Advanced Imaging and Plasma Diagnostics

# Multi-wavelength Imaging of Solar Plasma

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# Outline

- Standard model of solar flares and activities
- Open issues and new observations
- Magnetic properties of plasma
- A new solar flare model
- Necessity of multi-wavelength imaging
- Currently available telescopes

# Standard Solar Flare and Activity Model

1. Solar Corona is low beta, hence the energy must be stored as magnetic free energy.

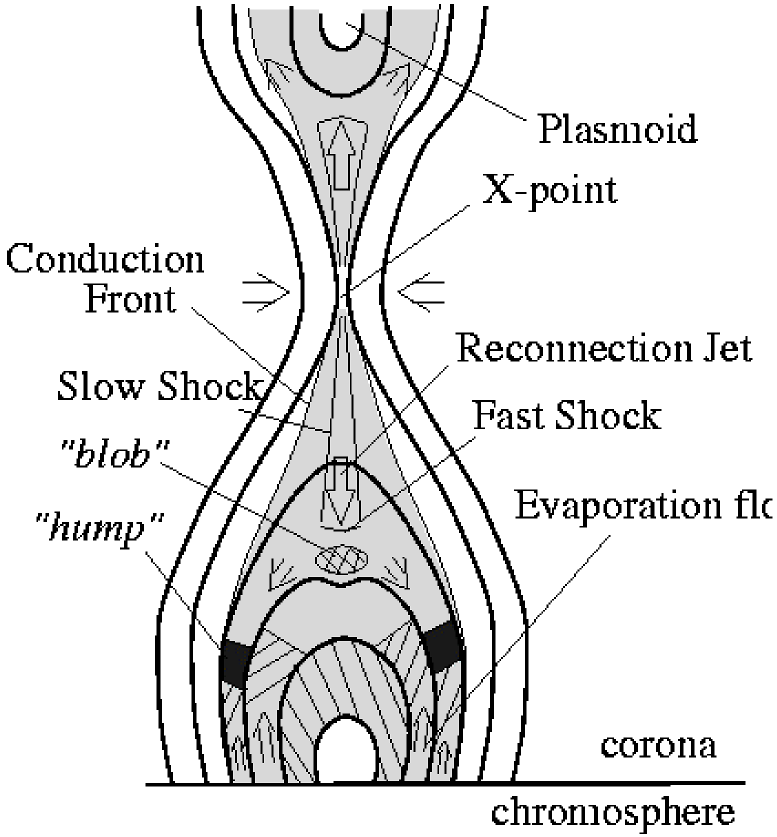
2. Magnetic free energy is due to electric current flowing in the solar atmosphere.

3. Stored energy in current sheet is released by reconnection.

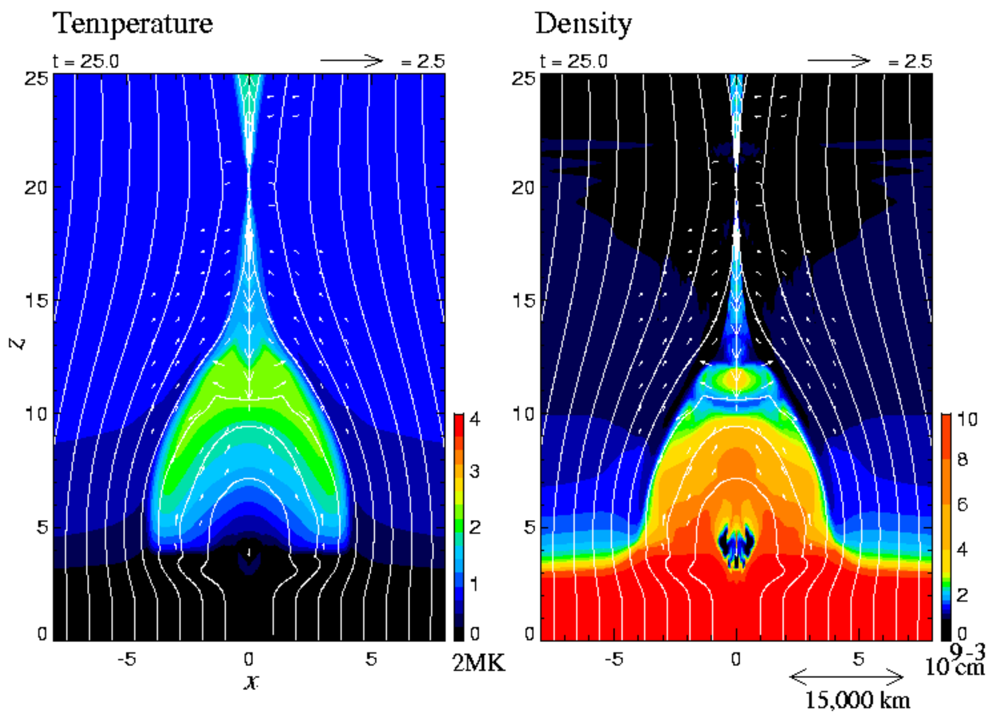
   **High-beta**

4. Plasma is supplied by ablation (evaporation) from the lower dense atmosphere.

# Standard Solar Flare and Activity Model

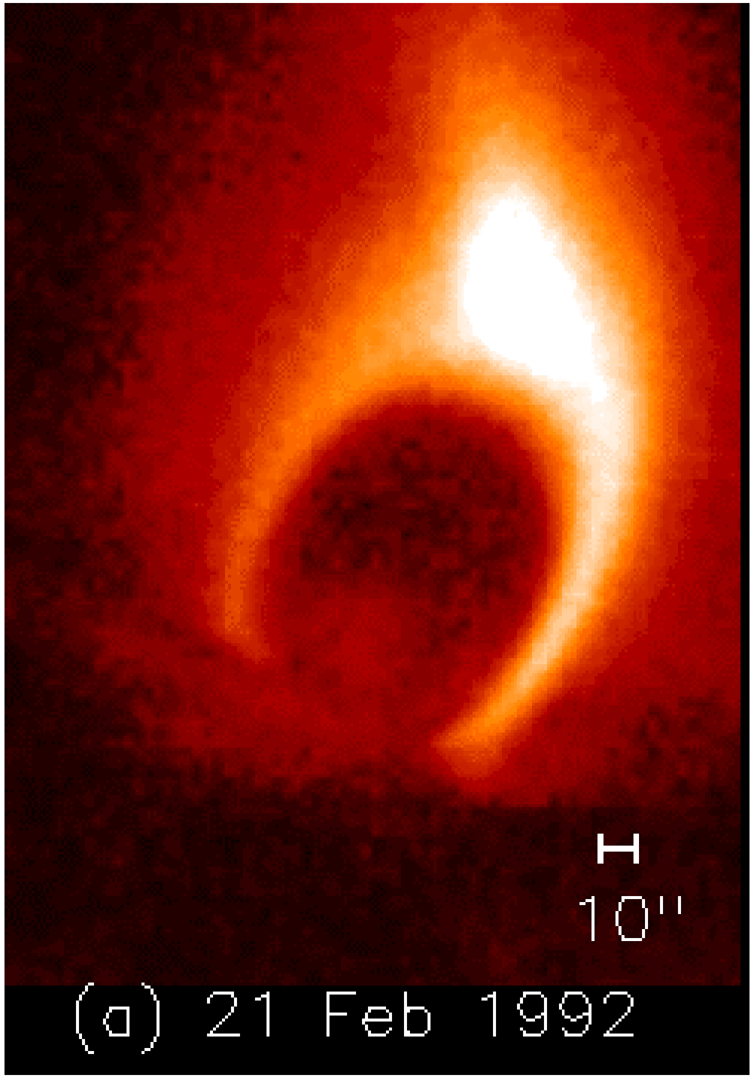



Model



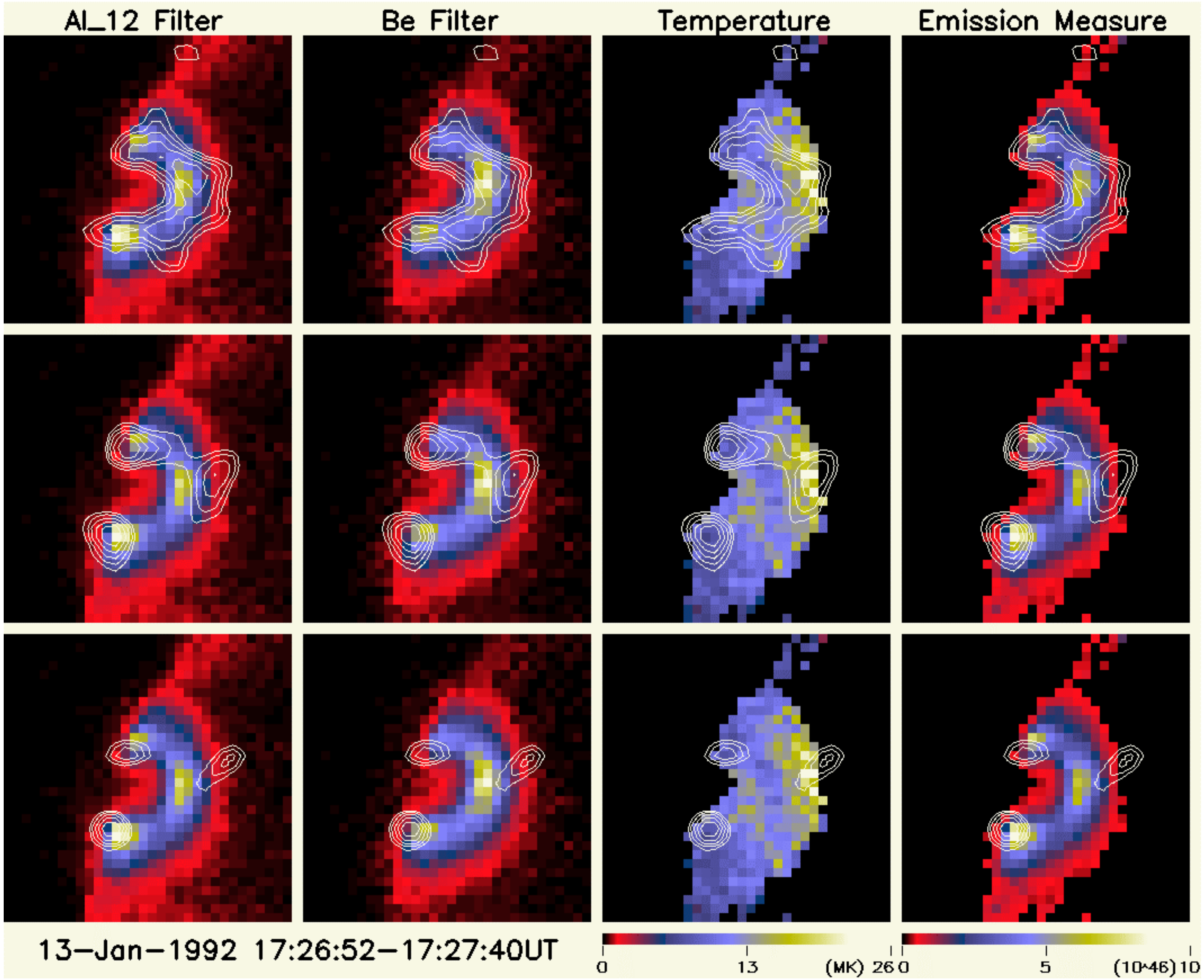

Numerical simulation by Yokoyama

# YOHKOH Observation ①




Soft X-ray Telescope（SXT)

# YOHKOH observation（II）




SXT
&HXT

# Open Issues

- No direct observations of magnetic reconnection
- No direct observations of current sheet (thin)

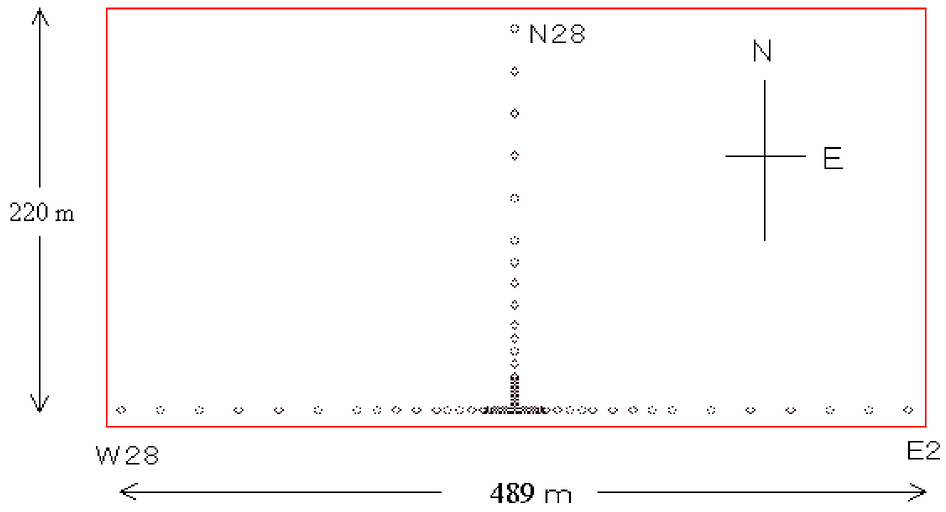
  (? current driver and current circuit)
- How to create very thin current sheet?
- How to sustain very thin current sheet?
- Cause of localized anomalous resistivity

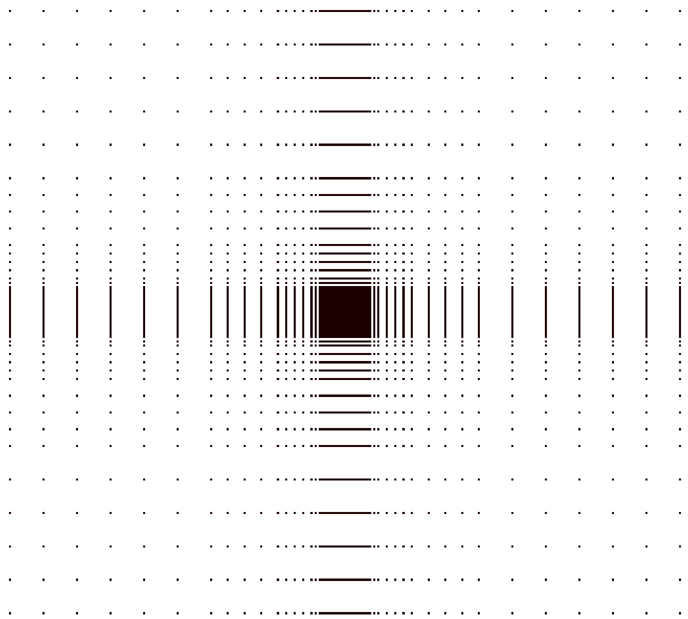
# Nobeyama Radioheliograph
# (野辺山電波太陽写真儀)

# Nobeyama Radioheliograph

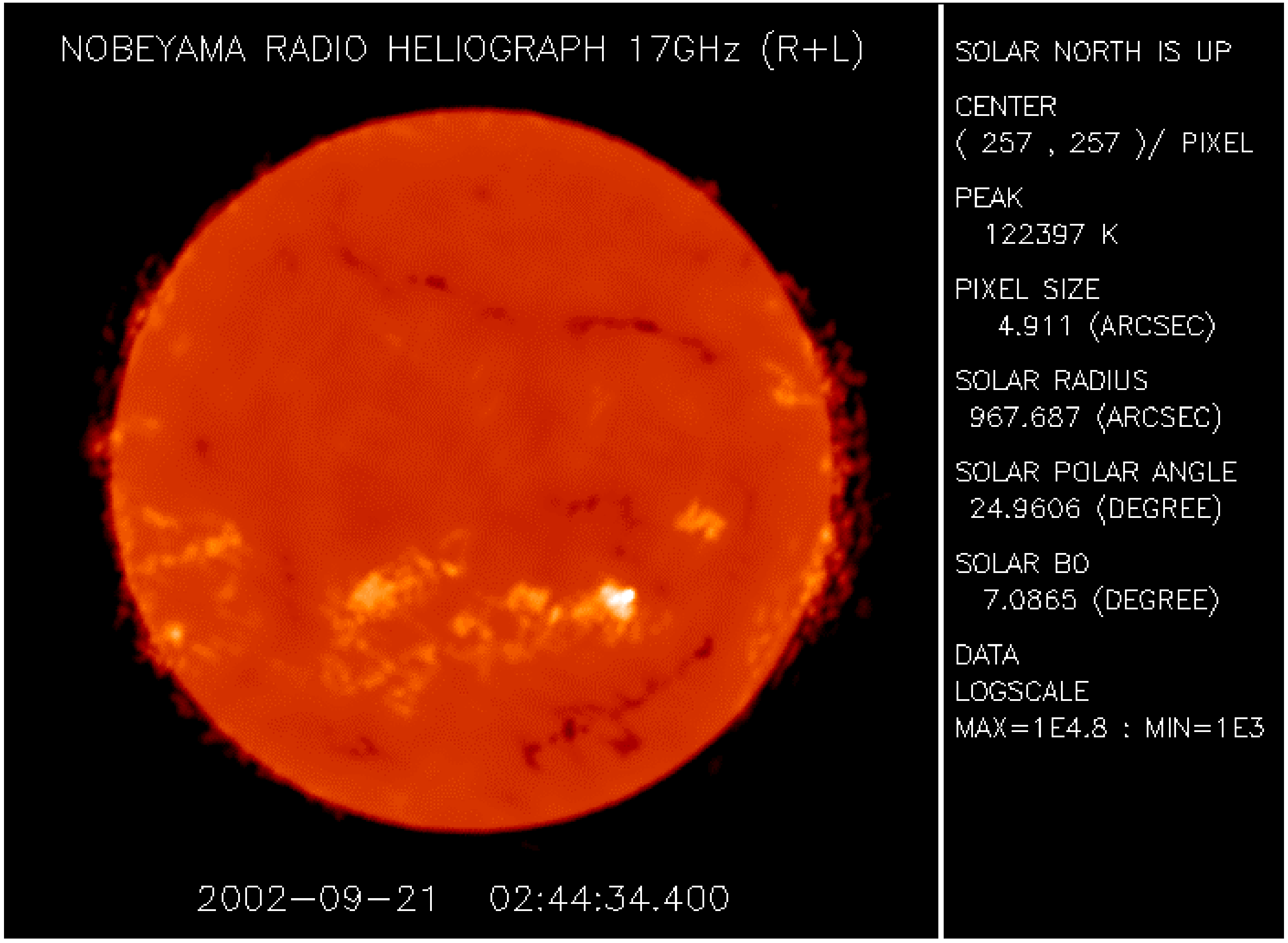
- Radio interferometer dedicated for solar observation
  - Constructed in 1990-1991
  - Routine observation since 1992 ( > one solar cycle obs.)
  - Array configuration: T-shape, EW:490 m, NS:220m
  - Antennas: 80 cm diameter, EW:56, NS:28 (total 84)
  - Observing frequency: 17 & 34 GHz ( $\lambda$ :1.76cm, 8 mm)
  - Imaging capability
    - 1 (Max 10) set of images per second (17 GHz I & V, and 34 GHz I)
    - Full disk image with 10 (5) arc sec. resolution at 17 (34) GHz
    - 8 hours per day without interruption by weather condition (cloud, rain, or snow)

# Array configuration and UV plane



# Radio Heliogram



# Observation by Nobeyama Radio Heliograph

# EUV observations by TRACE

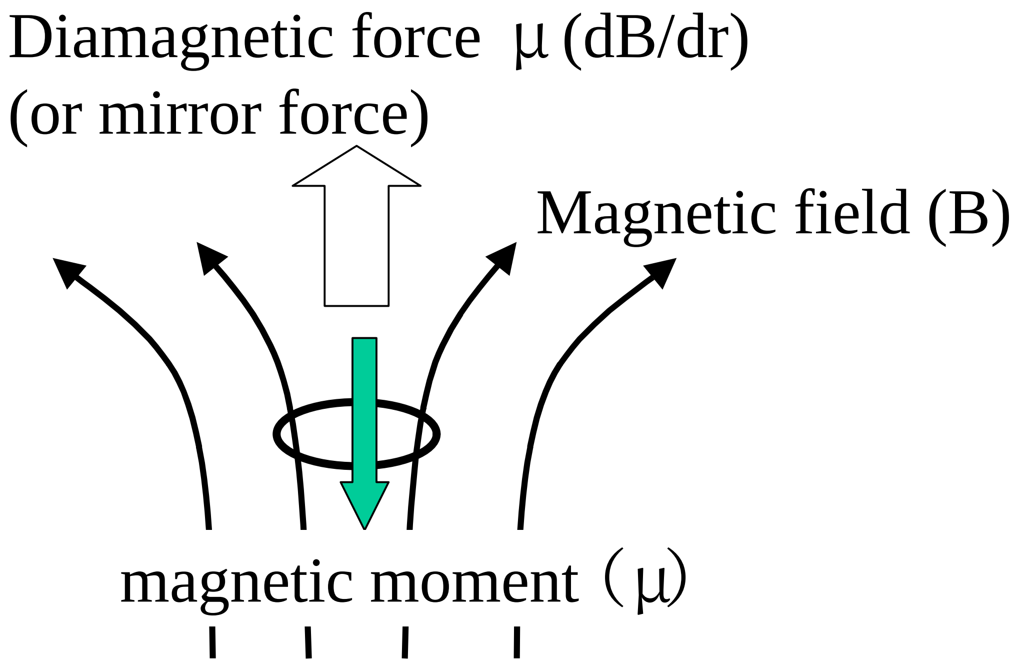
- 1999 Oct. 22 (171Å, 1MK)
- 2001 Nov. 01 *
- 2001 Nov. 27
- 2001 Sep. 18
- 2002 Apr. 21
- 2002 May 27 *
- 2003 May 02 *

# Magnetic Properties of Plasma

- **Non-linear** & **Diamagnetic** Media
  - Magnetic moment: $$\vec{M} = -\left(\frac{2Nk_BT}{B}\right)\left(\frac{\vec{B}}{B}\right)$$
  - $\mathbf{B} = \mu_0 \ (\mathbf{H}+\mathbf{M})$
  - $B^2/\mu_0$ - HB + $2Nk_BT = 0$ ; scalar relation along **B**
    - $0 \leqq \beta = P / (B^2/2\mu_0) \leqq 2$ ; plasma beta limit
  - Magnetic energy
    - $\delta U = \mathbf{H} \cdot \delta \mathbf{B} = \delta (B^2/2\mu_0) + 2Nk_BT(\delta B/B)$
  - Magnetic force
    - $F = - dU/ds = - d/ds (B^2/2\mu_0) - 2Nk_BT/B \; dB/ds$

# Magnetic force

**Plasmas are pushed where magnetic field is weak and localized high-beta region is created spontaneously**
**⇒ high-beta disruption (non-linearity of plasma)**



# Plasma flow along magnetic field

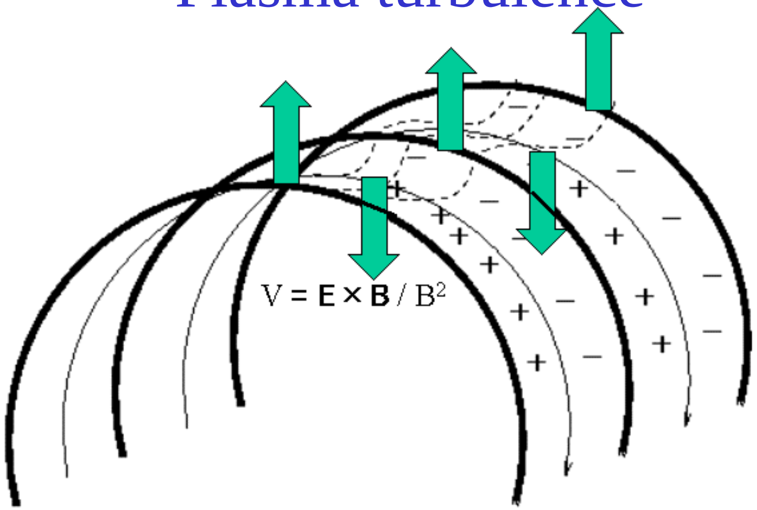
- Solar atmosphere is filled with magnetic field.
- Magnetic field intensity decreases upwards in and on the Sun $\Rightarrow$ Ubiquitous plasma upward flows driven by diamagnetic force against gravity (free energy for activities)
  - Plasma flows along curved magnetic loops in active regions
    - $F = 2NkT/l_B \sim 2NkT/\sqrt{R}$ ; R is the curvature radius of the loop
  - Even in open radial field
    - $F = 2NkT/l_B = 4NkT/r$ ; r is the distance from the solar center (Solar wind driving term by Parker)

# Coronal Loops

- Magnetic loops are anchored at both ends
- Bad curvature region around the loop top
- Edge plasma must be unstable
- We can observe highly developed non-linear phase of plasma instability

# A new flare model (High-beta Disruption)

Plasma turbulence

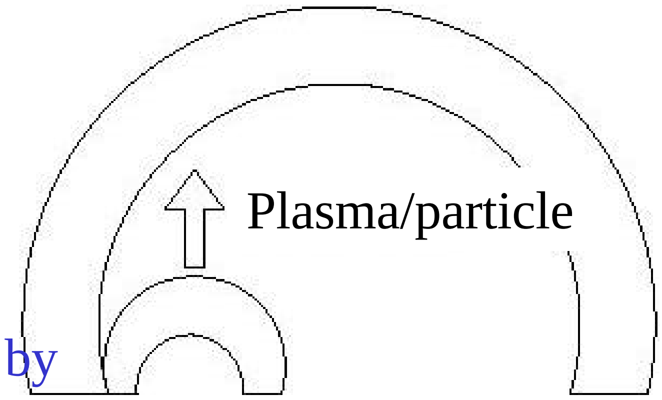



Ballooning instability

(interchange instability)

by Flow&Curvature

Particle acceleration by E field along loops



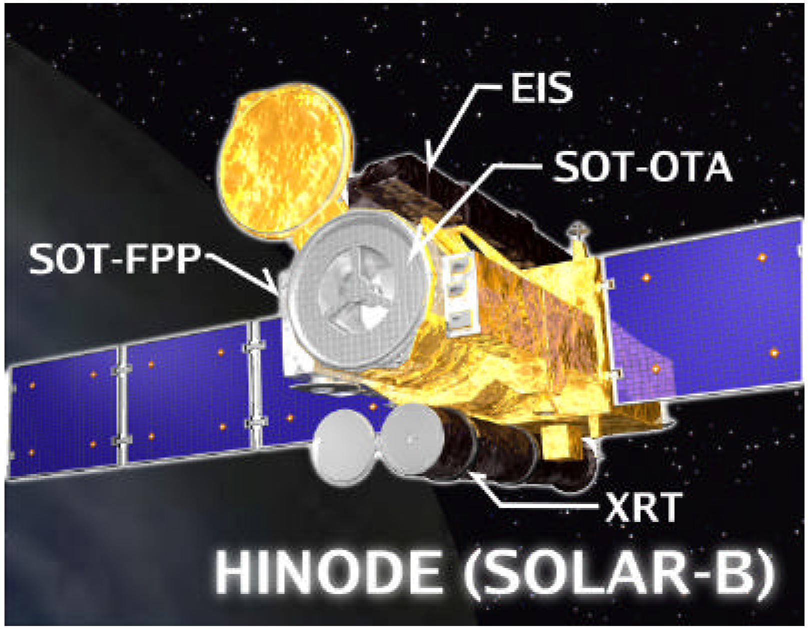
# To understand high-beta disruption process on the Sun

- We need high-cadence, high spatial resolution imaging with multi-wavelengths
  - Soft X-ray, EUV and optical telescopes
    - Heating process of plasmas from low temperature to higher temperature
  - Hard X-ray and microwave telescopes
    - High energy particle production process
  - High cadence and high spatial resolution are important to understand the interchange instability process
  - Spectral line observations are needed to measure flow velocity of plasmas.
- Quantitative studies of physical parameters (temperature, density, magnetic field and velocity)

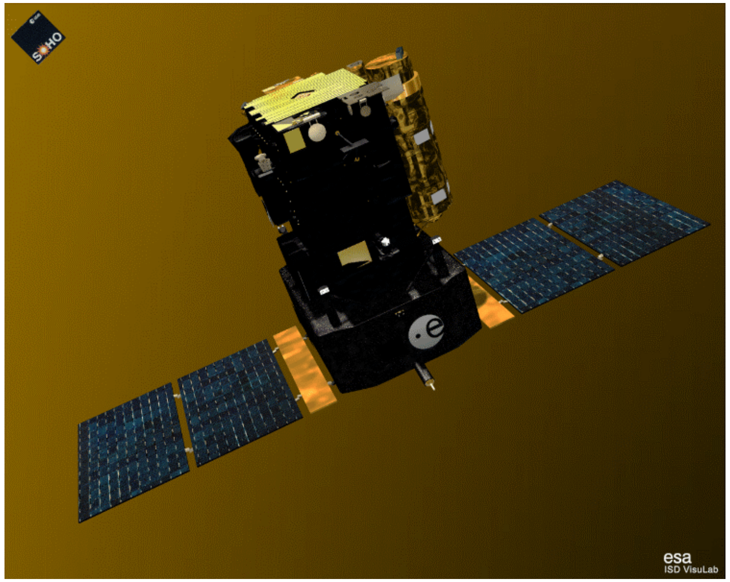
# Available Telescopes

- HINODE:
  - SOT: optical imaging, magnetic field, velocity
  - XRT: soft X-ray imaging, temperature and density
  - EIS: EUV spectroscopy and imaging, temperature, density, velocity
- Nobeyama Radioheliograph: microwave imager, high-energy particle, magnetic field in the corona
- RHESSI: hard X-ray imager, high-energy particle
- TRACE: EUV imager
- SoHO: optical, EUV imager and spectrometers

Free Data Exchange !




SoHO




Nobeyama Radio Heliograph

RHESSI

# Future direction

- **High-beta plasma physics**