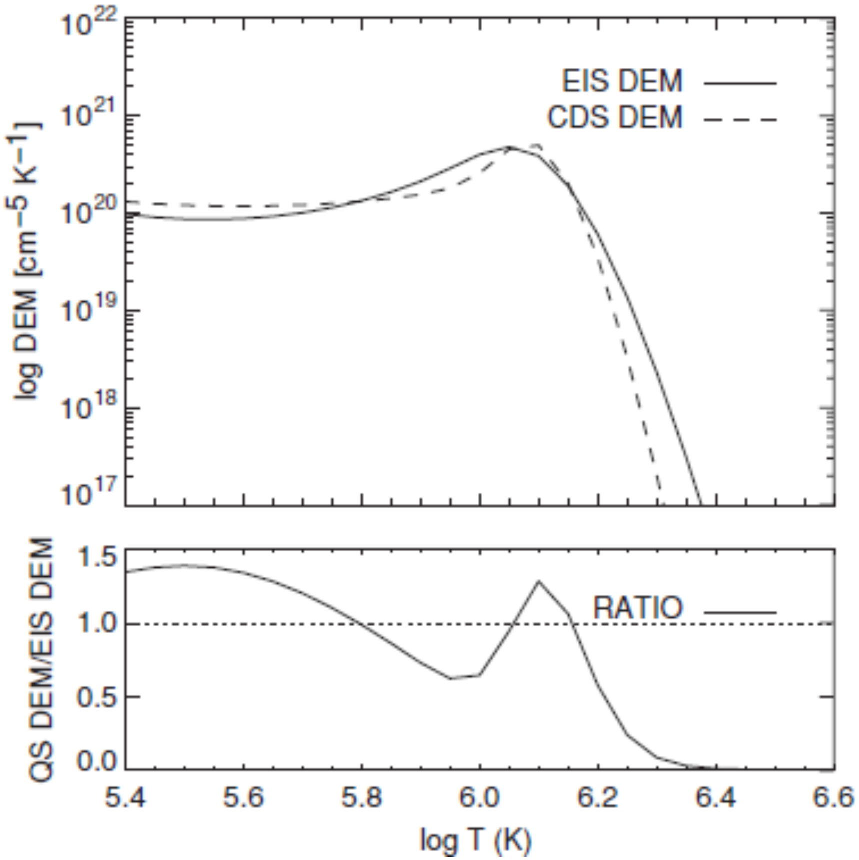
Achievements of Hinode: Part 1

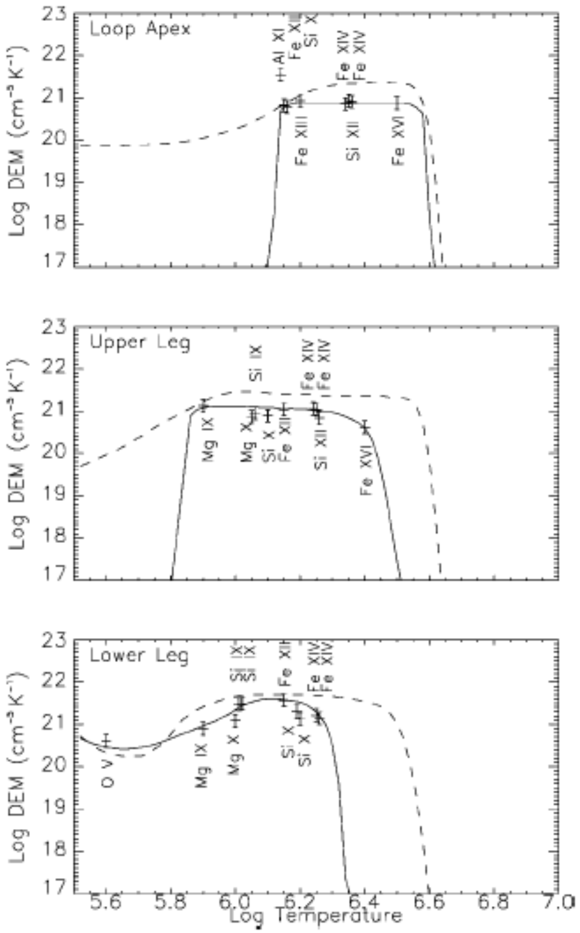
- coronal heating and the acceleration of the solar wind
  - waves
  - nanoflares
- magnetic coupling between the surface and the corona
- physics of flux tubes and convection
  - elementary flux tubes
  - sunspots

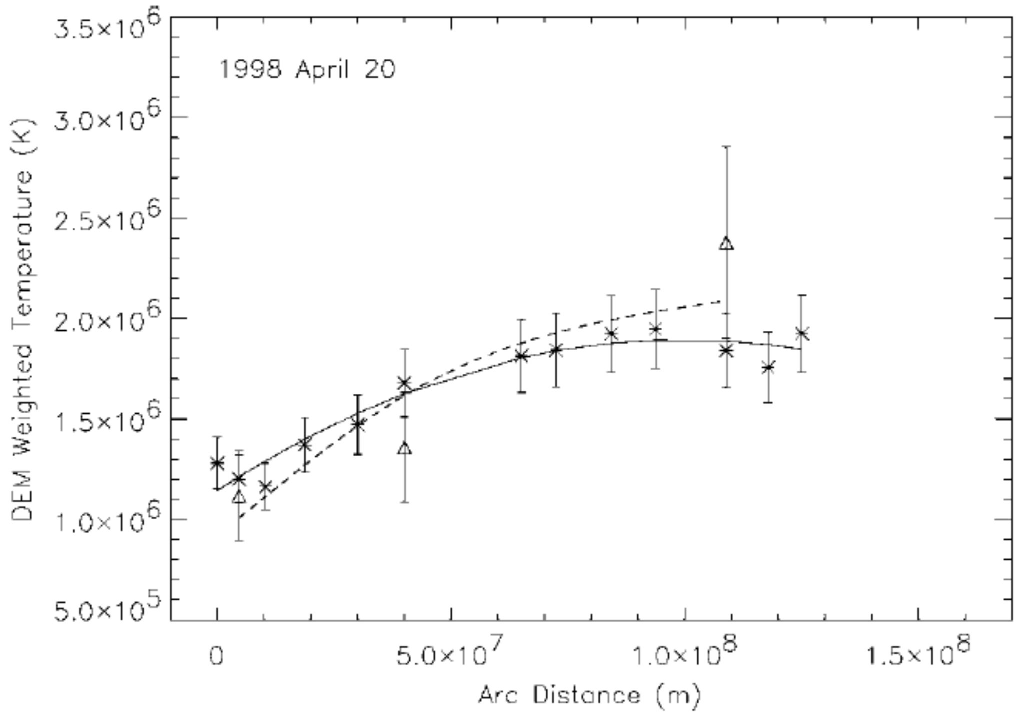
Coronal Heating: Temperature Distribution, DEM

- EIS quiet-sun DEM（Brooks et al. ApJ 2009）
- similar to CDS results



CDS: Temperature Variations with Height
Schmelz & Martens 2006 ApJ





EIS: ?

XRT: Kano et al. 2008 PASJ

XRT filter ratio
➔ high temperature component log T>7

Reale et al. 2009 ApJ

(Cf. Yohkoh Yoshida & Tsuneta 1996 ApJ)

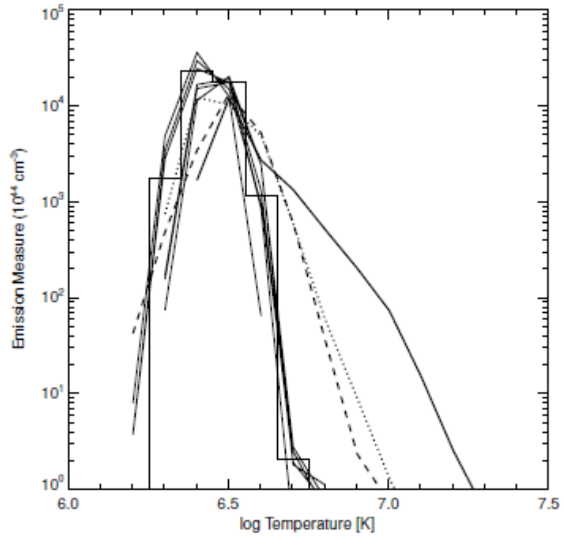


Figure 3. Emission measure distribution vs. temperature for the whole active region (with emission above threshold of acceptance) obtained from available filter ratios: soft filter ratios (thin solid lines), CIFR (histogram), F5/F3 (dotted line), F4/F3 (dashed line), F4/F5 (thick solid line). The latter is obtained from the map binned over boxes of 4 × 4 pixels.

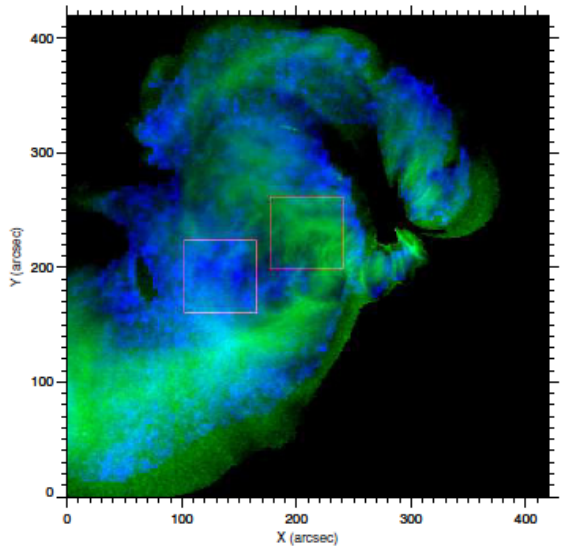
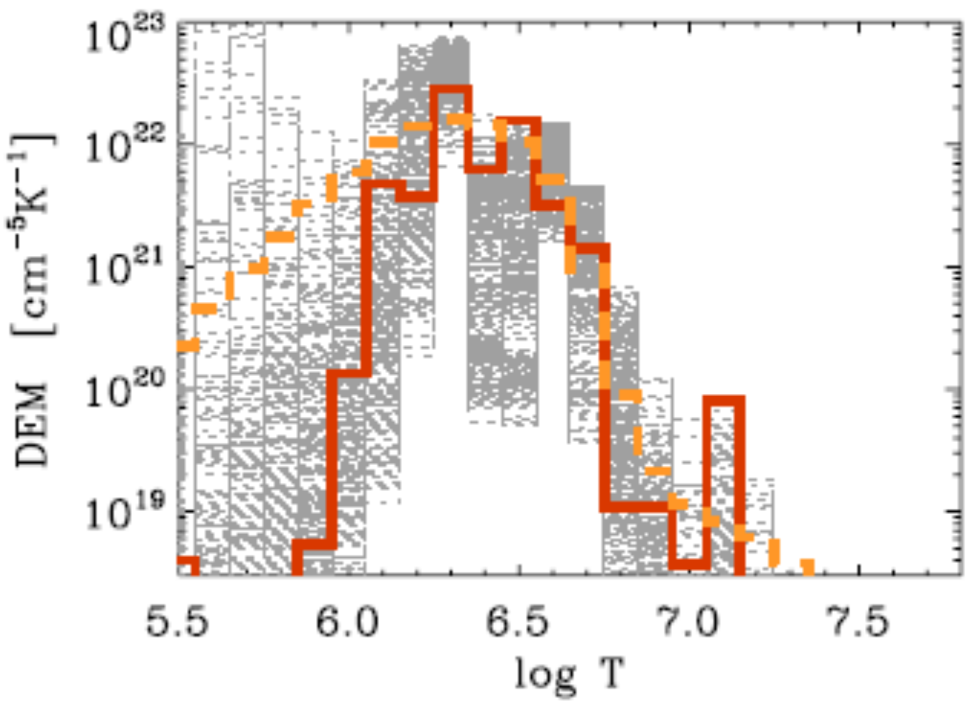


Figure 4. Maps of temperature as in Figure 2 obtained with CIFR (green scale) and hard (F4/F5) filter ratio (blue scale). The red boxes mark the regions of different temperature regimes analyzed separately: the one on the left is hotter in the hard filter ratio (hereafter hard-hot region), and the one on the right is hotter in the soft filter ratios (hereafter soft-hot region).

Active Region DEM
Schmelz et al. ApJ 2009

- combination of XRT and RHESSI data
- high temperature component logT>7 signature of nanoflares
- EIS?

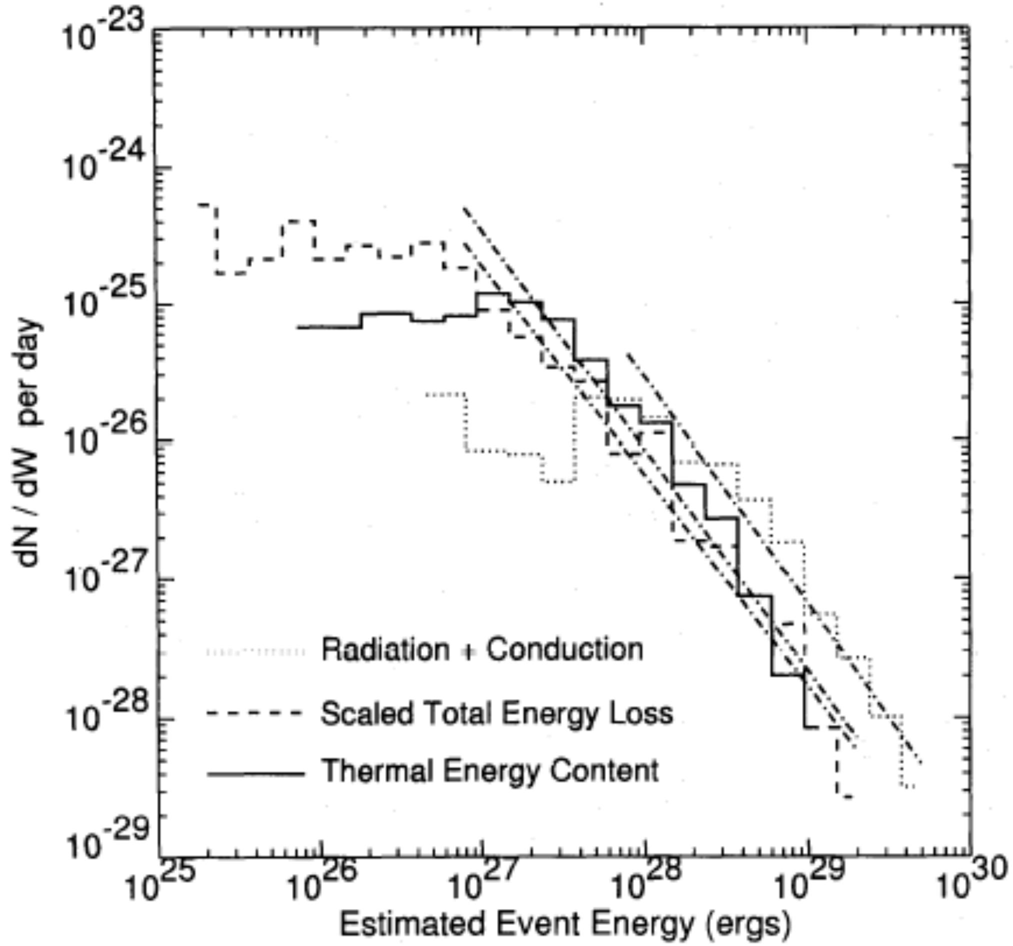


- wave heating, if any, is not due to coherent (large-scale, > a few arsec) waves.
- Important is the origin of nonthermal broadening.
- Is it due to upflows from the footpoints （Hara et al. 2008 ApJL; McIntosh & De Pontieu 2009 ApJL; De Pointieu et al. 2009 ApJL) or waves in flux tubes (Fujimura & Tsuneta 2009) ?

- So is it due to nanoflares? But EIS observations of moss show only weak time variability（Brooks & Warren 2009 ApJL).
- Loops in the core of active region seen with EIS 0.4-2.5MK +XRT are in a cycle of heating and cooling（Ugarte-Urra et al. 2009 ApJ).
  (Cf. Nagata et al. 2003 ApJ
  Hot loops and cool loops are mutually exclusive）

Distribution Function of Small Flare Events

- Yohkoh SXT
  slope −1.5
  <20% of required
  heat input
- How about
  Hinode XRT?



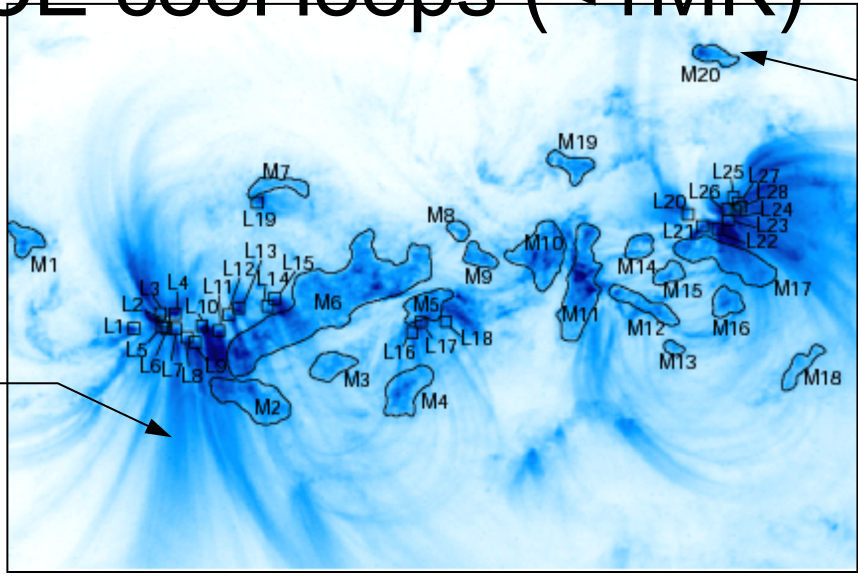
Shimizu 1995 PASJ

Magnetic Coupling between the Surface and the Corona

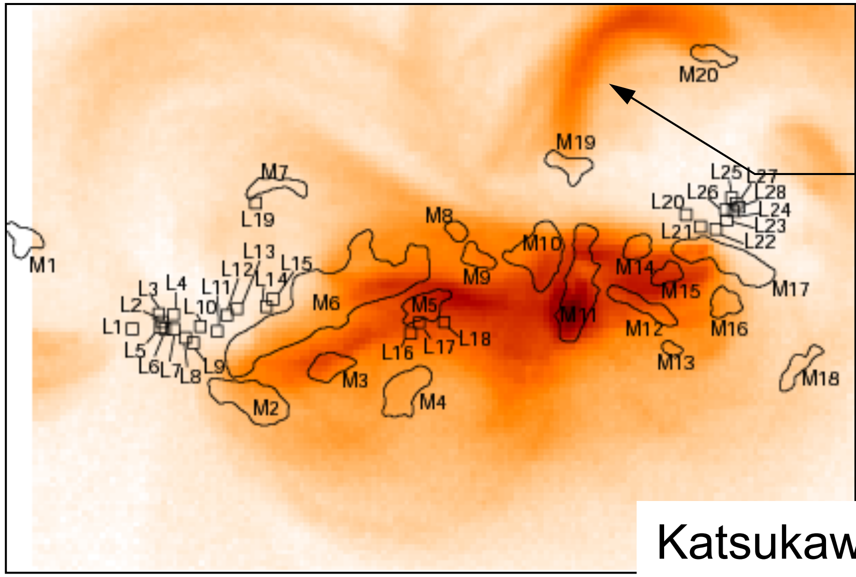
- many studies on flare energy build-up and NLFFF modeling based on SP vector field data
- flux emergence, cancellation, and their effects on the corona: needs wide FOV and high time cadence, ideally by NFI.

Yohkoh SXT hot loops (>2MK) and EIT, TRACE cool loops (<1MK)

TRACE 171Å cool loops (1 MK)



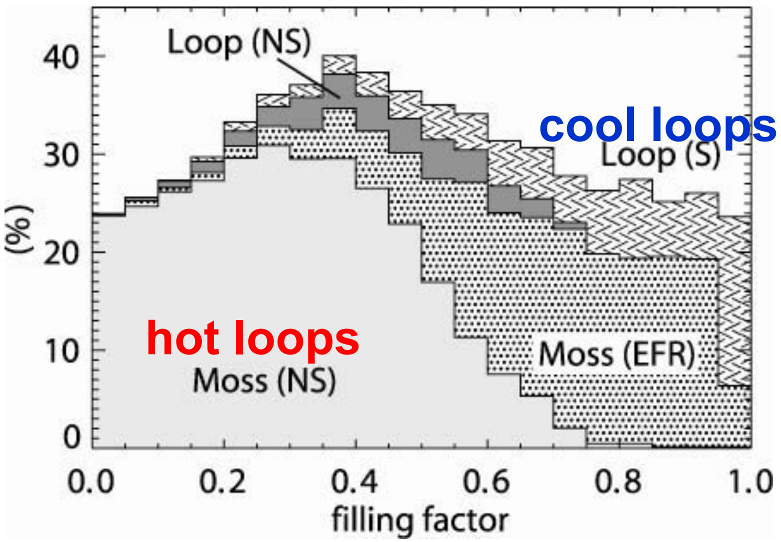
TRACE "moss" structure: footpoints of hot loops



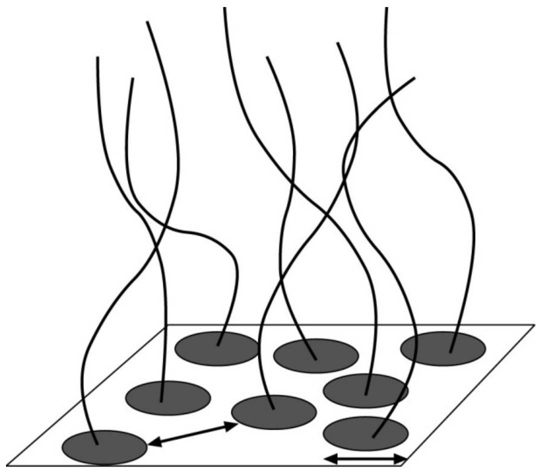
Yohkoh/SXT hot loops (> 2 MK)

Katsukawa and Tsuneta (2005)

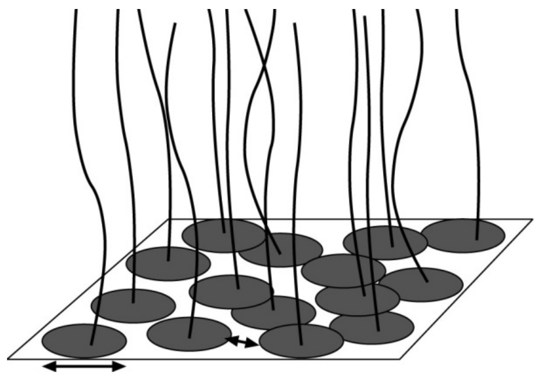
difference in magnetic filling factor?



Loosely packed flux tubes are easier to be moved and more energy is supplied, leading to hot loops.



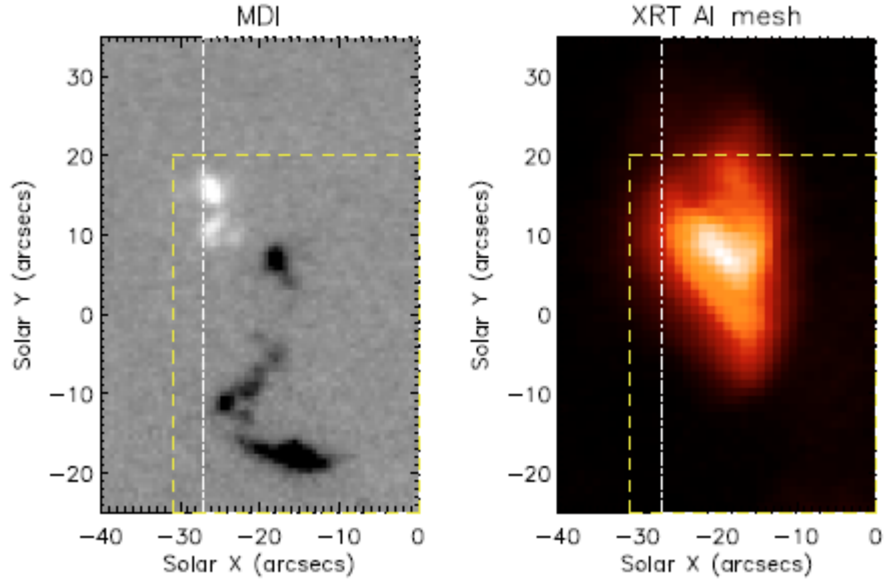
Tightly packed flux tubes are harder to be moved and less energy is supplied, leading to cool loops.



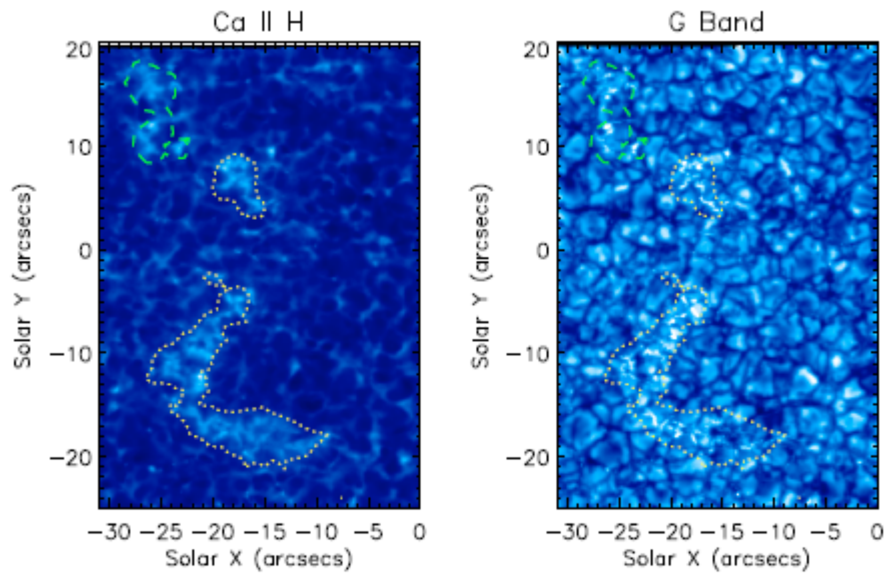
SOT + EIS (Brooks et al. 2008 ApJL)

- chromospheric/TR transient events
  - mixed polarity, dynamic areas with flux cancellation
- hot coronal loops
  - moss region, unipolar

- XBPs are made of several smaller loops (Kotoku et al. 2007 PASJ).
- At the footpoints of XBPs there are many Ca H and G-Band bright points (Perez-Suarez et al. 2008 A&A).



l 2007. *Left to right*: EIT (22:00:11 UT), MDI (22:01:01 UT) and XRT (22:01:05 U
/hile the dot-dashed box is the region shown in Fig. 3.



Flux Emergence and Heating of the Chromosphere and Corona

- flux emergence → dark lanes in G-band and Ca H (Ohtsuji et al. 2007 PASJ)
- activity in the sequence of B→Ca H→XRT （Li et al. 2007 PASJ）
- B→Ca H: high correlation, but less tight correlation with G-band (Guglielmino et al. 2008 ApJL)

Coronal Heating Problem: What to Do?

- to discriminate between wave heating and nanoflare heating
  （or decide the ratio of contributions）
- data are available, (only) one step further
  （wisdom?）

Origin of the Solar Wind

- XRT outflow (Sakao et al. 2007 Science)
- EIS outflow (Harra et al. 2008 ApJL)
- polar-region activity (Tsuneta et al. 2008 ApJ; Shimojo & Tsuneta 2009 ApJL)

Physics of Elementary Flux Tubes

- convective collapse
  - discovery (one event) by Nagata et al. 2008 ApJL
  - statistics (49 events) by Fisher et al. 2009

Type of event	max v down [km s^{-1}]	start B [G]	peak B [G]	r 1 [arcsec]	r 2 [arcsec]	duration [min]
11 without Mg downflow	3.80	819	1093	0.48	0.41	10.36
28 with Mg downflow	3.92	886	1356	0.48	0.34	10.37
10 Mg out of FOV	3.33	900	1262	0.34	0.31	9.09

Physics of Elementary Flux Tubes

- motion, diffusion
  - rms motion 1.56 km/s (de Wijn et al. 2008 ApJ)
  - diffusivity 0.9 km^2/s (Chae et al. 2008 ApJ)
  - vortex flows
life time longer than 1 hour (Attie et al. 2009 A&A)

Chae et al. 2008 ApJ

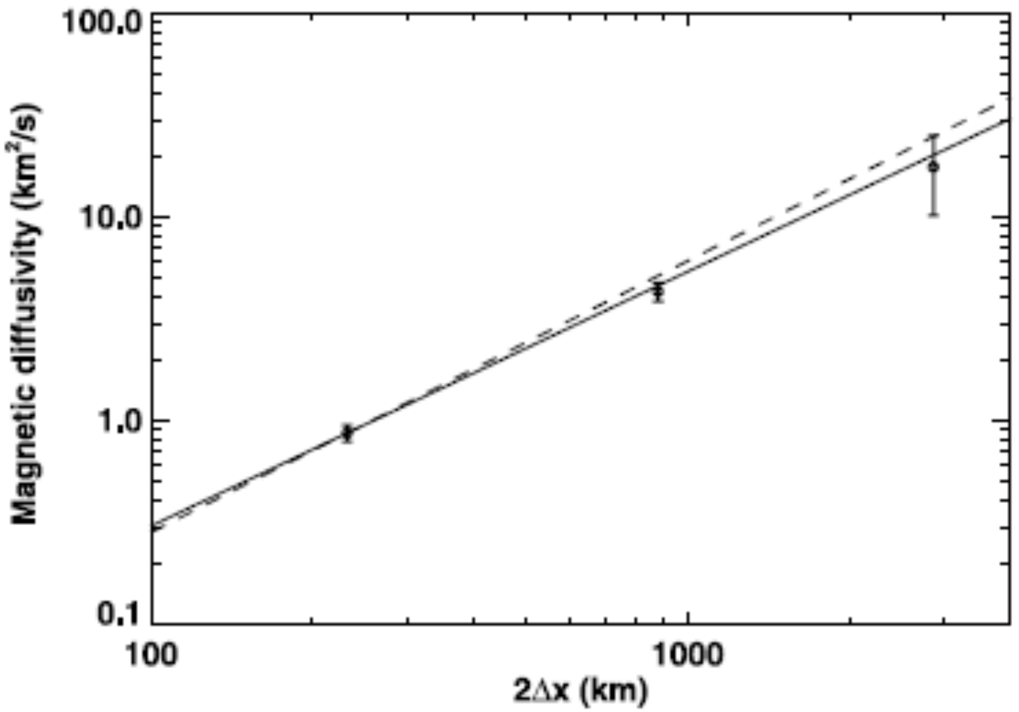
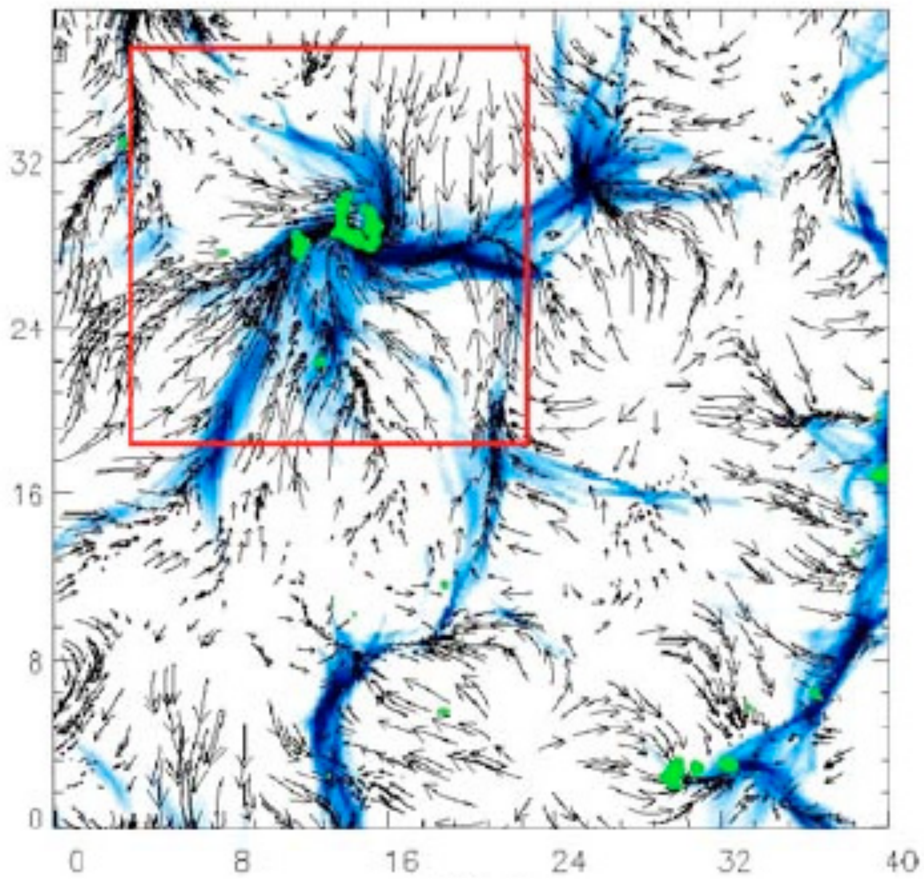


FIG. 4.—Plot of magnetic diffusivity vs. spatial resolution length. The solid curve represents the Iroshnikov-Kraichnan scaling $\sim l^{5/4}$, and the dashed curve the Kolmogorov scaling $\sim l^{4/3}$.

Attie et al. 2009 A&A



Ubiquitous Horizontal Field (Ishikawa et al. 2008 A&A)

- A classical picture of ‘canopy’ has been replaced by a dynamic process.
- Ubiquitous (Ishikawa & Tsuneta 2009 A&A)? Then they may not be the main contributor to coronal heating.

Missing Physics of Flux Tubes

- decay process
- interaction with convection
- behavior of weak intra-network field; needs deep magnetograms by NFI

Sunspots

- convection in umbrae（Umbral Dots)
- structure of penumbrae
- sources and sinks of Evershed flow
  - physical mechanism still not clear
- decay process
  - removal by MMF
  - internal destruction by light bridge
- formation process is less clear yet

Helioseismology

- sunspot oscillation (Nagashima et al. 2007 PASJ)
  - not so new results?
- 3D structure of supergranules (K.Nagashima, thesis）
  - smaller and deeper near the poles

Summary

- Many unexpected discoveries,
  110 points out of 100.
- However, topics that should have been studied are left untouched.
  80 points
- In overall, 95 points out of 100.