The persistence of apparent non-magnetohydrostatic equilibrium in NOAA 11035

Sarah A. Jaeggli

made possible by
The Thomas Metcalf SPD Travel Award
The persistence of apparent non-magnetohydrostatic equilibrium in NOAA 11035

Sarah A. Jaeggli

made possible by
The Thomas Metcalf SPD Travel Award

IAU Symposium 305 ~ Punta Leona ~ 2014 Dec 1
NOAA 11035

- Rapid emergence starting 14-15 Dec 2009
- Very early cycle, high latitude, large tilt
- Highly sheared configuration
- Produced several small flares
- Decays as it reaches the limb on Dec 20-21

Observed with:
- TRACE 171 Å Whitelight
- SOHO MDI Ni I 6767 Å
- Hinode SOT/FG Ca II H 3968 Å Na I 5896 Å
- Hinode SOT/SP Ni I 6767 Å H I 6563 Å
- DST/FIRS Fe I 6302 Å Fe I 6302 Å
- DST/IBIS He I 10830 Å Fe I 15650 Å
- Ca II 8542 Å
Overview of evolution
Overview of evolution
Overview of evolution

*not associated with a GOES x-ray source
Photospheric magnetic fields

2009-12-17 13:30 - 13:54

Hinode SOT/SP Fe I 6302 I
Merlin

Hinode SOT/SP Fe I 6302 B
Merlin
Photospheric magnetic fields

2009-12-17 13:30 - 13:54

Hinode SOT/SP Fe I 6302 I
Merlin

DST FIRS Fe I 15650 I
2CMO

Hinode SOT/SP Fe I 6302 B
Merlin

DST FIRS Fe I 15650 B
2CMO
Chromospheric structure
Chromospheric structure

FIRS He I 1083 nm 2009–12–18 16:44:42–17:08:10

0.5 < Continuum Intensity < 1.05

-0.3 < Line Amplitude < 0

SOT/FG
Ha 6563 Å

-10 < Velocity < 10 km/s

0 < Width < 15 km/s
Problem?

• In General:
  • Magnetic fields are:
    • strong and vertical in the umbra
    • weak and horizontal in the penumbra
  • Strong horizontal fields cannot be maintained because of buoyancy
  • For magnetic pressure balance we must be seeing something at an equivalent pressure of at least

\[
(3800 \text{ G})^2/8\pi = 5.7 \times 10^5 \text{ dyn/cm}^2
\]

\[z \sim 375 \text{ km below } \tau [500\text{nm}] = 1 \text{ in the Spruit convective model (Spruit 1974 Sol. Phys.)}\]
Magnetostatic equilibrium

Say we have a horizontal magnetic tube

\[ P_{\text{out}} = P_{\text{in}} + \frac{1}{8\pi} \left( B_z^2(r, z) + F_c(r, z) \right) \]
Say we have a horizontal magnetic tube

\[ P_{out} = P_{in} + \frac{1}{8\pi} \left( B_z^2(r, z) + F_c(r, z) \right) \]

and assuming

\[ P_{out} = P_{in} \]
Magnetostatic equilibrium

Say we have a horizontal magnetic tube

\[ P_{out} = P_{in} + \frac{1}{8\pi} \left( B_z^2(r, z) + F_c(r, z) \right) \]

and assuming

\[ P_{out} = P_{in} \]

then

\[ -B_z^2(r, z) = F_c(r, z) = 2 \int_{r}^{a} B_z(r', z) \frac{\partial B_r(r', z)}{\partial z} dr' \]
Magnetostatic equilibrium

assume a functional form with no radial dependence
Magnetostatic equilibrium

assume a functional form with no radial dependence

\[ B_z(z) = F_c = 2B_z(z) \frac{\Delta B_r(z)}{\Delta z} \alpha \]
Magnetostatic equilibrium

assume a functional form with no radial dependence

\[ B_z = F_c = 2B_z(\hat{z}) \frac{\Delta B_r(\hat{z})}{\Delta \hat{z}} \alpha \]

say

\[ \alpha \sim \Delta \hat{z} / 2 \]
Magnetostatic equilibrium

assume a functional form with no radial dependence

\[ B_z \begin{cases} = F_c = 2B_z(z) \frac{\Delta B_r(z)}{\Delta z} a \end{cases} \]

say \( a \sim \Delta z / 2 \)

then \( -B_z \sim \Delta B_r \)
Magnetostatic equilibrium

assume a functional form with no radial dependence

\[ -B_z^2 = F_c = 2B_z(z) \frac{\Delta B_r(z)}{\Delta z} a \]

\[ a \sim \Delta z/2 \quad \quad \quad \quad -B_z \sim \Delta B_r \]

then at \( z \) where \( B_z = \max(B_z) \), \( r=0 \)
Are the inversion results accurate?
2CMO inversion code

- “2 Component Magneto-Optical” inversion code
- Milne-Eddington inversion code with model options (QS, 1M, 1M+QS, 1M+SL, 2M, 2M+SL)
- comparable to MERLIN

**Magnetic Component**
- $B_0$: source function
- $B_1$: source function gradient
- $\lambda$: wavelength
- $\Delta \lambda$: doppler width
- $a$: damping parameter
- $\eta_0$: line to continuum absorption ratio
- $B$: magnetic field strength
- $\gamma$: magnetic field inclination
- $\phi$: magnetic field azimuth

**Non-Magnetic Component**
- $B_1$: source function gradient
- $\lambda$: wavelength
- $\Delta \lambda$: doppler width
- $a$: damping parameter
- $\eta_0$: line to continuum absorption ratio
2CMO inversion code

- “2 Component Magneto-Optical” inversion code
- Milne-Eddington inversion code with model options (QS, 1M, 1M+QS, 1M+SL, 2M, 2M+SL)
- comparable to MERLIN

**Magnetic Component**
- $B_0$: source function
- $B_1$: source function gradient
- $\lambda$: wavelength
- $\Delta \lambda$: doppler width
- $a$: damping parameter
- $\eta_0$: line to continuum absorption ratio
- $B$: magnetic field strength
- $\gamma$: magnetic field inclination
- $\phi$: magnetic field azimuth

**Non-Magnetic Component**
- $B_1$: source function gradient
- $\lambda$: wavelength
- $\Delta \lambda$: doppler width
- $a$: damping parameter
- $\eta_0$: line to continuum absorption ratio
Inversion results
Suspicious Profiles

fit with 1 magnetic, 1 non-magnetic components
Hinode SOT/SP
Suspicious Profiles

fit with 2 magnetic, 0 non-magnetic components
Hinode SOT/SP

Fe I  Fe I

I  Q  U  V

B: 5 G  0°  159°  -0.39 km/s

I

B: 2327 G  66°  34°  -0.50 km/s

Q

B: 2835 G  78°  173°  -0.91 km/s

U

B: 3621 G  71°  24°  -0.23 km/s

V

B: 1084 G  130°  92°  -4.14 km/s

[I] > 3000 G

|B| > 3000 G
Results

• Magnetic field is 3600 G strong in 2C inversion, 3800 G strong in 1C inversion

• Complexity in profiles is obvious

• Component 1: Material in the photosphere is flowing up at ~4 km/s along vertical field lines

• Component 2: Small Doppler velocities and horizontal field

• There is optically thick, filamentary structure above the pore in the chromosphere
Interpretation

Coalescence

Migration
Interpretation

Coalescence

Migration
Interpretation

Upflowing, dense material
Interpretation

Upflowing, dense material

Contracting loops, flux pile-up
Conclusions

• Slow, continuous reconnection is happening in the photosphere

• Magnetic tension force on the contracting loops is significant

• This can be verified in detail because the horizontal gradient is known
Acknowledgements

Thanks to:

• The generous support of the AAS/SPD Thomas Metcalf Travel Award

• DST observing staff (J. Elrod, D. Gilliam, M. Bradford), and the TRACE and Hinode SOT planners for picking good targets

• V. Martinez-Pillet, H. Lin, P. Judge, C. Kankelborg, D. Longcope, L. Tarr for useful discussion

The work of S. Jaeggli is supported by the NASA/IRIS mission via sub-contract from LMSAL to MSU
Suspicious Profiles

**Fe I**

<table>
<thead>
<tr>
<th>B</th>
<th>γ</th>
<th>φ</th>
<th>v</th>
<th>I/Q/U/V</th>
</tr>
</thead>
<tbody>
<tr>
<td>583 G</td>
<td>90°</td>
<td>135°</td>
<td>0.32 km/s</td>
<td></td>
</tr>
<tr>
<td>2498 G</td>
<td>61°</td>
<td>10°</td>
<td>-0.09 km/s</td>
<td></td>
</tr>
<tr>
<td>0 G</td>
<td>0°</td>
<td>106°</td>
<td>0.81 km/s</td>
<td></td>
</tr>
<tr>
<td>3804 G</td>
<td>89°</td>
<td>8°</td>
<td>-0.63 km/s</td>
<td></td>
</tr>
<tr>
<td>2206 G</td>
<td>124°</td>
<td>31°</td>
<td>-3.06 km/s</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- B: 3D magnetic field strength (G)
- γ: Inclination angle of magnetic field
- φ: Rotation angle
- v: Radial velocity (km/s)

**Image:**
- [BL > 3000]
Hinode Ca I/Na I and Ca I/H alpha movies
Hinode Ca I/Na I and Ca I/Halpha movies

TRACE Whitelight

2009-12-18T16:45:01.325