Brett Lester

UPII Section H1

Dr. Stewart

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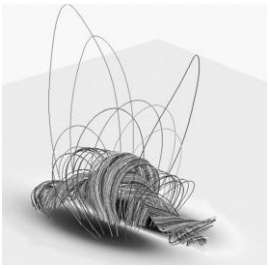
Magnetic Reconnection

Magnetic Reconnection has been used to explain solar events such as solar flares and coronal mass ejections (CME's) as well as terrestrial events like the Auroras. Magnetic Reconnection is the process in which two electric field interact with each other to find a mutually lower energy state. In order to return to a lower energy state the lines of one field will have to 'reconnect' with the lines of the second field. The creation of the two fields can be caused by interaction with solar wind with Earth's own magnetic field or the 'differential rotation' of the sun causing its field to overlap and tangle together[1,3,5]. Magnetic Reconnection can be observed using plasma outflows, plasma inflows, radio waves and chromospheric evaporation[3]

The distortion process produces ‘filaments’ and ‘flux ropes’. The figure to the right shows a mathematical model of a filament on the sun’s surface[4]. These are the twisted field lines that would be reconnecting.

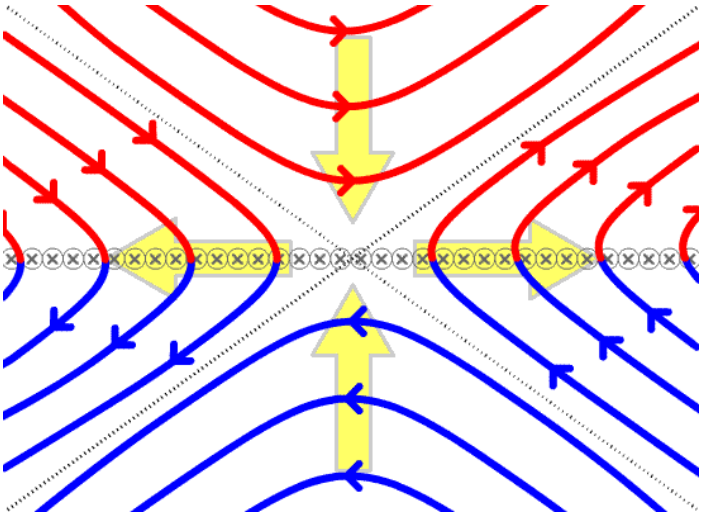


Mathematical model of a Filament on Solar Surface[4]

The flux ropes and filaments have been studied and are believed by some to be precursors of solar flares and CME’s[1,2,3]. Likewise current sheets (currents that move along a surface instead of a three-dimensional space) can provide similar reactions and are suspected to form before the emission process as well. The current sheets provide many points for a reconnection to occur; having current moving across a plane, the field loops around.

The directions of the fields in the filaments, sheets, and resulting solar flares are believed to be related to each other prior to the emissions of plasma[2]. If this is correct, this would allow not only a better prediction of when solar flaring may occur but also which direction the field of the flare points and whether or not it will have a large impact on Earth’s magnetic field.

The most common model of reconnection is shown in two-dimensions. The figure below shows the reconnection process. In this example the red lines are one field, and the blue another. The two fields are pointing in opposite directions at their interaction point. To fix this, the red and blue lines will disconnect and "reconnect" with the respective segment of the other. The newly formed electric field lines are to the left and right.

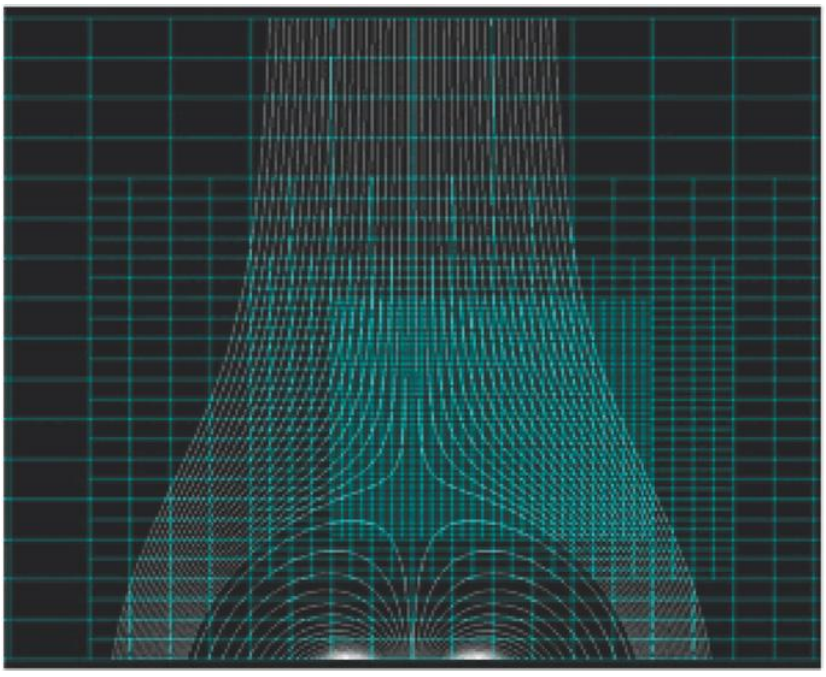


Cartoon of reconnection process[6]

The magnetic reconnection process creates plasma that moves with the field lines. The direction of the plasma's motion and field lines' motion is shown by the yellow arrows in the figure above. This illustrates the inflow and outflow of plasma occurring at a reconnection site. The out flowing plasma is measured to

have a large speed increase when compared to the inflowing plasma, giving evidence to the energy releases that occur and the role that magnetic connection may have in their occurances[2].

The following figure show a mathematical model of a three dimensional magnetic reconnection site involving two current sheets. It shows the fields on the y-z plane, and the reconnection is “translationally symmetric” along the x axis[2]. This allows for easier calculations and for viewing the model as a two-dimensional cross section.



3-D model of Current sheet interaction[2]

The Corona

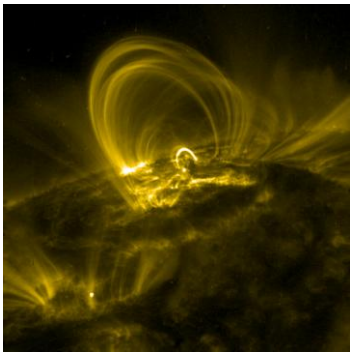
The Corona is the hottest layer of the sun, yet it is also the farthest from the core. Its temperatures range on average between 1MK to 3MK with a density is an order of 10^{-12} of the atmosphere, while the surface of the sun only reaches 5800K. These readings suggest the corona is not being heated by a thermal process. This is based upon the Second Law of Thermodynamics[5]. Temperature can be thought of as the collision of particles so to have both very low density but such a high temperature is a very difficult task. It is this counter intuitive find has created a problem for physicists.

Magnetic reconnection is being used to model the corona's heating process. The sun rotates at different speeds causing the field lines to become increasingly tangled. The electric field lines begin to cross or over lap and to return to their original state they must release the energy. This causes flows of plasma that are believed to greatly increase the temperature of the corona[2,3]. It is the increased speed of out flowing plasma resulting from the magnetic reconnection that provides the energy for the high temperature.

Solar Flares and CME's

Solar Flares, Magnetic Clouds and Coronal Mass Ejections are large amounts of the plasma emitted from the sun's surface, before mentioned as a possible result of the magnetic reconnection process believed to occur on the sun's surface. They are associated with the disappearing filaments and other erupting magnetic structures, and the disappearing filaments can be attributed to the magnetic reconnection.

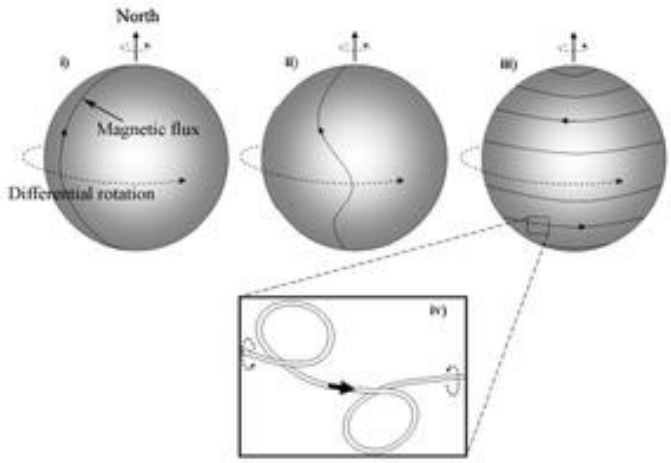
The plasma in the flares can form current sheets (currents that flow across a surface). The presence of these sheets in solar flares allows them to affect the earth's magnetosphere enough to start a magnetic reconnection with Earth's Magnetosphere. The field of the emitted flare or coronal mass emission needs to have a near anti-parallel field to that of the Earth's magnetosphere. This lessens the chance of anything more significant than the Earth's field being pushed from occurring when they encounter it[1,3].



Picture of a coronal loop[5]

To the left is a picture of a coronal loop that can be pushed off the sun's surface and become a Solar Flare.

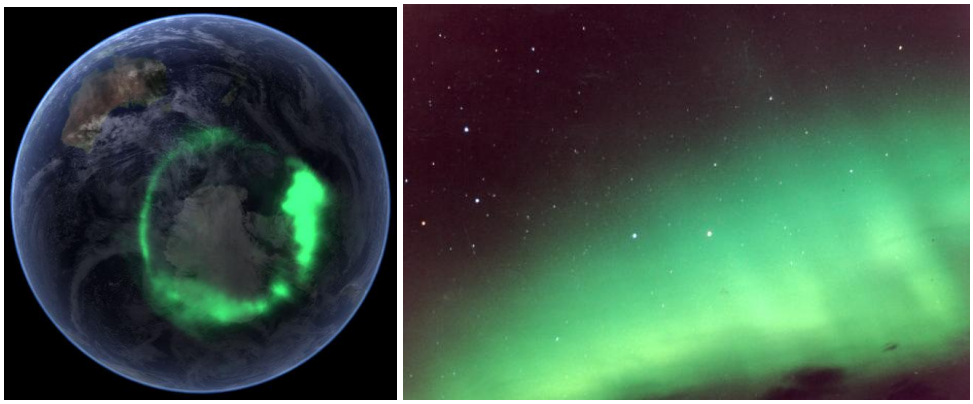
The sun has its own cycle that spans around approximately 11 years. At the end of the cycle the sun's field is greatly tangled and many Flares and CME's occur to return the field to a lower energy potential[1]. The figure below show the development of the entangled field lines on the sun's surface as the 11year cycle progresses.



Cartoon of Magnetic Flux during Cycle[5]

In the above figure the flux starts out circling the sun, but as time passed, the equator rotates further than the poles causing the distortion. By Image iii the lines are severely tangled and have developed into loops as shown in the magnified square.

The Auroras



Both photos from source 8

The interaction of solar flares with the earth's magnetosphere can cause the reconnection process to occur. It is when the fields of the earth and the flare are nearly anti-parallel that the chance is greatest[1]. The solar flare distorts the magnetic field of the Earth and can make a filament appear. The plasma is released during the reconnection of the Earth's field lines, resulting in an increase energy state in the atmosphere. This creates a 'Geomagnetic storm' with the atmosphere filled with the ionized particles from the reconnection process. To return to the lower states, the particles release photons. The resulting light is what we call the Auroras[8].

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2. J. K. Edmondson, S. K. Antiochos, C. R. DeVore and T. H. Zurbuchen, "Formation and Reconnection of Three-Dimensional Current Sheets in the Solar Corona," The Astrophysical Journal 718 (July 2010): 72-85.
3. Rui Liu, Jeongwoo Lee, Tongjiang Wang, Guillermo Stenborg, Chang Liu, and Haimin Wang, "A Reconnecting Current Sheet Imaged in a Solar Flare," The Astrophysical Journal 723 (November 2010): L28-L33
4. Sami K Solanki, Bernd Inhester and Manfred Schuessler, "The Solar Magnetic Field," Reports on Progress in Physics 69 (2006): 563-668.
5. "Solar Corona" last modified November 30, 2010 http://en.wikipedia.org/wiki/Solar_corona
6. "Magnetic Reconnection," last modified August 26, 2010, http://en.wikipedia.org/wiki/Magnetic_reconnection
7. "Current Sheet," last modified August 24, 2010, http://en.wikipedia.org/wiki/Current_sheet
8. "Aurora," last modified November 27, 2010, http://en.wikipedia.org/wiki/Aurora_(astronomy)