Escape of Magnetic Helicity from the Sun

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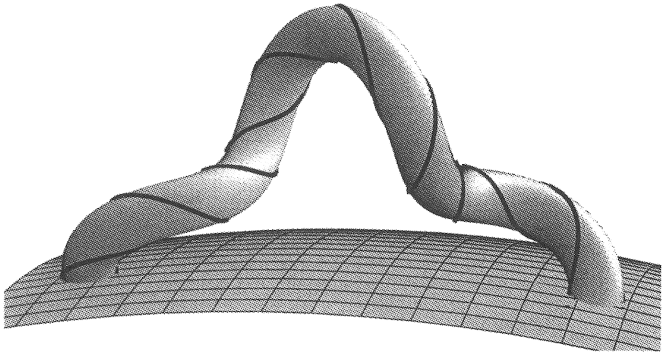
Abstract

Magnetic helicity provides a unifying thread for understanding solar activity. Where does it come from and how does it escape the sun?

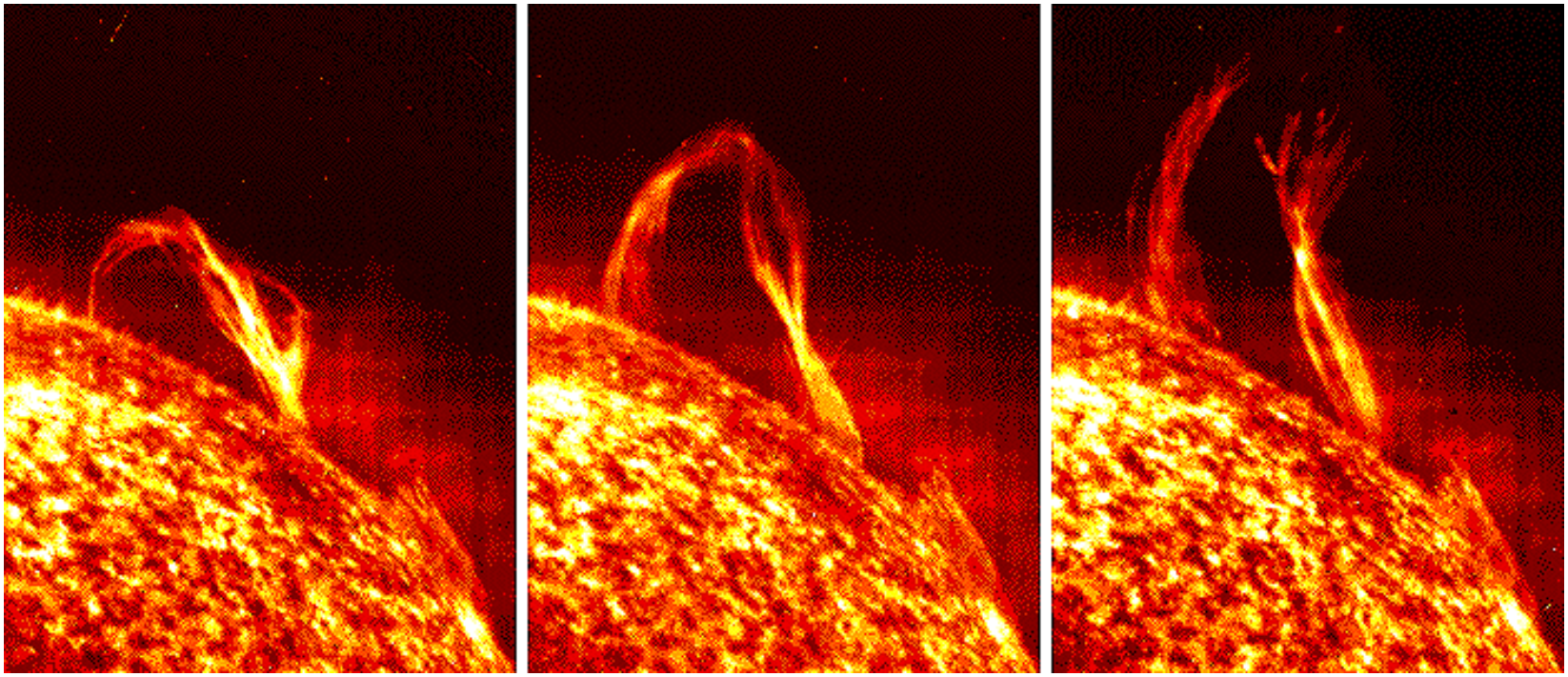
Basics of Magnetic Helicity

- **Magnetic helicity $H_m = \int \mathbf{B} \cdot \mathbf{A}\, dV$ (quantifies field twist and distortion)**
- **For a flux rope: H_m = (Twist + Writhe) *x* (Magnetic Flux)^2**



- **Magnetic clouds are very much like force-free flux ropes**
- **H_m is conserved even in non-ideal MHD**
- **H_m is conserved in the sun and heliosphere**
- ***Magnetic helicity in interplanetary space = magnetic helicity escaping the sun***

Example of an erupting filament that appears to have writhe and twisted elements



Empirical Facts about Solar Helicity

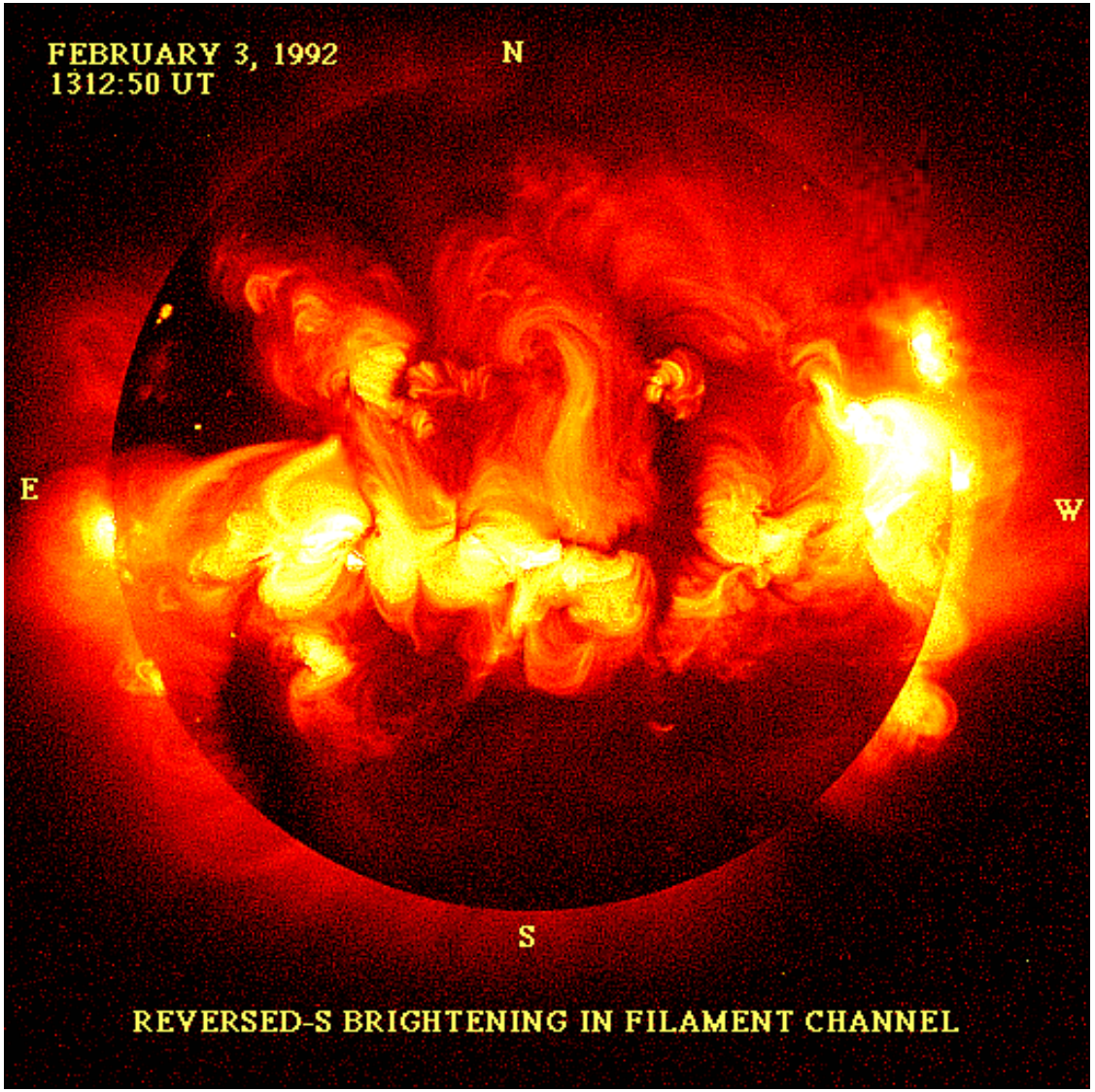
- **Hemispherical Rule: H_m is mostly positive in the south and negative in the north**

- **Sigmoids probably reflect writhe (kink instability) in twisted flux ropes: S-shape in south; Z-shape in north**

- **Chirality (sign of H_m) and flux of sigmoids and eruptive filaments = chirality and flux of corresponding magnetic clouds**

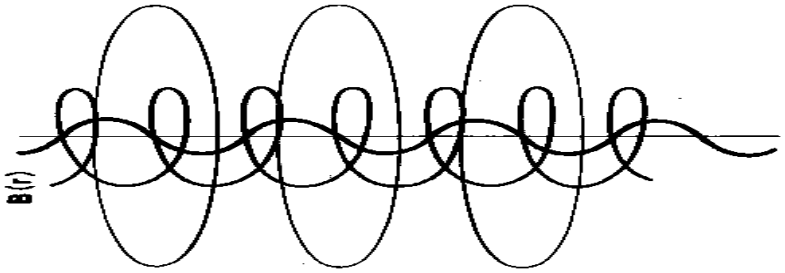
- **Orientation of filament and clouds' axial fields agree and are most often E - W**

- **Conclusion: toroidal magnetic flux is ejected into the heliosphere This accounts for the observed 'overwinding' of the Parker spiral**


FEBRUARY 3, 1992
1312:50 UT
N
E
W
S
REVERSED-S BRIGHTENING IN FILAMENT CHANNEL

Estimating Solar H_m Loss from Magnetic Cloud Measurements

- **Lundquist force-free flux rope model: $H_m = 0.60\, B_0^2 r_0^3 l$**



- **$\langle H_m \rangle = 2 \times 10^{42}$ Mx^2 per MC (Lepping et al. 1990; Lynch et al. 2002)**
- **1000 – 5000 MCs per solar cycle carry off 2×10^{45} to 10^{46} Mx^2 of helicity**
- **Consistent with H_m leakage from an $\alpha\Omega$ dynamo**

Magnetic Helicity is Produced by the Solar Dynamo

- **Internal differential rotation and zonal flows generate helicity**
- **Models are now constrained to produce positive H_m in the south and negative H_m in the north**
- **Estimates of H_m flow per solar cycle: 10^{46} - 10^{47} Mx^2 from both hemispheres**
- **Since magnetic energy $E_m \sim H_m r_o^{-1}$, flux rope expansion under helicity conservation can heat coronal plasma, as observed in X-ray and EUV images**
- **Blackman and Field (2000) estimate a lower limit on magnetic energy deposited in the corona by the helicity flow ~ 10^{28} ergs/s**

Magnetic Helicity of Active Regions

- **Flow of helicity from the photosphere**

$$\frac{dH_m}{dt} = -2\int_S [(\mathbf{A}_0 \bullet \mathbf{v})\mathbf{B} - (\mathbf{A}_0 \bullet \mathbf{B})\mathbf{v}] \bullet d\mathbf{S}$$

footpoint motion **emergence**

- **Estimate of AR helicity budget (e.g., Démoulin et al. 2002)**

$$\Delta H_{emergence} + \Delta H_{diff.\ rot.} = N_{CMEs} H_{CME} + \Delta H_{corona}$$

- **Determine ΔH_{corona} by fitting force-free fields to soft x-ray loops**

- **<u>Conclusion:</u> Differential rotation makes a negligible contribution.**

Emergence of Twisted Flux Ropes

- **Follow analogy to thermodynamics (Bellan 1999):**

$$thermal\_flux = -k\nabla T$$

$$helicity\_flux = -D_k \nabla \alpha$$

- **Conclude that H_m flows from photosphere to corona until $\alpha_{corona} = \alpha_{photosphere}$**

- **Pevtsov et al. (1997) verified equality of α in corona and photosphere**

Conclusions

- **Magnetic Helicity Conservation ties many things together**
- **H_m from an Internal Dynamo emerges through the photosphere**
- **H_m collects in the corona and destabilizes magnetic structures**
- **Helicity Conservation in Flux Ropes unifies understanding of Hα filaments, X-ray and EUV Sigmoids, CMEs and Magnetic Clouds**