

Y O H K O H

A D E C A D E O F D I S C O V E R Y

LOCKHEED MARTIN

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

Yohkoh Launch
The Yohkoh satellite was launched on August 30, 1991, as a collaborative science mission between Japan, the US and the UK to explore high energy phenomena on the Sun. In its first ten years of operation Yohkoh has significantly advanced our knowledge of the solar atmosphere, solar flares, and the Sun as a star. As shown in this poster, Yohkoh has observed almost an entire solar activity cycle, with the distribution of X-ray emission (images) closely following the sunspot cycle (curve). An important ingredient in attempting to understand a complex astrophysical body like the Sun is the close collaboration between the various solar observatories, both on the ground and in space. The success of Yohkoh over the last ten years has been possible, in part, because of this close collaboration. Yohkoh provides unprecedented coverage of the hottest parts of the solar atmosphere yielding information about the most energetic processes on the Sun. Some of the scientific highlights of Yohkoh's "Decade of Discovery" are presented here.

Magnetic Reconnection
Large-scale magnetic structures in the solar atmosphere often form in loops or arcs. These structures display a shape which suggests that the magnetic field is undergoing a dramatic change, releasing vast amounts of energy into the Sun's atmosphere and heating it to over 20 million degrees. This interplay between the Sun's magnetic field and the plasma it contains is also believed to be responsible for the production of high energy particles and radiation which can impact the space around the Earth, causing temporary changes in the upper layers of the Earth's atmosphere and glitches in Earth-orbiting spacecraft.

Reshaping the Corona
Massive solar eruptions can significantly disrupt and restructure large regions of the solar atmosphere. These solar storms reach speeds of million kilometers and create major disturbances of the solar wind. These storms have been known to result in blackouts in North American cities and to cause permanent damage to instruments on board Earth-orbiting telecomunications satellites.

Coronal portion of solar flares
These Yohkoh observations also show of the location where the energy of a solar flare is being released.

Volume of the solar corona
may indicate the early stages of a solar storm. As the plasma erupts from the Sun it leaves behind a depleted volume in the low corona.

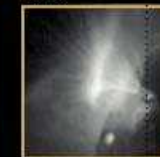
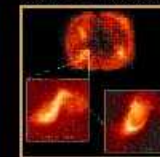
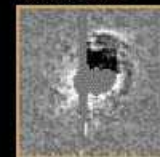
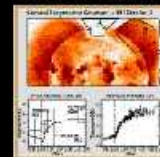
Observational parameter for the investigation of the solar atmosphere
Yohkoh's unique capabilities allow us to measure the variation of temperature with height above the solar surface.

Spot
The S-shape can often be observed for several days before an eruption and can be used as an indicator that a solar storm may occur.

Excess energy can be released in solar eruptions
The S-shape can often be observed for several days before an eruption and can be used as an indicator that a solar storm may occur.

Snapping Magnetic Fields
One of the expected consequences in the production of a solar flare is the relaxation of the magnetic field after being stretched out and restructured. Only recently have we seen evidence for restructured magnetic structures "snapping back" to the Sun, like stretched rubber bands, during solar flares. These observations have raised many questions about how well we understand the production of these energetic solar phenomena and underline their three-dimensional nature.

The Future
These ten years of Yohkoh observations have been fruitful in our quest to understand the physical processes occurring in the atmosphere of the Sun. After a decade in orbit, the Yohkoh spacecraft is in good health and the instruments in good working order. Yohkoh continues to provide a unique view of the solar atmosphere and works in concert with other solar observatories, in space and on the ground, to expand our knowledge of our neighborhood star. As we move into a new solar cycle, a network of spacecraft and a network of advanced ground-based telescopes are contributing the Sun in ever increasing detail encouraging us to look forward a new and exciting decade of discovery.



Contents

Introduction

- * *Why do we need study the Sun?*

- * *Golden Age of Solar Physics from Space*

Solar Interior: *Helioseismology*

Solar Atmosphere: *Structure and Dynamics*

Solar Wind: *Space Weather and Climate*

What's Next?

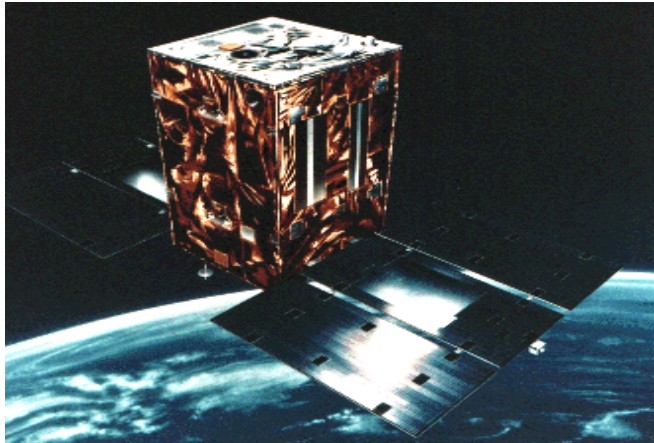
Introduction

** 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

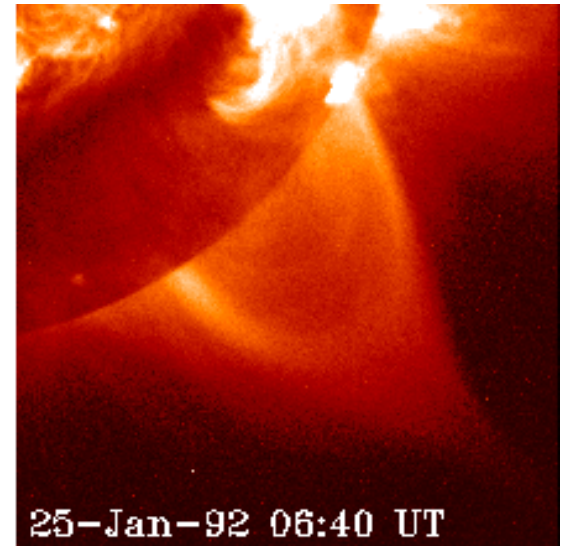
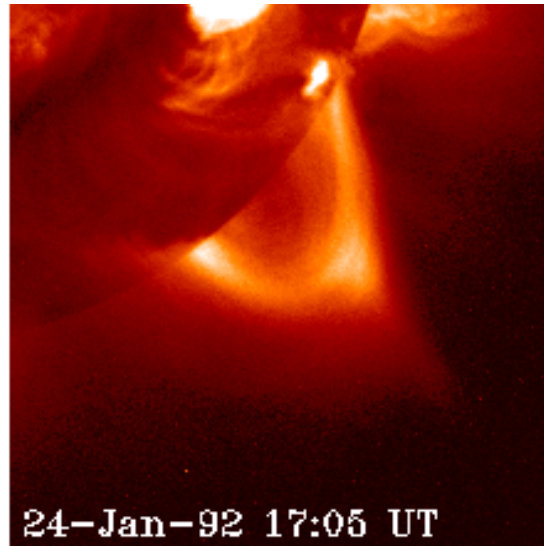
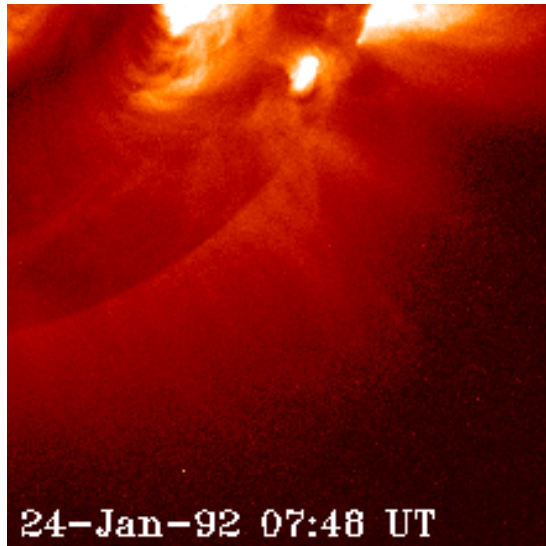
Golden Age of Solar Physics from Space

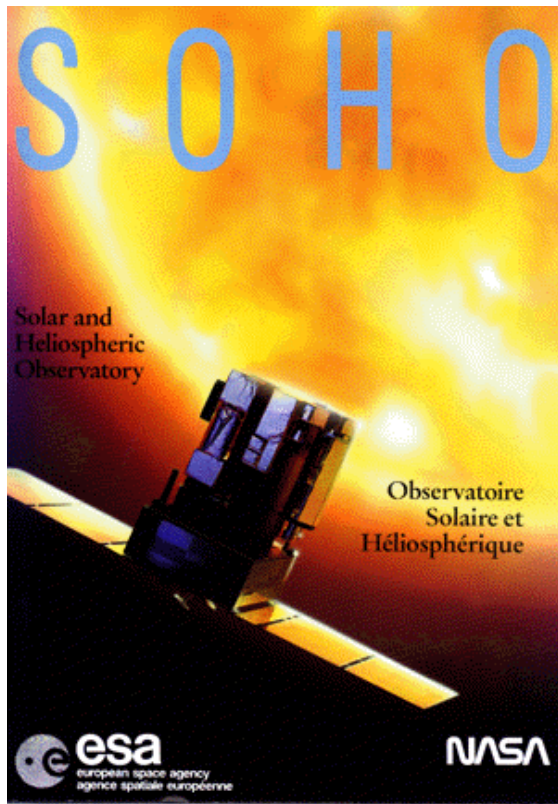
- **Yohkoh** (1991 - 2001) Japan / US / UK
Hard and Soft X-ray Imaging;
X-ray & Gamma-ray Spectroscopy; Flares
- **SoHO** (1996 -) ESA / NASA
Solar & Heliospheric Imaging; Helio-seismology
- **TRACE** (1998 -) NASA;
Highest Spatial Resolution UV & EUV Imaging
- **CORONAS-F** (2001 -) RSA
Coronal Imaging and Spectroscopy
- **RHESSI** (2002 -) NASA / other
High-Energy Solar Spectroscopic Imager; Flares
- **CGRO**, **Ulysses**, and other heliospheric missions



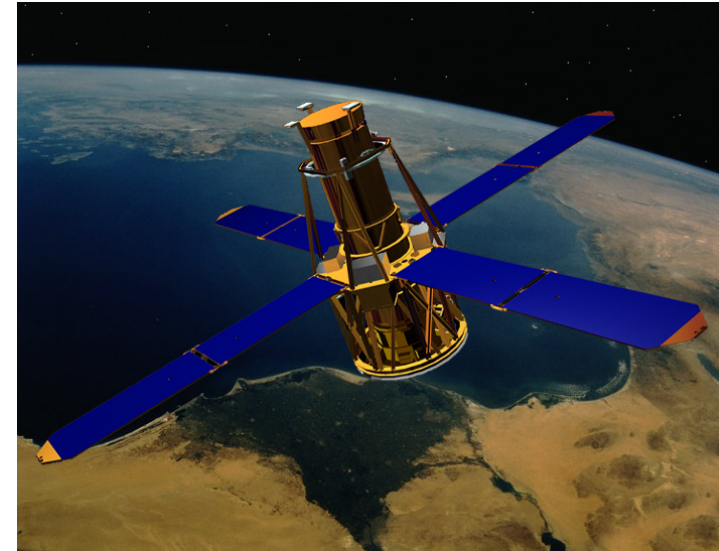
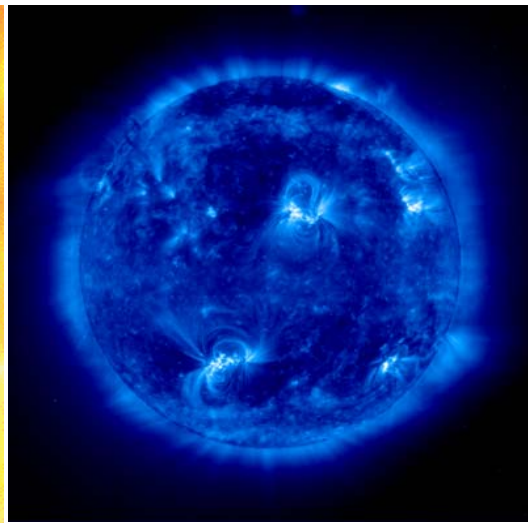
Ten Years with *Yohkoh* (1991 September – 2001 December)

**Energy Release
and Particle Acceleration
in the Solar Atmosphere**

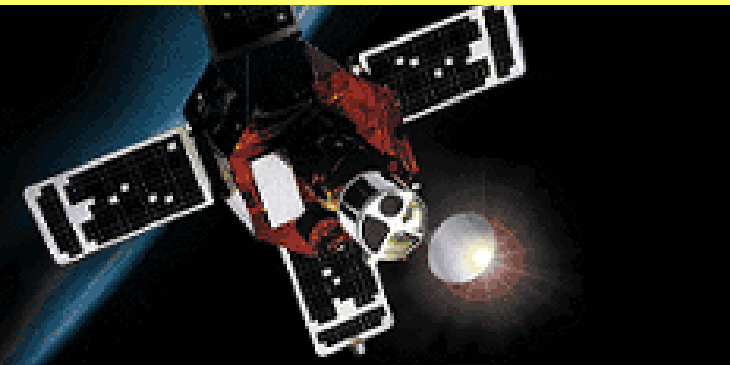




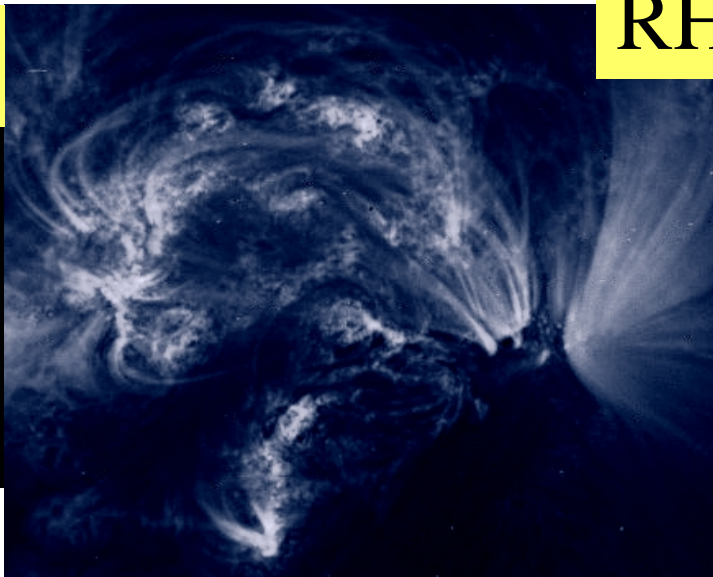
← SoHO (96 -)



TRACE (98 -)



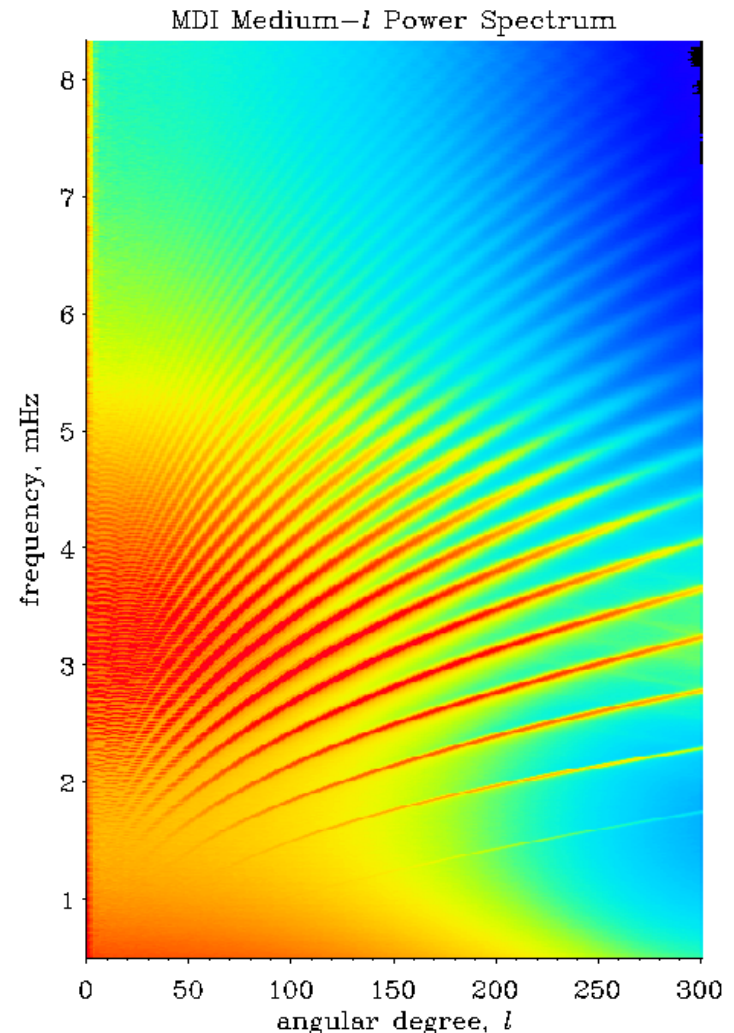
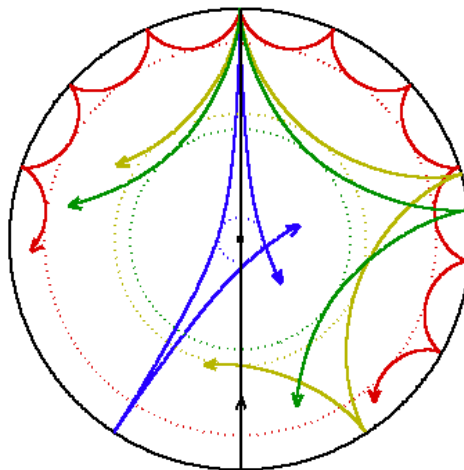
RHESSI (02 -)



Understanding the Solar Interior: -- Helioseismology --

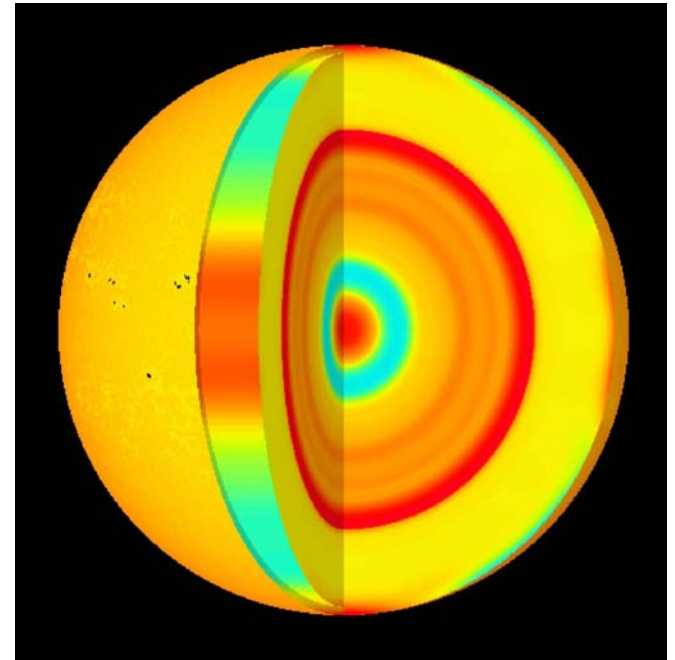
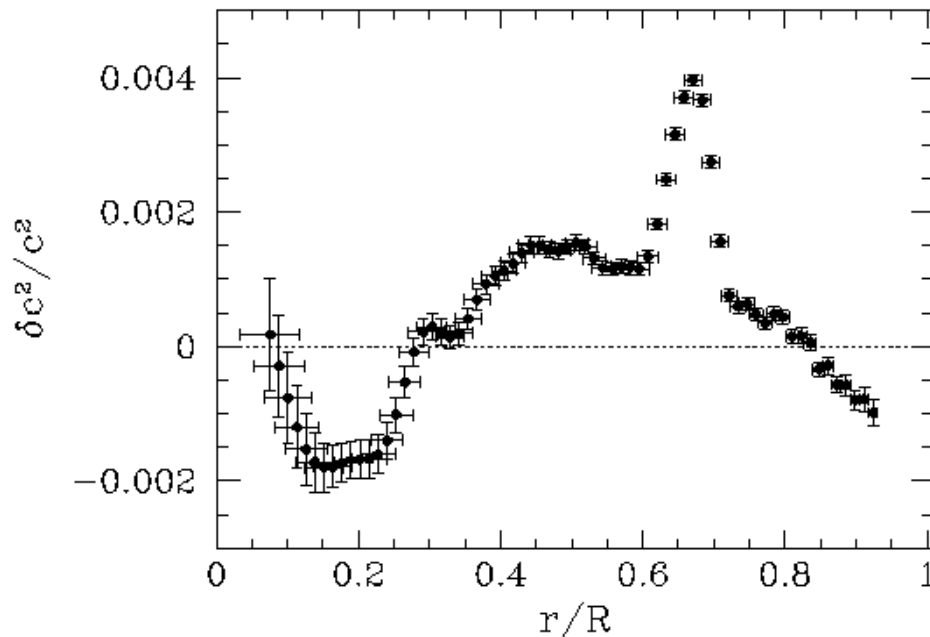
- High precision solar data from SoHO (as well as from GONG).
- Major Progress in three directions
 - Interior structure
 - Interior rotation
 - Subsurface dynamics

p-mode oscillation
detected and used
for diagnosing 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



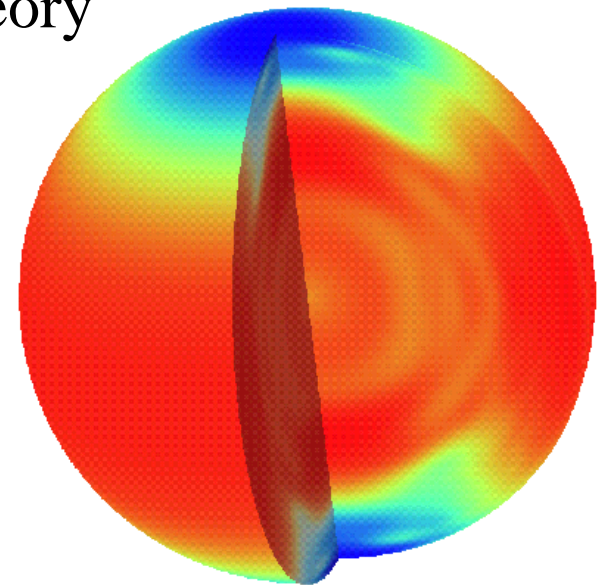
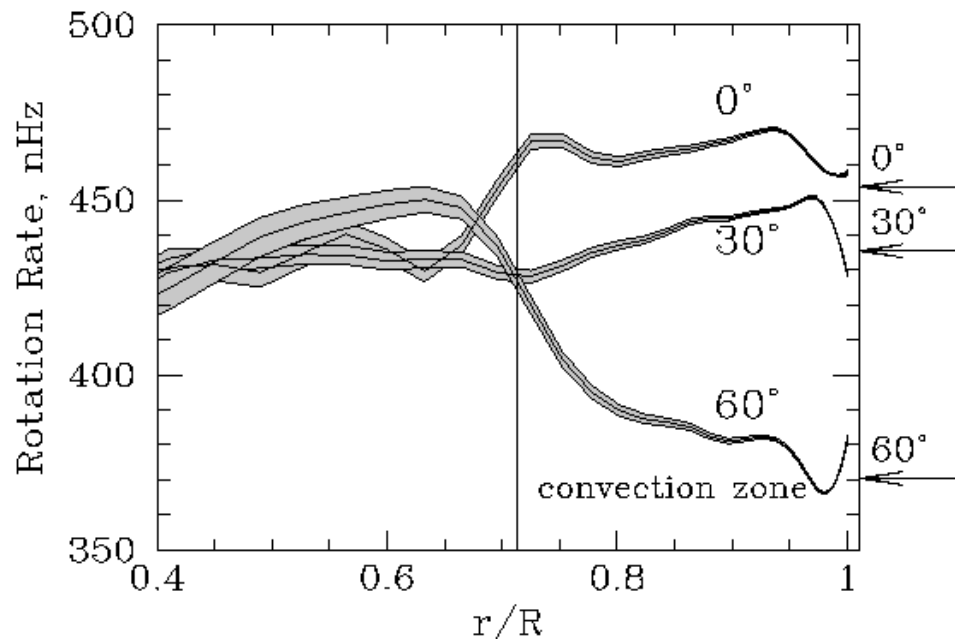
Difference of the sound speed between the measured and the model prediction (as a function of depth in the Sun). The “bump” at 0.7 R due o excess mixing.

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.

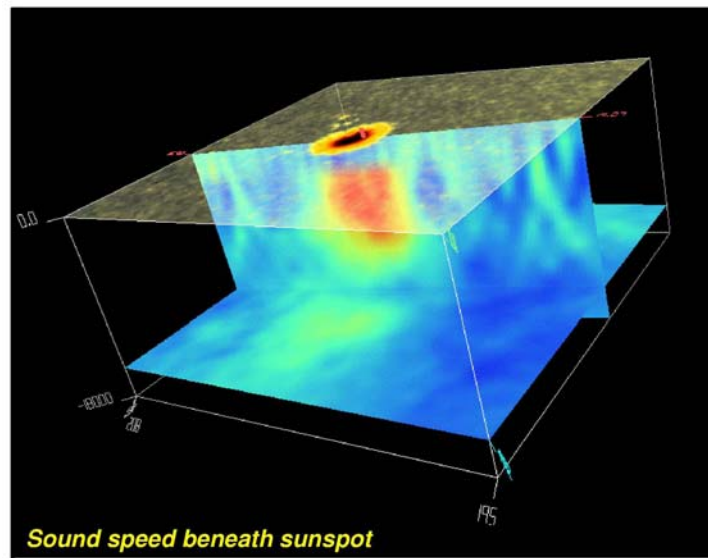
➔ Basic data for the solar dynamo theory



Red faster, blue slower.

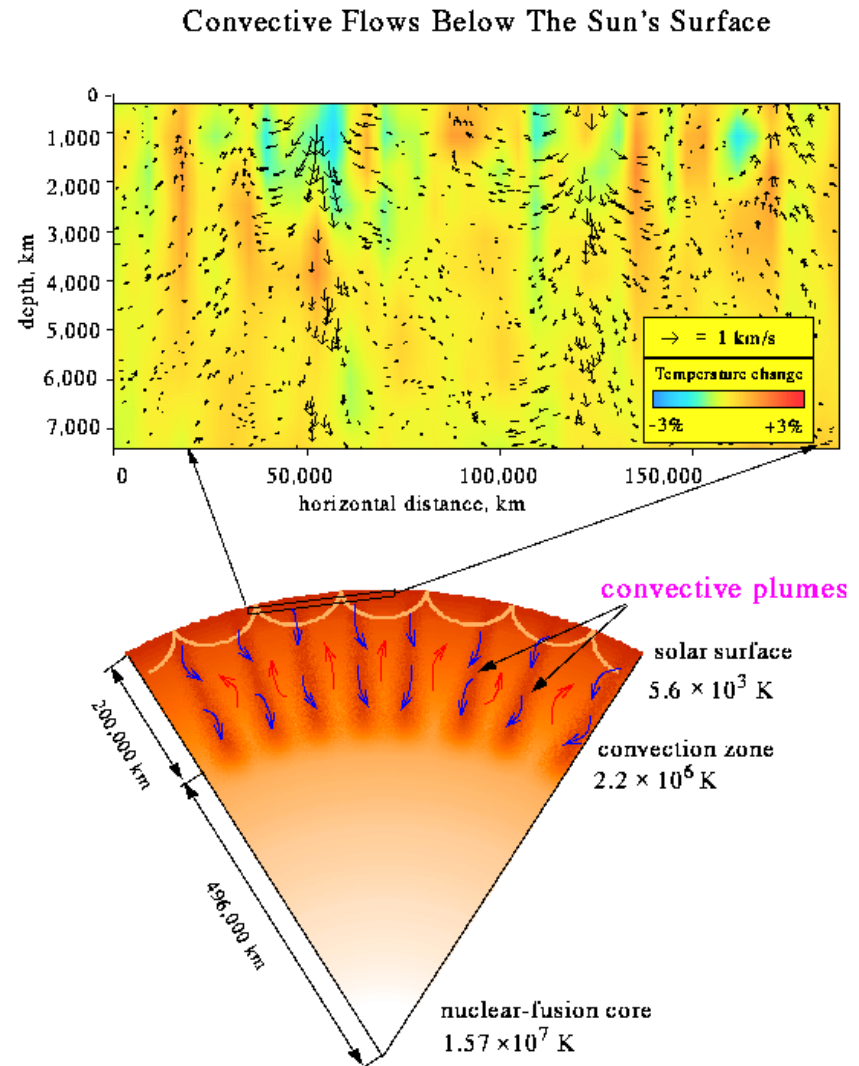
Subsurface Dynamics

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



Sunspot data from MDI High Resolution, 18 June 1998

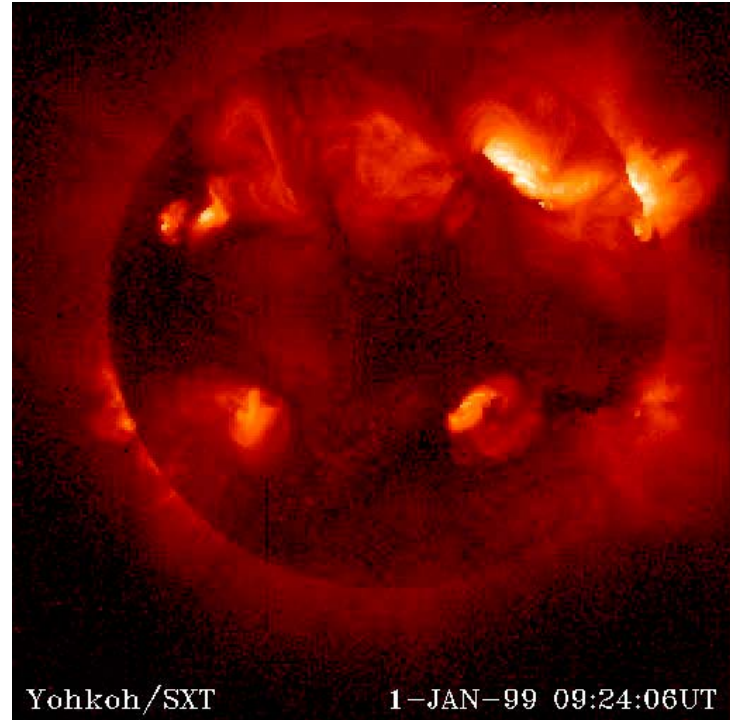
Thermal structure beneath sunspot



Various structures and dynamics,
governed by magnetic fields

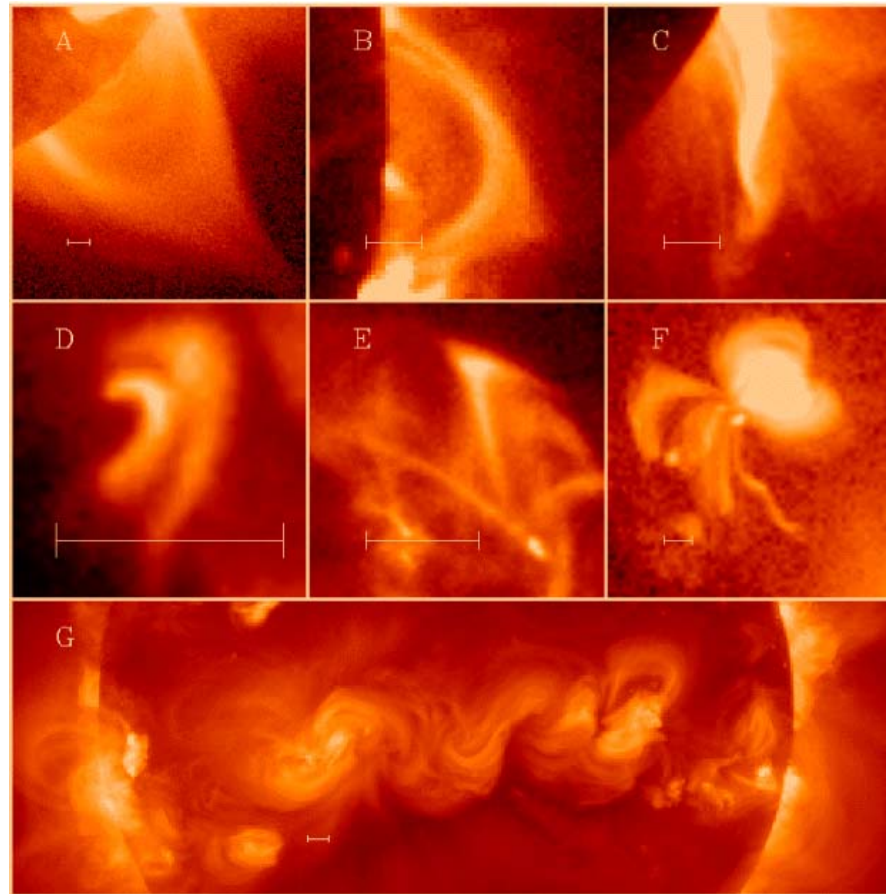
- **Coronal heating**
 - 11-yr cycle variation
- **Ejections and IP disturbances**
 - **Large-scale restructuring**
 - **X-ray plasmoid**
 - **X-ray dimming** (vs CME)
 - **X-ray sigmoid** (vs CME)
- **Solar flares as magnetic reconnection process**
 - Soft X-ray **loop-with-a-cusp structure**, increasing 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 Solar Atmosphere



The corona is full of magnetic features!

Cusps

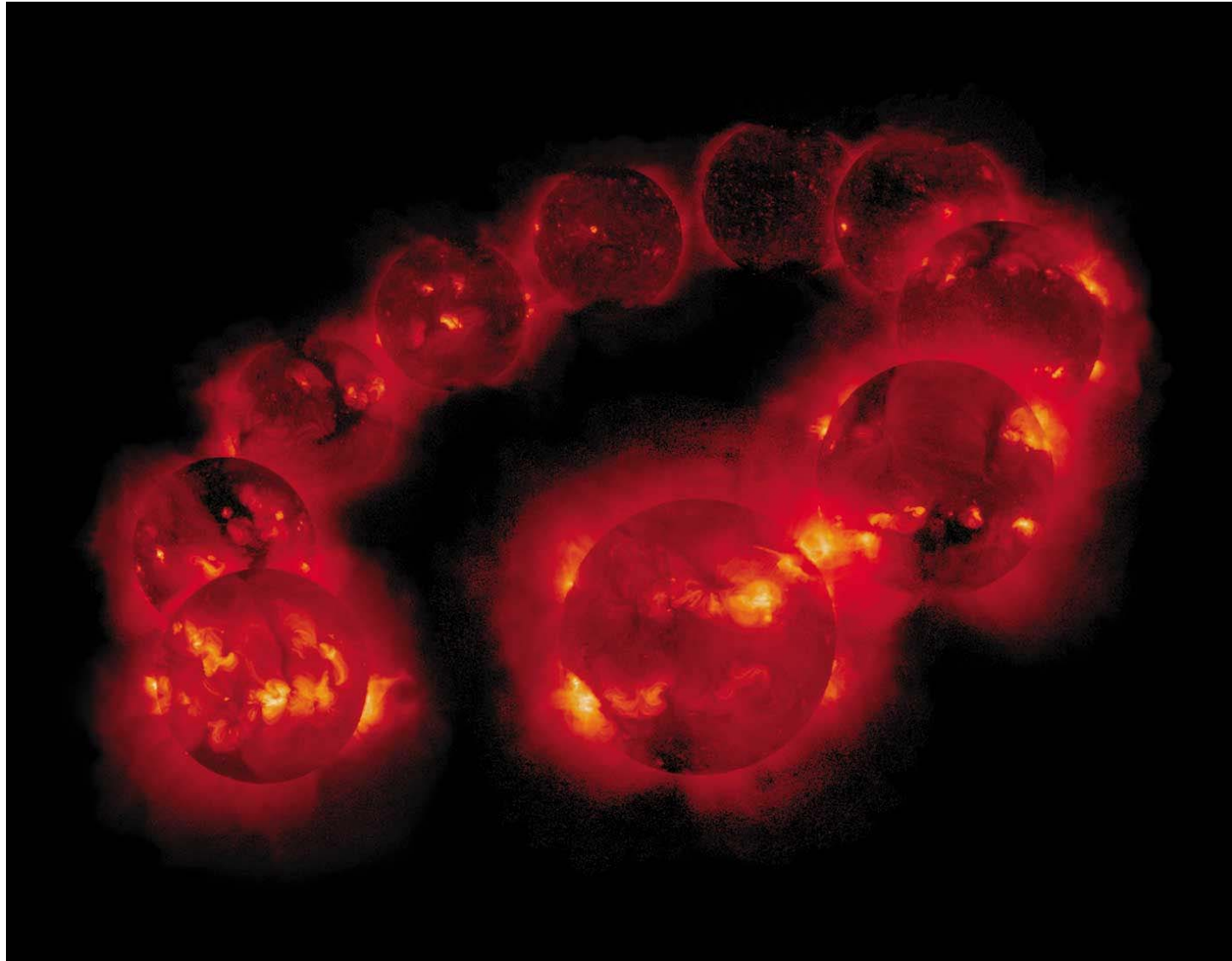


*Twisted
Loops*

S-shaped interconnecting loops

All change with time.

Highly variable the Sun is!

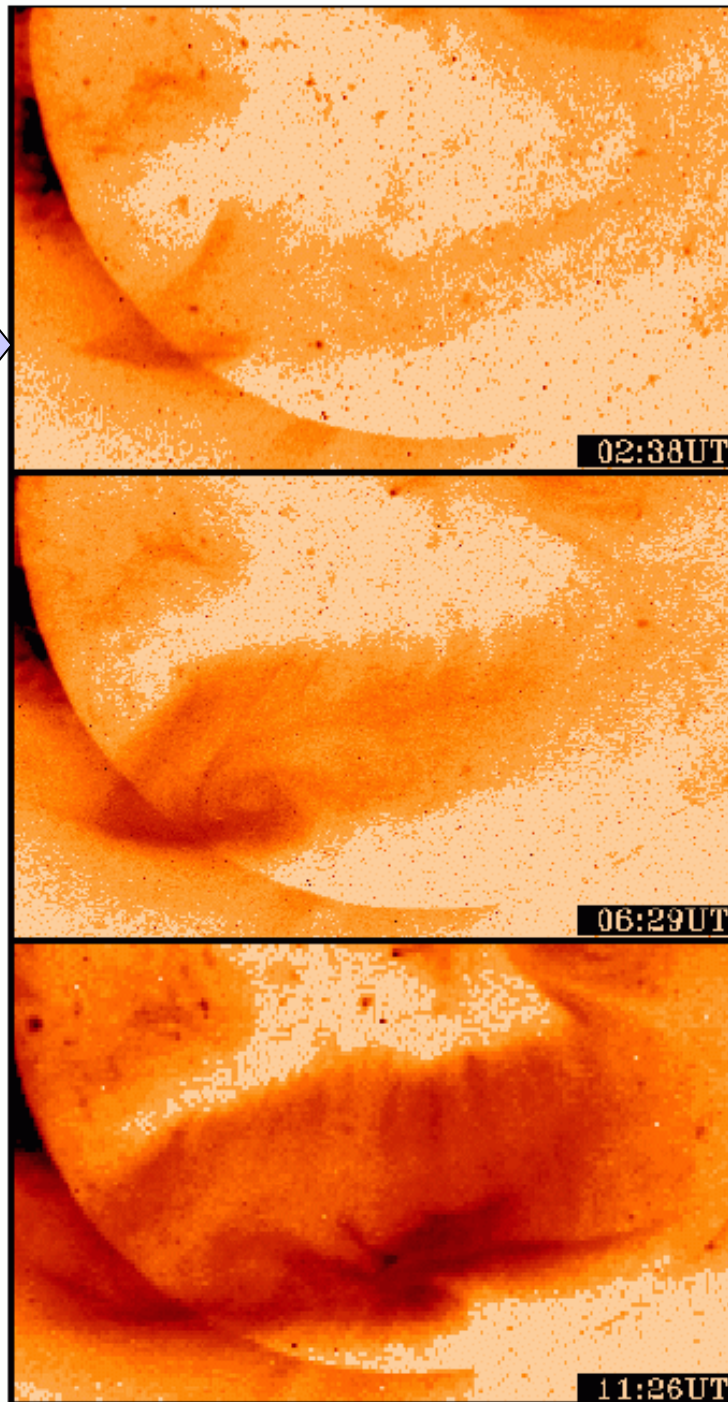
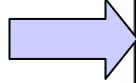


Global
Restructuring
Event

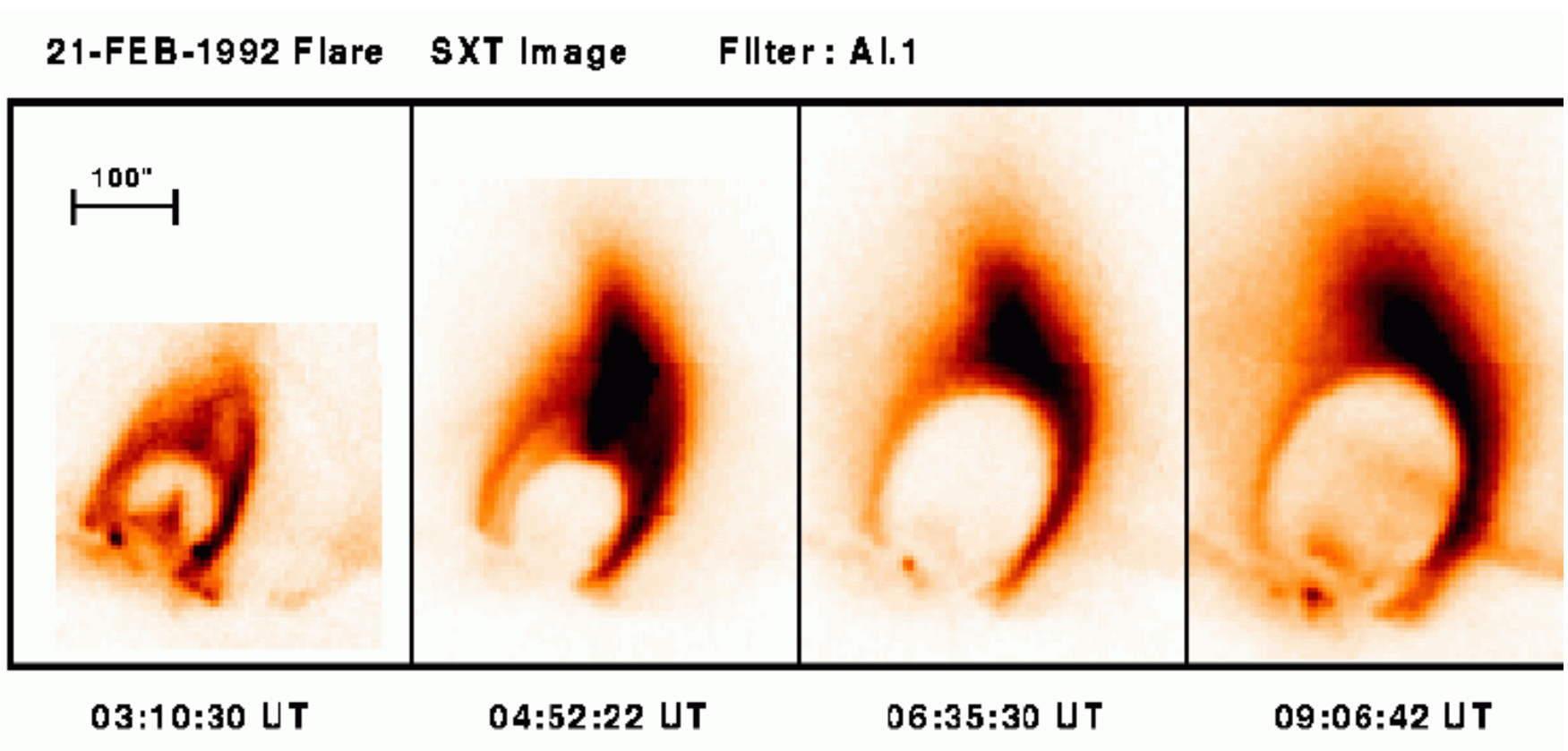
or

Giant
Arcade
Formation

Cusp

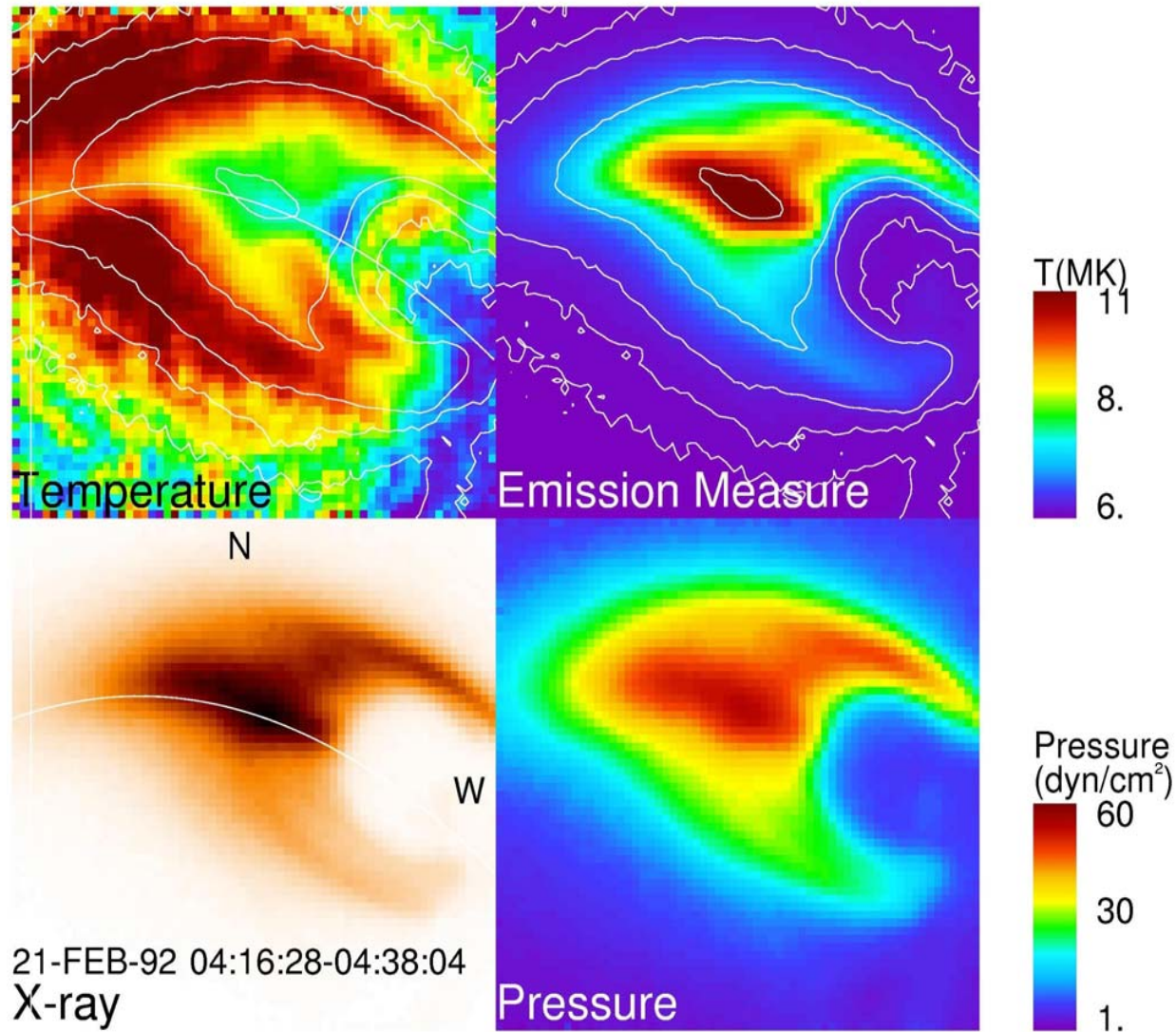


LDE flares with a growing cusp structure.

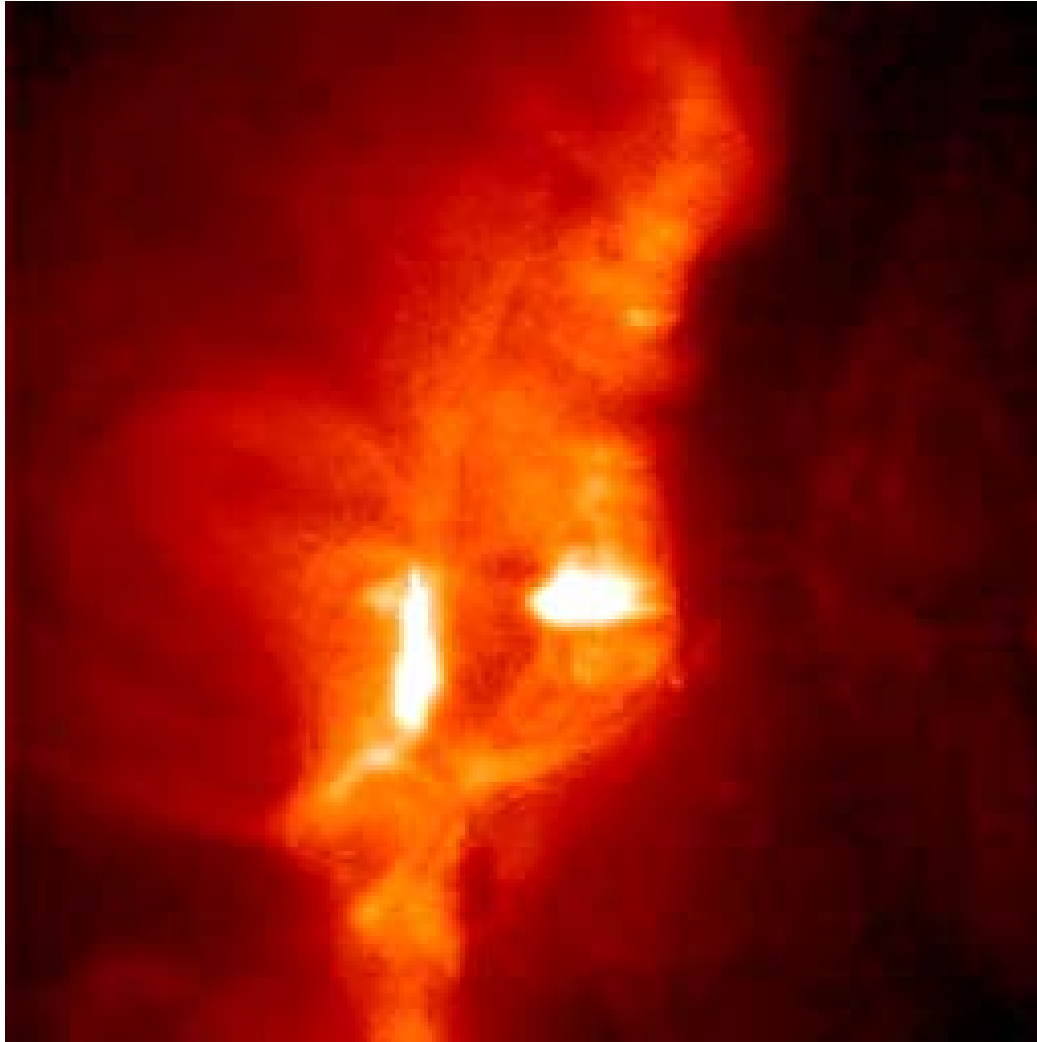


Higher temperatures (~ 20 MK) at the outer edge.
Upward motion (plasmoid) in the outer structure.

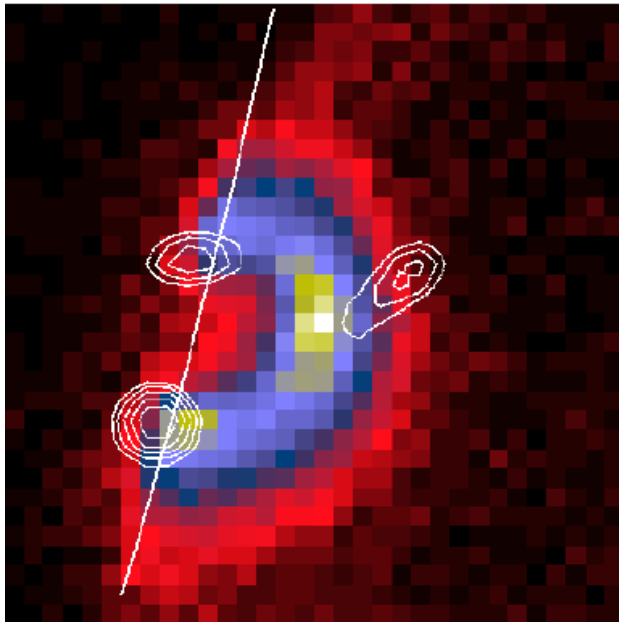
LDE flares with a growing cusp structure.



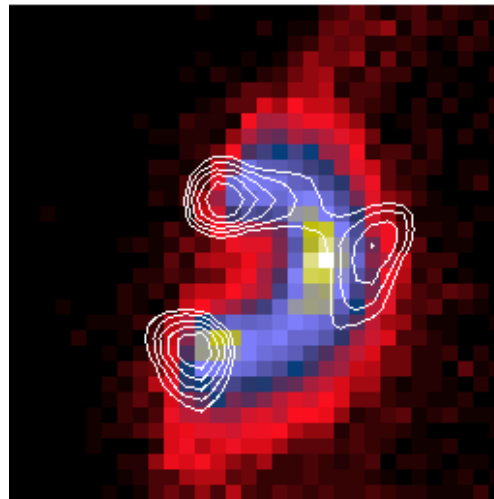
LDE flares with a growing cusp structure.



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

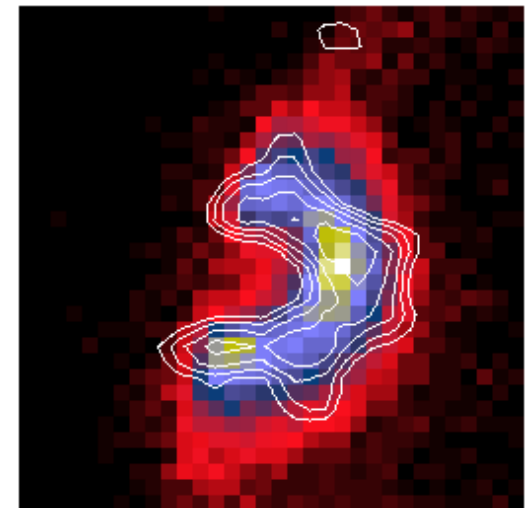


33 – 53 keV

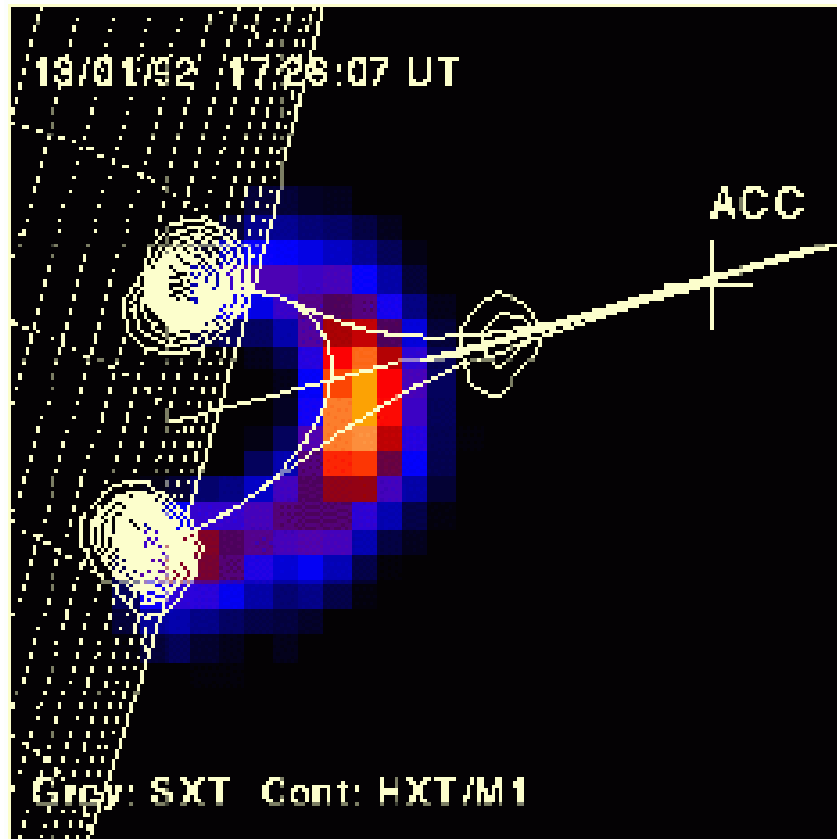


23 – 33 keV

14 – 23 keV

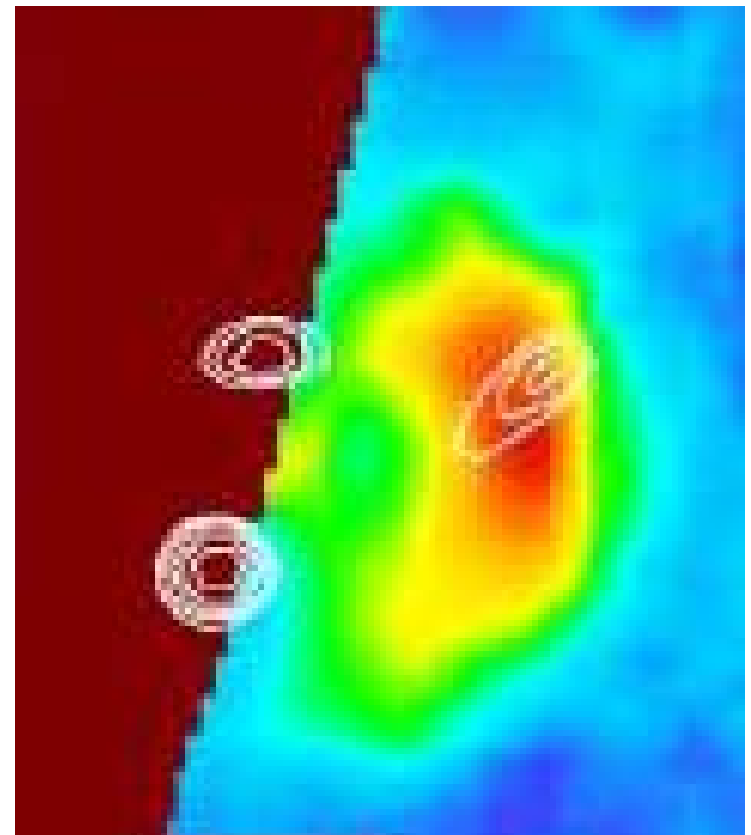


Particle Acceleration in the cusp region



TOF analysis reveals
the acceleration site.

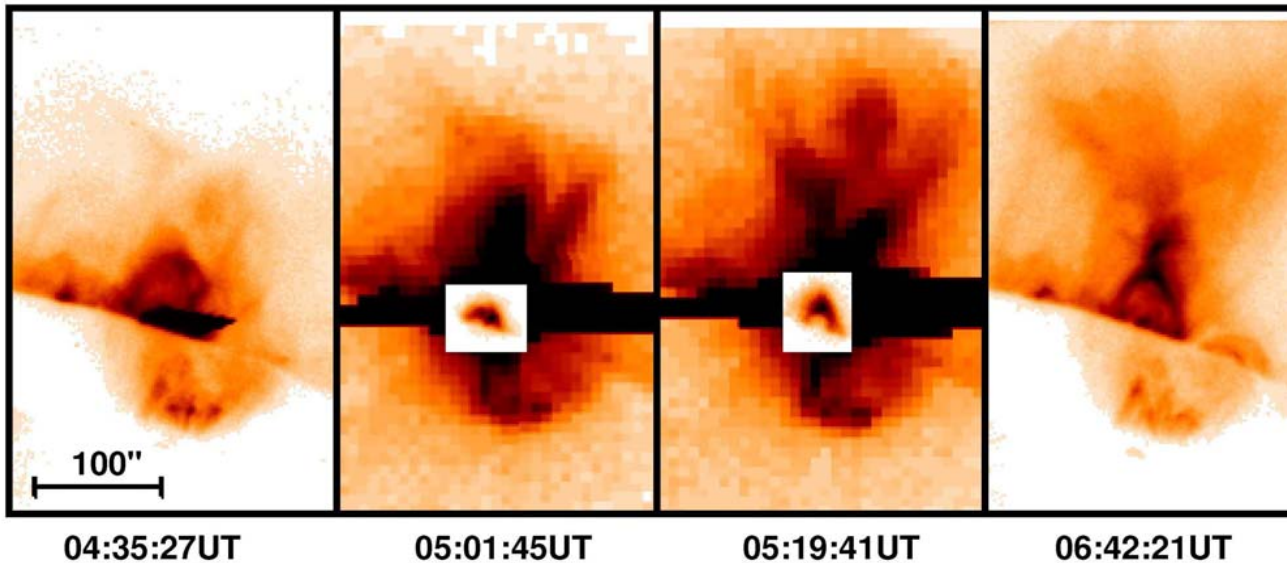
High-Temperature
region



00 1999-03-18 01:24:00 195

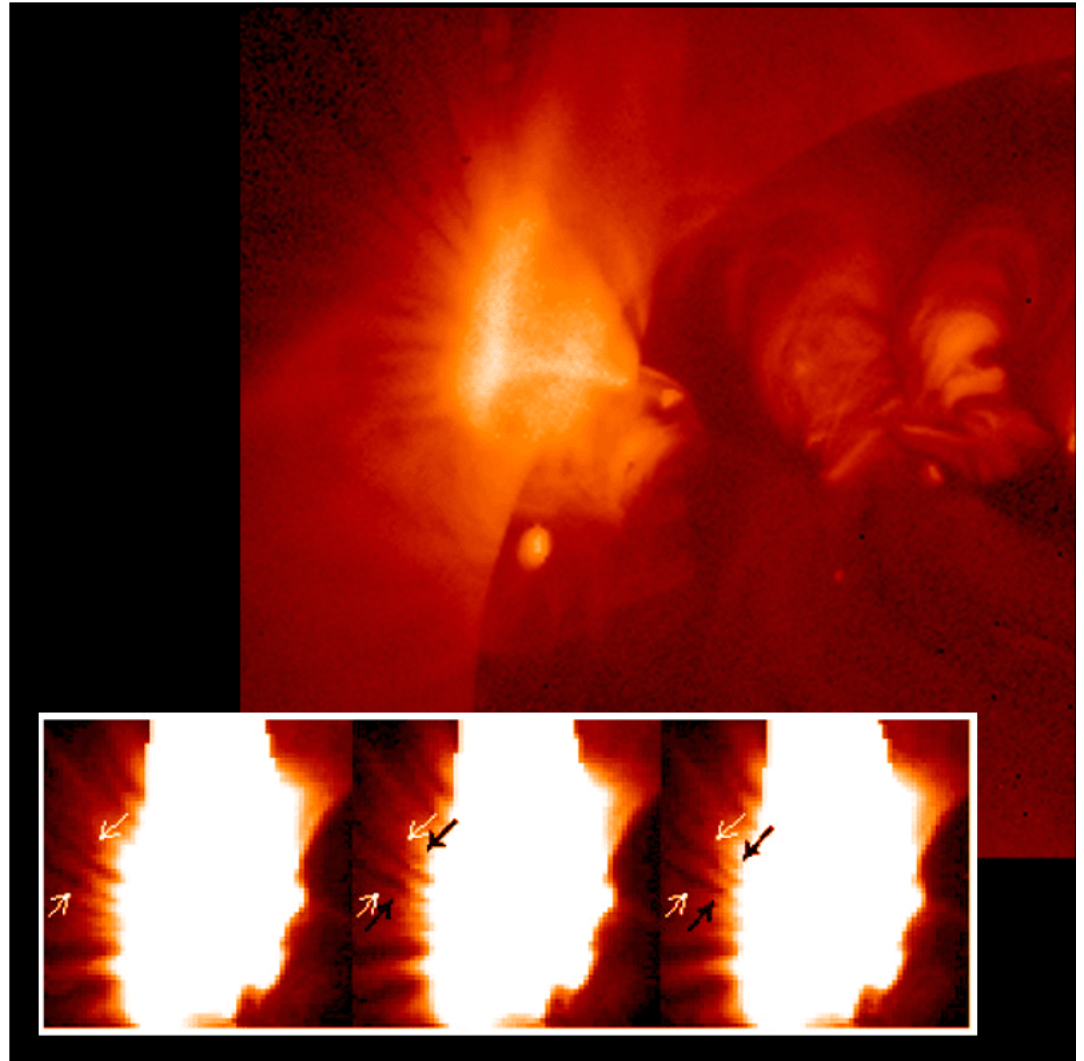
Flaring Loop and the Surroundings

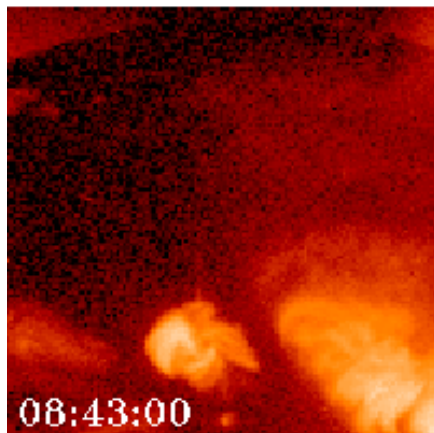
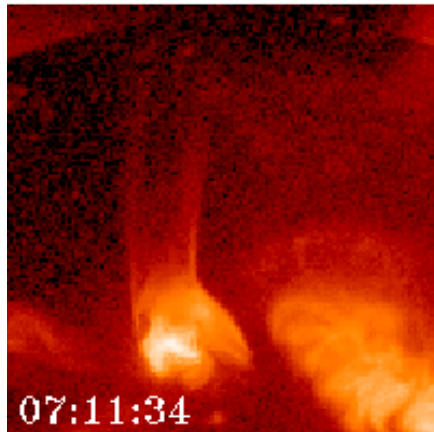
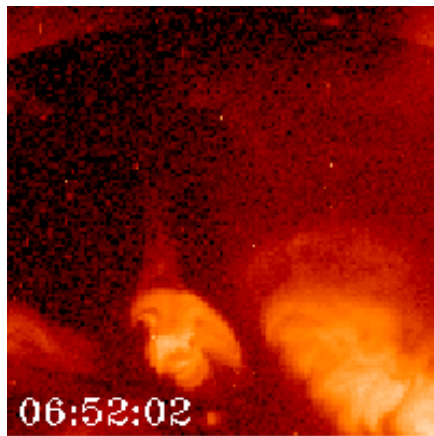
2-DEC-1992 Flare SXT Image Filter: Al.1



Downstreaming
blobs above the
arcade:

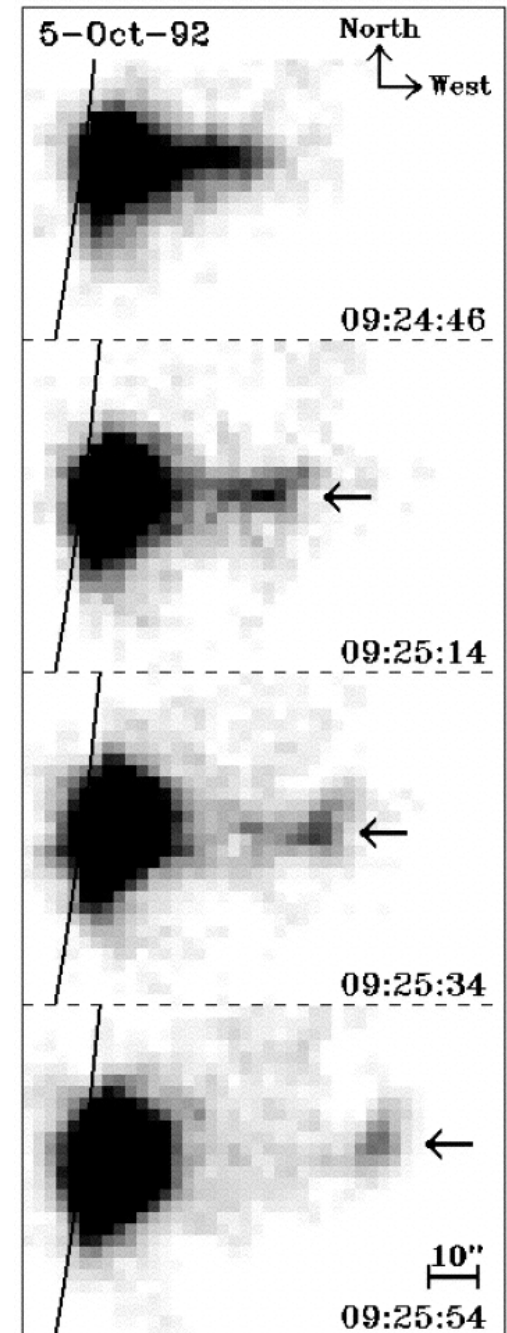
*What's going on
above
the reconnection
point ?*





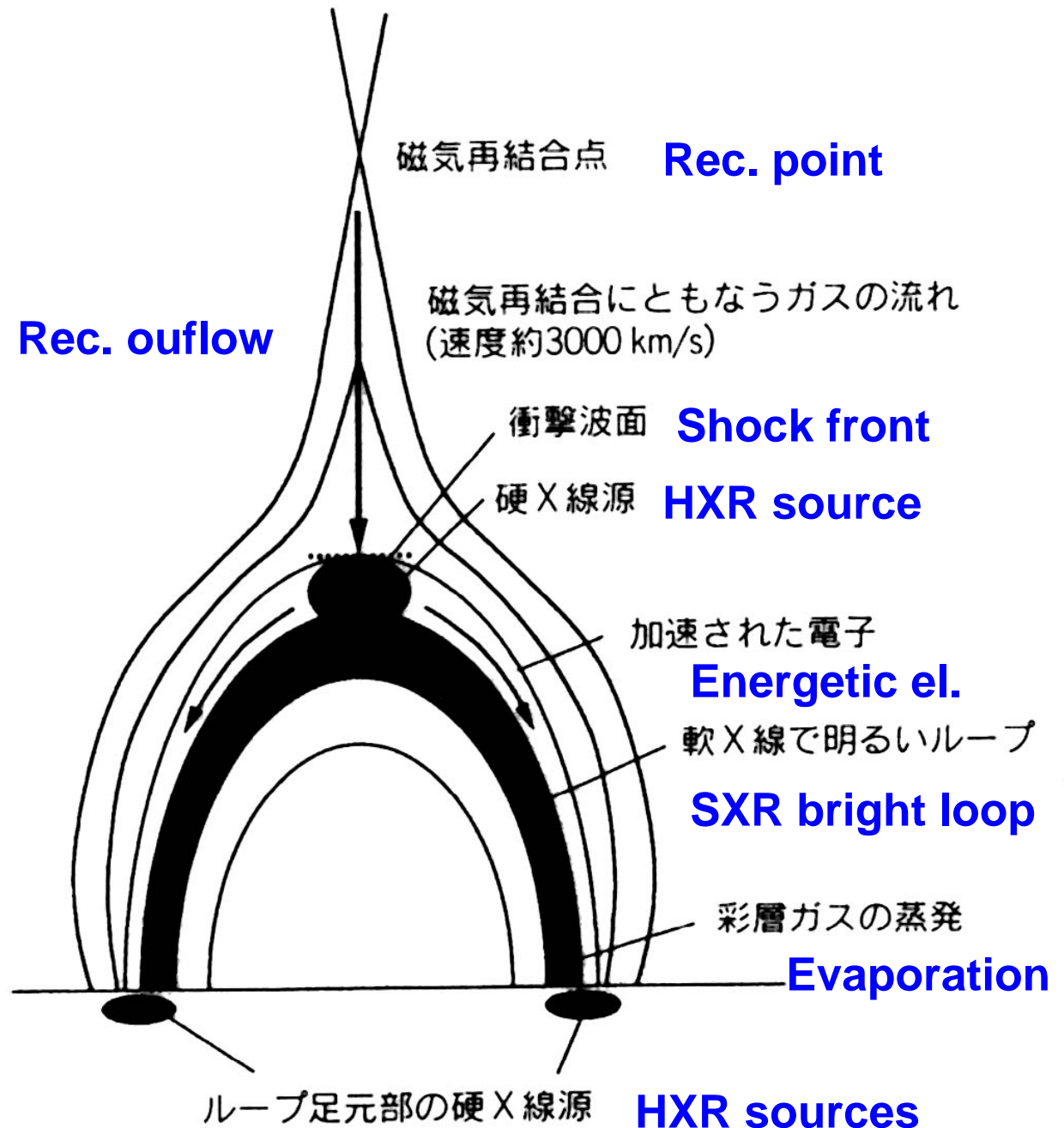
← X-ray jets

Plasmoid
ejection
in association
with flares →



Yohkoh
canonical
view:

Magnetic reconnection

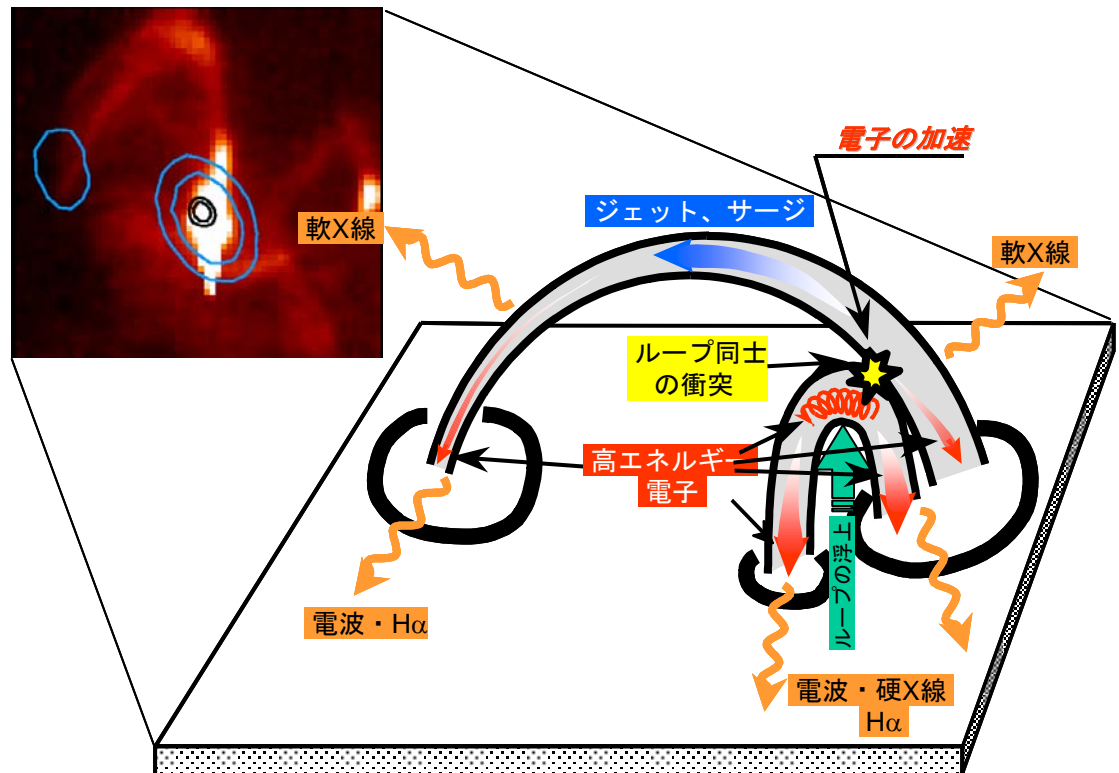


But, this is an oversimplification!

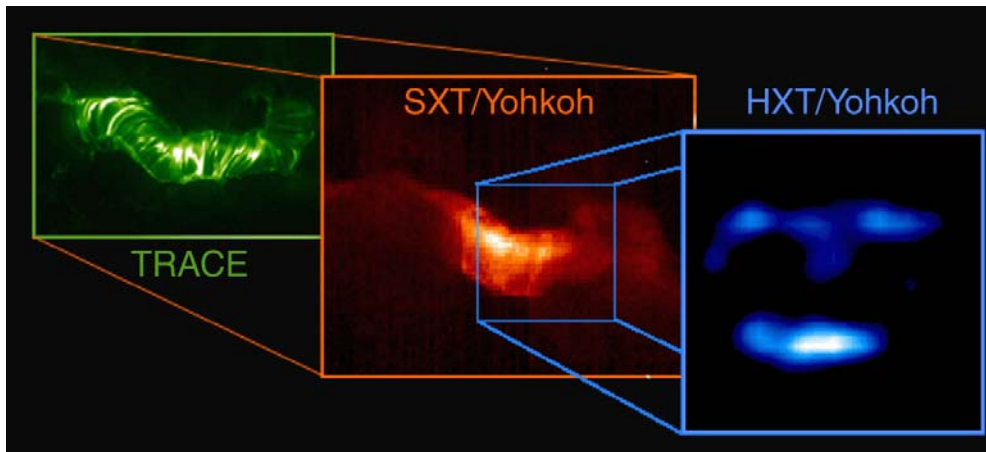
For example,
loop-loop
interaction may
be more realistic.



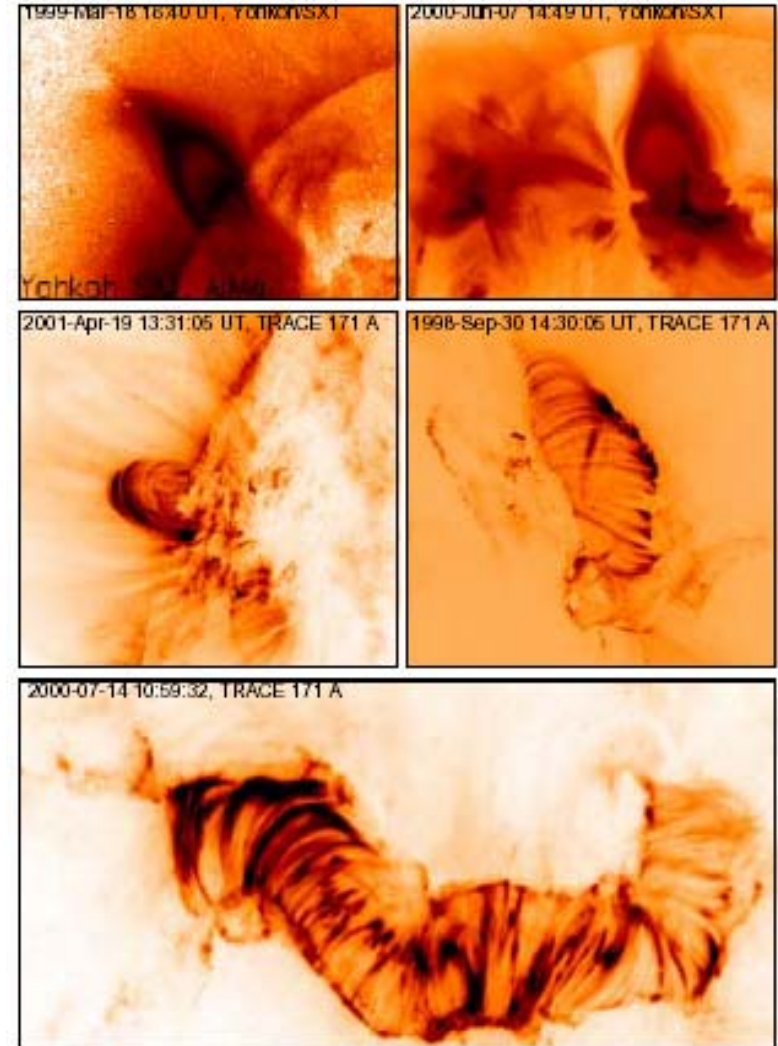
Nobeyama Radioheliograph
(+ Yokoh SXT/HXT)



Flare morphology
is very complex. →

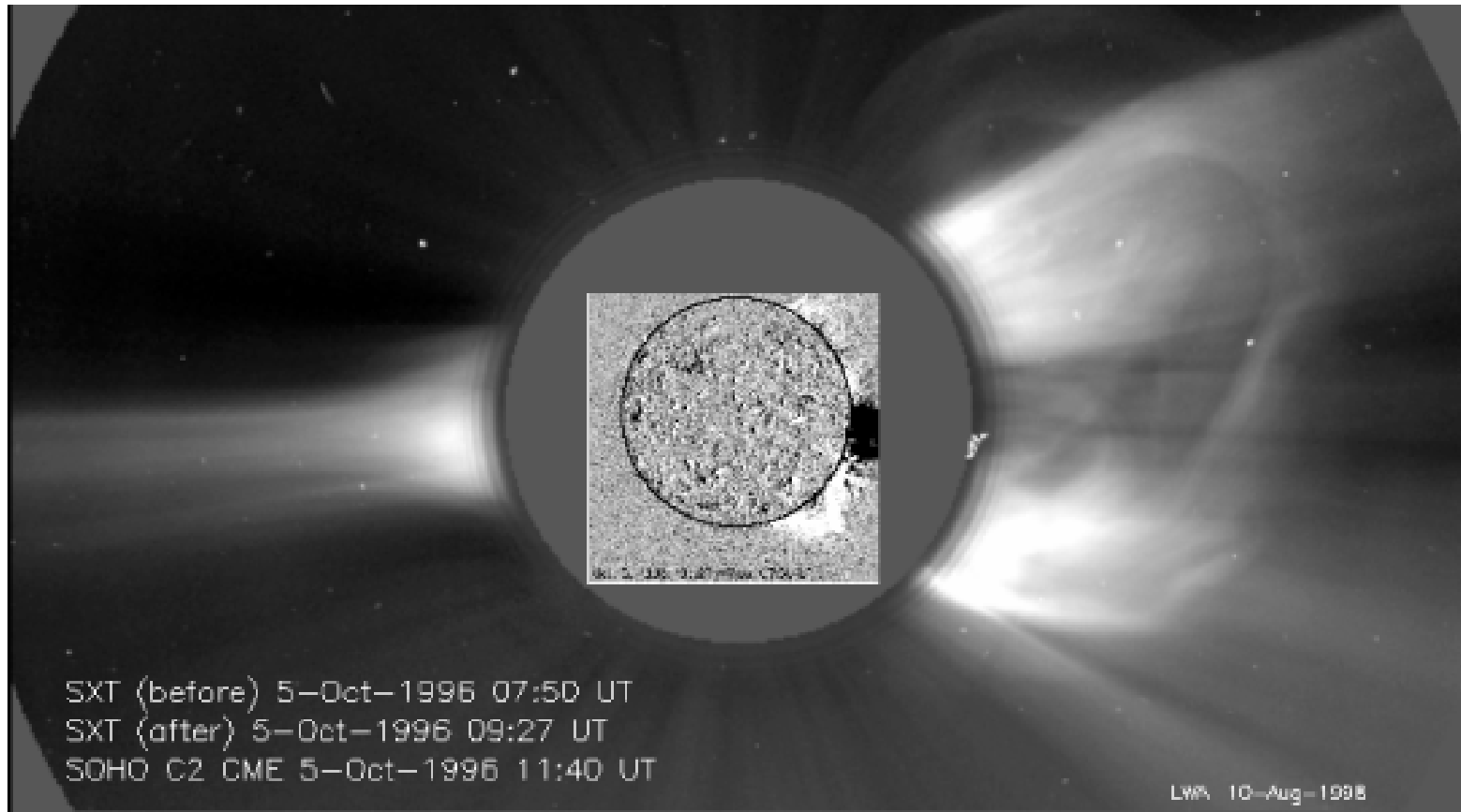


Hard X-ray two ribbons
versus
soft X-ray & EUV arcade

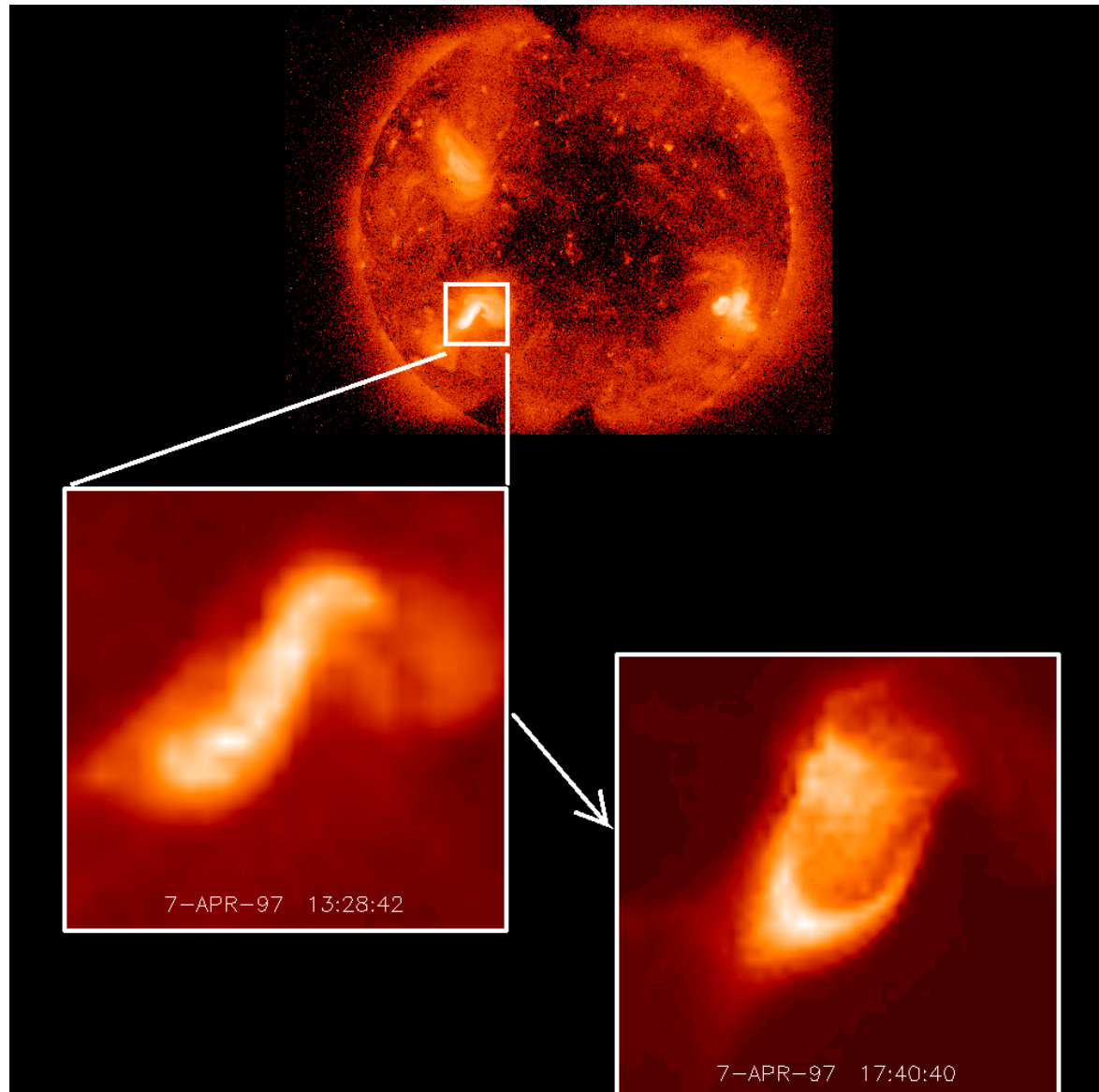


CME and Space Weather

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



Sigmoid Structure and Eruption/CME



What's Next ?

From **Yohkoh** to **Solar-B** and Beyond

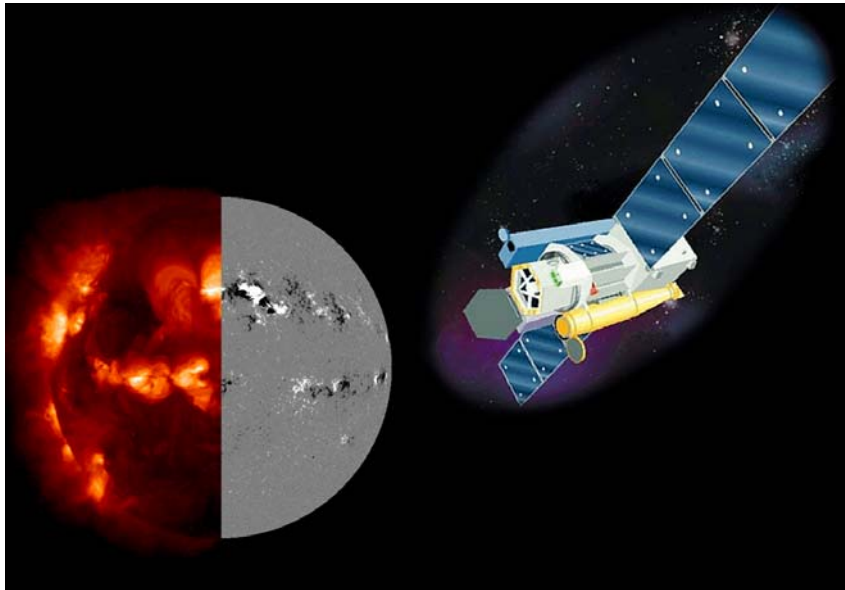
- Understanding **Magnetic Connection** from (sub)photosphere to corona structural and dynamical coronal heating → **Solar-B**
- Understanding **Solar Dynamo Mechanism**
- Understanding **Connected Sun – Earth System** (Space Weather and Climate) → **STEREO**

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 beautiful figures and movies are used
without acknowledgements.
Sorry for this.