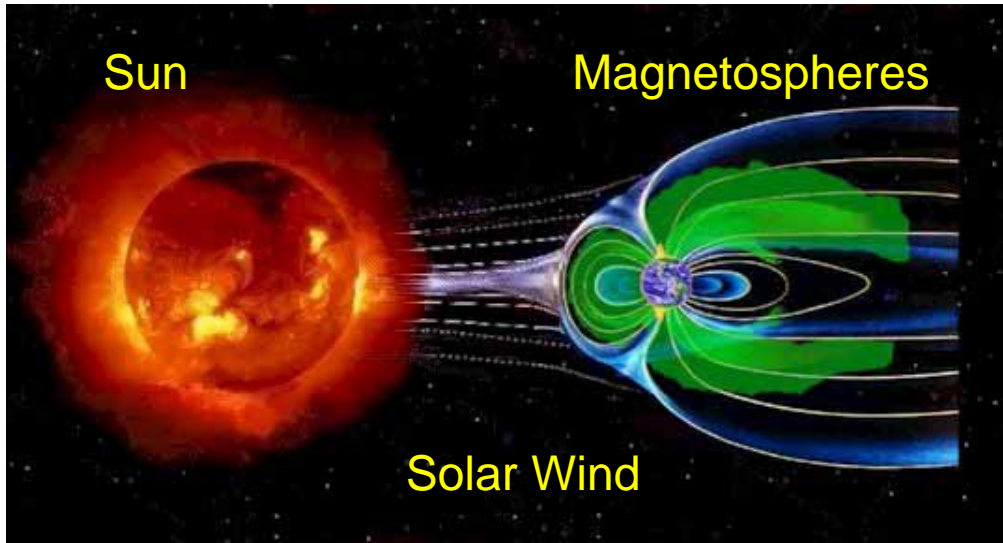


From Sun to Earth and beyond, The plasma universe

Study of the 'hot' solar system...



... a science of strongly coupled objects,
media and basic plasma processes

Philippe LOUARN
CESR - Toulouse

Science of Complex Interactions...

Axis 1. Fundamental Processes

Acceleration, Plasma instabilities...

'Cold' matter: **Structural complexity.**

'Hot' matter: **Spatial/temporal complexity.**

Enormous variety of dynamical modes.
-> OUR 'MOLECULES'

'Plasma processes': Consequences of the coupling of these dynamical modes.

Axis 2. Physics of environments

Interactions between the layers:

- of planetary environments

-of solar atmosphere, interplanetary medium

Structure and dynamics of 'plasma' objects

Axis 3. Long term evolutions of environments

Atmospheric loss

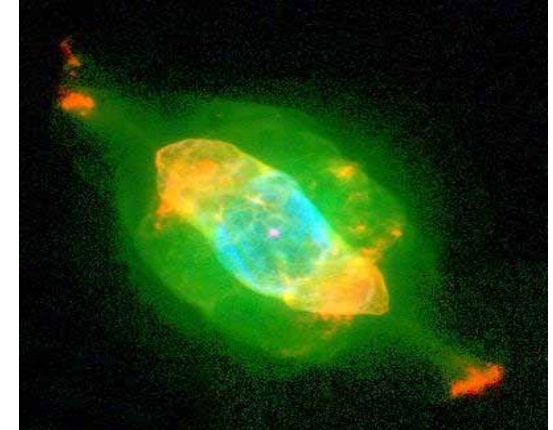
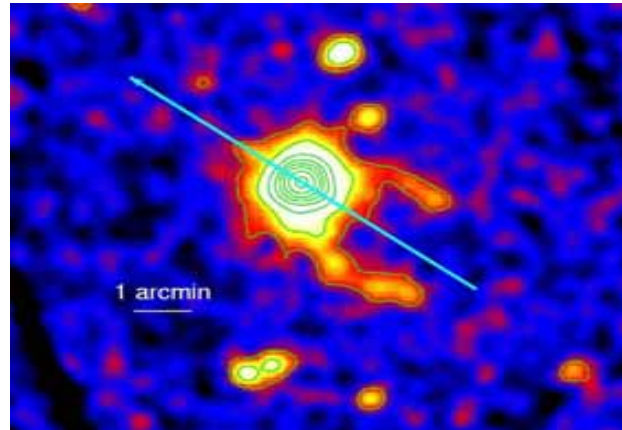
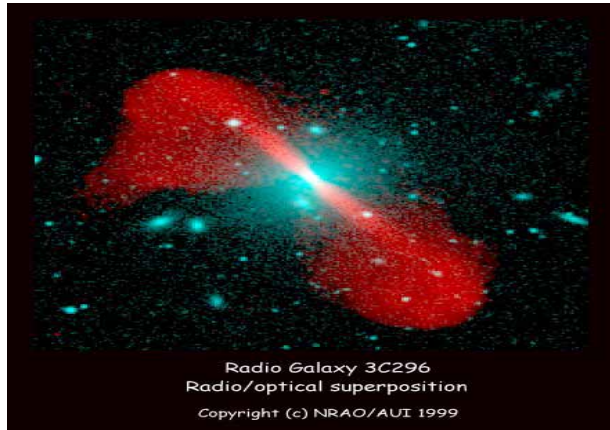
Global Sun/Earth, Sun/planets systems

Space weather, 'Living with a star'

Large variety of topics ...

Planetology: Specificities of environments with/without B, Atmosphere, Gravity
(comets). *Structure ? Dynamics ? small scale processes ?*

Astrophysics: Structure of jets, discs... Explosive energy releases.
Dynamics, organization of diffuse media. *Energy conversion, Accelerations ?
Loss of mass, of angular momentum ? Multi-phase interactions ?*



Exobiology: Life: a consequence of a 'special' relationship between a source of energy (*star*) and a 'world' (*planets*). *How potentially destructive sources of energy can be an essential element for the creation of complex system... and life ?*

Sun/Earth : A question with social implications...

MESSAGES FOR 2015-2025

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graph TD; A[MESSAGES FOR 2015-2025] --> B[EXPLORE!]; A --> C[QUANTIFY!];
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EXPLORE!

Giant Planets, Go to the
Outer Solar System

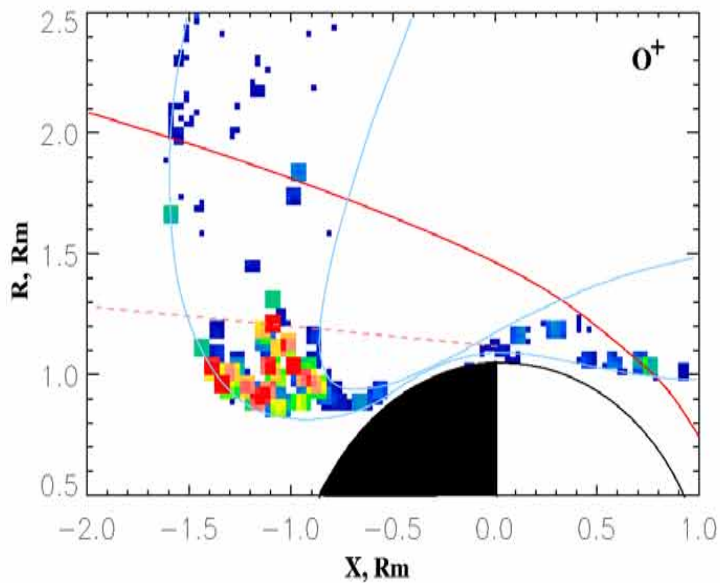
QUANTIFY!

Micro/Macro Physics Coupling
and Multi-Scale Interactions.
3 D Topologies
Extreme Energetic Processes

EXPLORE !

Space exploration, observations from space are fundamental sources of discoveries, new questions, inspirations...

- **3D Heliosphere.** *Out of ecliptic exploration, The different solar winds.
How a central object, its surface and atmosphere determine the properties of its most distant environment ?*
- **Cometary environments.** *Specificities of complex media in absence of gravity.
Multi-phase interactions? inter-penetration of ionized/neutral media ?*
- **A 'new' Sun.** (*Soho*)
- **3D probing of plasma processes** (*Cluster*).
- **Planets with/without atmosphere, intrinsic B.** (*Mars, Venus, Mercury*)
- **Saturn.** *Plasma/ring interactions, Fast rotation*



MarsExpress: Interaction between solar wind and Martian atmosphere.
(Aspera Exp.)

Different regimes of SW/planet interactions and ion escaping ?

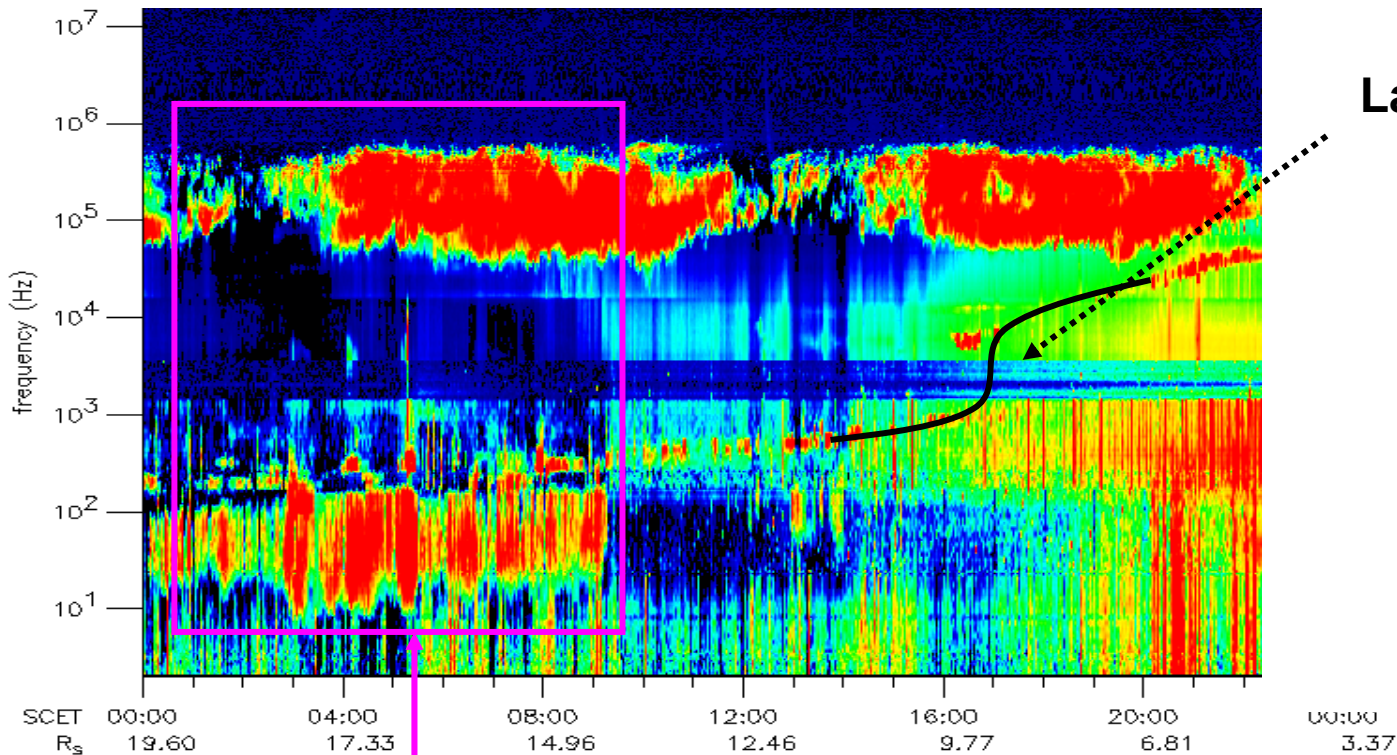
How the long term interaction between the solar wind and a planet could modify its atmosphere ?

- (1) Solar wind/obstacles interactions
- (2) Different aspects of sputtering, Plasma/neutrals interactions

Recent example - Giant planet

Cassini: - The study of the very complex environment of Saturn just begins.

First day in magnetosphere (28/06/2004) RPWS exp.



Large increase of density
(E ring ?)

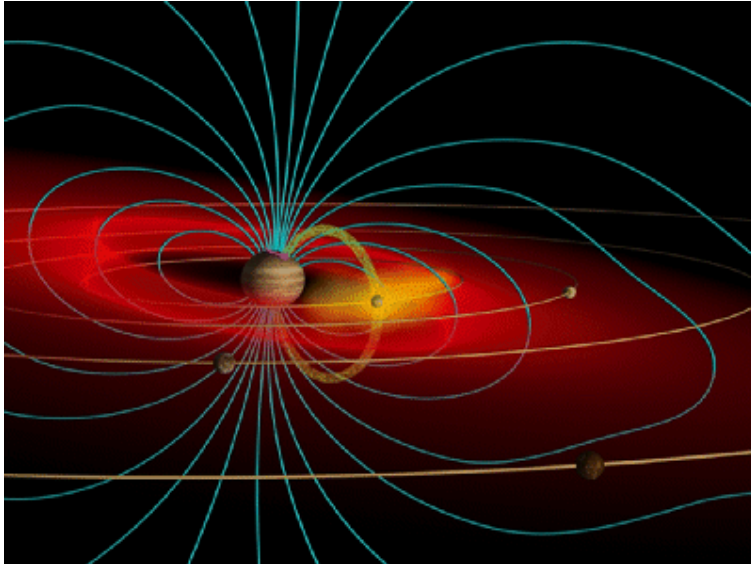
Specific plasma/matter interactions ?

Pulsations: Specific activity of a magnetosphere in fast rotation...

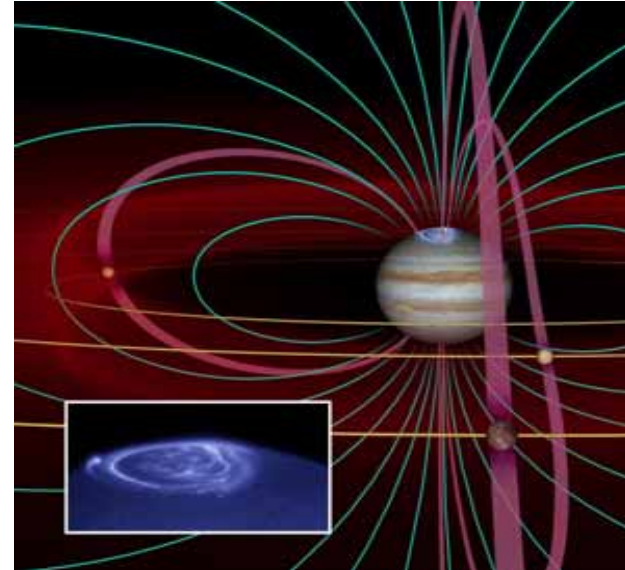
The potential of discovery of space physics is demonstrated at each new exploration of objects and environments.

After **Bepi Colombo** and **Solar Orbiter** (Inner solar system):
Explore the outer Solar System

Jupiter: System in rapid rotation with prolific plasma sources.



A situation dominated by rotation.
Instabilities of torus and disc of plasma

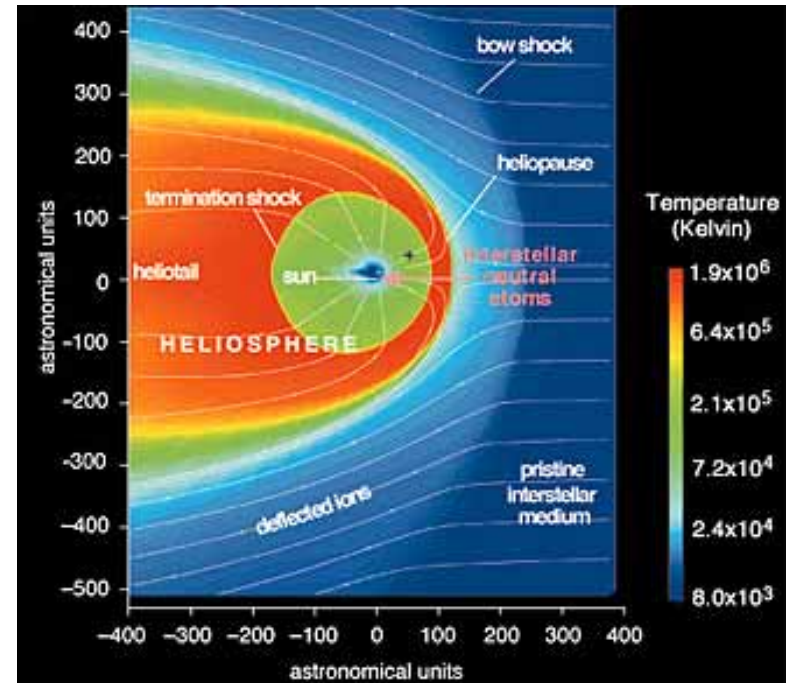
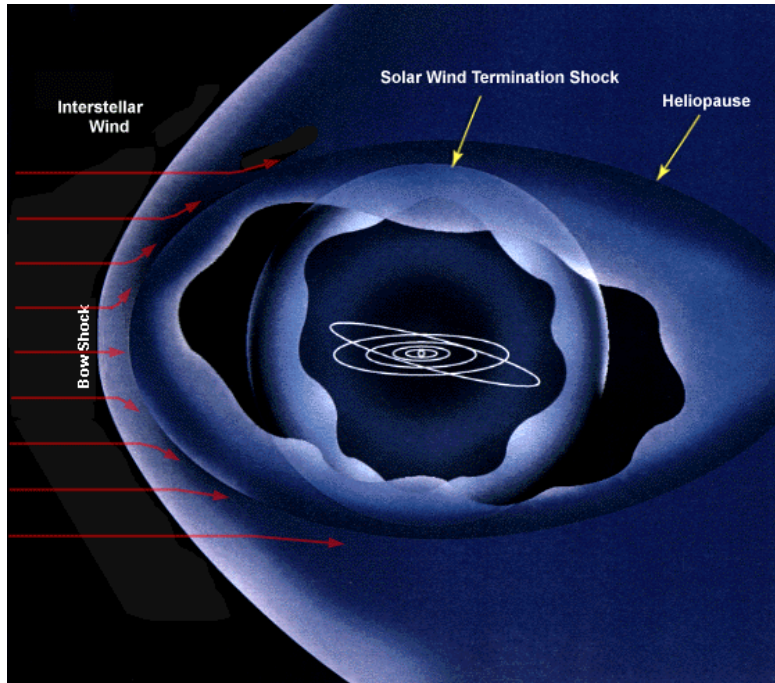


Specific satellites /magnetosph.
interactions- *Io, Europe, Ganymede*

Wonderful source of inspirations for understanding complex planetology and astrophysical situations. *Similar to binary system, pulsar...*

Direct in situ studies of radial transport of matter, loss of angular momentum and associated processes (specific instabilities, acceleration, radiations), interactions with very different satellites...

Heliospheric boundaries: Our more distant frontiers.



Interactions between ions, neutrals, cosmic rays, B field and plasma structures !

What are the characteristics of the heliosphere/galaxy interactions ?

What are their manifestations? Effects on objects and media in solar system ?

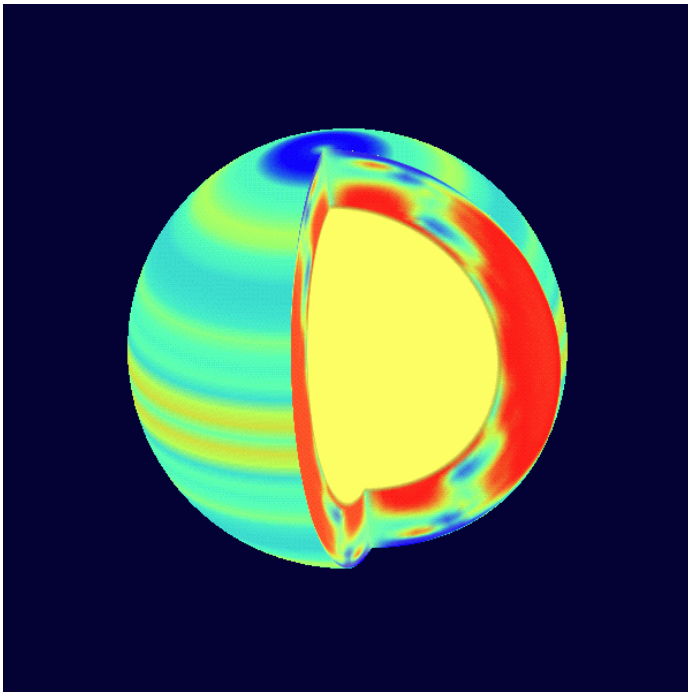
Link with fundamental physics (Pioneer effect).

EXTREME EXPLORATION
(don't forget inner corona...)

QUANTIFY !

Recent Lessons

SOHO completely renews our views about the structure, the dynamics and the activity of the Sun and its external layers.



Velocity variations in internal layers.

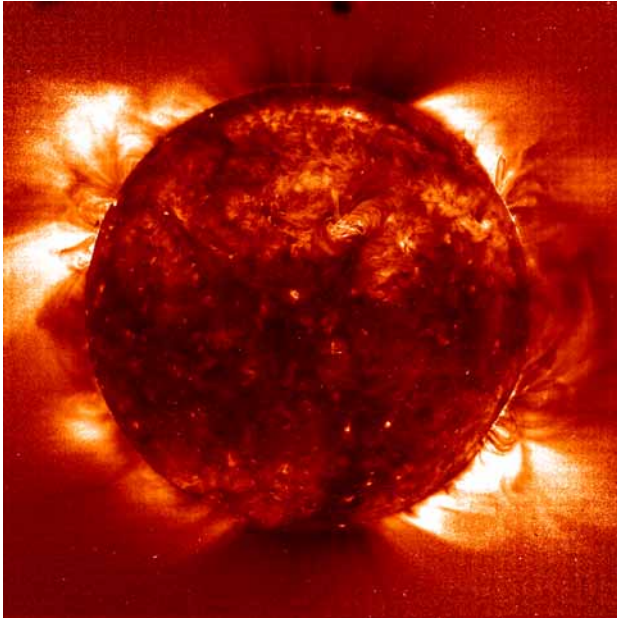
Very structured inner regions:

- 3D organization and diversity of the scales in the flow velocity field.
- Importance of thin velocity shears in magnetic field generation (tachocline).

Dynamics of thin layers: a crucial element in the regulation of solar cycles and magnetism.

How does the fine flow structuring determine the most global spatial/temporal organization?

Extraordinary variety of phenomena in external layers



-Activity crucially linked to the magnetic organisation. Importance of magnetic reconnection.

-Diversity of the 'modes' of ejections of the coronal plasma. Fast/slow winds.

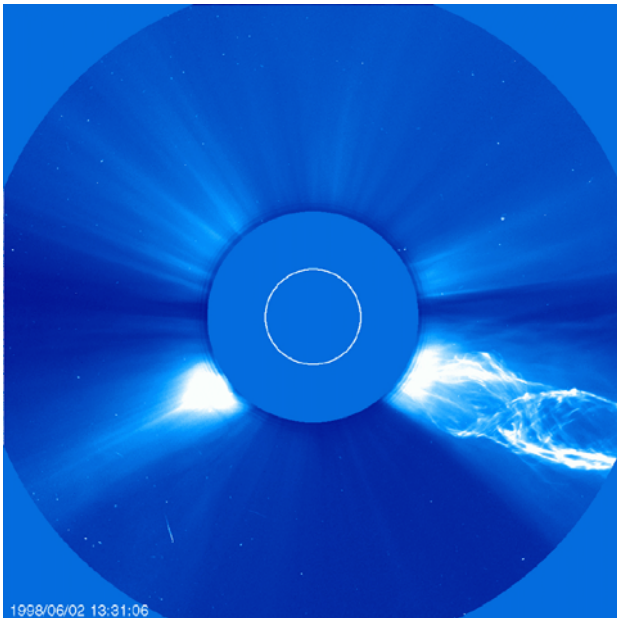
The 3 D topology (B,V...) is a fundamental element for the coronal dynamics.

Link between topological organization and the diversity of energetic processes ?

-Amazing efficiency of acceleration processes (not only Soho: Radio, X and Gamma, Rhessi...)

Extreme energetic phenomena...

Origin ? Specific processes ?

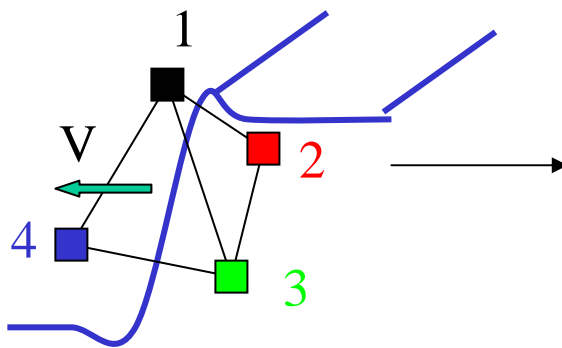


CLUSTER - A revolutionary tool for the analysis of basic plasma processes.

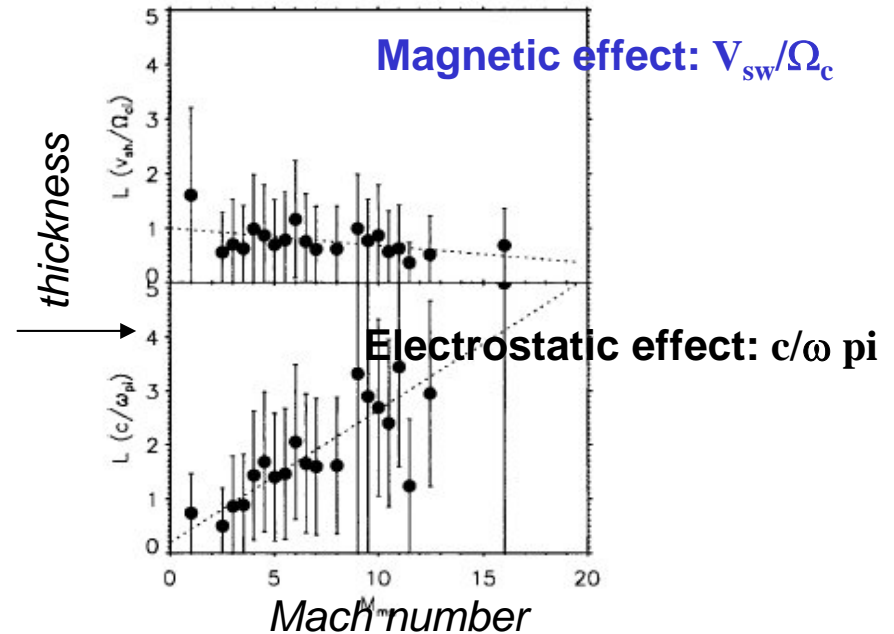
Example 1: Dissipation scales

Basic difficulty of collisionless plasmas: No 'equation of state'. 'Averaged' processes (resistivity, viscosity..) have almost no meaning

Classical media: Fine structure of shock \sim mean free path of particles - **What is this scale in a collisionless plasma ?**

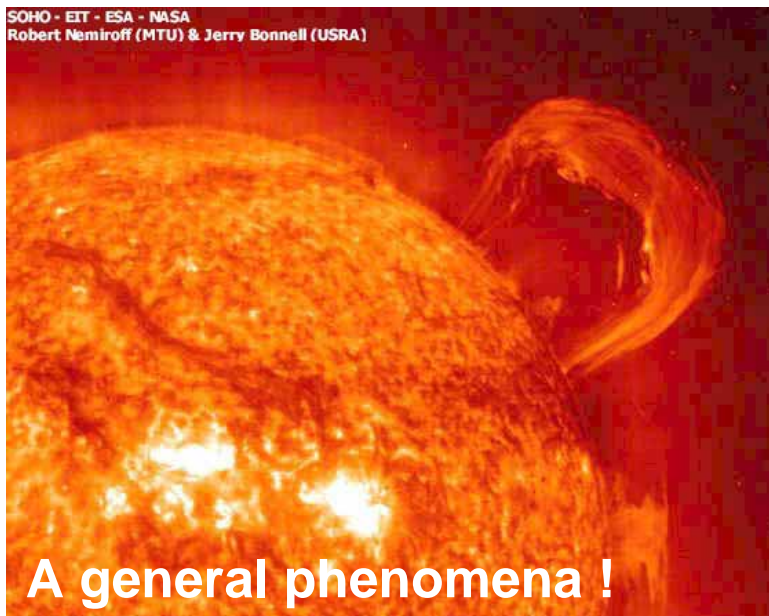
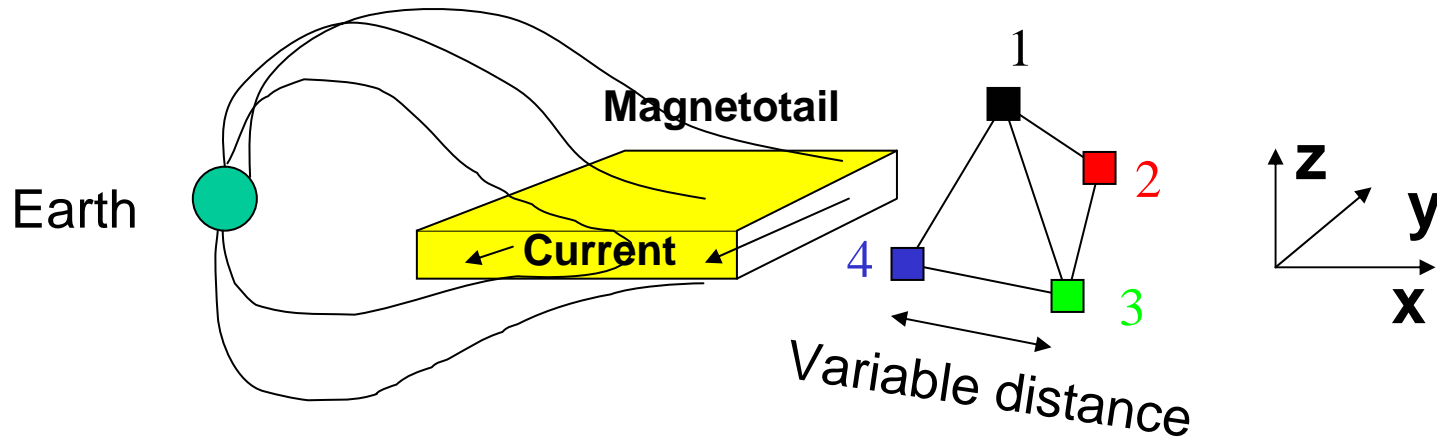


Accurate estimate of V and the shock thickness



Determination of scales of irreversible energy transformations
OK for this 1D example. What are these scales in 2D, 3D ?

Example 2: Physics of magnetic reconfiguration. *How far are we from the complete description of the phenomena ?*

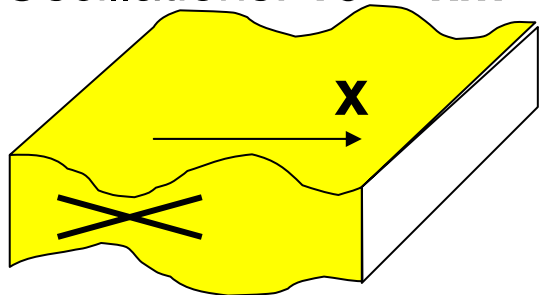


Adapting the Cluster interspacecraft distances (over periods of months...)
studies at successive scales.

(2001) 2000 km, (2002) 4000 km, (2003) 200 km

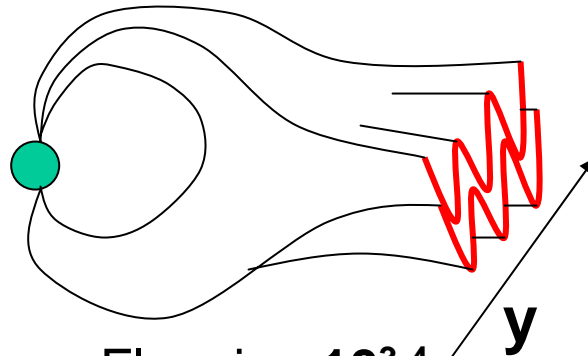
Reconfiguration: Different aspects are being determined

Oscillations: 10^{4-5} km (MHD)

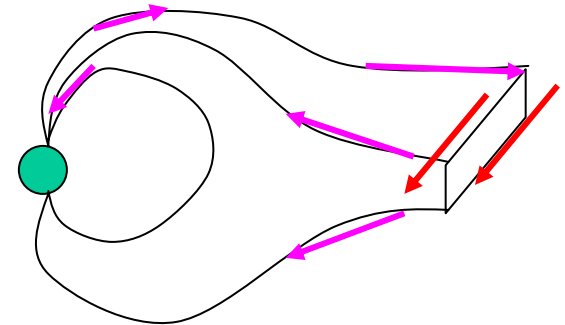


Reconnection
10-100 km
(Electron scale)

still not explored



Flapping 10^{3-4}
km (Ions ?)



Global scale
electrodynamics
 10^6 km

Identification of the dominant dynamical modes
Description of their structure, 4-6 orders in spatial/temporal scales,
from electron to global scales.

We are collecting the pieces of the puzzle... Our 'molecules'
How do they interact ? Can we quantify their mutual coupling ?
The key for understanding 'plasma processes'...

QUANTIFY !

NO CHOICE: Direct confrontation with fundamental questions:

- (1) Conceptualisation of the 'micro/macro' physics interactions,***
- (2) Topological reconfigurations, formation of structures,***
- (3) Turbulence, non linear dynamics ...***

in the SPECIFIC CASE OF PLASMAS.

Very severe difficulties linked to the absence of
'constitutive' or 'state' equations.

The way to solve our 'traditional' questions: dynamo effects, coronal heating, energy dissipation, particles acceleration...

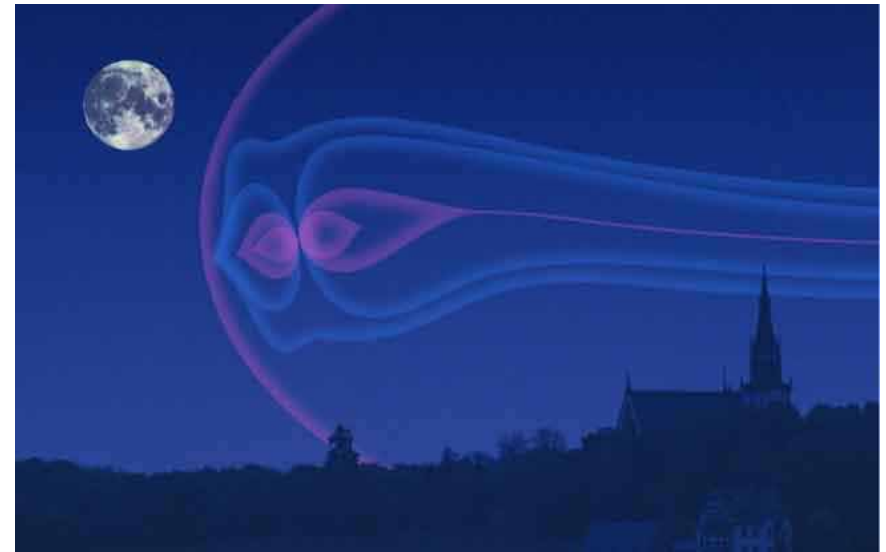
Until 2020, great advances in concepts and numerical possibilities:
New tools and methods for basic plasma and space physics.

***A firm basis for the interpretation of the most complex observations:
MULTI-SCALE ANALYSIS, 3D TOPOLOGIES***

EXPLORE !

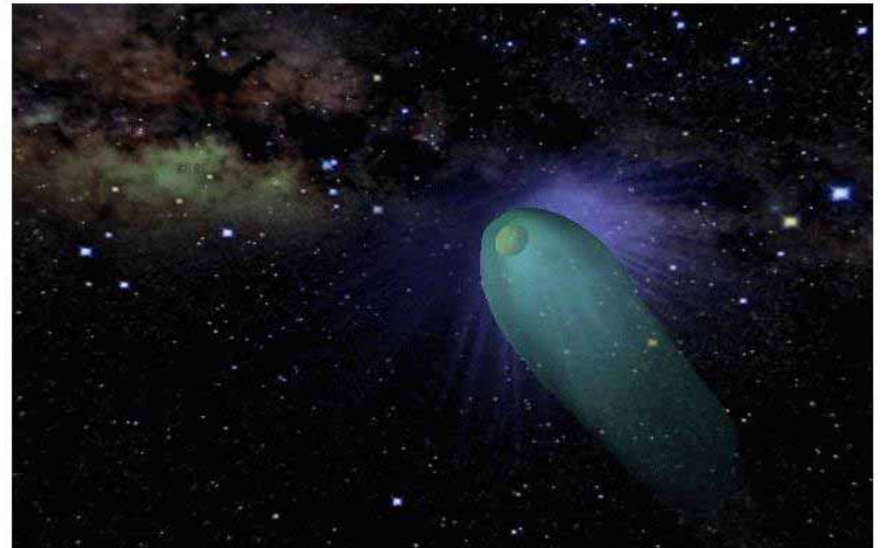
For a direct in-situ analysis of universal 'plasma processes', 30 years after the definition of Galileo exp.,

**Dive in the complex,
amazing environment of
JUPITER.**



*For the analysis of our connection
with cosmos,*

**Run to the frontiers of
solar system.**



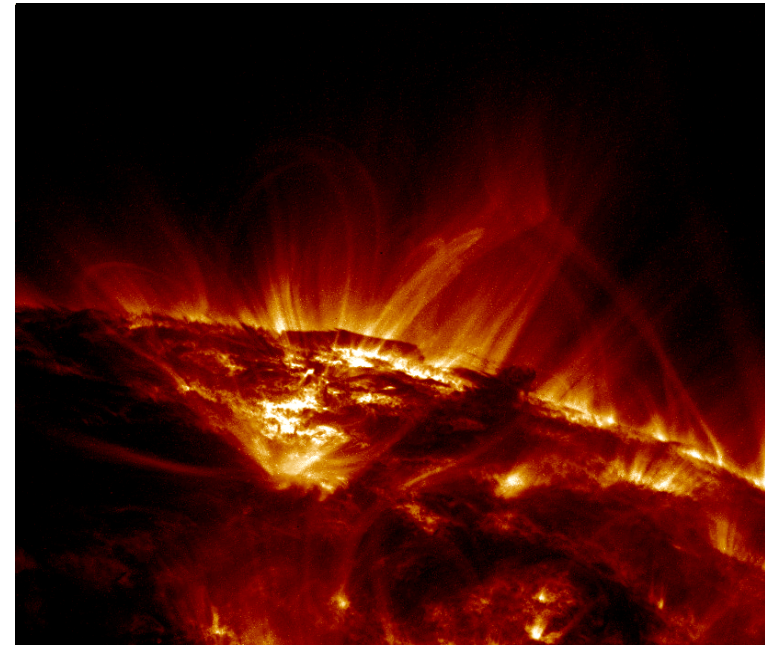
QUANTIFY !

Observations of solar processes are unique to get instantaneous views of 3D topology and energy evolutions of 'plasma objects'.

Decipher 3 D topologies

Vectorial B field analysis and underlying dynamo processes. **($\mathbf{B}, \mathbf{n}, \mathbf{V}$)**

Understand extreme accelerations



Direct in situ measurements are unique to get the thinnest analysis of dynamical processes, over the whole relevant range of spatial/temporal scales

Perform MULTI-SCALE analysis
micro/macro physics interactions
from electron scales to global scales.

CONSTELLATION of SPACECRAFT