New Understanding of the Sun from Space: View of a Japanese

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Contents

Introduction

** Why do we need study the Sun?*

1. "The Sun as a Star" (A Classical Field of Astrophysics)
   - Stellar Structure / Evolution
   - Dynamo Mechanism (Cosmic Magnetism)

2. Corona as a Prototype for Superhot Astrophysical Plasma
   - Why is the corona so hot?
   - Coronal Structure / Dynamics
   - Sudden Energy Release and Particle Acceleration

3. Factors Controlling the Space Weather and Climate
   - Solar Wind
   - Flares and CMEs as a Cause of IP Disturbances

Golden Age of Solar Physics from Space

- **Yohkoh** (1991 - 2001) Japan / US / UK

  Hard and Soft X-ray Imaging;

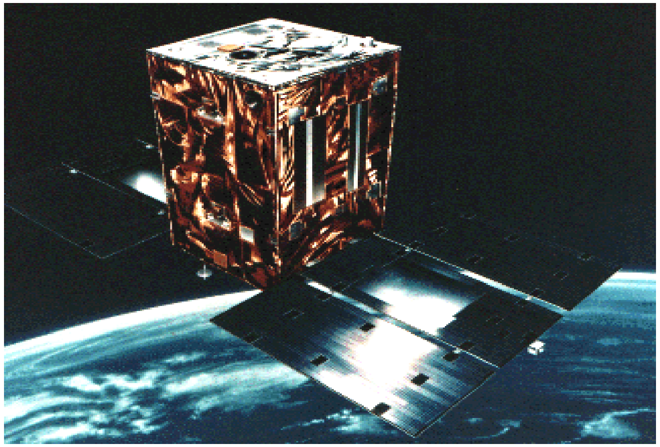
  X-ray & Gamma-ray Spectroscopy; Flares
- **SoHO** (1996 -) ESA / NASA

  Solar & Heliospheric Imaging; Helio-seismology
- **TRACE** (1998 -) NASA;

  Highest Spatial Resolution UV & EUV Imaging
- **CORONAS-F** (2001 -) RSA

  Coronal Imaging and Spectroscopy
- **RHESSI** (2002 -) NASA / other

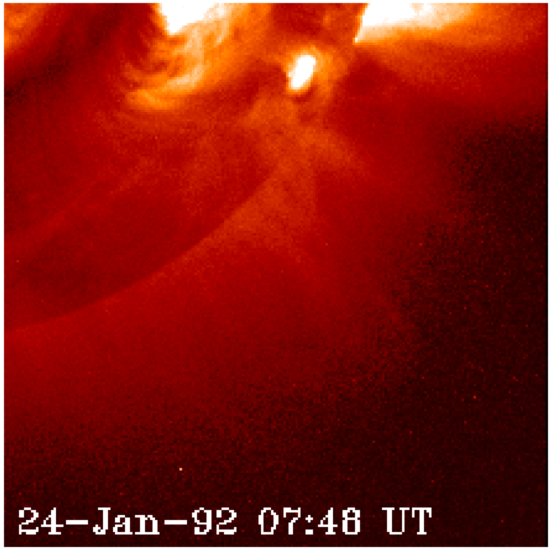
  High-Energy Solar Spectroscopic Imager; Flares
- **CGRO**, **Ulysses**, and other heliospheric missions

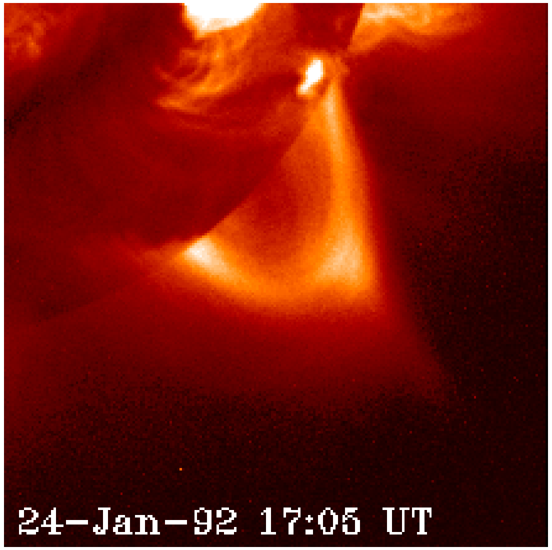


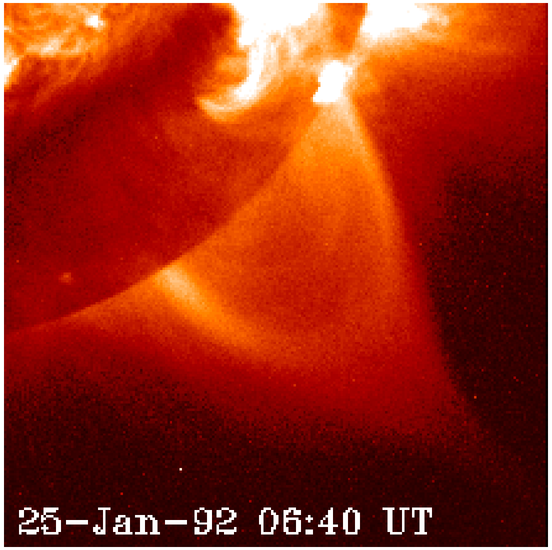
Ten Years with *Yohkoh*

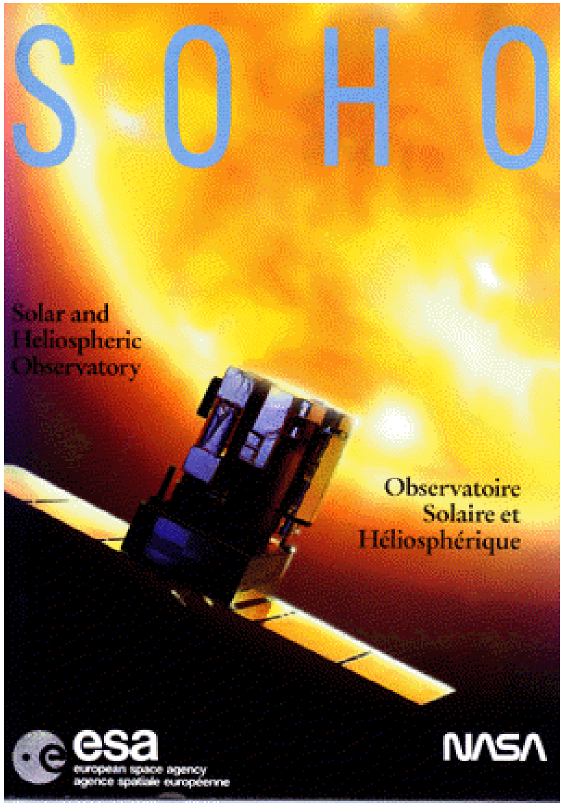
(1991 September – 2001 December)

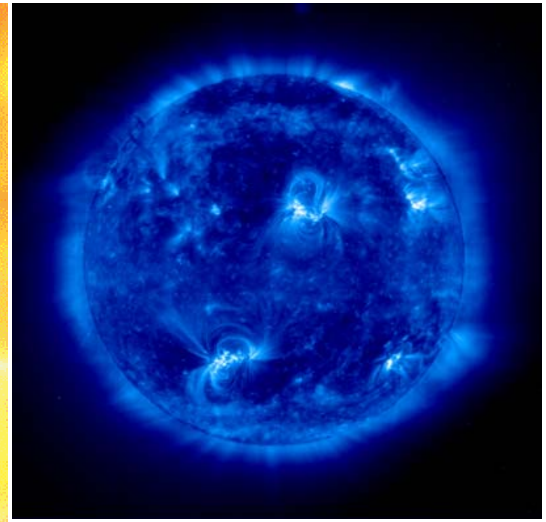
Energy Release and Particle Acceleration in the Solar Atmosphere



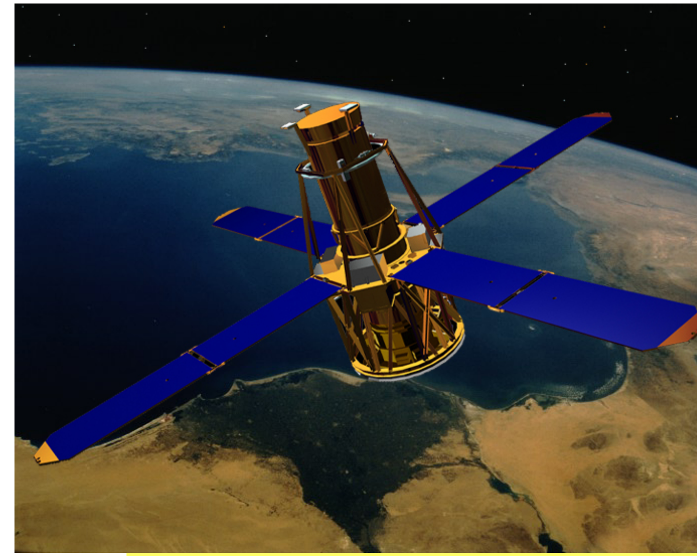






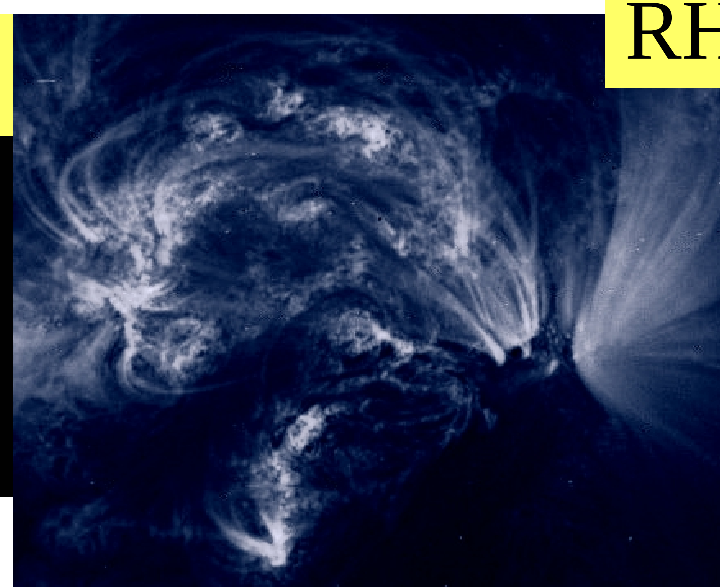


← SoHO (96 -)



RHESSI (02 -)

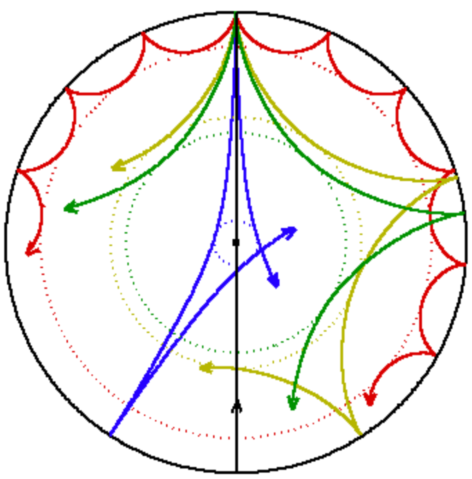
TRACE (98 -)

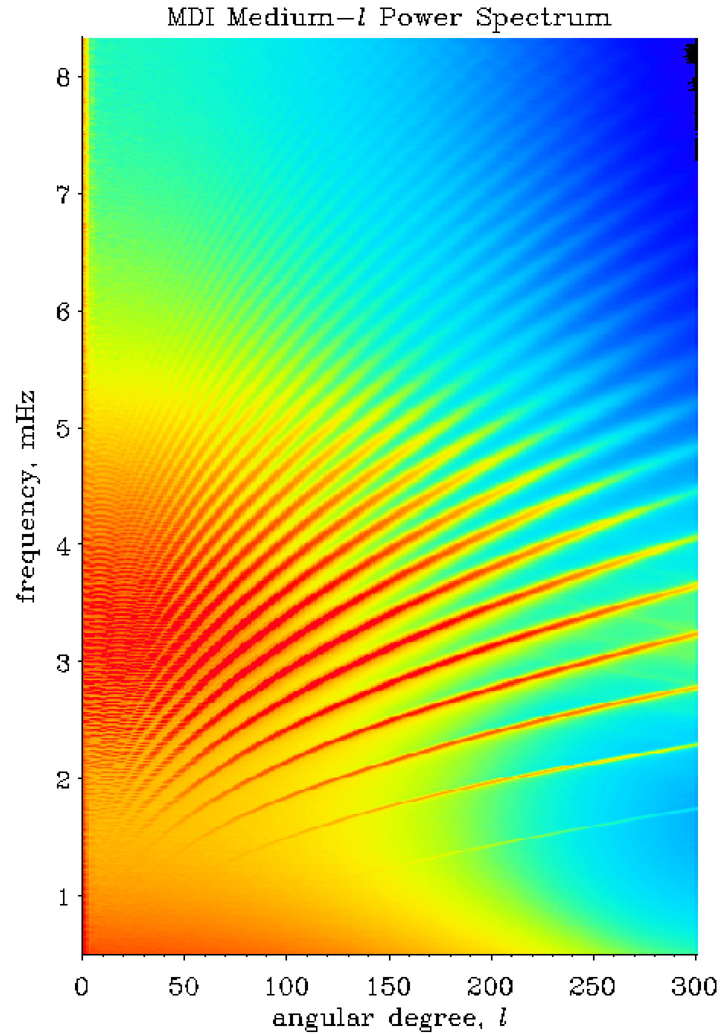


Understanding the Solar Interior:
-- Helioseismology --

- High precision solar data from SoHO (as well as from GONG).
- Major Progress in three directions
  - Interior structure
  - Interior rotation
  - Subsurface dynamics

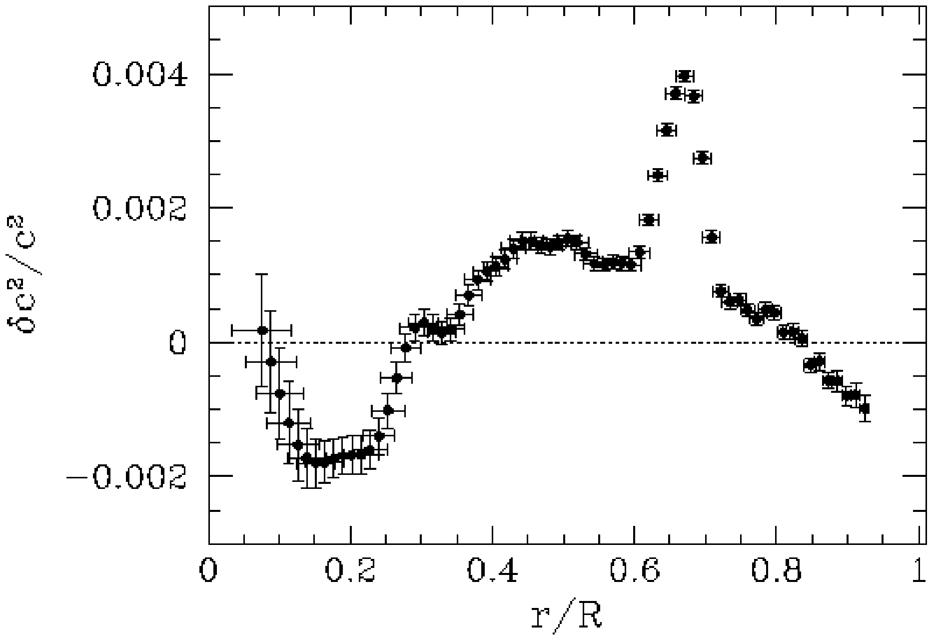
p-mode oscillation detected and used for diagnozing interior structure and rotation.

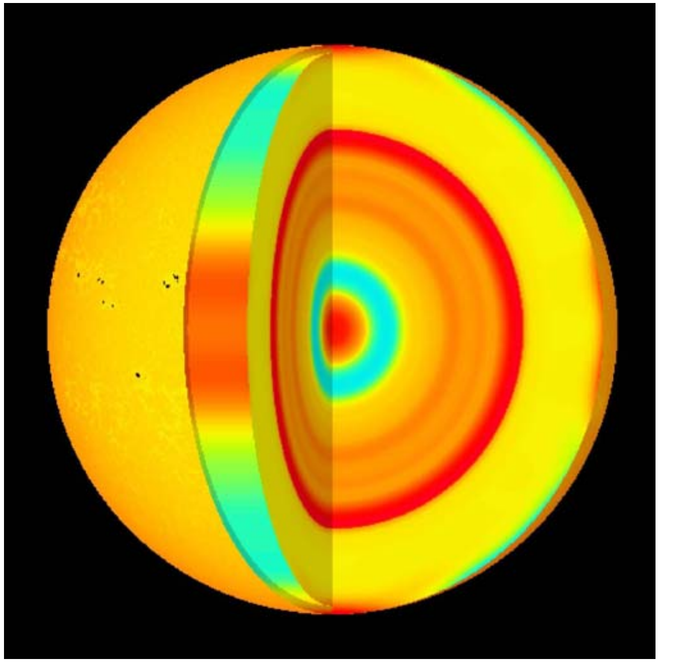




Interior Structure

- Comparison with the current solar model
  - Good agreement in general, but
  - Three regions that show non-neglectable discrepancy are: core, base of the convection zone, and near surface





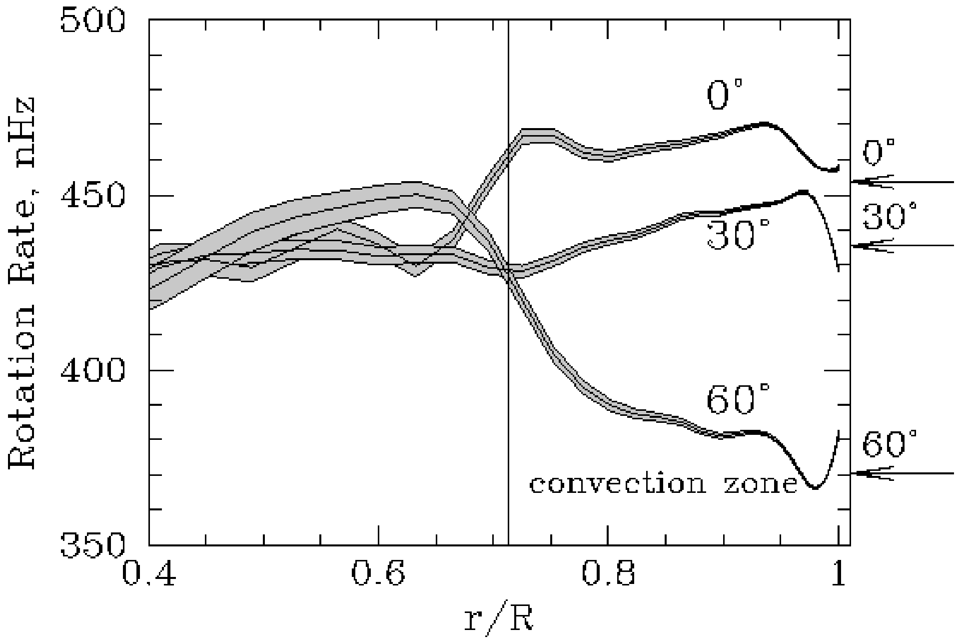
Difference of the sound speed between the measured and the model prediction (as a function of depth in the Sun). The “bump” at 0.7 R due o excess mixing.

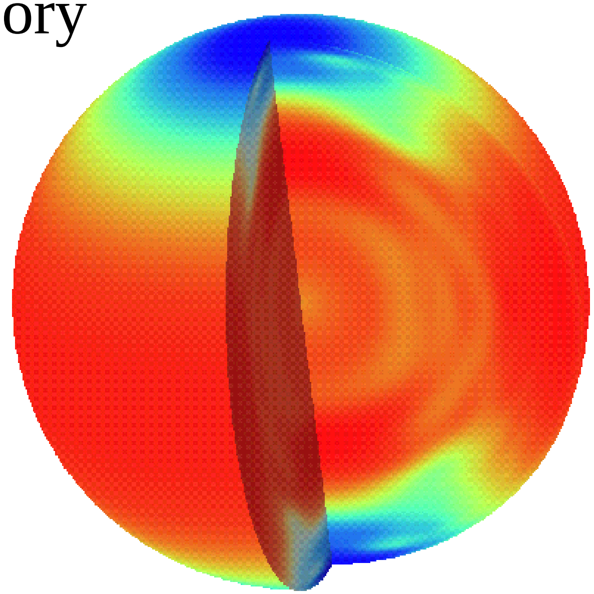
Internal Rotation and Flow

- Differential rotation inside
  - Underneath the convection zone is a layer of shear
  - The radiative zone below the shear rotates almost rigidly.
- Meridional circulation

  The shear layer, coinciding with the site of sound speed excess, could be the region where the solar cycle dynamo operates.

  ➔ Basic data for the solar dynamo theory

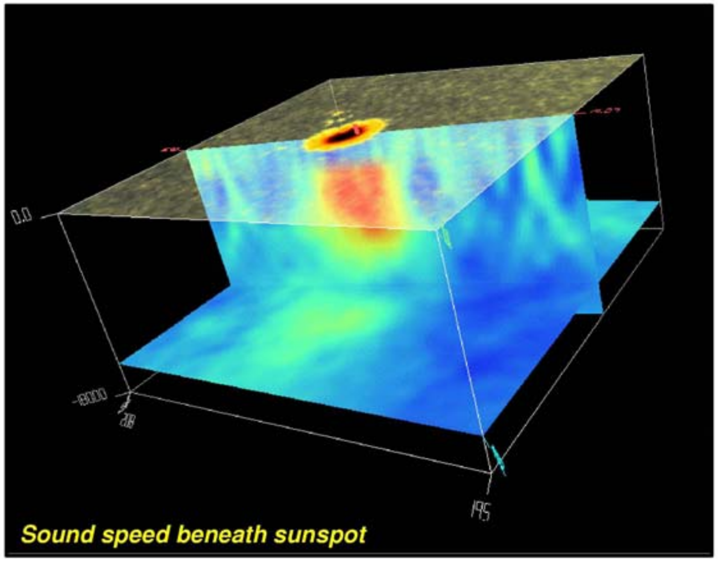




Red faster, blue slower.

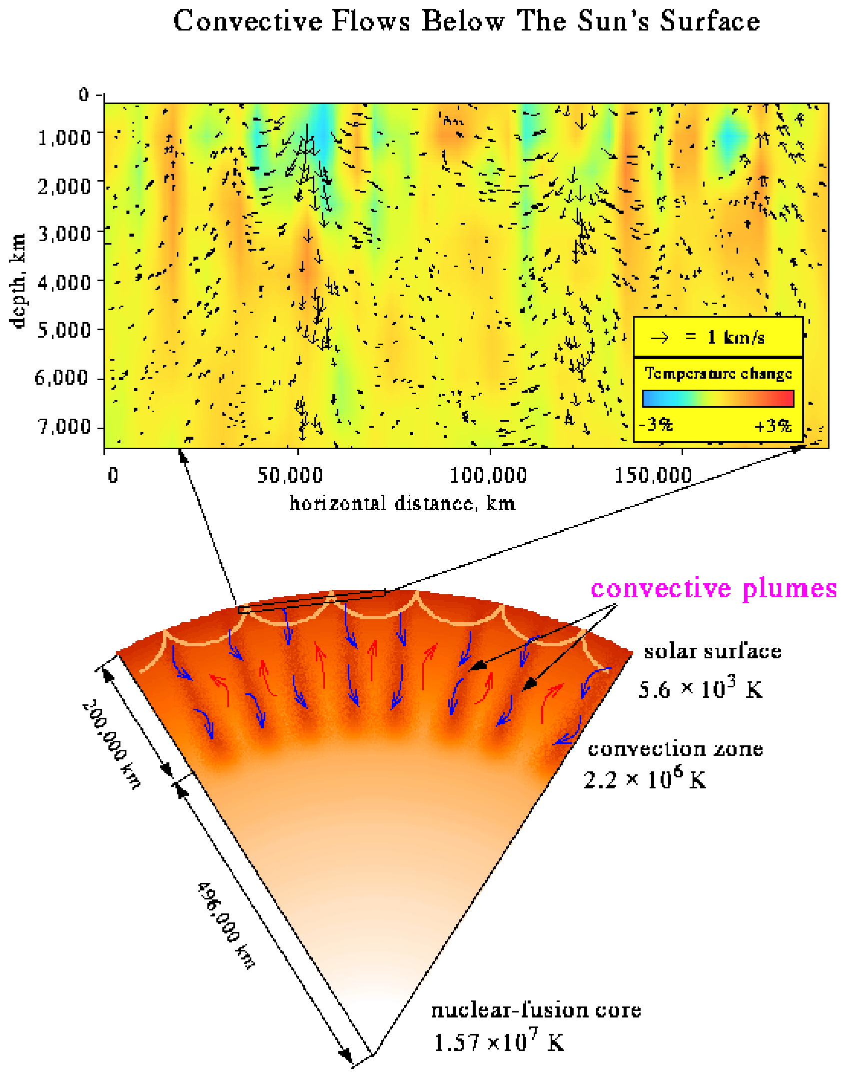
Subsurface Dynamics

- Time distance method is under development for investigating interior dynamics.
    - Supergranulation
    - Sunspots



Sunspot data from MDI High Resolution, 18 June 1998

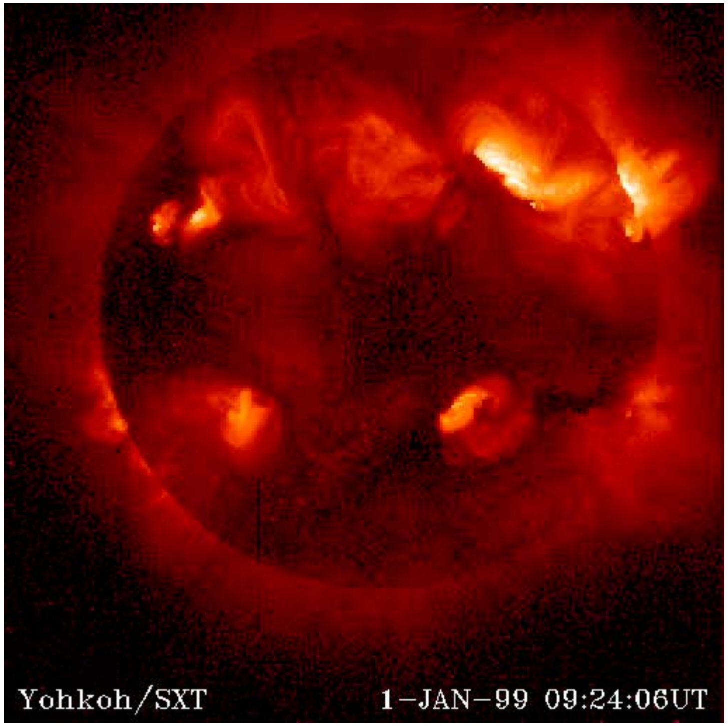
Thermal structure beneath sunspot



Subsurface flow

The Solar Atmosphere

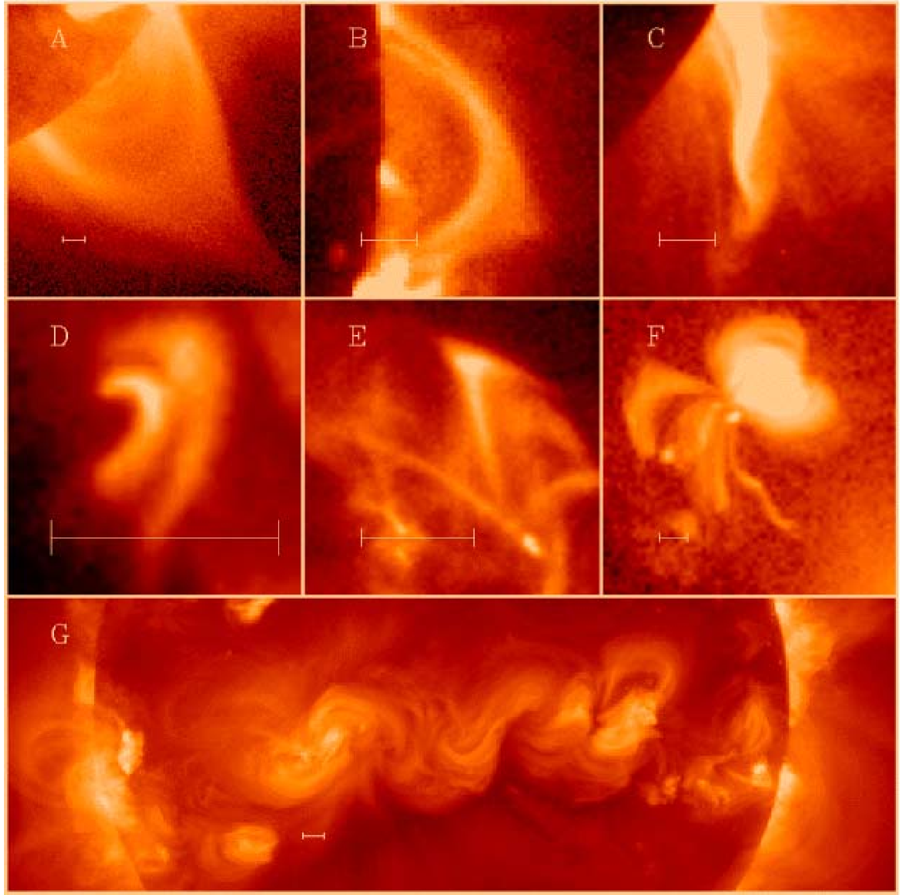
Various structures and dynamics, governed by magnetic fields



- **Coronal heating**
  - **11-yr cycle variation**
- **Ejections and IP disturbances**
  - **Large-scale restructuring**
  - **X-ray plasmoid**
  - **X-ray dimming (vs CME)**
  - **X-ray sigmoid (vs CME)**
- **Solar flares as magnetic reconnection process**
  - **Soft X-ray loop-with-a-cusp structure, increasing in size with time**
  - **Double-footpoint plus above-a-loop-top hard X-ray sources**
  - **Particle acceleration site in the above-a-loop-top hard X-ray source**
  - **X-ray jets**

The corona is full of magnetic features!

Cusps

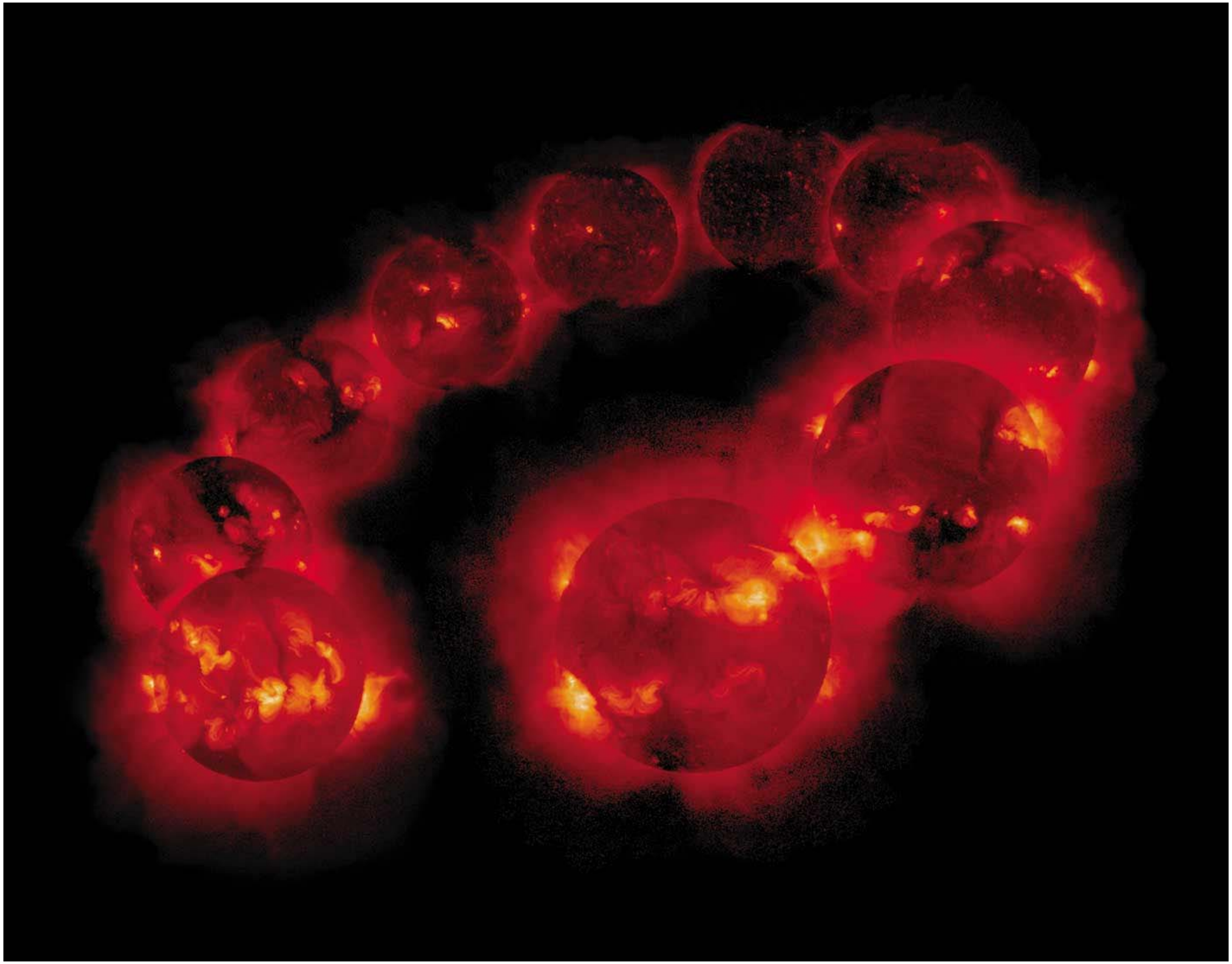


Twisted Loops

S-shaped interconnecting loops

All change with time.

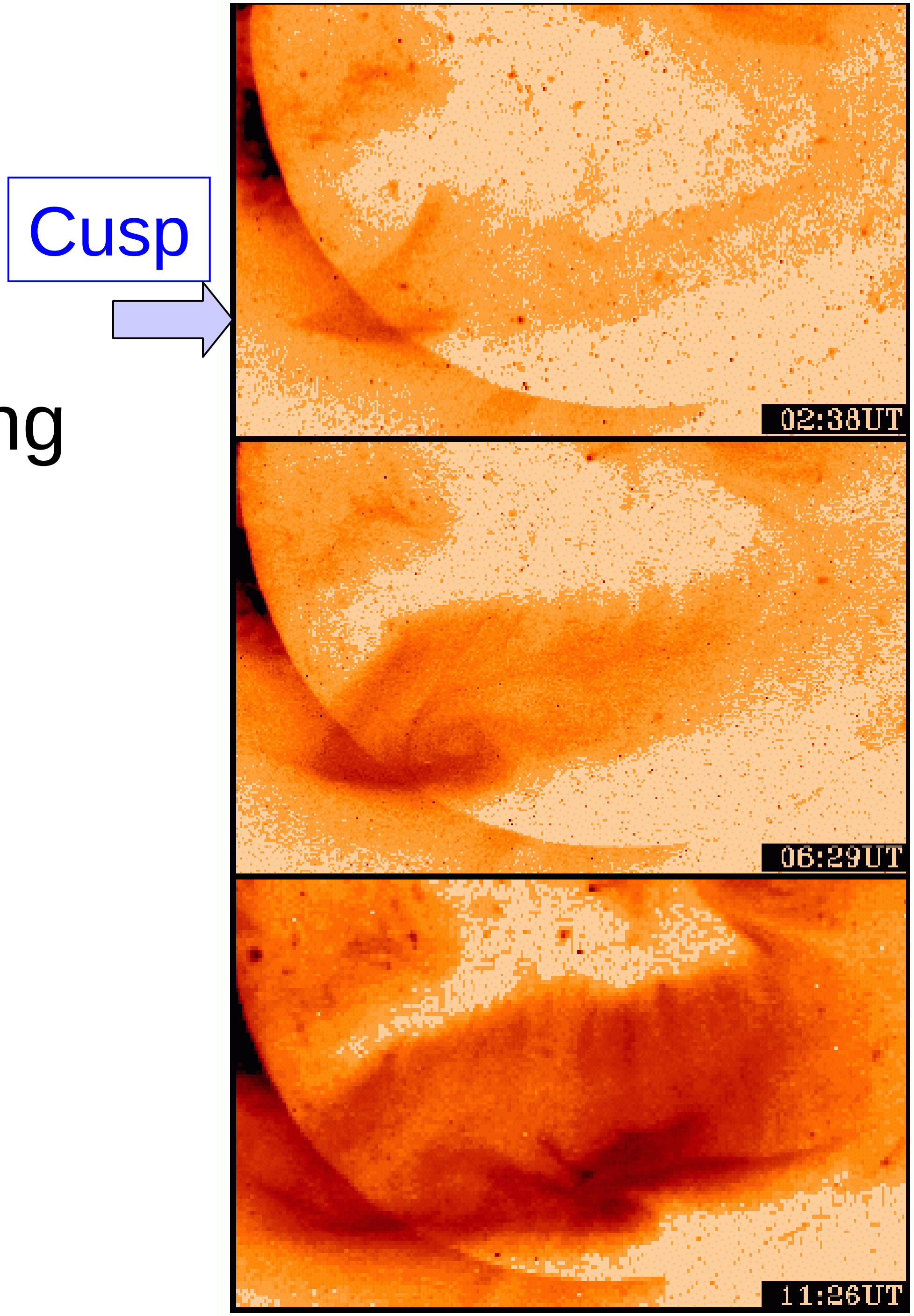
Highly variable the Sun is!



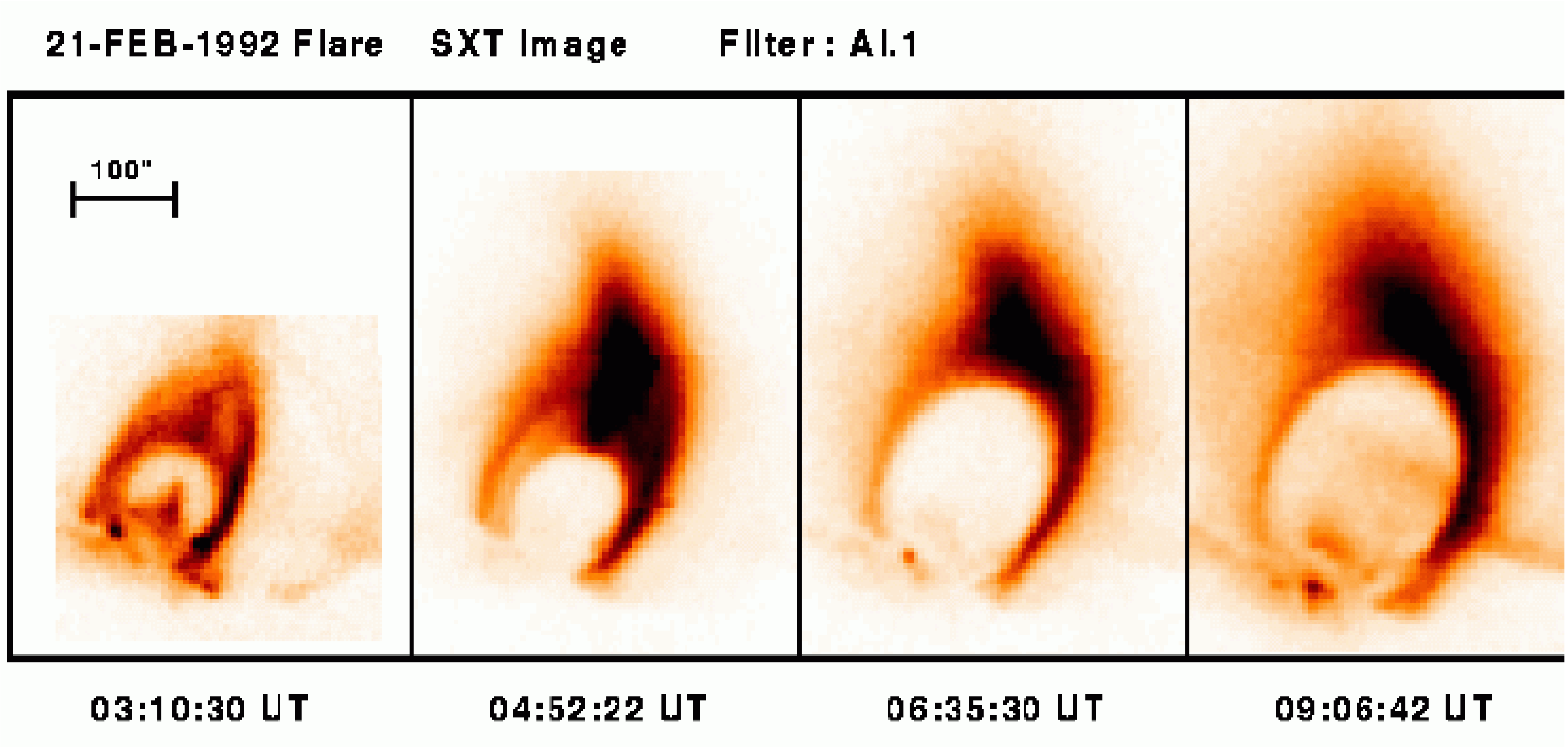
Global
Restructuring
Event

or

Giant
Arcade
Formation

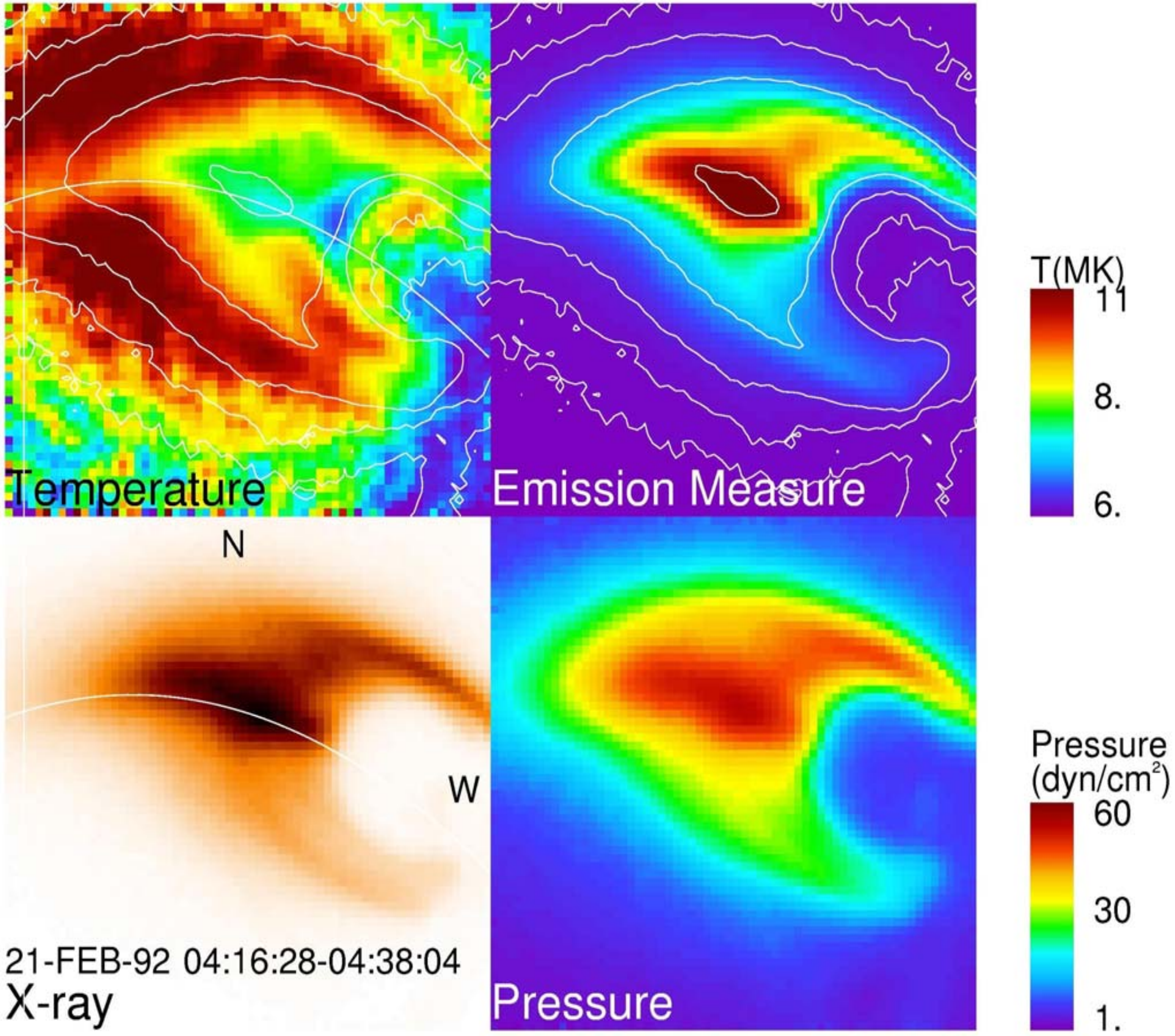


LDE flares with a growing cusp structure.

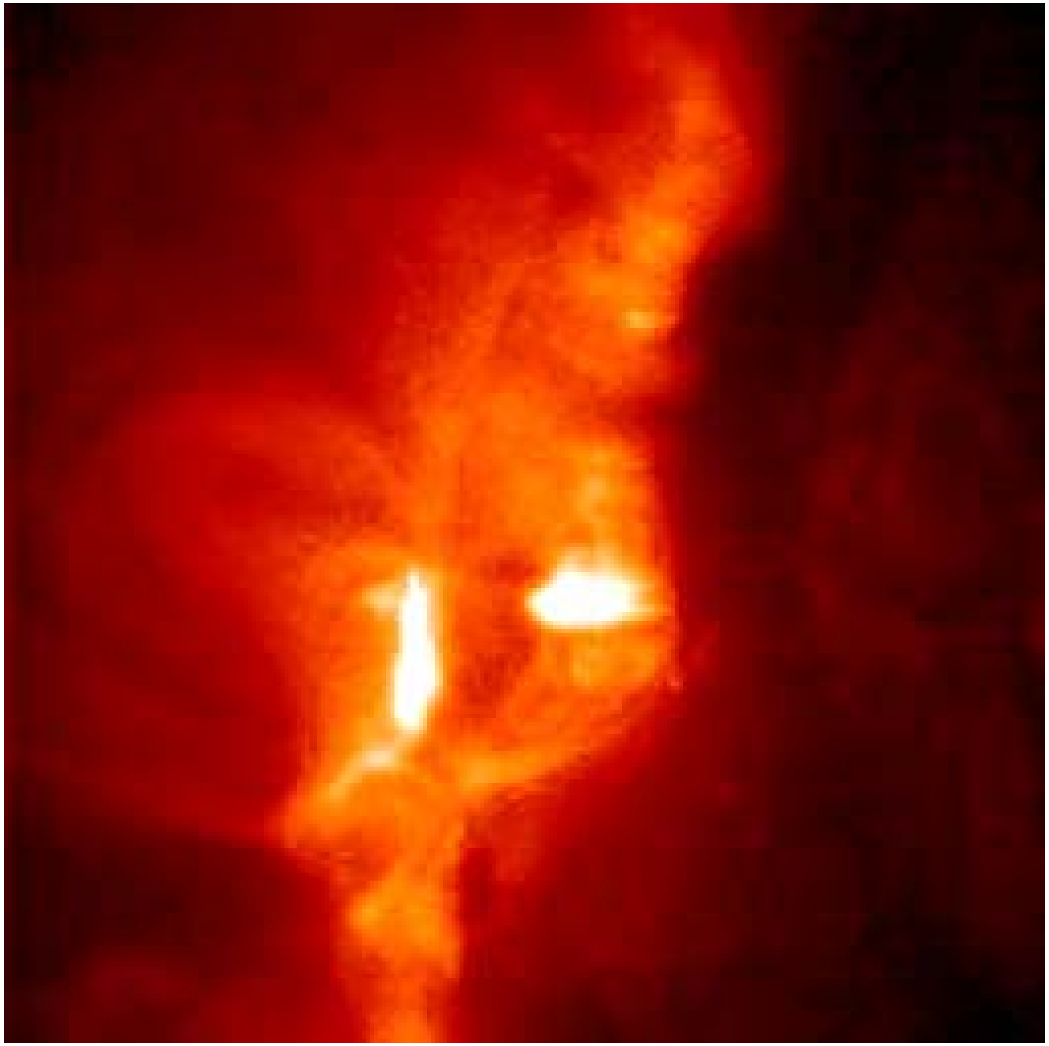


Higher temperatures (~20 MK) at the outer edge.
Upward motion (plasmoid) in the outer structure.

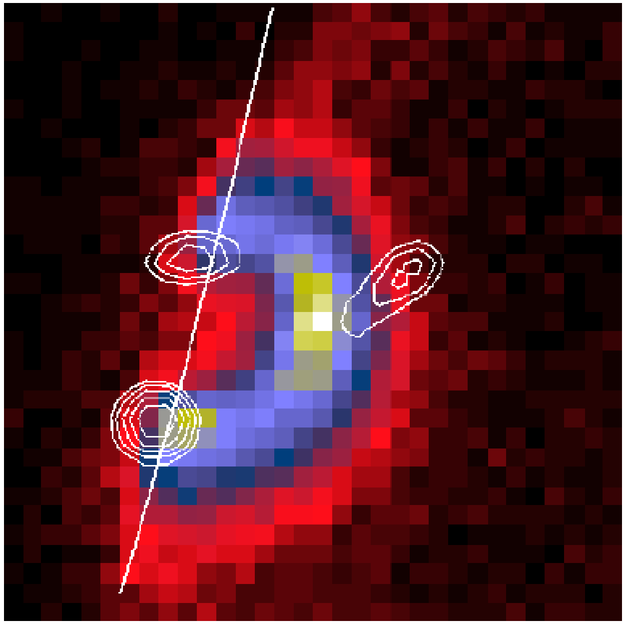
LDE flares with a growing cusp structure.



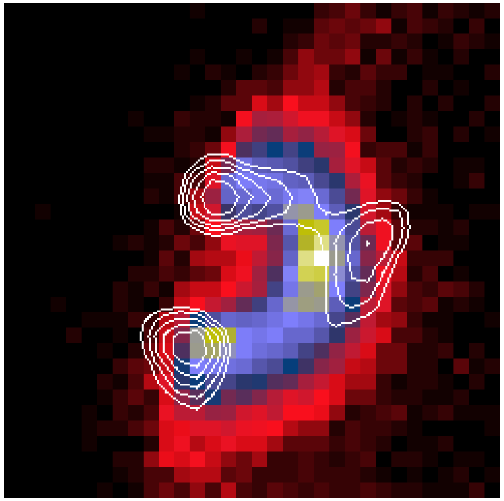
LDE flares with a growing cusp structure.



Above-the-looptop hard X-ray source in impulsive (compact) flares

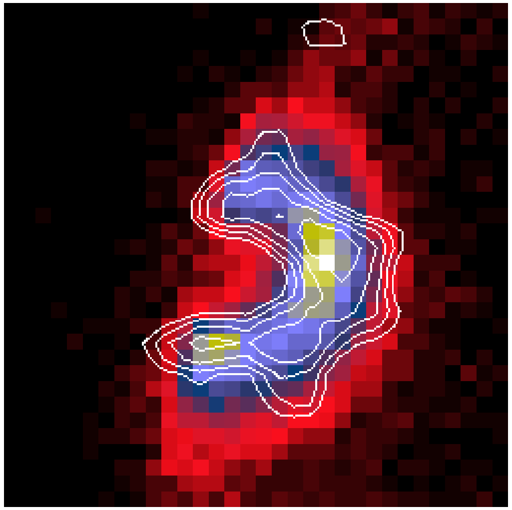


33 – 53 keV

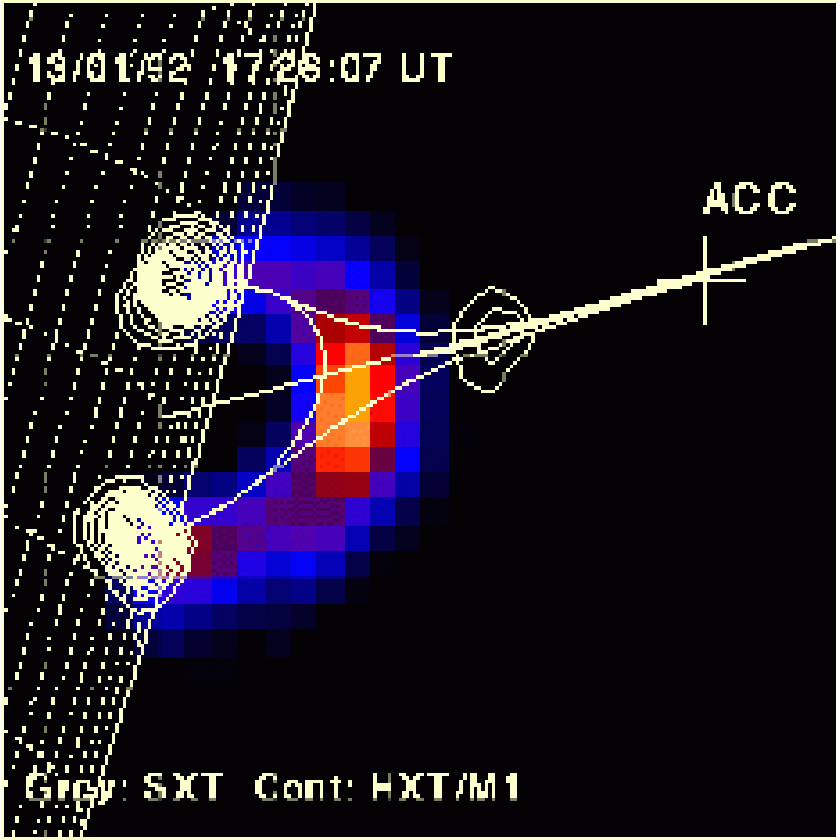


23 – 33 keV

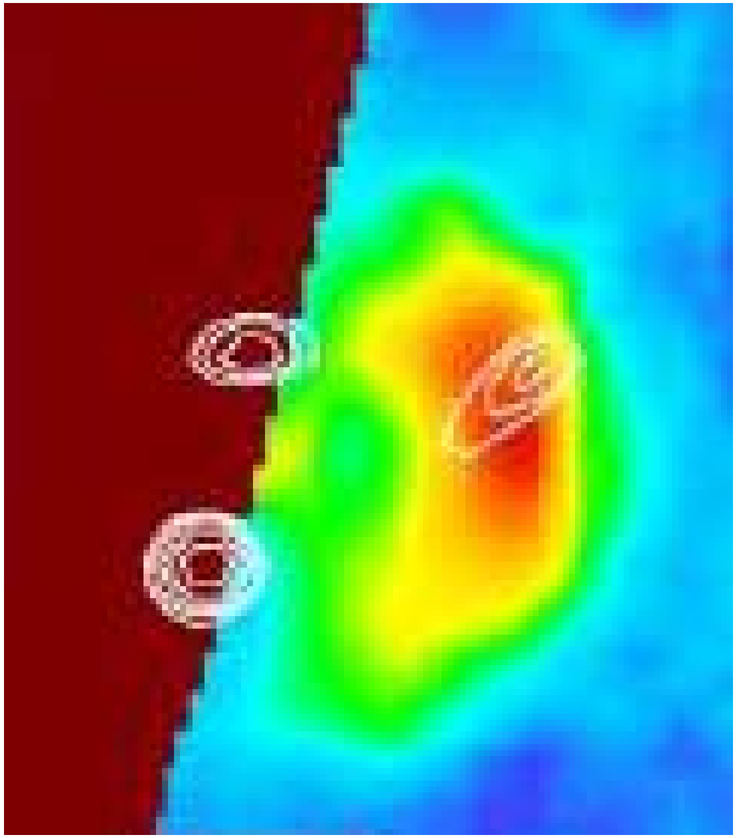
14 – 23 keV



Particle Acceleration in the cusp region

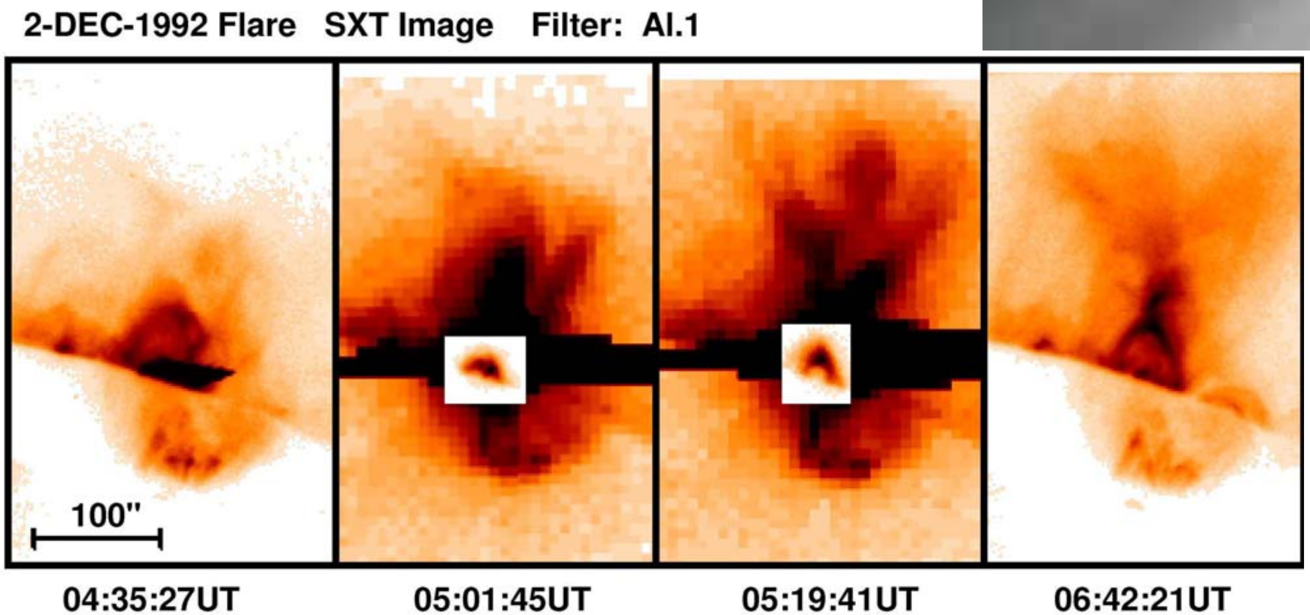


High-Temperature region



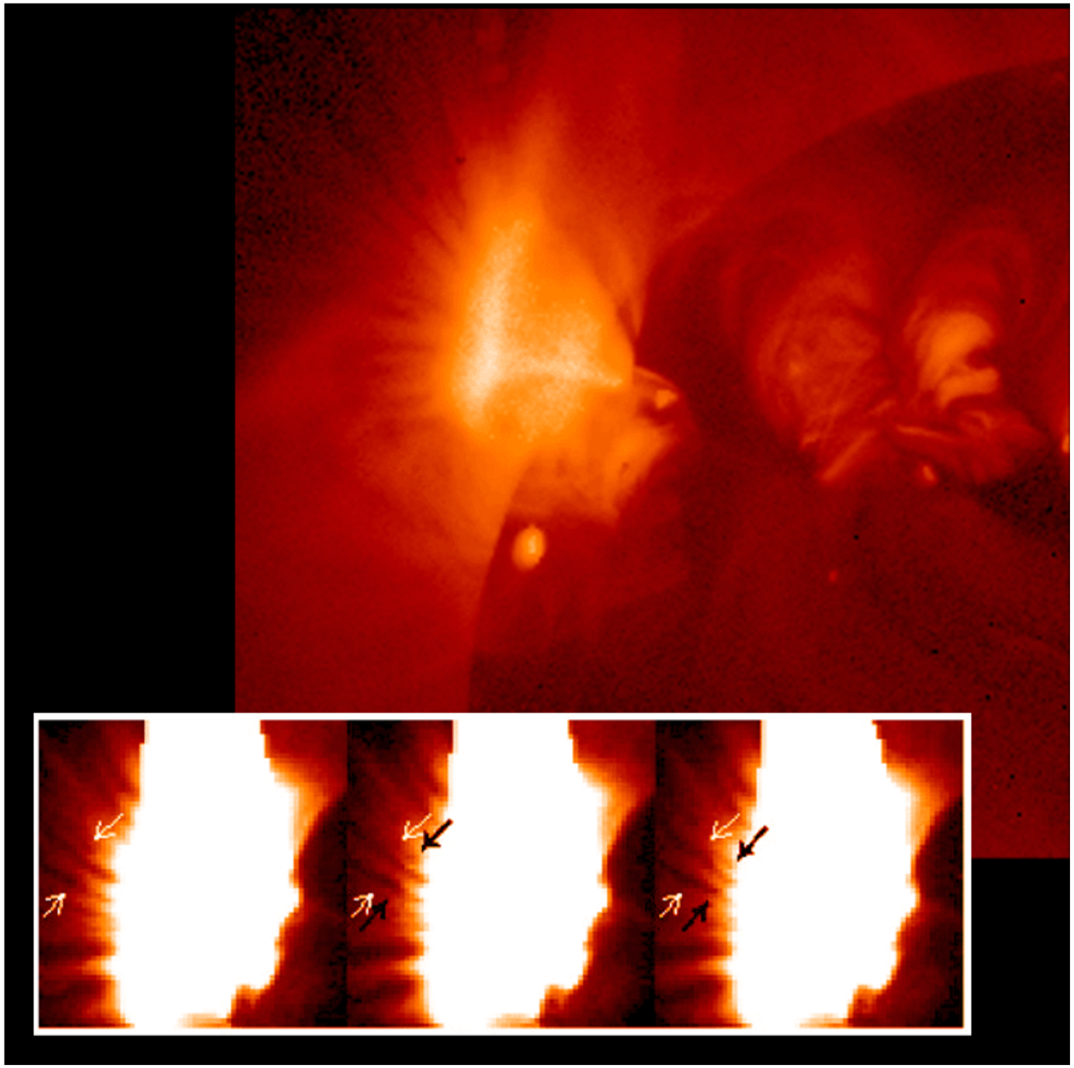
TOF analysis reveals the acceleration site.

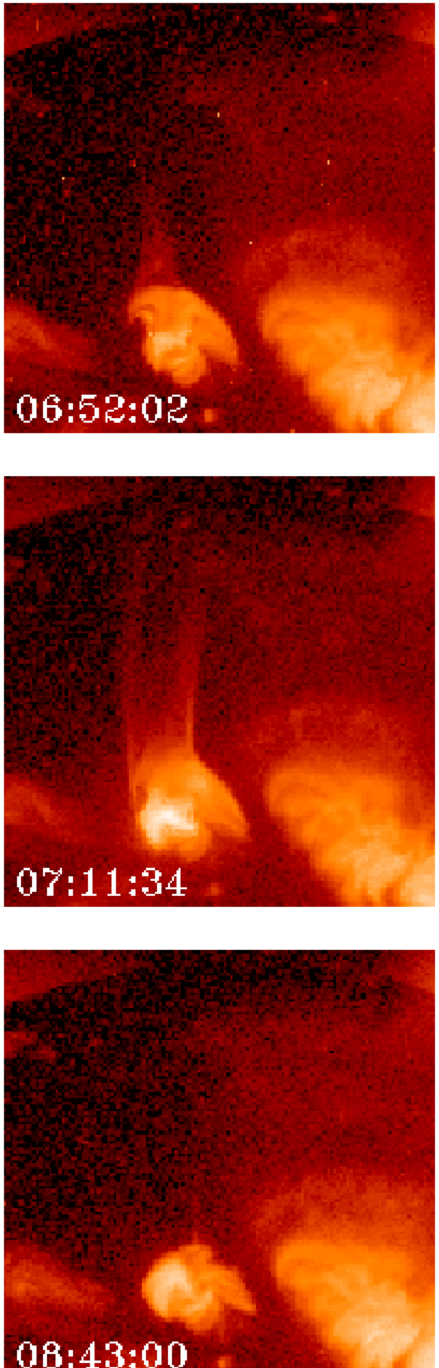
Flaring Loop and the Surroundings



Downstreaming blobs above the arcade:

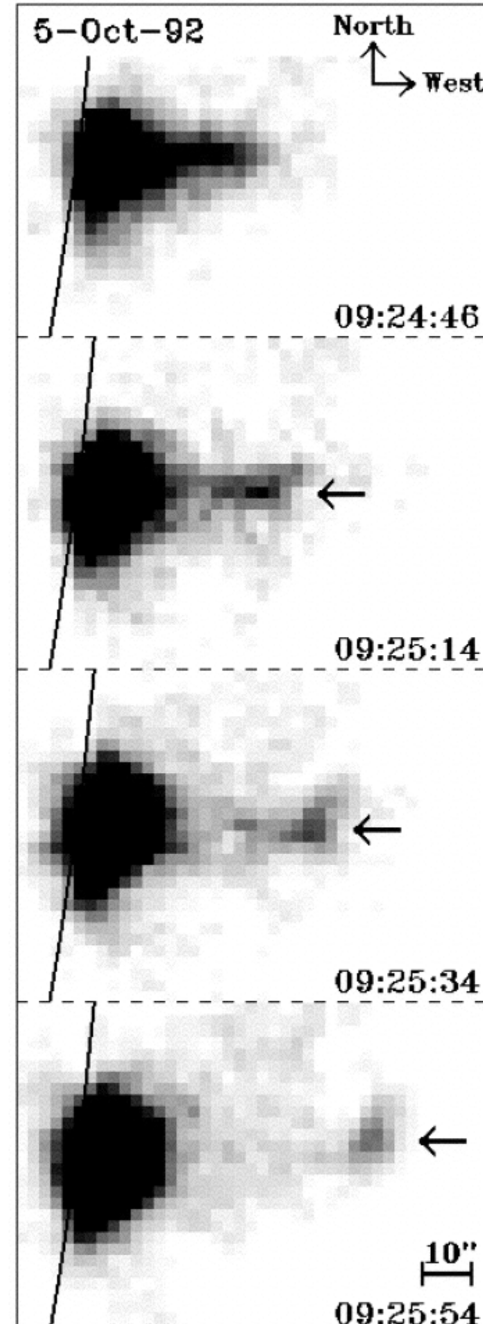
What's going on above the reconnection point ?





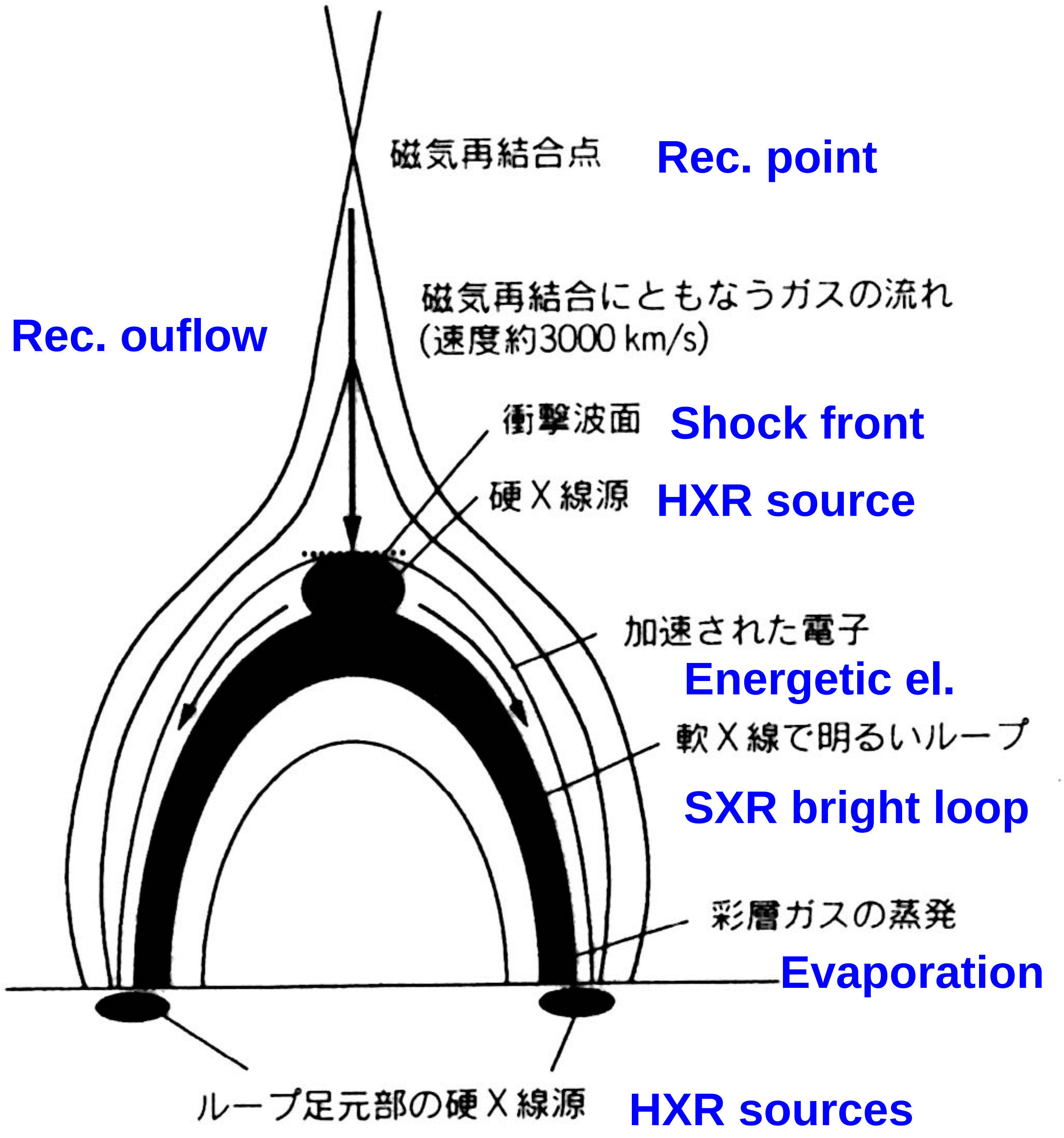
← X-ray jets

Plasmoid
ejection
in association
with flares →



Yohkoh canonical view:

Magnetic reconnection

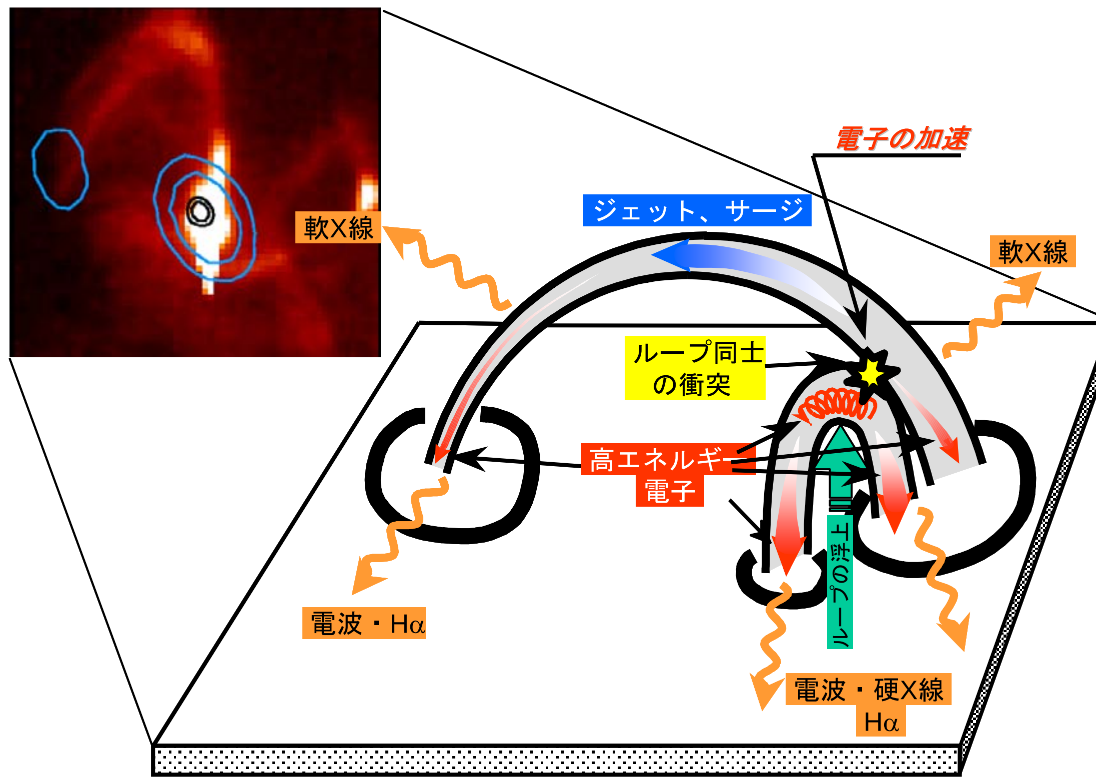


But, this is an oversimplification!

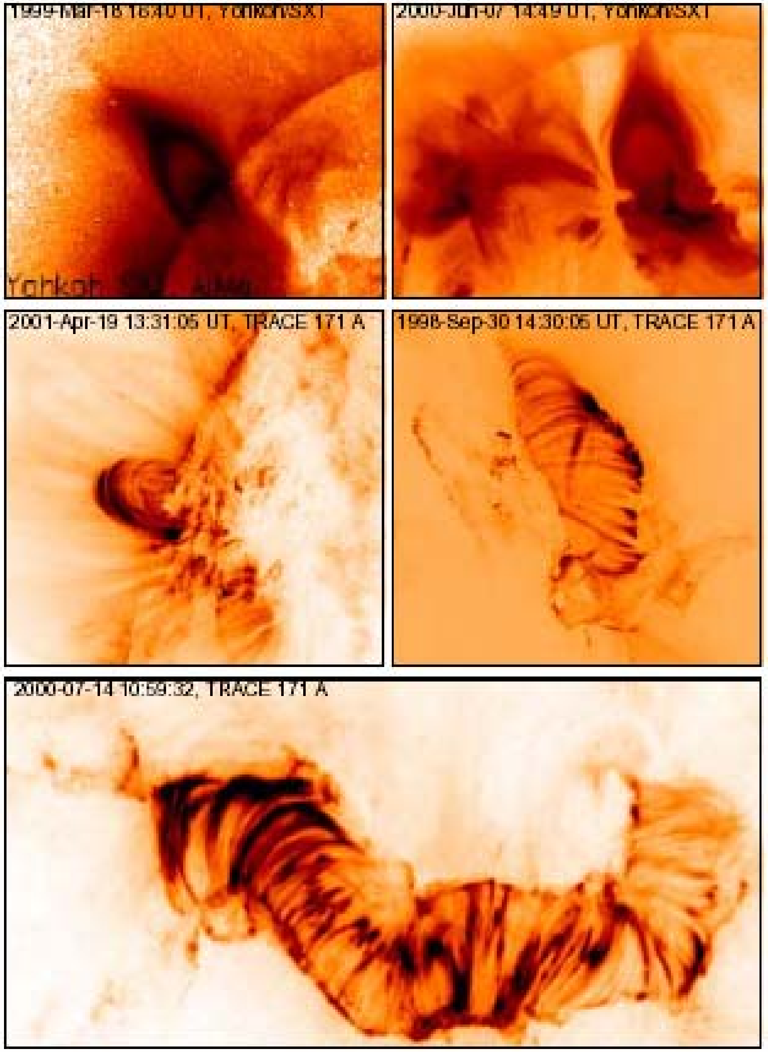
Nobeyama Radioheliograph

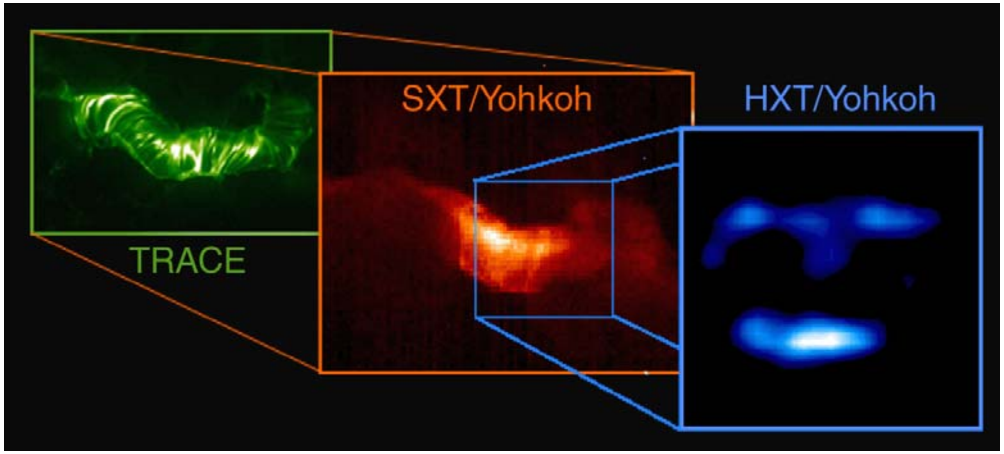
(+ Yohkoh SXT/HXT)

For example, loop-loop interaction may be more realistic.



Flare morphology
is very complex. →

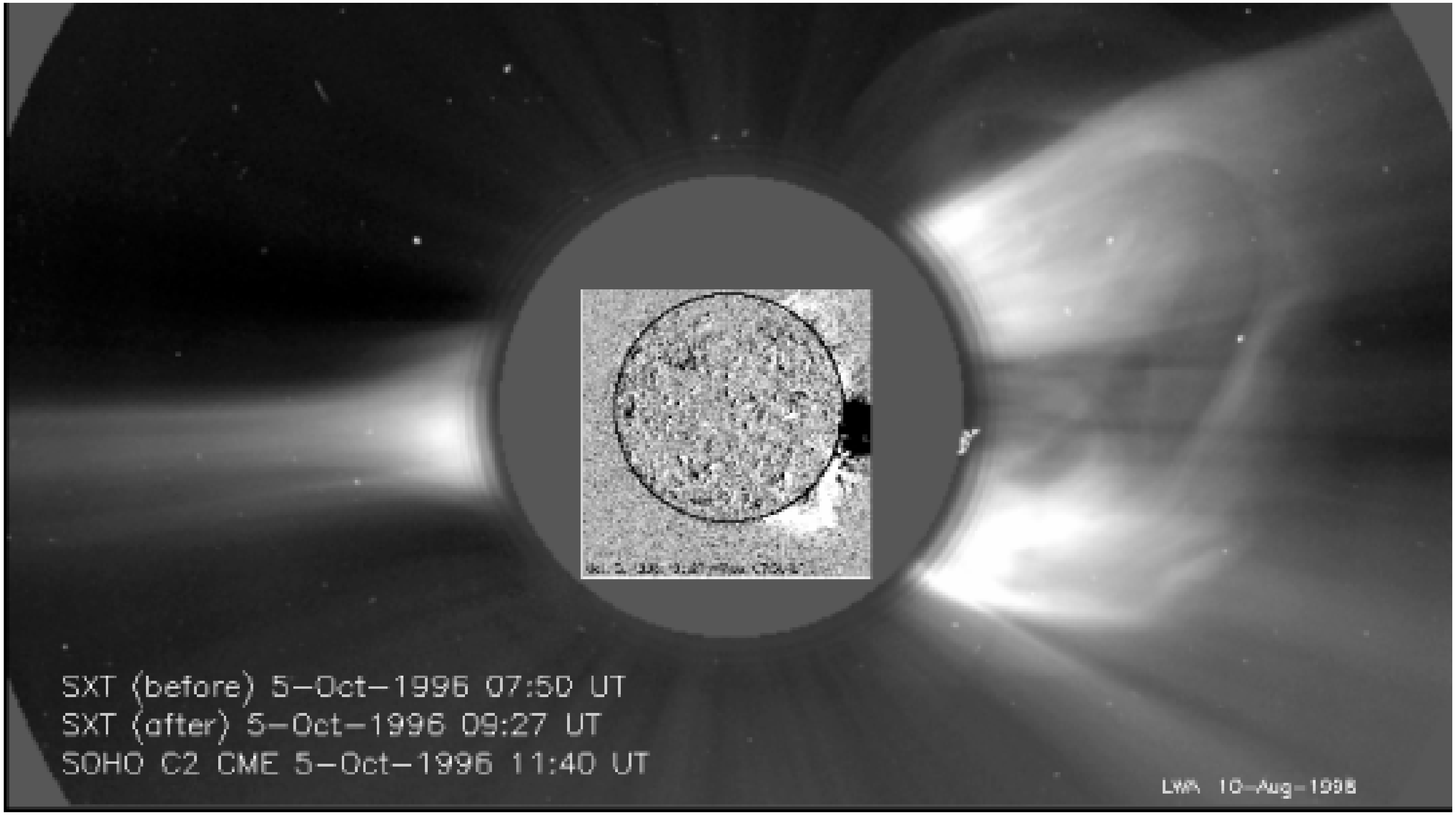




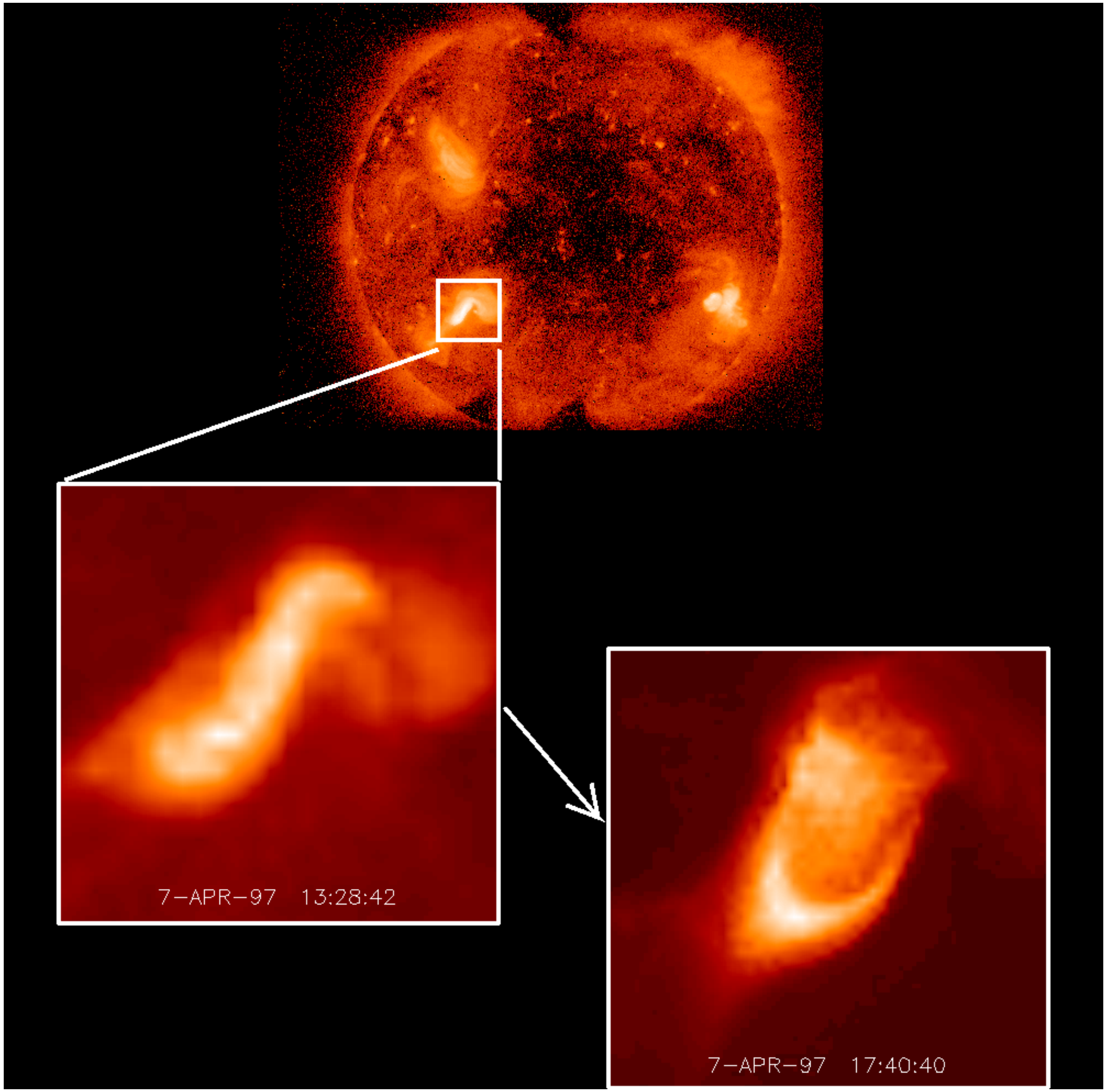
Hard X-ray two ribbons
versus
soft X-ray & EUV arcade

CME and Space Weather

Coronal dimming (*Yohkoh*) *versus*
Coronal mass ejection (LASCO/SoHO)



Sigmoid Structure and Eruption/CME



What's Next ?

From Yohkoh to Solar-B and Beyond

- Understanding Magnetic Connection
  - from (sub)photosphere to corona
  - structural and dynamical
  - coronal heating

  → Solar-B

- Understanding Solar Dynamo Mechanism

- Understanding Connected Sun – Earth System (Space Weather and Climate)

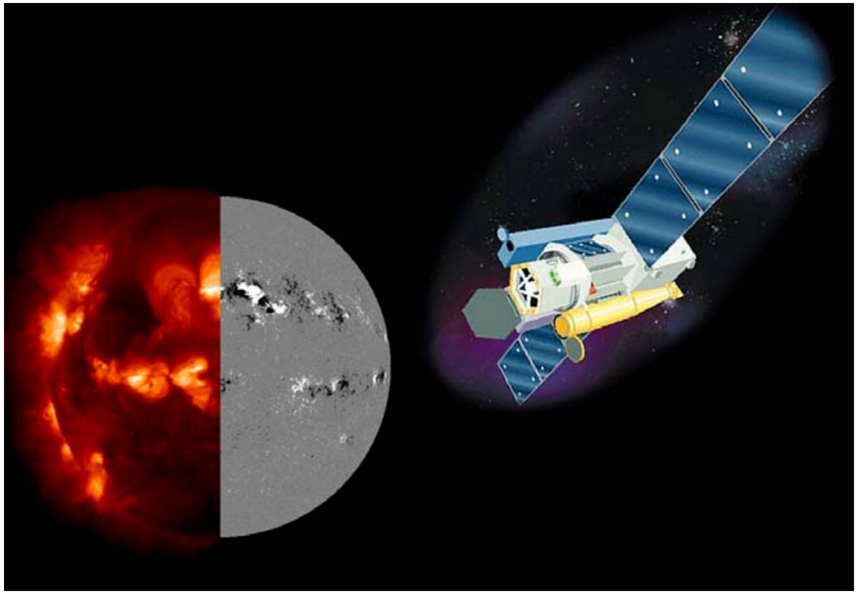
  → STEREO

Science

- Coronal heating
- Coronal structure / dynamics
- Elementary processes in Magnetic Reconnection

ISAS / NASA / PPARC / ESA

SOLAR-B



Launch Date:
Summer 2006
with ISAS M-V-7

Orbit:
Sun synchronous
altitude ~ 600 km

Weight: ~ 900 kg

Mission instruments

- Optical Telescope / Vector Magnetograph (SOT)
- X-ray Telescope (XRT)
- EUV Imaging Spectrometer (EIS)

Thanks for your patience!

Thanks are also to the Yohkoh team.

Many beatiful figures and movies are used without acknowledgements.
Sorry for this.