Unsolved problems in photospheric science

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Three key problems

- Magnetoconvection in the solar photosphere
  - Sunspots
- Origin and evolution of quiet Sun flux
  - Network
  - Internetwork
- Connection photosphere-chromosphere
  - Cancellation events
  - Emerging IN fields

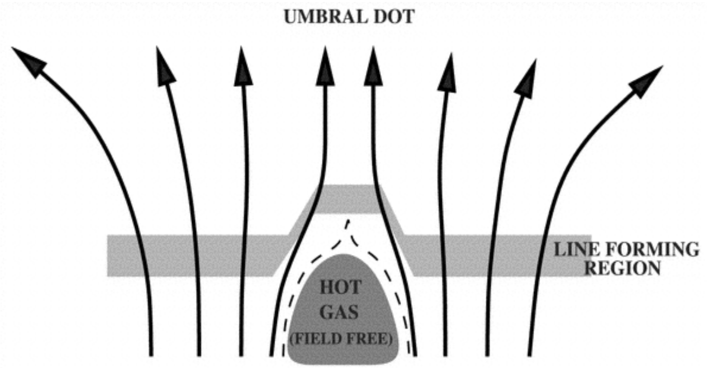
Magnetoconvection in the umbra

Ortiz, Bellot Rubio, Rouppe van der Voort, ApJ (in press)

CRISP @ SST + AO, Fe I 630 nm

Energy transport in the presence of vertical field?

What's the subsurface structure of a sunspot?



Socas-Navarro et al., ApJ (2004)

Magnetoconvection in the umbra

Ortiz, Bellot Rubio, Rouppe van der Voort, ApJ (in press)

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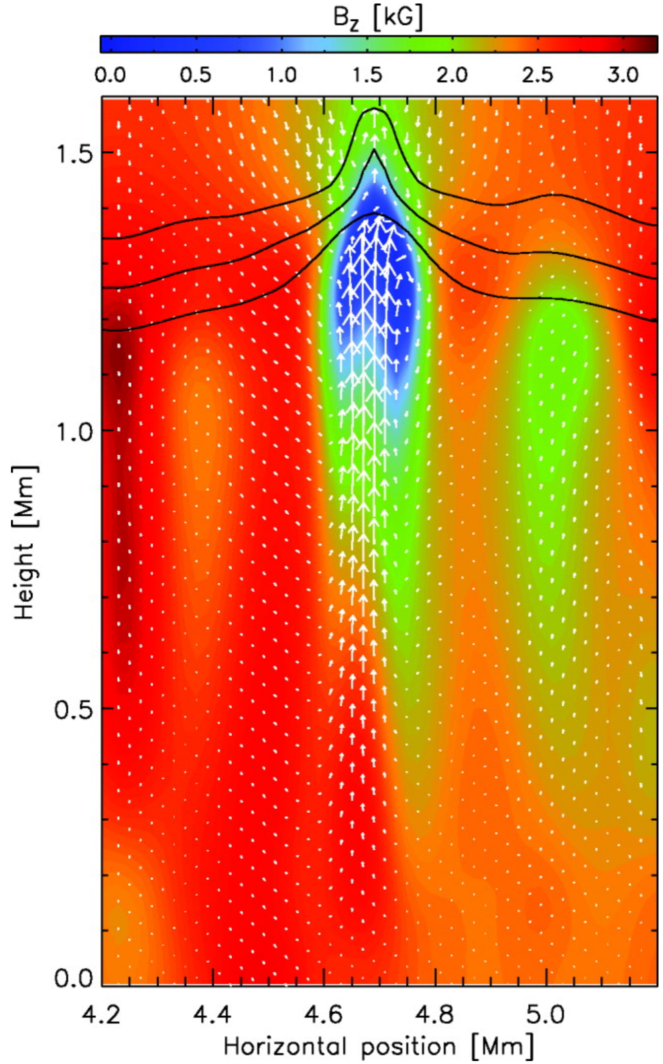
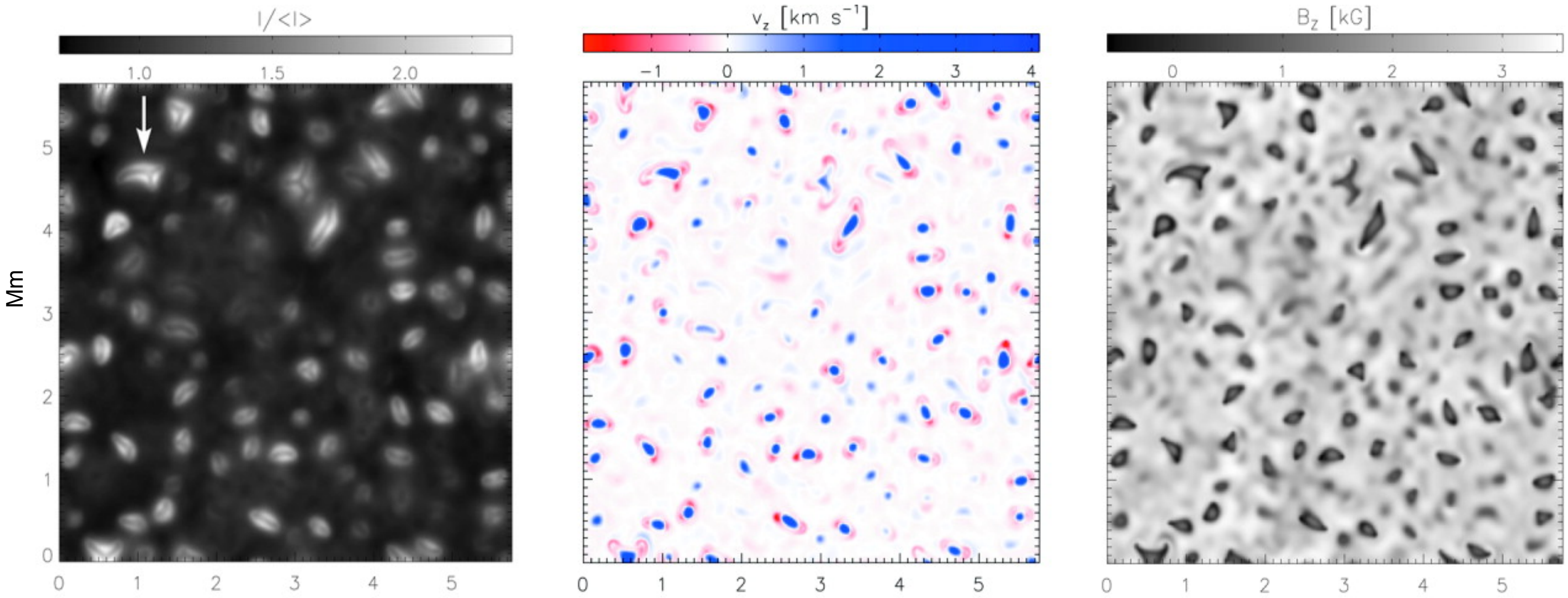


Schüssler & Vögler, ApJL (2006)

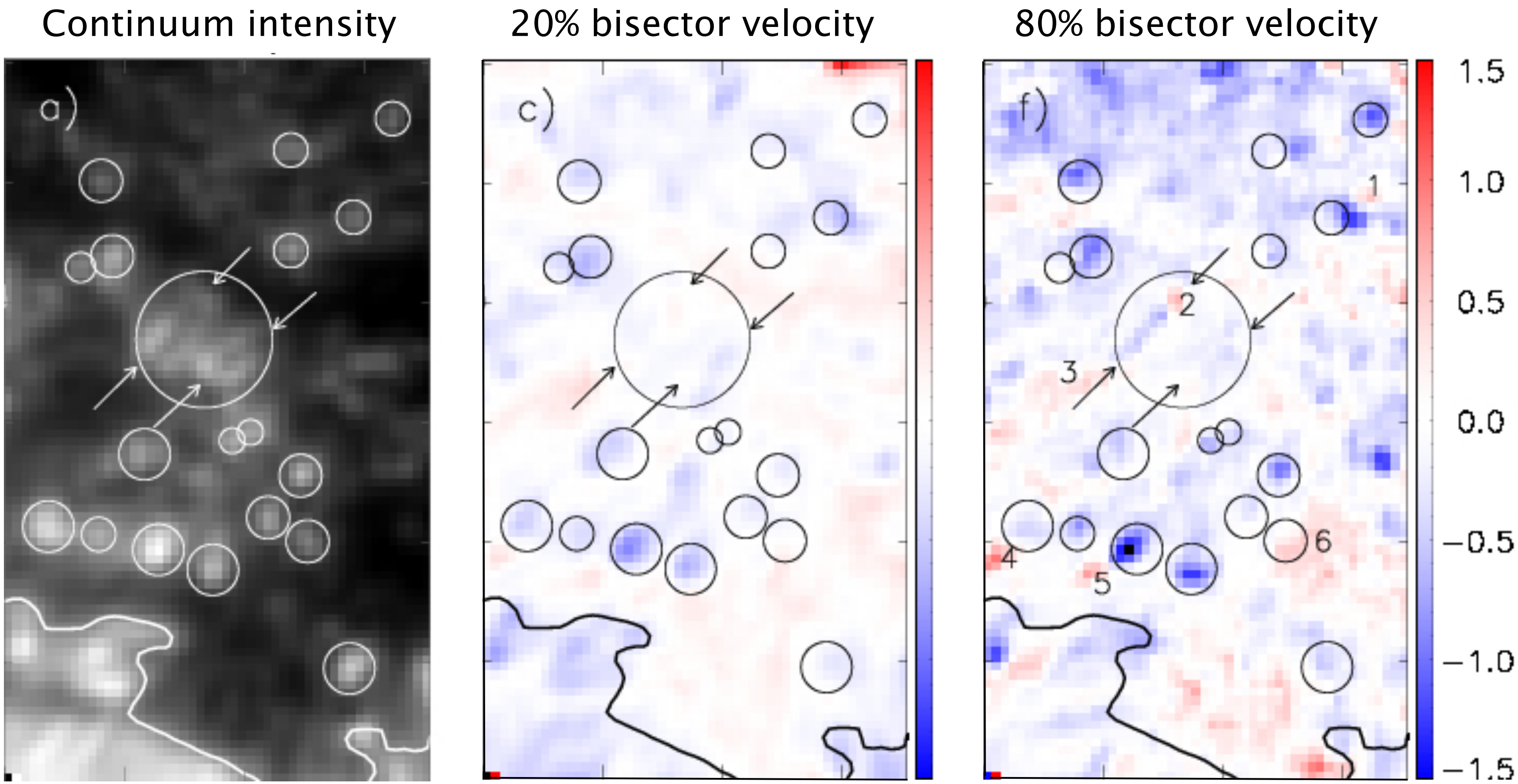
Magnetoconvection in the umbra



Schüssler & Vögler, ApJL (2006)

- Umbral dots with upflows and central dark lanes
- Downflows at ends of dark lanes and periphery of UDs
- High spatial resolution needed: ~ 0.1"
- Very low scattered light levels

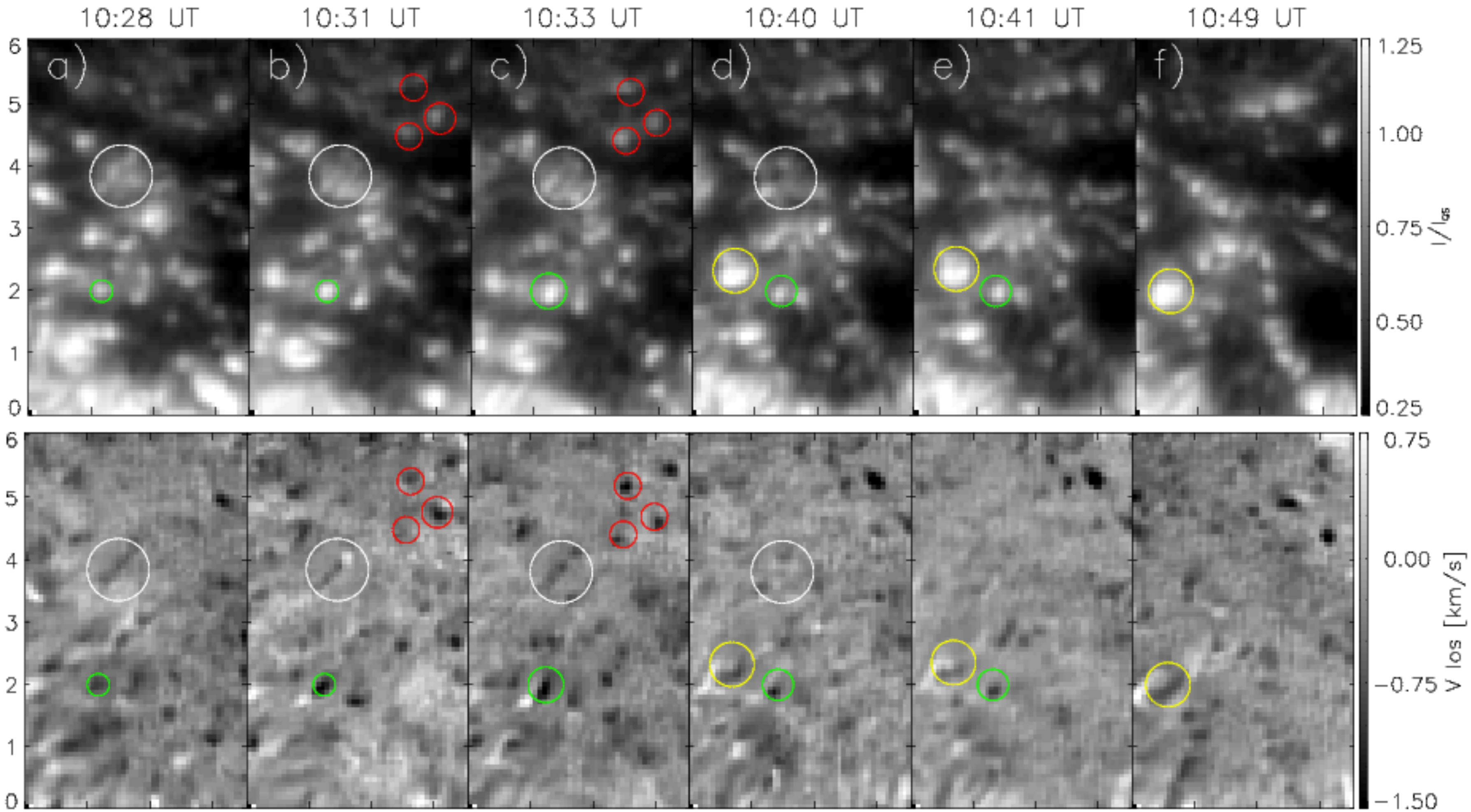
Magnetoconvection in the umbra



Ortiz, Bellot Rubio, Rouppe van der Voort, ApJ (in press)

Spectropolarimetry at 0.14": downflows observed near the edge of UDs

Magnetoconvection in the umbra

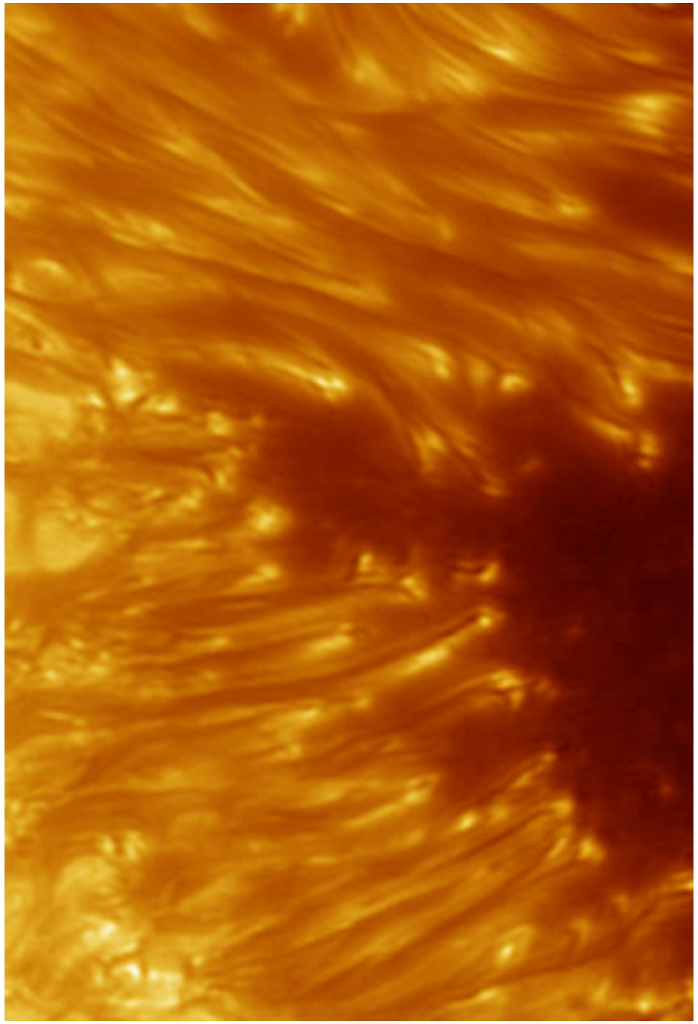


Ortiz, Bellot Rubio, Rouppe van der Voort, ApJ (in press)

Rapid temporal evolution of flow field. Lifetimes: a few minutes

Magnetoconvection in the penumbra

Scharmer et al., Nature (2002)



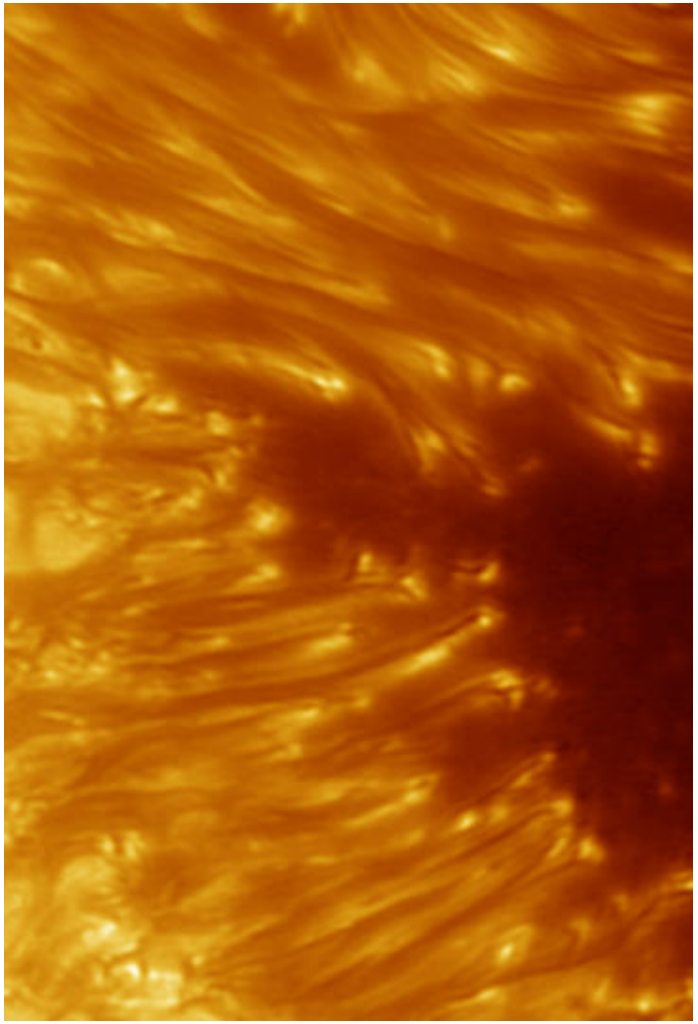
SST imaging, 0.1" resolution

Energy transport in the presence of inclined field?

What's the structure of the penumbra?

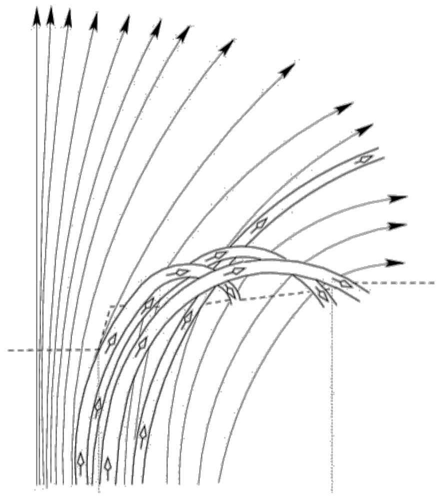
Magnetoconvection in the penumbra

Scharmer et al., Nature (2002)



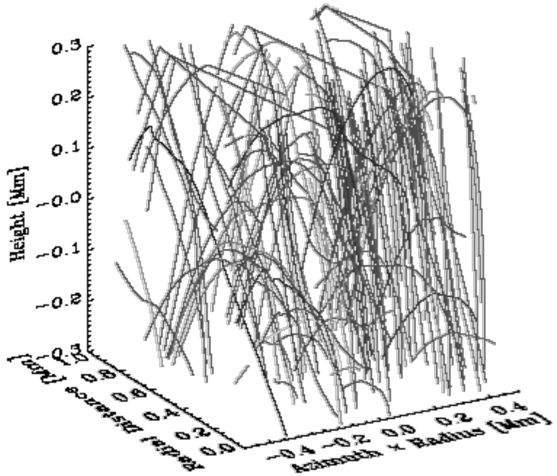
SST imaging, 0.1" resolution

Magnetic flux tubes?



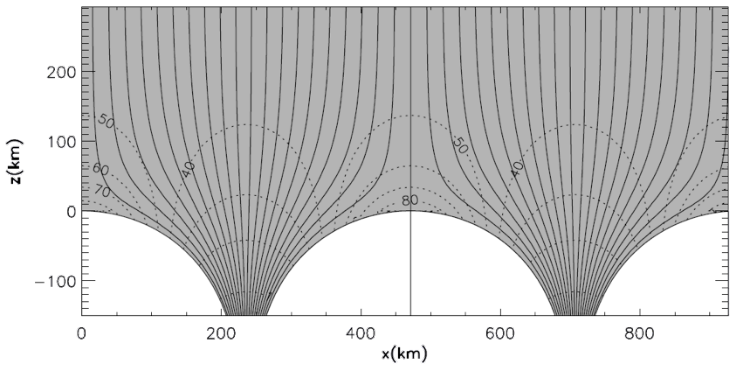
Solanki & Montavon, A&A (1993)

MISMAs?



Sánchez Almeida, ApJ (2005)

Field-free gaps?



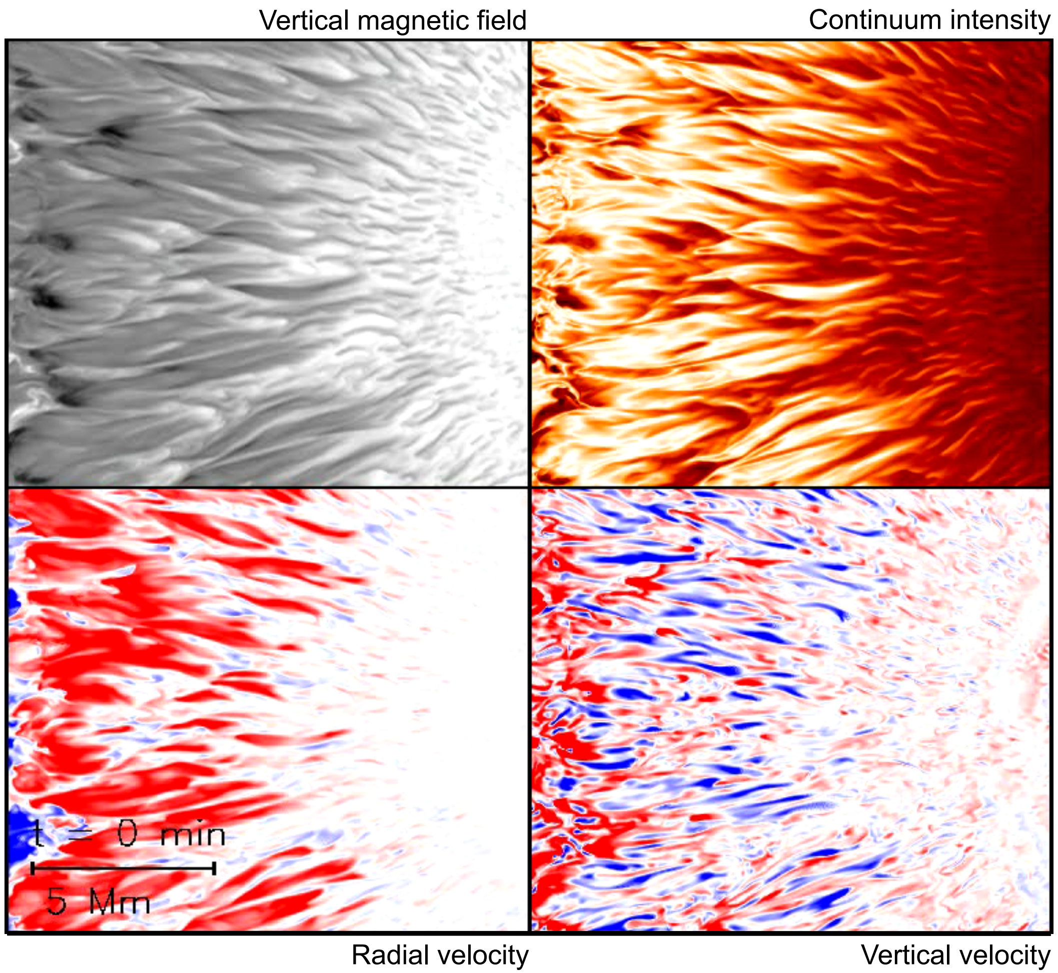
Spruit & Scharmer, A&A (2006)

Magnetoconvection in the penumbra

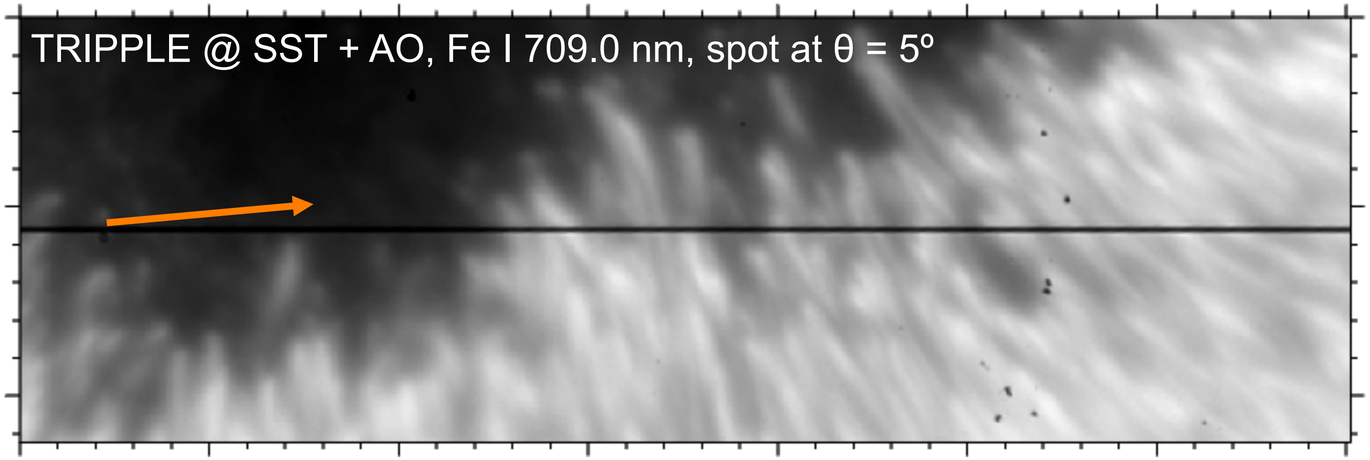
Rempel et al., Science (2009)

Overturning convection?

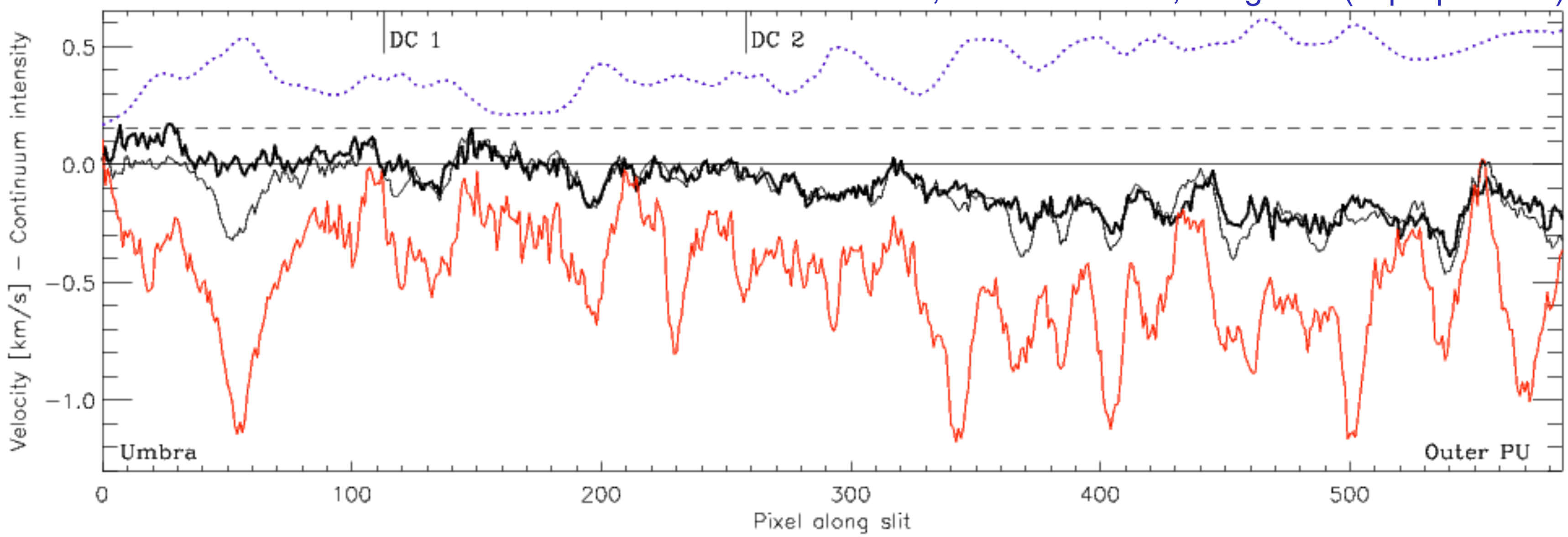
- Filaments are hot convective upflows deflected radially outward by inclined sunspot field
- Return downflows occur on either side of the filaments



Magnetoconvection in the penumbra

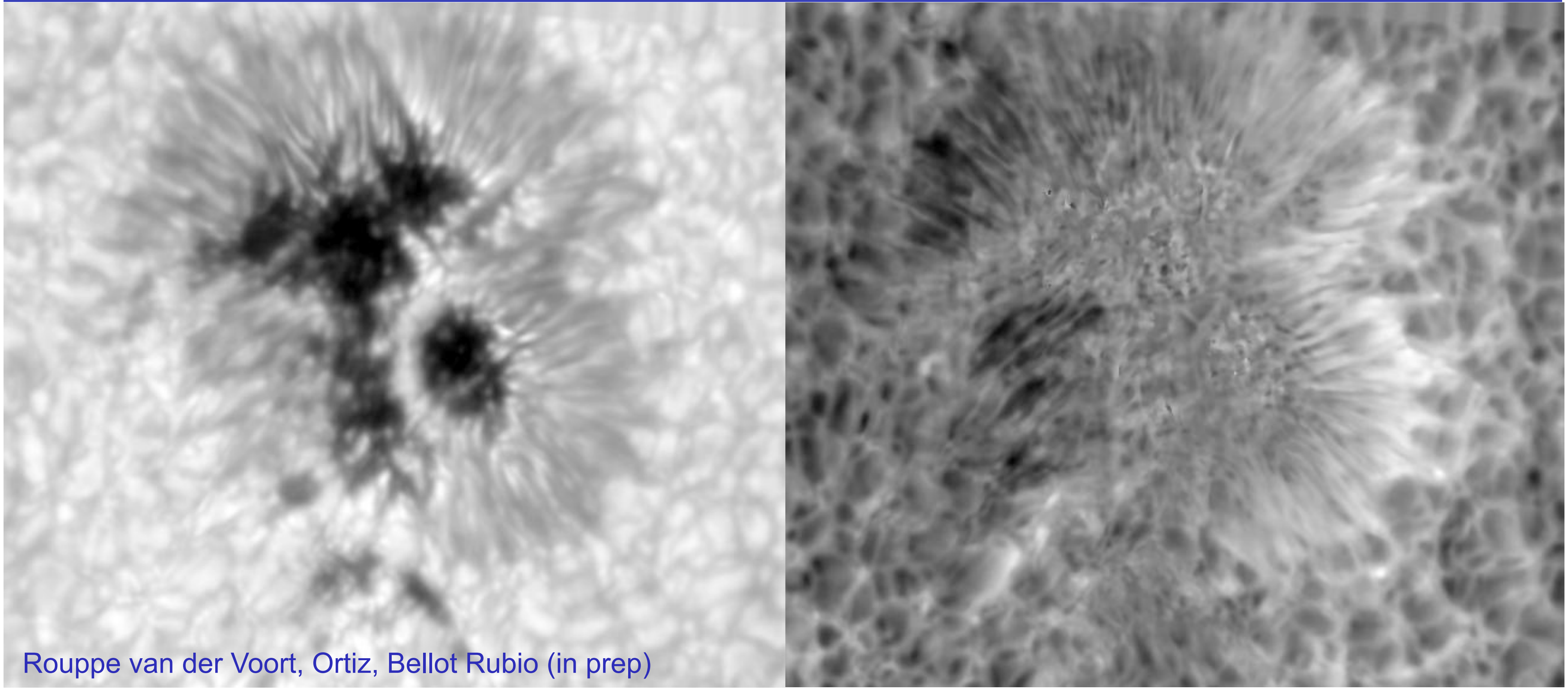


Bellot Rubio, Schlichenmaier, Langhans (in preparation)



Slit spectroscopy at 0.2": no overturning downflows larger than 100 m/s!!

Magnetoconvection in sunspot penumbrae

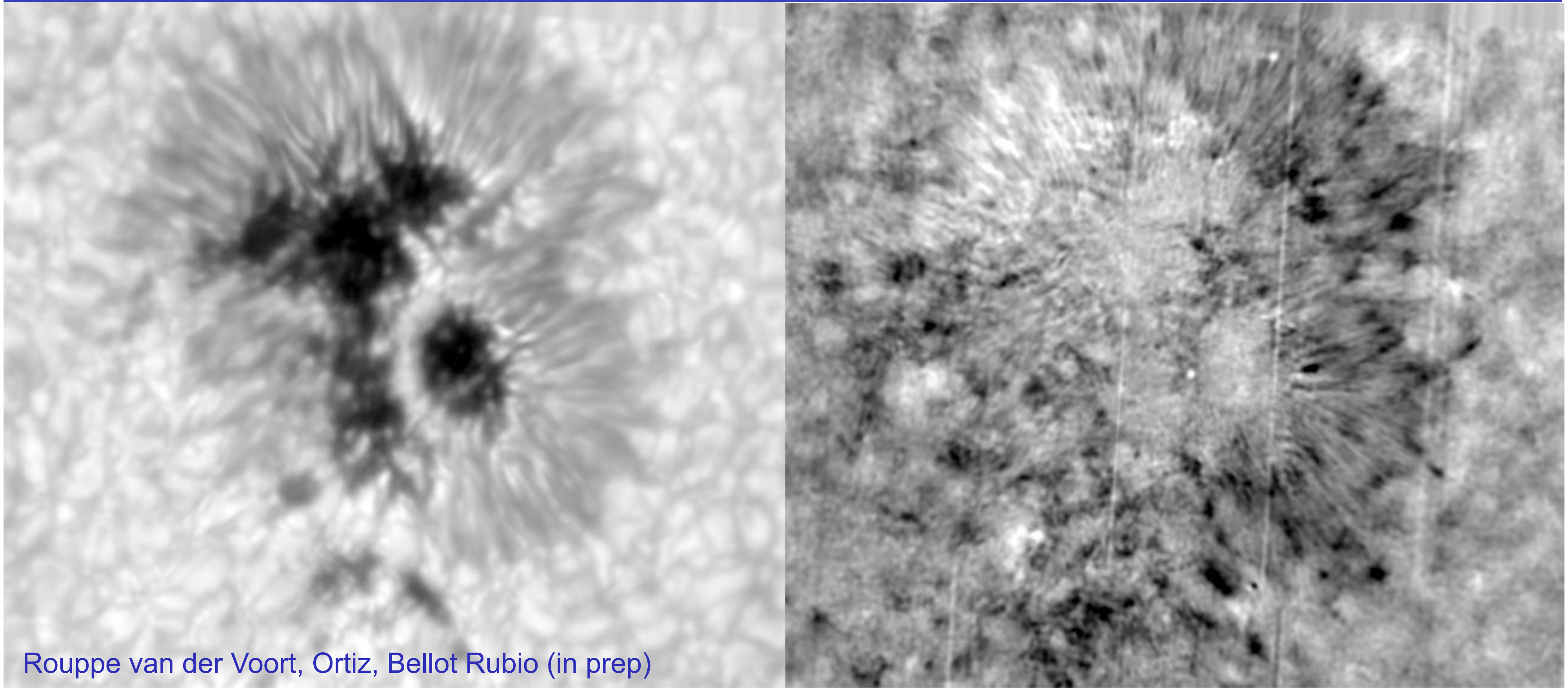


Rouppe van der Voort, Ortiz, Bellot Rubio (in prep)

- CRISP @ SST + AO, 5 July 2009
- Fe I 630 nm line pair , 17 λ's per line
- 2 hr time series, MOMFBD

The temporal evolution is the key to understand magnetoconvection in the penumbra

Magnetoconvection in sunspot penumbrae



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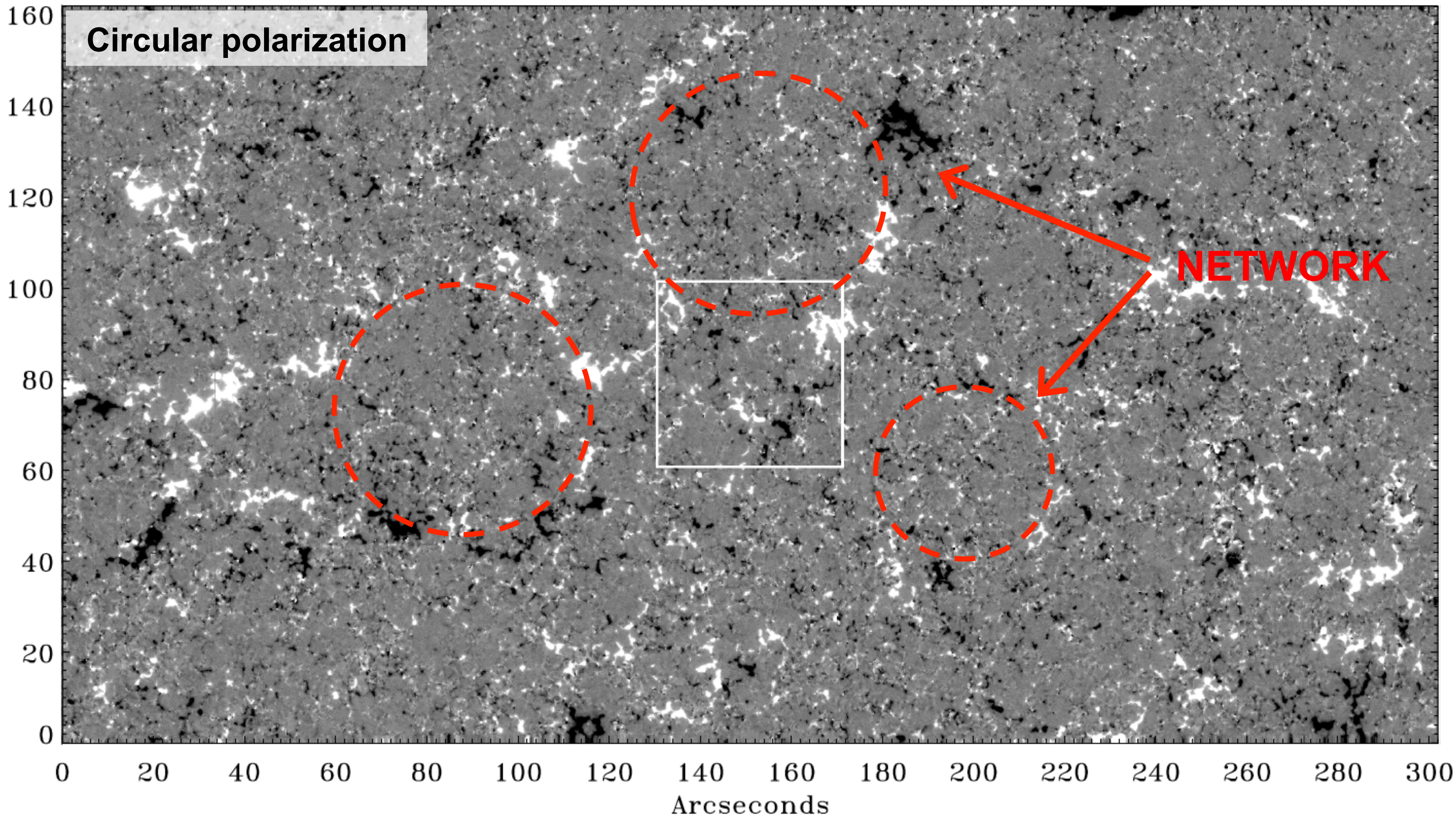
The quiet Sun



Lites et al., 2008, ApJ, 672, 1237

Hinode/SP normal map
Noise level: 1.1 x 10^{-3} I_c

- Network delineates supergranular cells
- Strong (kG) vertical fields
- Total network flux: ~ 4 x 10^{24} Mx

Ephemeral regions

- Small magnetic bipoles
- Emerge *near the center of supergranular cells*
- Early papers:

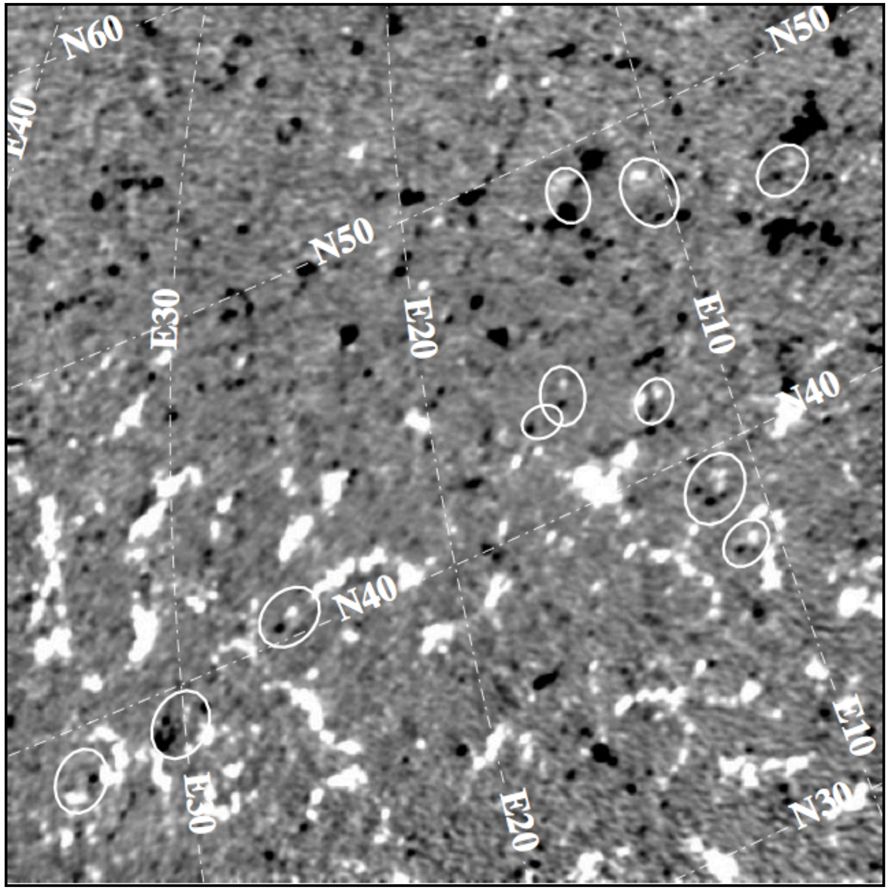
  Dodson (1953), citing Babcock

  Harvey & Martin (1973)

  Harvey et al. (1975)

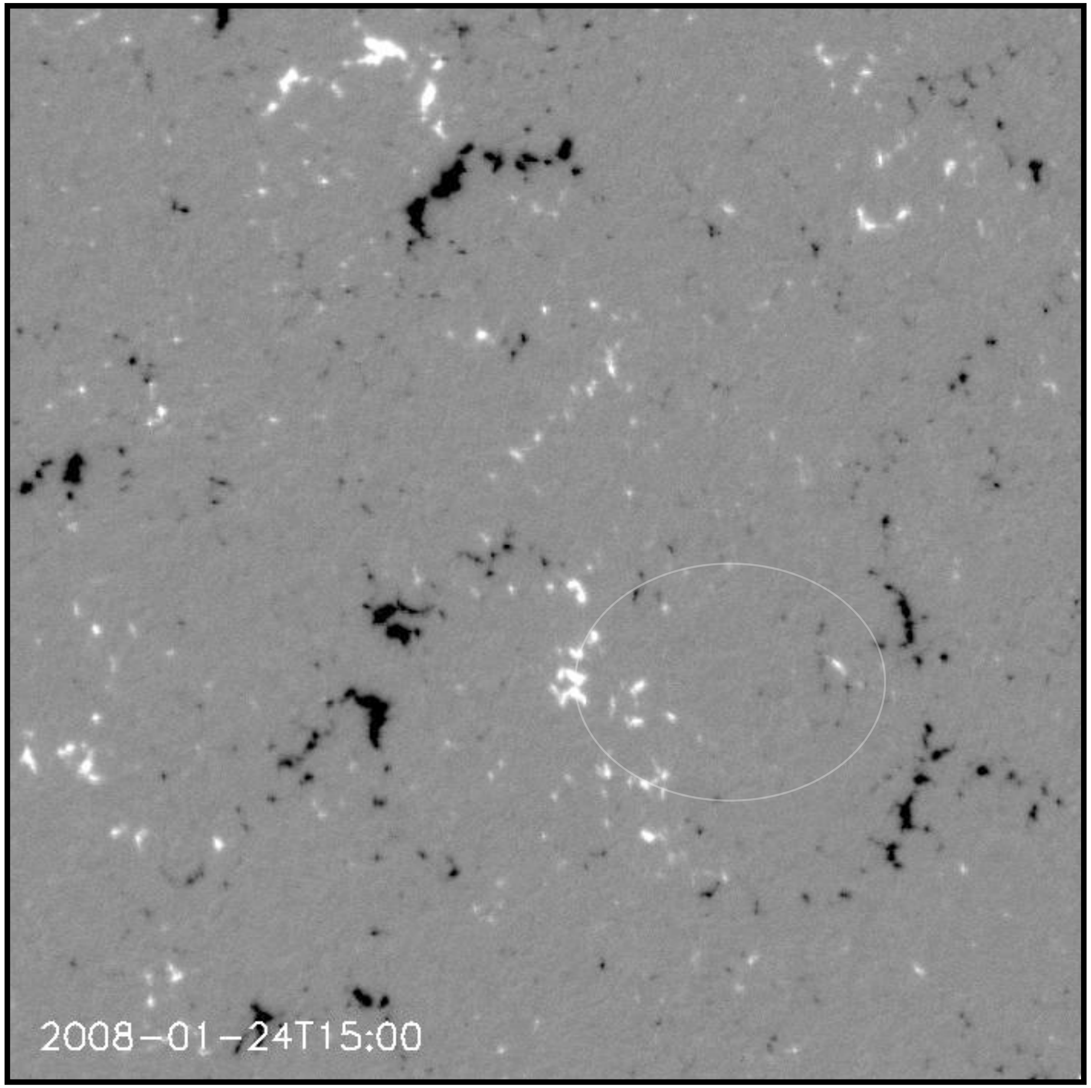
- Pole separation: ≤ 20"
- Horizontal speed: ~ 4 km/s
- Flux: 1-300 x 10^{18} Mx
- Mean flux: ~ 10^{19} Mx
- Lifetime: ~ 4 h

BBSO magnetogram, ± 50 Mx cm^{-2}



Chae et al. (2001)

Ephemeral regions

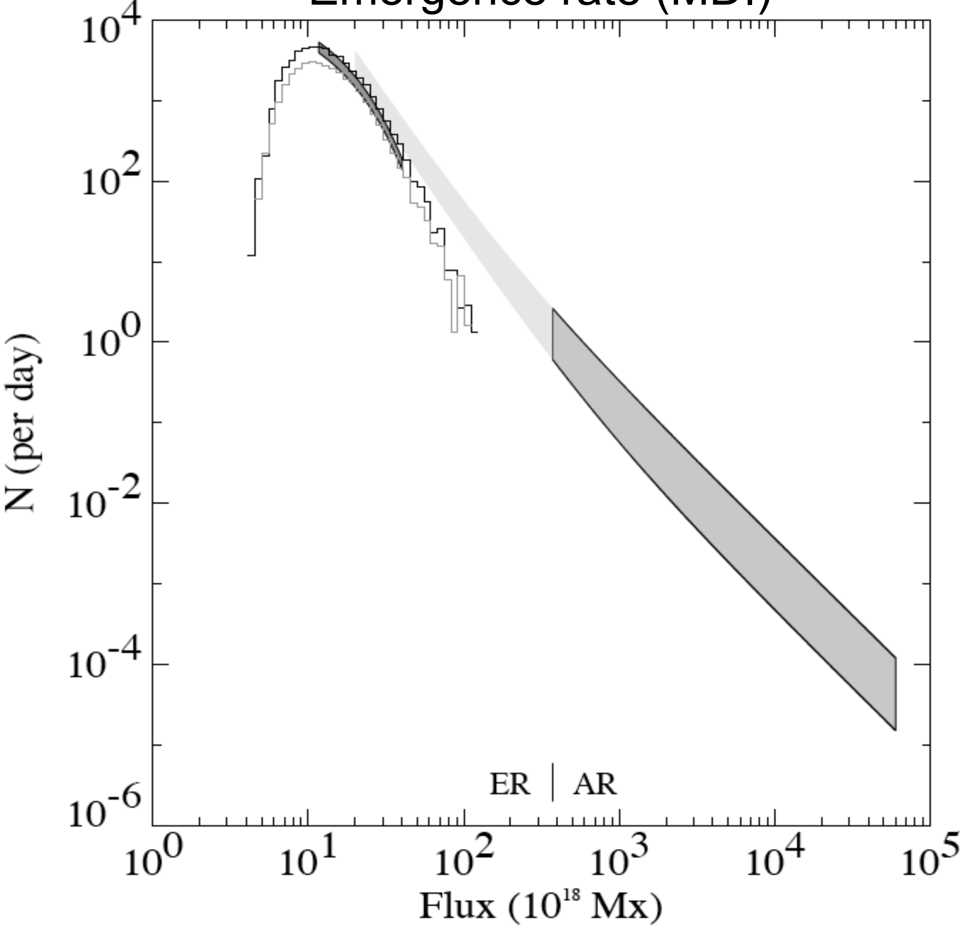


Hinode/NFI
Na I D1 589.6 nm
Cadence: 3 min
FOV: 112" x 112"

Bipolar ephemeral regions are large structures formed by small-scale, mixed-polarity elements

Source of network flux

Emergence rate (MDI)



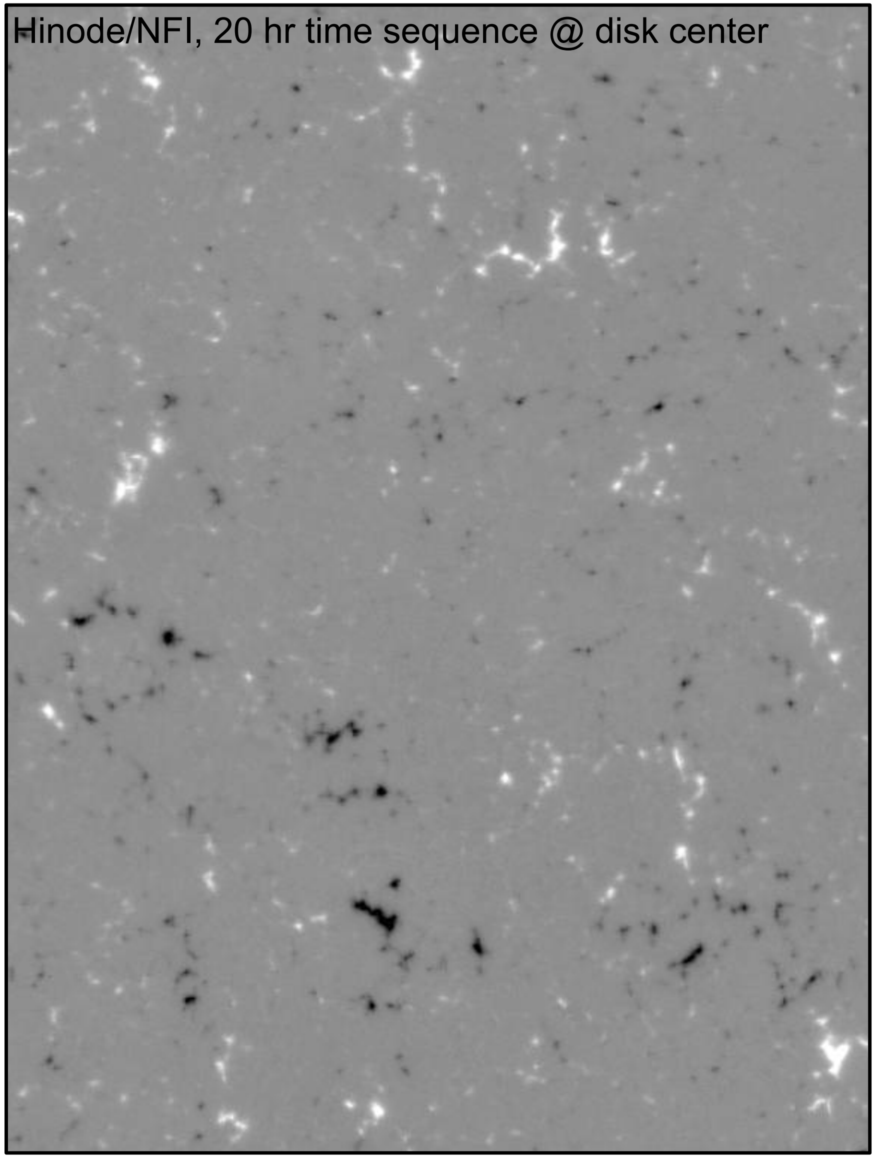
- Ephemeral regions are the main source of flux for the network

- Emergence rate: ~10^6 ERs/day
- Flux rate: ~ 10^{25} Mx/day

- Timescale for flux replacement
  - 40-70 h (Schrijver et al. 1997)
  - 40 h (Schrijver et al. 1998)
  - 8-19 h (Hagenaar et al. 2003)
  - 1-2 h (Hagenaar et al. 2008)

Hagenaar et al., ApJ (2003)

Source of network flux



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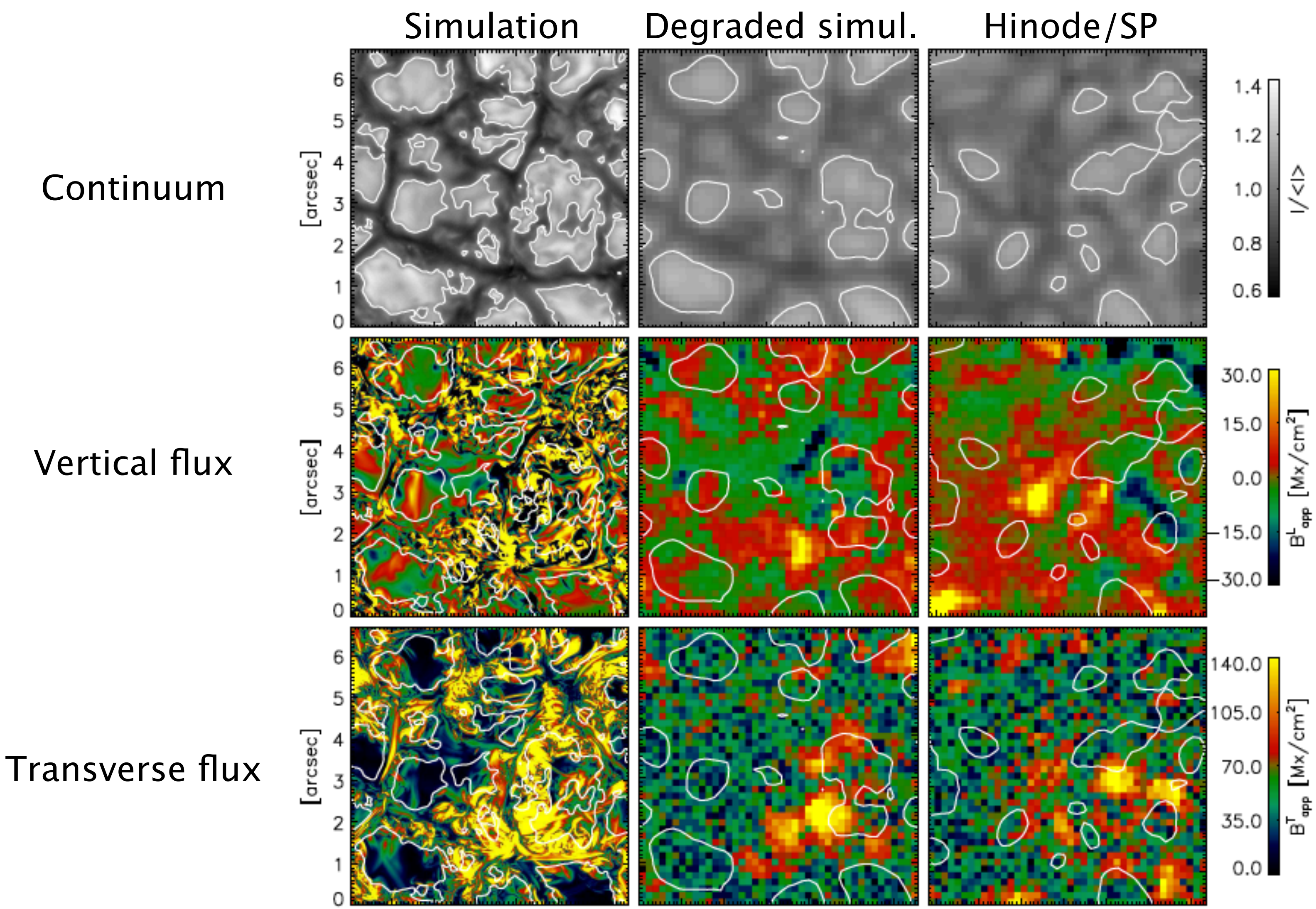
Is the replacement really that fast?

Local surface dynamo simulations

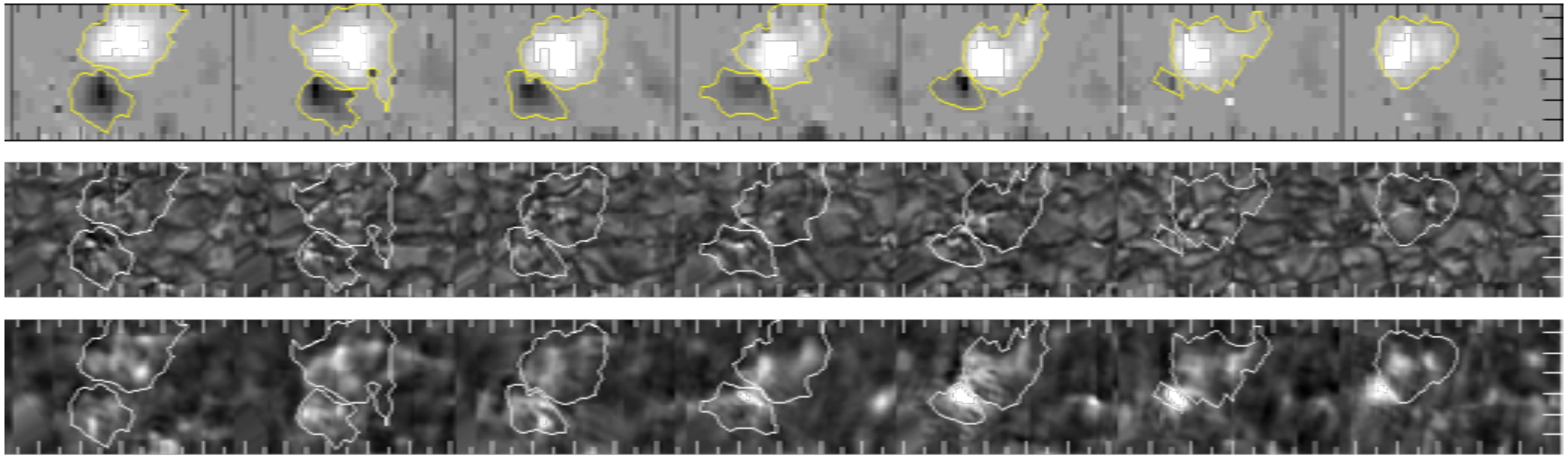
Danilovic, Schüssler, Solanki, A&A (2010)



General agreement, but field too weak by a factor 3. Temporal evolution?

Magnetic coupling: flux cancellation events

TIP+POLIS @ VTT, + DOT



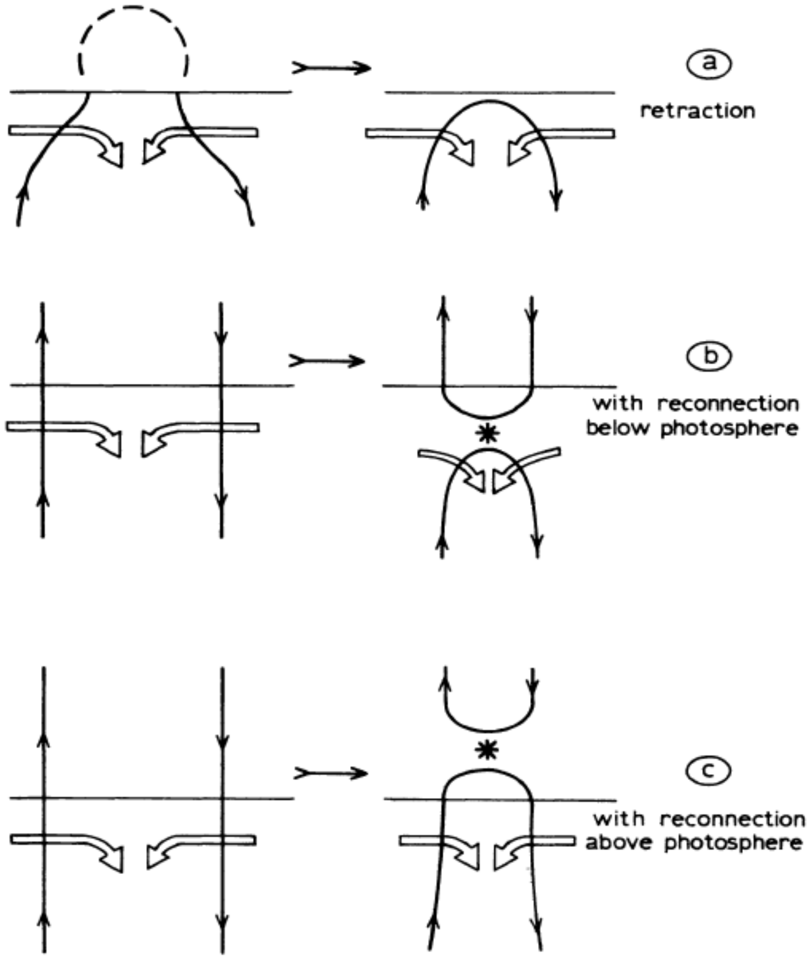
Time (Δt=7min) →

Bellot Rubio & Beck, ApJL (2005)

- Duration: minutes to hours
- Action occurs in thin contact line, but the two patches are affected
- Spatial resolution required: ~ 0.1"
- Multiwavelength observations, to follow process in different layers

Magnetic coupling: flux cancellation events

Zwaan, ARAA (1987)



Cancellation of opposite polarities can be interpreted as:

a) Flux retraction
b) Ascent of U-loop
c) Submergence of Ω-loop

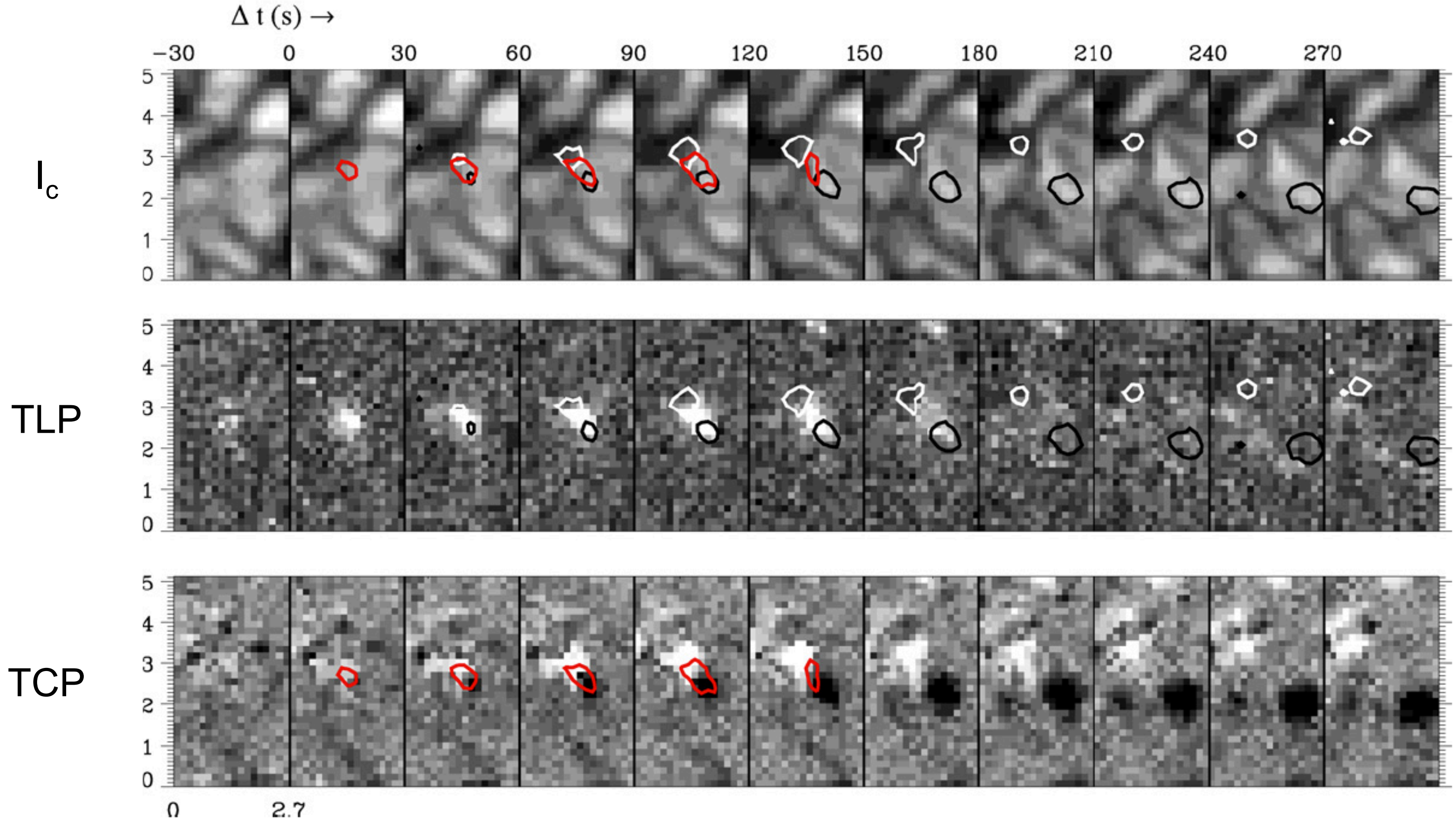
Processes (b)-(c) involve magnetic reconnection and may have consequences for chromosphere

Magnetic coupling: small-scale loops in the IN

Centeno et al. 2007

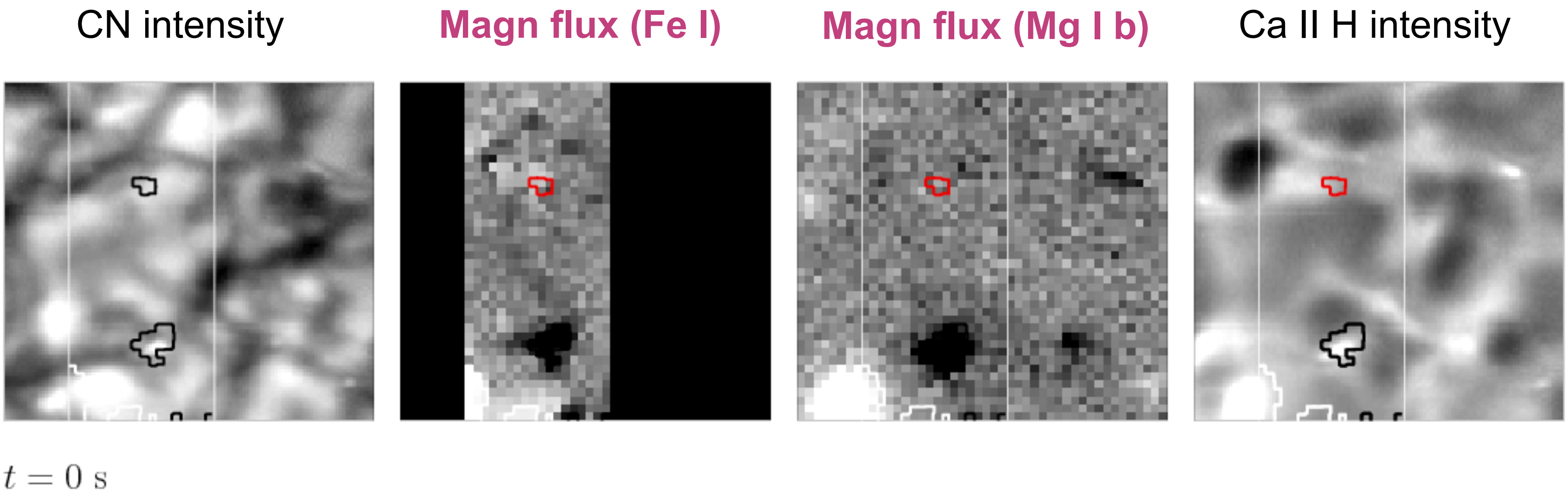
Martínez González & Bellot Rubio 2009; Ishikawa et al. 2010

Hinode/SP, 25 Sep 2007



Magnetic loops emerge in the internetwork on granular scales, showing linear polarization signal in between two-opposite polarity footpoints

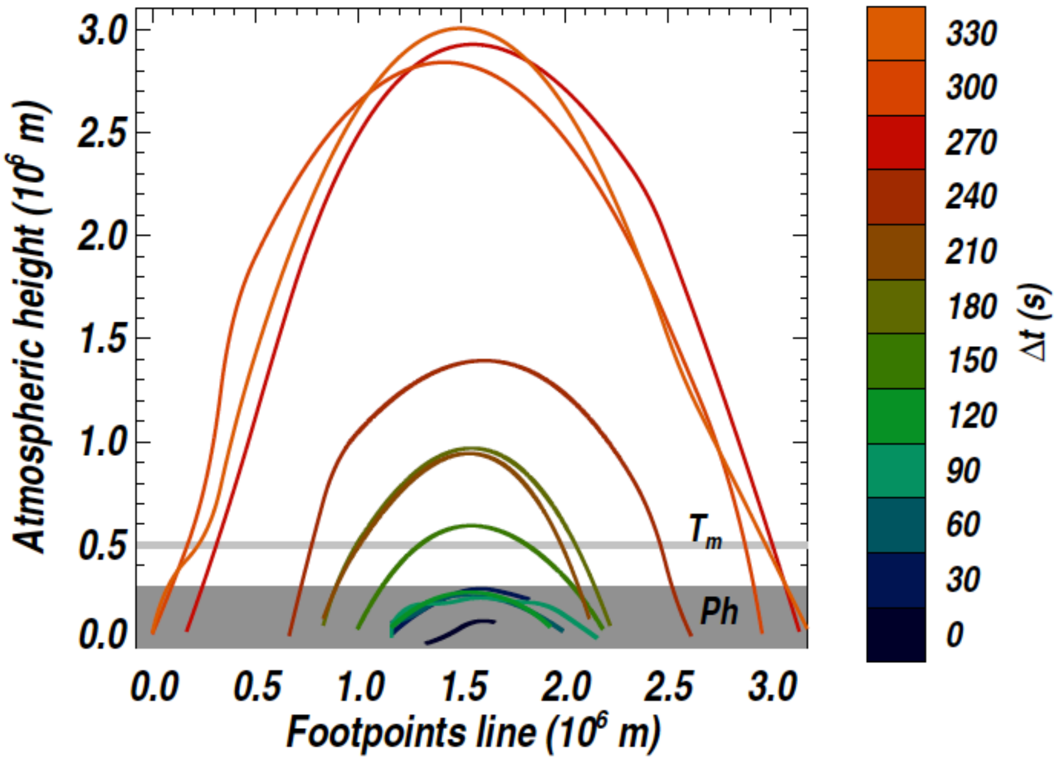
Magnetic coupling: small-scale loops in the IN



Martínez González & Bellot Rubio, 2009, ApJ, 700, 1391

Magnetic coupling: small-scale loops in the IN

Martínez González et al., ApJL(submitted)



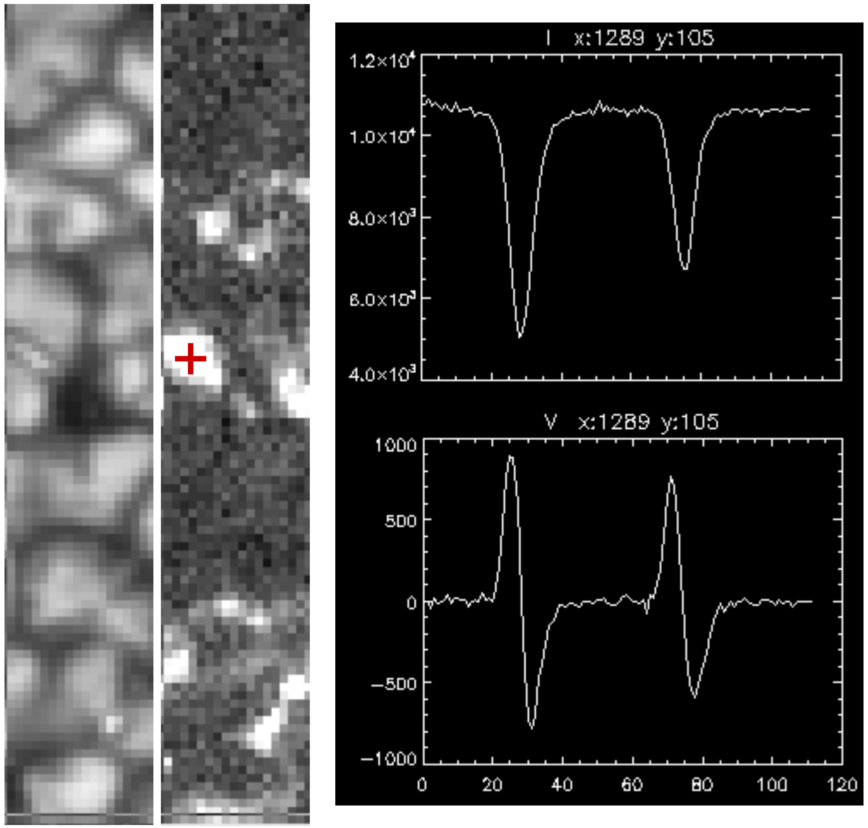
- 69 events in 28 hr
- FOV: 2.7" x 41"
- Flux: 9 x 10^{16} Mx
- Flux density: 25 G
- Max separation: ~2"
- Lifetime: ~12 min
- Vertical velocity: 3 km/s

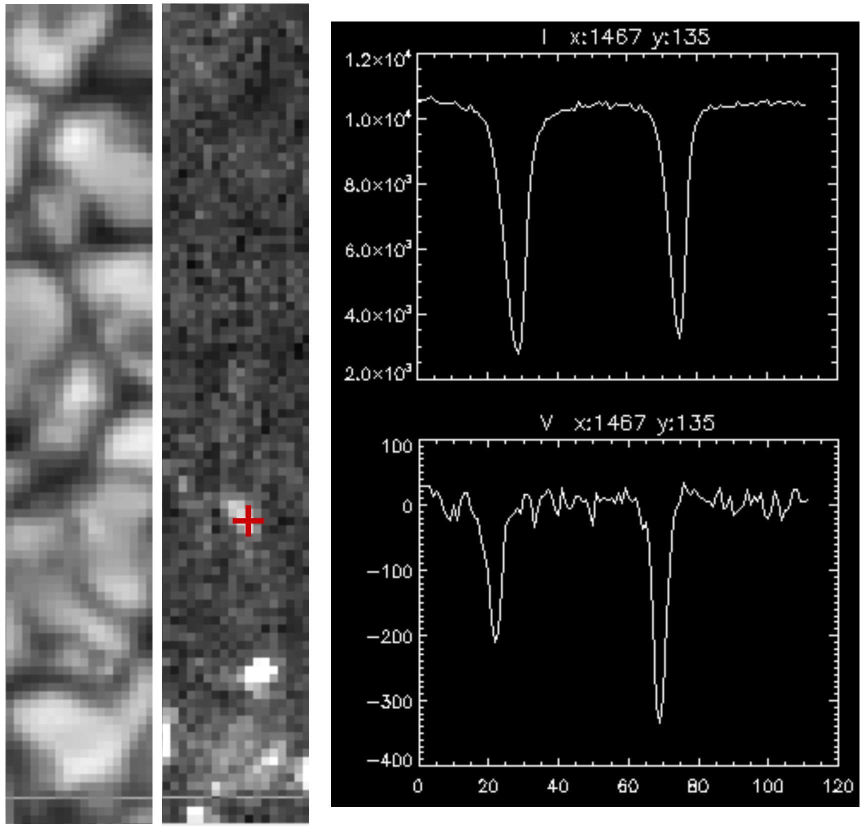
Important source of flux for the IN: ~ 10^{24} Mx/day in the entire Sun

About one quarter of the loops reach the chromosphere.

Downflows and Ca II H brightenings at those heights: signature of heating?

Magnetic coupling: complex Stokes profiles



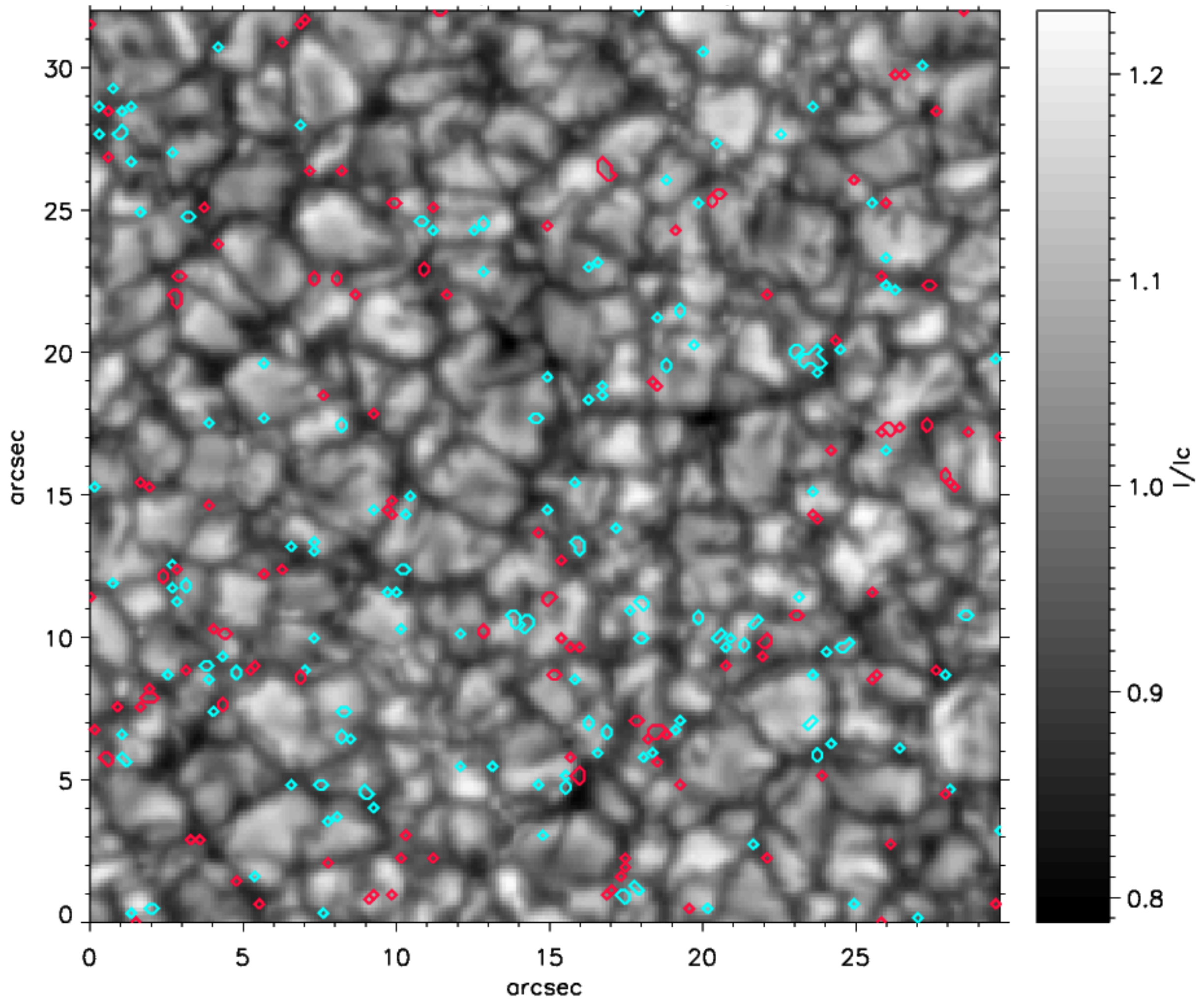


Quiet Sun at disk center
25 Sep 2007
Hinode/SP

Exposure time:	1.6 s/slit
Pixel size:	0.16″
FOV:	2.9″ x 40″
Cadence:	30 s

Magnetic coupling: complex Stokes profiles

Sainz Dalda, Title, Bellot Rubio

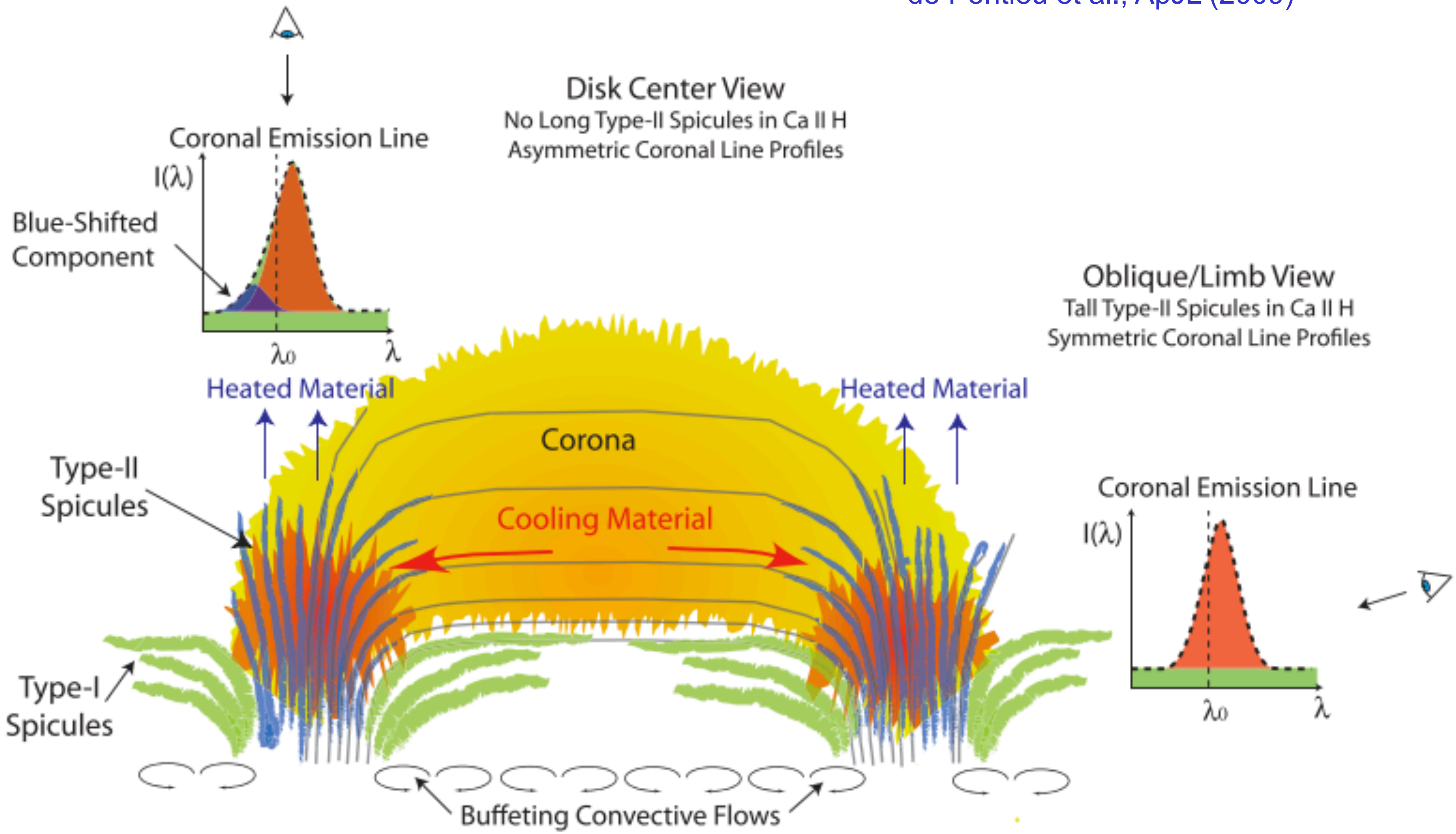


One-lobed Stokes profiles are associated with strong flows

Origin and effects on chromosphere?

Magnetic coupling: complex Stokes profiles

de Pontieu et al., ApJL (2009)



One-lobed Stokes profiles are associated with strong flows

Origin and effects on chromosphere?

What do we need to solve these problems?

Excellent stability

Uninterrupted observations (hours-days)

Access to chromosphere, TR, and corona

PLUS

Spatial resolution of ~0.1"

Excellent throughput (fast cadence)

What can SOLAR-C offer us?

Excellent stability

Uninterrupted observations (hours-days)

Access to chromosphere, TR, and corona

PLUS

Spatial resolution of ~0.1"

Excellent throughput (fast cadence)

(with 1.5m telescope)