The Sun's Magnetic Atmosphere

Dana Longcope

Department of Physics
Montana State University
Outline

I. In what state is the magnetic field when it enters the atmosphere?
   Twist / Current / Helicity

II. How does its state affect the atmosphere?
    Propagation of Twist / Current / Helicity

III. What kind of atmosphere does it create?
     Magnetic Flux / X-ray flux relation

IV. How does this happen? Reconnection

Imprint of the magnetic field on the atmosphere
I. How sunspots are born

- generated in dynamo layer (tachocline)
- mostly toroidal (E-W)
- forms slender flux tubes
- emerge buoyantly through convection zone

- Hale’s law (E-W)
- Joy’s law (tilt)
- Proper motion after emergence

Emerging flux - simply

Interpretation: rising flux tube
The importance of twist

(Abbett Fisher & Fan, 2001)
Twist in the magnetic field

\( \alpha_{\text{best}} < 0 \)

in North

\( \alpha_{\text{best}} > 0 \)

in South

( courteous Hinode )

\[ \alpha = \frac{J_z}{B_z} \]

466 ARs from Longcope & Pevtsov 2003
Source of Twist

Left-handed deformation of axis

⇒ Right-handed twist (current)

Helicity Conservation

\[
\frac{dT_w}{dt} = -\frac{dW_r}{dt}
\]
II. Emergence

(Abbett & Fisher 2003)
Coupling flux tube to corona

Low-\(\beta\) coronal
Equilibrium: FFF

High-\(\beta\) CZ
Field: twisted
Thin flux tube
Coupling flux tube to corona

**corona:** $\beta << 1$

(force-free field)

**CZ:** $\beta >> 1$

(thin flux tube)
Coupling flux tube to corona

Radial shunting

\[ \Sigma \text{torques} \neq 0 \]

rarefaction pulse

(Longcope & Weslch 2000)
Observational Evidence
(Pevtsov, Maleev & Longcope 2003)

Fit Model to Data

\[ v = 264 \text{ m/s} \]

\[ \bar{\alpha} = 2 \times 10^{-8} \text{ m}^{-1} \]
\[ v_A = 158 \text{ m/s} \]

\[ \alpha(t) = \bar{\alpha} \frac{v}{v+1} \left[ 1 - \left( \frac{d}{d_0} \right)^{-(v+1)} \right] \]
corona

photosphere

courtesy D. Alexander
Net effect: helicity

\[ H = \int_{\text{corona}} \mathbf{A} \cdot \mathbf{B} \, d^3x = \Phi^2 N_{\text{twist}} \]

\[ \frac{dH}{dt} = -\frac{\Phi^2}{2\pi} \frac{d\theta}{dt} \]

Longcope, Ravindra & Barnes 2007
III. The corona

EUV image (17.1 nm) ~ 1,000,000 K

Fe X

Aug 11, 2001

obvious suspect: magnetic field

June 3, 2008
X-ray bright points

Golub et al. 1977, Harvey 1985

June 3, 2008
Magnetic features of all sizes

(Pevstov et al. 2003)

more magnetic flux

→ more X-ray flux
A Consequence

Yohkoh

(Stern, Alexander & Acton 2003)
What does not explain it

Fisher et al. 1998
What might: reconnection
Longcope & Kankelborg 1999

Photospheric flux concentrations sources of coronal field

June 3, 2008
When 2 Poles Collide

All field lines from positive source P1

All field lines to negative source N1
June 3, 2008

Poles approach
When 2 Poles Collide

June 3, 2008

Poles approach: domains intersect
When 2 Poles Collide

Reconnection = new field lines
• Transfer flux: $\Delta \Psi$
• In presence of coronal current $I$
• Release energy

$$\Delta W = I \Delta \Psi$$
Reconnection from emergence

Emergence: (Longcope et al. 2005)
Why this is reconnection

Baum & Bratenahl 1976

Reconnected flux

Emerged flux

Old flux
Quasi-static Evolution

I=42 GA

I=88 GA

I=5 GA

No reconnection

Δψ

Δψ
Heating then cooling

Yohkoh SXT

Hot (~7.5 MK) after reconnection...
Cool into TRACE pass-band

movie

TRACE 171 A

EM

T

$\tau \sim 10$ hrs

June 3, 2008
Reconnection observed

24 hour delay

Heating \( \sim 5 \times 10^{26} \) erg/sec

\( \Delta \psi = 10^{21} \) Mx

Reconn’n burst

10^{17} \) Mx/sec
Summary

- Magnetic field reaches atmosphere from dynamo layer as slender, twisted tubes
- Twist (current) emerges into corona
- Field produces hot corona: power related to magnetic flux
- Coronal response to flux changes & emergence (reconnection) supplies heat