Solar flares in the chromosphere

H. S. Hudson

SSL, UC Berkeley

Abstract

- Flares and CMEs remain theoretically ill-understood - “magnetic reconnection,” perhaps, but there are many unknowns
- I suggest that the chromosphere holds the secret to flares:

  - Flare energy appears as particles, then UV continuum

  - The preflare energy must be in the low corona/chromosphere
- A renewed emphasis on UV-optical-IR spectroscopy at high spatial and temporal resolution is necessary

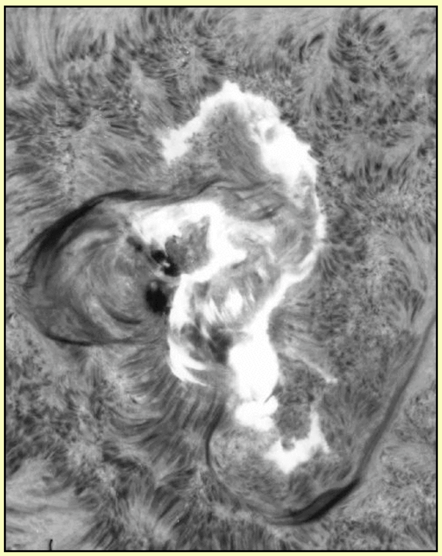
Three epochs of flare observation

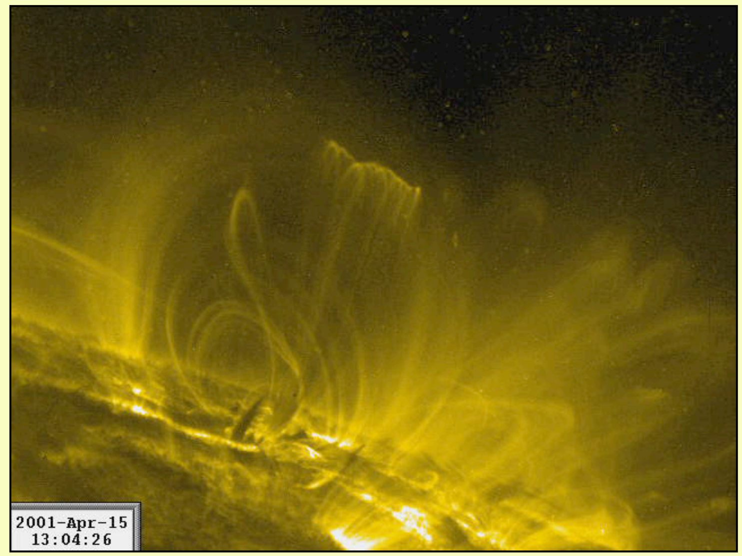
Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was,

19th century: the photosphere

20th century: the chromosphere



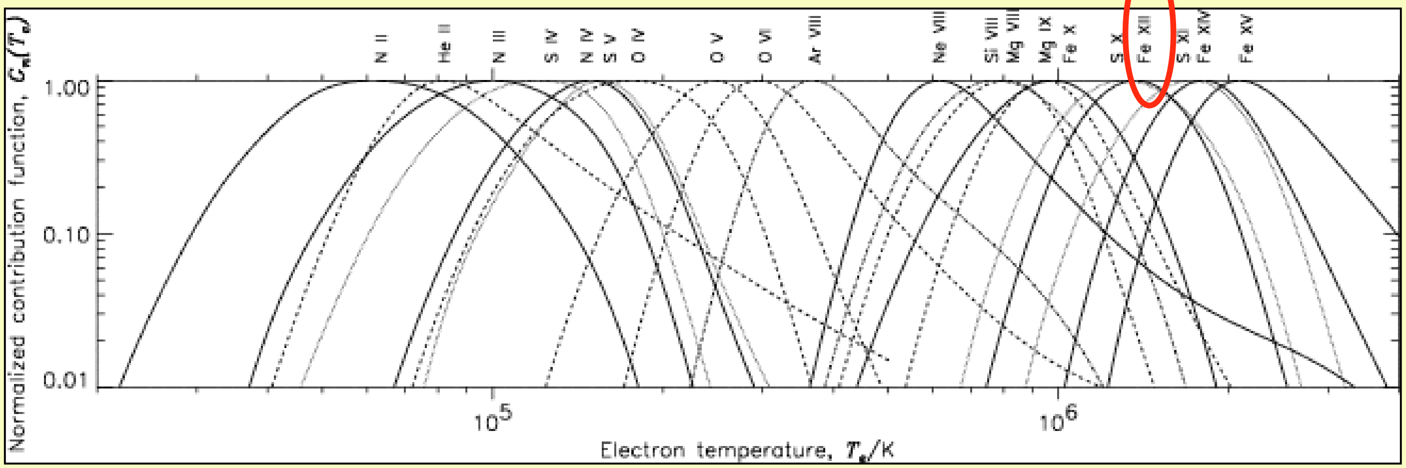


Present: the corona

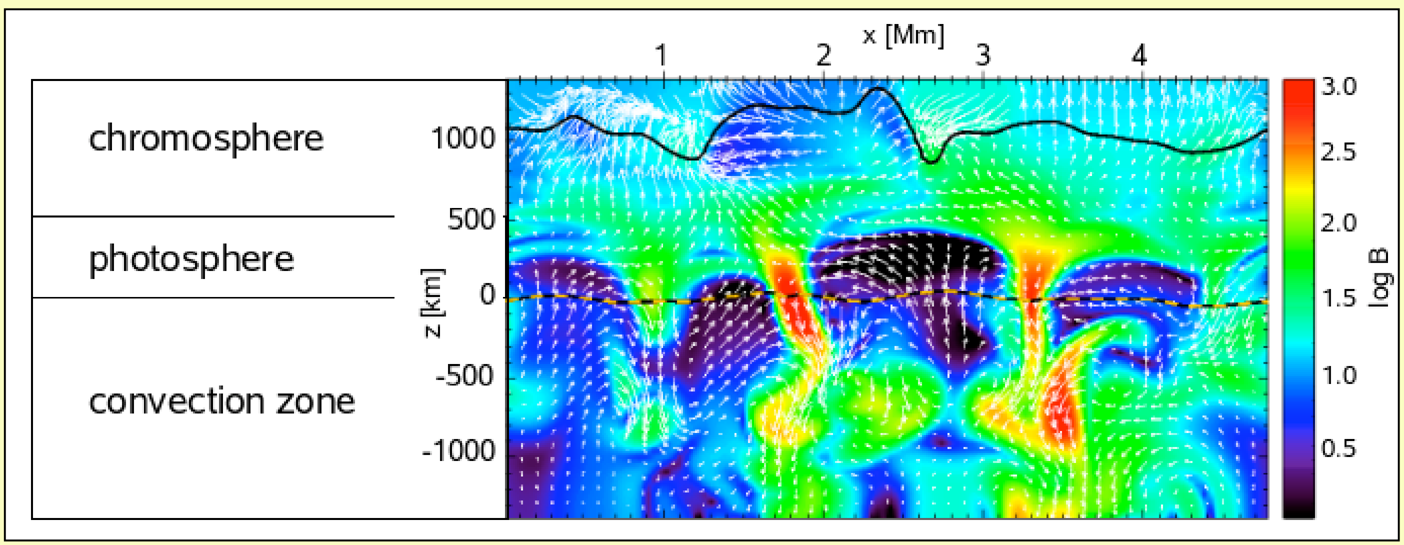
What are the properties of a flare?

- A sudden disruption of the coronal magnetic field
- The equally sudden appearance of large amounts of energy as accelerated particles (hard X-rays, γ-rays)
- A more gradual injection of chromospheric mass into the corona (soft X-rays)
- A coronal mass ejection (if a major event)
- *A flare is not one of Parker's "nanoflares"*

Some background



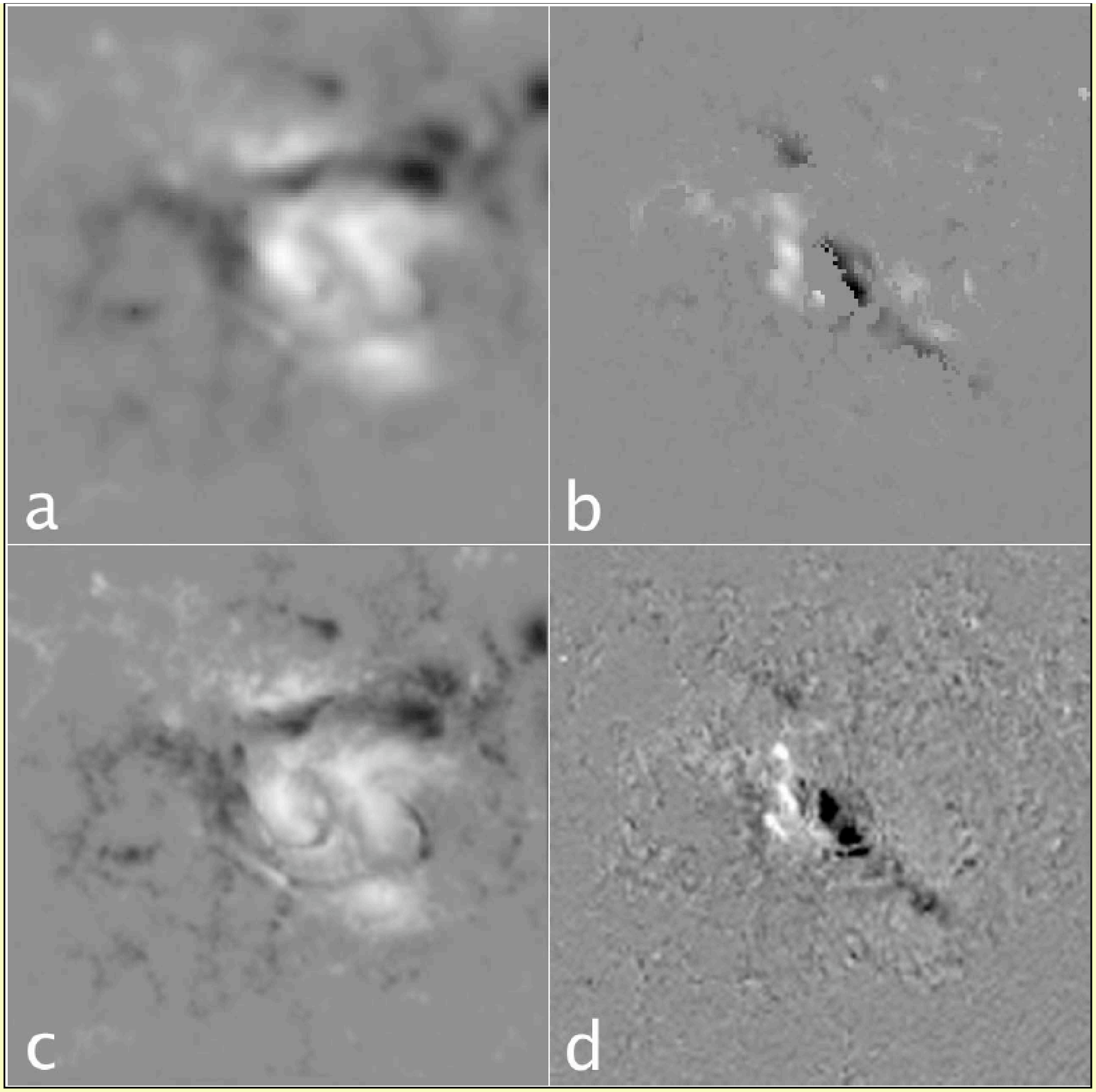
K. Wilhelm, 2006



KIS home page, Dec. 2005

Some new flare-related observations

- Flare-related field changes in the photosphere
- Ubiquitous microflares on small scales
- “Imperturbability” (see STEREO EUV movies)



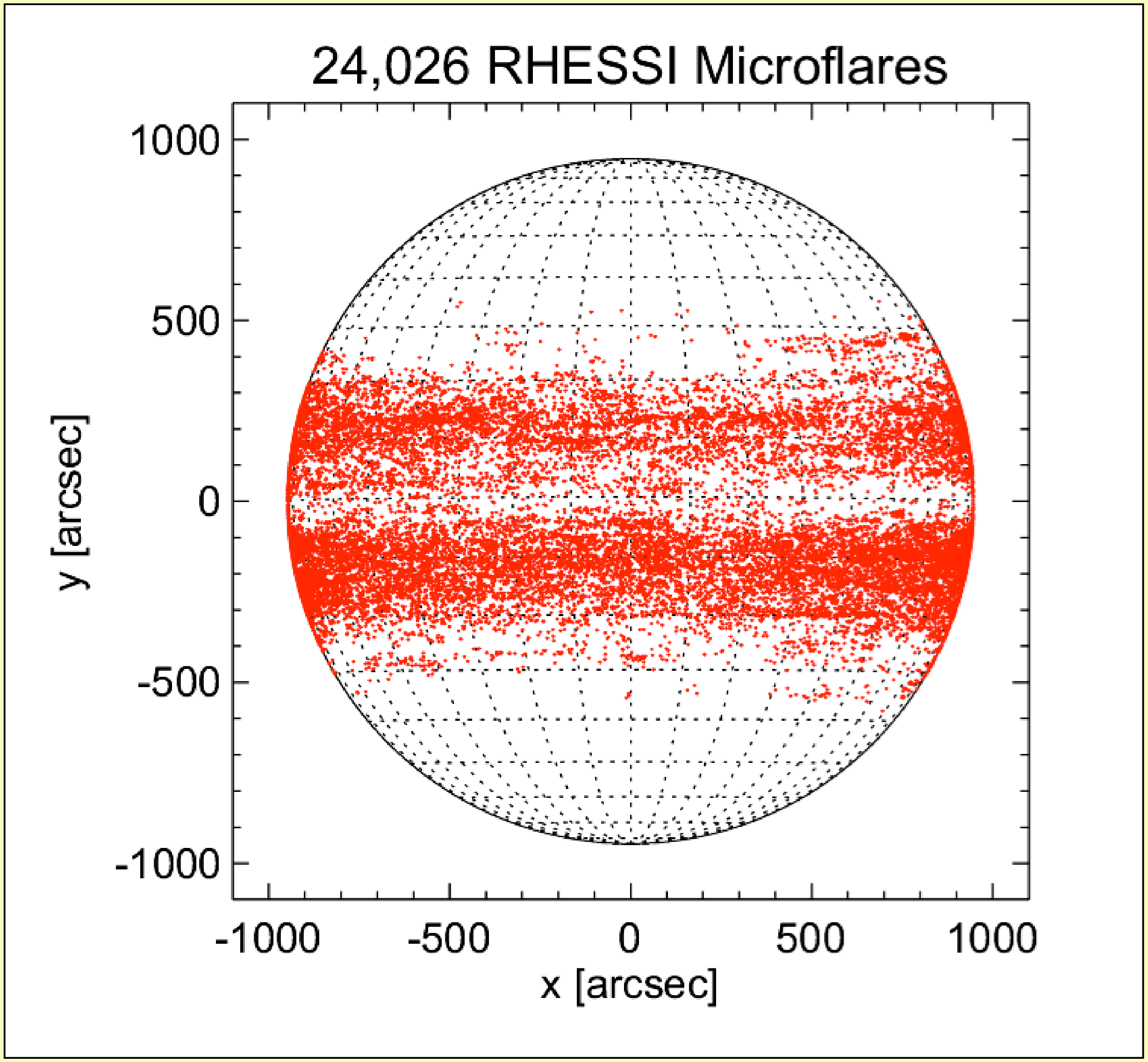
GONG

SOHO/MDI

$\mathbf{B}_{LOS}$ Maps $\delta\mathbf{B}_{LOS}$ Maps

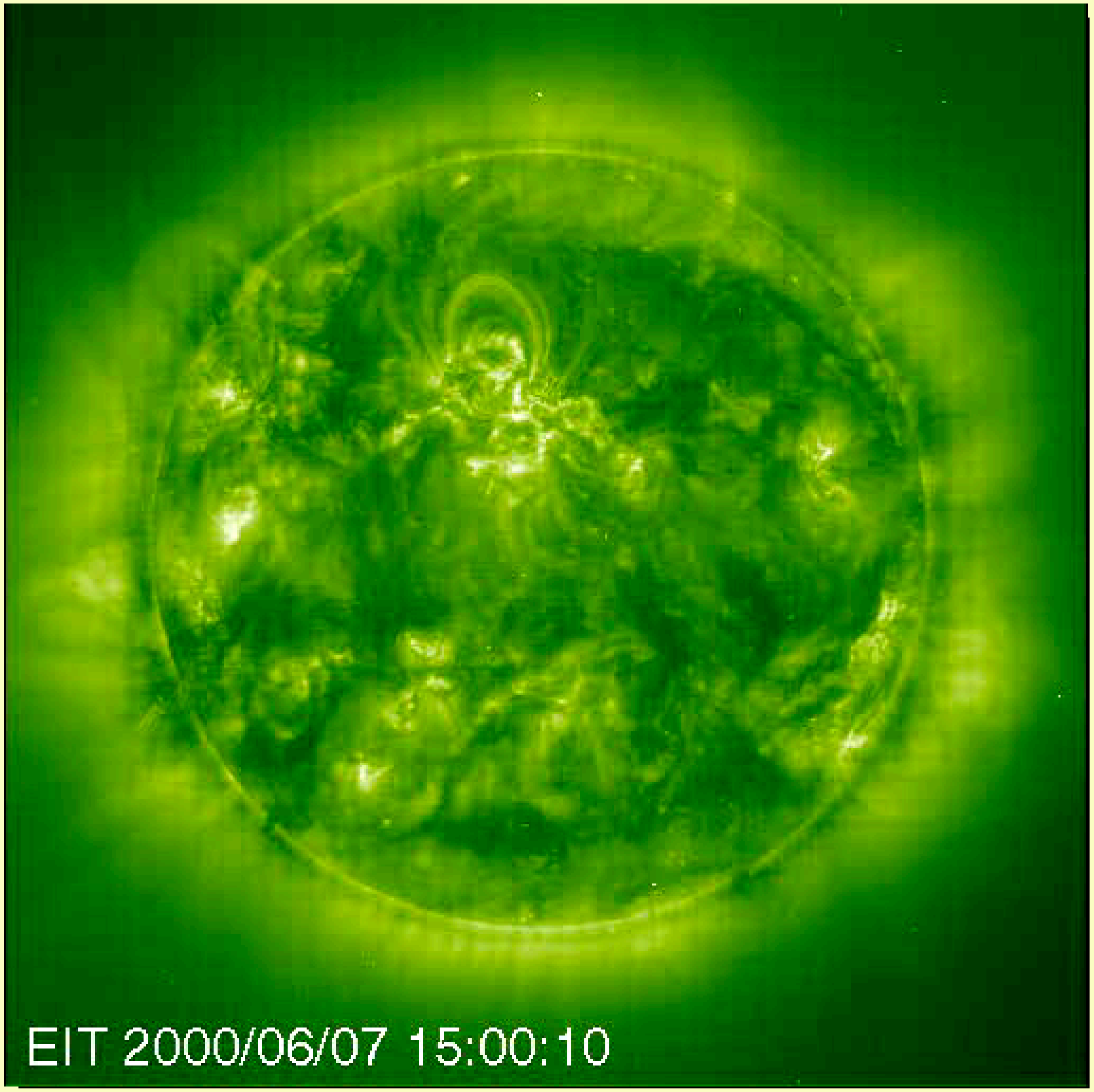
Sudol & Harvey (2005), X10 flare of 2003 Oct. 29

The Ubiquity of microflares



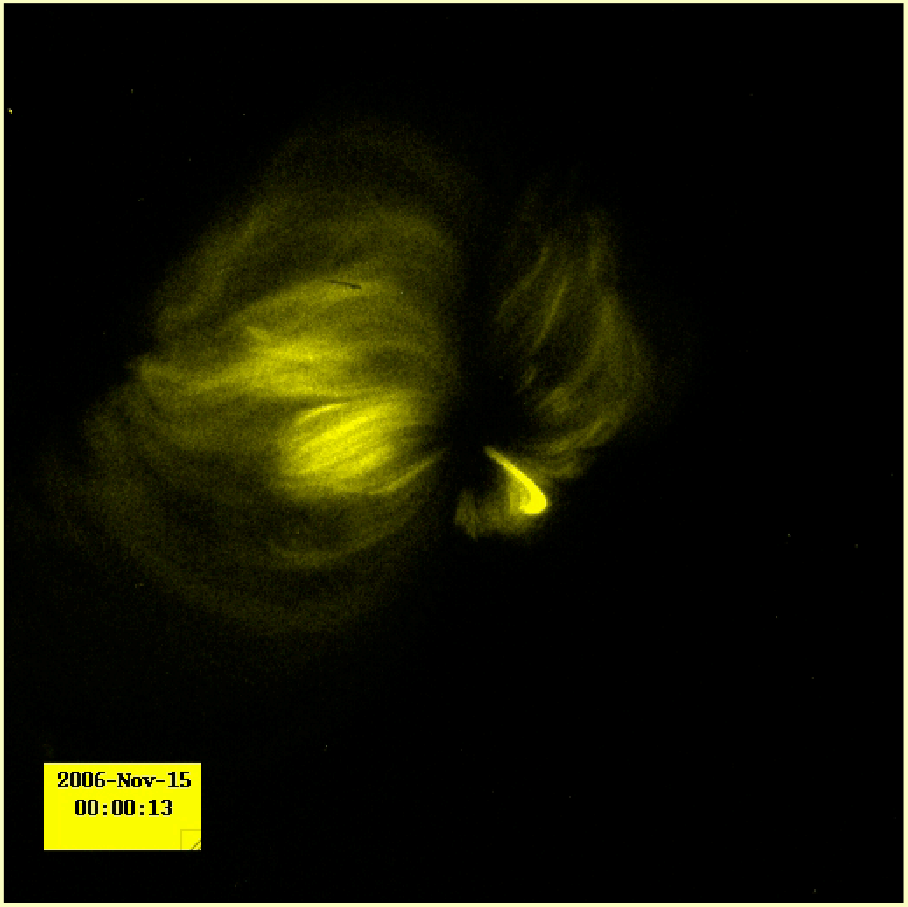
I. Hannah, 2007

The Imperturbability of the Corona



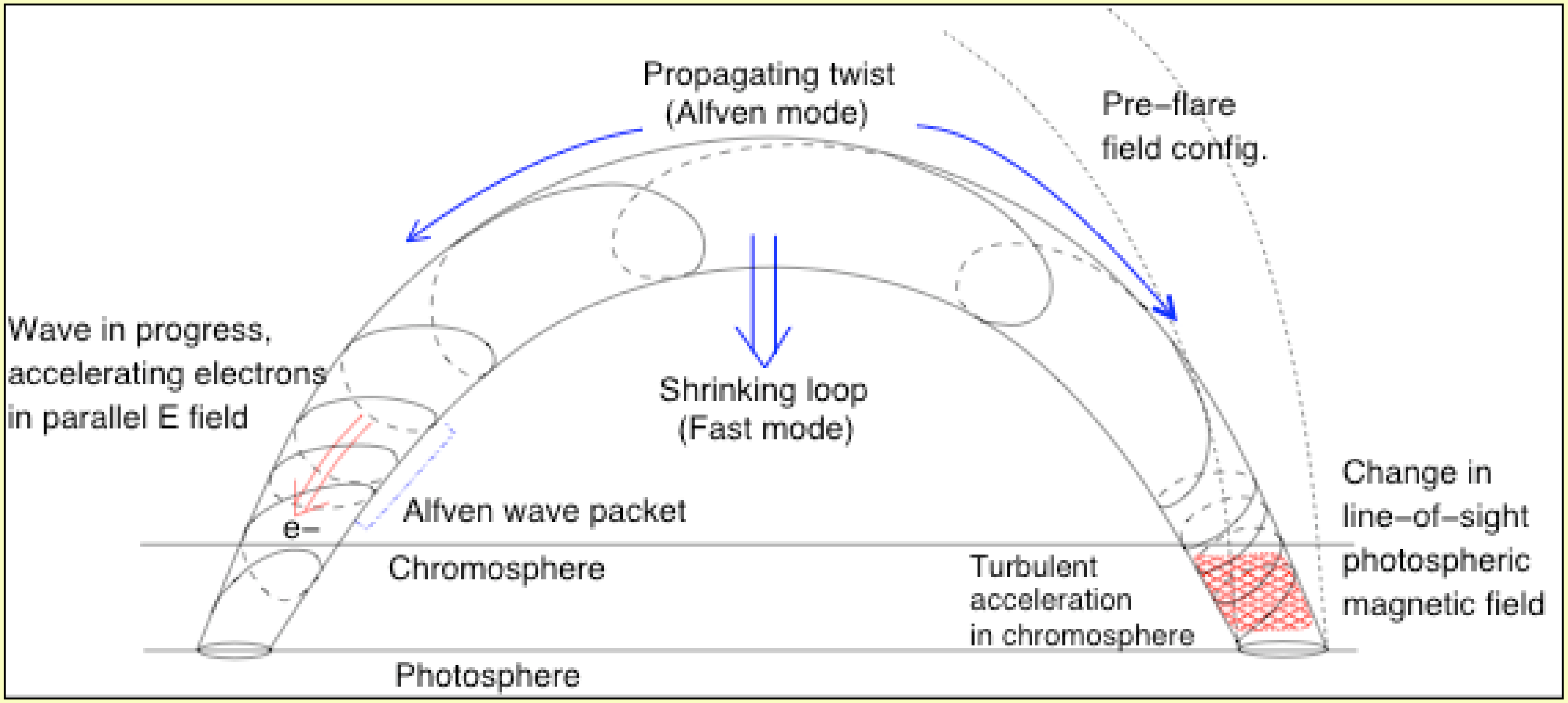
Yohkoh science nugget, 9 Jan. 2000

Conclusion: the chromosphere acts as an isolator that magnetically separates the changing solar interior from the "stick and slip" corona



Replacing the thick-target model

- Large-scale restructuring => flare energy
- Large Alfvén speed in the low corona
- Energy transport by Alfvén-mode waves, not electron beams



Fletcher & Hudson 2007

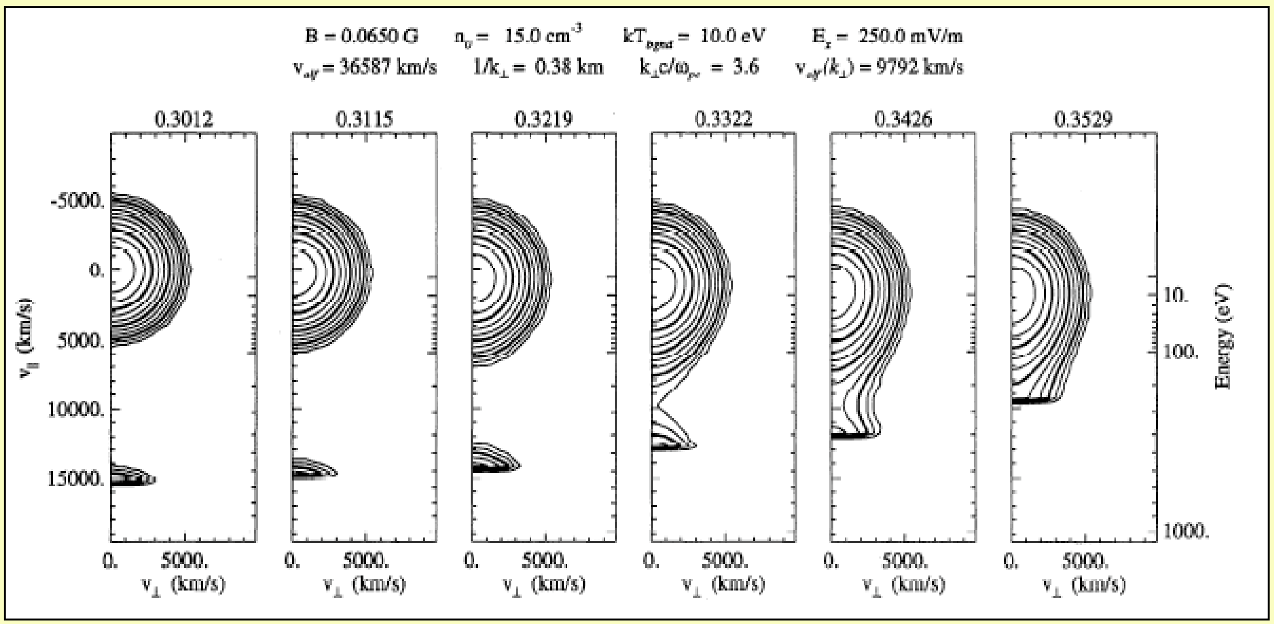
High Alfvén speeds

- The literature often underestimates active-region field strengths and Alfvén speeds; $v_A > 0.1c$ must be considered likely (500 G, 10^9 cm^{-3})
- The "magnetic scale height" in an active region is of order 10^9 cm (Brosius & White, 2006)

\- *The condition $\beta < m_e/m_p$ is also certainly possible, hence "inertial" Alfvén waves*

What is an inertial Alfvén wave?

- Inertial effects become important in Ohm's law
- Electric field parallel to B develops



Simulations of electron distribution function (Kletzing, 1994) evolving with time as the wave passes a fixed point

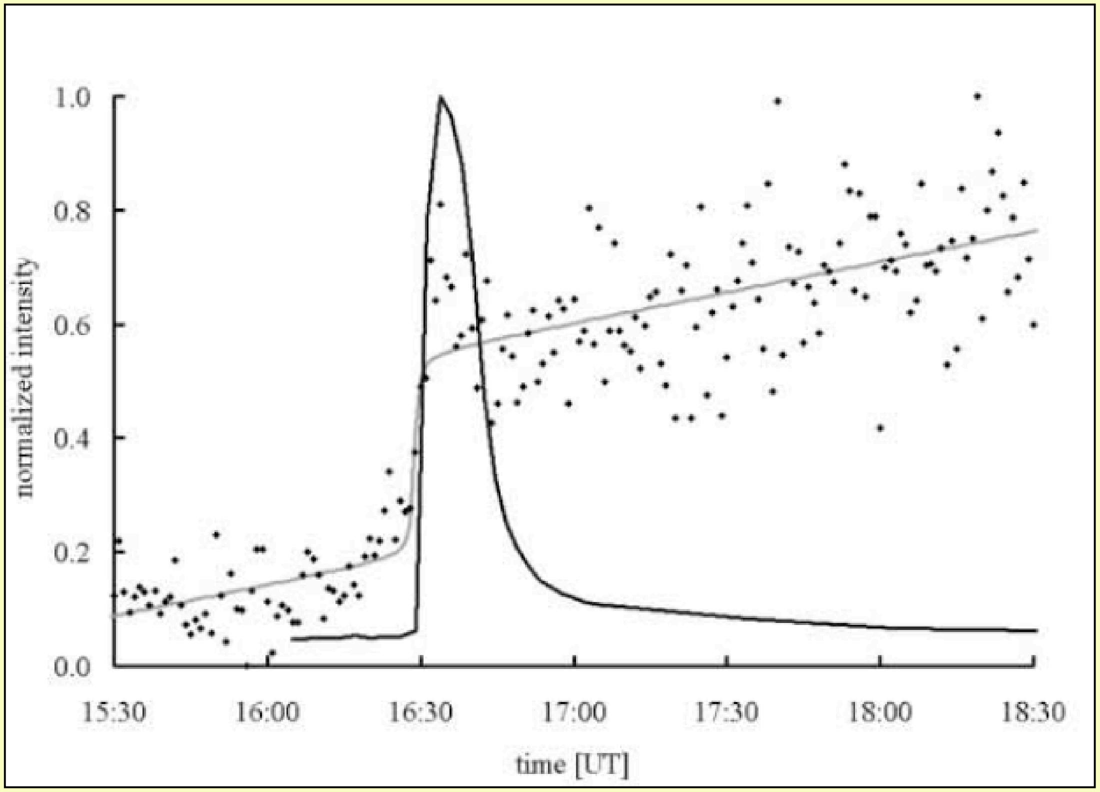
Possible mechanisms for electron acceleration

- Parallel fields in inertial Alfven-wave energy transport
- Fermi acceleration between wave front and chromospheric field
- Turbulent cascade development in reflected/mode-converted waves

Thesis

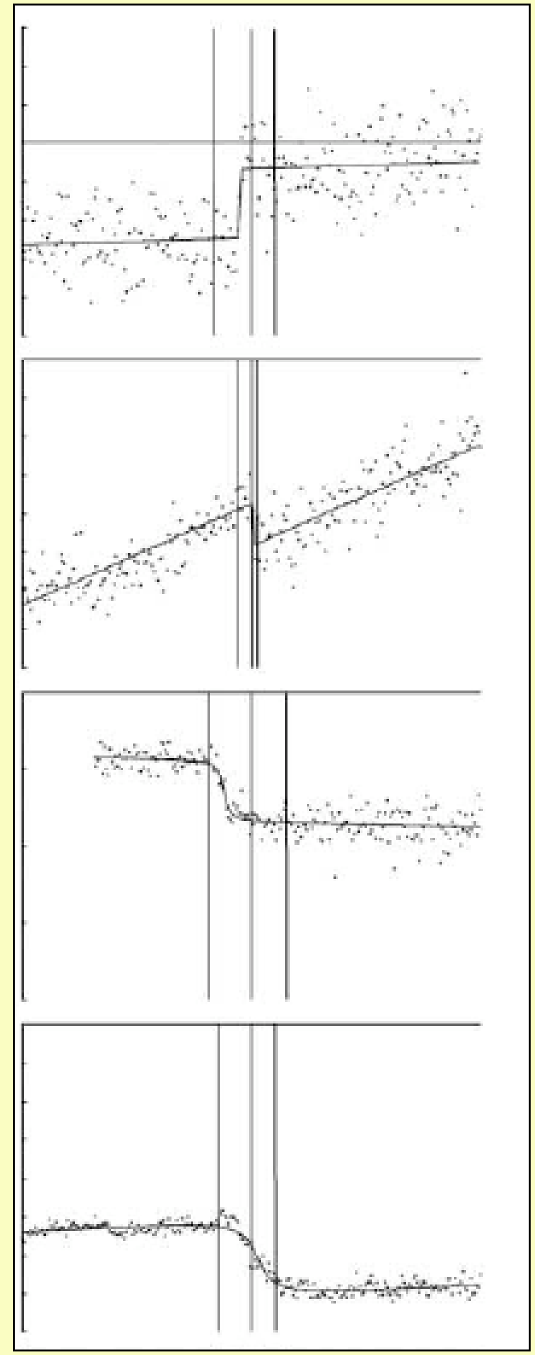
- The chromosphere/transition region acts to map solar convective motions to the almost stable corona
- The interesting physics involves kinetic plasma effects that allow the magnetic field to link the stable and unstable regions
- It is time for renewed study of this interface layer with high-resolution spectroscopy and polarization in the IR, visible, and XUV bands
- To understand the plasma physics we must depend heavily upon computational tools, ie large-scale numerical simulations

The end, thanks



Flare of 2001 Aug. 25
GONG + TRACE 1600A

Figure 2. *Flare-related photospheric field changes. They are stepwise, of order 10% of the line-of-sight field, and primarily occur at the impulsive phase of the flare (Sudol & Harvey 2005)*



Other examples, with GOES times

Spare slides…

Wave propagation time

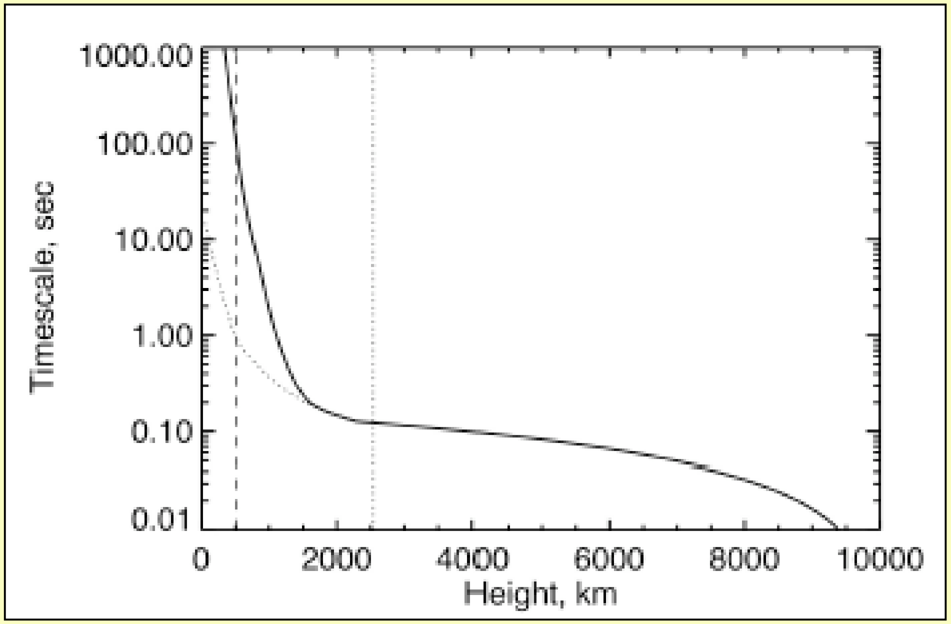


Figure 4. *The time required for wave propagation from a given height through a hydrostatic coronal model grafted onto VAL-C. Dotted line marks the VAL-C transition region, dashed line the temperature minimum.*