Toward Understanding the Sun’s Magnetic Field Topologies

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There is an Hierarchy of Convection Cells and Large Scale flows in the Solar Surface

The solar surface is covered by turbulent convection cells - solar granulation. The granules have a spatial scale of about 1000 km and a mean lifetime of about 10 minutes. Granules move and maintain the local magnetic fields in their downflow boundaries. The constant motion braids, twists, and forces restructuring the field above the surface.

In addition there exists a supergranulation pattern with a spatial scale of about 20,000 km and a lifetime of about a day.
Granules push magnetic flux elements into their boundaries.
The small scale mixed polarity seen over the entire disk can not occur from diffusion of active regions...
AR vary by a factor of 8 over cycle
ER vary by a factor of 2 over cycle
SB vary by factor of 2/3 over cycle

Magnetic Resolution \sim 4 \text{ arcsecond}
Strong Field Appears to Emerge on the Scale of Granulation
Numerical simulations of convection produce magnetic structures on the scale of the convection. *Local Dynamo Action*
The transfer of energy from convection to magnetic fields

- How does convection generate or regenerate fields?
- How much work is done on magnetic fields by convection?
- How does the work done by convection on magnetic flux elements transfer energy into the upper atmosphere?
Estimate of the Magnetic Energy Input by Convection

- Estimate the magnetic energy as the magnetic energy in the emerging loop and use the area of the typical cell as the area factor and the replacement time as the rate, then the energy dissipation rate, $E_D$ (ergs/cm$^2$/sec) is

  - $E_D = \frac{B F}{8 \pi^2 R T}$,

- where $B$ is the magnetic field strength (gauss), $F$ is the total flux (Mx), $R$ is the cell radius (cm), and $T$ is the flux replacement time (sec).

- Alternatively, this can be considered as an estimate of the work done by the flow field to move the magnetic field to where it can cancel with an opposite polarity flux element.
Energy Estimates for the Various Scales of Emergence

- For ephemeral regions the average properties are:
  - \( F = 8 \times 10^{18} \) Mx, \( B = 1200 \) gauss, \( R = 10^9 \) cm, and \( T = 36000 \) seconds, so
  - \( E_D \) (network) = \( 3.4 \times 10^6 \) ergs/cm\(^2\)/sec.
- For the internetwork fields:
  - \( F = 1 \times 10^{17} \) Mx, \( B = 50-200 \) gauss, \( R = 10^8 \) cm, and \( T = 3600 \) seconds, which yields
  - \( E_D \) (internetwork) = \( 2-7.0 \times 10^5 \) ergs/cm\(^2\)/sec.
- For the granulation scale fields:
  - \( F = 5 \times 10^{16} \) Mx, \( B = 1200 \) gauss, \( R = 5 \times 10^7 \) cm, and \( T = 300 \) seconds, which yields an energy dissipation rate of
  - \( E_D \) (granulation) = \( 5 \times 10^7 \) ergs/cm\(^2\)/sec.
- \( E_{Sun} \) (emittance) = \( 6.3 \times 10^{10} \) ergs/cm\(^2\)/sec.
The complex mixed polarity on the surface causes a complex mixture of magnetic loops in the corona.
As new flux emerges it rapidly connects to previously existing magnetic structures.
The role of topology in energy release

- How does the local and global topology of magnetic fields affect the release of energy?
- What do potential fields tell us about the topology of magnetic fields?
- How do topologies change?
- How much energy is released with a topological change?
A rotating spot causes complex restructuring in the corona above it.
Flux - Flux Interactions

New Magnetic flux emerging into a larger pre-existing pattern can cause the transfer of energy from smaller to larger scales.
Filaments unlike loops are not approximated by a potential or force free extrapolations.
The “internetwork” field steals flux from the network, so that the field geometry is inconsistent with the classical canopy concept.
Photosphere-Corona Magnetic Connection

Starting field lines from above the surface shows connections to the entire surface not just the network point.
(Intra-) Network flux into the corona

For intranetwork field at \( \sim 20 \text{ Mx/cm}^2 \), approximately 10-70\% of the network flux that reaches into the corona may be rooted in the intranetwork field.
Results for mixed-polarity network are very similar.
$H_- \ 700 \text{ mÅ}$
H_ line center
Old View of the Surface-Corona Connection
New View of the Surface-Corona Connection
Outer Atmosphere Summary

The outer atmosphere is finely structured and essentially dynamic with a constantly changing mixture of temperatures.

Many structures are not in hydrostatic equilibrium.

Magnetic reconnection occurs rapidly over large volumes.

There is not a magnetic canopy, rather fields extend for long distances from all of the quiet Sun.

Magnetic topology is critical for both “quiescent” and rapid energy release processes.
Number of Connections in Source Plane

Total Number of Connections