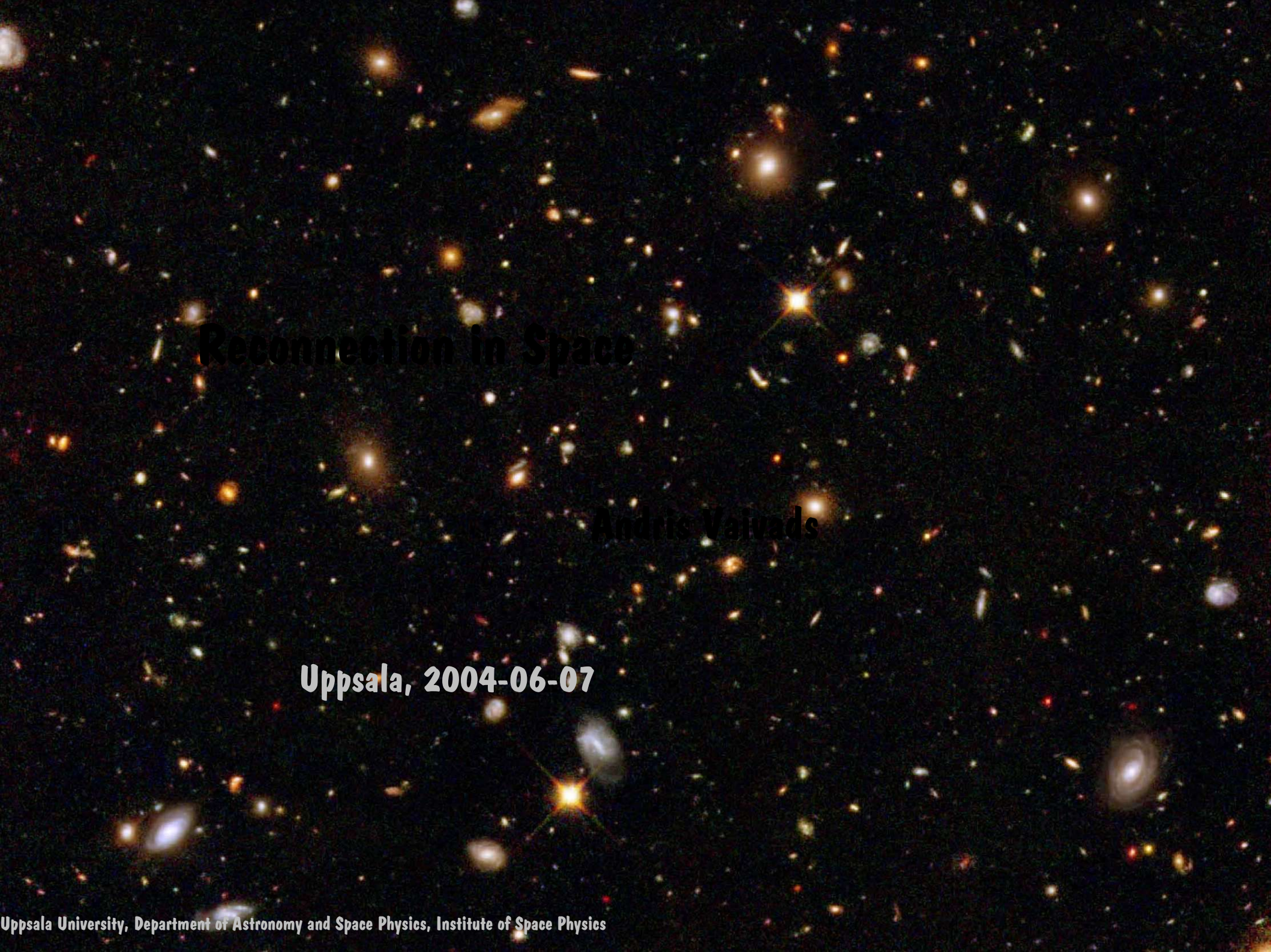


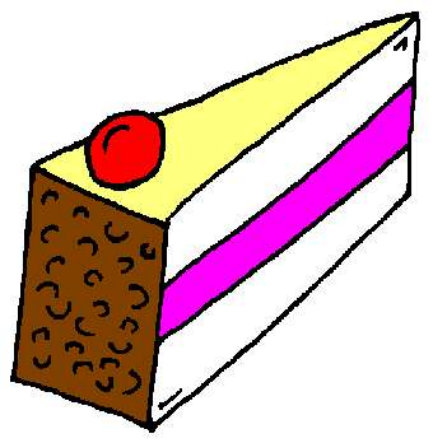
Reconnection in Space

Andris Vaivads

Uppsala, 2004-06-07

Uppsala University, Department of Astronomy and Space Physics, Institute of Space Physics

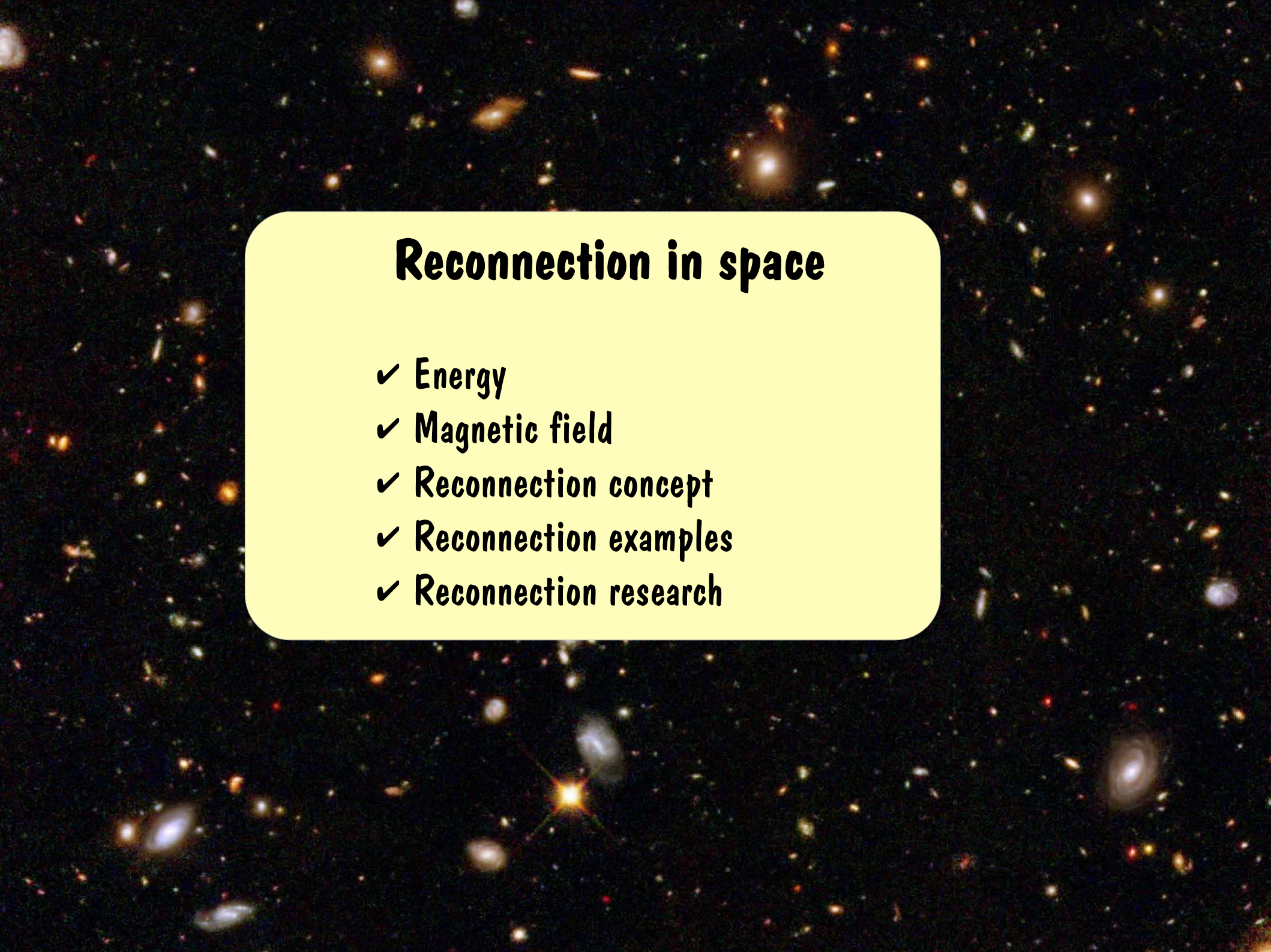
Docent lecture



after lecture - ~~cake~~ refreshments at 3rd floor

... include parts that my 1 year old daughter could understand
... include parts that nobody understands

research


Reconnection in space
✔ Energy
✔ Magnetic field
✔ Reconnection concept
✔ Reconnection examples
✔ Reconnection research

Energy

For those who want some proof that physicists are human, the proof is in the idiocy of all the different units which they use for measuring energy.

The Character of Physical Law (1967) R.P. Feynman.

J, °C, °F, K, degrees, eV, erg, cal, ...

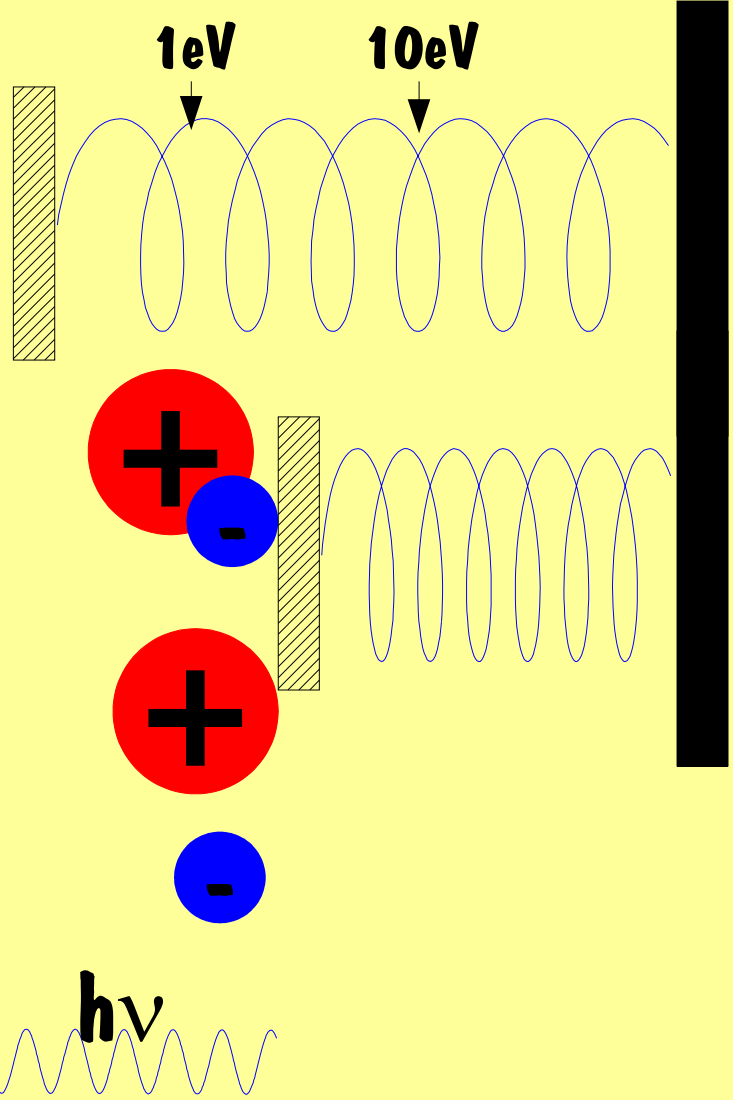
Measuring energy

atoms

ions

electrons

photons



1 eV – infrared

2 eV - visible light

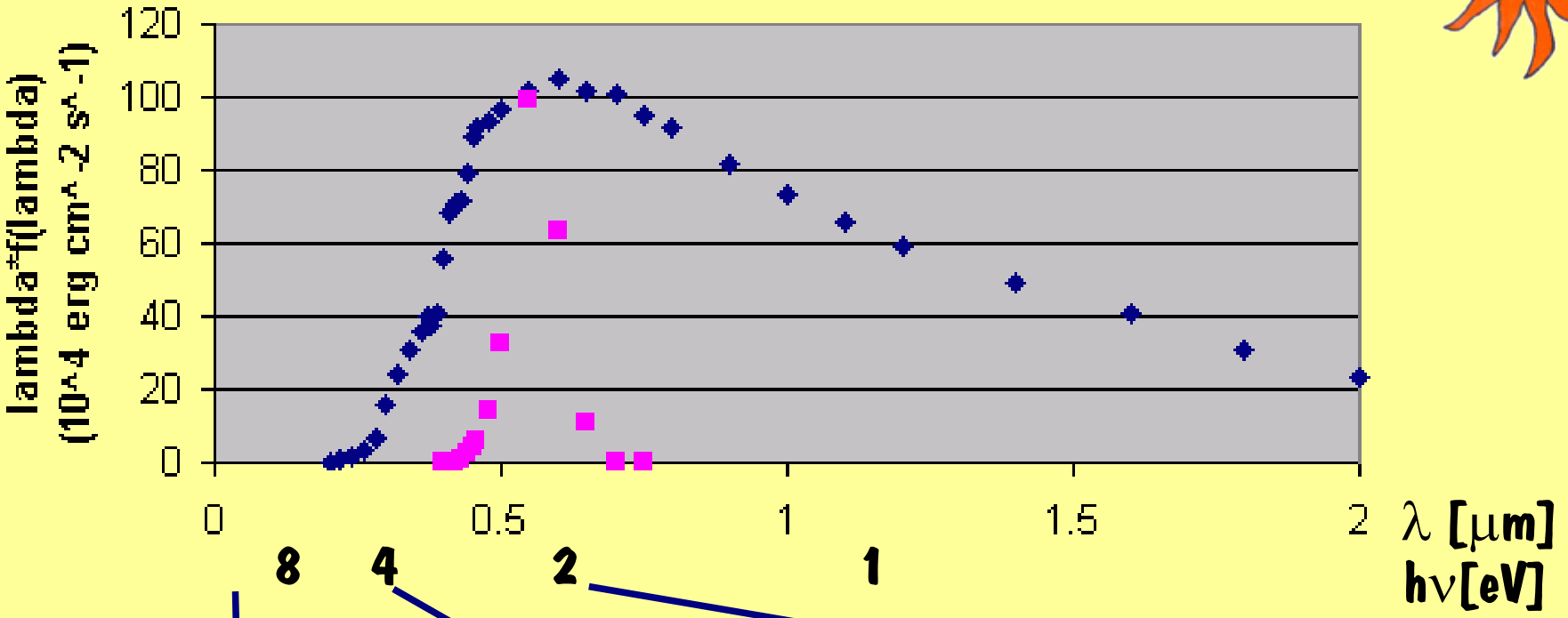
4 eV – ultraviolet

1keV – X rays

1MeV – gamma rays

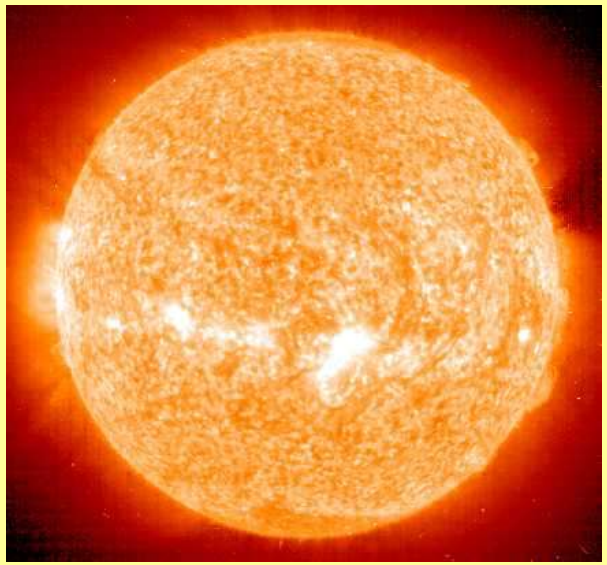
Sun

Surface temperature ~6000 °C



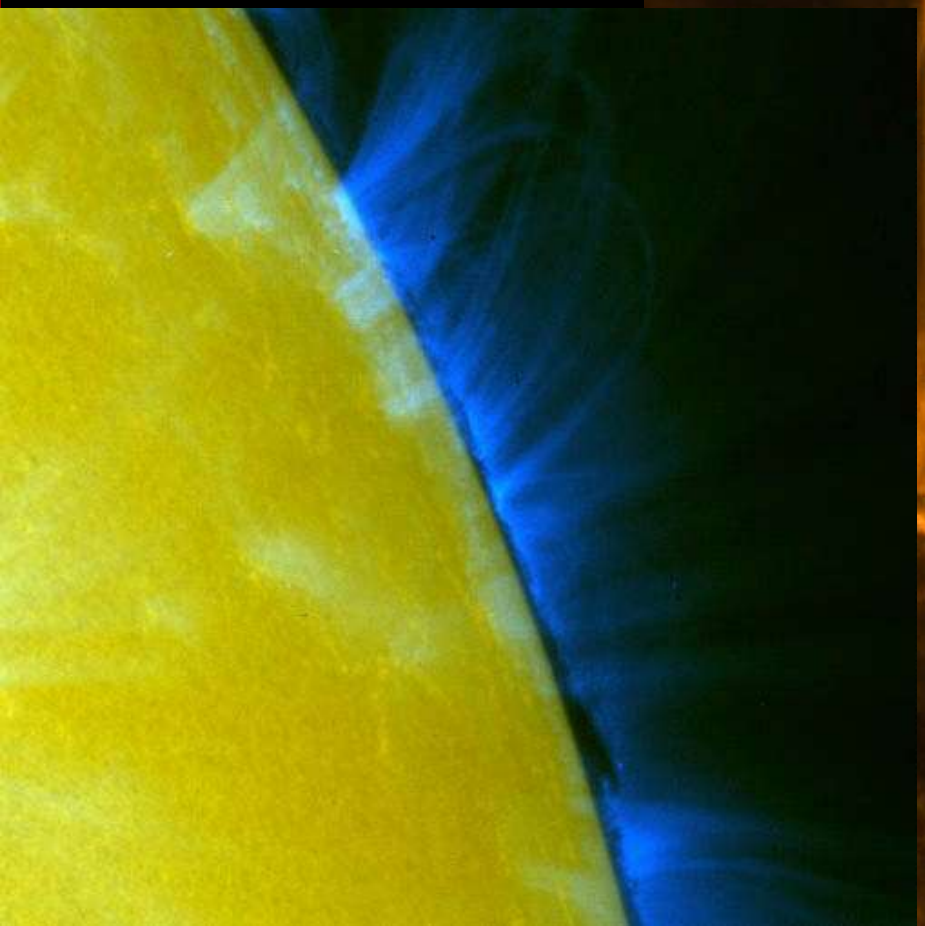
1keV

4 eV



2 eV

Highest energies in space above the Sun!
Energy should come from somewhere!



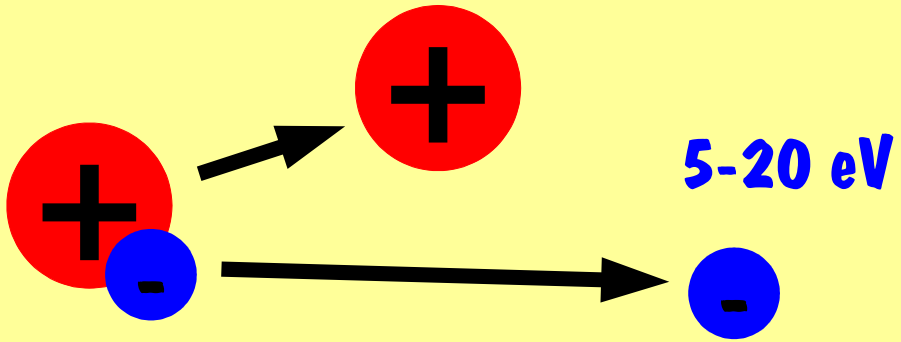
Sunny day on Earth

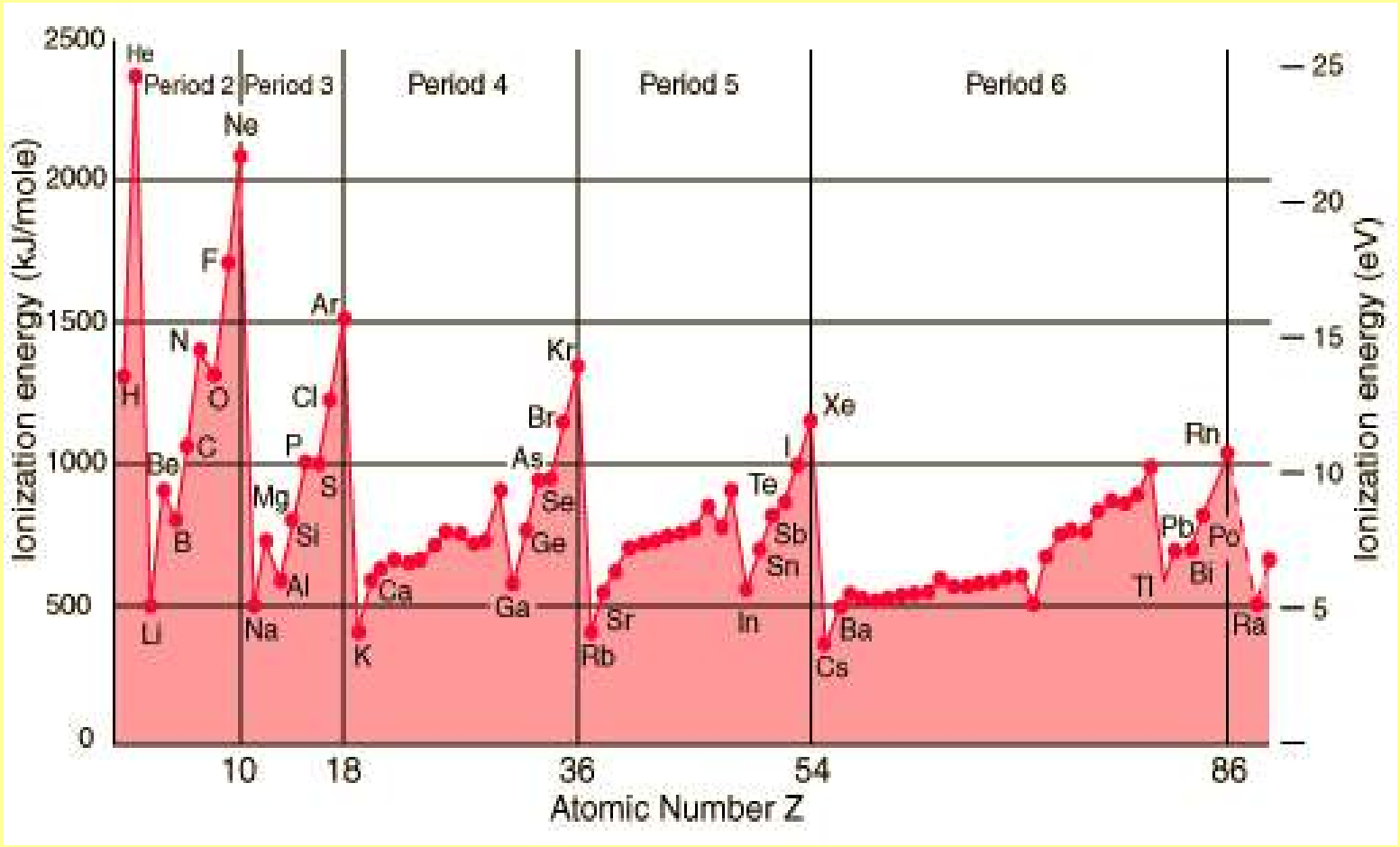
Particle energies

	°C	eV
on Sun	6000	0.5
space around Sun	10^6	100
on Earth	30	0.026
space around Earth	10^3-10^8	0.1-10000
center of Sun	15 10^6	1300

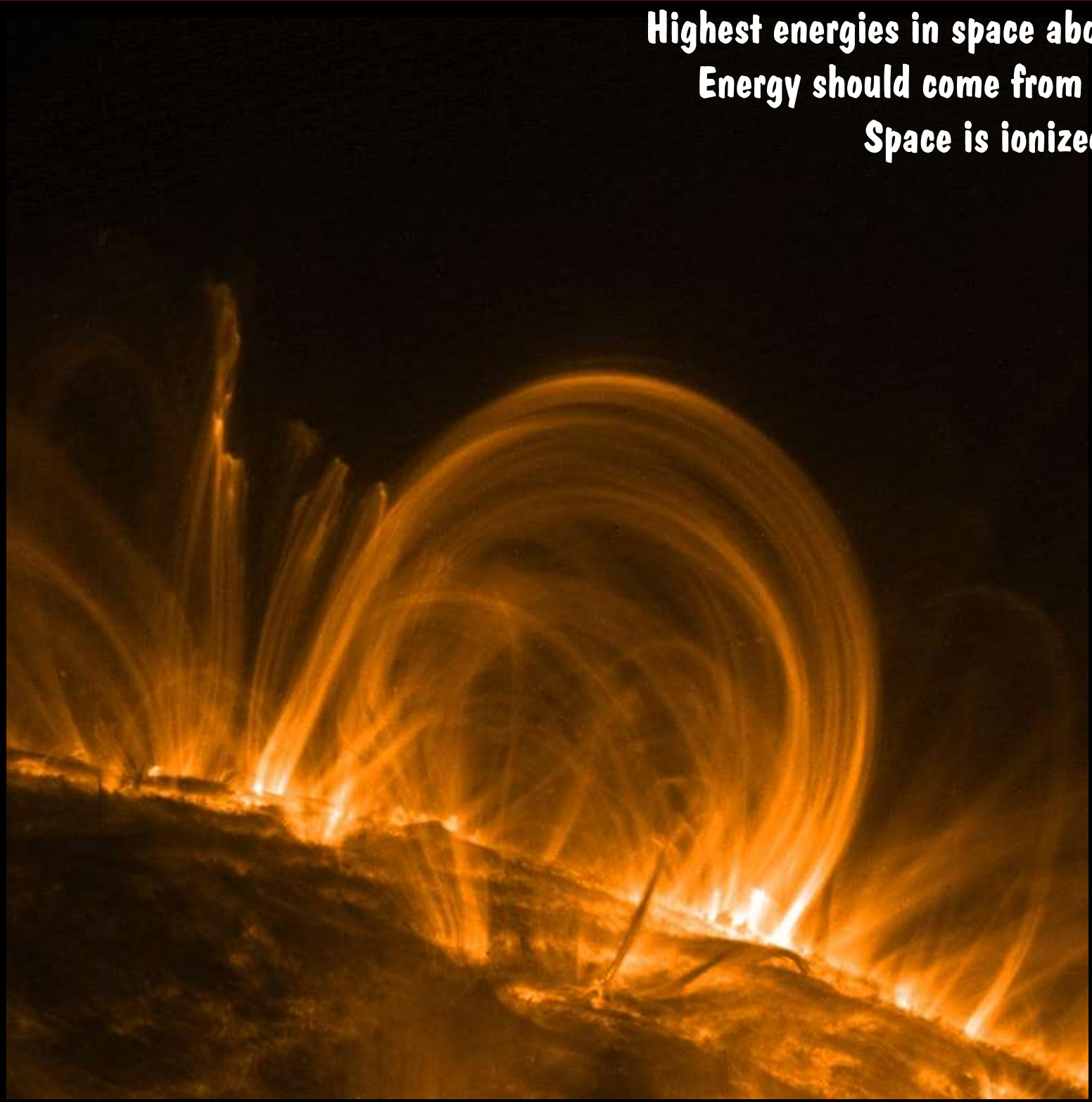
Ionization

Energy necessary to create an ion and electron from one atom

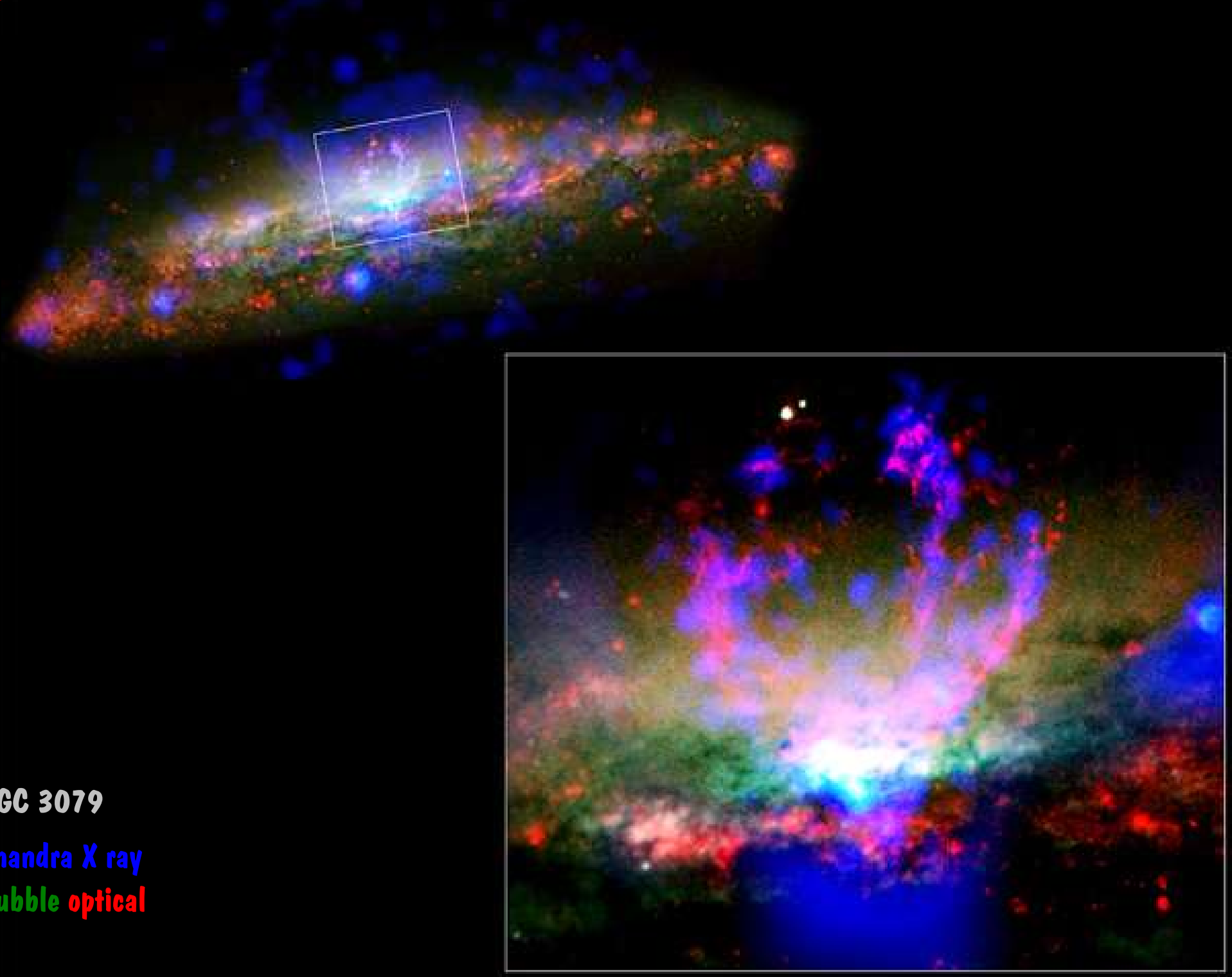




Highest energies in space above the Sun!
Energy should come from somewhere!
Space is ionized – plasma!




Where are the highest energies in universe?
Hubble Ultra Deep Field ,



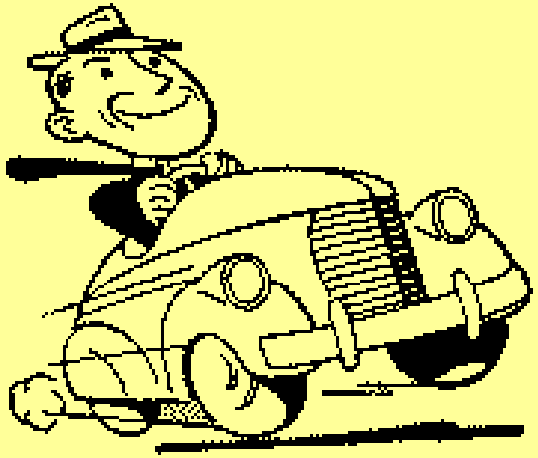
NGC 3079

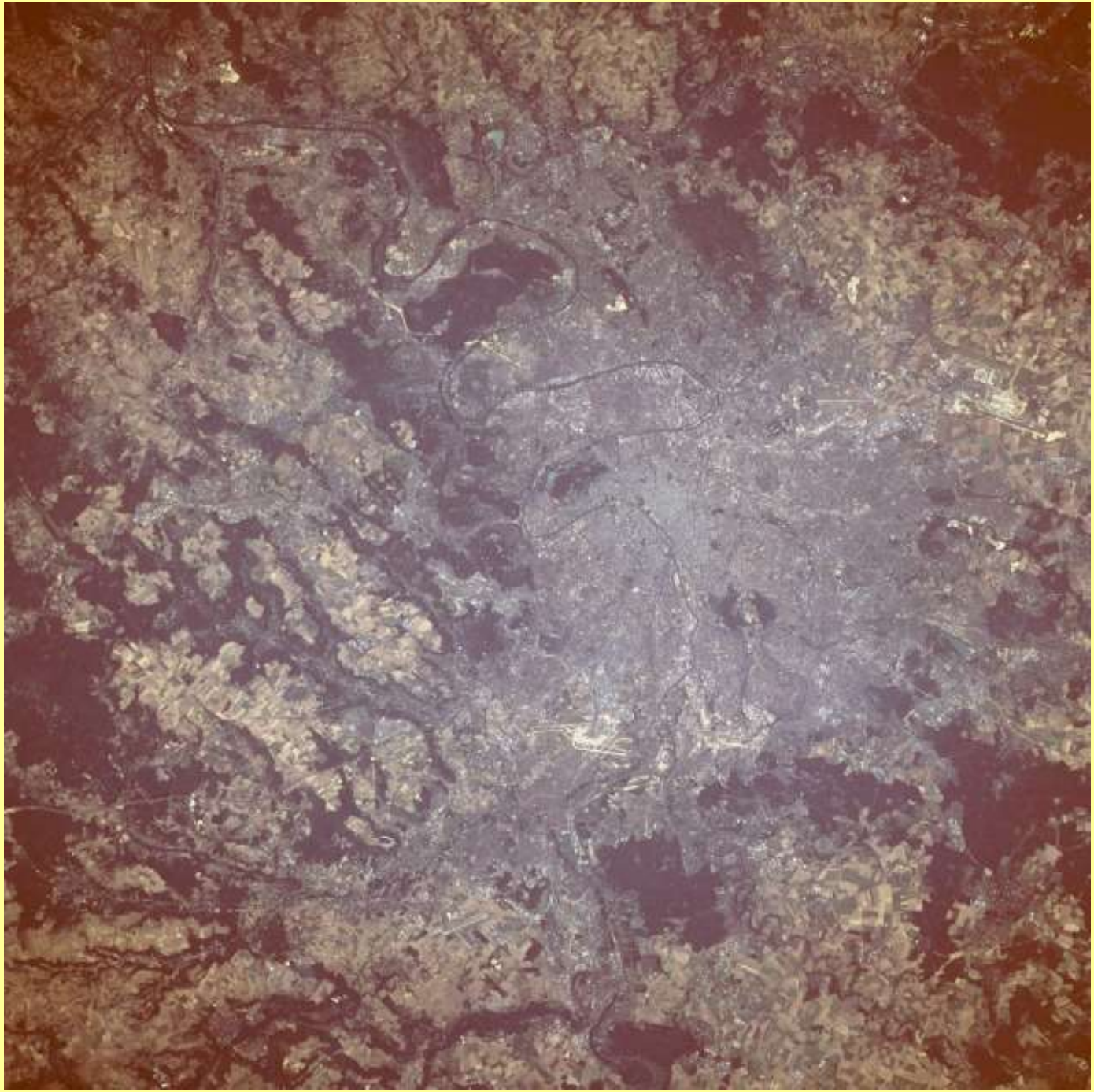
Chandra X ray

Hubble optical

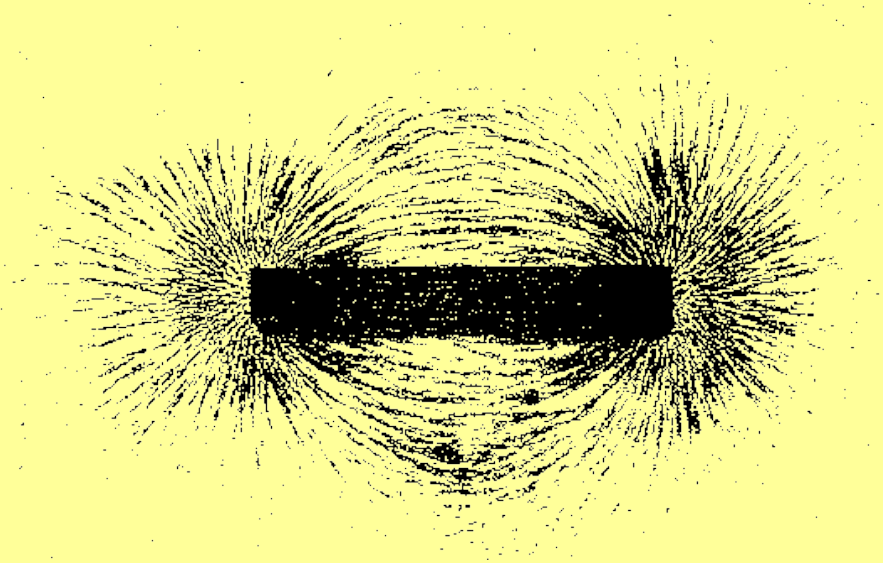
Credit: NASA/CXC/STScI/U.North Carolina/G.Cecil

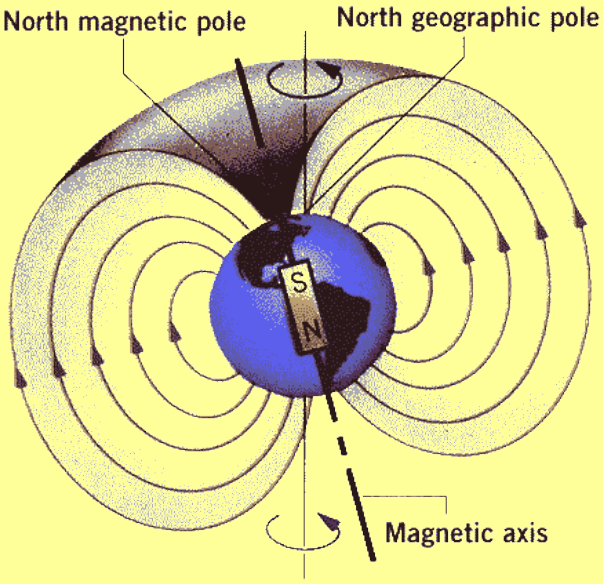
Paris
sunny working day



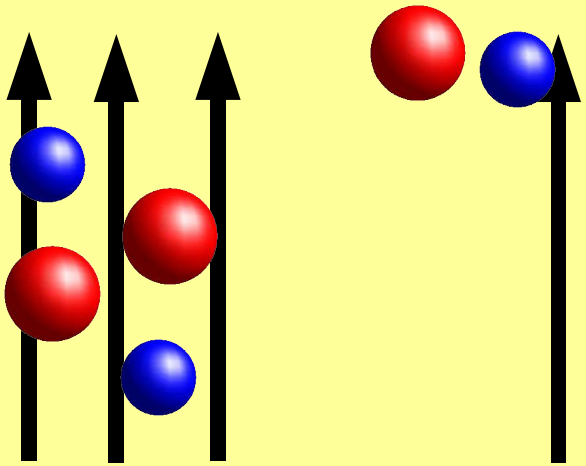


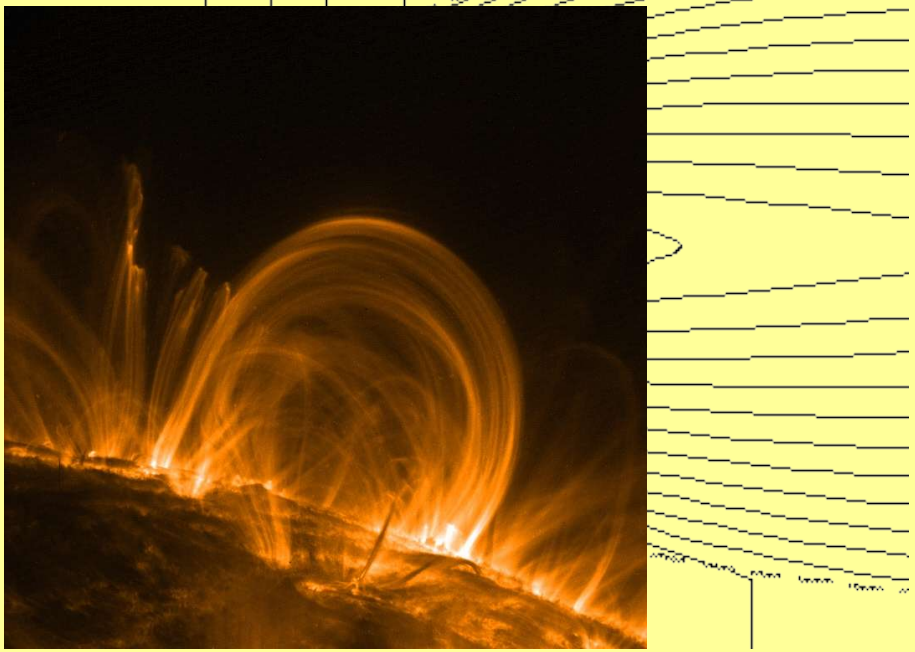
Magnetic field



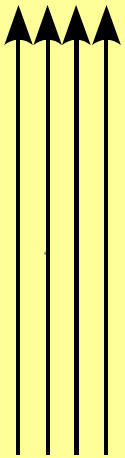


Think in magnetic field lines! .. without ends!

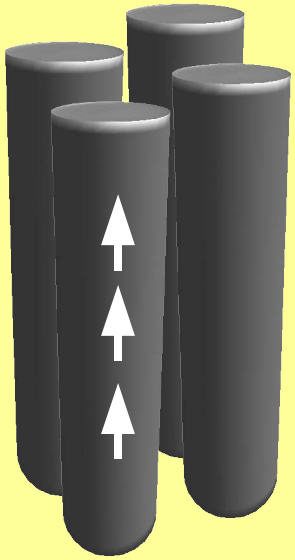




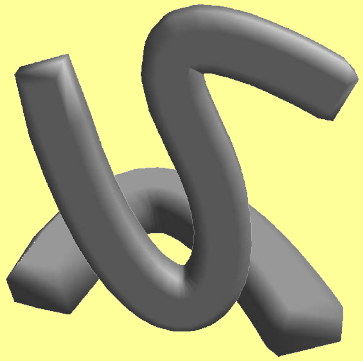
Magnetic flux tube energy W

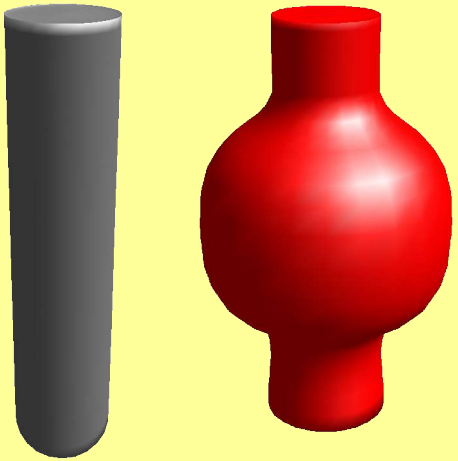


Magnetic
field lines



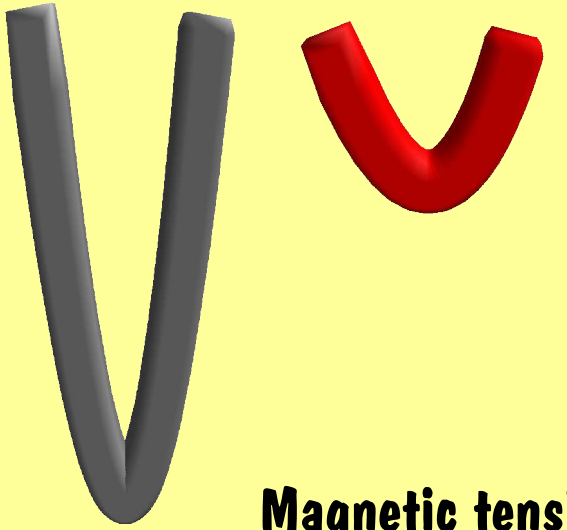
Magnetic
flux tubes





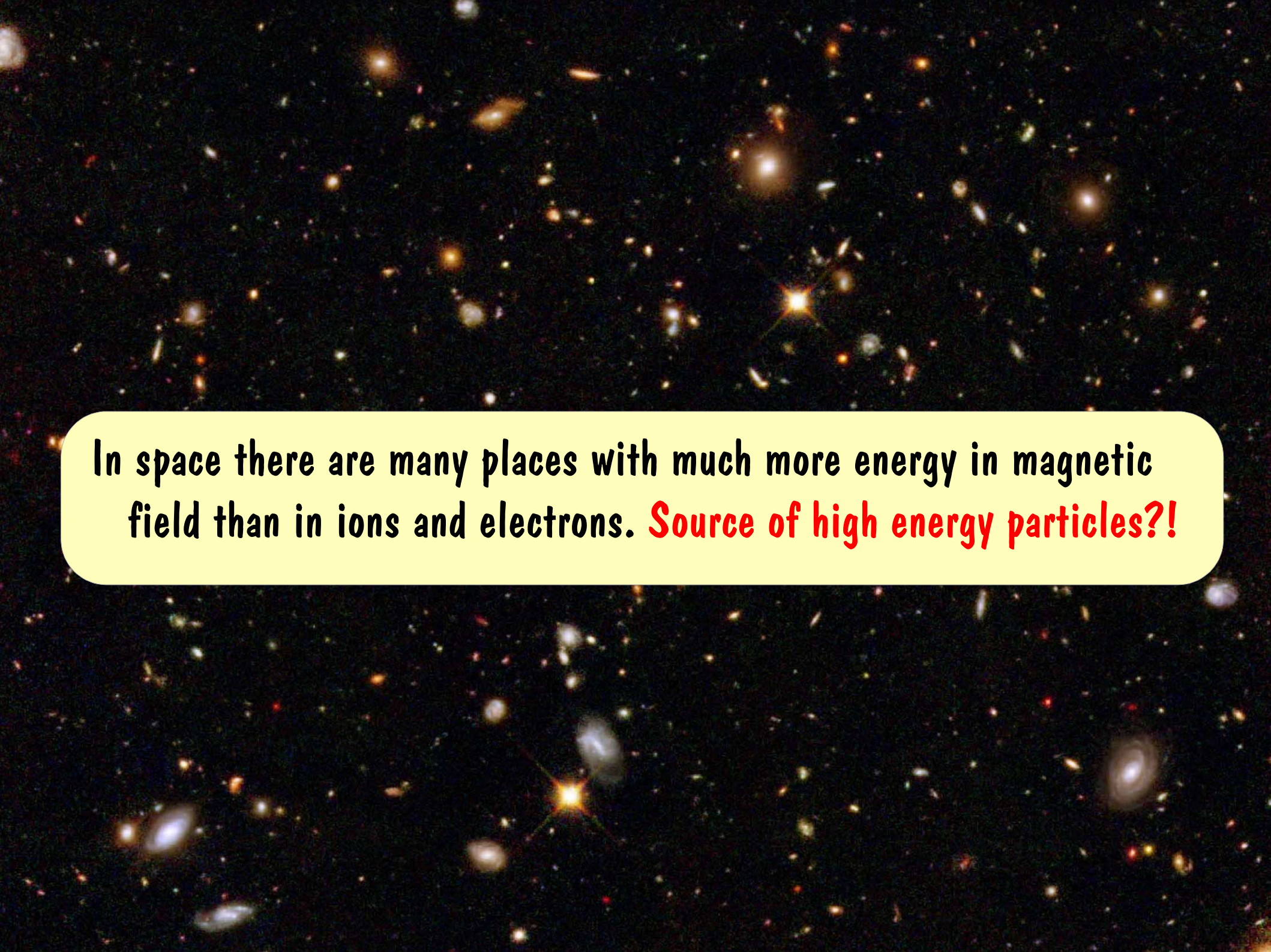
Magnetic pressure

$W > w$

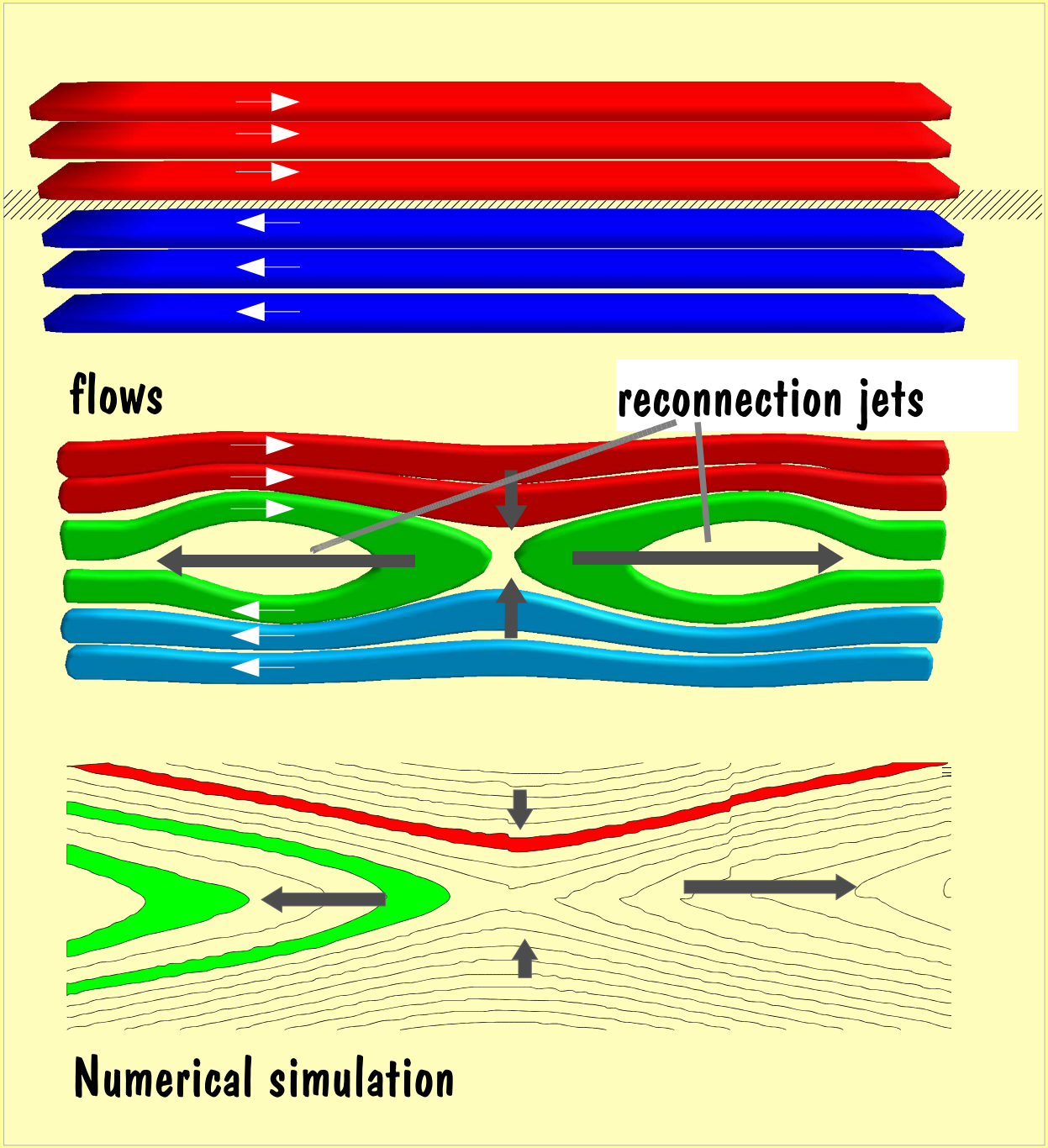


Magnetic tension

Magnetic energy converted into kinetic energy of ions and electrons

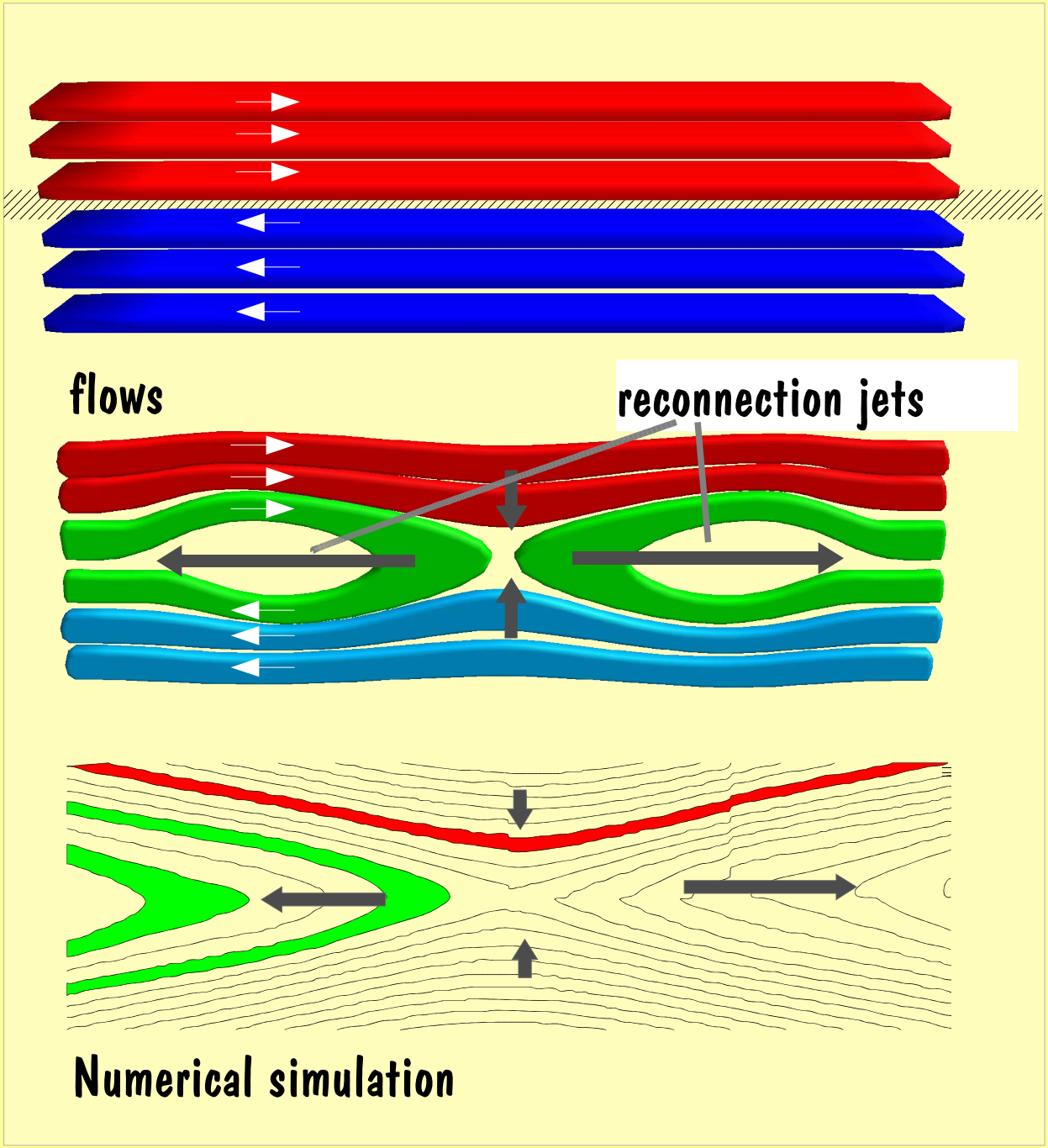

In space there are many places with much more energy in magnetic field than in ions and electrons. Source of high energy particles?!

Reconnection – the idea



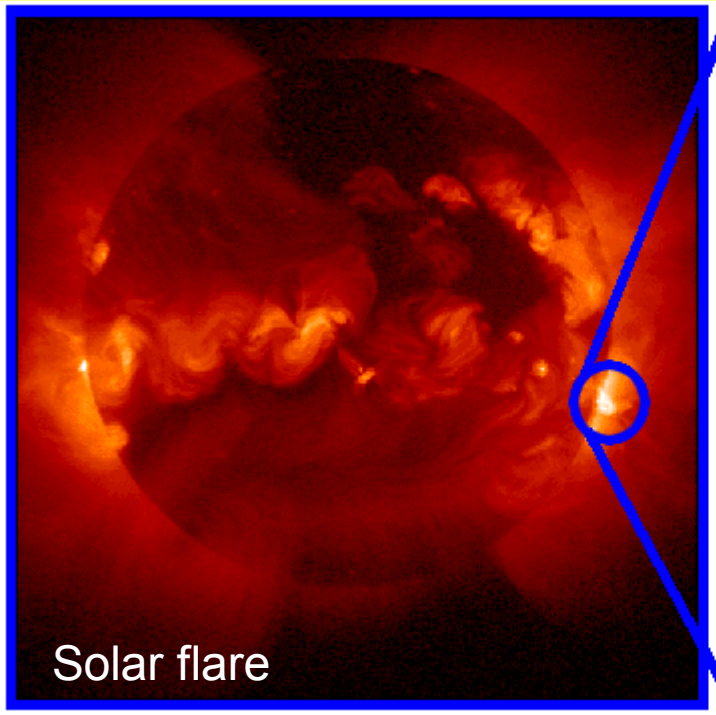
- ✔ A narrow current sheet separates in space regions of different plasmas and oppositely directed magnetic field
- ✔ Reconnection – topology changes allowing interconnection of magnetic field lines from both regions. Two ways 1) $E_{||} \neq 0$, 2) $B = 0$.
- ✔ Reconnection – energy conversion as a result of reconnection

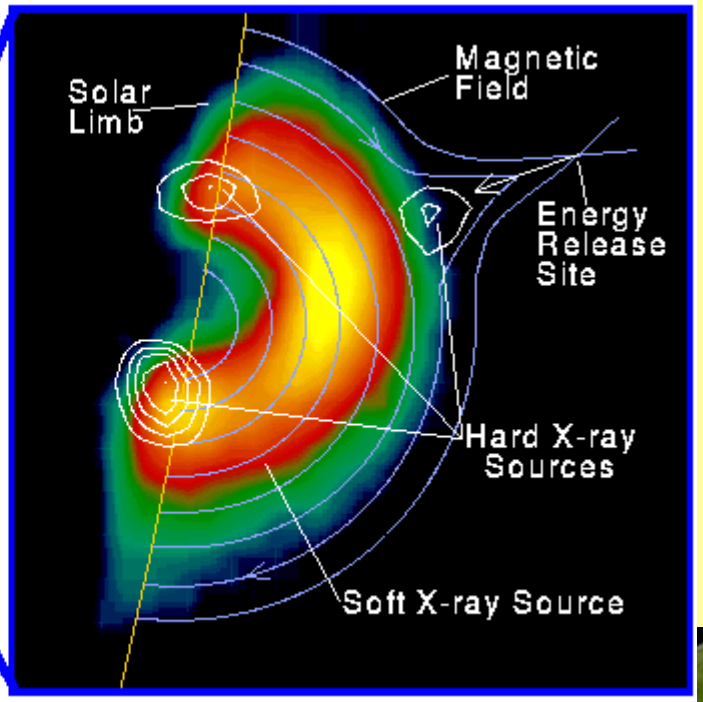
Reconnection – the point



- ✔ Topology – allows energy and mass transport across boundary
- ✔ Energy – the magnetic field energy is built up by many particles but is converted to the kinetic energy of few which therefore receive high energies.
- ✔ topology vs. energy

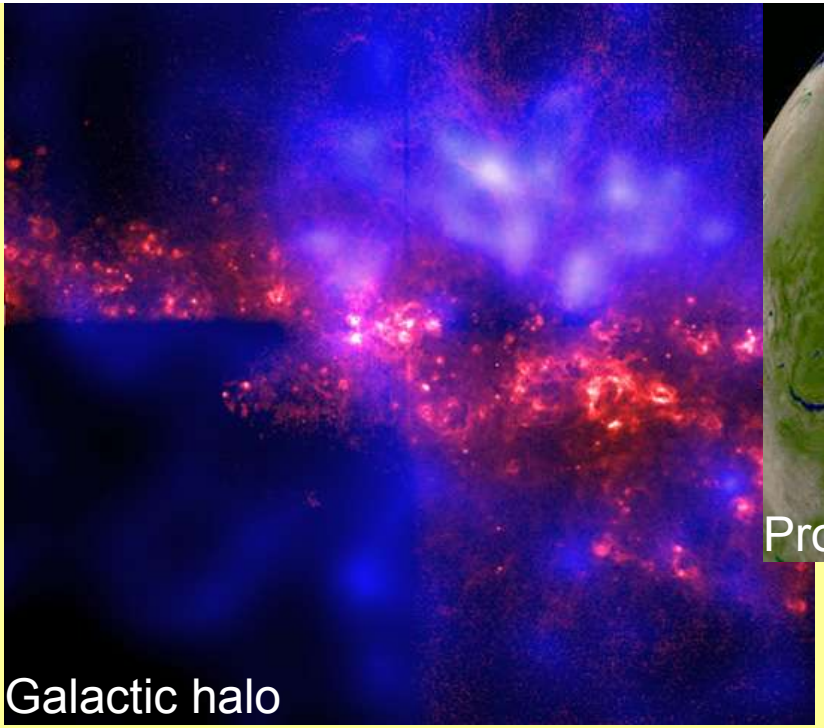
Examples from space

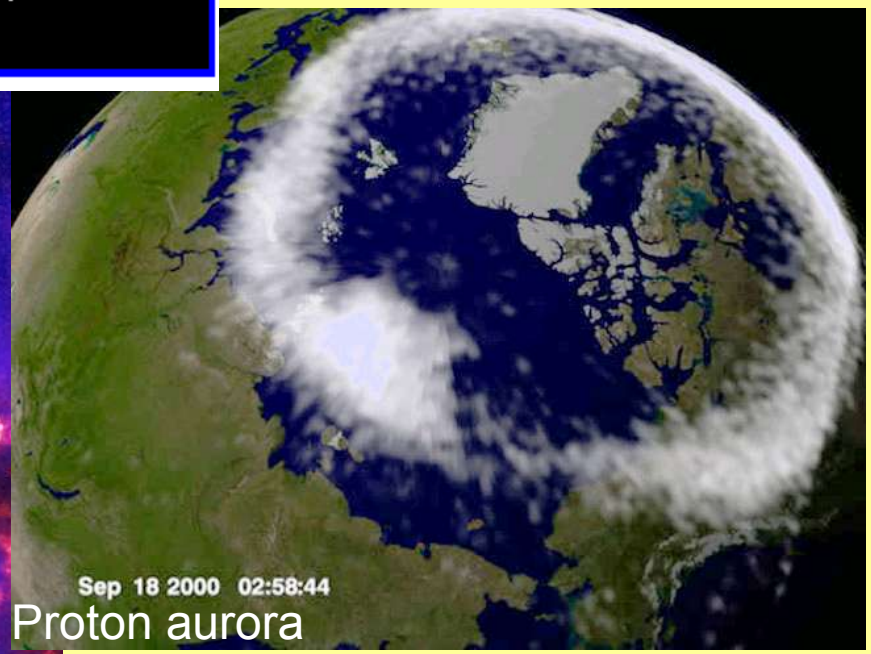




Sun

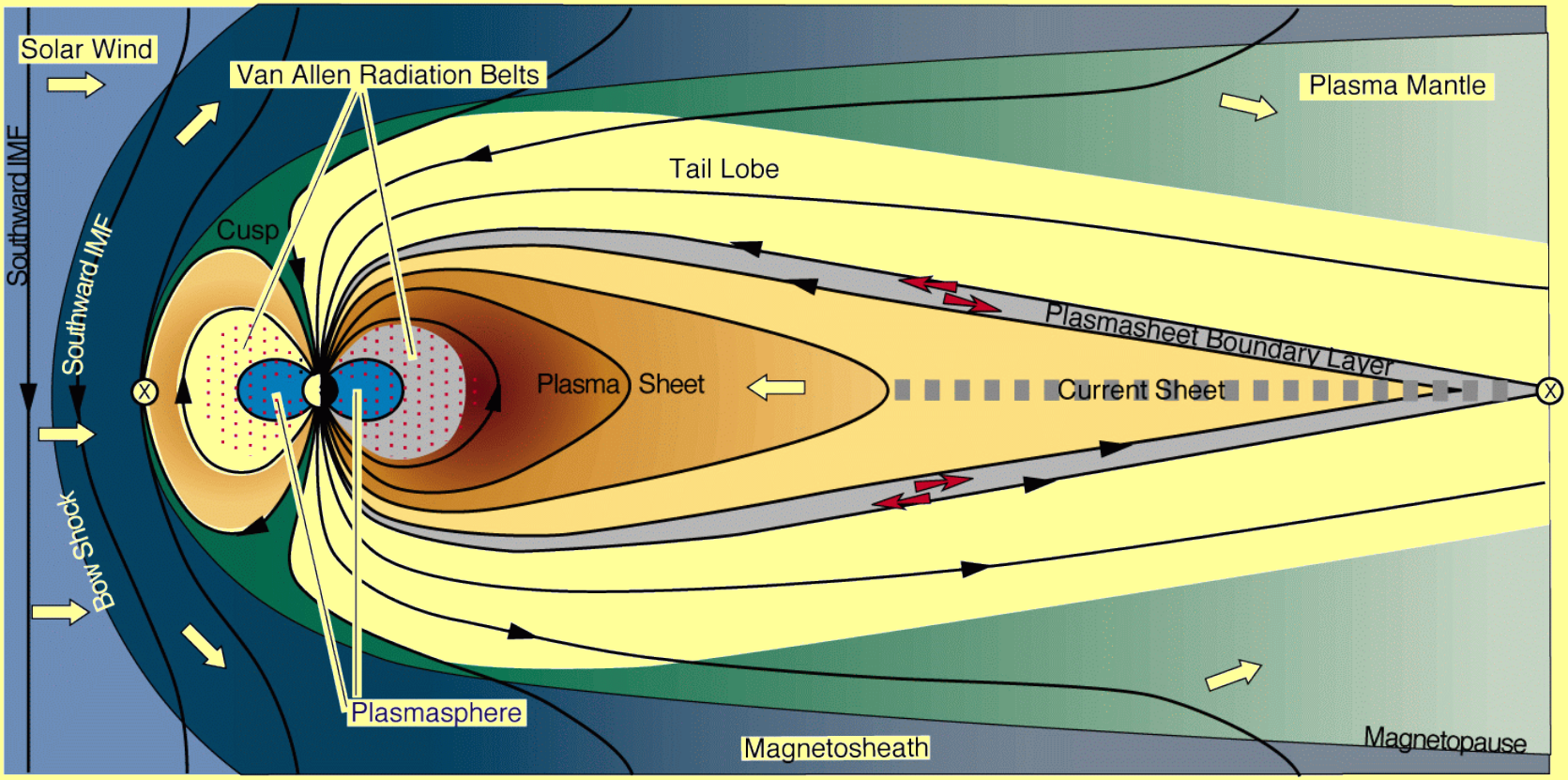
Galaxies





Earth

Solar wind and Earth magnetosphere

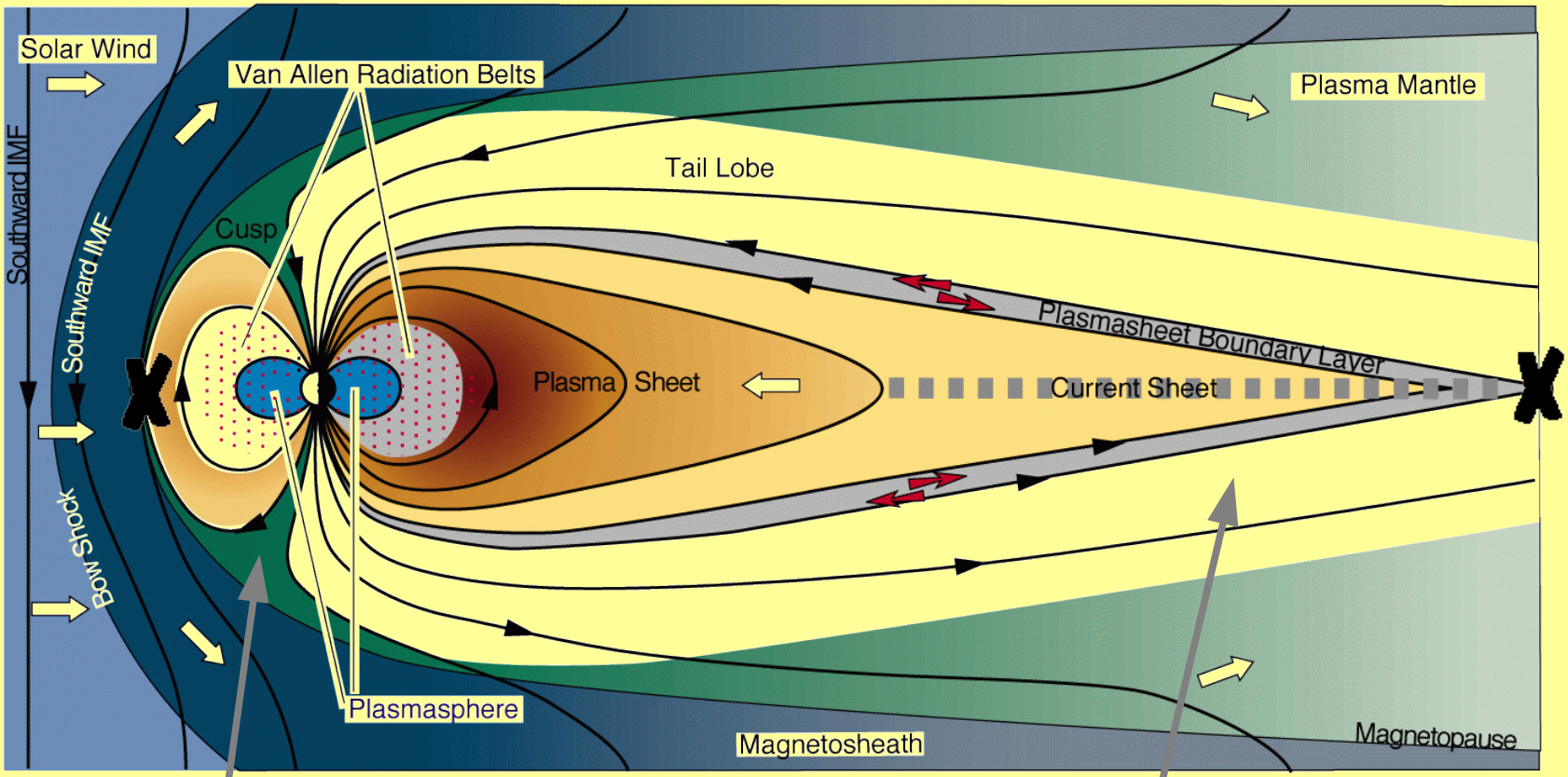


Solar wind and Earth magnetosphere

Reconnection

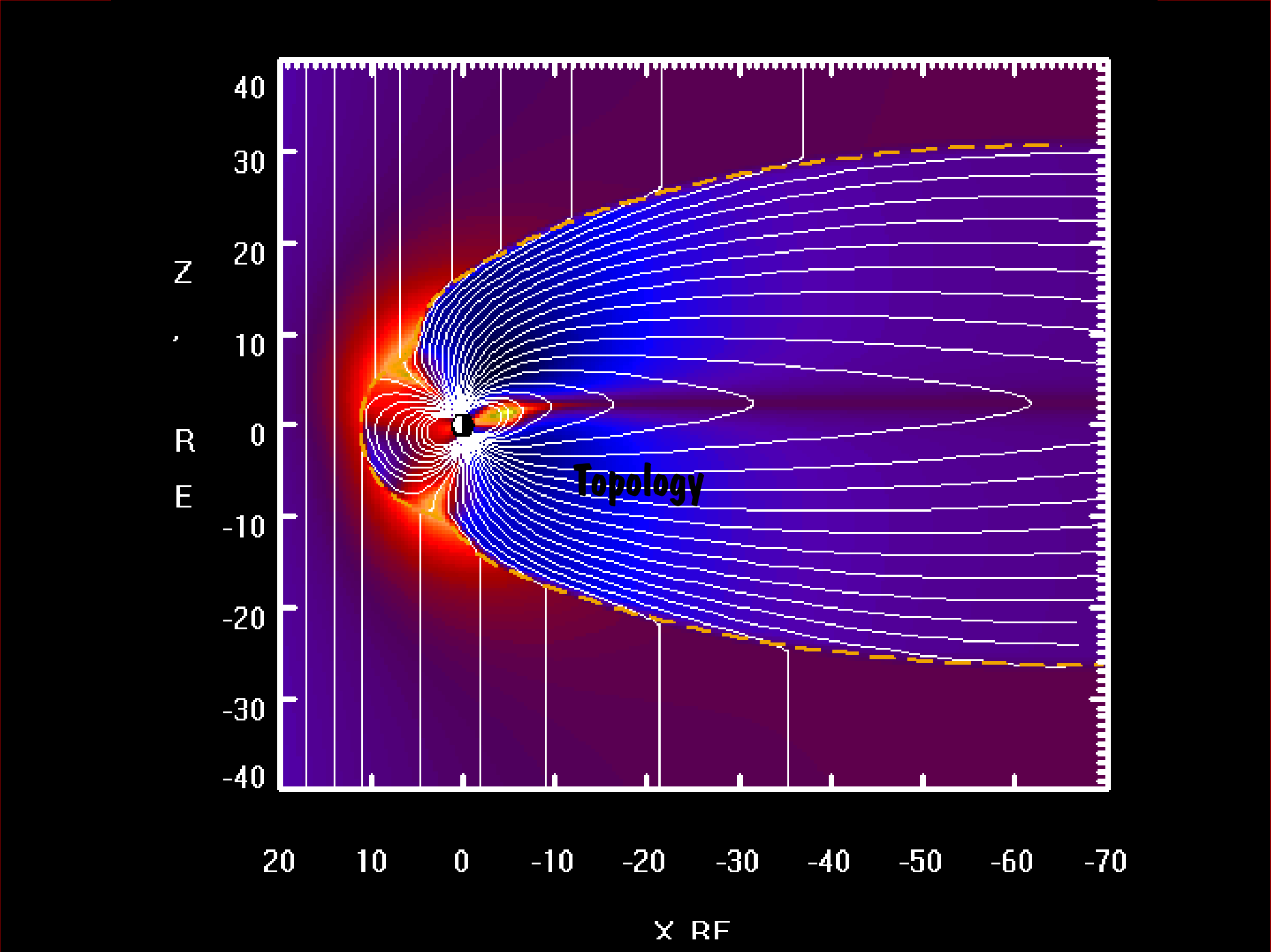
Topology

Energy



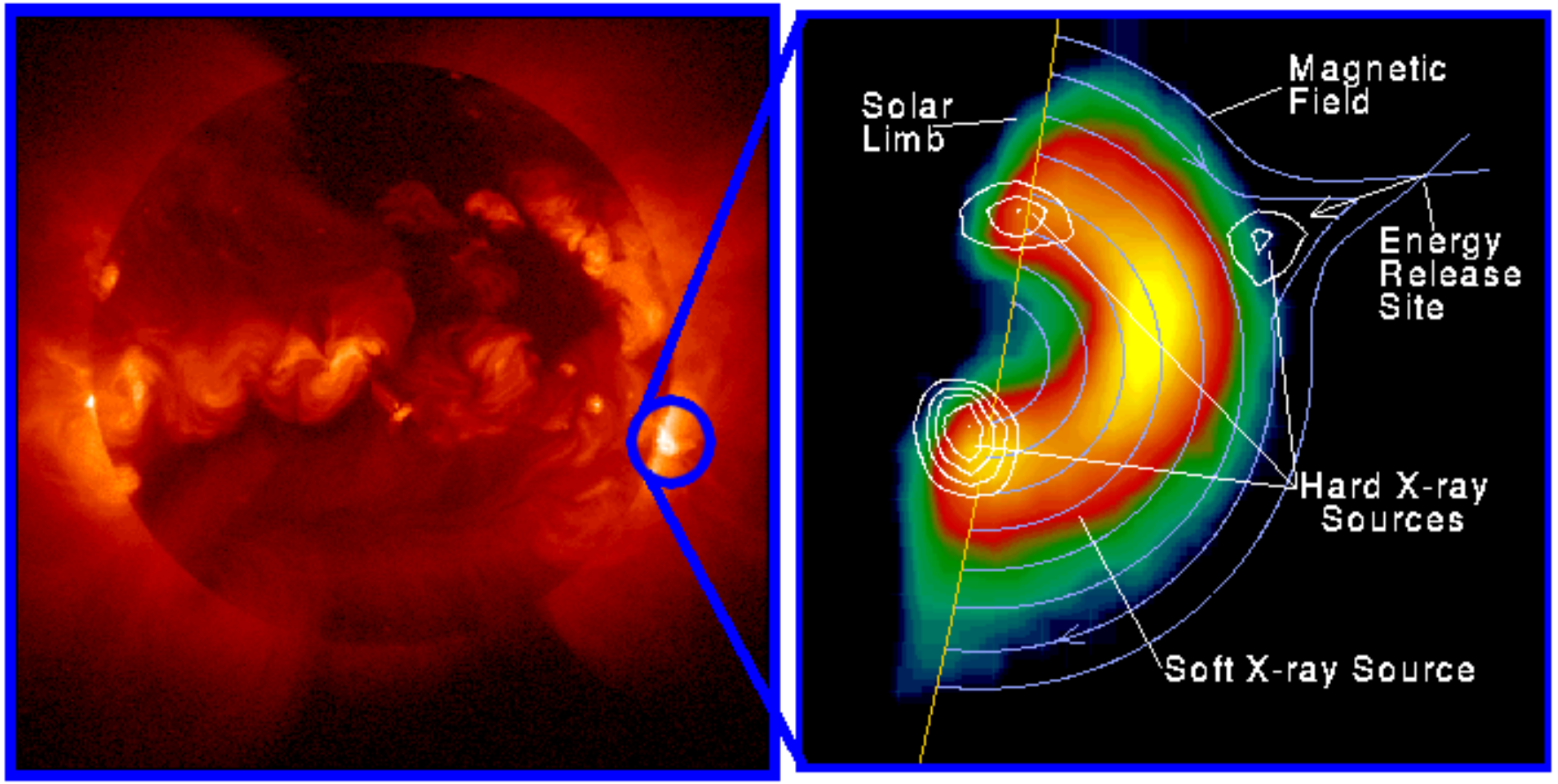
Magnetopause
energy transfer

Magnetotail
energy storage (B)


Topology
Z
R
E
40
30
20
10
0
-10
-20
-30
-40
20
10
0
-10
-20
-30
-40
-50
-60
-70
X RE

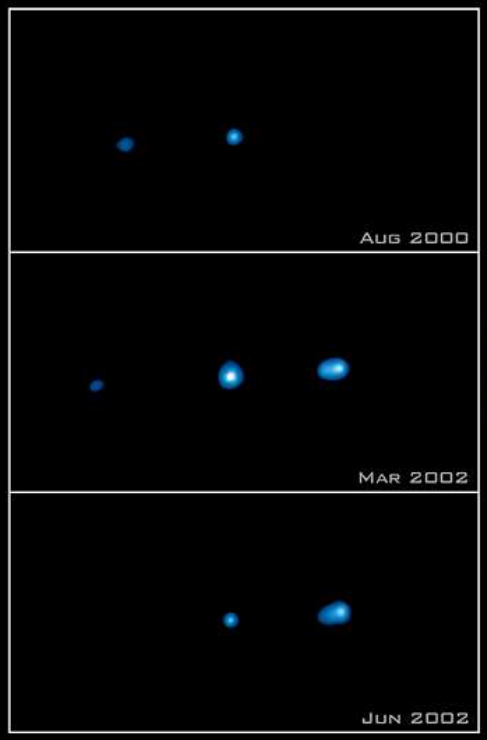
Solar flares

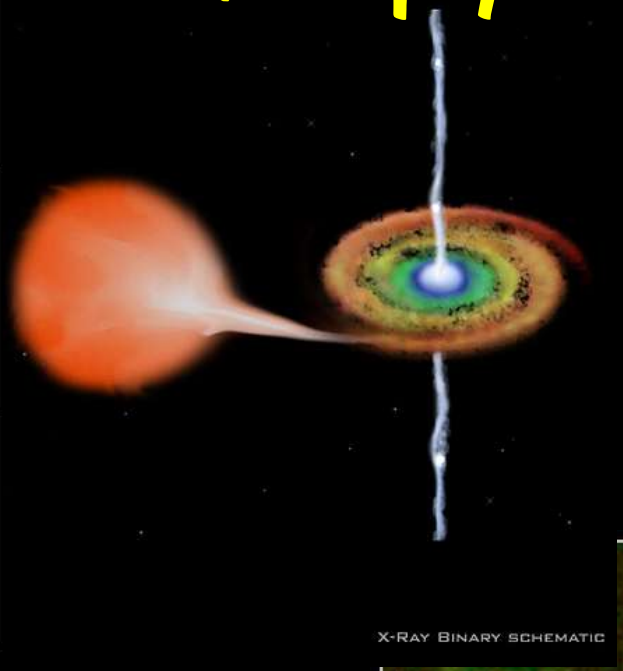
Xflare movie

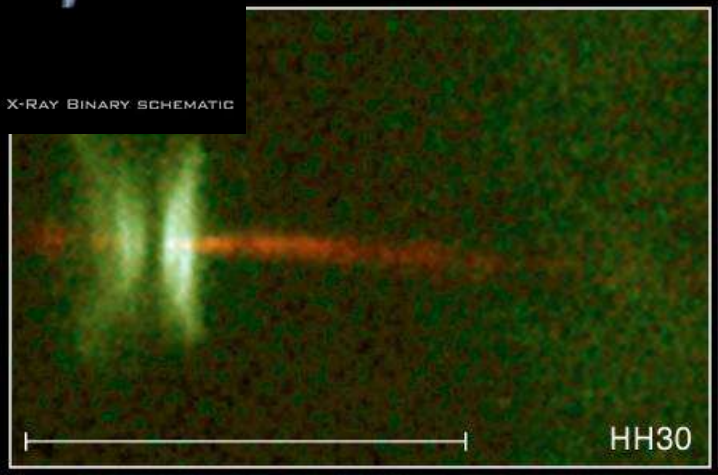


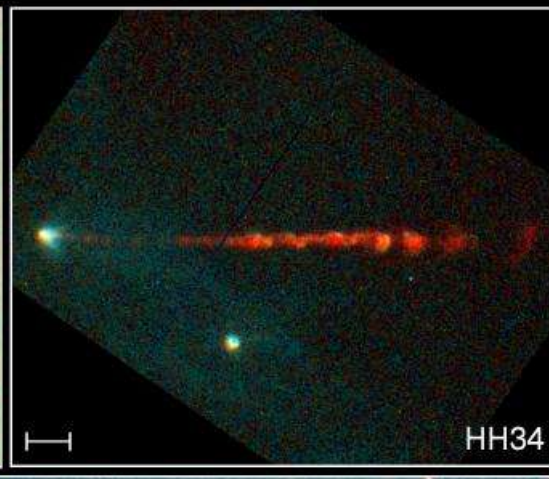
Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

Astrophysical jets









Jets from Young Stars HST · WFPC2

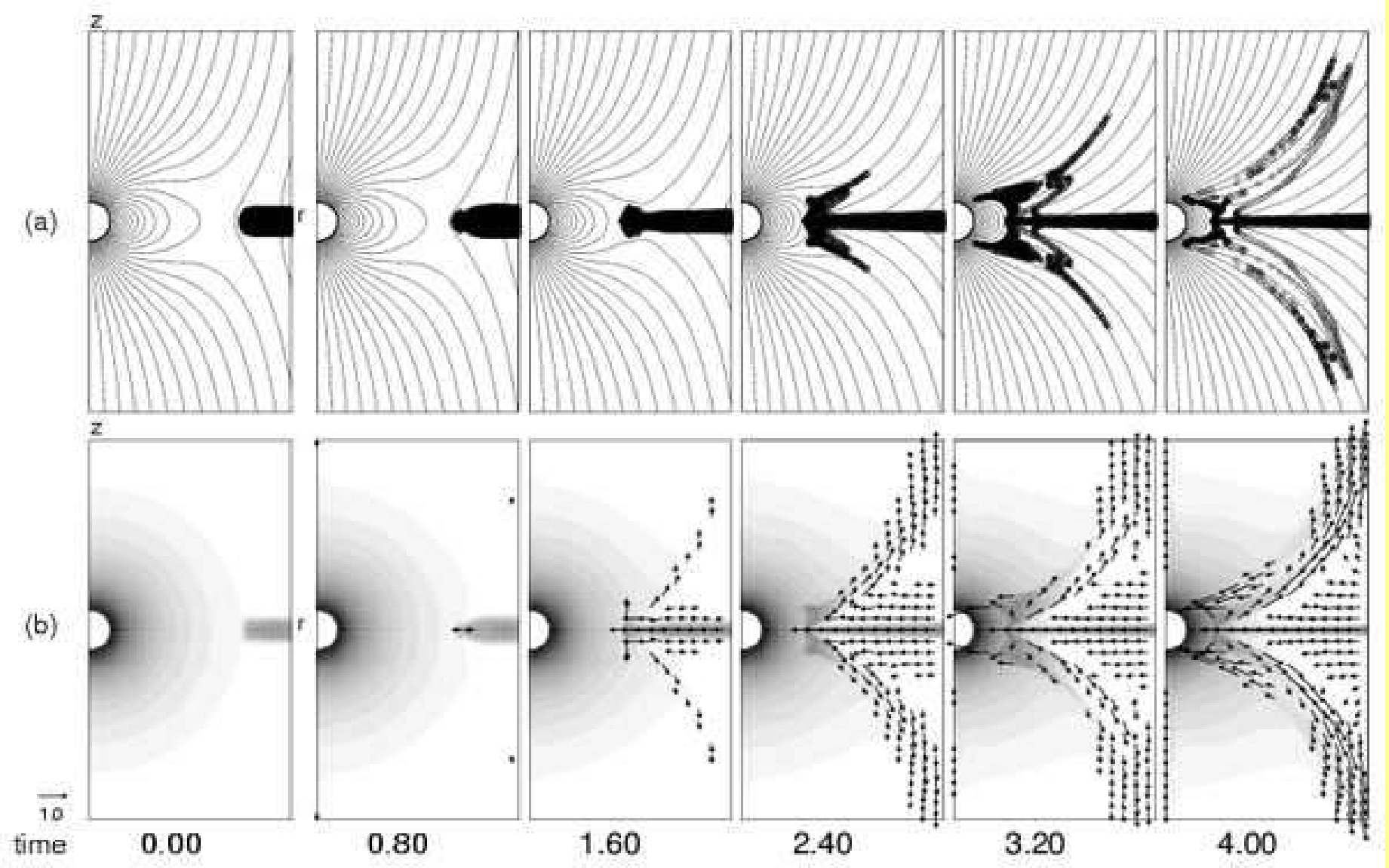
PRC95-24a · ST ScI OPO · June 6, 1995

C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

Optical jets from young stars

Numerical simulations

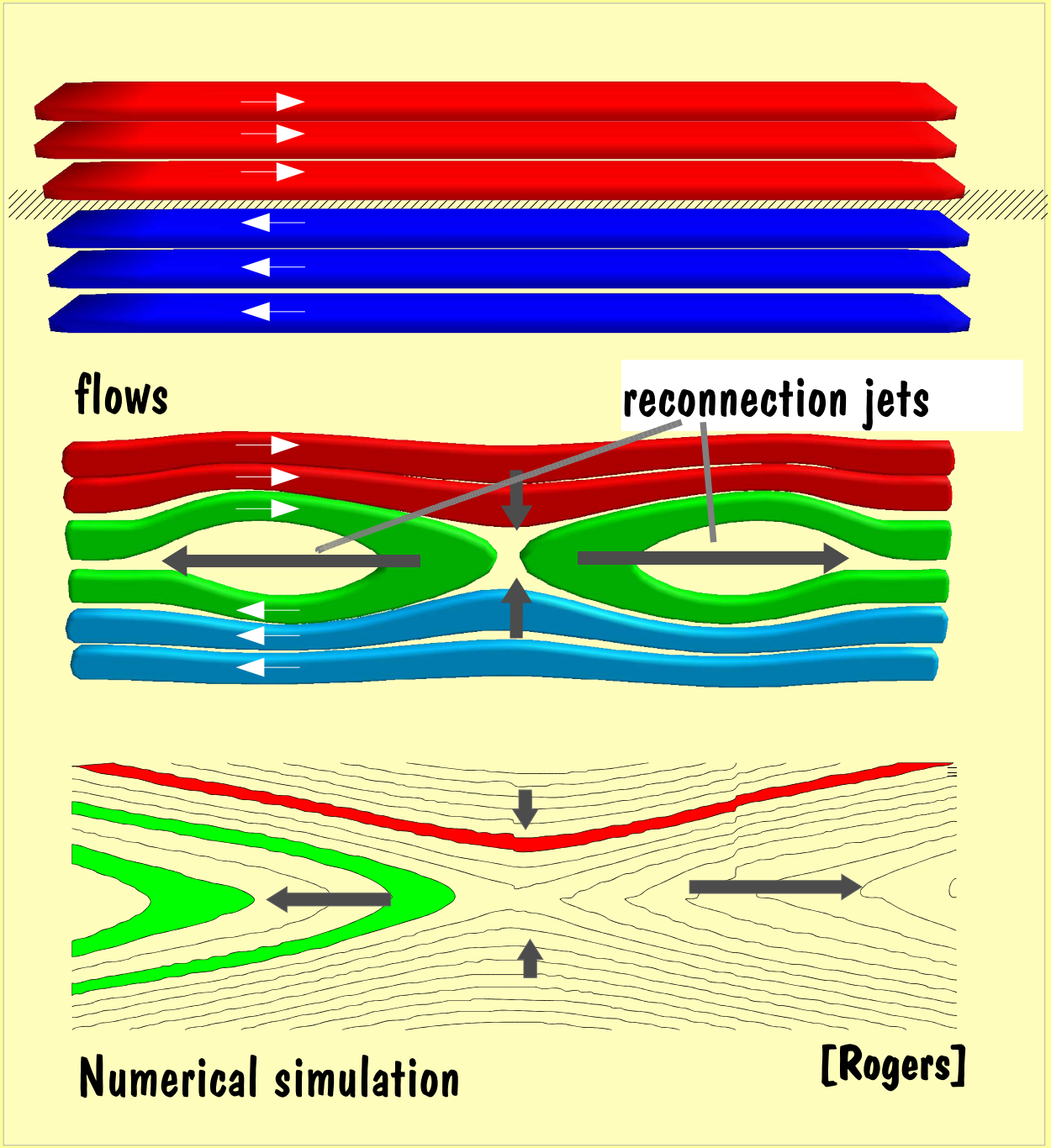
[Hirose at al. 1997]



On a way to understand reconnection

- ✔ Theory
  - do the right approximations
  - give up and turn to numerical simulations
- ✔ Numerical simulations
  - take the right equations (MHD, HMHD, particles)
  - put into the code and study results
- ✔ Experiment
  - space in situ / astro / laboratory
  - most detailed observations from space in situ!

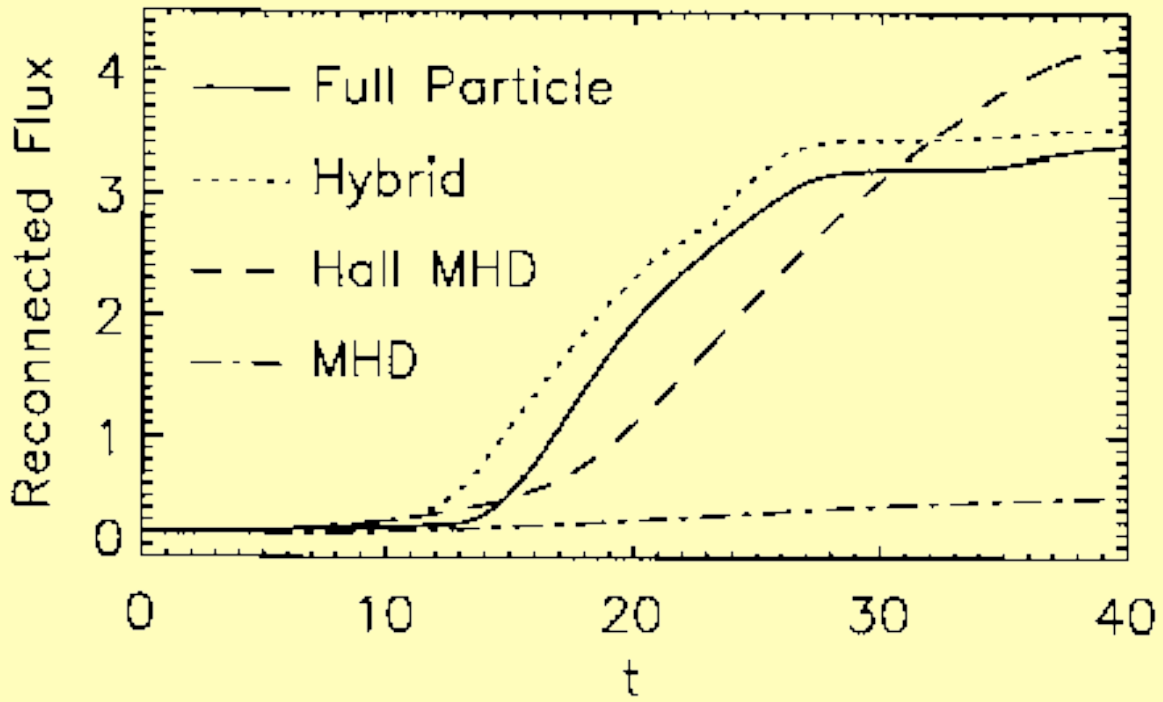
Reconnection – topics



- ✔ Structure
- ✔ Continuity
- ✔ Remote sensing
- ✔ Reconnection rate
- ✔ Guide field
- ✔ Relative importance
- ✔ Acceleration mechanisms (E)
- ✔ X-line

Numerical simulations

[Birn et al., 2001]



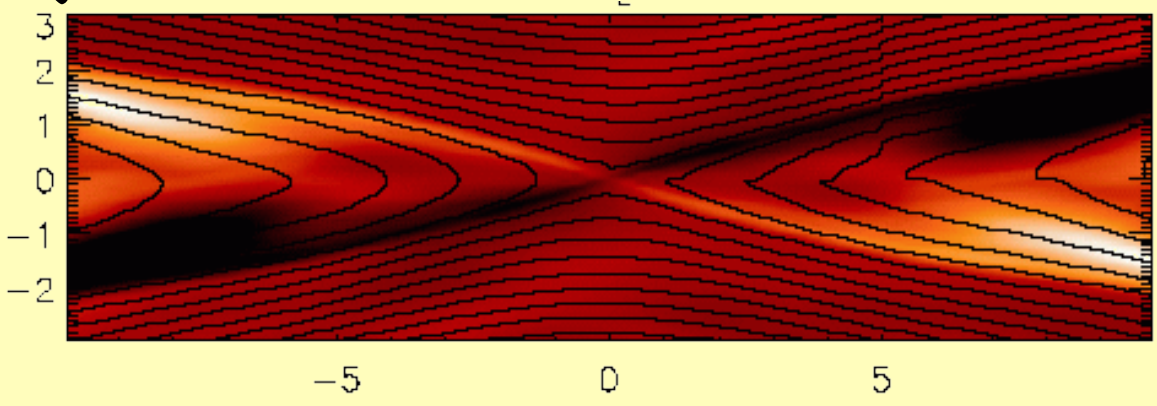
Reconnected flux

GEM challange

Hall term important!

- whistlers
- Kinetic Alfvén waves

[Rogers]

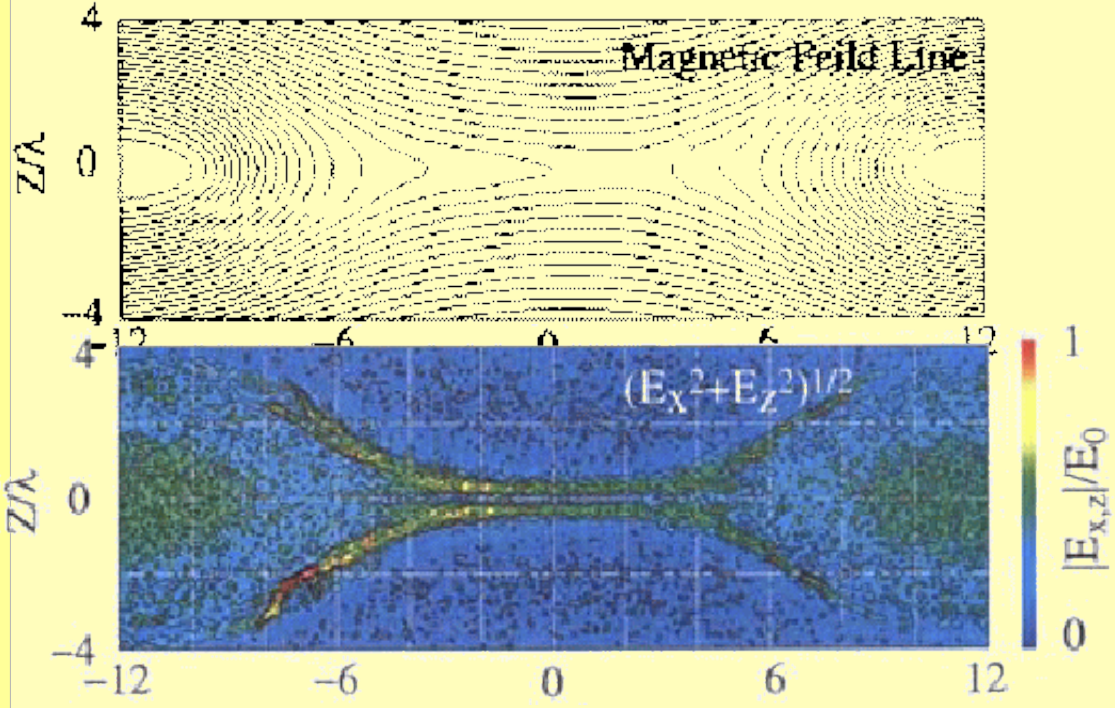


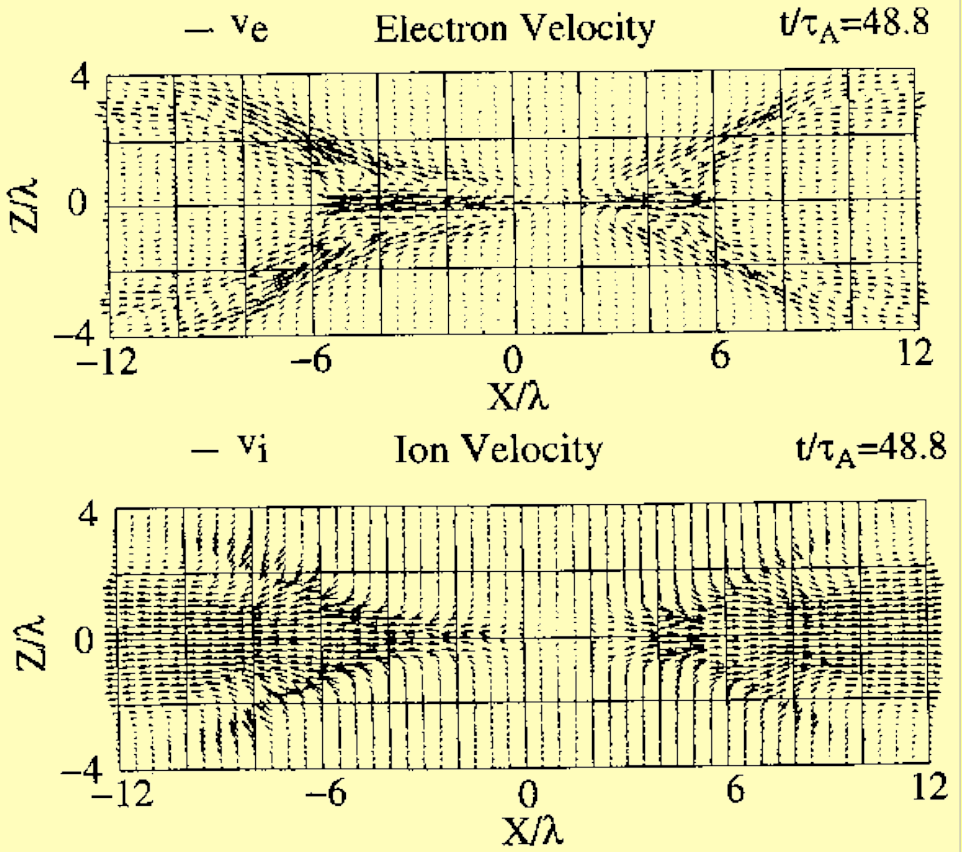
out of plane magnetic field

- quadrupolar structure

Numerical simulations

[Hoshino et al., 2001]



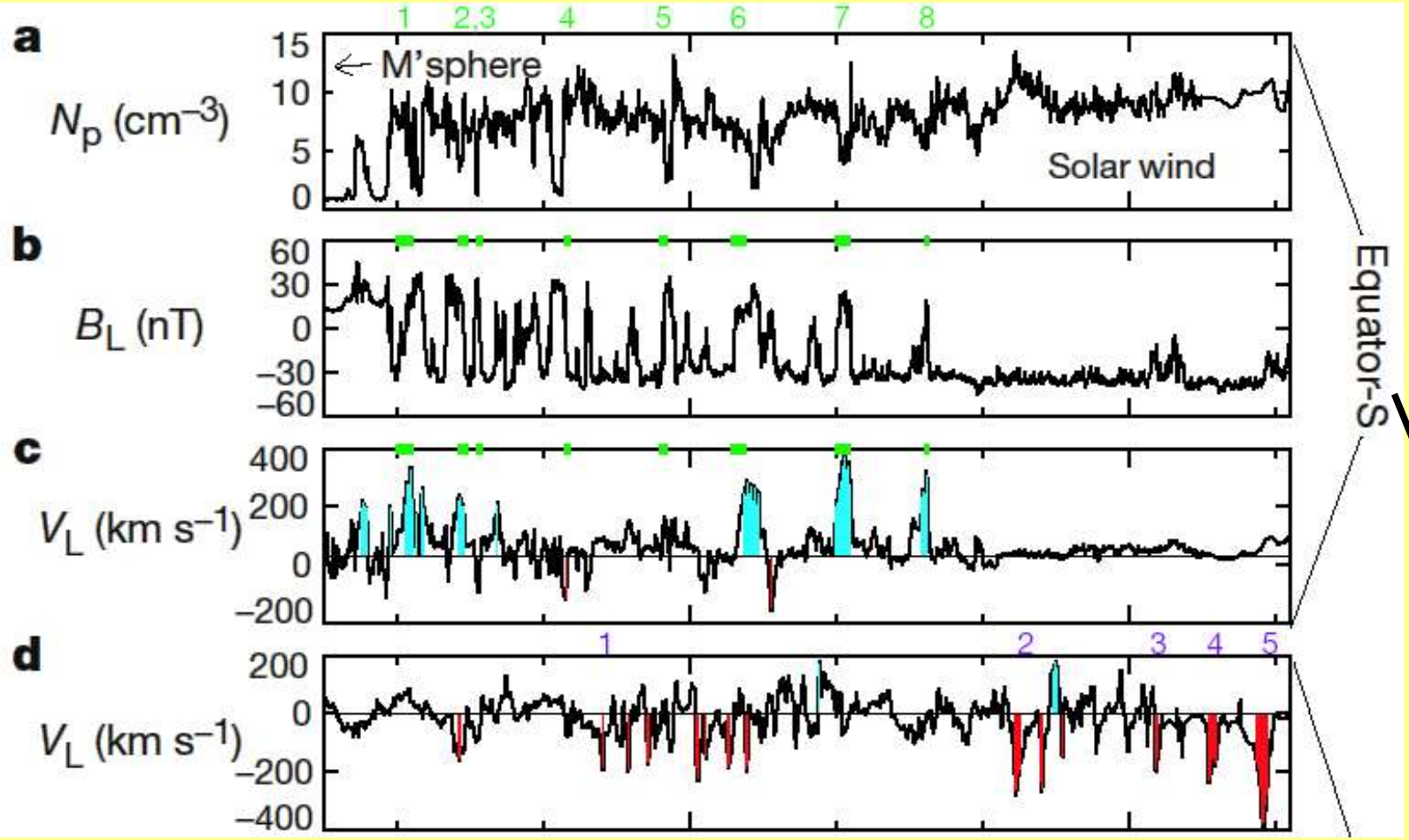


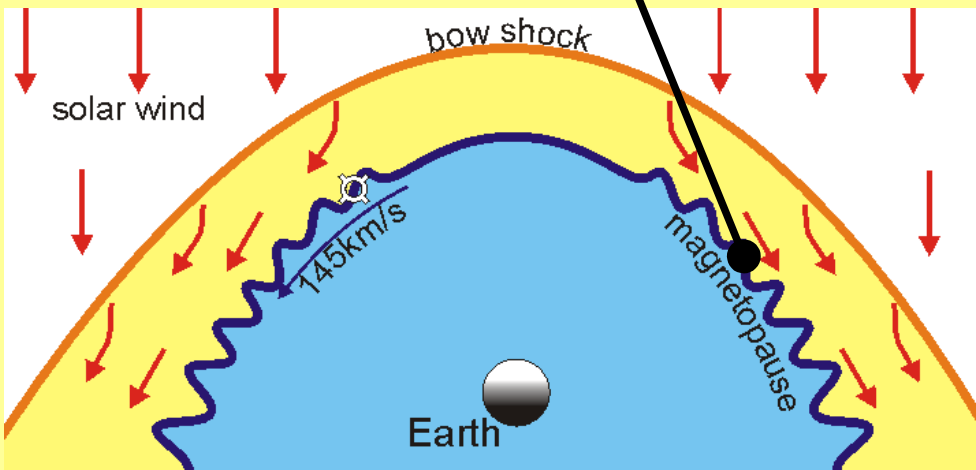
Separatrices

- strong electric fields
- strong parallel currents
- electron beams

Reconnection & space physics

[Phan et al., 2000]

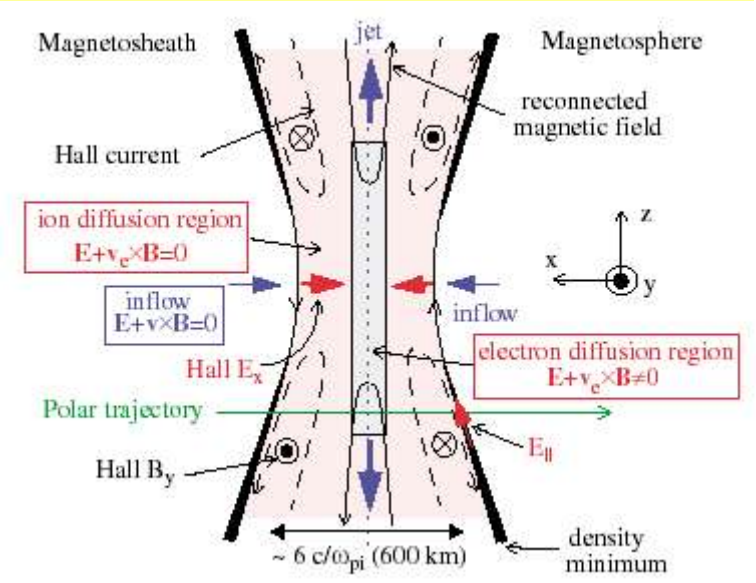


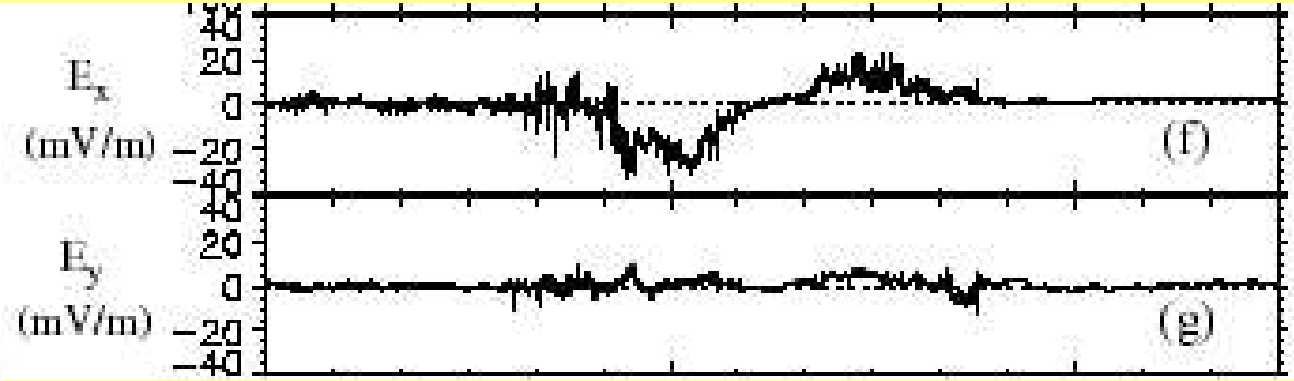


- ✔ Reconnection jets
- ✔ Continuity

Reconnection & space physics

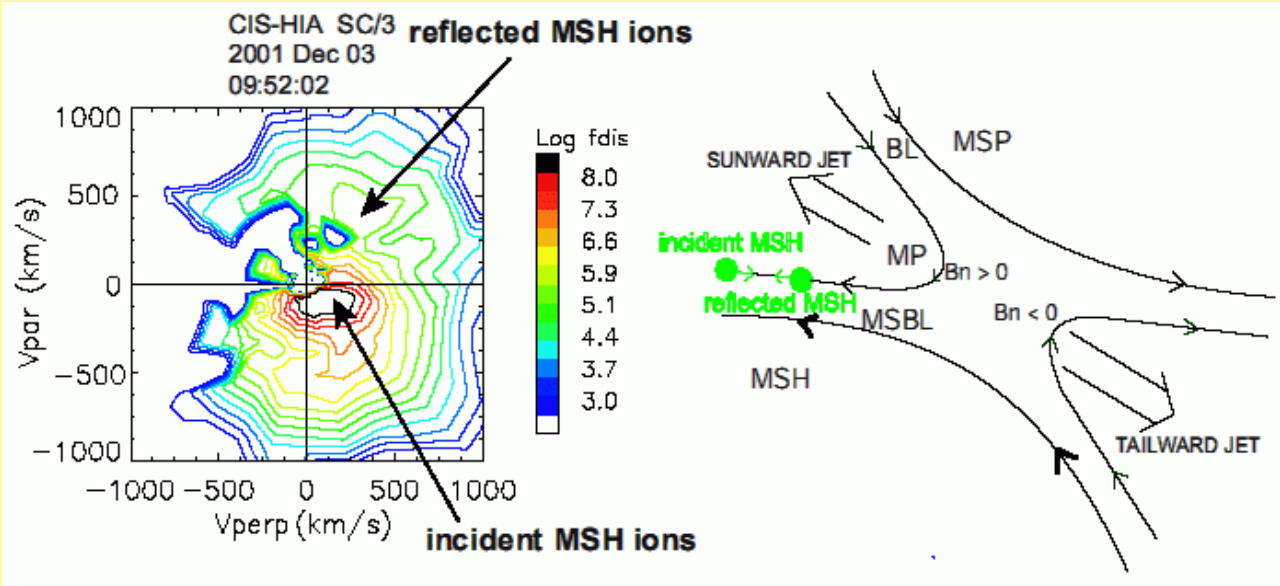
Why space in situ : we can measure local magnetic and electric fields, as well as ion and electron distribution functions.



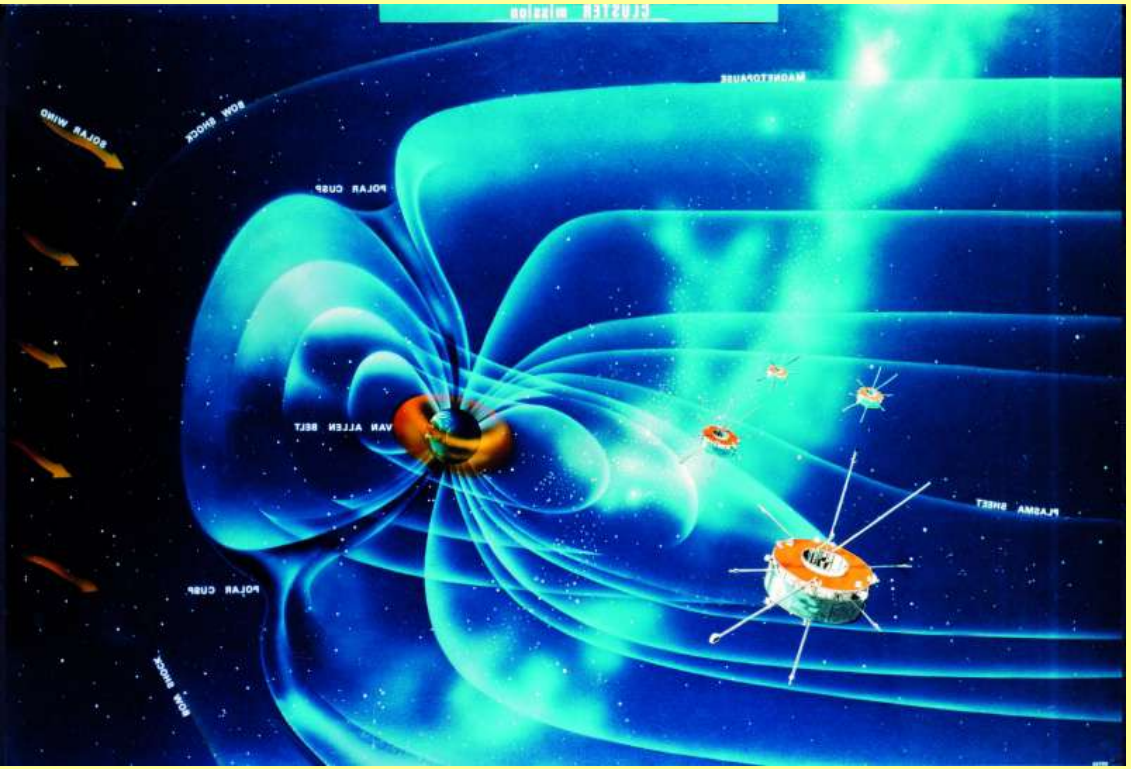


[Mozer et al., 2002]

[Retino et al., 2004]

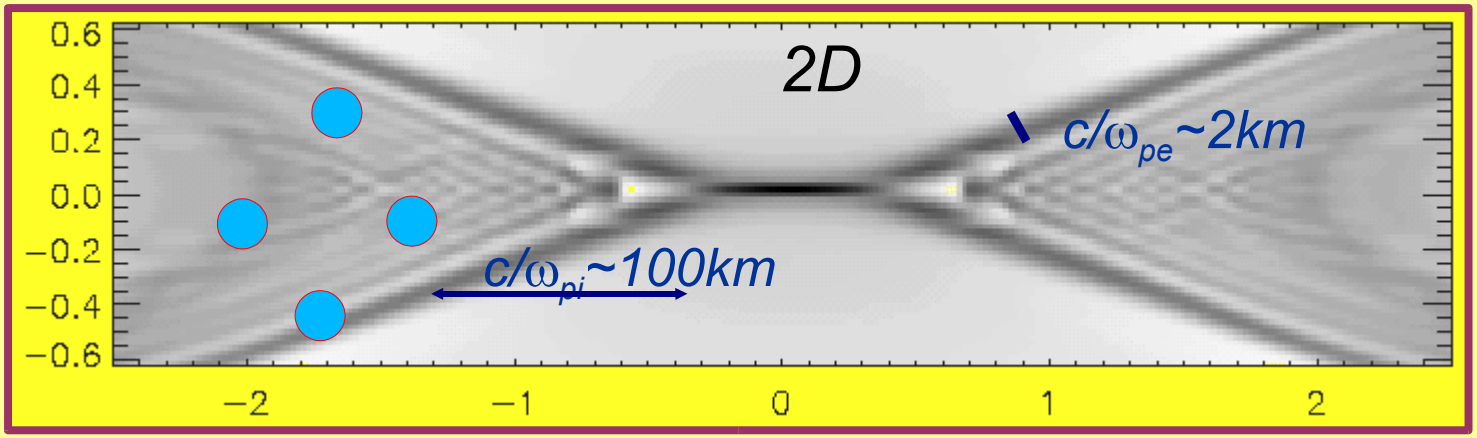


Cluster chasing X-line



- ✔ 4 s/c ESA "Cornerstone"
- ✔ 2000-2005
- ✔ First time we can reliably solve time-space ambiguity
- ✔ First time reliable measurements of current

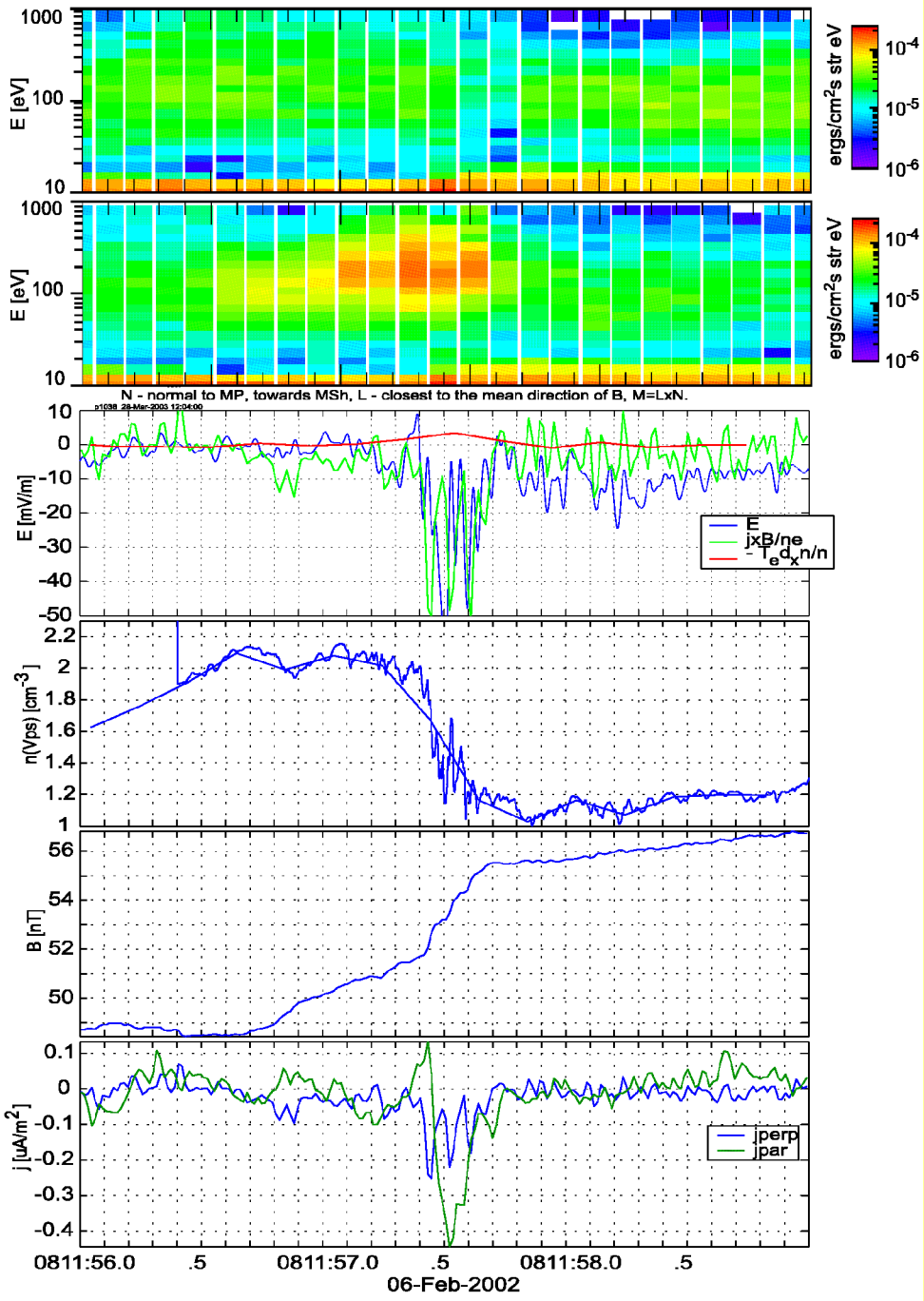
Current



[Rogers et al., 2000]

Cluster, separatrices far from X-line

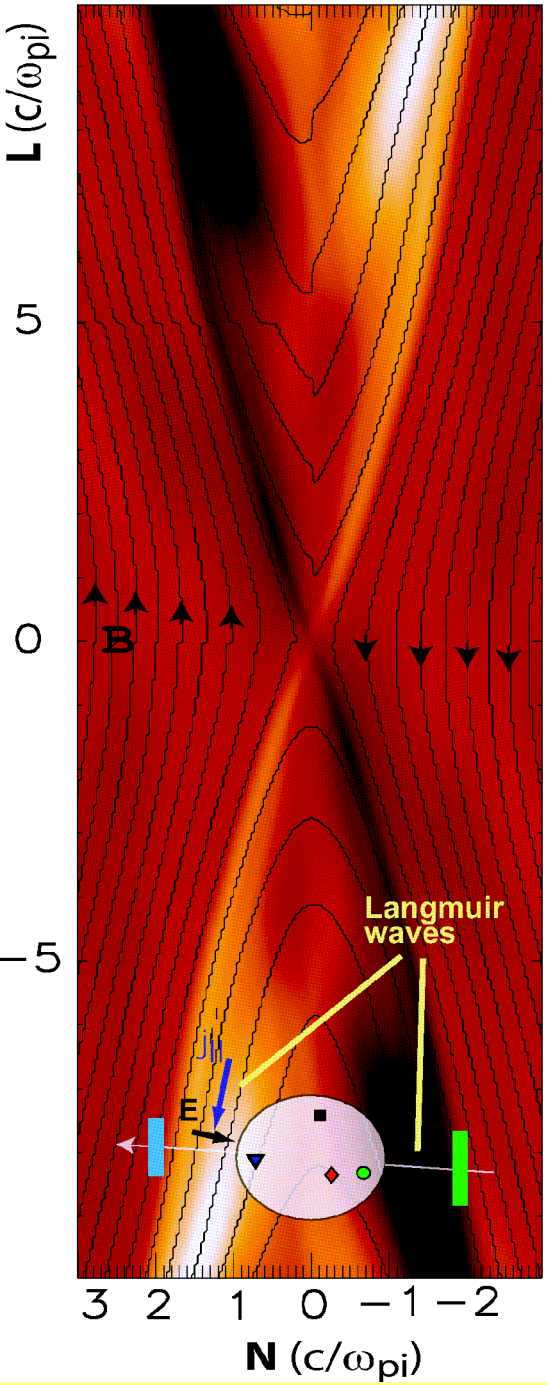
[André et al., 2004]

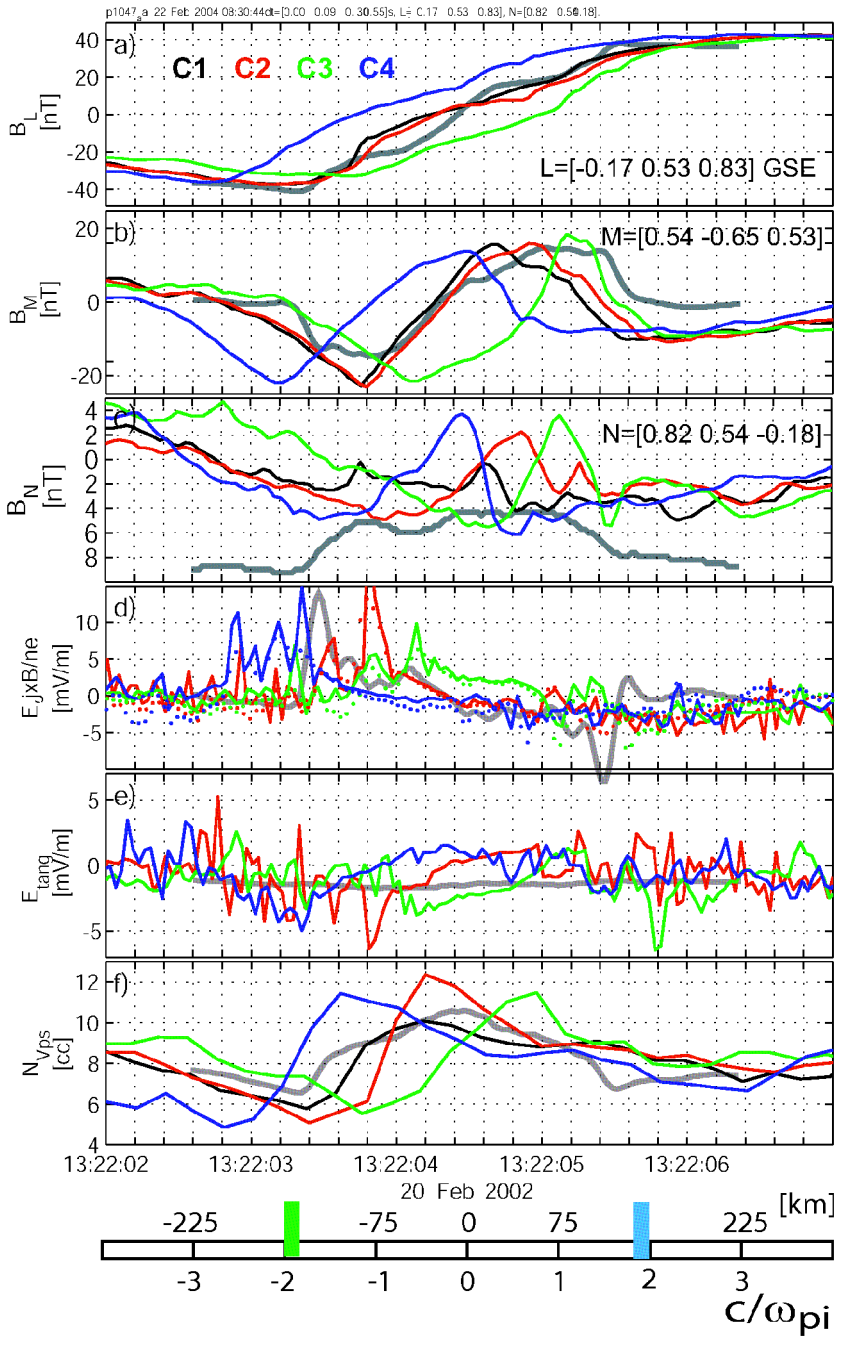


- ✔ Narrow strong current sheet
- ✔ e- beams
- ✔ Hall dynamics

Cluster, close to X-line

[Vaivads et al., 2004]

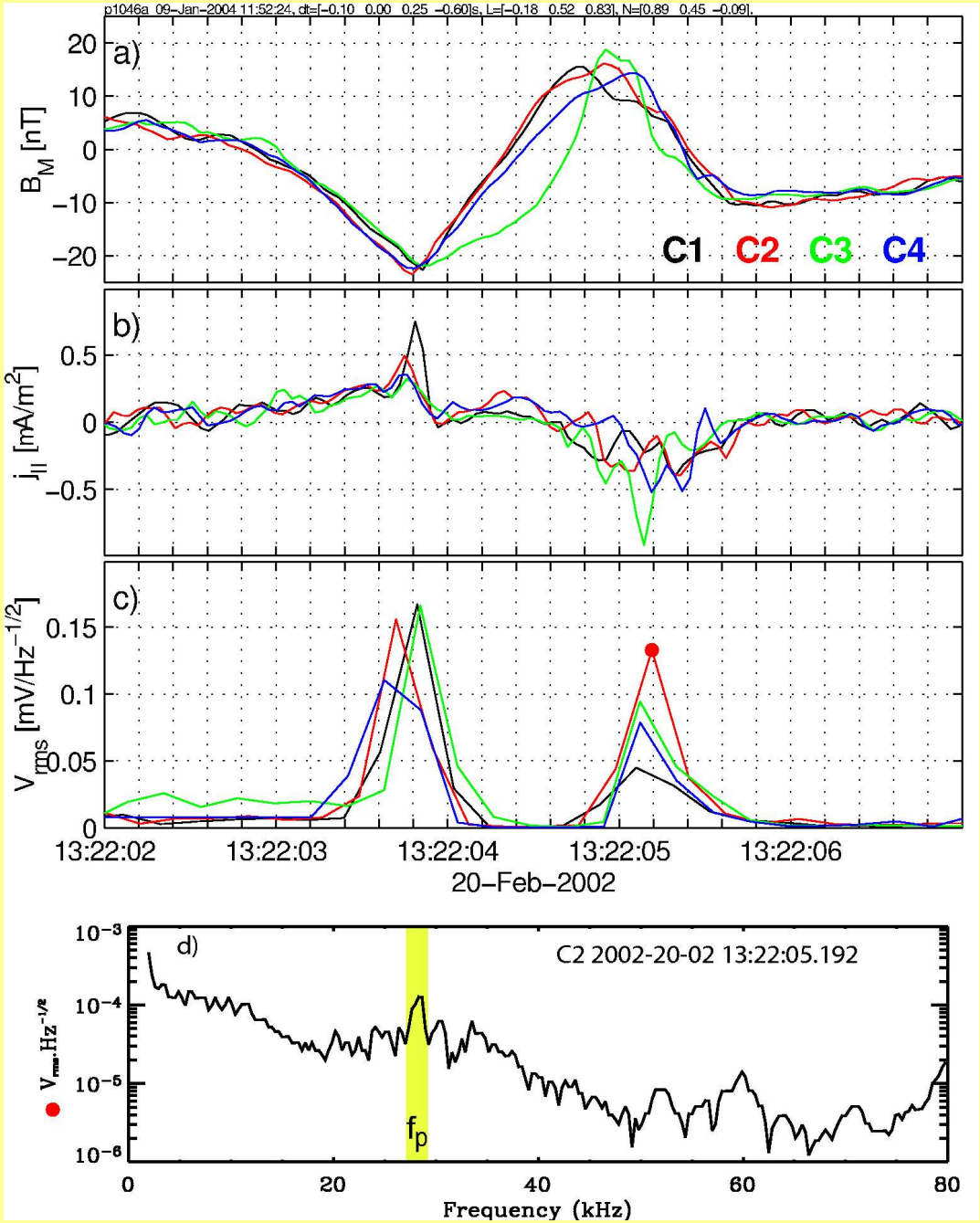




- ✔ Reliable structure estimate
- ✔ Hall dynamics
- ✔ Fast reconnection

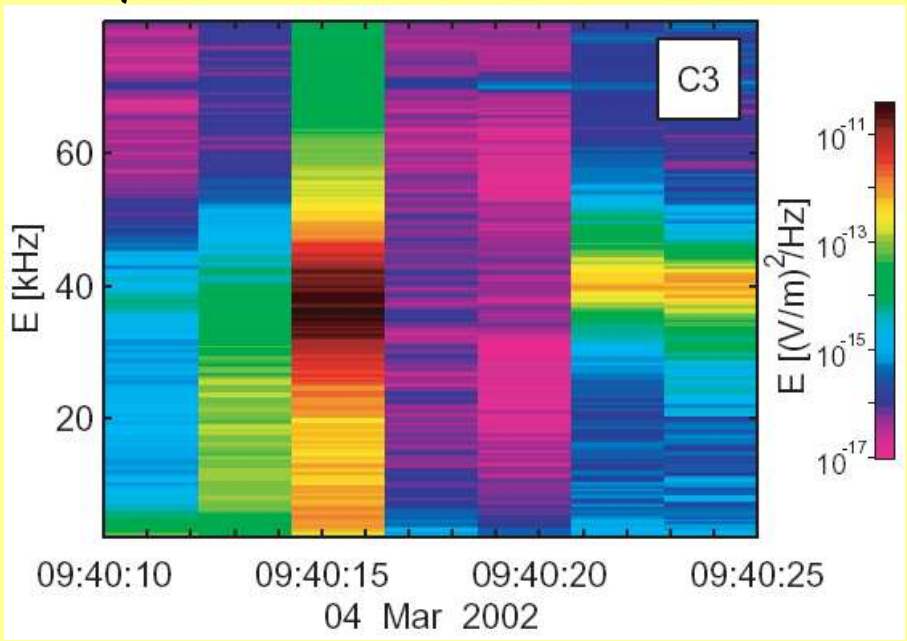
Separatrices, $j_{||}$ and HF waves

[Vaivads et al., 2004]



- ✔ Strong parallel currents
- ✔ Langmuir/upper hybrid emissions
- ✔ The role of waves?
  (anomalous resistivity, diffusion)

[Khotyaintsev et al., 2004]



Reconnection summary:

- ✔ Magnetic field topology changes and energy conversion
- ✔ Reconnection jets, plasma energization
- ✔ PLASMA (low energy) > B > plasma (HIGH ENERGY)
- ✔ In space around planets, stars, black holes, ...
- ✔ We start to understand details

Chandra Deep Field