The determination and hierarchy of scale sizes

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Introduce yourself to your neighbor and tell them the time and length scale of your particular area of research

- What structures and processes do you study?
- What are their temporal and spatial scales? (e.g., what units do you "think" in (m, km, Re, Mm, AU or msec, sec, min, hour, day, month, year, decade)?
- What physics is important or that you can neglect?

Conceptual Framework

- One organizing principle is structure and processes
- Magnetic Fields are important wherever there are plasmas!
- Magnetic fields contain energy, define plasma boundaries, particle motion and wave propagation (E&M and Alfvénic)
- Basic plasma parameters (Beta, Alfvén Velocity, plasma and particle frequencies) depend on B
- We live on a magnetic planet, in a magnetic solar system…. in a magnetic universe.
- So for this discussion, I will focus on scales of magnetic fields

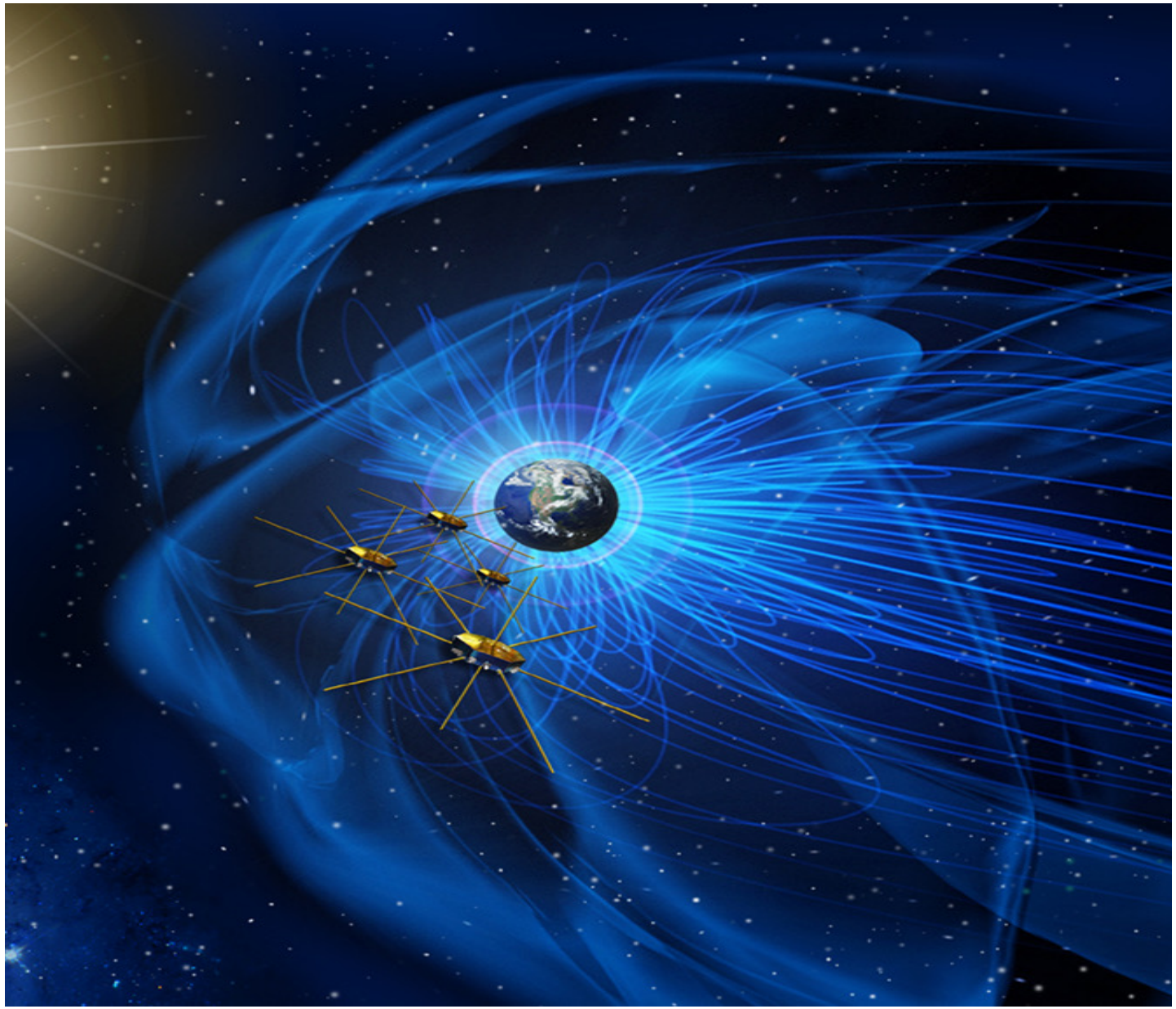
Three fundamental magnetic structures

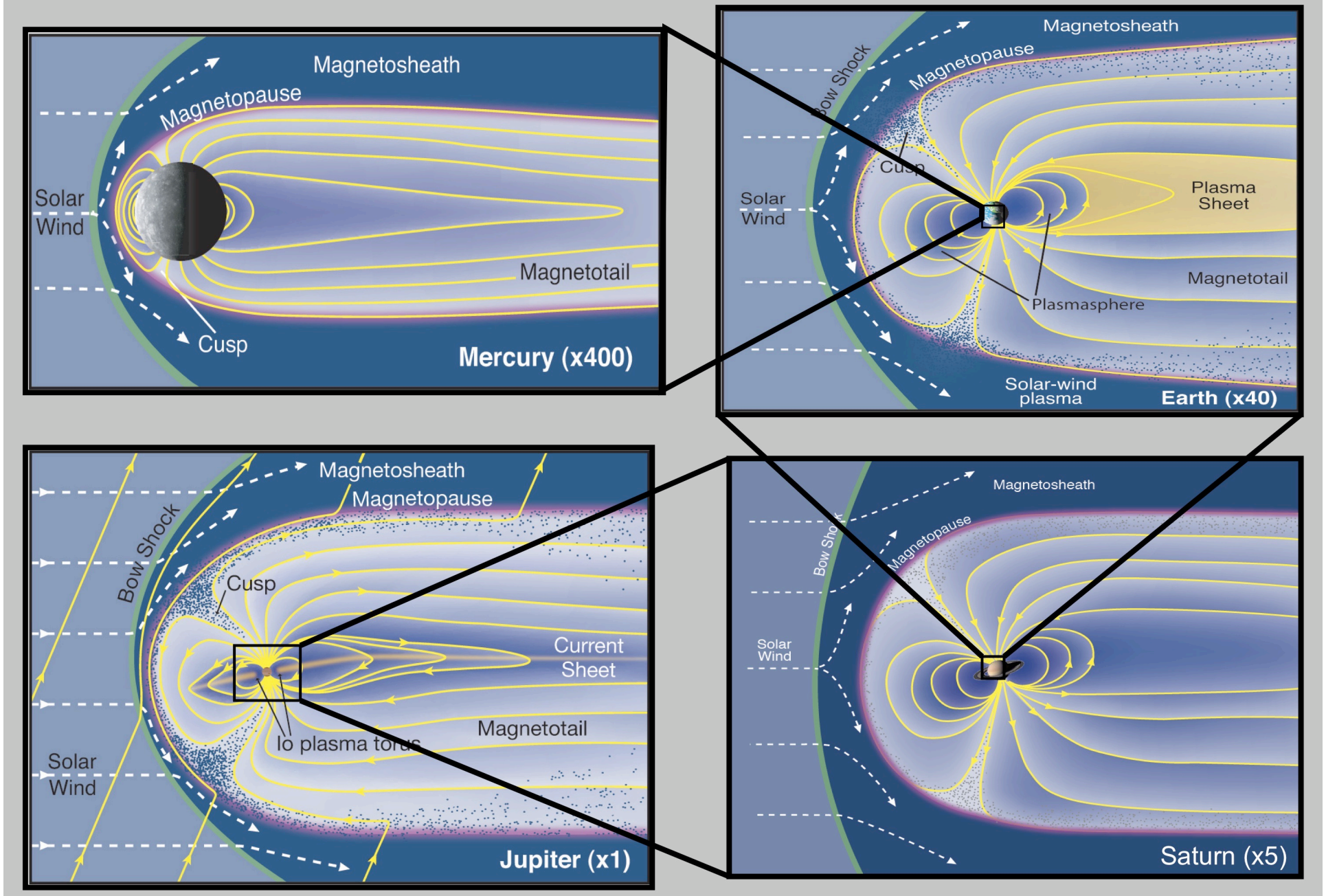
Cavities (magnetospheres)

Current Sheets

Flux Tubes

Moldwin et al., 2009



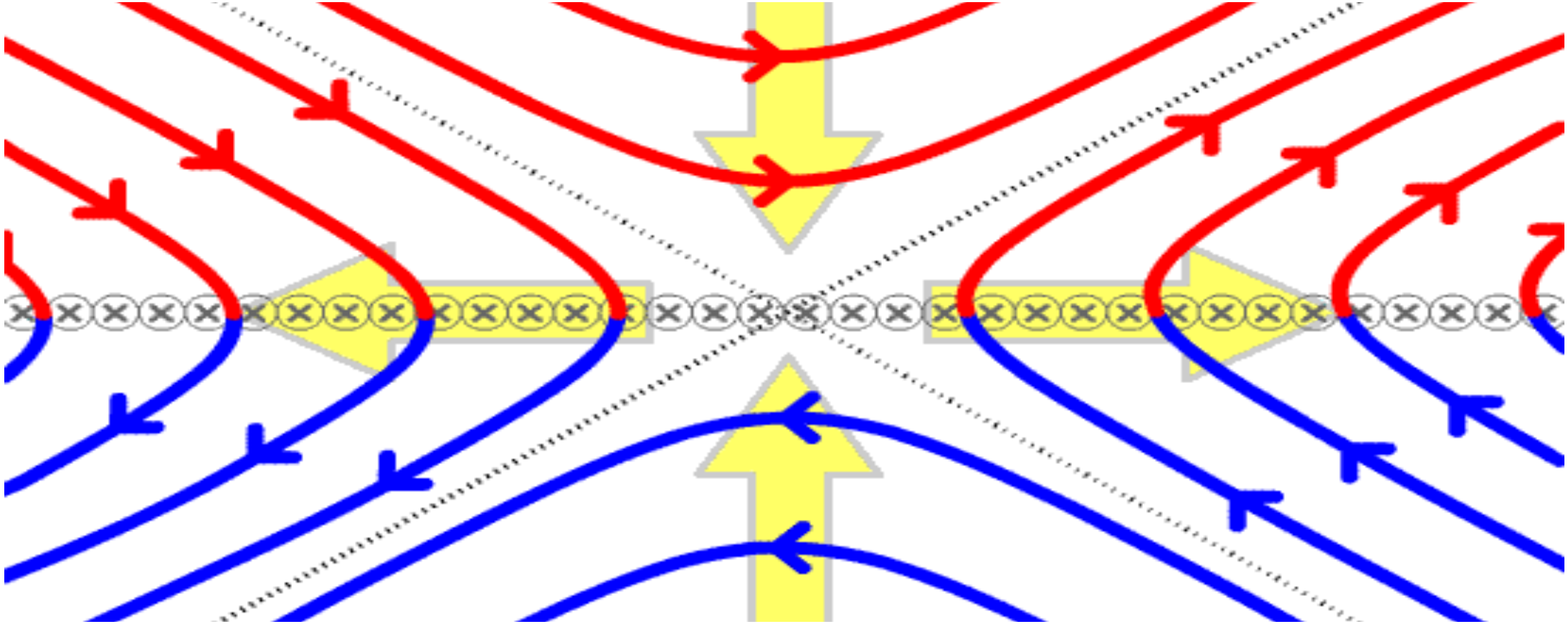

Magnetosheath
Magnetopause
Solar Wind
Magnetotail
Cusp
Mercury (x400)
Bow Shock
Plasma Sheet
Plasmasphere
Solar-wind plasma
Earth (x40)
Current Sheet
Io plasma torus
Jupiter (x1)
Saturn (x5)

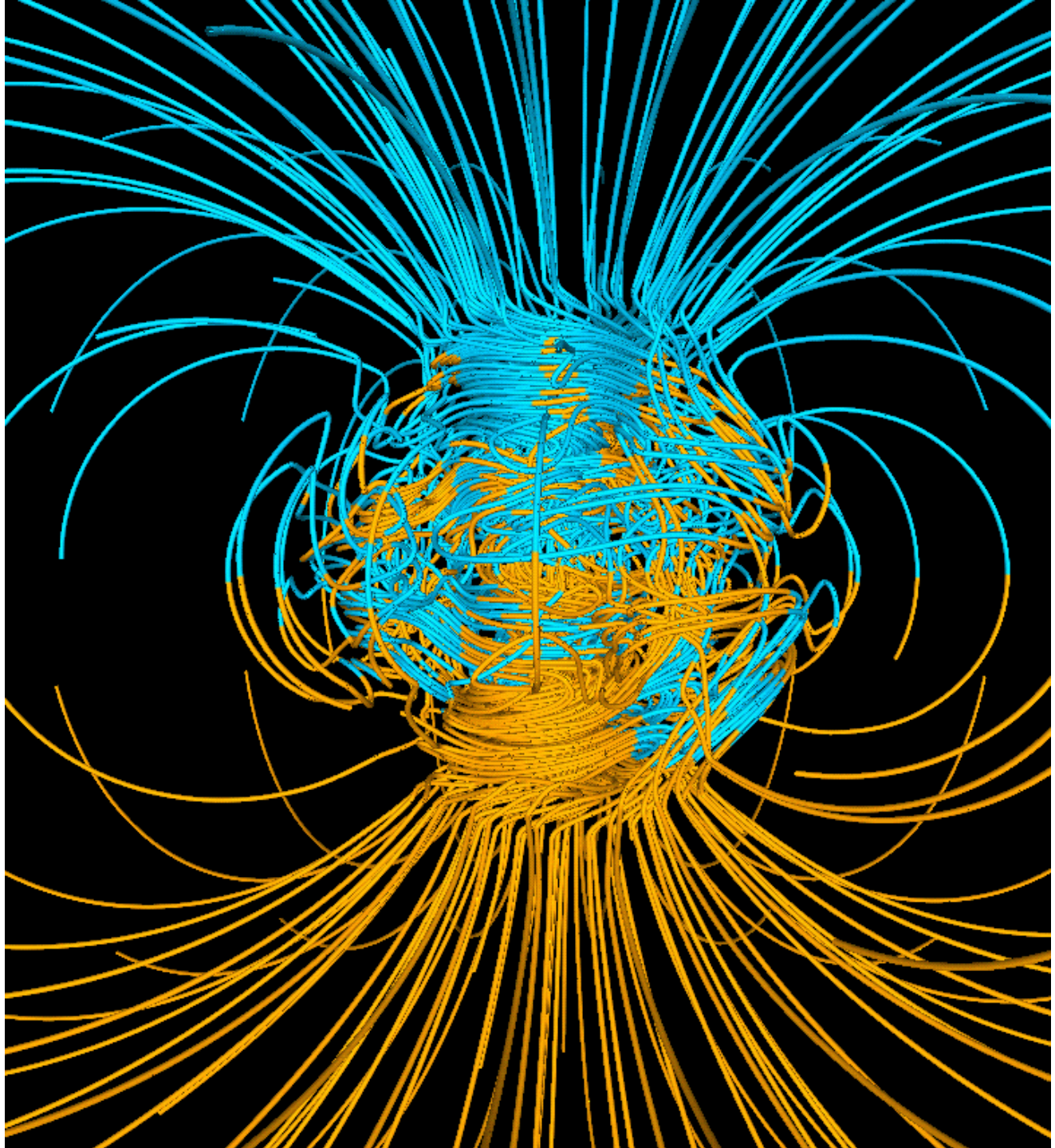
Magnetic Energy Evolution

$$U = \frac{B^2}{2\,\mu_0}.$$

$$\frac{\partial \mathbf{B}}{\partial t} = \eta \nabla^2 \mathbf{B} + \nabla \times (\mathbf{u} \times \mathbf{B})$$

RXN is the conversion of magnetic energy and change in topology of field





Creation and destruction of magnetic energy, flux, fields, pressure, tension gives rise to heliophysics structure and dynamics.

Magnetohydrodynamic Equations

Mass density (density and composition)
Velocity
Pressure (gas (nkT) and magnetic (B) and ram (ρV^2)
Fields E, B (DC and AC and waves)
Add Energy and radiation, chemistry etc.

You've seen these in your Space Physics and in HSS….

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = 0$$

$$\frac{\partial (nm\mathbf{v})}{\partial t} + \nabla \cdot (nm\mathbf{vv}) = -\nabla \cdot \mathbf{P} + \rho\mathbf{E} + \mathbf{j} \times \mathbf{B}$$

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \eta\mathbf{j} + \frac{1}{ne}\mathbf{j} \times \mathbf{B} - \frac{1}{ne}\nabla \cdot \mathbf{P}_e + \frac{m_e}{ne^2}\frac{\partial \mathbf{j}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0\mathbf{j} + \mu_0\epsilon_0\frac{\partial \mathbf{E}}{\partial t}$$

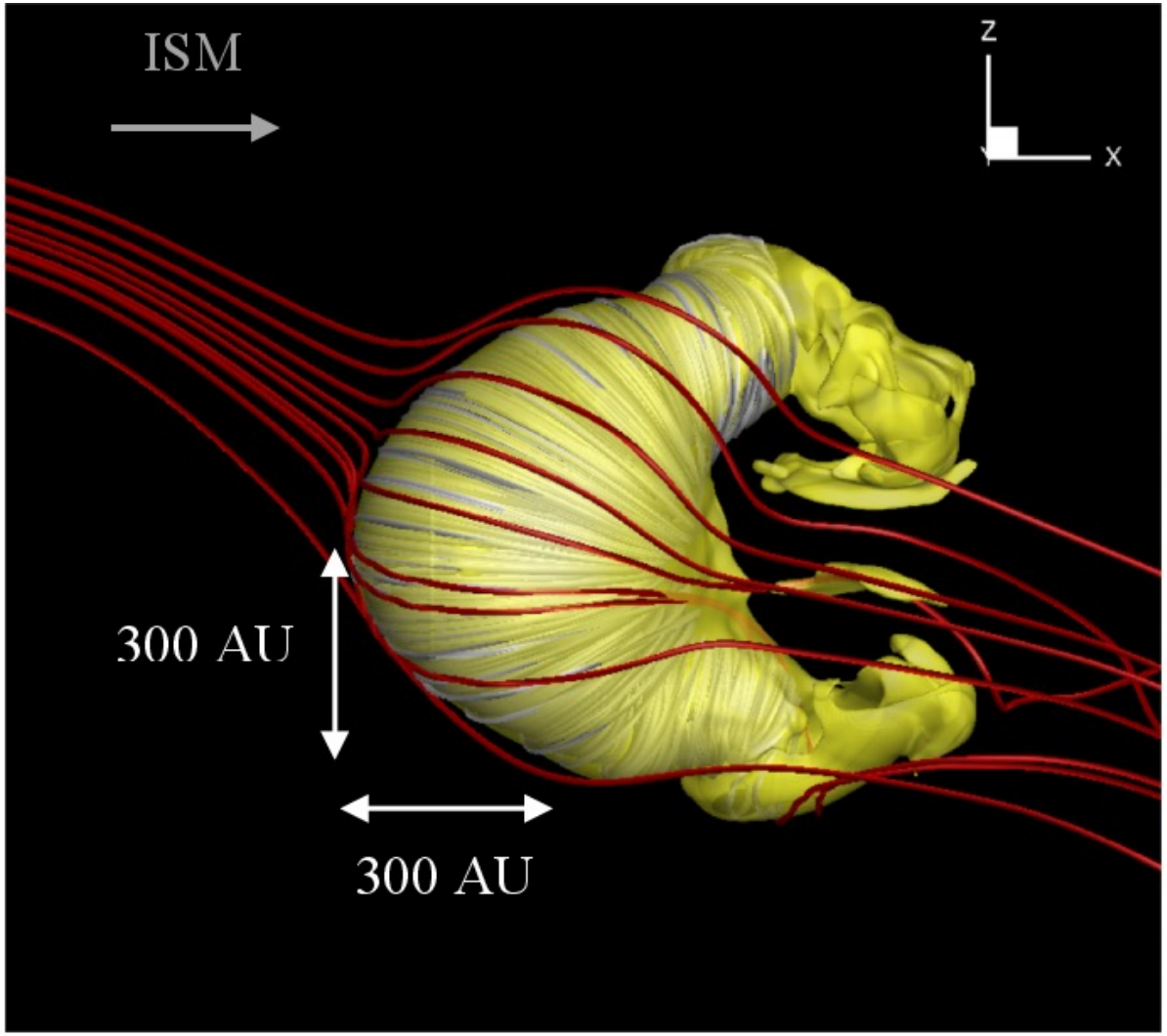
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0$$

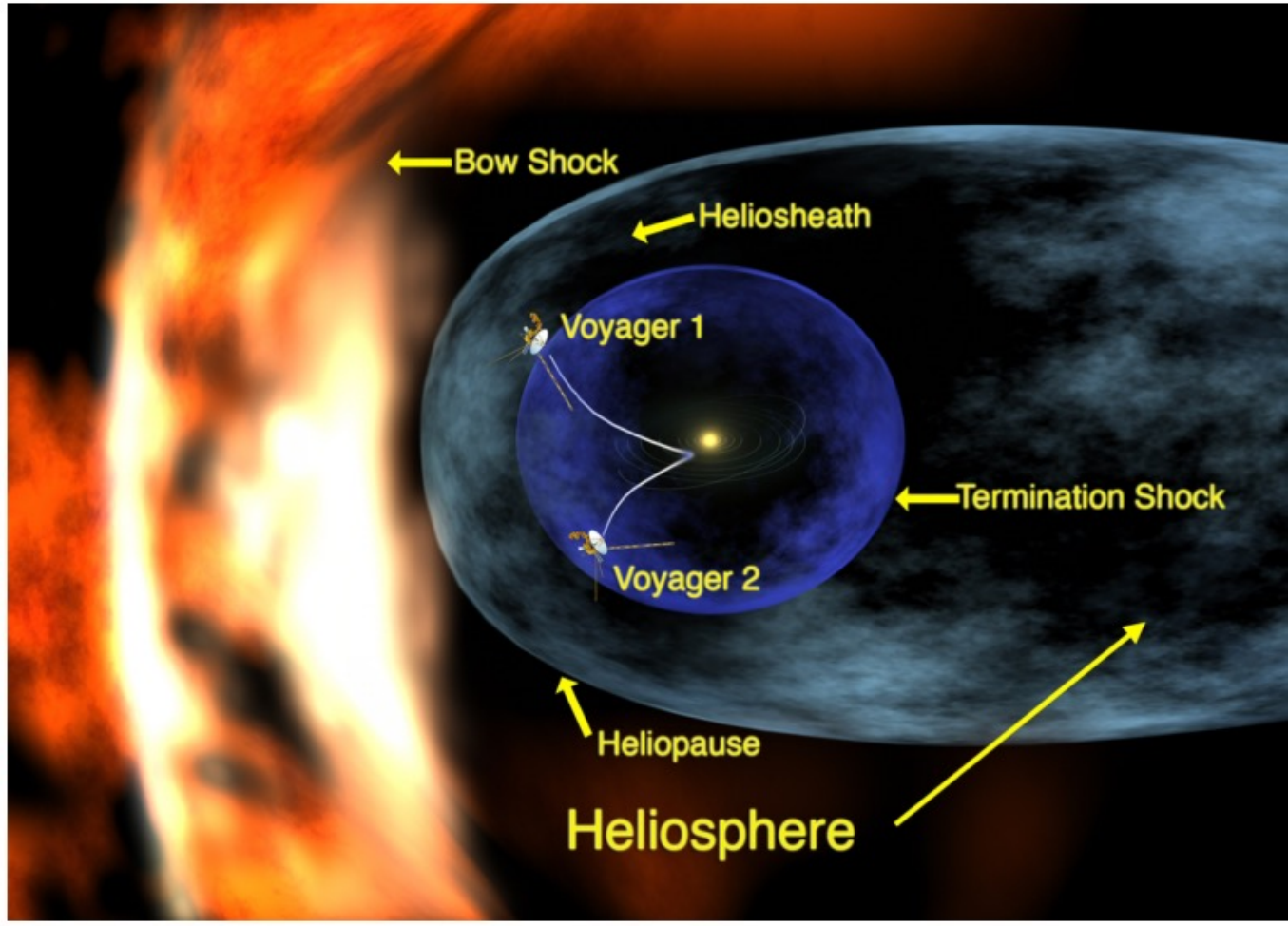
How do you measure scale size of magnetic fields in the solar wind?

- Tell neighbor overall structure of IMF
- What are the time and space scales of the IMF?

- How do we know?



(A)

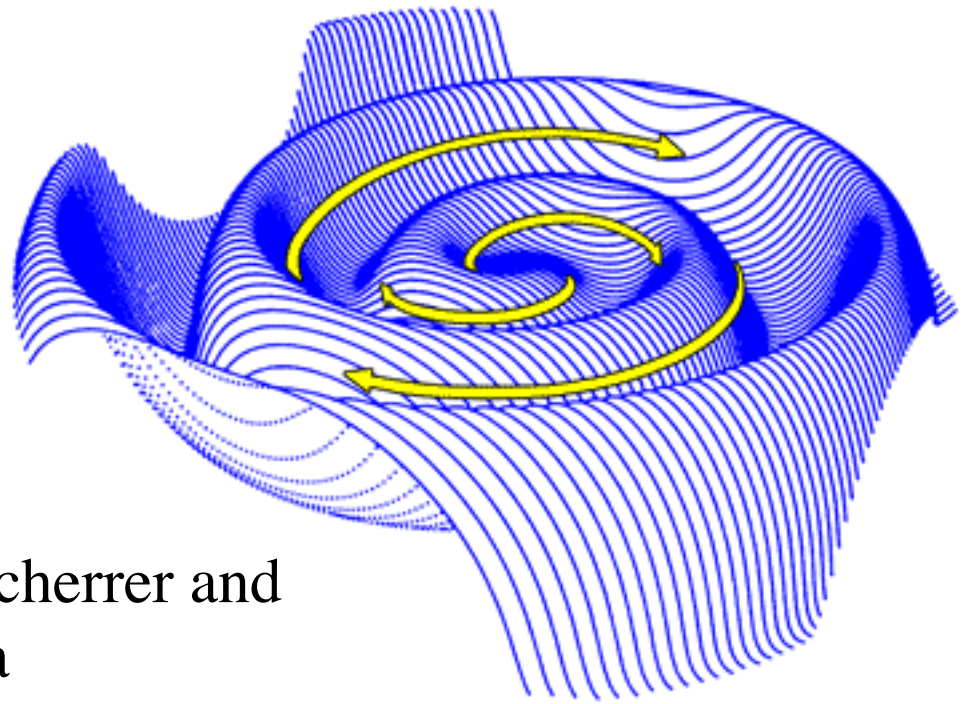


(B)

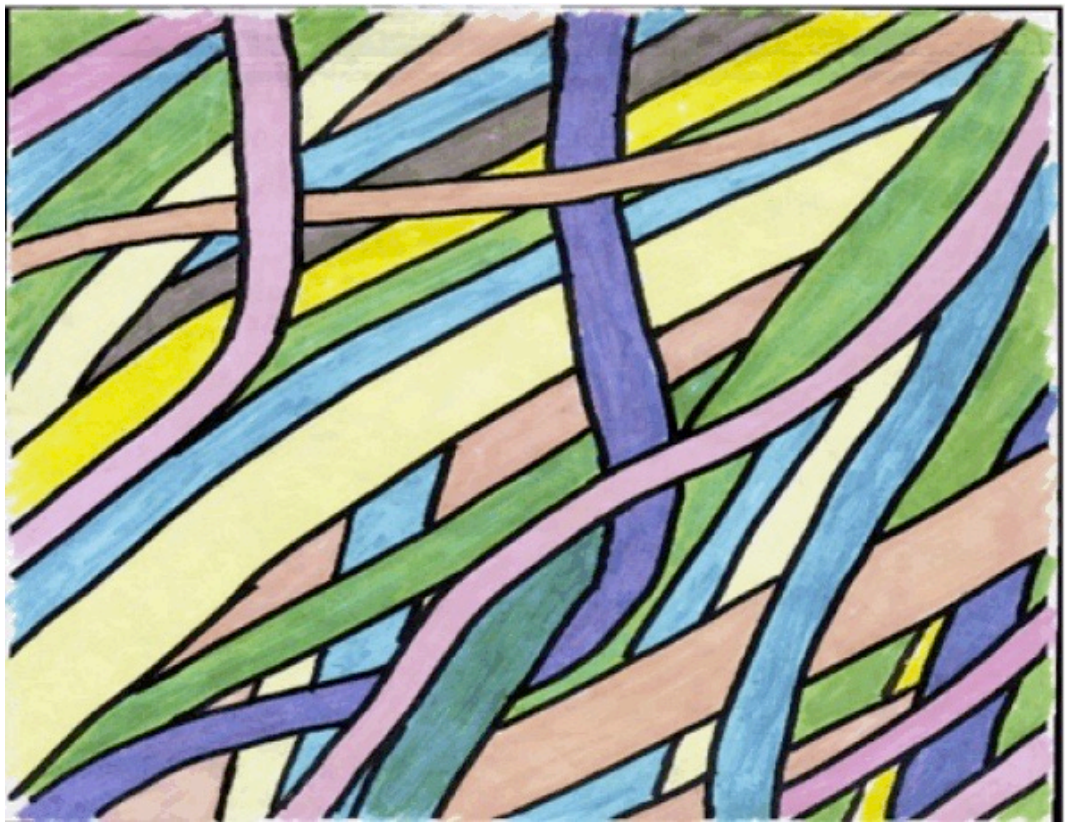
Opher et al., Nature, 2020

IMF Structure

- Cavity (heliosphere)
- Current Sheet
- Flux Tube



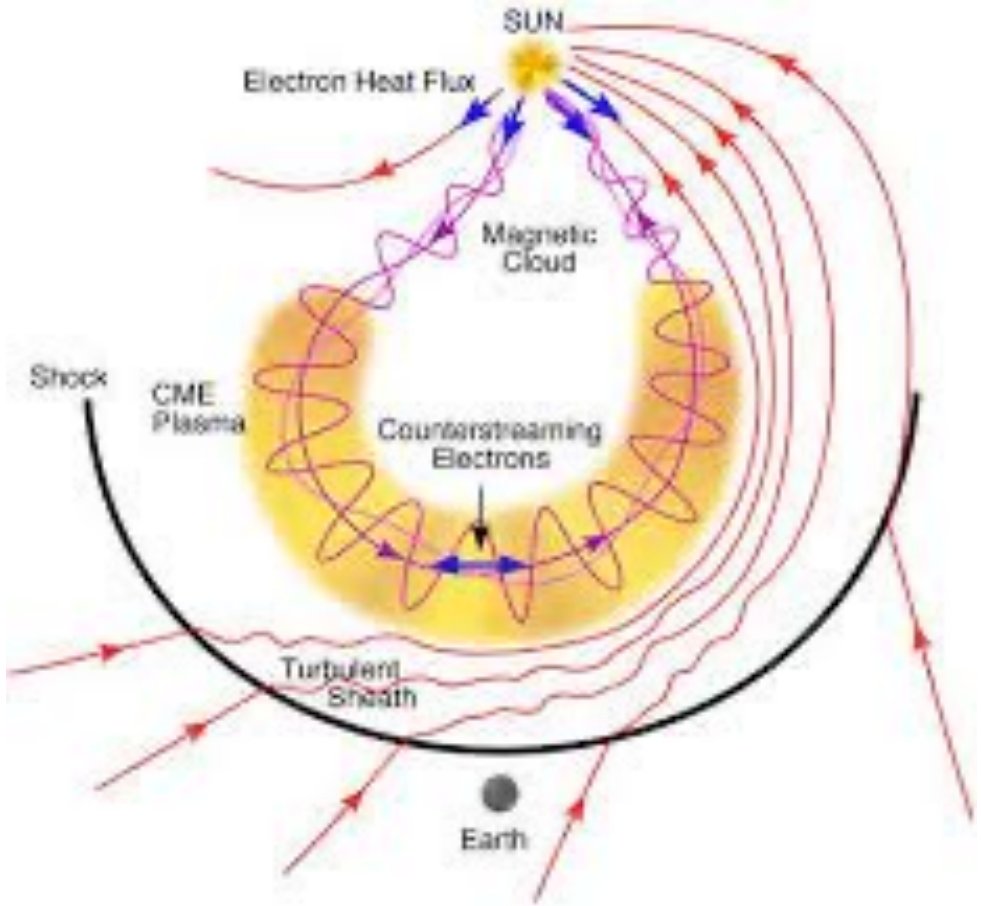
Wilcox, Scherrer and Hoeksema



Borovsky, JGR, 2008

Transients

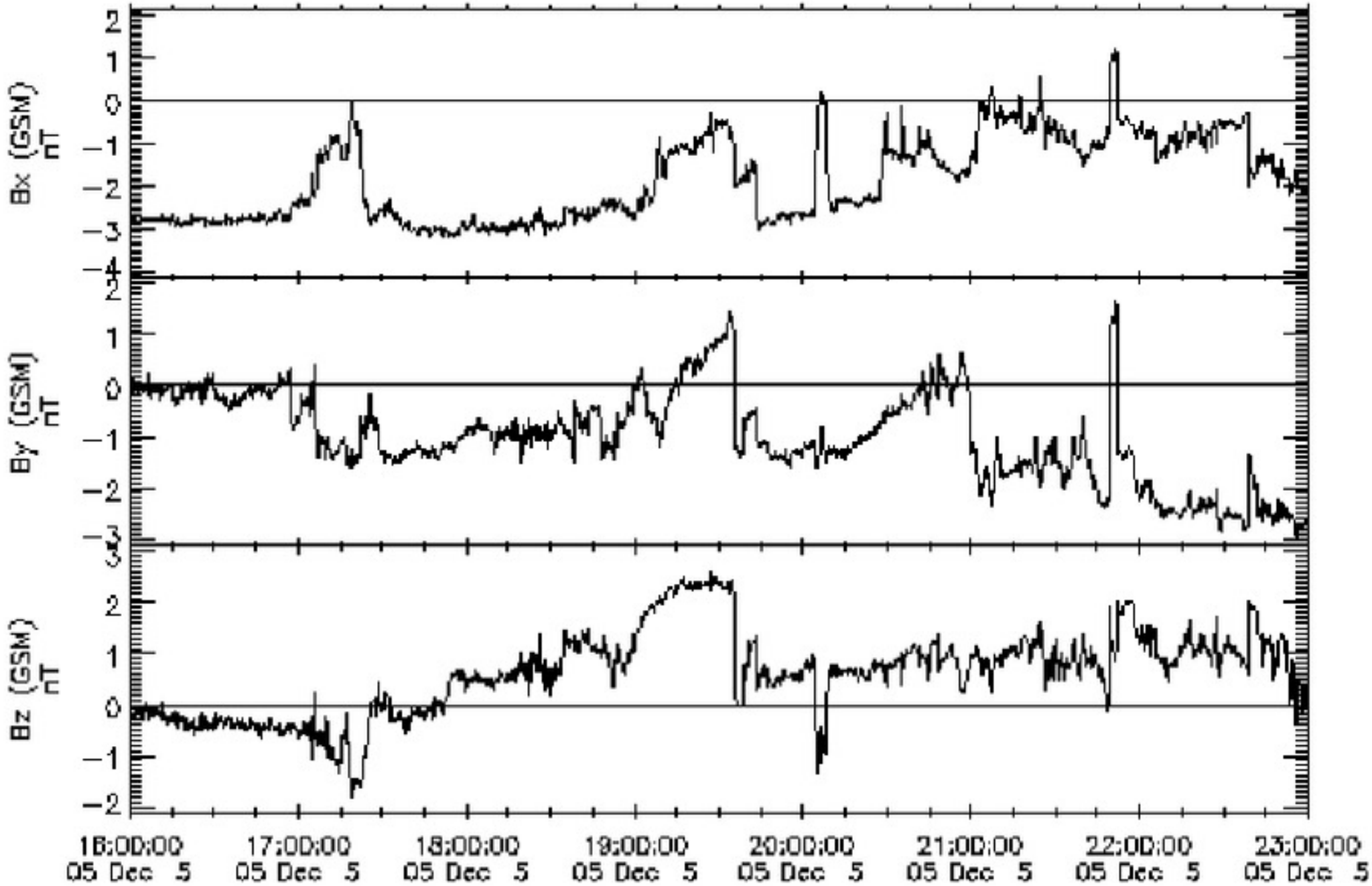
- CMEs, magnetic clouds, sheaths
- Flux ropes
- Shocks and interaction regions
- Discontinuities and rotations
- Turbulence



Lepping et al., 1990

What can you determine with one spacecraft?

- What dimension (space and time) can you measure?
- What assumptions?


Bx (GSM)
nT
By (GSM)
nT
Bz (GSM)
nT
2
1
0
−1
−2
16:00:00
05 Dec 5
17:00:00
05 Dec 5
18:00:00
05 Dec 5
19:00:00
05 Dec 5
20:00:00
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21:00:00
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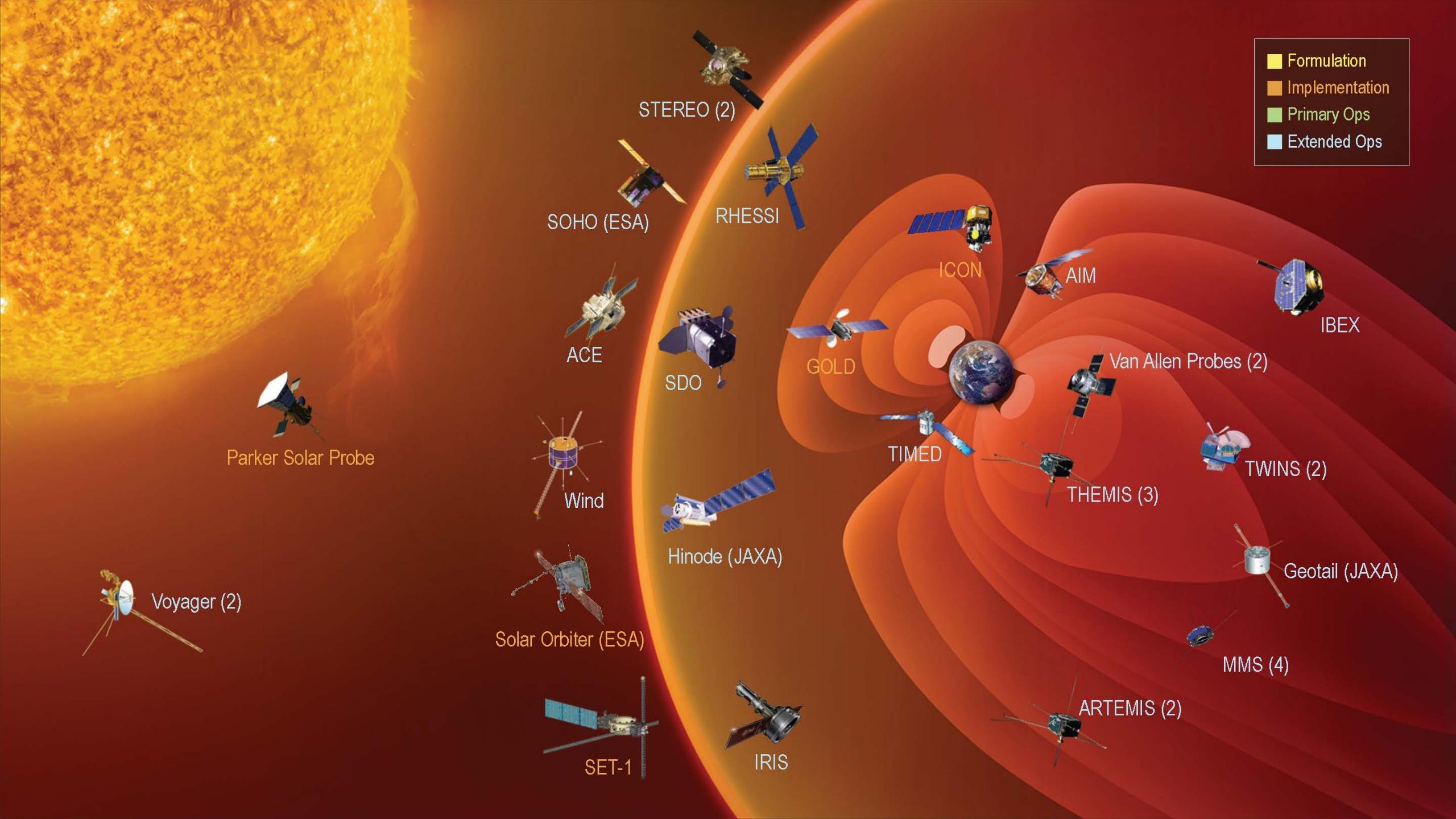
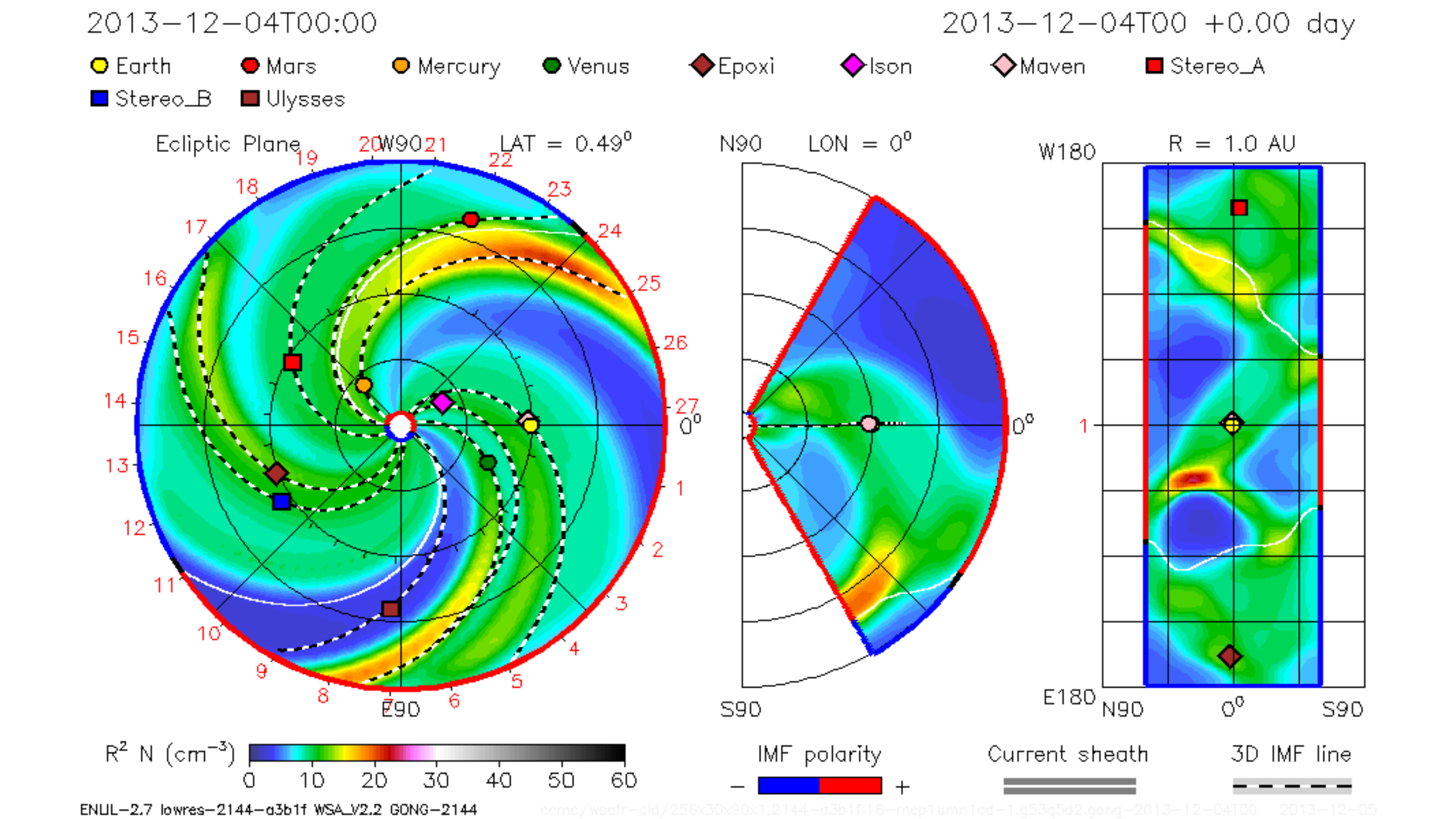

Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
SOHO (ESA)
RHESSI
ICON
AIM
IBEX
ACE
SDO
GOLD
Van Allen Probes (2)
Parker Solar Probe
Wind
TIMED
TWINS (2)
THEMIS (3)
Hinode (JAXA)
Geotail (JAXA)
Voyager (2)
Solar Orbiter (ESA)
MMS (4)
ARTEMIS (2)
SET-1
IRIS

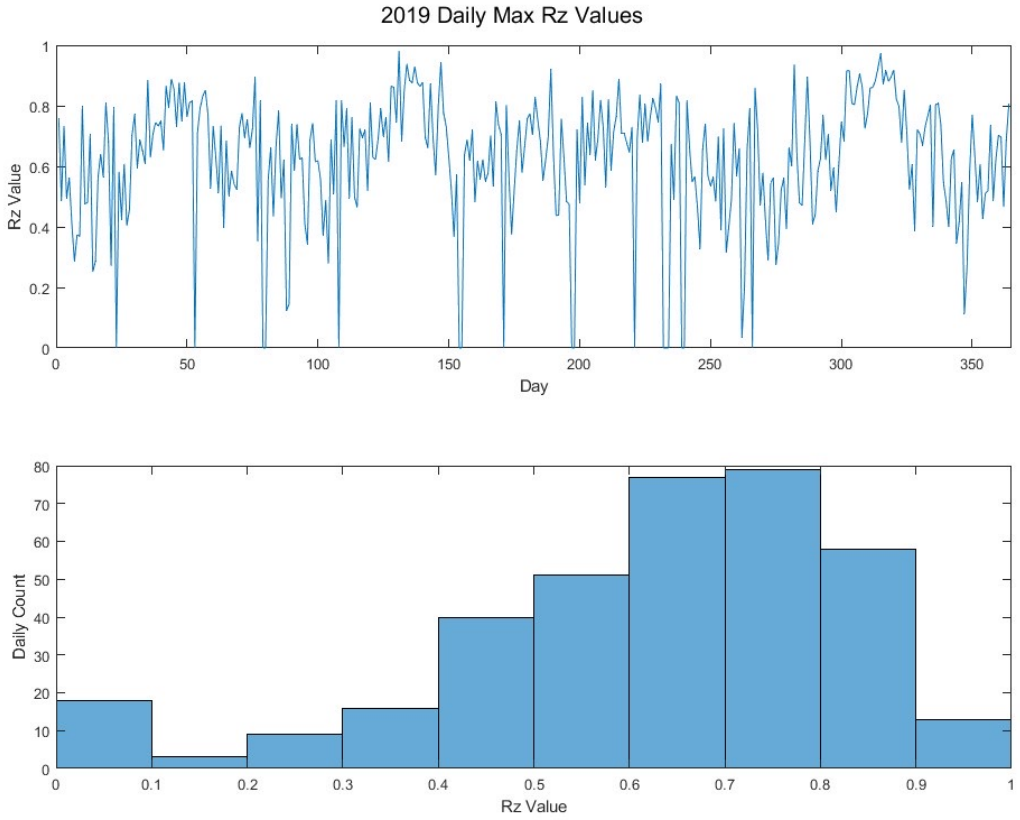

2013-12-04T00:00
2013-12-04T00 +0.00 day
Earth
Mars
Mercury
Venus
Epoxi
Ison
Maven
Stereo_A
Stereo_B
Ulysses
Ecliptic Plane
W90
LAT = 0.49°
E90
N90
LON = 0°
S90
W180
R = 1.0 AU
E180
0°
R² N (cm⁻³)
0
10
20
30
40
50
60
IMF polarity
Current sheath
3D IMF line
ENLIL-2.7 lowres-2144-a3b1f WSA_V2.2 GONG-2144

What can you measure with two or more satellites?

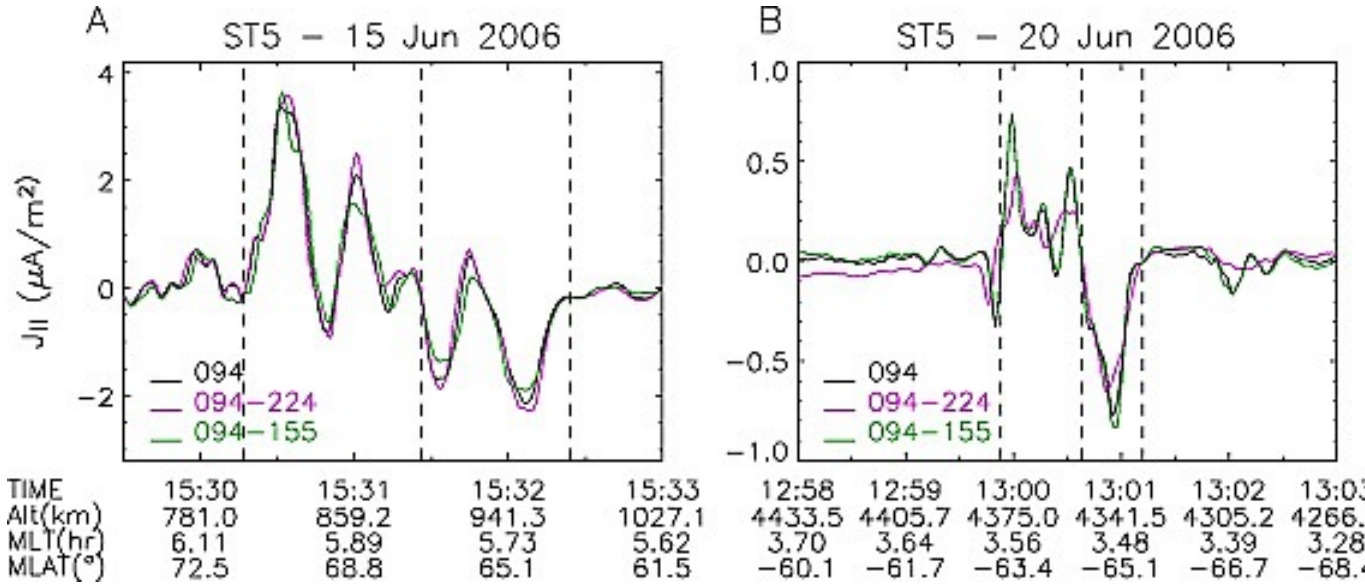
- What dimension (space and time) can you measure?
- What assumptions?

De-tangling time and space and correlations

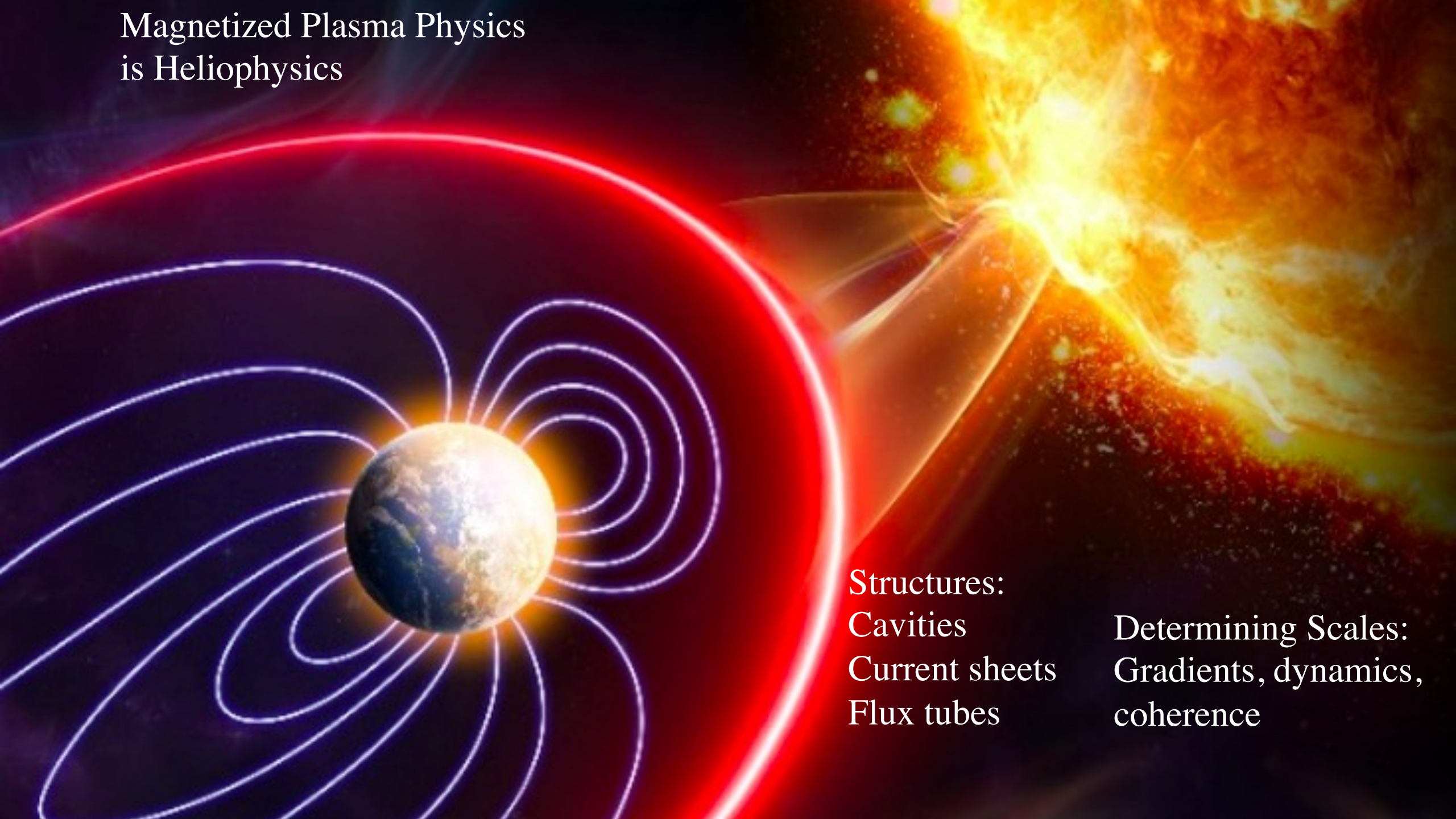
Correlation length scales: Wind and Ace of IMF Bz at L1



Space – Time detangle (gradient or time change or both?)



Magnetized Plasma Physics
is Heliophysics



Structures:
Cavities
Current sheets
Flux tubes

Determining Scales:
Gradients, dynamics,
coherence