Flare energy and fast electrons via Alfvén waves

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Motivations for this work

I Difficulties with the electron beam for energy transport

- Return current physics
- Number problem
- Self-field and stability issues
- Lack of evidence for directivity/albedo

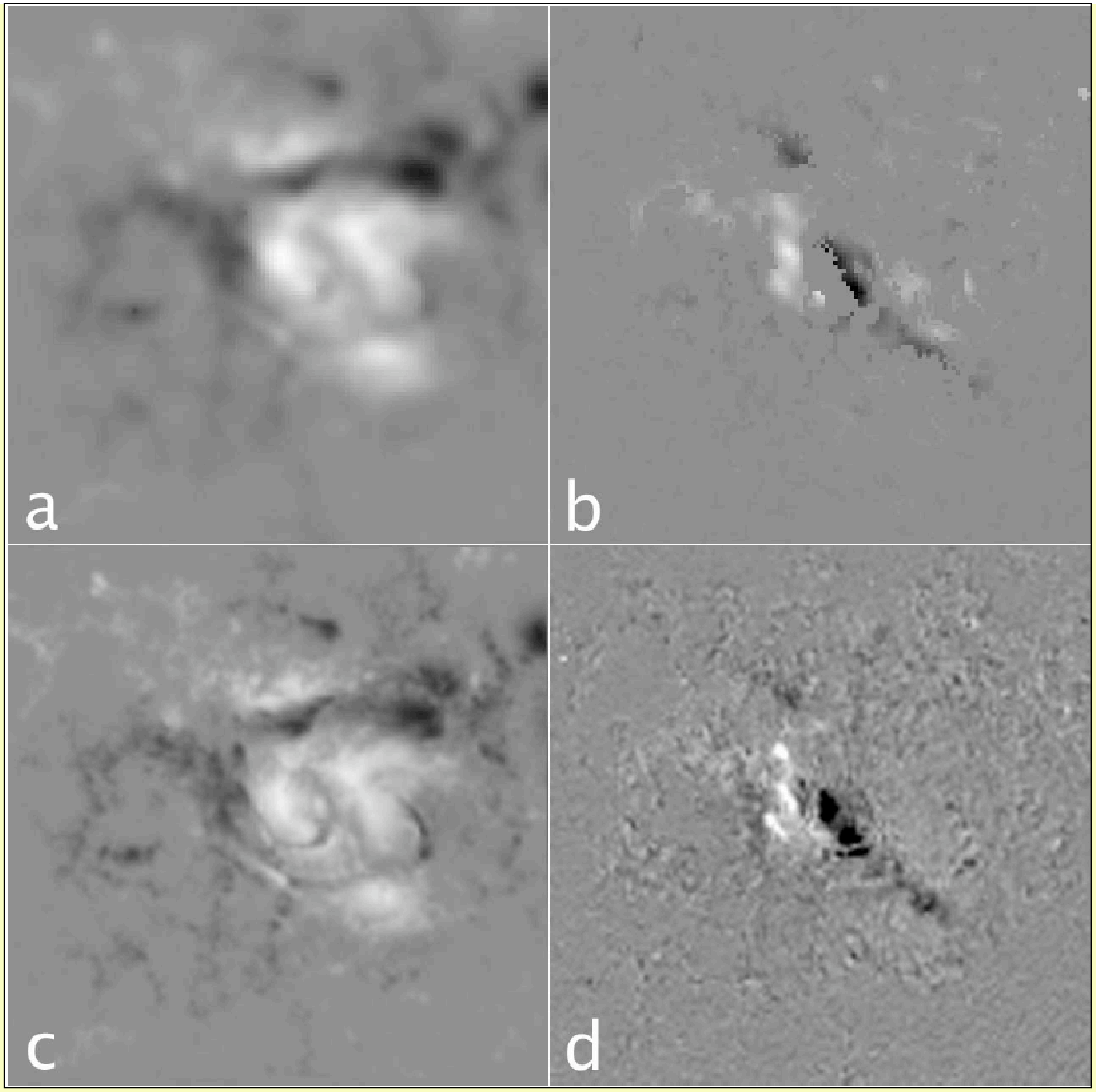
II Observation of large-scale field deformations at the photosphere

- Wang and others; Sudol-Harvey 2005
- Magnetic reconnection as a source of large-scale waves

Demise of the thick-target model?

- Footpoint spatial scales have become very small and make extreme requirements of energy transport by a beam:

  - unstable particle distribution functions
  - strong self-field (inductive) effects
  - the "number problem"
- The "dentist's mirror" of albedo shows no significant X-ray directivity (Kontar & Brown, 2006)
- The occurrence distribution of >100 keV events shows no significant directivity (Datlowe et al. 1974; Kasparova et al. 2007)



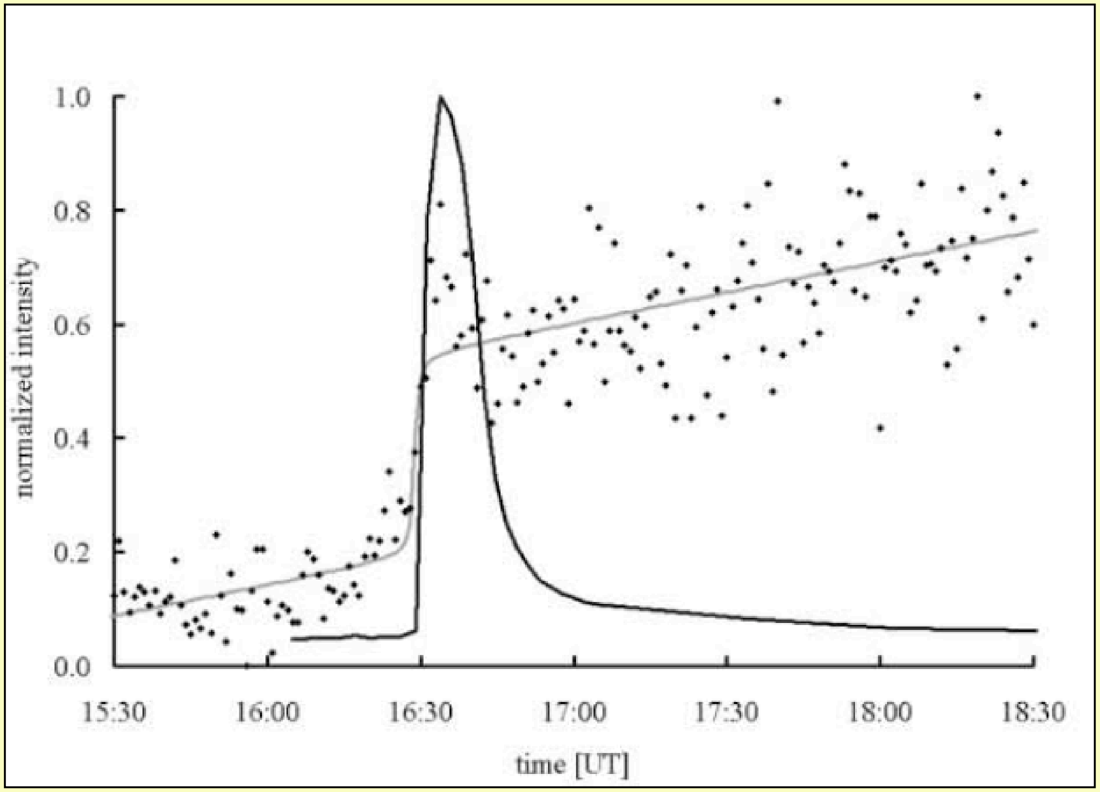
GONG

SOHO/MDI

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

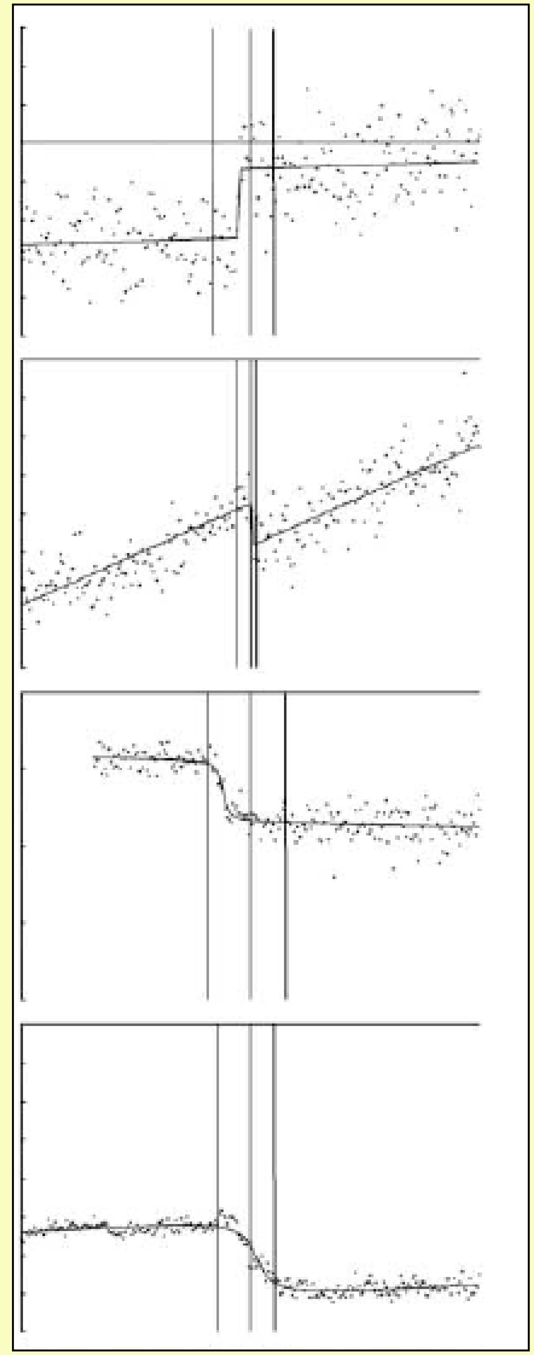
$\delta\mathbf{B}_{LOS}$ Maps

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



Flare of 2001 Aug. 25
GONG + TRACE 1600A

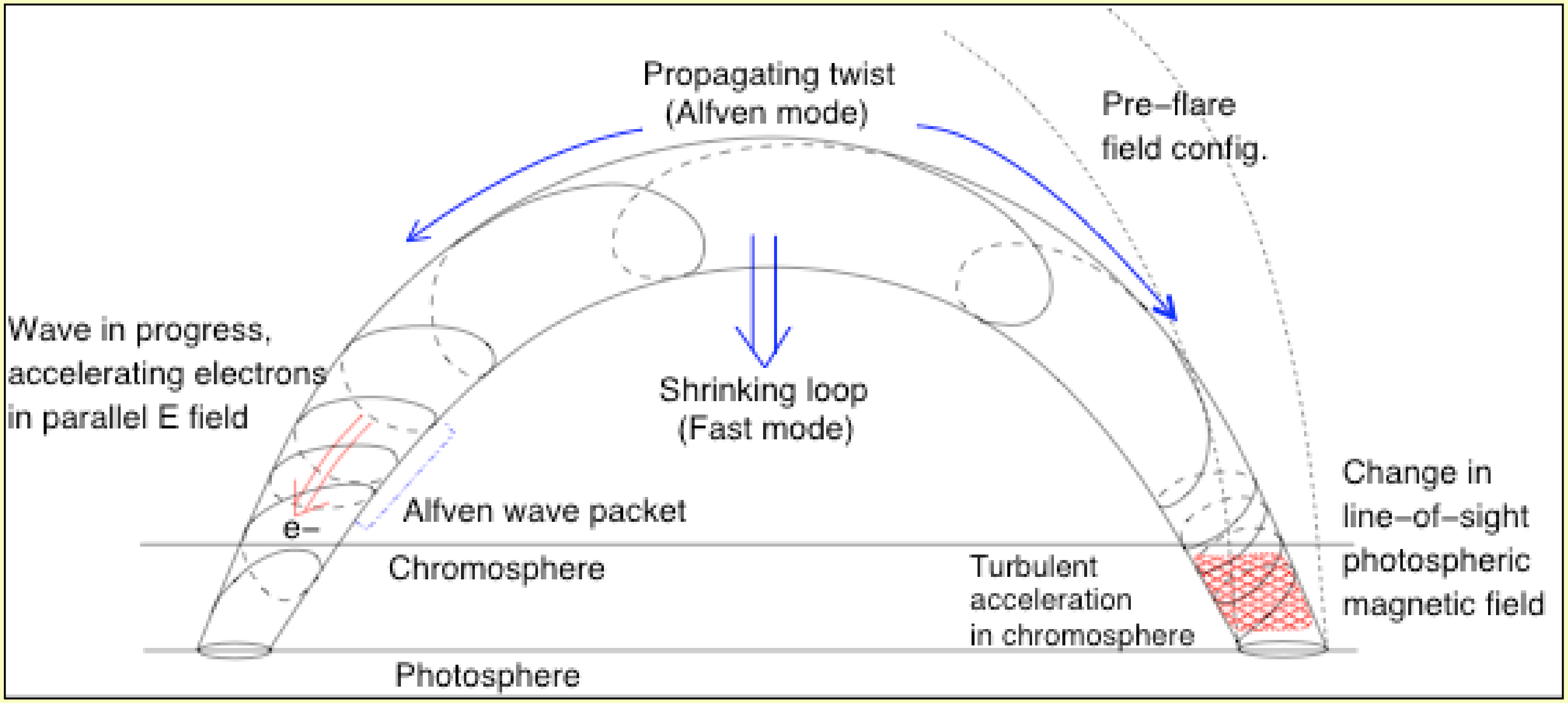
Figure 2. *Flare-related photospheric field changes. They are stepwise, of order 10% of the line-of-sight field, and primarily occur at the impulsive phase of the flare (Sudol & Harvey 2005)*



Other examples, with GOES times

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



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High Alfvén speeds

- The literature often underestimates active-region field strengths and Alfvén speeds; $v_A \sim 0.1c$ must be considered likely (500 G, 10^9 cm^{-3}) at h = 10^9 cm
- The "magnetic scale height" in an AR is of order 10^9 cm (Brosius & White, 2006)
- Wave propagation times are short enough for conjugacy
- The condition $\beta < m_e/m_p$ is also certainly possible, hence "inertial" Alfvén waves

Wave propagation time

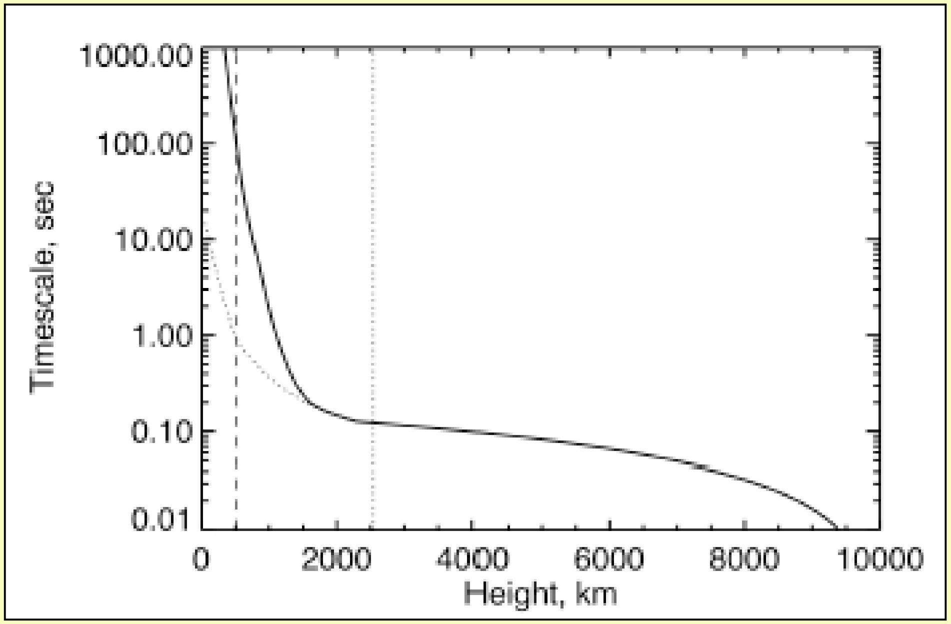

Figure 4. *The time required for wave propagation from a given height through a hydrostatic coronal model grafted onto VAL-C. Dotted line marks the VAL-C transition region, dashed line the temperature minimum.*

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

What is an inertial Alfvén wave?

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

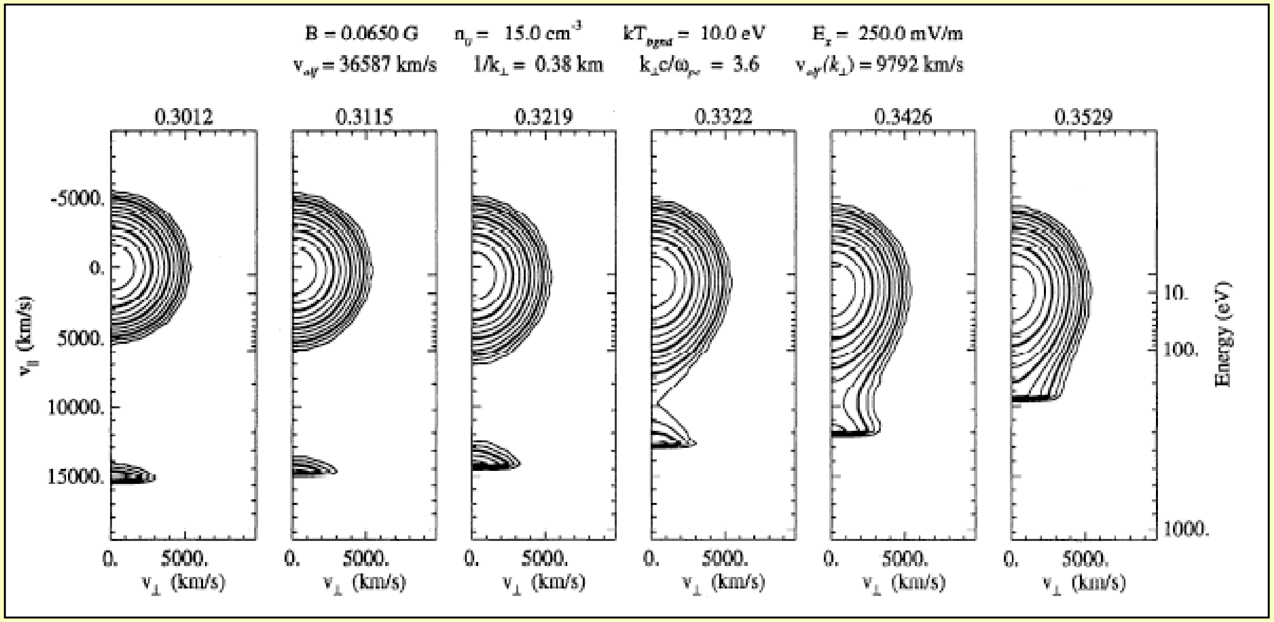

Figure 5. *Simulations of electron distribution function(Kletzing, 1994) evolving with time as the wave passes a fixed point*

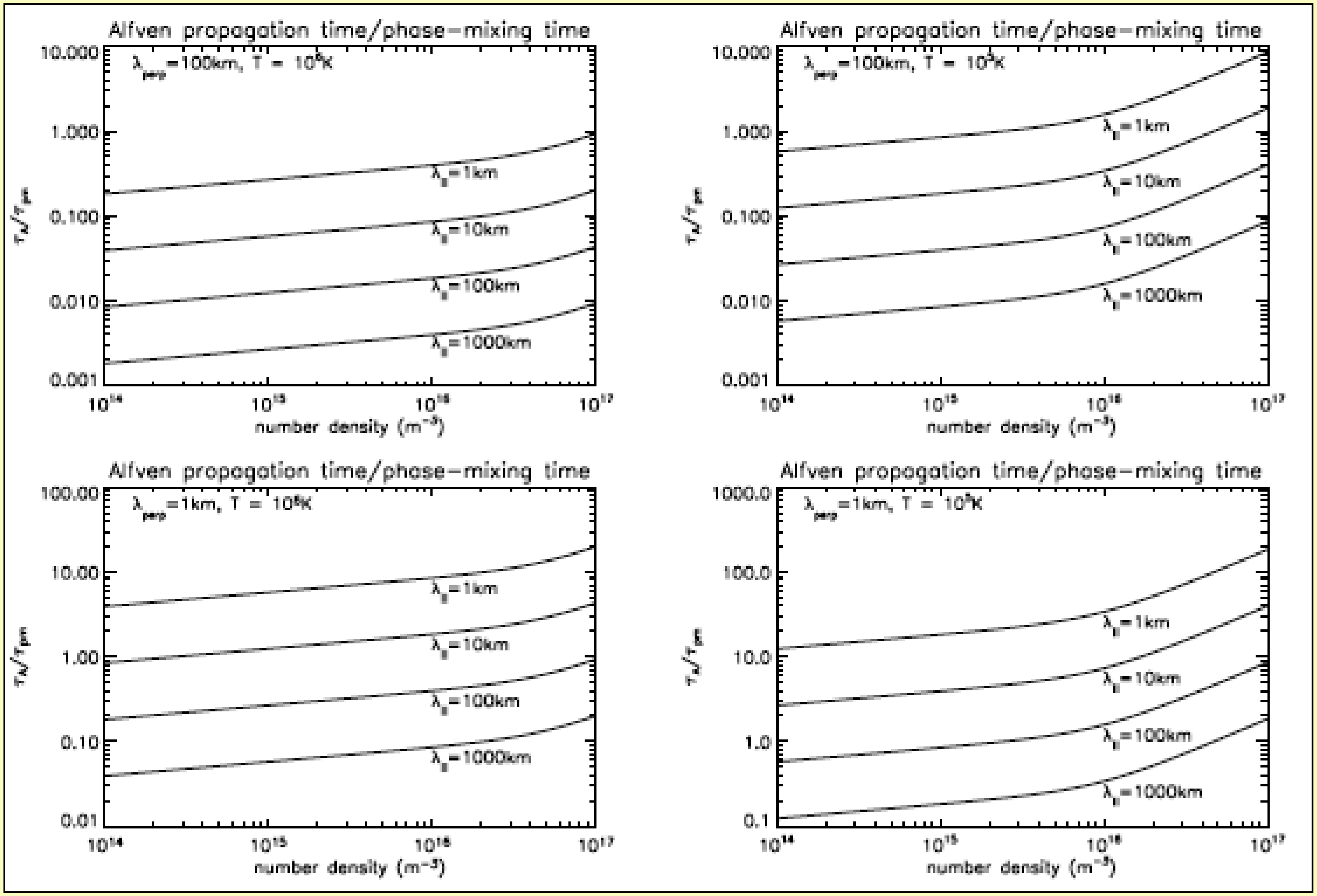

Figure 6. *Ratio of propagation time to phase-mixing time, for various combinations of horizontal wavelength and field strength.*

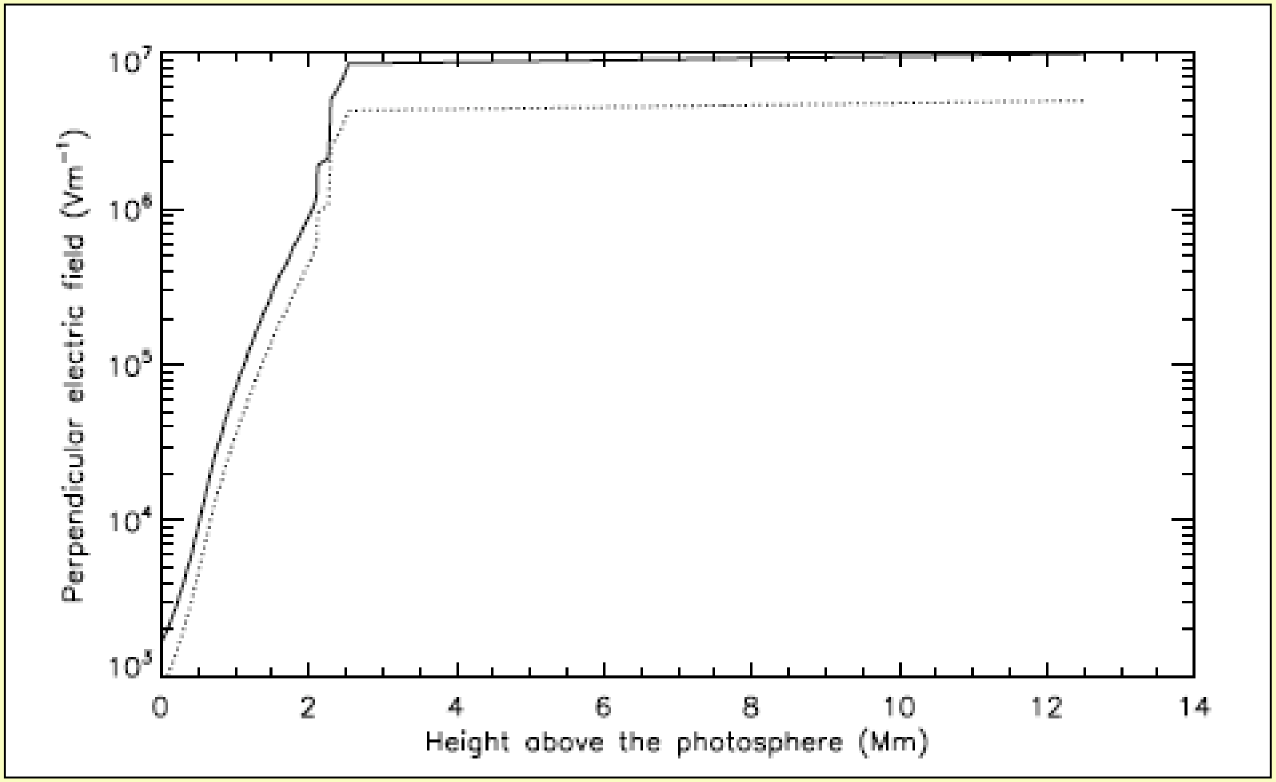

Figure 7. *Perpendicular electric field of wave.*

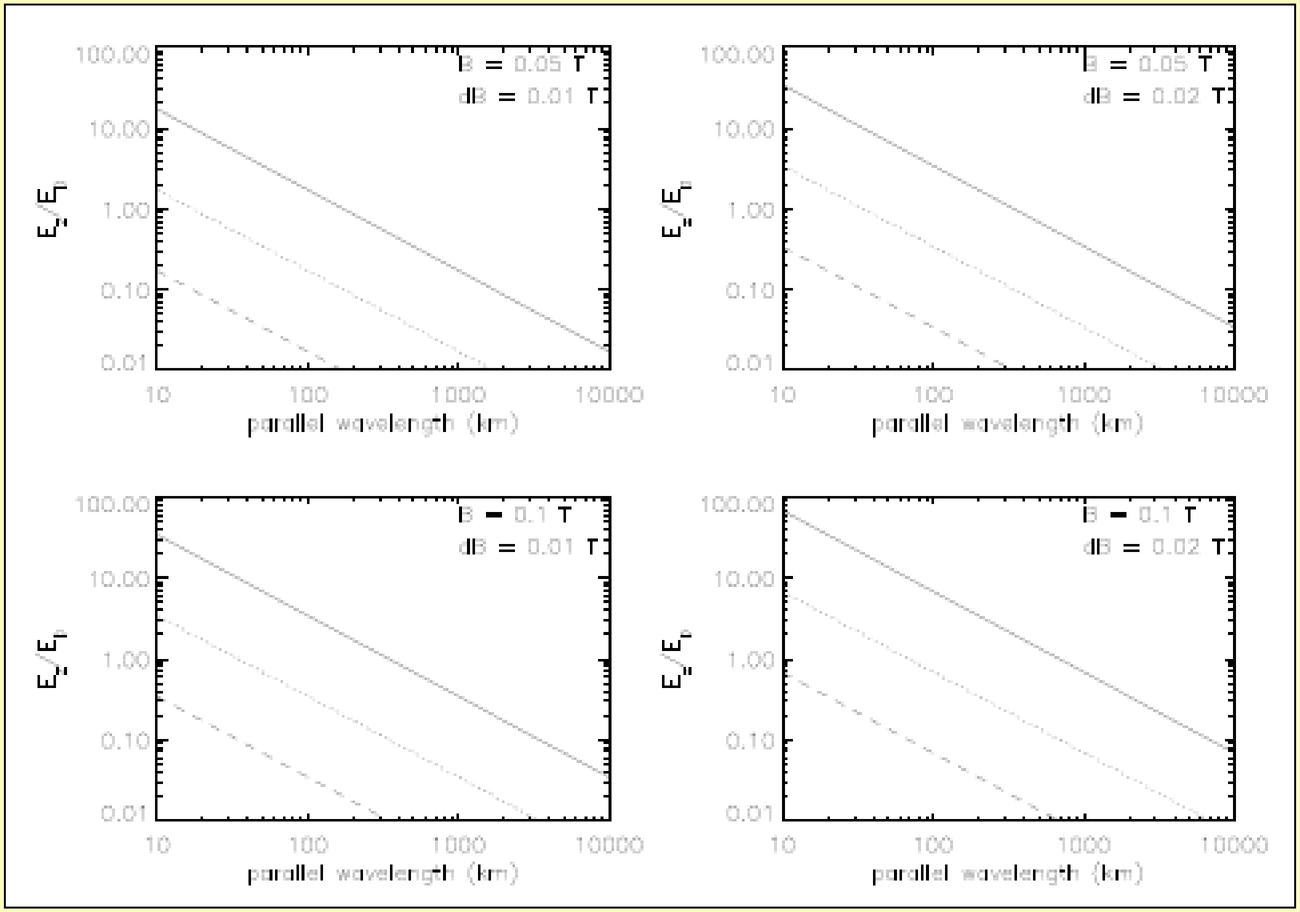

Figure 8. *Ratio of parallel field to Dreicer field for perpendicular wavelenths 0.5, 5, 5 km for density 10^9 cm^{-3} and temperature 10^6 K.*

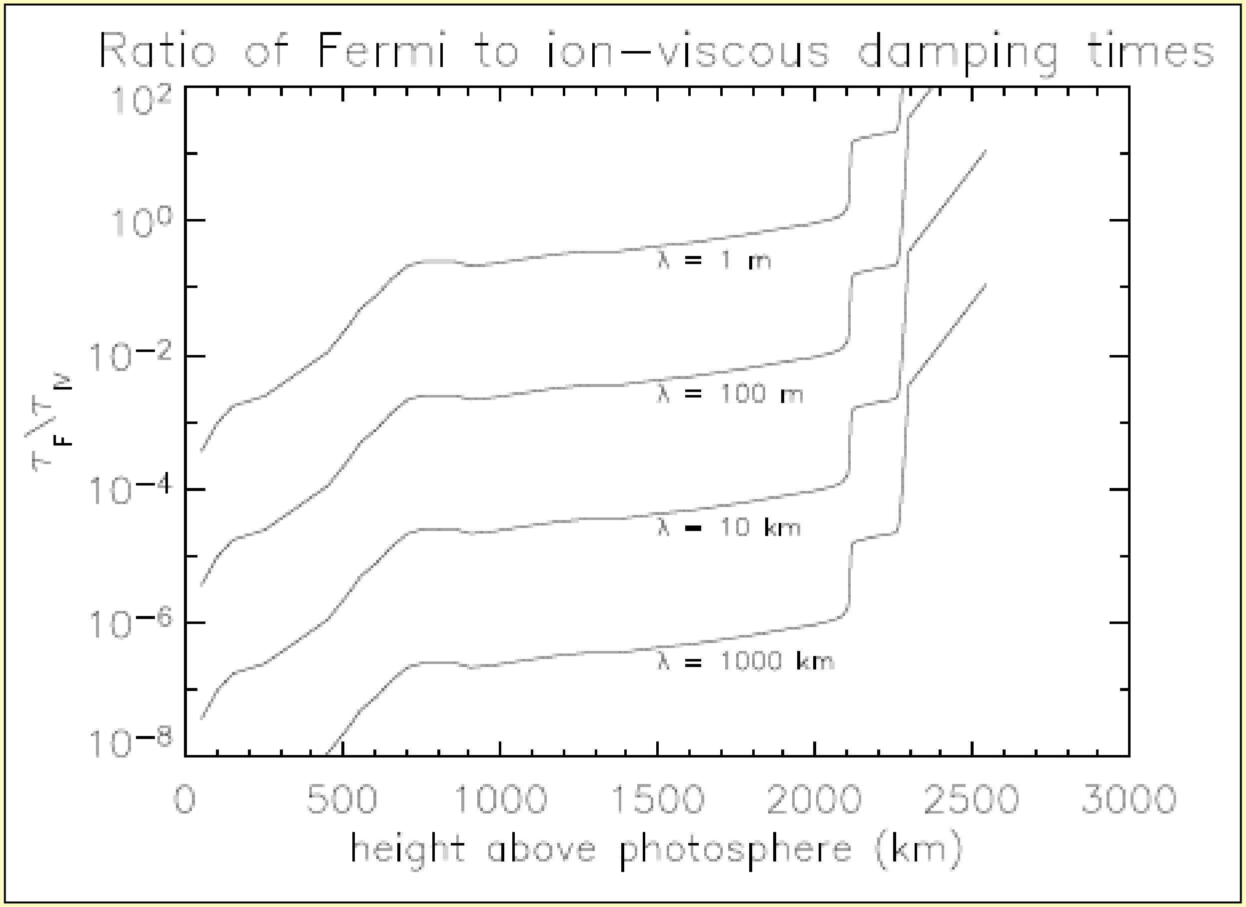

Figure 9. *Ratio of Fermi to ion-viscosity damping times in the chromosphere. It is greater than unity in the corona.*

Unknowns in the new scenario

- The partition of flare energy release into Alfvén mode and fast mode is unknown
- The fast-mode energy probably is lost to the system, but there is no consensus on the damping mechanism and no clear observations in the impulsive phase
- There are mechanisms for diffuse electron acceleration, but again no consensus in the literature
- The time-of-flight analysis of Aschwanden et al. may be in conflict with this mechanism

Conclusions

- We propose a variant of the standard thick-target model for energy transport in the impulsive phase: large-scale Alfvén waves
- Efficient and prompt energy transport requires a high Alfvén speed in the low corona, which we find appropriate
- There are several possible avenues for electron acceleration and we do not have a full theory