Beyond Solar Dermatology
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what lies deeper still?

★ Supercomputers simulation of solar granulation

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Eventually the hierarchy must culminate in motions large enough to sense the spherical geometry and rotation.

Giant Cells

radial velocity, $r = 0.98R$

$L \sim 100 \text{ Mm}$

$U \sim 100 \text{ m s}^{-1}$

$\tau \sim \text{days - months}$
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Giant Cells

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$t \sim \text{days - months}$

radial velocity, $r = 0.98R$
Giant Cells carry energy and redistribute angular momentum

That’s how the Sun shines (Carrying energy from 0.7R to surface)

That’s why the equator spins faster than the poles (Only giant cells are big and slow enough to sense the rotation and spherical geometry)
Giant cells and the global circulations they produce build magnetic fields

The Solar Dynamo
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*The Solar Dynamo*
The Solar Dynamo

Building magnetic fields by means of turbulent convection, shear, magnetic buoyancy and global circulations.
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Some solar dynamo models suggest that a slow equatorward flow near the bottom of the convection zone may regulate the cycle period. Why 11 years?

How slow? 2 m/s (5 mph) gets you from the pole to the equator in 11 years!
Simmering below the Surface
The structure of the solar interior

Sphere No. 6 (Sphere Within a Sphere)
Arnaldo Pomodoro
Hirshhorn Museum and Sculpture Garden
Washington, DC
http://hirshhorn.si.edu
We are now in the deepest solar minimum of the space age!
COSMOLOGY MARCHES ON

Where the hell did it all come from?

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In the perfectly conducting limit ($\eta = 0$), the flow can’t cross magnetic field lines.

**Corona**

- Magnetic energy $\gg$ kinetic energy
- Flow follows field $\Rightarrow$ coronal loops!

**Convection Zone**

- Magnetic energy $\ll$ kinetic energy
- Flow pushes field around $\Rightarrow$ dynamo!
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*Alfvén’s Theorem (flux freezing)*
Violation of Alfven’s Theorem
Reshapes magnetic Topology
Releases Energy
Accelerates Particles (important for solar flares)

Zweibel & Yamada (2009)
Differential Rotation

P ~ 35 days

P ~ 27 days
Differential Rotation

Monotonic decrease in $\Omega$ of $\sim 30\%$ from equator to high latitudes in CZ

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Convection Implicated as source of DR
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Nearly radial contours at mid-latitudes in CZ
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Radial $\Omega$ gradients near top & bottom: Tachocline
Near-surface shear layer
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Interior rate intermediate between equator & poles in CZ
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**Nearly radial contours at mid-latitudes in CZ**

**Radial $\Omega$ gradients near top & bottom:**
- **Tachocline**
- **Near-surface shear layer**

**Interior rate intermediate between equator & poles in CZ**

**Persistent in time**
Meridional Circulation

Systematically poleward at mid latitudes near surface \((r > 0.95R)\)

Much weaker than differential rotation
\((\sim 20 \text{ m/s})\)

Variable in time

...and that’s about all we know!

Observational techniques

Local helioseismology
(left and below)

Surface Doppler measurements (right)

Feature Tracking

Hathaway & Rightmire 2010

Zhao et al 2013

Hathaway & Rightmire 2010

Ulrich

Ulrich

Zhao et al 2013

Hathaway & Rightmire 2010