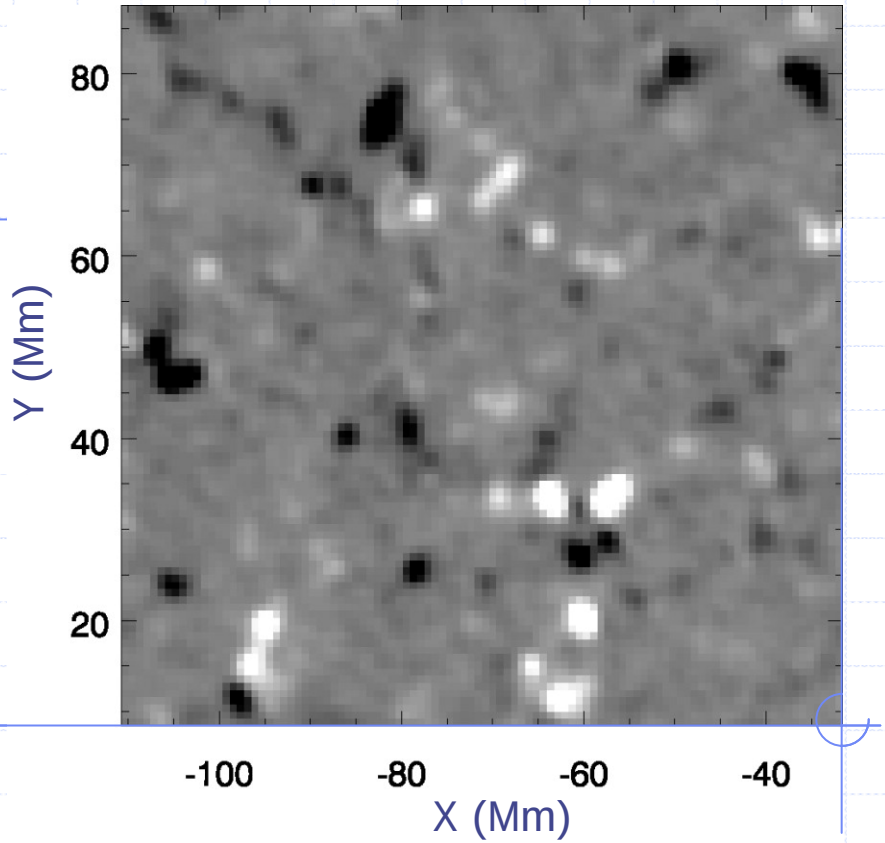
Small-scale magnetic activity

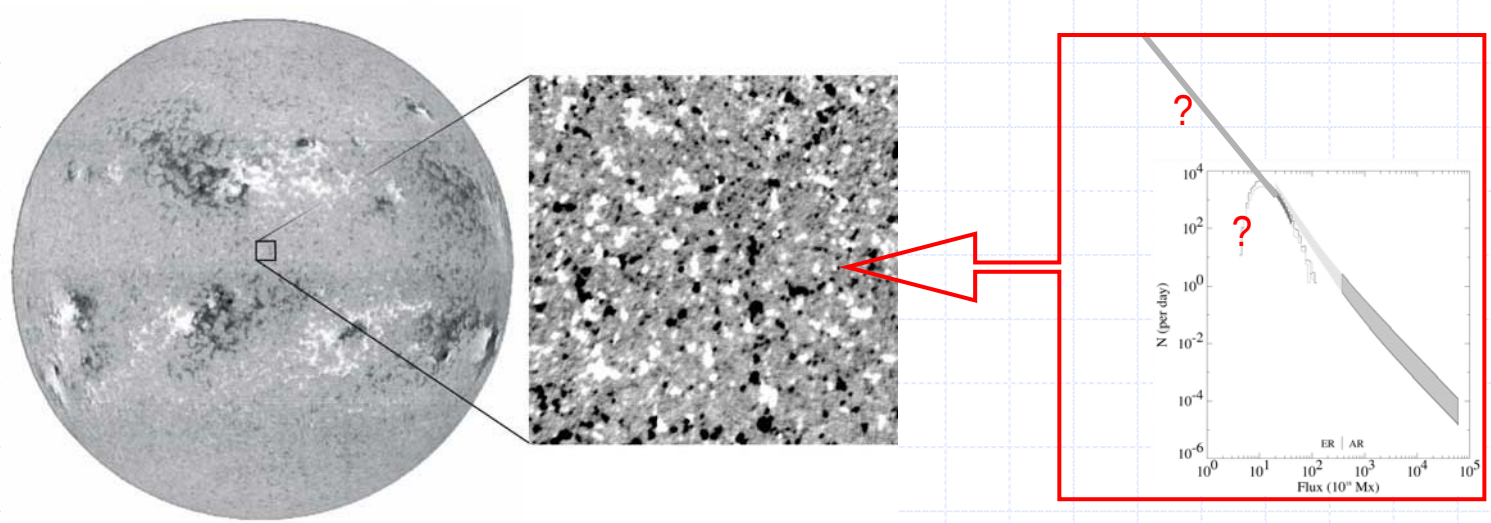
Karel Schrijver

Lockheed Martin
Advanced Technology Center
Palo Alto, CA



The magnetic carpet

- The magnetic carpet is the evolving, multi-scale magnetic field in a stellar atmosphere that results from the continual emergence, displacement, and eventual disappearance of magnetic bipolar regions ranging from the (sub?)granular scale to the largest active regions.
- More restrictive definitions:
  - ... the atmospheric field geometry over quiet Sun
  - ... the mixed-polarity network field in the solar photosphere

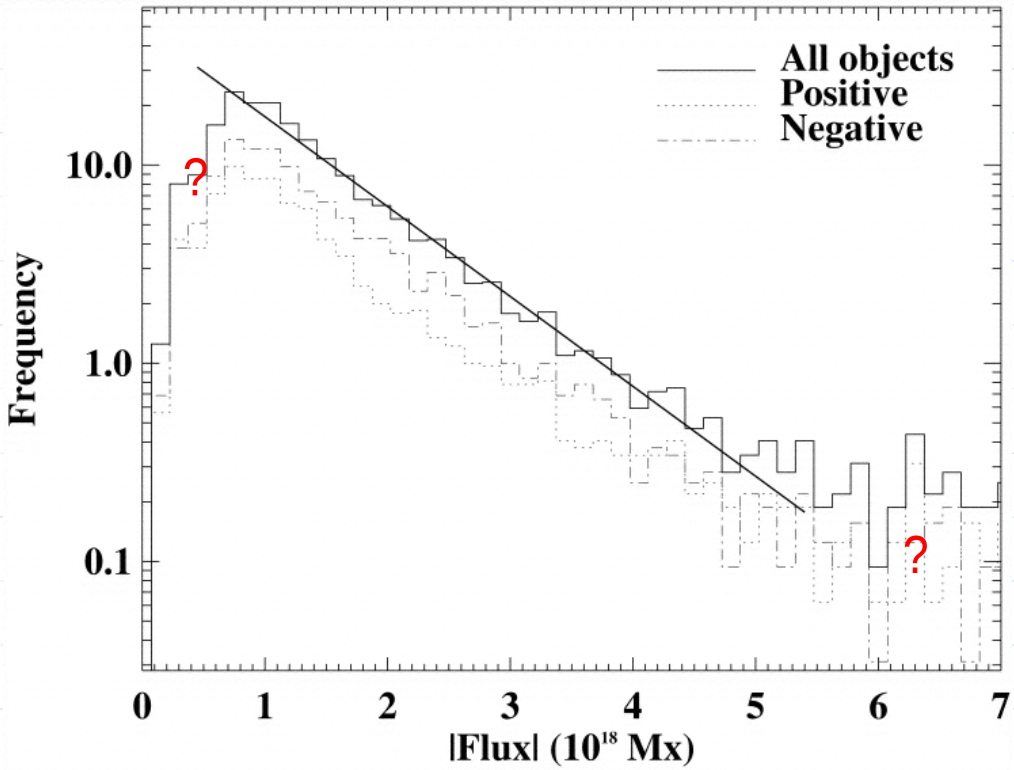


Observations of small-scale activity

- Ubiquitous mixed-polarity “magnetic carpet”
- Part of quiet-Sun flux has dispersed from decaying active regions, but most of it emerges (and retracts) locally
- All of the quiet-Sun flux is continually replaced by newly emerging bipolar regions (ephemeral regions and smaller); only patterns in the surface field survive for months or years→
- The ephemeral-region population
  - leads the new sunspot cycle by 1-2 yr;
  - shows a weak preference for proper orientation;
  - is a continuation of the active-region spectrum.→
- Small, ephemeral regions (~10^{19} – 10^{20} Mx) in anti-phase with the sunspot cycle, but with much reduced amplitude (x1.5 vs. x8).→
- : Solar magnetic activity occurs on a continuum of scales, extending down to the resolution limit; its properties change smoothly with flux

Magneto-chemistry of quiet network

- Collisions and fragmentations lead to a quasi-exponential distribution of fluxes in very quiet solar regions;
- the source-flux spectrum is of little importance;
- fragmentation rates, collision cross sections, and the net flux density together determine the shape of the flux spectrum.

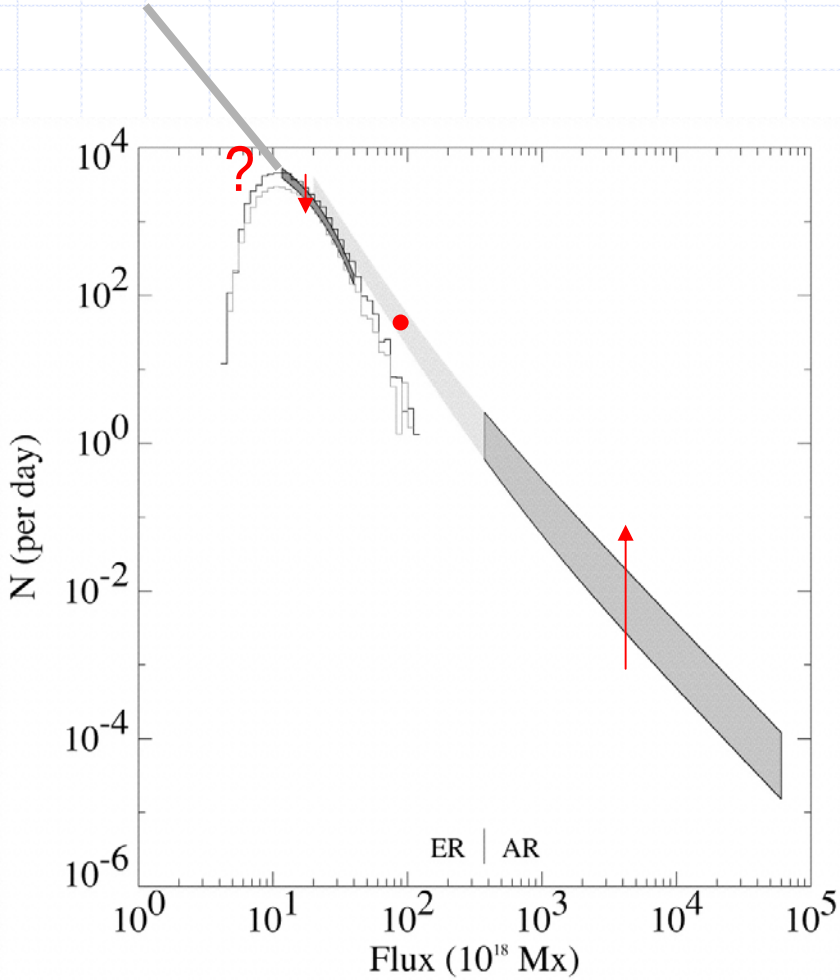


Schrijver et al. (1997)

Bipole spectrum and cycle variation

- Anti-phase variation at opposite ends of the flux spectrum
- Ephemeral regions and chance flux encounters form X-ray bright points (XBPs)
- XBP population shows no significant cycle dependence.

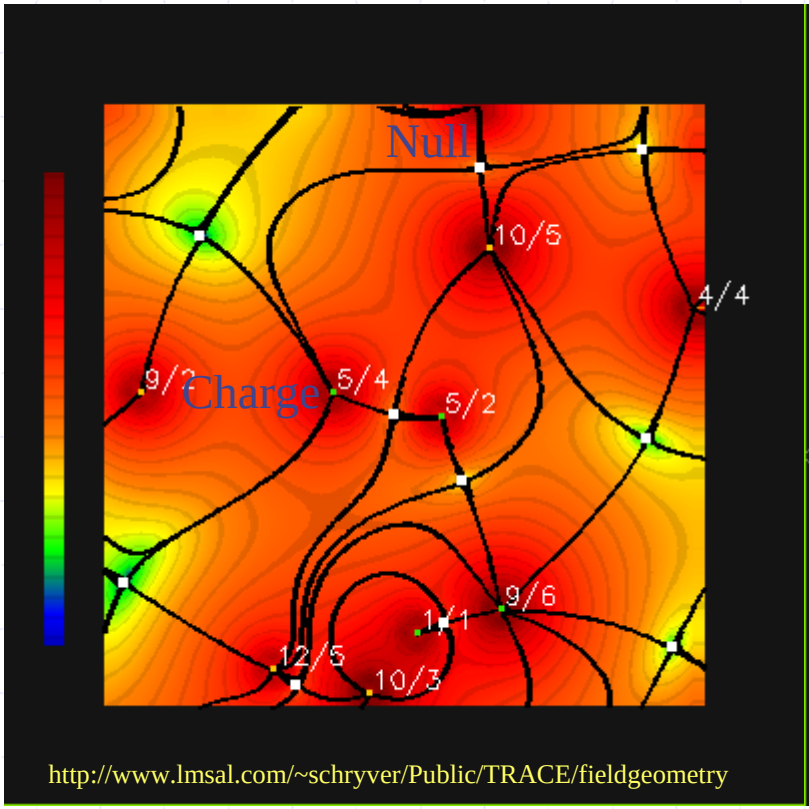
Hara & Nakakubo-Morimoto (2003)



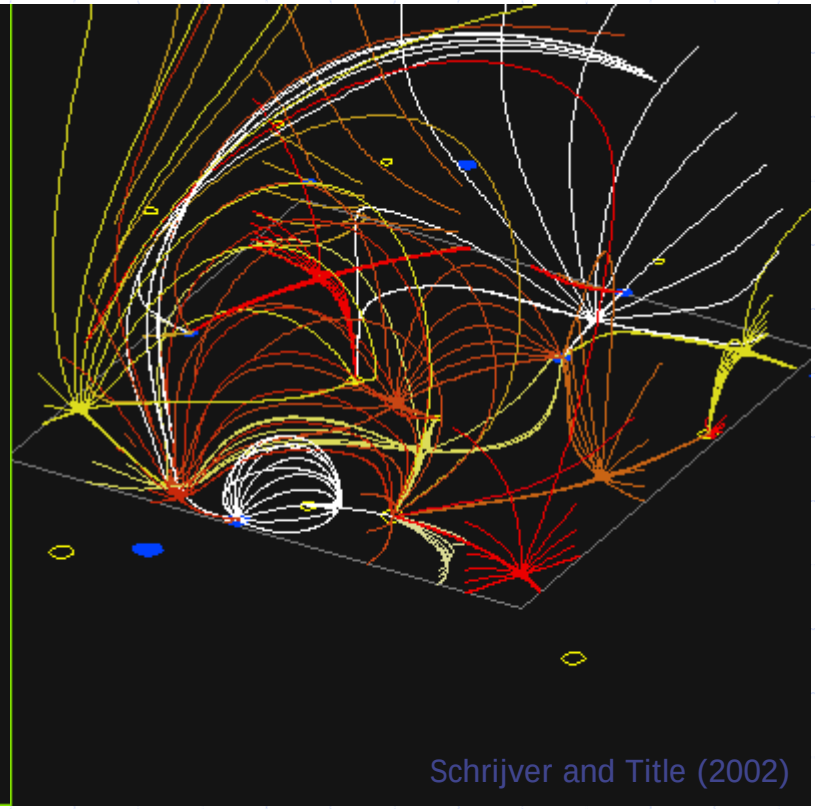
Hagenaar et al. (2003)

Quiet-Sun corona

- Potential-field of mixed-polarity pattern reveals a multitude of connections:



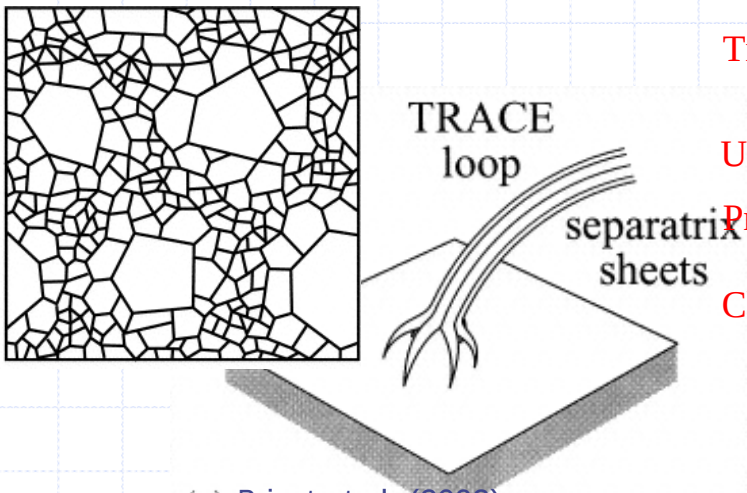
http://www.lmsal.com/~schryver/Public/TRACE/fieldgeometry



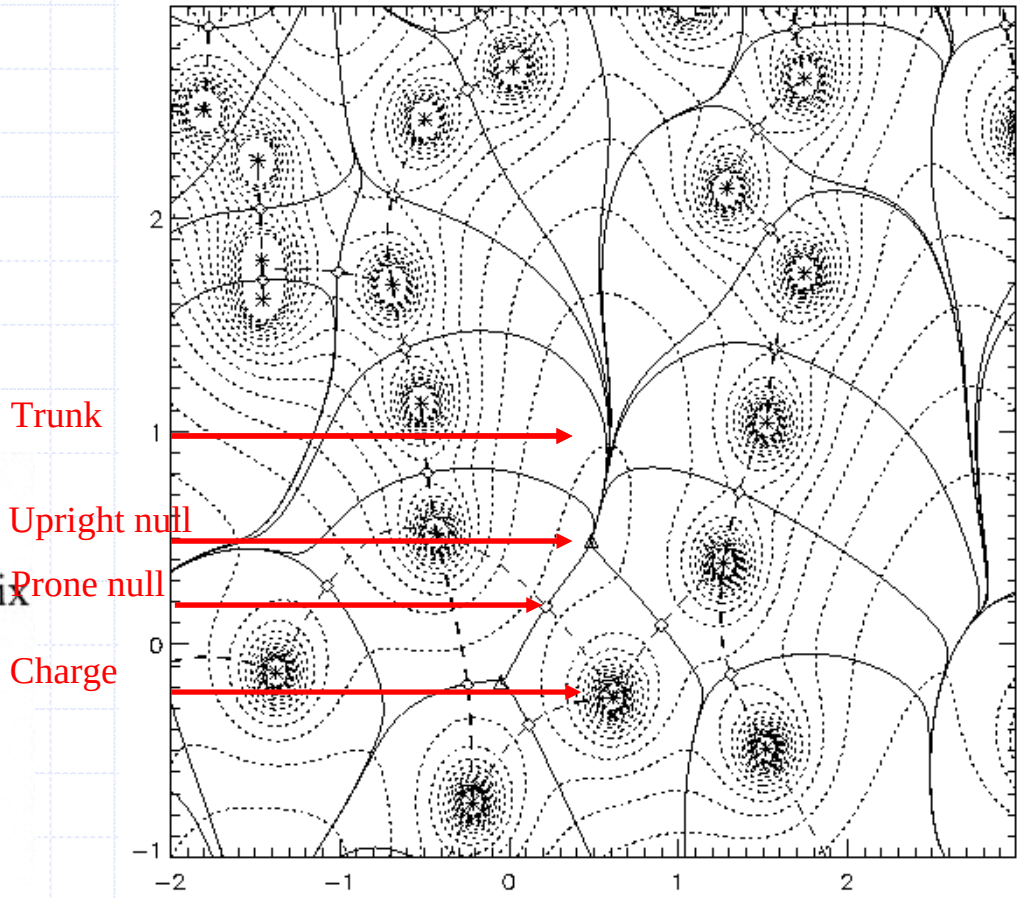
Schrijver and Title (2002)

Coronal-loop tectonics

- Flux tubes in a mixed-polarity environment may be connected to dozens of sources?



(a) Priest et al. (2002)



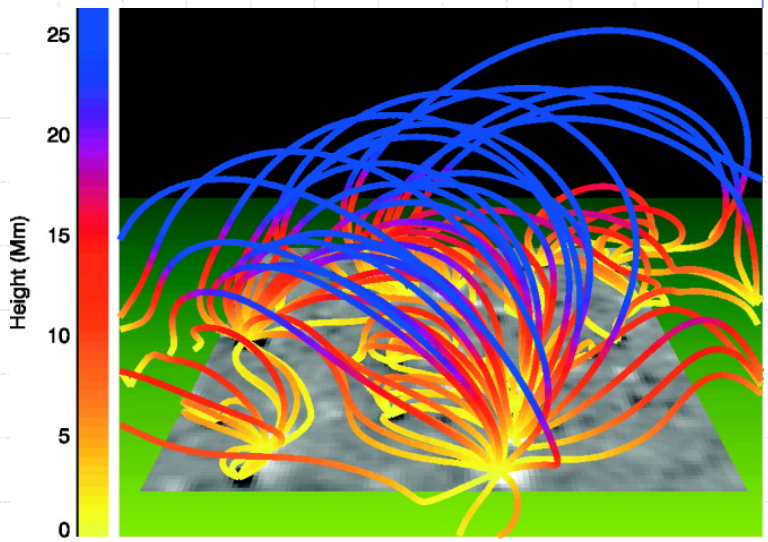
Beveridge et al. (2003)

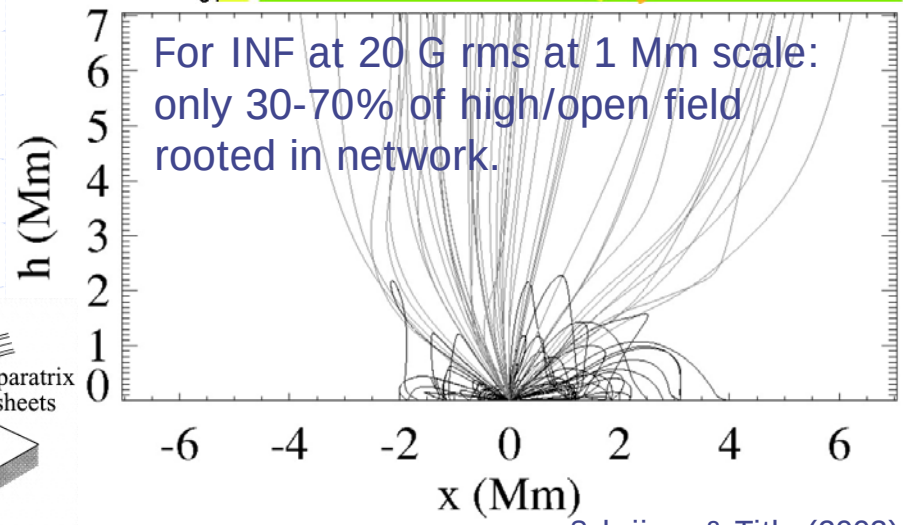
What is the “weak intranetwork field”?

- “Weak field” away from the network discovered in the mid 70s *(Livingston and Harvey [1975], Smithson [1975])*
- “Canopy” concept to separate “non-magnetic” from “magnetic” introduced in late 70’s *(Gabriel, 1976, Giovannelli [1980], Giovannelli and Jones [1982])*
- Maybe “weak field,” but lots of flux: ~5 - 50 Mx/cm^2 , ave. ~20 Mx/cm^2 *(Stenflo et al. [1998], Lin and Rimmele [1999], Faurobert et al. [2001], Domínguez Cerdeña et al. [2003], Sánchez Almeida et al. [2003]),*
- Maybe not weak, but merely small: $10^{16\text{-}18}$ Mx compared to $10^{18\text{-}20}$ Mx? *(Domínguez Cerdeña et al. [2003], Sánchez Almeida et al. [2003]),*
- *Average unsigned flux density may be as high as 100-200 Mx/cm^2 in the downflow lanes(Trujillo-bueno et al. [2004])*

Photosphere – corona connections

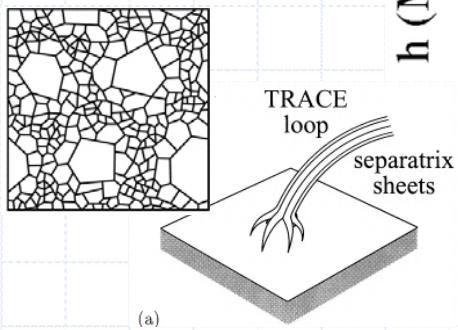
- Complex, evolving connections
  - flux life time of 0.5-5.0 days (quiet to enhanced network) to 5-10 min. (intra-network);
  - connectivity life time of hours (network [Close et al., 2004]) to likely less than 1 min. (INF);
  - often inclined field;
  - without traditional canopy; only a partial canopy exists (in β and in geometry), with extent depending on net flux density..





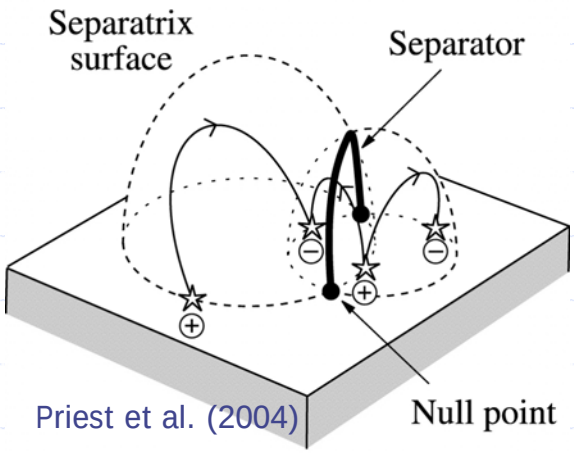
For INF at 20 G rms at 1 Mm scale: only 30-70% of high/open field rooted in network.

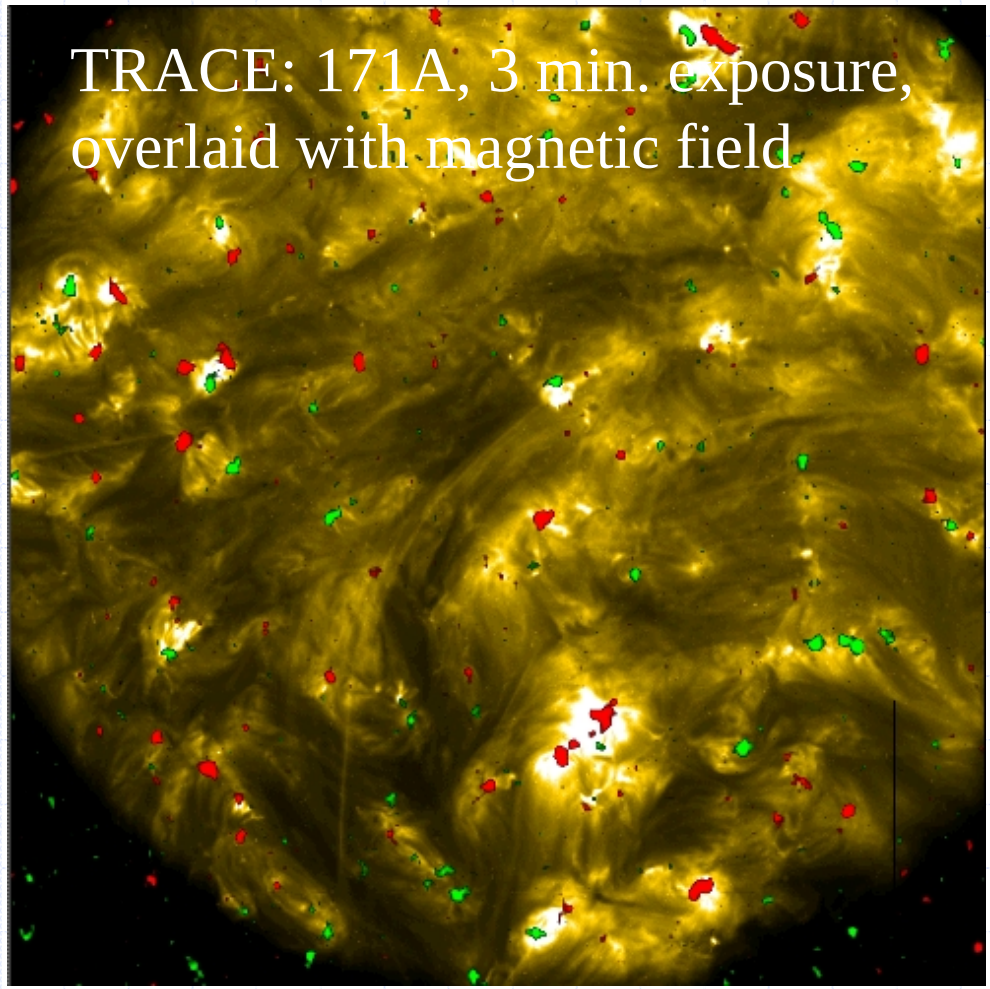
Schrijver & Title (2003)



Nulls and atmospheric heating

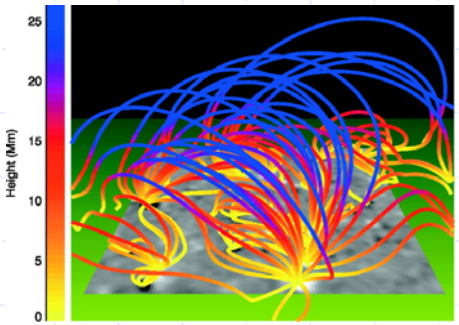
- Compact coronal brightenings only occur over flux concentrations, or between compact pairs *(diverging or converging)*: no obvious support for a dominant role of heating at “macro-field” nulls.

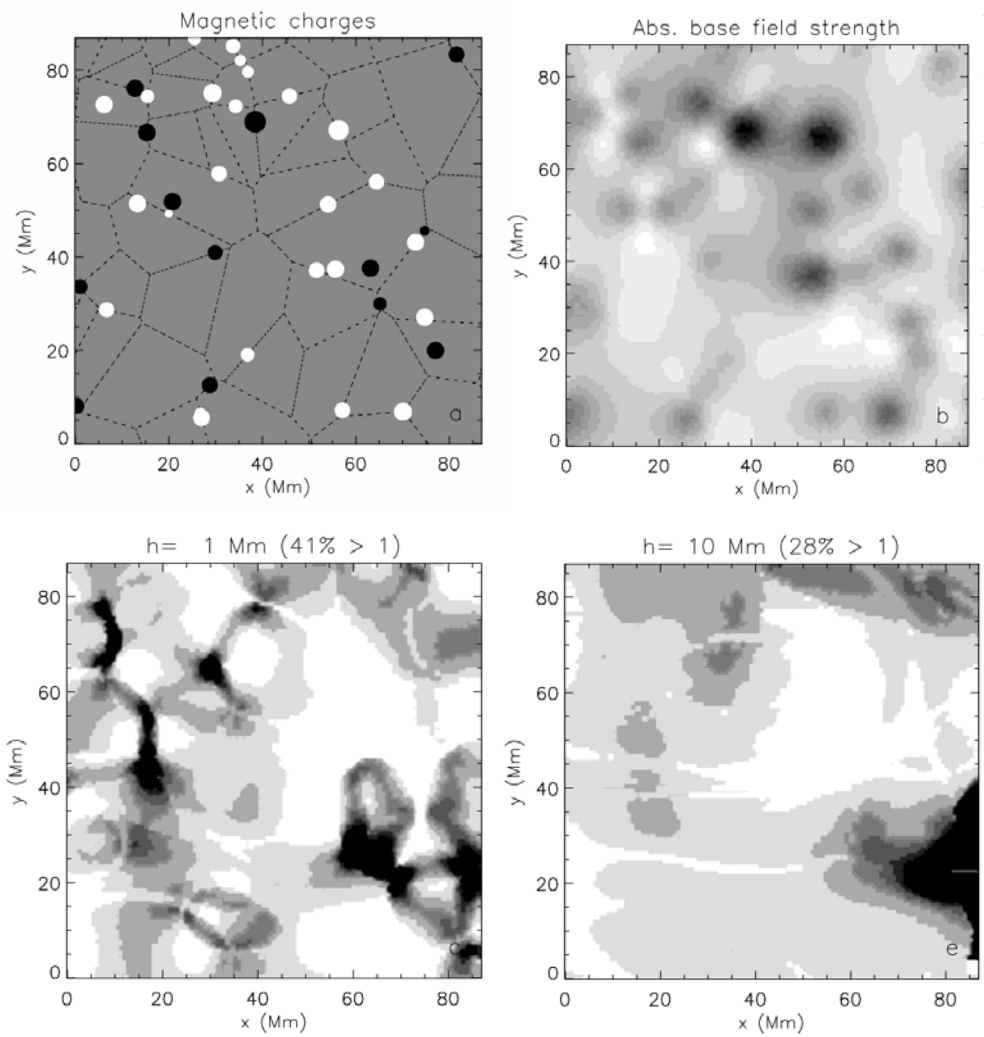




Field vs. plasma

- QS and AR coronal heating: P= 8×10^{14} B/L. Compatibility suggests same mechanism.
- The corona over the *quietest Sun* is *not force free:*
- 30% of the quietest-Sun corona has $\beta \geq 1$, 90% has $\beta \geq 0.4$
- Lower β at wind base where net flux density is higher.

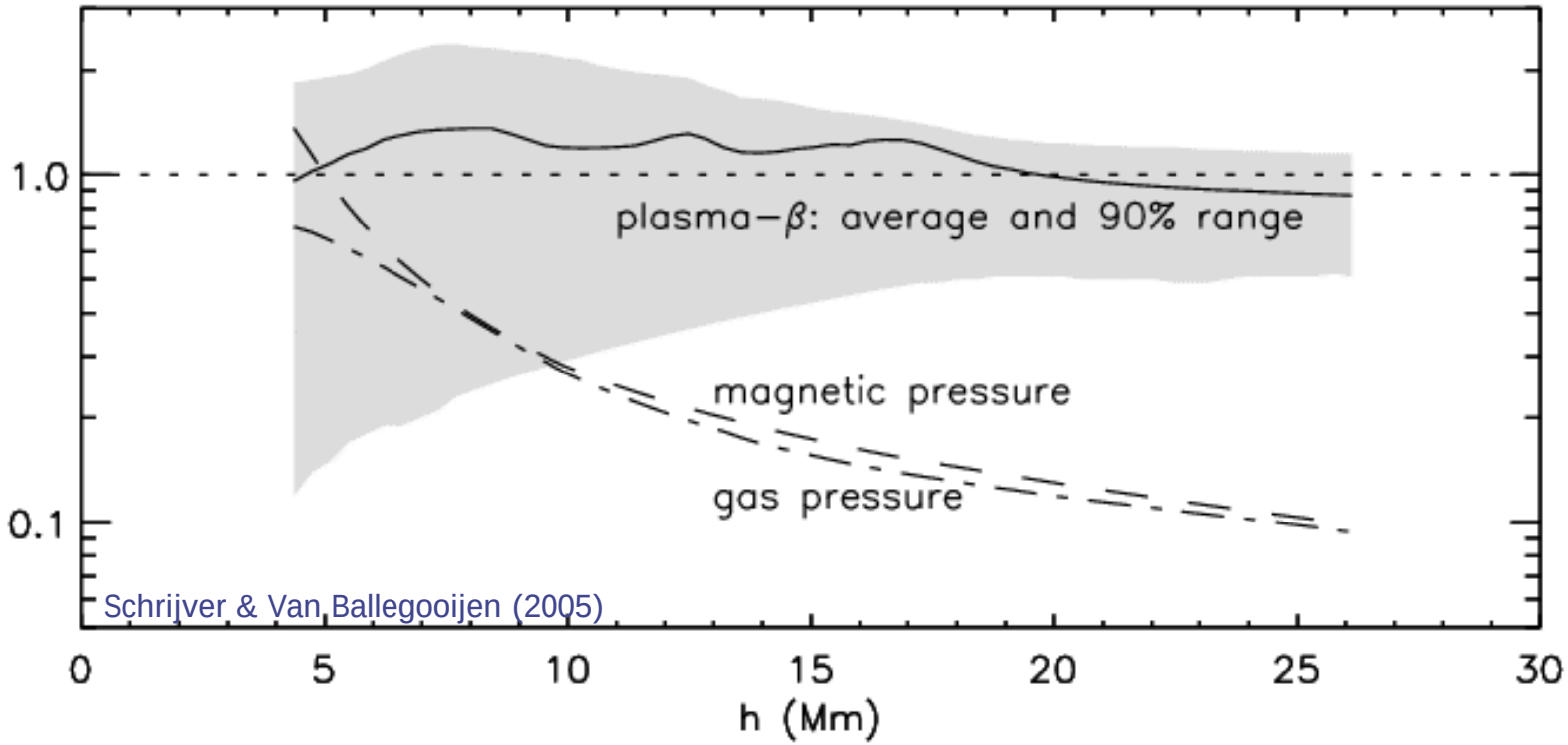




gray: $\beta \geq 0.5$

Field vs. plasma

- Characteristic plasma β is unity throughout the quietest coronal emission region (zero net flux).



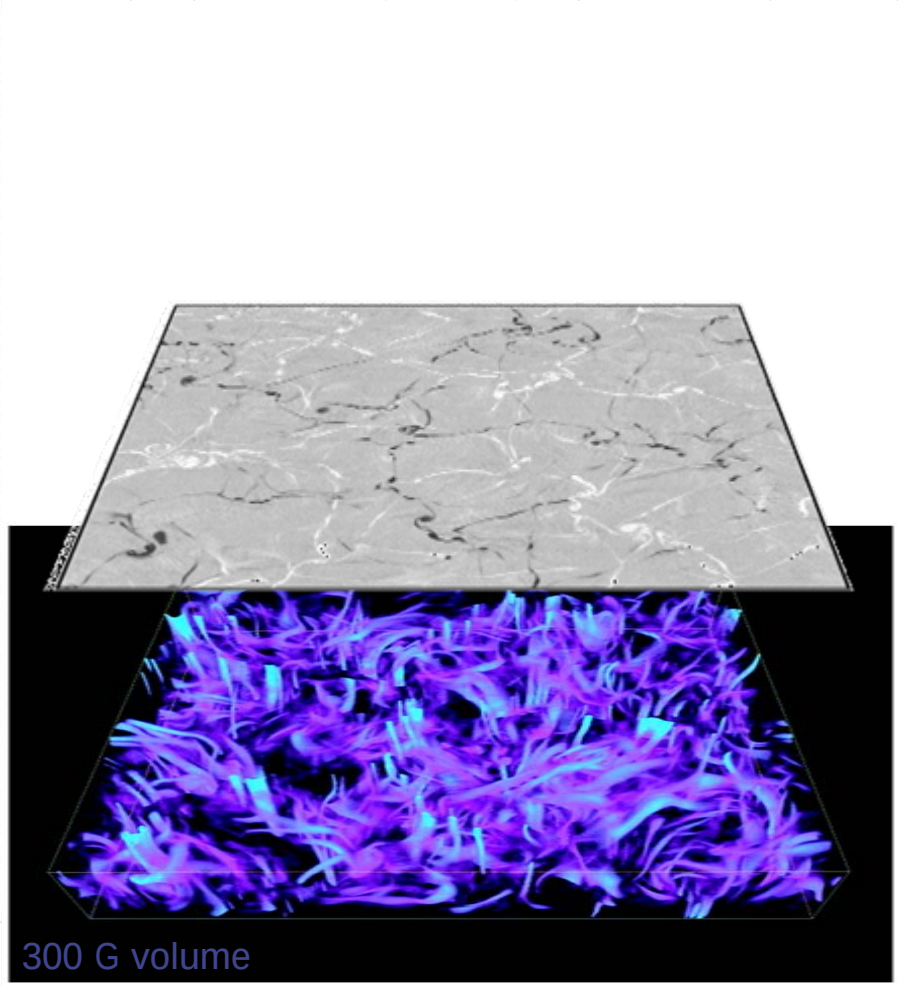
Sound and the small-scale dynamo

- If the basal chromosphere is not heated acoustically, there must be a small-scale, near-surface dynamo:

A key differentiating study: Fossum and Carlsson, 2005, Nature	A: insufficient acoustic power for basal atmosphere	B: acoustically heated basal chromosphere
1: large-scale dynamo only; the intranetwork field is composed of decayed flux concentrations from Ers/ARs	F&C: incompatible with stellar basal emissions; & Small ephemeral regions in anti-phase with spot cycle *Falsify: is the lower chromosphere acoustically heated?*	Ephemeral regions weakly in anti-phase with spot cycle; incompatible with decay concept of intranetwork flux through that as intermediate stage.
2: multi-scale dynamo, including near-surface small-scale dynamo	Possible: **if** small-scale dynamo **near** saturation *Falsify: intranetwork field cycle dependence* *Problem: Acoustic power generation models*	**Occam's favorite,** but appears incompatible with Fossum & Carlsson *Falsify: is the lower chromosphere magnetically heated?*

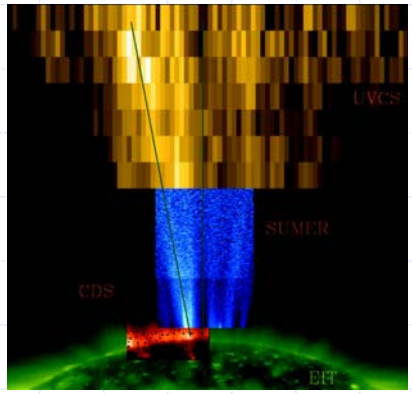
Origin of the (intra-)network carpet

- Dynamo range of magneto-convection: $E_B/E_k \sim 0.20$ (Boussinesq)
- Mixed-polarities
- Cycle coupling unclear
- Emergence details?
- Field strengths: up to kilogauss (value ranges seen in observations and simulations are converging)

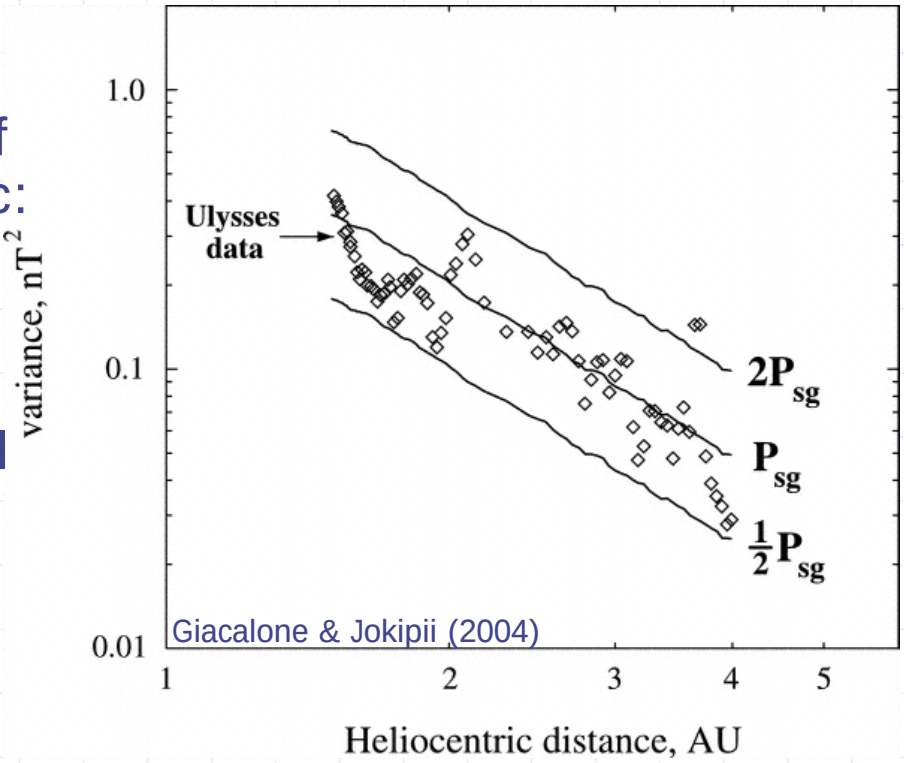


Cattaneo et al. (2004)

Heliospheric signature of the carpet



- Random-walk motions of field-line 'footpoint' introduce tangential field components.
- These scale with distance as expected from the heliospheric-coronal field model
- If cause is indeed footpoint motions, then the magnitude of the fluctuations are problematic:
  - (Super-)granular velocity spectrum appears to yield proper scaling,
  - the associated flux dispersal is then ~6x too large!
  - Cause: reconnections in the magnetic carpet?



Giacalone & Jokipii (2004)

In conclusion

- Much of the quiet-Sun (intra-)network field appears to be generated by a small-scale turbulent dynamo,
- generating a (weakly varying?) background field,
- which may dominate basal chromospheric heating.
- The mixed-polarity field has often inclined field which tunnels acoustic waves, in spicules, and into corona.
- Quiet-Sun field lines reconnect every few hours to minutes depending on scale and environment,
- in an corona with plasma-$\beta = O(1)$,
- in which reconnection may induce strong transverse components that propagate into interplanetary space.