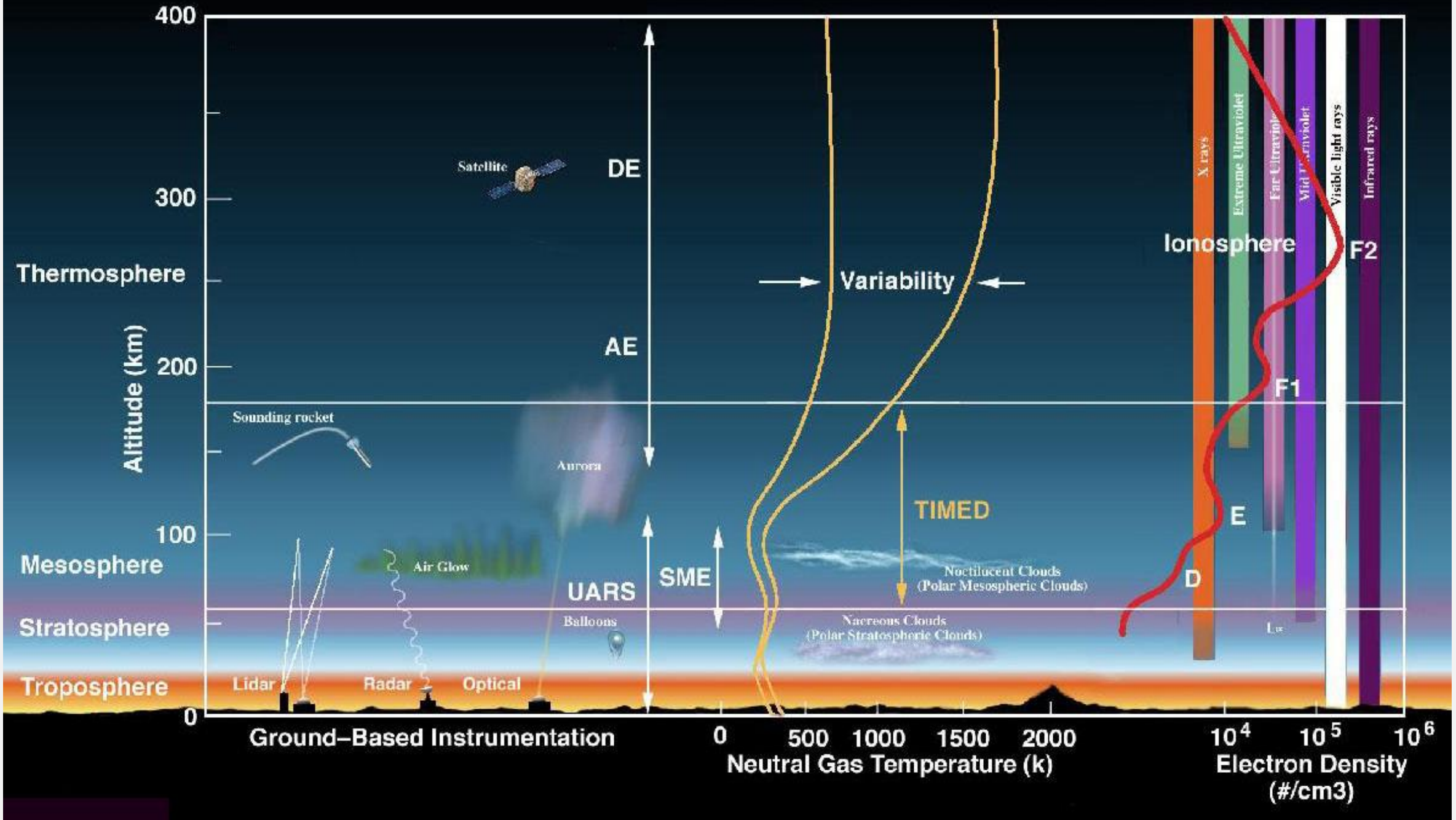


Blake et al. (2013)



[From Wuest et al., 2007; Cluster mission proposal]

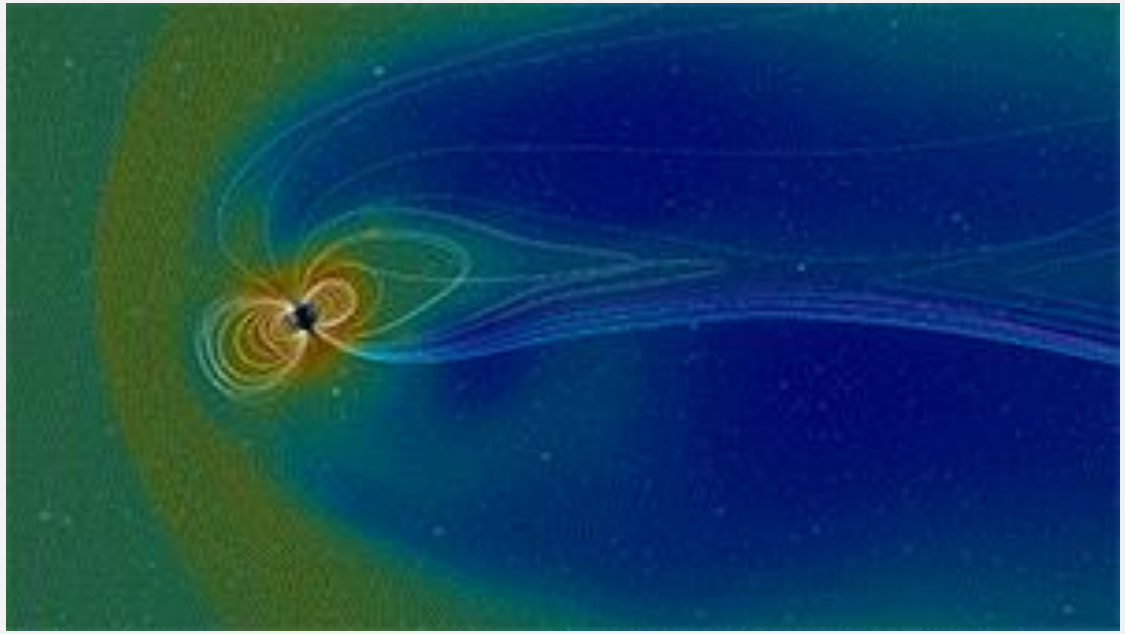
The Atmosphere and Ionosphere



PAUSE… QUESTIONS?

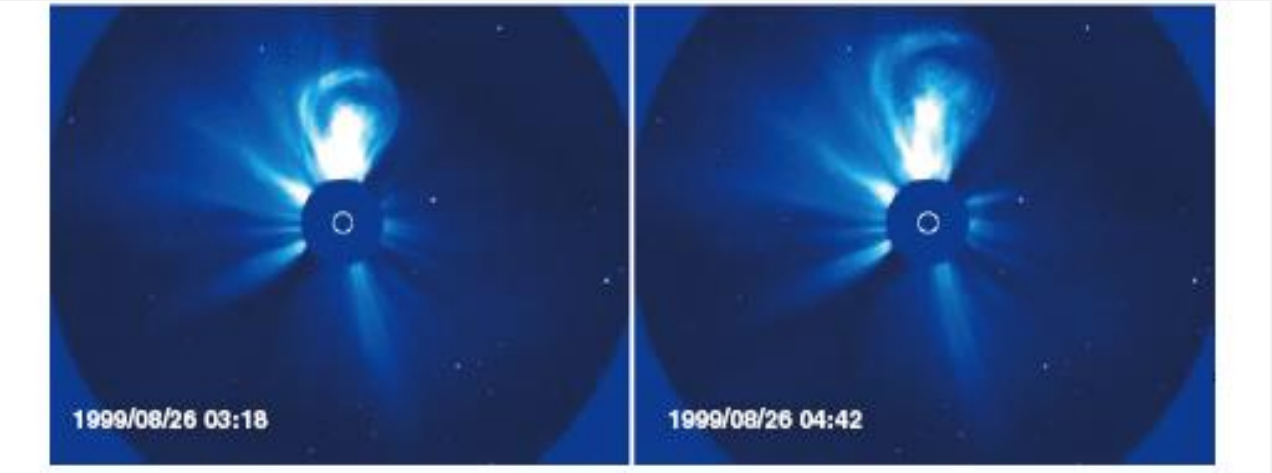
MAGNETOSPHERIC DYNAMICS

- Particle populations ranging from eV to MeV
- Waves from mHz to kHz
- System responds on timescales of seconds to years

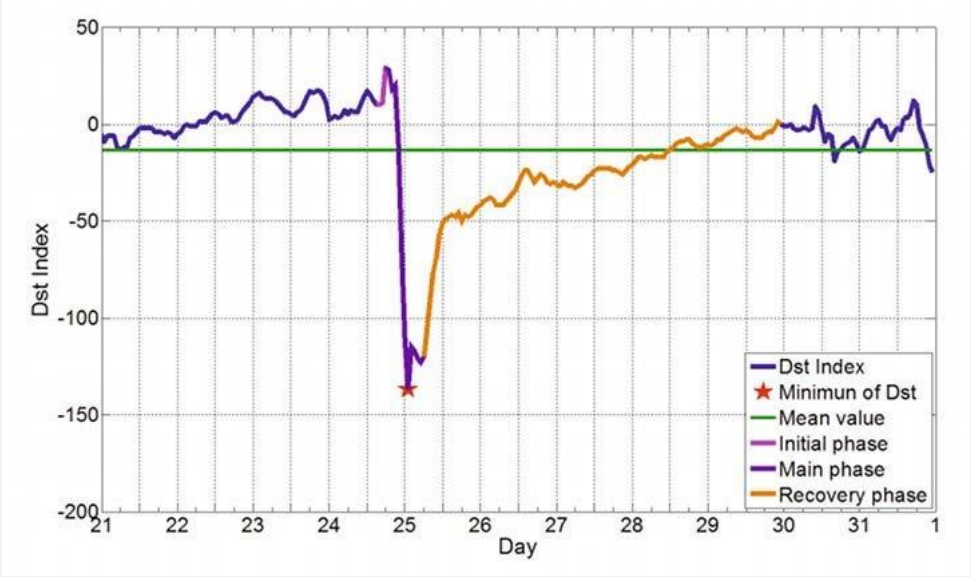


Geomagnetic Activity

Geomagnetic Storms: Temporary (~days) global disturbances of the Earth's magnetosphere caused by conditions in the solar wind



Substorms: Temporary (~hours) more frequent and localized disturbances



Geomagnetic Activity

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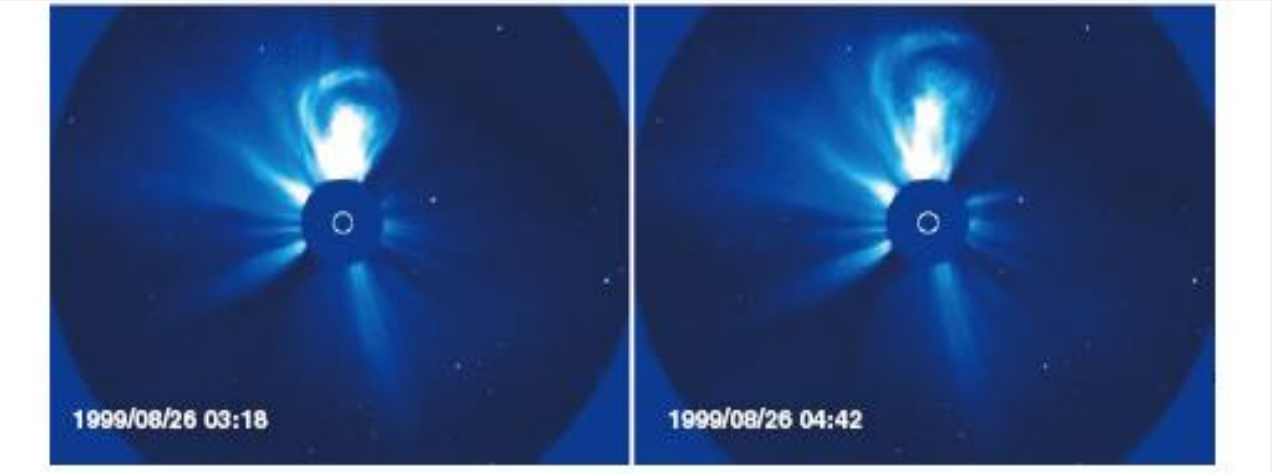
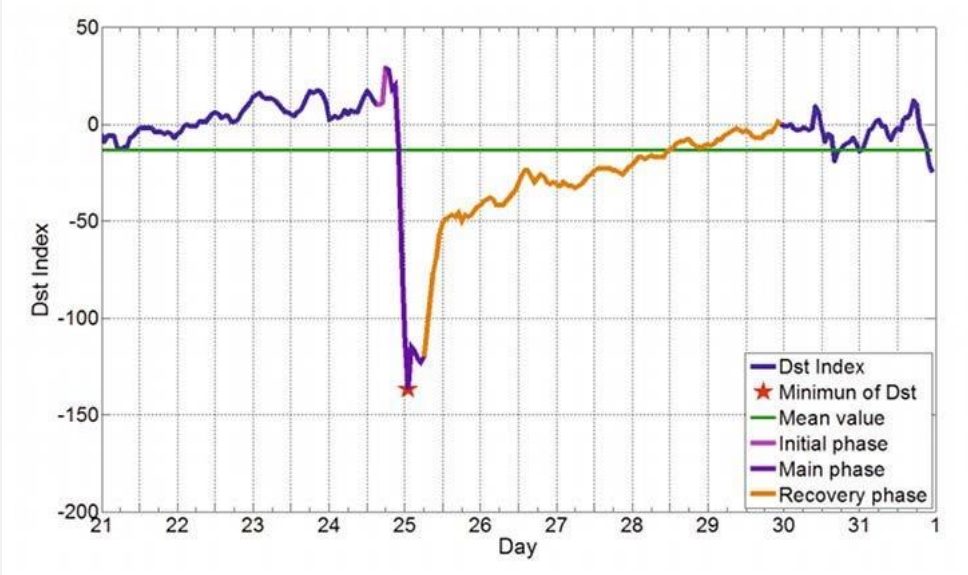


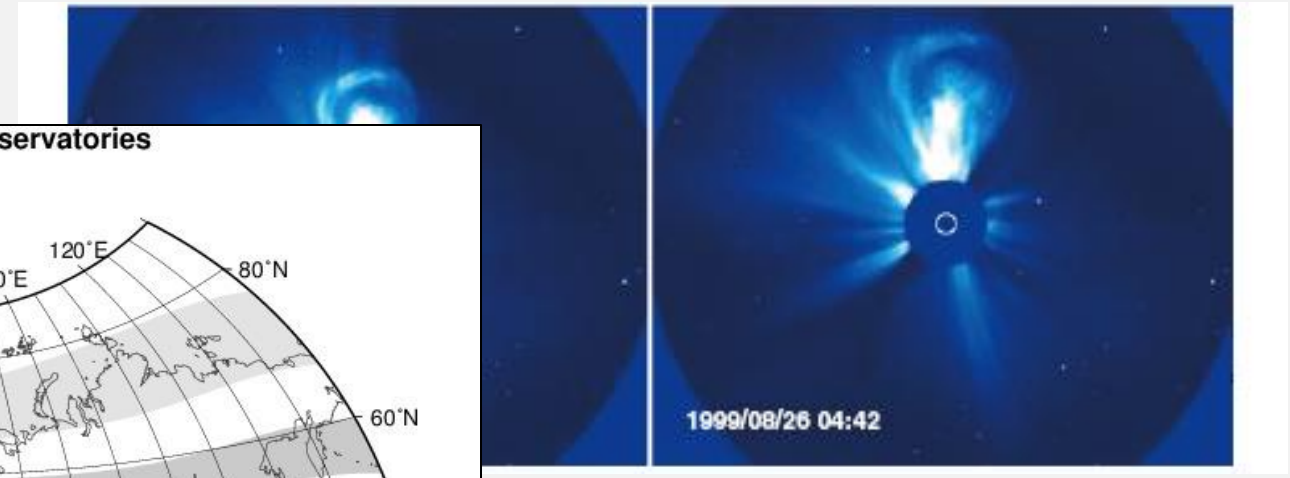


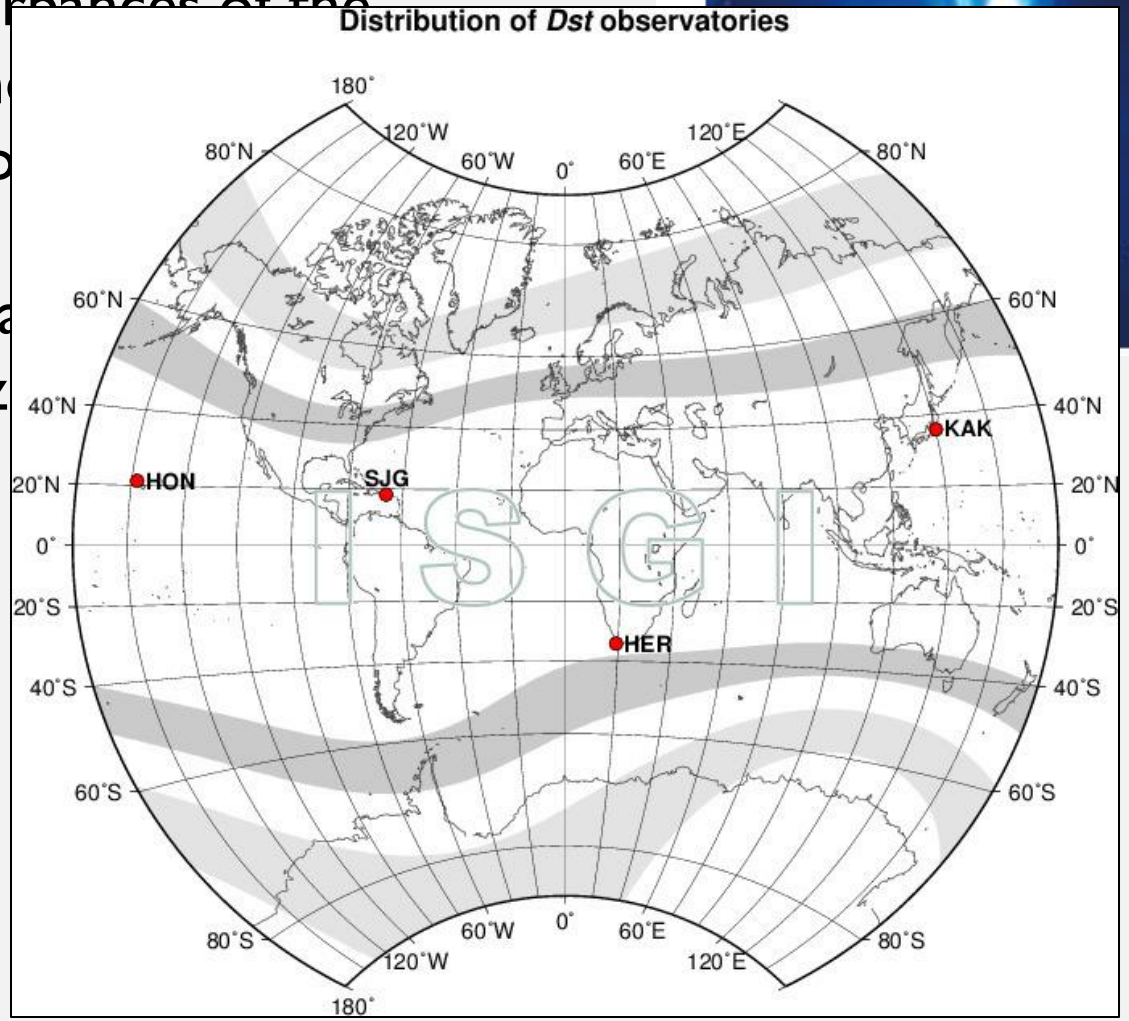
Kp vs Dst vs AE?

Geomagnetic Activity

Geomagnetic Storms: Temporary (~days) global distur… of the Earth's magnetosph… conditions in the so…

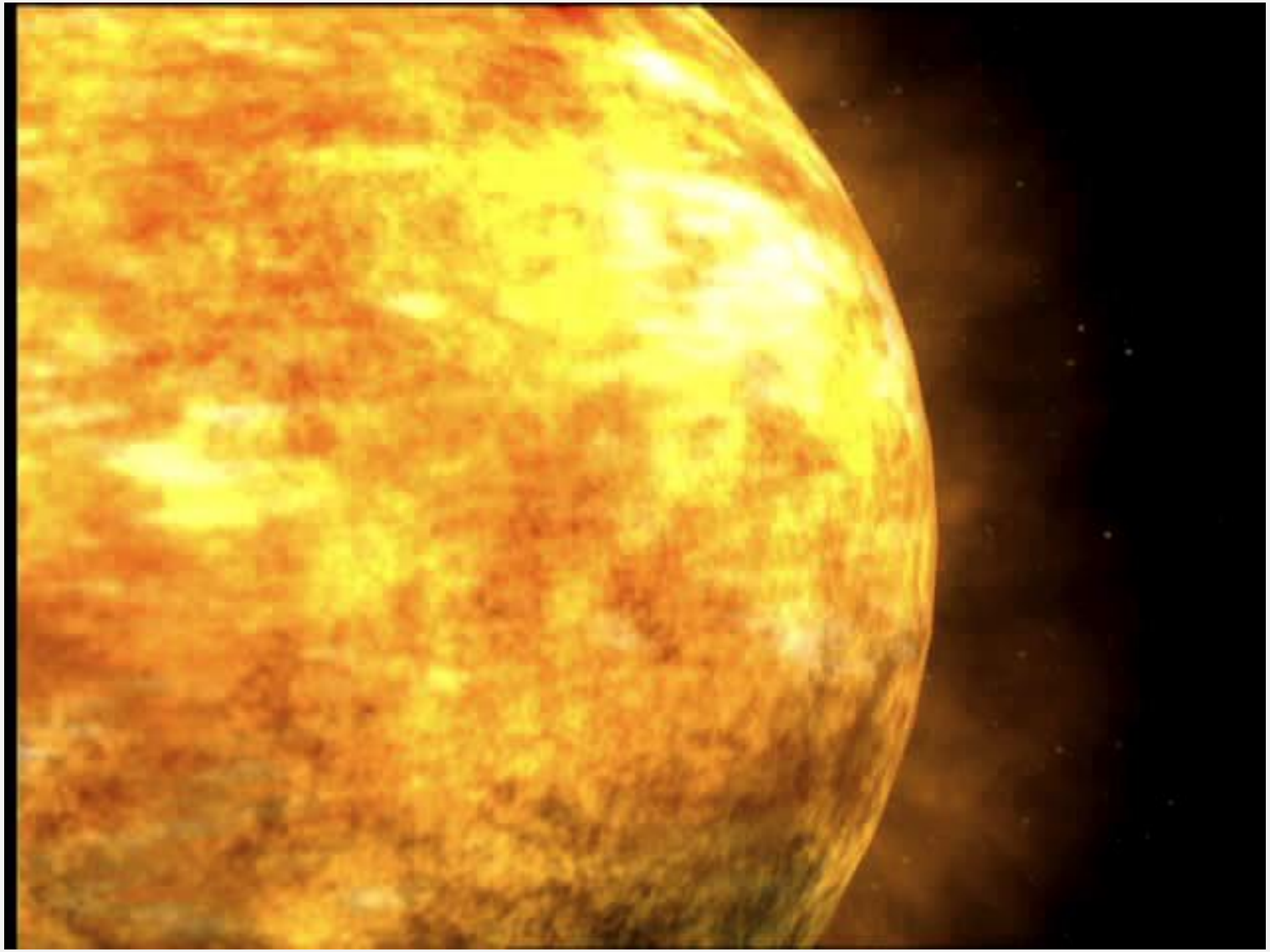
Substorms: Tempora… frequent and localiz…



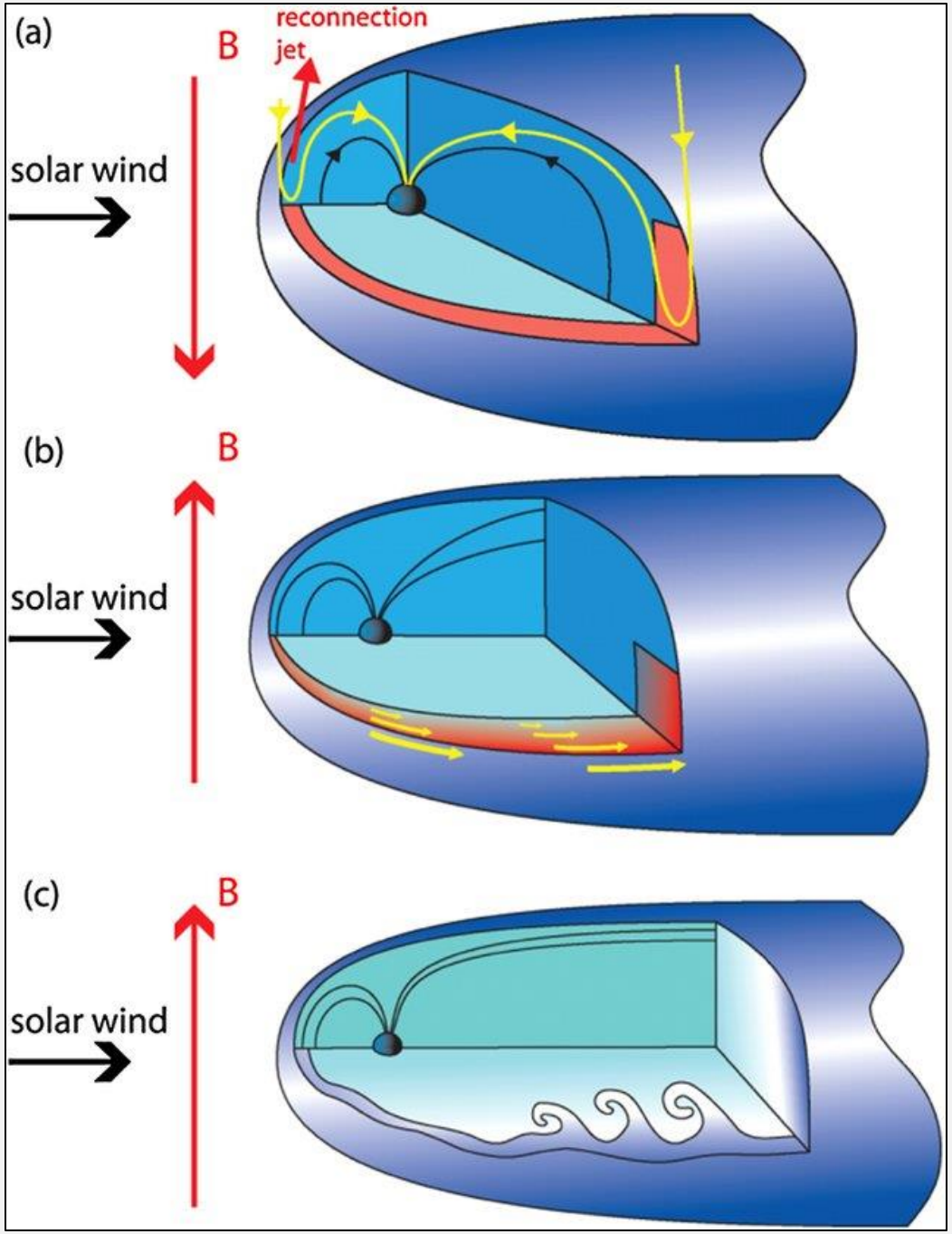


Kp vs Dst vs AE?

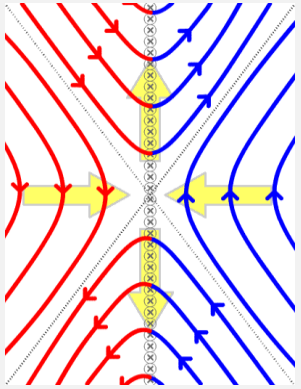
SUN-EARTH SYSTEM



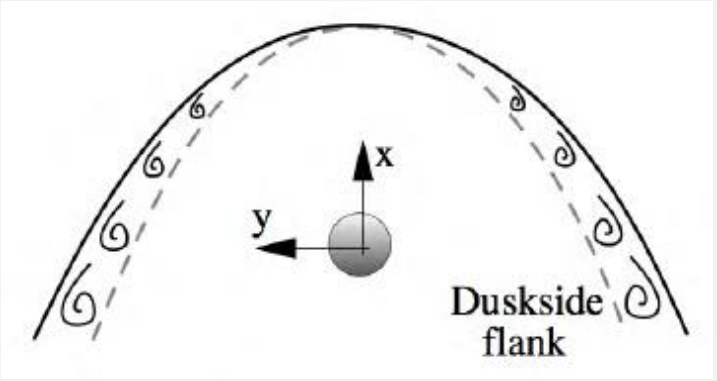
SOLAR WIND ACCESS TO THE MAGNETOSPHERE

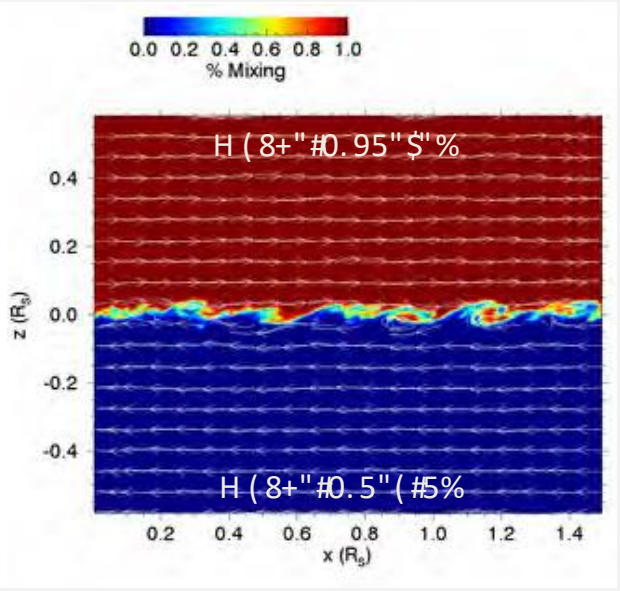


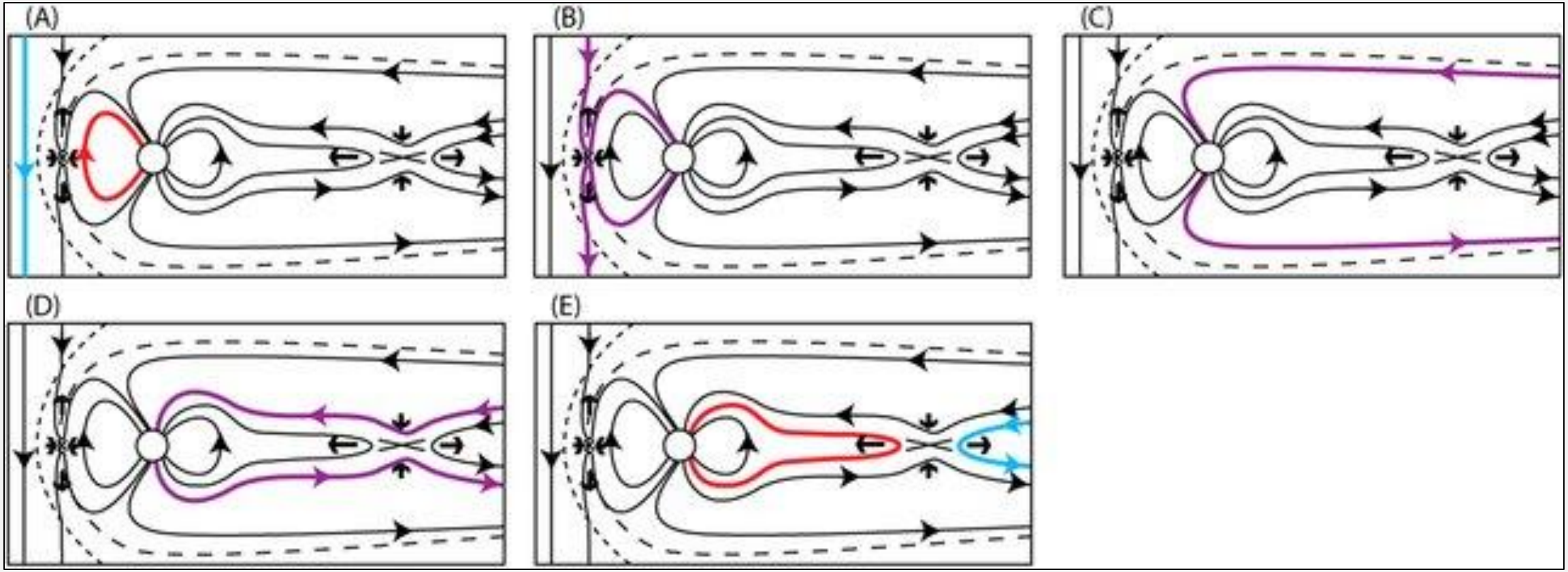
Magnetic Reconnection



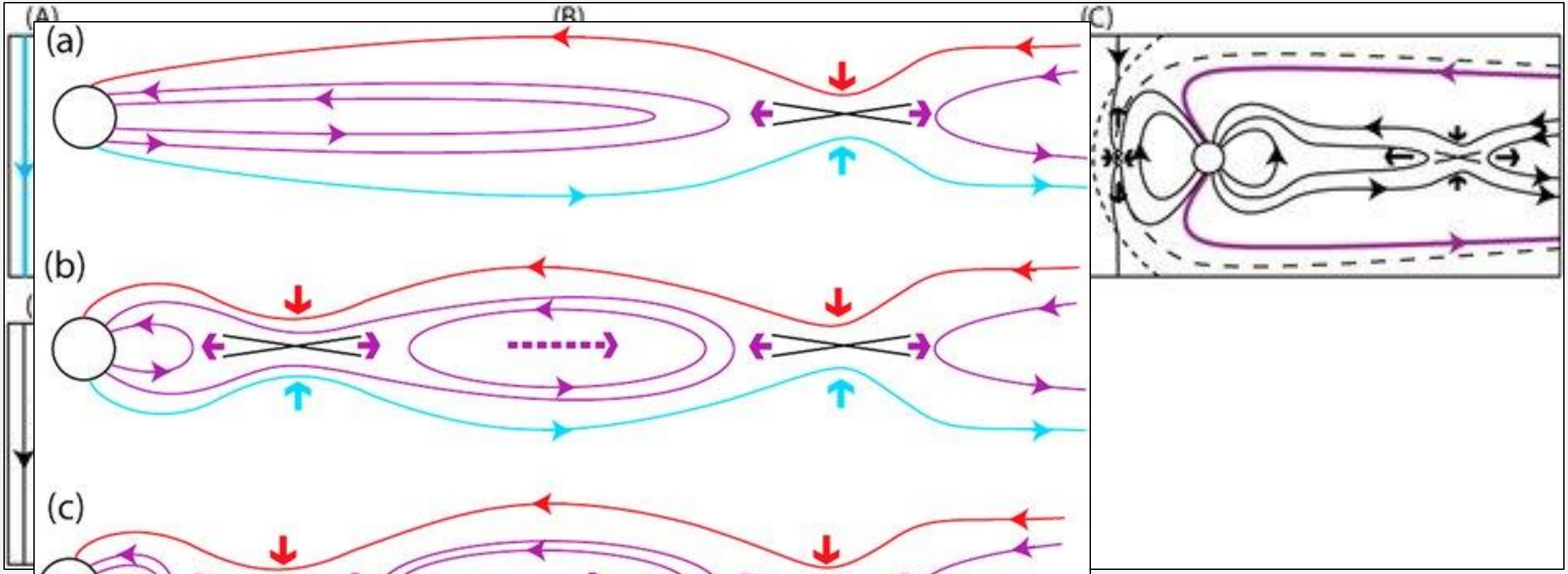
Kelvin-Helmholtz Instability

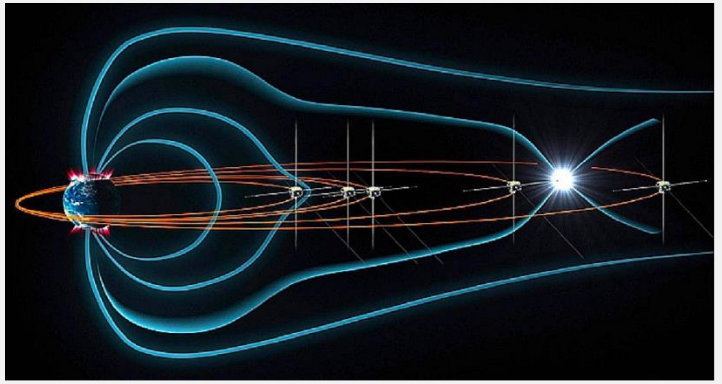






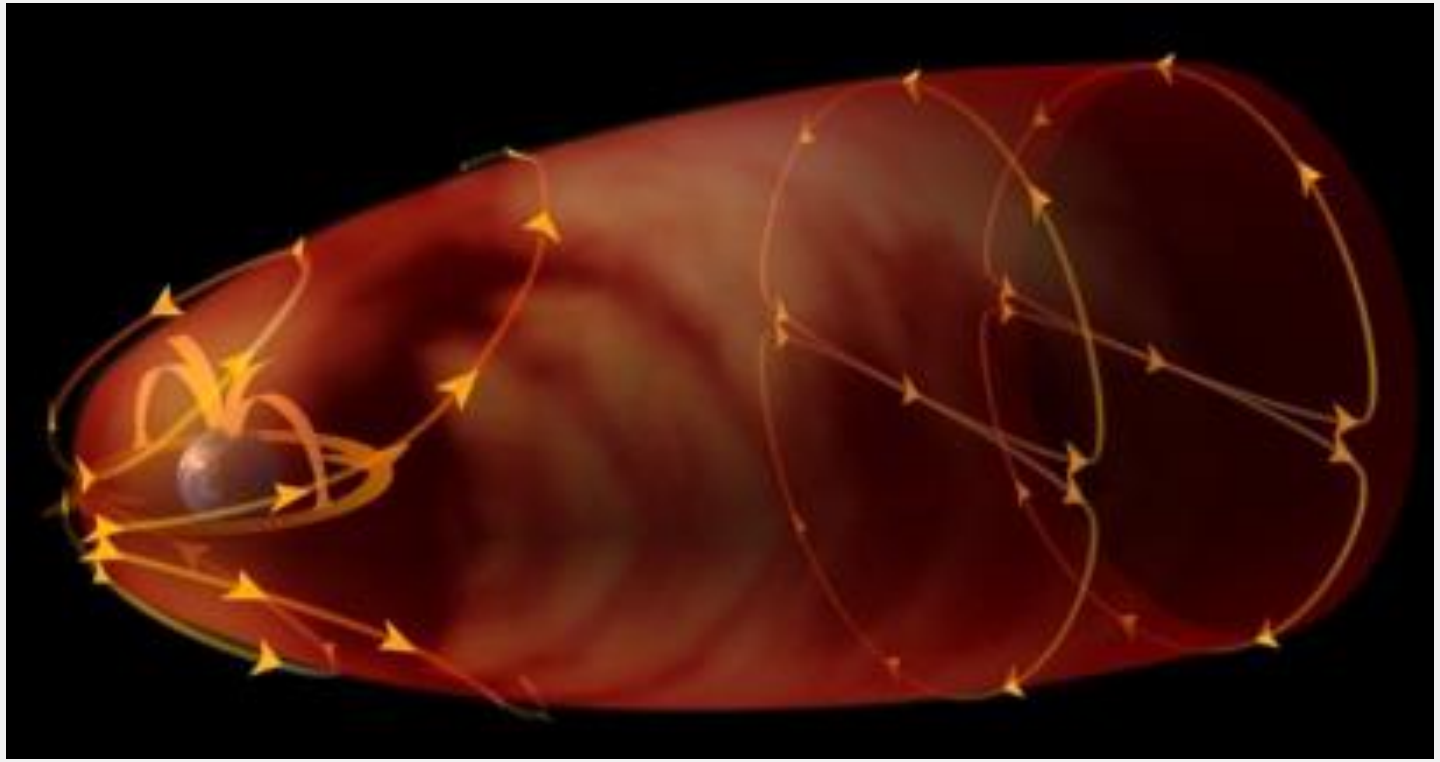
Eastwood et al., Space Sci. Rev., 2015

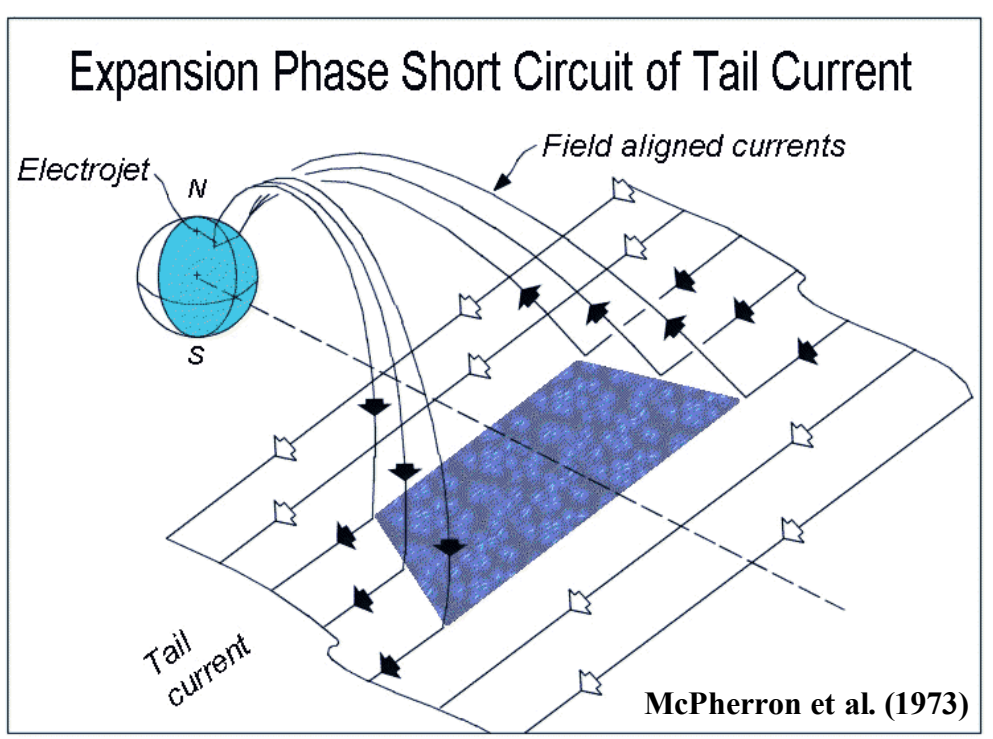




NASA's THEMIS mission

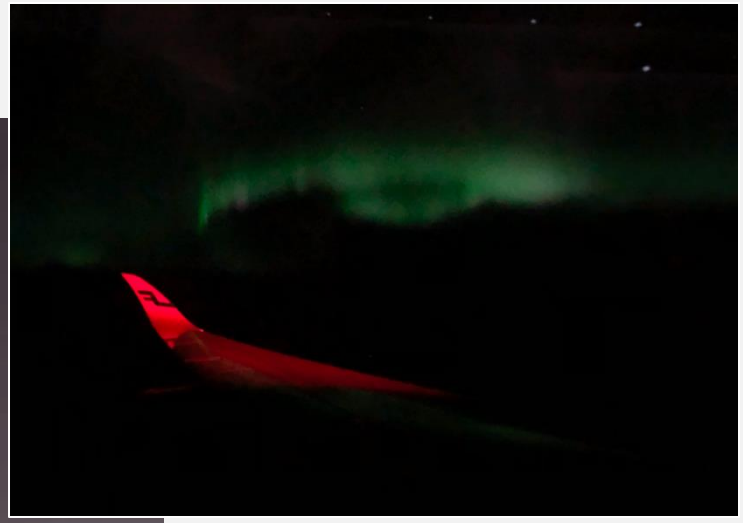
MAGNETOSPHERIC CURRENT SYSTEMS





THE AURORA

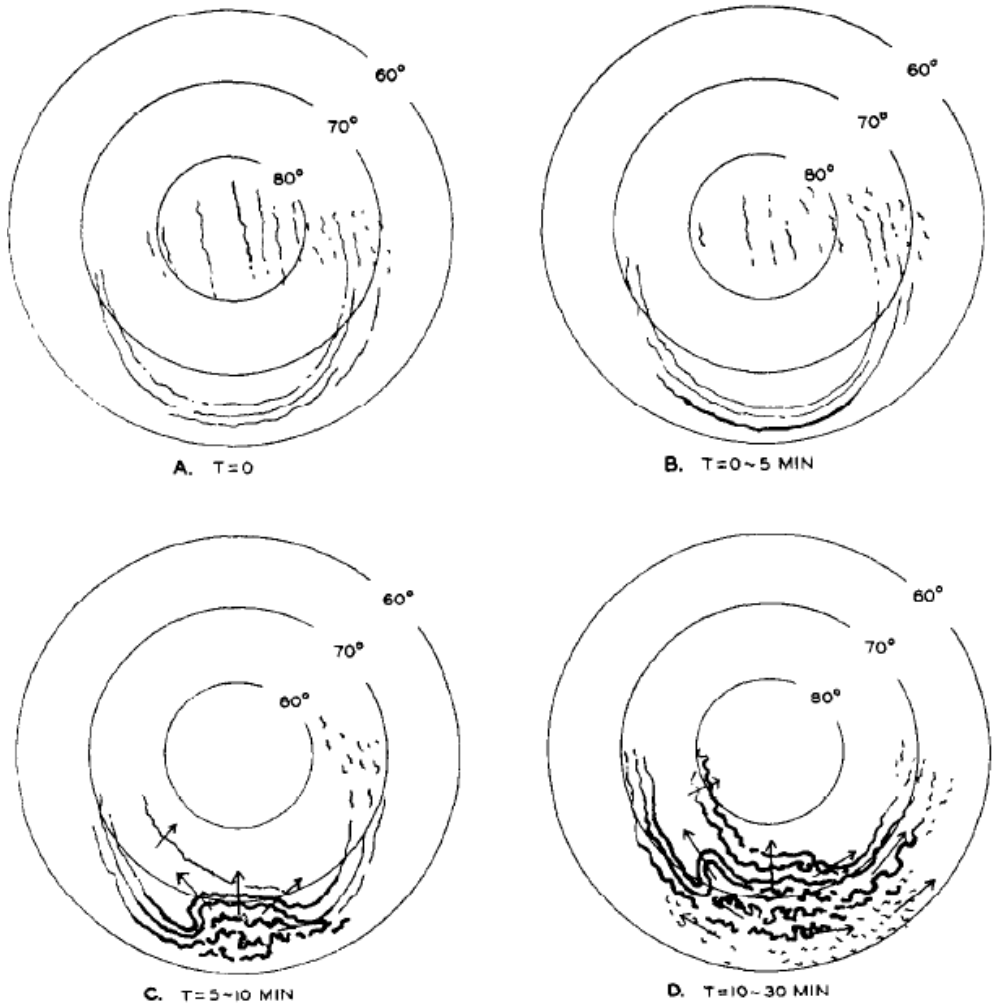
Why I like aurora (part I)



Credit: Longzhi Gan; Boulder CO May 2024

Why I like aurora (part II)

Auroral Onset

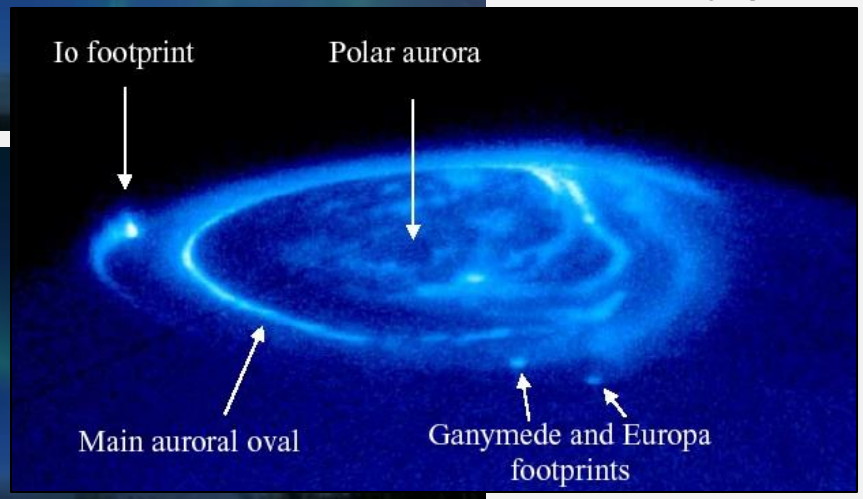


Adapted from Akasofu
(Planetary and Space Sciences, 1964)
886—1578 citations

Why I like aurora (part III)

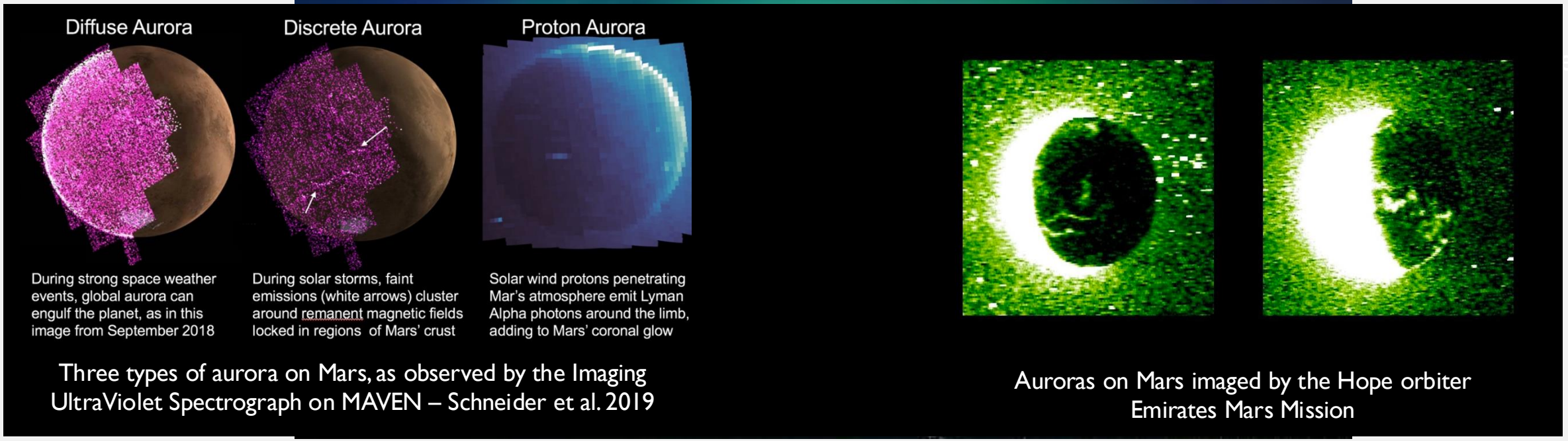
NASA's Juno mission

Aurora at Jupiter



Why I like aurora (part III)

Aurora at Mars

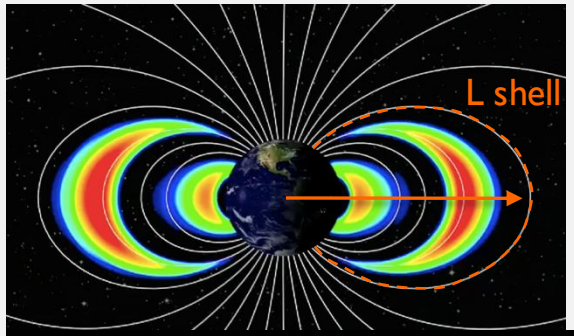


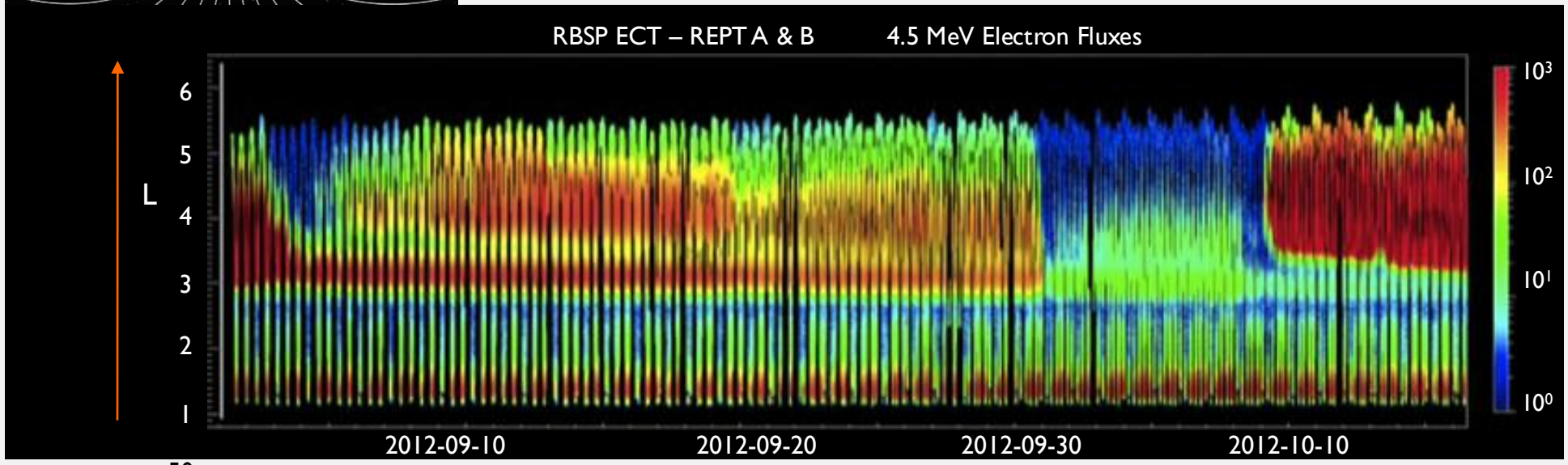
Three types of aurora on Mars, as observed by the Imaging UltraViolet Spectrograph on MAVEN – Schneider et al. 2019

Auroras on Mars imaged by the Hope orbiter Emirates Mars Mission

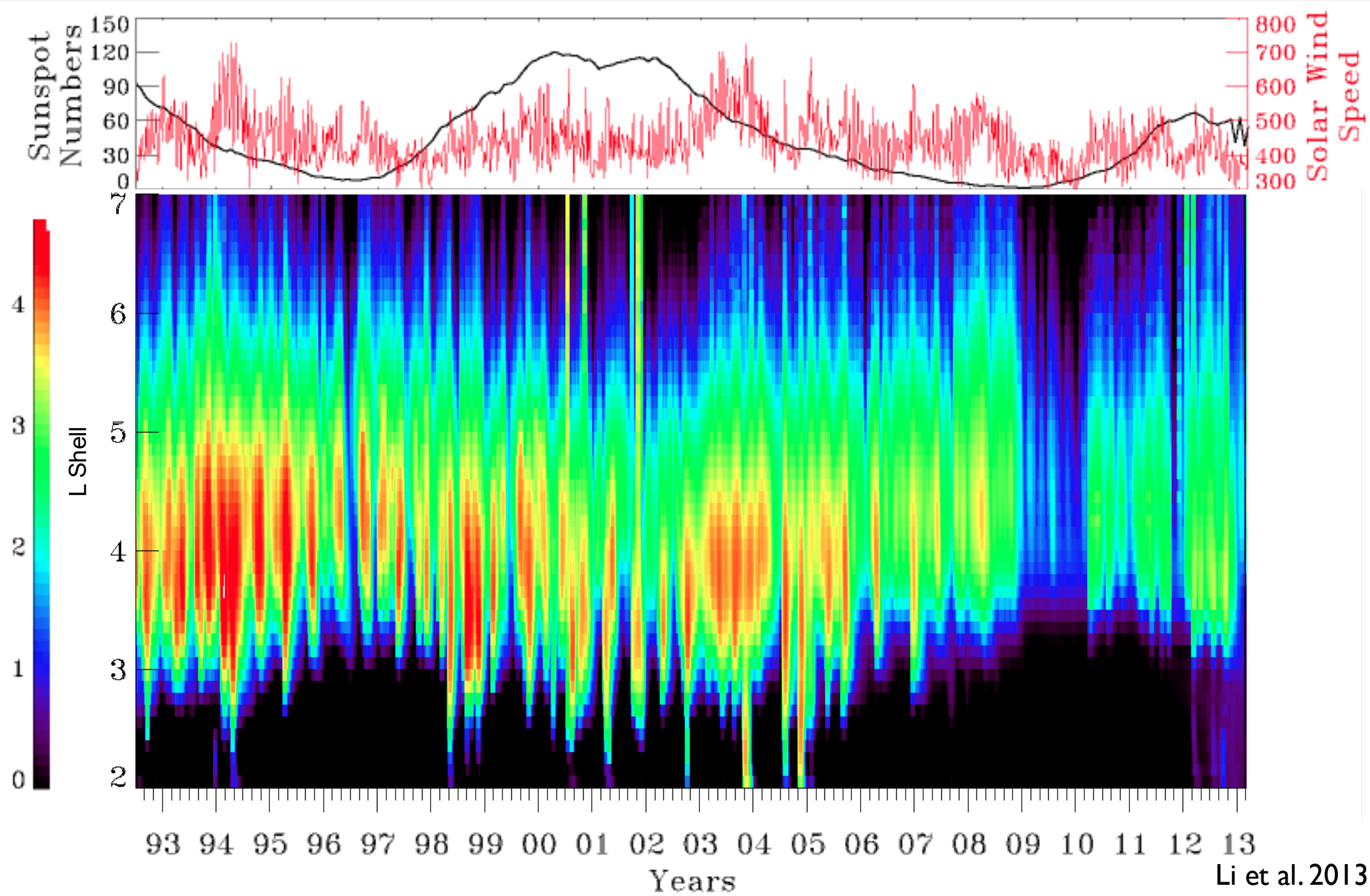
TIMESCALES OF MAGNETOSPHERIC DYNAMICS

RADIATION BELT DYNAMICS





Baker et al., Science (2013)


Sunspot Numbers
150
120
90
60
30
0
800
700
600
500
400
300
Solar Wind Speed
W
L Shell
7
6
5
4
3
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4
3
2
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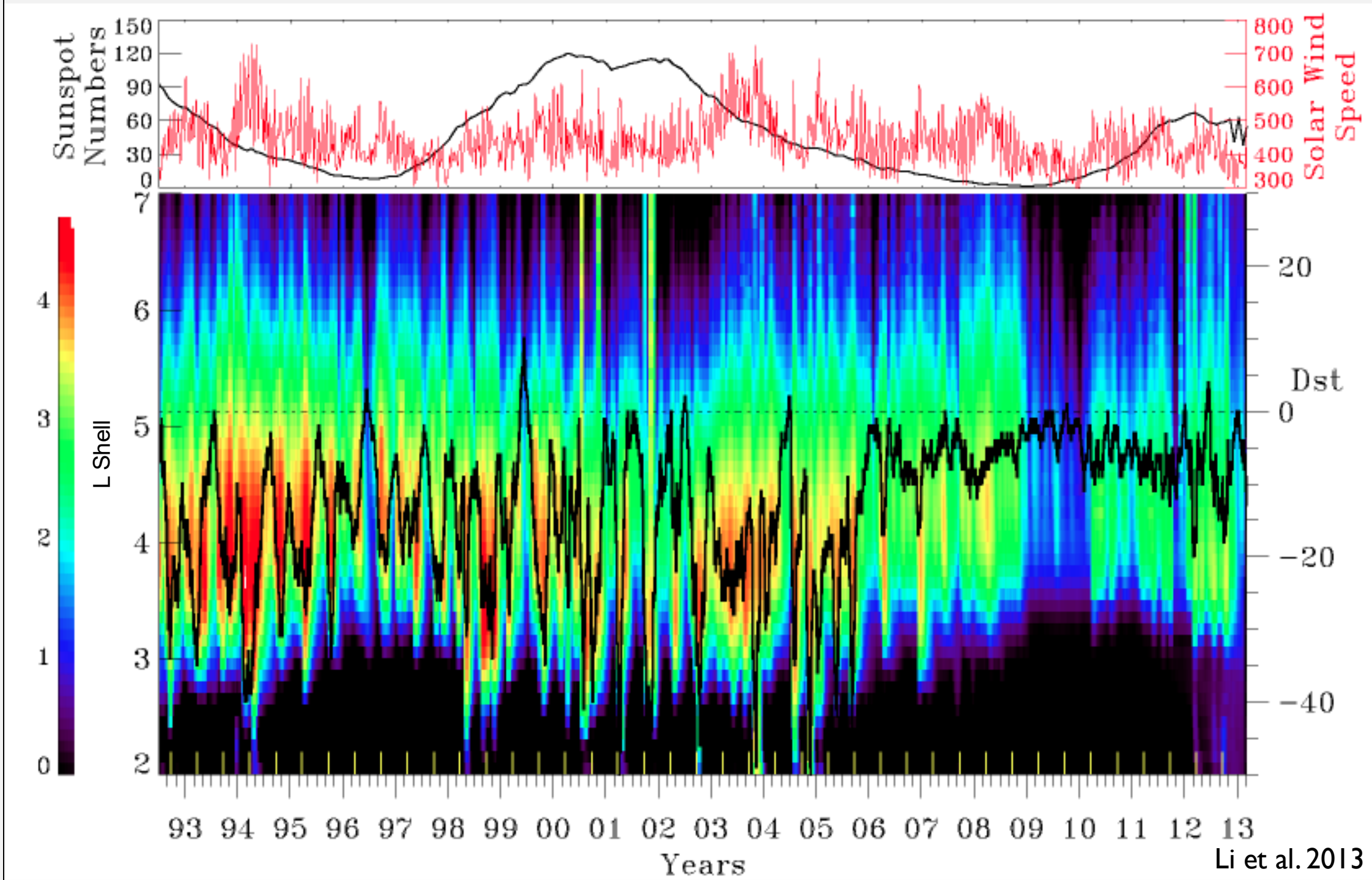
0
93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13
Years

Li et al. 2013


Sunspot Numbers
150
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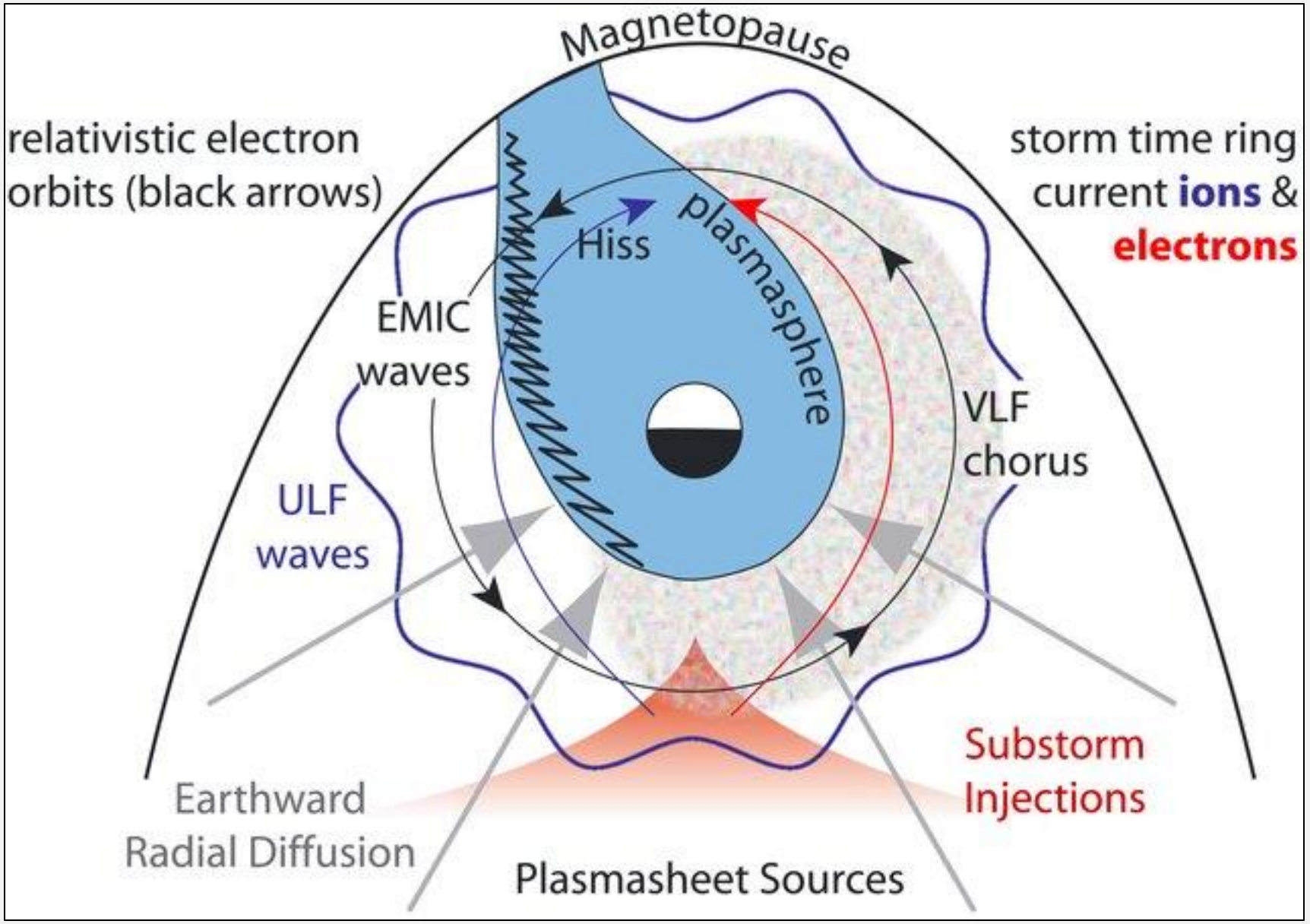
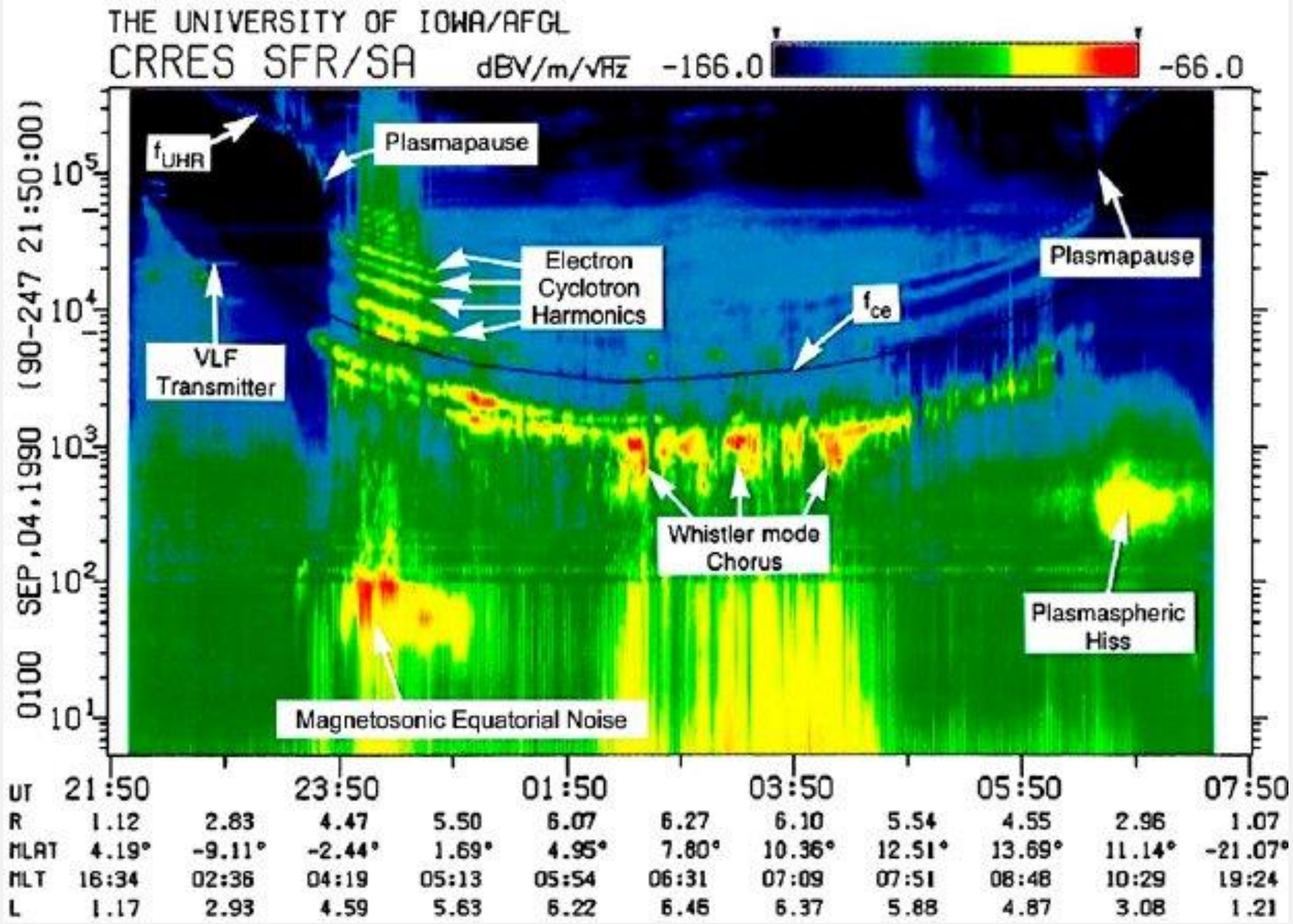
Years

Li et al. 2013



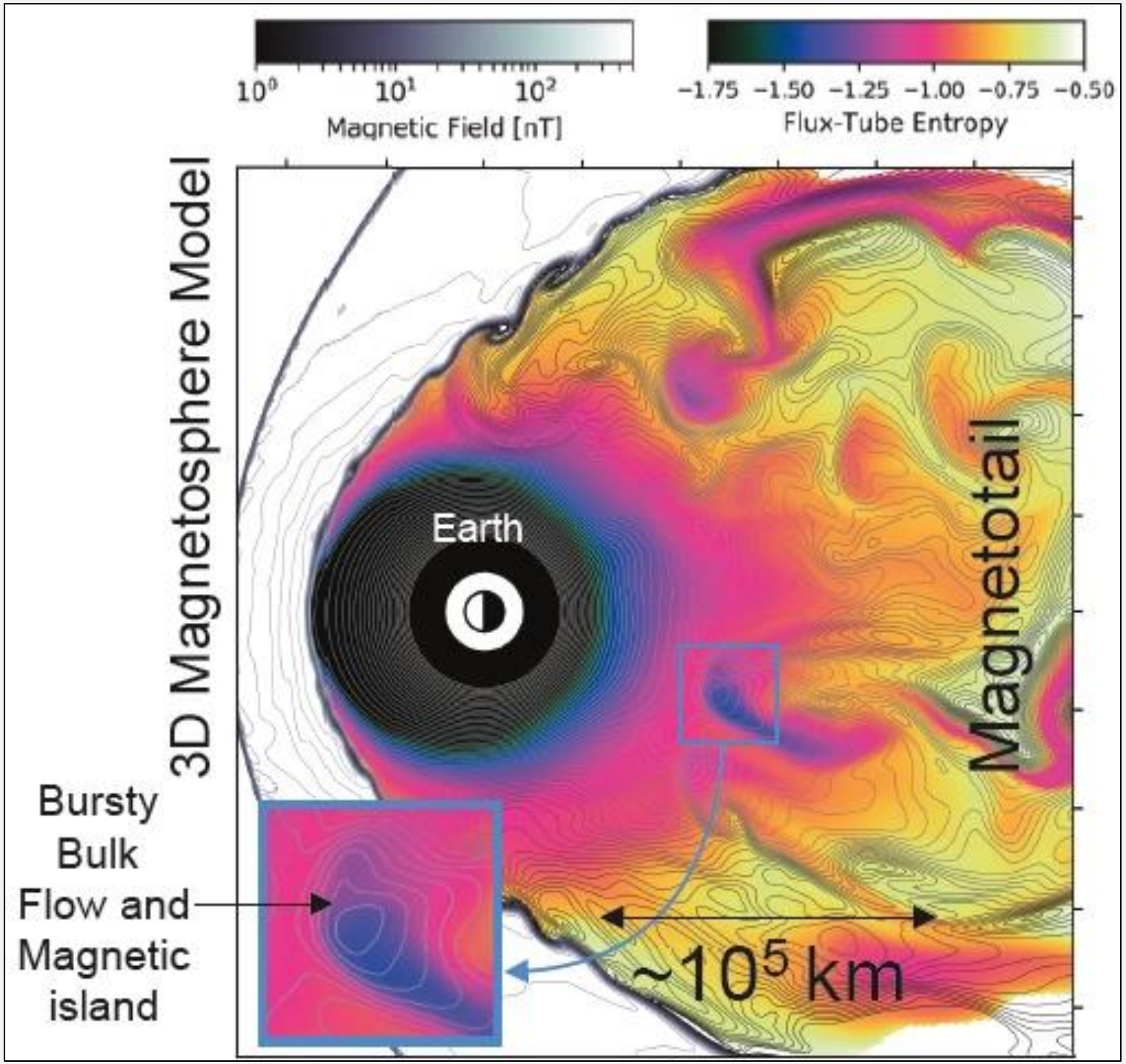
Reeves et al. (2016)



Kletzing et al. (2013)

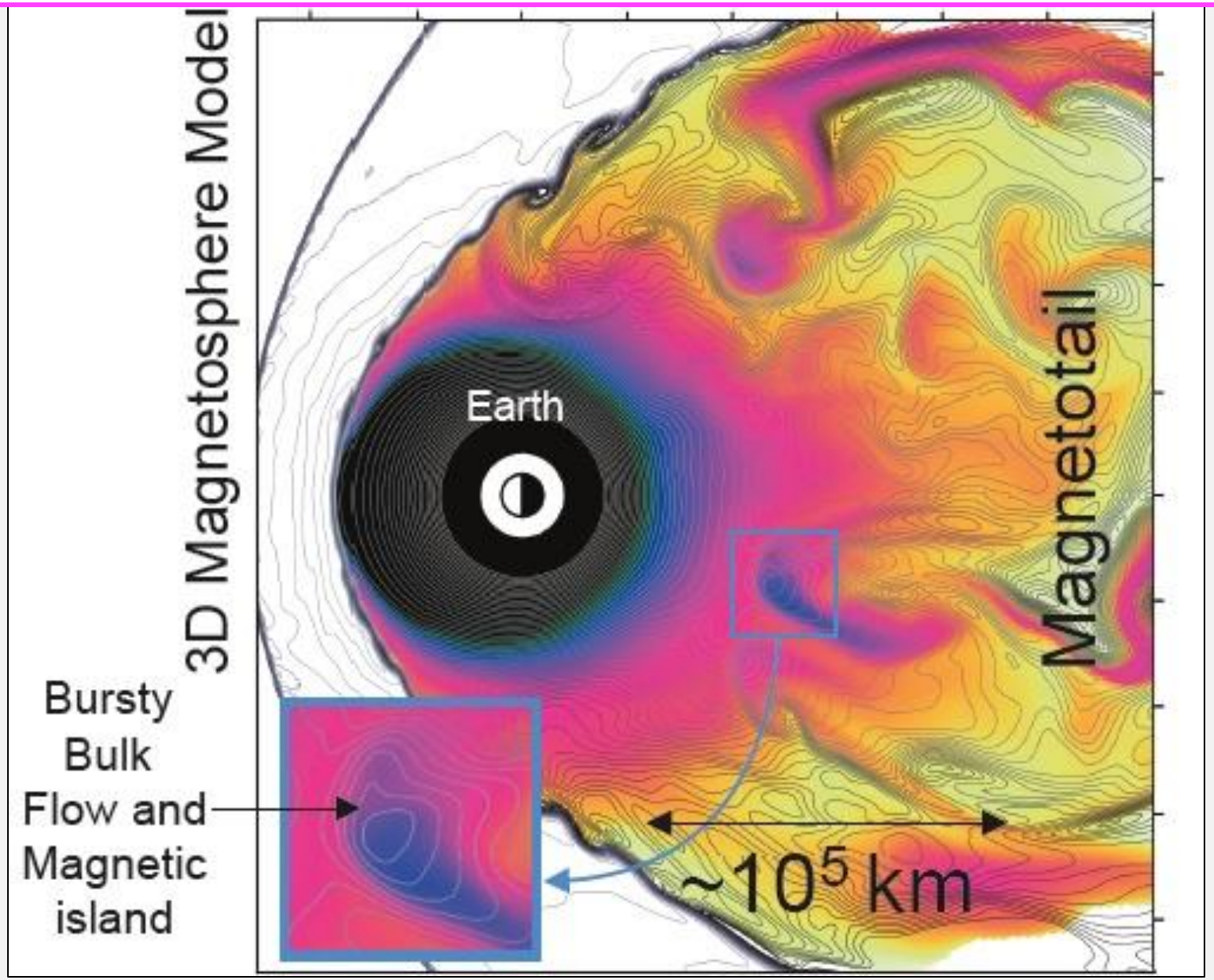
PAUSE – QUESTIONS?

GROUP EXERCISE



Adapted from Sorathia et al. (2021)

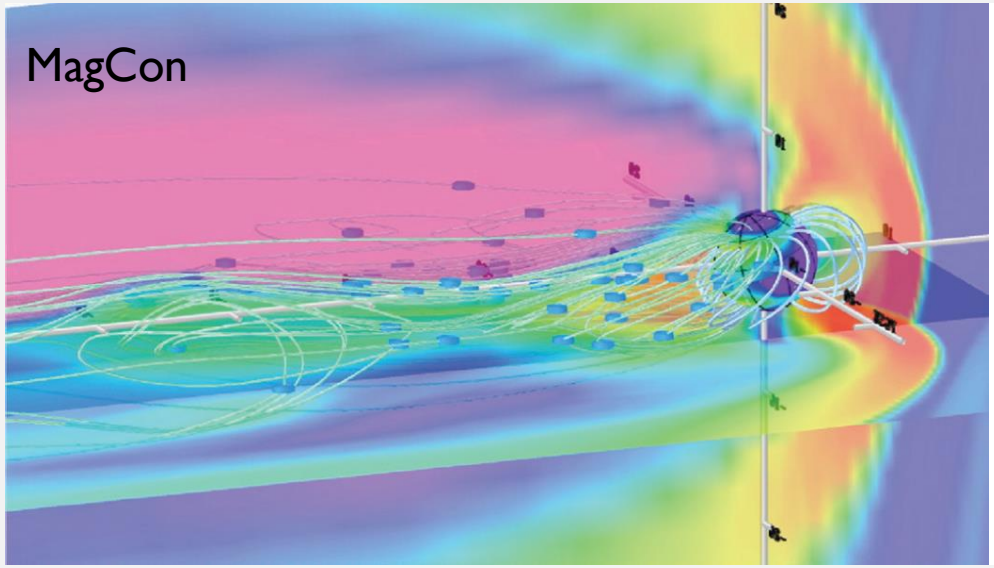
Design a mission to study these meso-scale flows, energy and mass transport from the tail to the inner magnetosphere

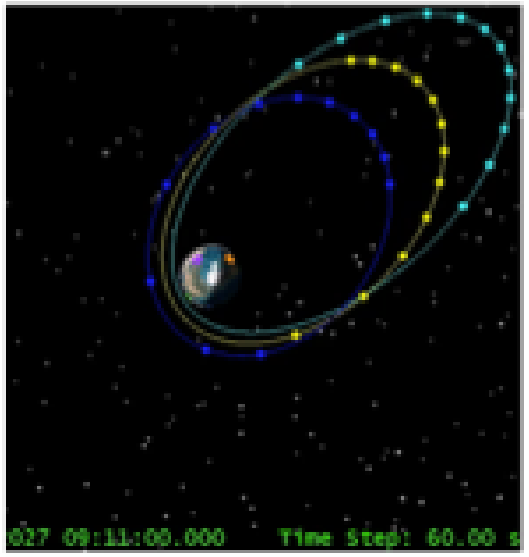


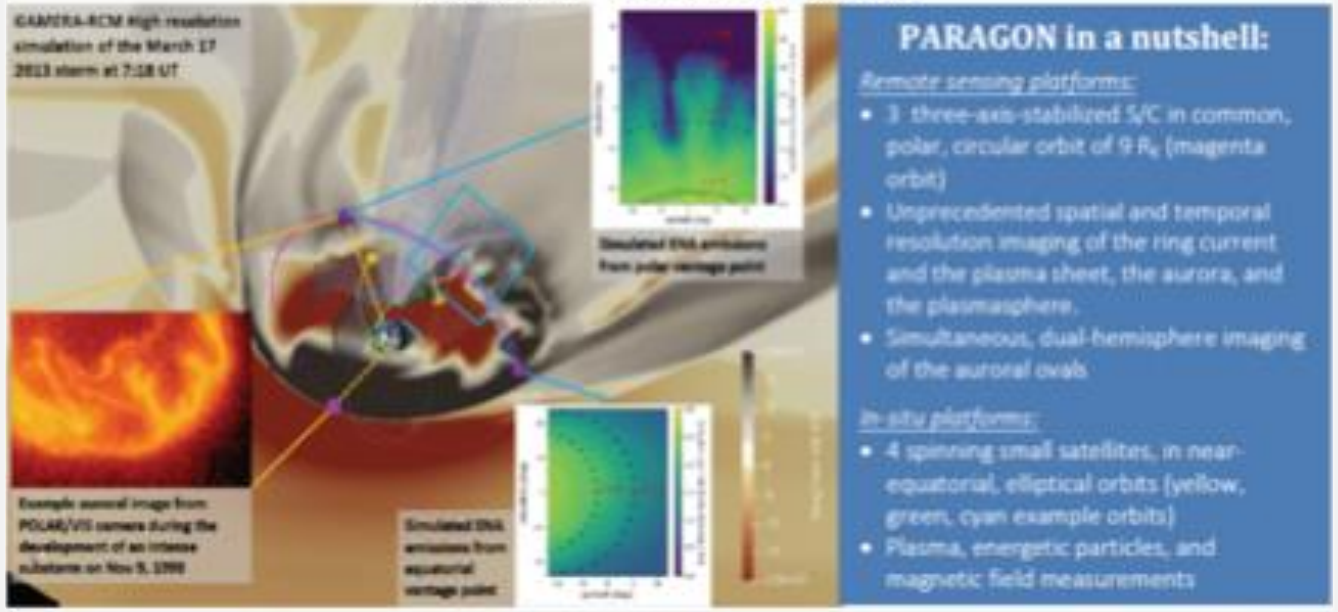
Adapted from Sorathia et al. (2021)

SOME EXISTING MISSION CONCEPTS

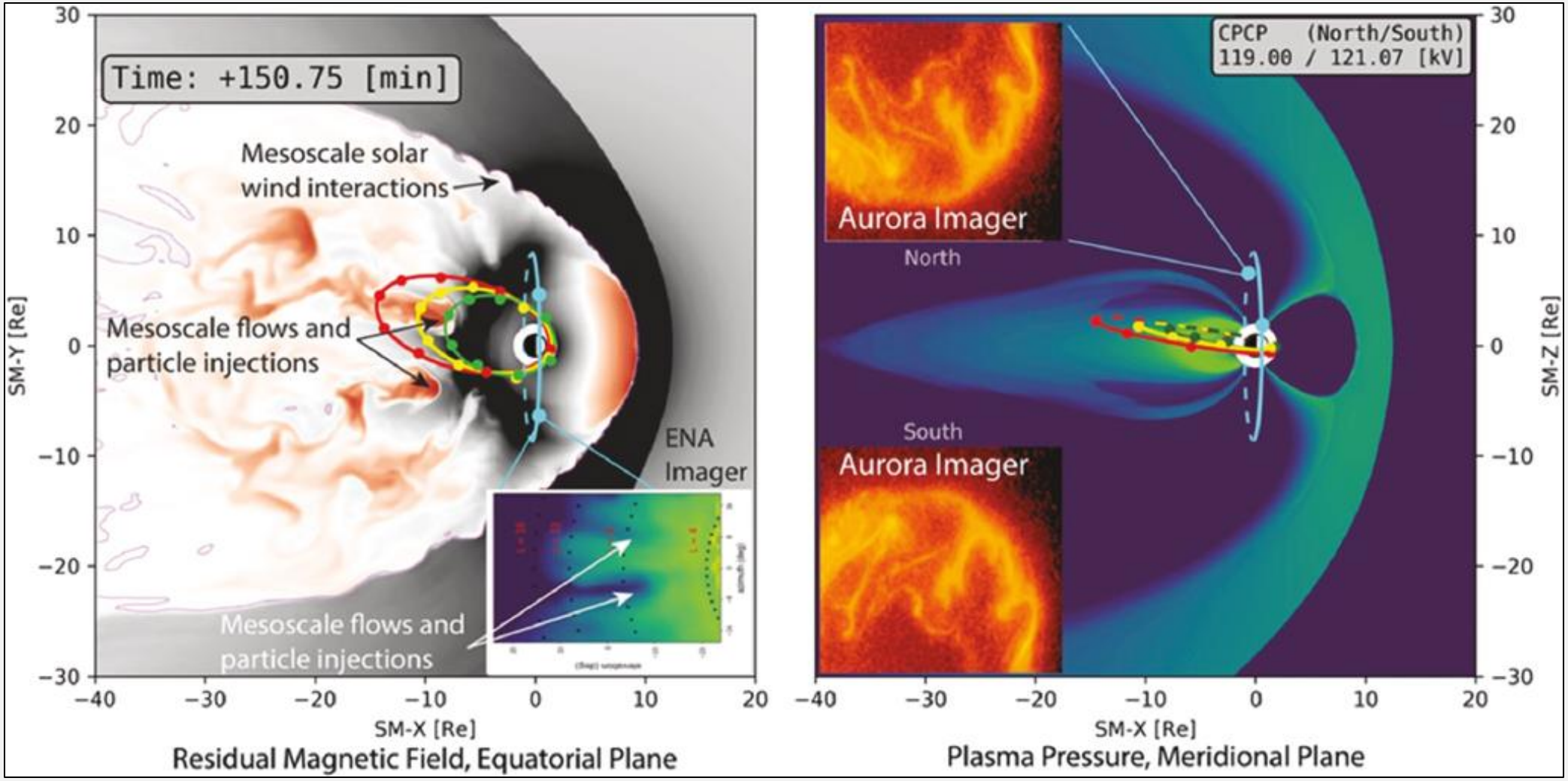
- MagCon
- CINEMA
- PARAGON
- …





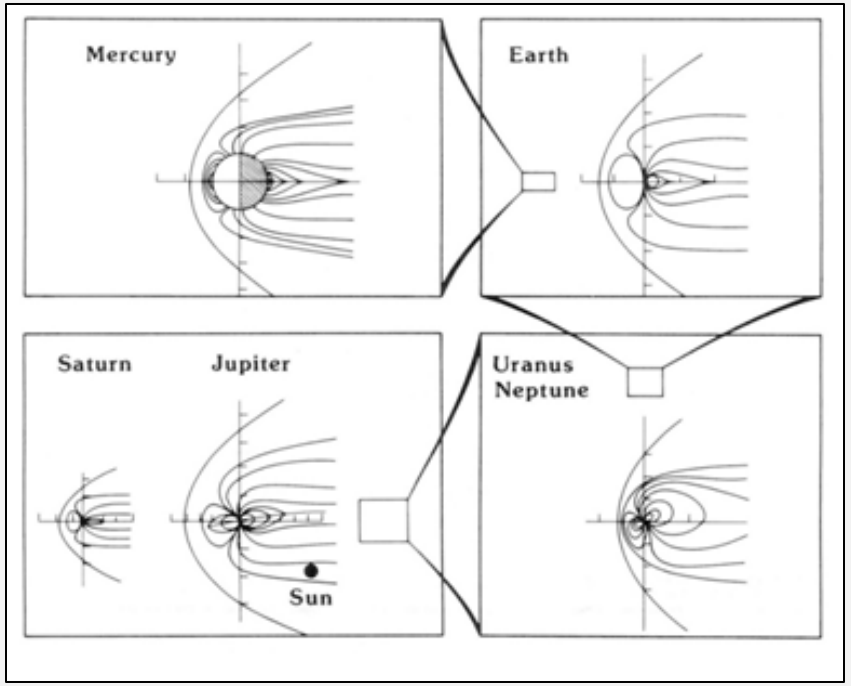


2024 HELIO DECADAL SURVEY RECOMMENDATION: LINKS MISSION

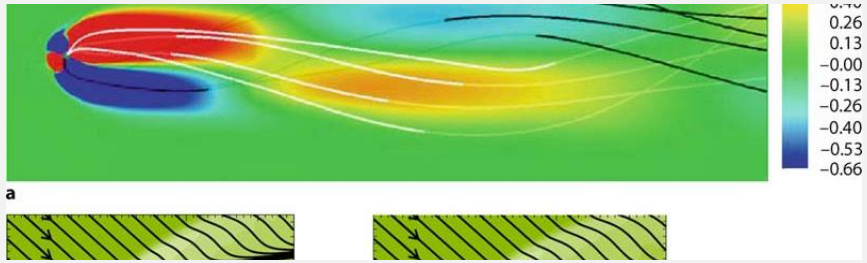


TAKE-AWAYS

- The near-Earth space environment is fascinating both from a pure physics as well as applied perspective
  - Shock physics, particle acceleration, magnetic reconnection…
  - Studying our own magnetosphere can teach us a lot about planetary magnetospheres and star-planet interactions in general
  - Earth's dynamic magnetosphere directly impacts society, ground and space-based assets
- The system is complex and interconnected
  - "system-of-systems" where each component may feed back and influence another
  - Other star-planet-moon interactions provide a laboratory to learn how different variables affect the overall system, how well we really understand our own system

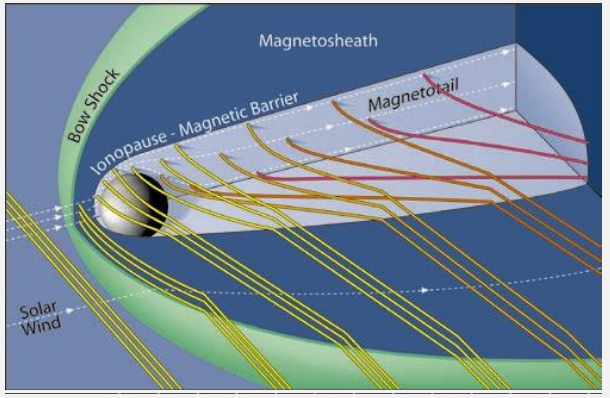


Uranus:

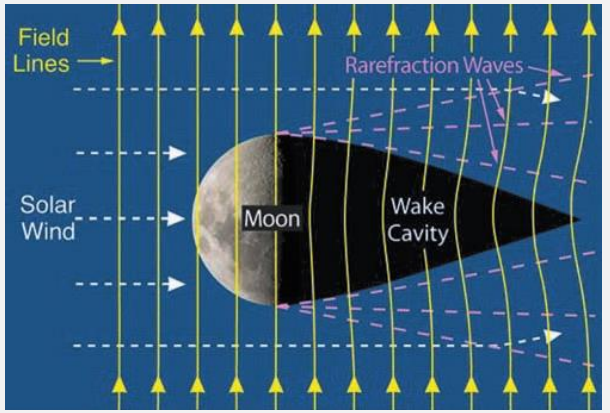


Neptune:

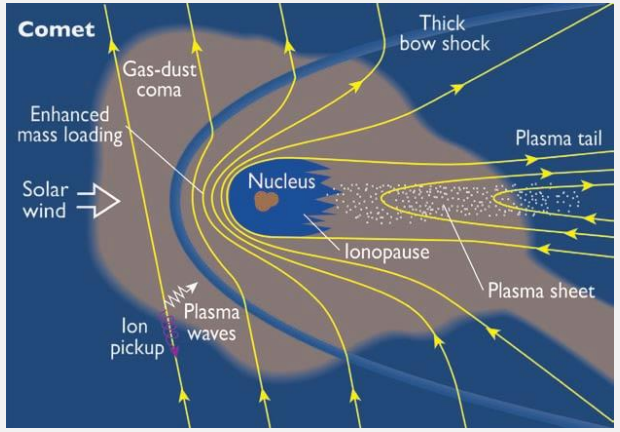
Unmagnetized conducting bodies (e.g. Venus):



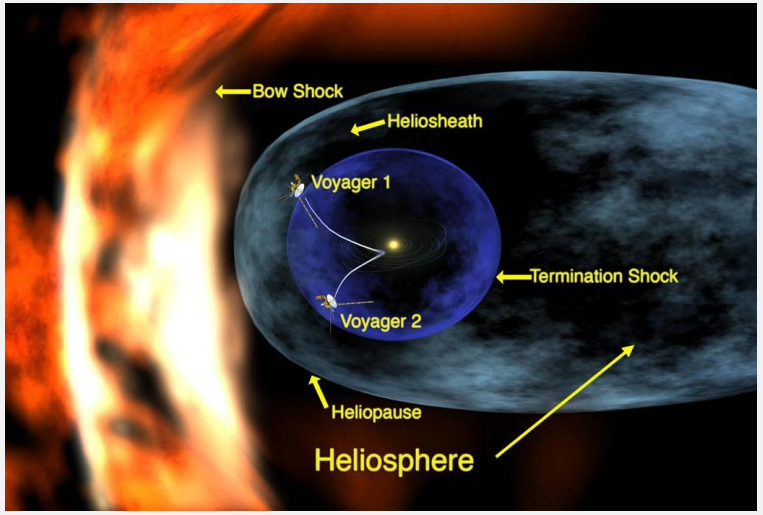
Unmagnetized non-conducting bodies (e.g. the Moon):



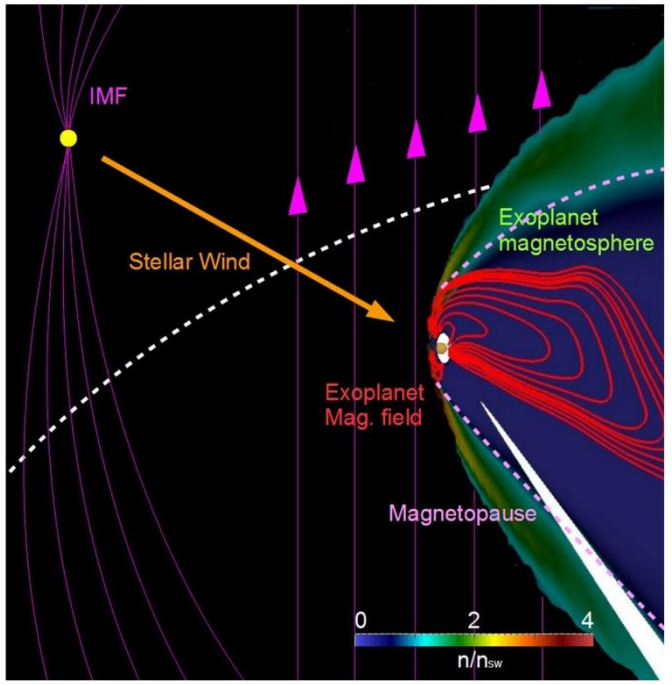
Comets:



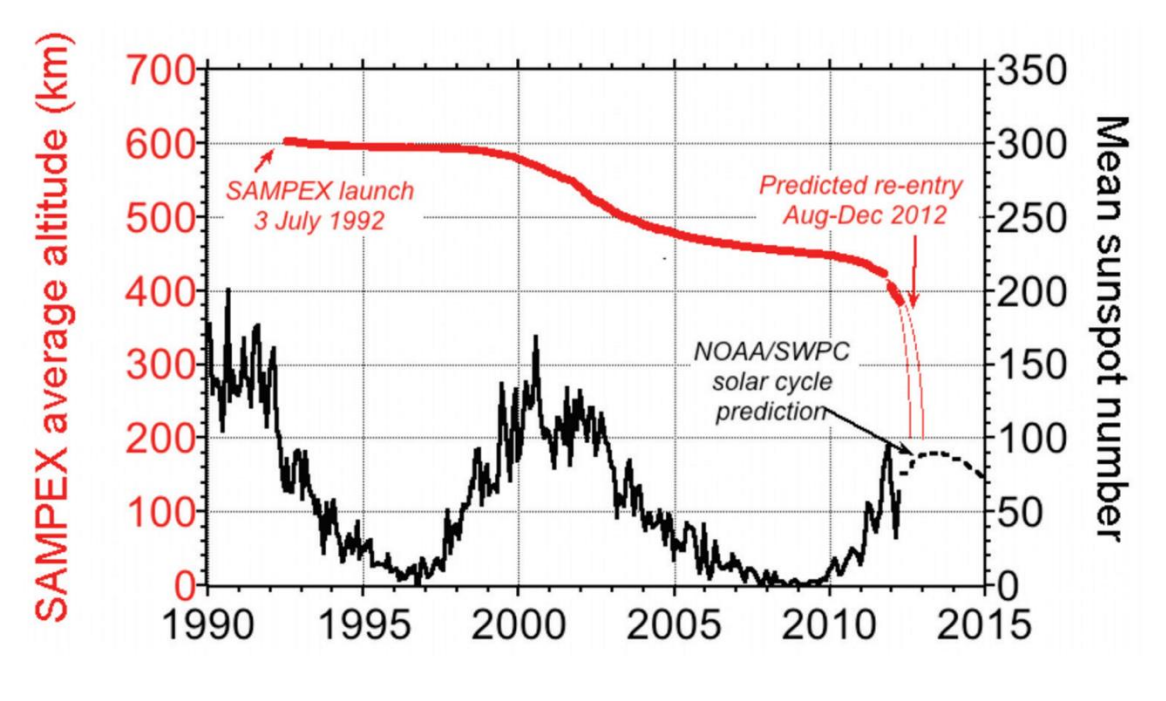
Heliospheres:



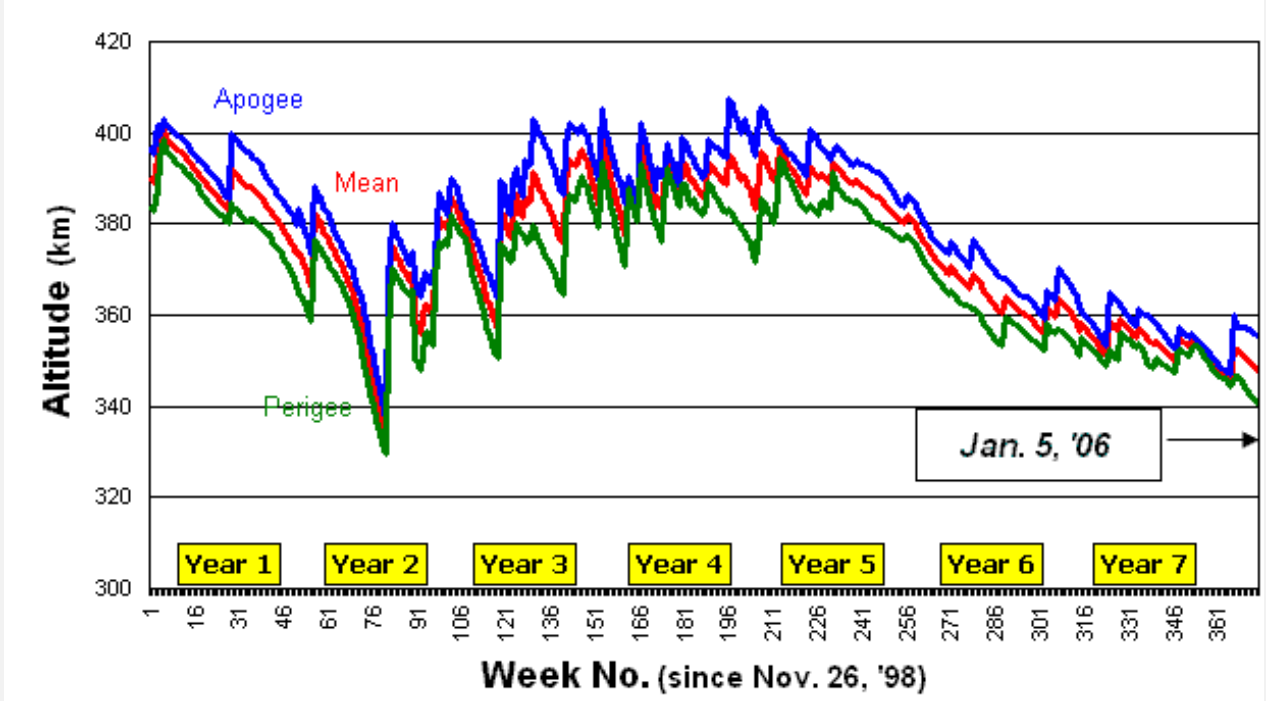
Exoplanets:



ATMOSPHERIC DENSITY AND SPACECRAFT DRAG

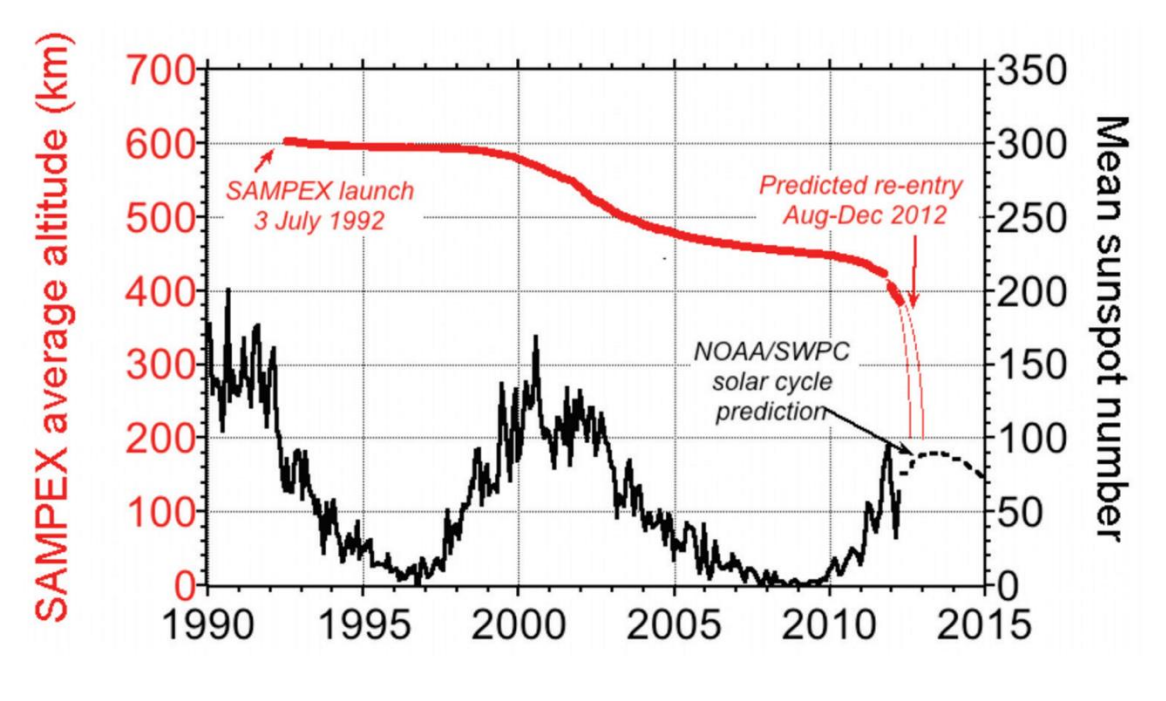


Daily averaged SAMPEX altitude (red) in the context of the past 22 years of solar activity shown by the monthly averaged sunspot number (black). From Baker et al. [2012].



ISS altitude over time. Credit: Heavens_above.com

ATMOSPHERIC DENSITY



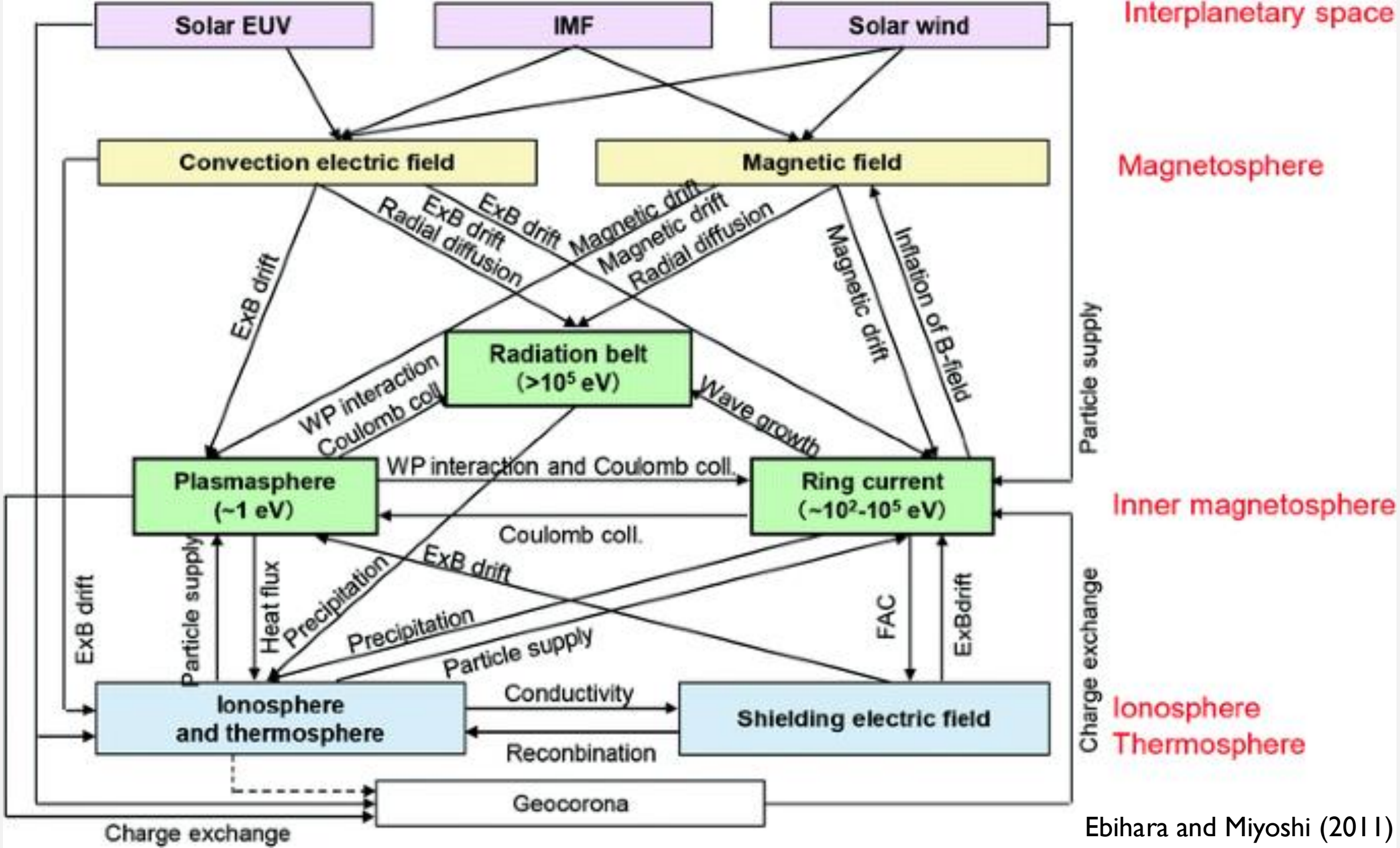
Daily averaged SAMPEX altitude (red) in the context of the past 22 years of solar activity shown by the monthly averaged sunspot number (black). From Baker et al. [2012].

SpaceX says a geomagnetic storm just doomed 40 Starlink internet satellites

News By Tariq Malik published February 08, 2022

The satellites launched on Feb. 3, only to be hit by the storm a day later.

A SpaceX Falcon 9 rocket launches 49 Starlink internet satellites into orbit from Pad 39A of NASA's Kennedy Space Center in Cape Canaveral, Florida on Feb. 3, 2022. (Image credit: SpaceX)



Ebihara and Miyoshi (2011)

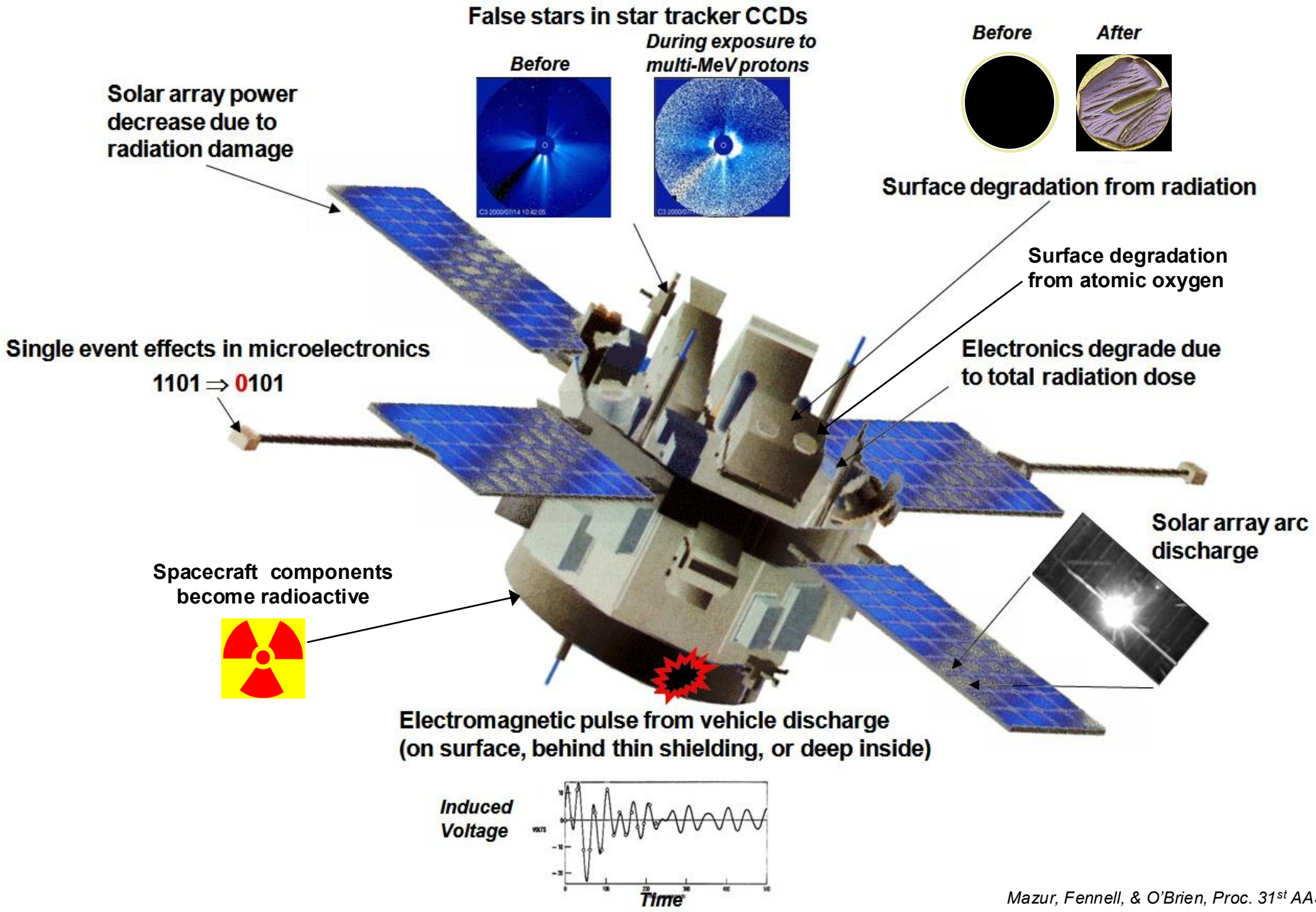
Solar EUV
IMF
Solar wind
Interplanetary space
Particle
Conductivity
Ionosphere and thermosphere
Reconbination
Shielding electric field
Charge ex
Ionosphere
Thermosphere
Geocorona
Charge exchange

Ebihara and Miyoshi (2011)

BEFORE WE LEAVE…

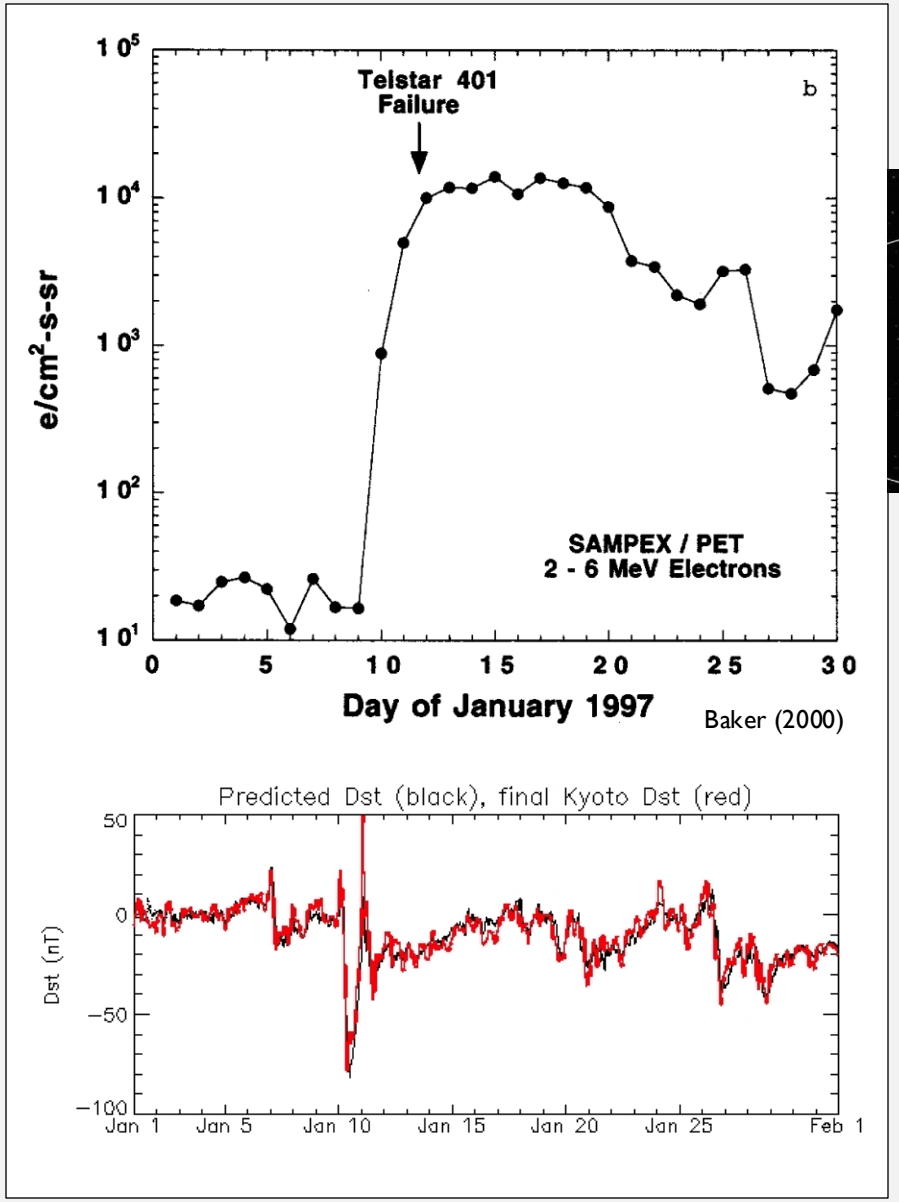
Write down:

1. one thing you found interesting
2. one question about today's material

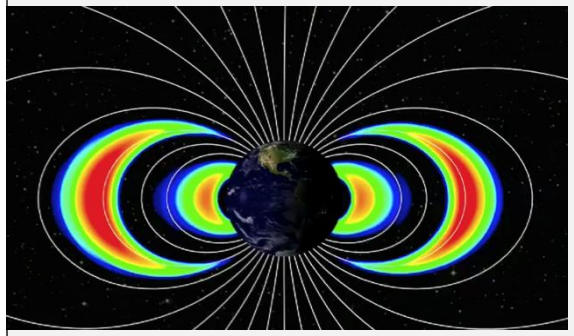


Mazur, Fennell, & O'Brien, Proc. 31st AAS Guidance and Control Conf., vol 131, 2008

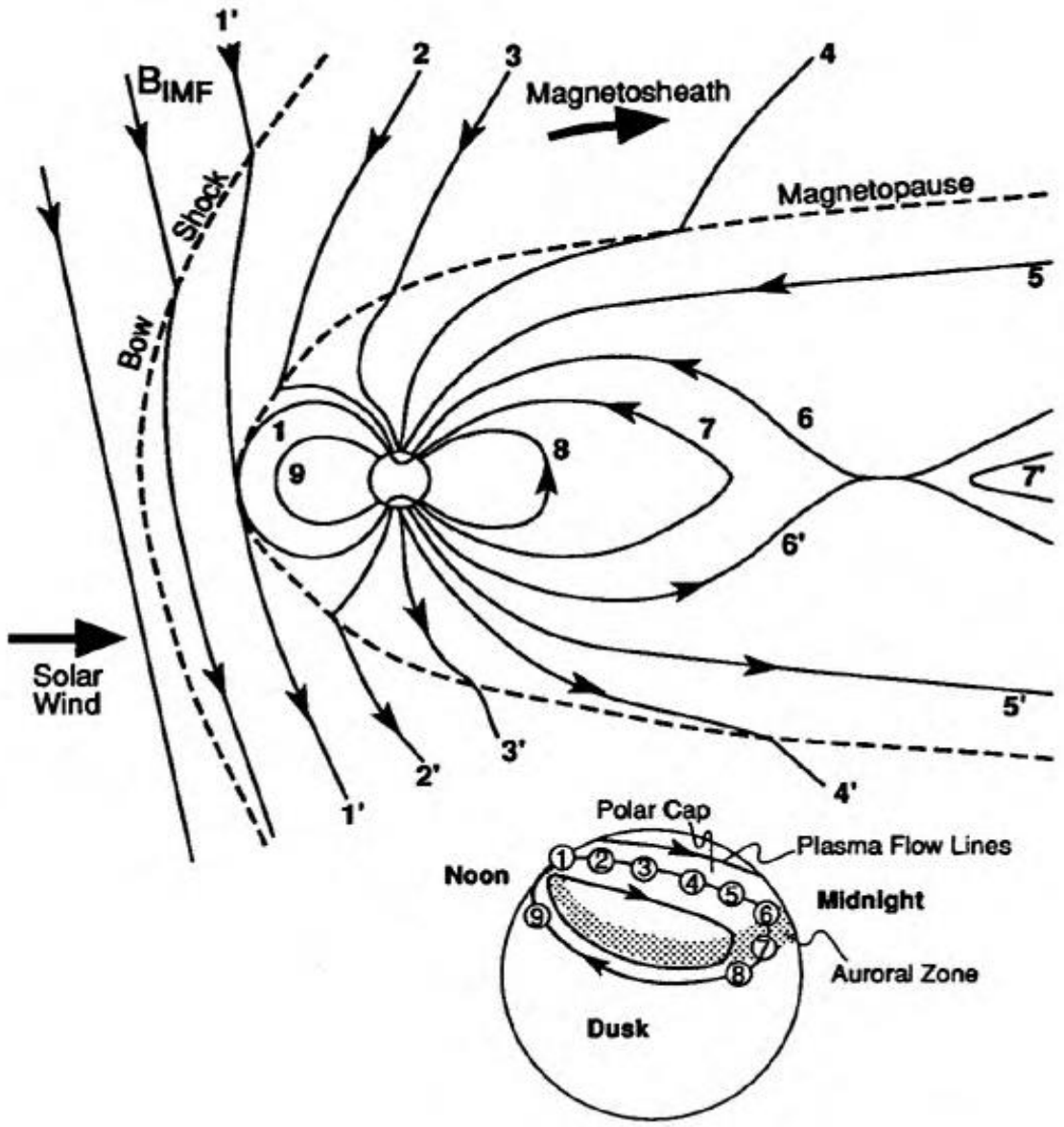
SPACE WEATHER IMPACTS



Baker (2000)



DUNGEY CYCLE



F_{pc} = open magnetic flux in the polar cap!

Φ_D = dayside reconnection rate!

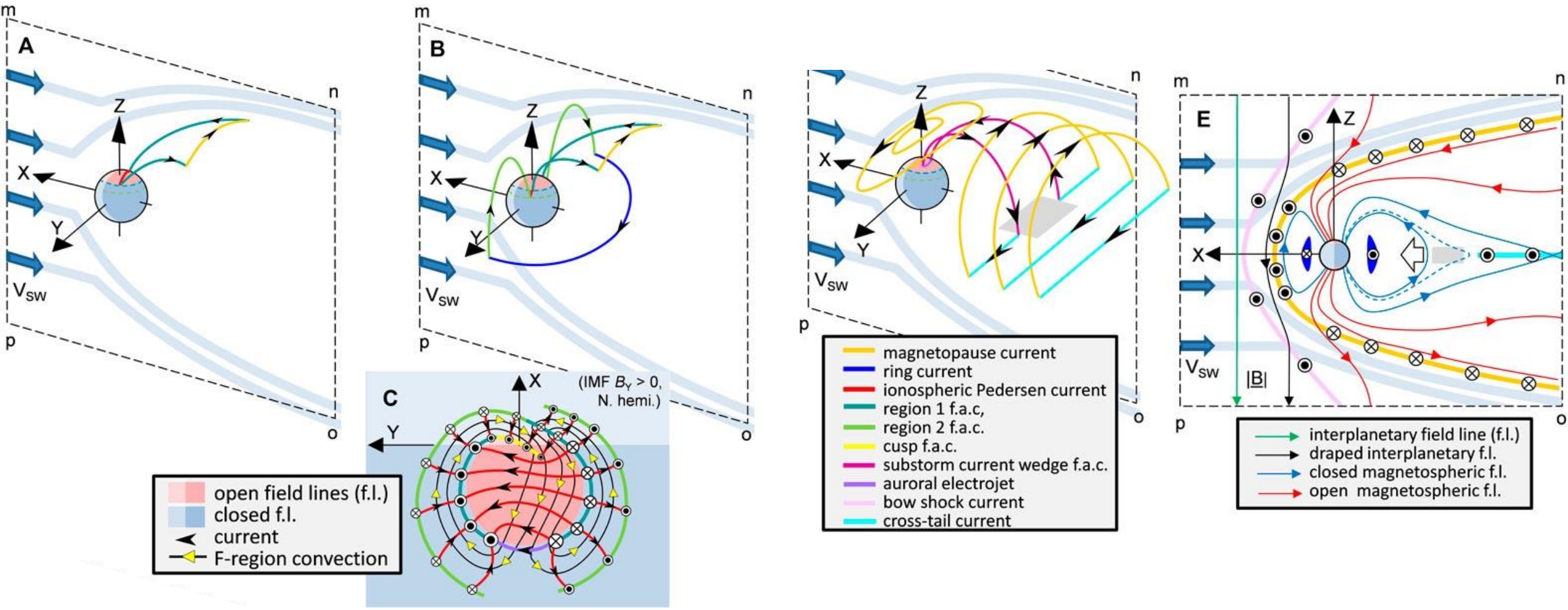
Φ_N = nightside reconnection rate!

$$\frac{dF_{PC}}{dt} = \Phi_D(t) \# \Phi_N(t)$$

$$R_{MP}/R_{planet} \sim 1.2 \{B_o^2 / 2 \mu_o \rho_{sw} V^2_{sw}\}^{1/6}$$

Slide from Fran Bagenal
2014 HSS lecture

	Mercury	Earth	Jupiter	Saturn	Uranus	Neptune
B_o Gauss	.003	.31	4.28	.22	.23	.14
R_{MP} Calc.	1.4 R_M	10 R_E	46 R_J	20 R_S	25 R_U	24 R_N
R_M Obs.	1.4-1.6 R_M	8-12 R_E	63-92 R_J	22-27 R_S	18 R_U	23-26 R_N



Lockwood (2022) Frontiers
"The Joined-up Magnetosphere"

QUICK EXERCISE: WHY SHOULD ___ LEARN ABOUT ___?

E.g. why should a magnetospheric physicist learn about the ionosphere or sun?

Pick the region seemingly least connected to your own research and think about how the two might interact or relate