Is the polar region different from the quiet sun?

Hinode Observations on polar fields

Saku Tsuneta (NAOJ)
What is going on in polar region?

Source of fast solar wind
Location of global poloidal fields
sink of meridional flow

High speed solar wind

Ulysses
(McComas et al. 2000)

Kitt Peak
(Wang et al.)

Polar fields

Cirtain et al.
Polar landscape kG field

Tsuneta et al. (2008 in press)
Red : vertical
Blue : horizontal

Polar region consists of same-sign vertical B with horizontal B
Probability Distribution Function of polar field

- PDF
- Vertical
- Horizontal
- Total

- Stronger B dominates

- Weaker B dominates

- Continuum intensity

- Filling factor

- Magnetic field (G)

- Magnetic field (G)

- Continuum intensity

- Filling factor
**Horizontal field**

PDF comparison with Quiet Sun and Plage region

Ishikawa & Tsuneta (2009, in press)

Tsuneta et al. (2008 in press)
<table>
<thead>
<tr>
<th>Region</th>
<th>Outward Flux</th>
<th>Inward Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Pole</td>
<td>96.3%</td>
<td>3.7%</td>
</tr>
<tr>
<td>East Limb QS</td>
<td>50.5%</td>
<td>49.5%</td>
</tr>
<tr>
<td>West Limb QS</td>
<td>64.0%</td>
<td>36.0%</td>
</tr>
</tbody>
</table>

(Stokes Q > 0.01)

- Quiet sun has bipolar field, while polar region is uni-polar.
- Polar region has stronger fields.
- No difference in terms of horizontal fields.

- One order of magnitude higher flux in strong B region.
Inflation of polar flux tubes near photosphere-chromosphere boundary

All the flux tubes are connected to interplanetary space.

Very small fraction of flux tubes is connected to interplanetary space.

Higher polar coronal field due to uni-polarity and higher Surface B.

Figure Courtesy Joten Okamoto
Low pressure coronal hole is sustained by higher magnetic pressure of coronal hole

- CH pressure is a factor of 2 (T-diff.) x 3 (n-diff.) = 6 smaller than that of surrounding quiet Sun.
- This must be balanced by stronger CH magnetic field.

Kano et al (2008)
Total and average magnetic flux

- Magnetic filling factor: $0.05 < f < 0.35$
- Total magnetic flux in a pixel
  - $B \times f \times \text{pixel size with foreshortening correction}$
- Total magnetic flux in SOT FOV
  - Vertical flux: $2.2-9.9 \times 10^{21} \text{ Mx}$
  - Horizontal flux: $0.4-2.0 \times 10^{22} \text{ Mx}$
- *Horizontal flux factor of 2 larger*
- Average vertical flux 10.0 G
- Total vertical magnetic flux for > 70 degree
  - $0.6-2.5 \times 10^{22} \text{ Mx}$
- Ulysses observations
  - $2 \times 10^{22} \text{ Mx}$ (above 35 degree)
Variation of total polar flux over one year

North polar region
South polar region

Exact balance of north and south total flux
Constant flux over 1 year

Total vertical flux (Q>0.002)
Temporal evolution of kG patches

- kG patches have canopy structure
- Life time $\sim 10$-20 hours
- Super Equi-partition & unipolar
- Small flux tubes merge to form large patch
- Large patch disintegrates to smaller patches

1hr x 5

Stokes-U
Velocity map obtained from Stokes-I and kG patches (contour)

Relation between flow-field and magnetic patches are being analyzed.
What is the implication of the kG polar field for acceleration of fast solar wind

- A factor of 345 inflation of the flux tubes near photosphere-chromosphere-corona boundary

Polar field extrapolation (potential) using polar SP data embedded in MDI data (Shiota, Ito, Tsuneta, 2009)

Flares and jets

Horizontal field

reconnection

Figure Courtesy Joten Okamoto
Fanning-out kG patch
Chimney for Alfven waves

- **Uniform magnetic field**: Alfven wave reflection in the photosphere-corona boundary

  \[ V_A = \frac{B}{\sqrt{4\pi \rho}} \]

- **Fanning-out flux tube**: serves as chimney for Alfven waves
  - more Alfven wave flux that accelerates fast solar wind is transmitted to the corona due to the fanning-out structure.
Summary
Properties of polar fields

• *Vertical* field component
  – PDF with extension to super-equipartition (400-500G) field strength seen as kG patch
  – kG patch fanning-out structure
  – Unipolar in contrast to QS
  – Appear from nothing to disappear to nothing
  – 10-15 hour life time
  – North flux same as south flux

• Ubiquitous *horizontal* fields component everywhere as seen in Stokes V
  – PDF similar to those of quiet sun and plage region
  – Local dynamo process (Ishikawa and Tsuneta 2009)
Impact to solar dynamo

• Magnetic flux is transported to the polar regions with meridional flows and supergranular diffusion. Flux transport would be done via an aerodynamic (drag) force against magnetic tension force, and may be more difficult than the case for the mean field case.

• If the flux tubes seen on the surface of the Sun are maintained inside the Sun, they may affect a known difficulty in $\Omega$-mechanism to generate intense toroidal field
  – an amplification factor of 100 that is needed to explain a combination of 1kG poloidal field with 100kG toroidal field may be achievable within a solar cycle.
  – There remains, however, a serious energetic problem.
Stokes Q black polarity = North-South magnetic component

Polar flux tube Fanning-out structure

Stokes V dominant black polarity = magnetic field away from the Sun

(b) Stokes Q

Unipolar structure in Stokes Q

(c) Stokes U

Bipolar structure in Stokes U & V

(d) Stokes V
Milne-Eddington least-squares fit

• To minimize the influence of noise, fitting is performed for pixels whose \( Q, U \) or \( V \) signals are larger than 5 sigma.
  – 10.5\% of the area meets the criteria.
• Formation layer at 80 degree latitude is approx. 100 km above the nominal height.
• \textit{ME} works fine for the extreme limb!
• Parameters
  – vector magnetic field (strength, inclination angle, and azimuth angle), the line of sight velocity, two parameters describing the source function, the line-to-continuum absorption coefficient ratio, Doppler width, damping parameter, stray light factor(filling factor)
Stokes-Q

N

E

W

S

minus minus minus

plus plus plus