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

Energy transport in the presence of vertical field?

What’s the subsurface structure of a sunspot?


CRISP @ SST + AO, Fe I 630 nm

Magnetoconvection in the umbra


CRISP @ SST + AO, Fe I 630 nm

Magnetoconvection in the umbra

- 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

Continuum intensity 20% bisector velocity 80% bisector velocity


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


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

Magnetoconvection in the penumbra


SST imaging, 0.1" resolution

Energy transport in the presence of inclined field?

What’s the structure of the penumbra?
Magnetoconvection in the penumbra


Magnetic flux tubes?

MISMAAs?


Field-free gaps?


SST imaging, 0.1" resolution
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

TRIPPLE @ SST + AO, Fe I 709.0 nm, spot at $\theta = 5^\circ$

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

- 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


Hinode/SP normal map
Noise level: $1.1 \times 10^{-3} \, I_c$

- Network delineates supergranular cells
- Strong (kG) vertical fields
- Total network flux: $\sim 4 \times 10^{24} \, Mx$
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 \( \times 10^{18} \) Mx
- Mean flux: ~ \( 10^{19} \) Mx
- Lifetime: ~ 4 h

Chae et al. (2001)

BBSO magnetogram, ± 50 Mx cm\(^{-2}\)
Bipolar ephemeral regions are large structures formed by small-scale, mixed-polarity elements.
Ephemereral regions are the main source of flux for the network.

- Emergence rate: $\sim 10^6$ ERs/day
- Flux rate: $\sim 10^{25}$ 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)
Source of network flux

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Hinode/NFI, 20 hr time sequence @ disk center

Is the replacement really that fast?
Local surface dynamo simulations


Continuum

Vertical flux

Transverse flux

General agreement, but field too weak by a factor 3. Temporal evolution?
Magnetic coupling: flux cancellation events

- 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

Cancellation of opposite polarities can be interpreted as:

a) Flux retraction
b) Ascent of U-loop
c) Submergence of $\Omega$-loop

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

$CN$ intensity   | $\text{Magn flux (Fe I)}$   | $\text{Magn flux (Mg I b)}$   | $\text{Ca II H intensity}$

$t = 0 \text{ s}$

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: $9 \times 10^{16}$ Mx
- Flux density: 25 G
- Max separation: ~2"
- Lifetime: ~12 min
- Vertical velocity: 3 km/s

Important source of flux for the IN: $\sim 10^{24}$ 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
One-lobed Stokes profiles are associated with strong flows. Origin and effects on chromosphere?
Magnetic coupling: complex Stokes profiles

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?

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(with 1.5m telescope)