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Role of Magnetic Carpet in Coronal Heating

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Abstract. One of the fundamental questions in solar physics is how the solar corona maintains its high temperature of several million Kelvin above photosphere with a temperature of 6000 K.

Observations show that solar coronal heating problem is highly complex with many different facts. It is likely that different heating mechanisms are at work in the solar corona. The separate kinds of coronal loops may also be heated by different mechanisms.

Using data from instruments onboard the Solar and Heliospheric Observatory (SOHO) and from the more recent Transition Region and Coronal Explorer (TRACE) scientists have identified small regions of mixed polarity, termed magnetic carpet contributing to solar activity on a short time scale.

Magnetic loops of all sizes rise into the solar corona, arising from regions of opposite magnetic polarity in the photosphere. Energy released when oppositely directed magnetic fields meet in the corona is one likely cause for coronal heating. There is enough energy coming up from the loops of the "magnetic carpet" to heat the corona to its known temperature.

Key words. Sun—corona—magnetic field—magnetic carpet—reconnection.

1. Introduction

How the nature of the processes that heat the corona, maintain it at this high temperature and accelerate the solar wind is a great solar mystery. Usually temperatures fall as we move away from a heat source. This is true in the Sun's interior right up to visible surface. Then, over a relatively small distance, the temperature suddenly rises to extremely high values. This high temperature of corona requires a permanent heating mechanism. There is no definite answer to this question yet, but there are some questions, which can help us to follow this track.

- Where does the energy come from?
- How does the energy get up into the corona?
- How is the energy released in the corona?
- How can we model this heating using physics, mathematics and computer?

There are some clues to help us know how the temperature changes as we go higher in solar atmosphere.

- All energy from the Sun is produced in the solar core – far below the solar atmosphere.
- The laws of thermodynamics suggest that heat energy from a gas of a high given temperature cannot normally be used to heat another gas to a higher temperature.

From the above discussions it is clear that the temperature of corona requires energy by non-thermal processes because simple laws of physics prevent heat from flowing directly from solar surface or photosphere, at about 6000 Kelvin to much hotter corona at about 1 million to 2 million Kelvin.

Two classes of models have been proposed namely magnetic waves (Goossens 1991; Roberts 1991) and magnetic reconnection (Priest *et al.* 2000) to explain the coronal heating.

2. Recent space observations

Using data from instruments onboard the Solar and Heliospheric Observatory (SOHO) (Kohl *et al.* 1997) and from the more recent Transition Region And Coronal Explorer (TRACE) (Nakariakov *et al.* 1999), solar physicists have identified small patches of magnetic field covering the entire surface of the Sun. Contrary to the bright, large magnetic field loops which are linked to the "active regions" during periods of solar maxima, these patches seem to appear and disappear randomly in time scales of the order of 40 hours. Scientists now think that this magnetic carpet is probably a source of the corona's heat.

According to recent observations, the 'magnetic carpet' shows a very dynamical evolution: photospheric magnetic fields constantly move around, interact with each other, dissipate and emerge at very short periods of time.

3. How is reconnection working in corona?

Magnetic reconnection between magnetic fields of opposite polarity may change the topology of the field and release magnetic energy. The reconnection process will also result in the dissipation of electric currents which will transform electric energy into heat.

Understanding how the magnetic field interacts with plasma is the key to many solar phenomena including coronal heating.

Reconnection is a fundamental process in a plasma. It

- changes the topology,
- converts magnetic energy to heat/K.E,
- accelerates fast particles.

The heating of the corona is linked to the interaction of the magnetic field lines radiating out of the small patches mentioned above. Because the laws of electromagnetism prohibit the intersection of two magnetic field lines, every time magnetic field lines come close to crossing they are "rearranged", and this magnetic reconnection continuously heats the solar corona. It is a fairly inefficient source of energy, but the sheer number of these small magnetic patches on the surface of the Sun makes the process a viable solution to the 50-year old problem of what heats the solar corona.

Over the years several different mechanisms of heating corona have been proposed using Reconnection Theory as listed below:

(i) Drive Simple Reconnection (Priest & Forbes 1986; Priest *et al.* 2000)
At nullpoint by photospheric motion
X-ray bright point supported by TRACE

(ii) Binary Reconnection (Parker 1979, 1994)
Relative motion of pairs of sources in the solar surface
Suppose unbalanced and connected.

(iii) Separator Reconnection (Longcope & Cowley 1996; Longcope & Silva 1998)
High order interaction between several sources
Initially unconnected

(iv) Braiding (Parker 1979, 1994)
Parker's Model
Initial B uniform/motions braiding
In this paper we are discussing the Tectonic model of Coronal Heating.

4. Coronal tectonics

Reconnection can be driven at many of the separatrix that separate from each other all the tiny narrow elementary coronal loops whose foot points are the intense flux tubes (Priest *et al.* 2000). The driving will be by the lateral relative motion, the fragmentation and the cancellation of the minute magnetic fragments in the photosphere. The formation and dissipation of current sheets on separatrix surfaces are referred as "flux-tube tectonics". The behaviour of majority of the photospheric magnetic flux in the quiet Sun is that it emerges as ephemeral regions, which split into network elements. Each network consisting of about 10 unresolved intense flux tubes, and that the flux then migrates to the boundaries of supergranule cells and moves along them, fragmenting, merging and canceling.

4.1 *Dissipation of current sheets and rate of heating*

The shearing motions of flux elements at the photosphere cause current sheets to grow at the separatrices of the magnetic cells in the corona. These current layers either are very thin (two-dimensional case) or grow straight away as singularities (three dimensional case). Therefore, even ohmic dissipation will soon become very active, possibly enhanced by anomalous resistivity or reconnection in these sheets (Priest & Forbes 1986).

The heating power delivered by the coronal segment of a loop $2L$ and width of the order of the transverse size (2ω) of magnetic cells.

$$H_{\text{loop}} = \frac{4L\grave{u}L^2}{\ddot{a}\acute{o}}$$

where σ is the effective electrical conductivity of coronal plasma, I is surface current at the separatrix, and δ is sheet thickness in coronal region.

In the carpet region, at a distance r from the flux element, the width of the current channel scales as r/ω, and the contribution to the heating of the region that carries the surface current I from the loop to the flux source element scales as

$$H_{\text{carpet}} = \int_0^{\omega} 2\pi r r dr \frac{\delta r}{\omega} \frac{I}{\sigma} \left[\frac{I}{\delta(r/\omega)} \right]^2 = \frac{8\pi\omega^2 I^2}{\delta\sigma}.$$

5. Conclusions

The spreading with height above photosphere of the magnetic of the corona which is rooted in the solar surface in myriads of tiny magnetic fragments, intense flux tube of field strength $B = 1200\,\text{G}$ and radius 100 km is likely to have profound implications for the mechanism of coronal heating. Theoretical modeling and the latest space-based observations suggest that unresolved observations of coronal loops should exhibit enhanced heating near their feet in the carpet, while the upper parts of large-scale loops should be heated rather uniformly but less strongly.

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