A Long-term Sunspot Magnetic Field Decrease

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Dark umbral cores observed
• Magnetostatics can be used to describe horizontal pressure balance between spot and surrounding solar photosphere.
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\[ P_p = n k T_p \]

\[ P_s = n k T_s + \text{magnetic pressure} \]
If sunspot magnetic fields changed, and the solar photosphere remained constant, then the sunspot temperatures should also change: this would impact the sunspot intensities, and the abundance of molecules.

Solid: 18 Sep 98, $I = 0.55 \ I_{qs}$
Dashed: 27 Dec 05, $I = 0.78 \ I_{qs}$

\[
\frac{1}{8\pi} (B_z^2(r) + F_c(r)) = nk(T_p - T_s(r))
\]

Jaeggli 2009
KPVT data archive

First work: 4000 spots: $I_{	ext{min}}, N_{	ext{umbra}}$

Current work: 13,000 spots, $I_{	ext{min}}, N_{	ext{umbra}},$ Magnetic Field
Although variations in Intensity were seen, no radius change was seen in this sample from the archive.

This was in conflict with well-known empirical B vs radius correlations.
\[
\frac{1}{8\pi} (B_z^2(r) + F_c(r)) = nk(T_p - T_\theta(r))
\]
### Structural Invariance of Sunspot Umbrae over the Solar Cycle

#### Table 2  Magnetic field versus intensity power-law fit parameters.

<table>
<thead>
<tr>
<th>Cycle Phase</th>
<th>$N$ spots</th>
<th>Const.</th>
<th>Exponent</th>
<th>$\chi^2/N$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KPVT/SPM Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falling (March 93 – September 96)</td>
<td>884</td>
<td>855 ± 20.1</td>
<td>$-0.680 ± 0.029$</td>
<td>0.0319</td>
</tr>
<tr>
<td>Rising (October 96 – March 01)</td>
<td>3832</td>
<td>824 ± 10.0</td>
<td>$-0.731 ± 0.015$</td>
<td>0.0096</td>
</tr>
<tr>
<td>Falling (April 01 – September 03)</td>
<td>3360</td>
<td>797 ± 9.9</td>
<td>$-0.711 ± 0.015$</td>
<td>0.0090</td>
</tr>
<tr>
<td>Minimum (1995 – 1997)</td>
<td>435</td>
<td>858 ± 29.4</td>
<td>$-0.703 ± 0.042$</td>
<td>0.0909</td>
</tr>
<tr>
<td>Maximum (2000 – 2002)</td>
<td>4268</td>
<td>813 ± 8.9</td>
<td>$-0.710 ± 0.013$</td>
<td>0.0064</td>
</tr>
<tr>
<td>All data (1993 – 2003)</td>
<td>8076</td>
<td>817 ± 6.8</td>
<td>$-0.716 ± 0.010$</td>
<td>0.0042</td>
</tr>
<tr>
<td><strong>McMath-Pierce IR Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falling (April 01 – June 05)</td>
<td>698</td>
<td>1465 ± 22.6</td>
<td>$-0.520 ± 0.014$</td>
<td>0.0291</td>
</tr>
<tr>
<td>Maximum (2000 – 2002)</td>
<td>156</td>
<td>1317 ± 144</td>
<td>$-0.612 ± 0.083$</td>
<td>0.0364</td>
</tr>
<tr>
<td>Minimum (2005 – 2007)</td>
<td>340</td>
<td>1467 ± 77.6</td>
<td>$-0.522 ± 0.071$</td>
<td>0.0084</td>
</tr>
<tr>
<td>All data (April 90 – March 08)</td>
<td>1084</td>
<td>1463 ± 13.3</td>
<td>$-0.523 ± 0.009$</td>
<td>0.0270</td>
</tr>
</tbody>
</table>
The automated sampling also showed that the B vs. radius relationship remained constant through solar cycle 23.
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• Only small changes were seen in $I$ and $B$ vs. time in the larger sample, but importantly the change seen were fully accounted for by changes in the radius.
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• Conclusion: the fundamental structure of a sunspot doesn’t change through the cycle… the only support for the IR measurements is a slightly changing mean radius.
Normalized Spot B Distribution

2010 Spots

Cycle 23

Number

Magnetic Field [Gauss]

1000 1500 2000 2500 3000 3500
Normalized Spot B Distribution

2010 Spots
Conservative interpretation

- The distribution of the sunspot magnetic fields during the declining phase of the sunspot cycle are different from the fields during the rise phase of the sunspot cycle.
Cycle 23
...possible implication

• Making three assumptions:
  – Livingston’s cycle 23 IR measurements represent the “true” sunspot magnetic field probability distribution function
  – There is a real physical cut-off so that no sunspots form with maximum magnetic fields less than 1500G
  – The decrease in the mean field continues

• …then Solar cycle 24 will peak with a spot number of 57, and cycle 25 will peak with a spot number of 3.
Critical observations

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  – Will umbrae with B>3000G return?
  – Will most cycle 24 spots have B<2000G?
• Efforts are underway to cross-calibrate Livingston’s observations with 2-D maps of the IR sunspot magnetic fields from the NAC.