Solar Magnetism and Dynamics

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The Sun’s magnetism is an active and dynamic system with countless interactions with other celestial bodies, though this can have its consequences. In fact, solar dynamics and magnetism have a much greater effect on the earth and society than people take into account.

The thought of there being a “solar weather patterns” has been mentioned in countless records throughout the ages, the most detailed early description being in Medieval Europe. Upon first sight, people couldn’t understand the bright lights of what would come to be called an aurora. Many took these displays of light to be religious omens, rather than the result of charged particle collisions in the thermosphere. Actually, these auroras couldn’t be explained up until the 19th century, a time when telegraph use was in high demand. This is where the solar storm of 1859, also known as the Carrington Event, came into play. The largest geomagnetic storm on record, the event was caused by the change in the earth’s magnetic field due to a colossal solar flare that had occurred just before noon on September 1st. The flare forced a coronal mass ejection (CME) or solar wind towards the earth, reaching it in just 18 hours, far less than the predicted three or four days.[1] The storm ended up taking out telegraph systems across the nation as well as illuminating the night sky with bright red. The glow of the resulting auroras enveloped the Earth and could be seen from anywhere; it wasn’t until afterwards that connections between these auroras and the telegraph interference were drawn (Ex. Fig 1&2). Reports of the incident were collected from around the world and compiled for later research. It was such research that led to a much greater understanding of Sun-Earth reactions.

As mentioned before, in the early stages of meteorology and astronomy, the only true way to measure the effects of solar weather was to gather observations and come up with reasonable hypotheses. However, as greater technological advances were made in those fields, the uncertain aspects of hypotheses became theories with legitimate concrete support. Now, scientists can gauge different quantitative characteristics of the sun and the solar system using a wide array of special tools. The most common of these is the telescope, oftentimes fitted with custom lenses in order to detect ultraviolet and infrared light. Some are even so advanced that they can detect electromagnetic radiation from the Sun in addition to plain, visible light.[2]These telescopes are can be mounted in either observatories or satellites themselves for more precise readings. Other scientists use coronagraphs to measure the atmosphere of the sun. A coronagraph is a merely telescopic attachment that blocks direct light in the center of the telescope in order to resolve any interference from glare. To that end, other devices known as spectroscopes are used to identify the elemental makeup of certain objects based on the wavelengths of the light received from a certain object. There even exists a new technique of analyzing the composition of different objects. This new method, helioseismology, examines the propagation of solar waves in relation of their travel to earth. In terms of the Sun, this is an extremely effective method in detecting sunspots as it can measure both the near and far side of celestial bodies. Through the use of technological advances such as these, astronomers can assemble information to predict spatial weather patterns.

By far, the most essential factor in comprehending how the dynamic of space weather and magnetism come together is by understanding how the sun works in relation with Earth. This can become difficult, however, as the stellar magnetic field only becomes more intricate due to its size and shape; the movement of the plasma creates varied changes in the field from the center of mass uniformly throughout the star's photosphere, or origin of light. Constant variations in field produce the sunspots on the surface in addition to coronal loops, which lead back to the coronal mass ejections mentioned earlier. Depending on the size, speed, and composition of the ejections, these ejections can directly affect the living conditions on earth[3].

Through effective research and observations of the solar system, there has been the theorized the concept of a large magnetosphere. A magnetosphere is the region in space consisting of the solar wind plasma, the intrinsic magnetic field of other celestial bodies in the solar system, and what's known as the interplanetary magnetic field (Fig 6 & 7). The Earth's magnetosphere is formed most notably by the interaction with solar plasma, creating formations in the Earth's dipolar magnetic field. As seen in Figure 2, the field lines are compressed on the near side but stretched out on the far side, creating a shape that mimics a Doppler effect in relation to the distance from the Sun. Its outer boundary, known as a "magnetopause" is roughly shaped like a bullet and conforms to the total shape of the field[4]. As dynamic as the entire structure is, the main source driving various magnetospheric processes is the presence of the solar winds (Fig 3 &4). This energy is stored in the magnetotail and later released as small strong disturbances in space called substorms. Most of the energy is in fact transferred from solar wind to the magnetosphere through "reconnection", a process in which the interplanetary magnetic field is perpendicular or antiparallel to Earth's field lines (Trajectory, Fig 5). This lets a merging of field lines occur and creates an energy transfer "reaction", which can result in various geomagnetic effects.

With an upper level energy transfer comes the necessary introduction of a new topic: Aeronomy. This is the study of planetary atmospheres as well as the physical and chemical processes that entail. A multidisciplinary science, in strict terms of solar weather, consists of the deep solar reactions that take place regularly in the upper atmosphere, even more specifically, the ionosphere.[5]The ionosphere consistents of parts of the thermosphere, exosphere, and mesosphere, but is distinguished due to its ionization properties. Since this layer of the atmosphere becomes ionized by solar radiation, it has a very important role in helping to form the inner edge of the magnetosphere. It plays an even larger part in the atmospheric electricity that forms through the induction of the magnetic fields. After induction, energy is then transferred from the higher part of the atmosphere to the lower through a system of atmospheric tides. These are regarded as global-scale movements of the atmosphere are most excited by the day/night cycle and atmosphere insulation. Since part of the atmosphere is heated up while the other isn't, this switch between pressures generates tides that oscillate across the globe creating various changes in the ozone and stratosphere.[6] Other solar energy is absorbed through the troposphere; the combination of all of these factors creates a widely distributed, additionally dynamic system within the Earth's own atmosphere.

From here, the focus on the atmosphere shifts from upper to lower once again as the domino effect continues to synoptic scale meteorology. The aforementioned dynamic atmosphere in addition to solar and lunar tides creates weather fronts with help from the water cycle.

These weather fronts can be considered a direct result of periodic solar flares. Up until this point connections have been made from the center of the sun all the way to the troposphere. Any solar heat that was absorbed in the atmosphere would slowly increase temperature and raise air pressure in affected areas. The differences between high and low pressure zones would then cause movement; based on the geography and climate of the area, the interaction between these zones would create easily noticeable weather patterns[7]. This goes to show that the weather patterns seen today can be traced back to the presence of solar weather.

The geomagnetic storms created from all of these processes affect the earth in an assortment of ways, many of them being potentially detrimental to society. Recent research shows that solar weather as a whole can do damage to a wide range of systems, electronic and non-electronic, in space and on the ground.

Because of the complexity of the sun's magnetic field and the processes it's involved in, systems based in space stand a high chance of being damaged or destroyed from the high amounts of energy involved. Recently there have been a number of errors in spacecraft software because of remnants of geomagnetic storms. It seems that the most detrimental damage done to these space craft are electromagnetic charging and radiation. Recognized as "single event upsets" and "single event latchups" respectively, the development of these errors in isolated complex integrated circuits can put the livelihood of entire companies at stake. What's even more intriguing about this dilemma is the effect on low orbit objects just out of Earth's atmosphere.[8] Left unhindered, objects such as satellites would have an easily predictable trajectory based upon orbit decay and the Earth's magnetic field. Some of these objects even have small propulsion systems to help maintain a more constant orbit. If the geomagnetic storm were to occur, the result would be a heated thermosphere. This would, in turn, increase the density of Earth's atmosphere and thereby increase drag on the satellite. The cost of these malfunctions became all too clear in February 2010, when two such satellites collided with each other due to faulty systems and an inconstant orbit prediction. Space weather also has its effects on the ground systems, both inorganic and otherwise. Obviously the human body does not respond well to certain amounts of radiation, which can be an after effect of reduced ozone layer. This in itself is a result of the increased ultraviolet rays that can come from solar flares. Solar emissions such as these have been known to interfere with the Earth's magnetosphere in such a way that the Ozone layer is actually reduced after a certain period of exposure. Minute variations in ozone readings due to solar winds now may correlate with later more evident observations.

The sheer strength of some solar magnetic events tends to disrupt the Earth's ionosphere, disturbing the medium through which much satellite and radio information is transferred. Depending of the frequencies of some of the signals, oftentimes signals are received incorrectly, or not at all. Global Positioning Systems can easily have distorted signals with very significant consequences.[9] Long range radio signals are even more susceptible to unfavorable space weather as the medium for transmission can consist of more than one layer of the atmosphere. At certain latitudes and under the right (or wrong) circumstances, still the smallest solar event can disrupt and bend shortwave bands and sometimes reflect them back to their origin.

Underground processes don't go unaffected either, with numerous instances of power grid failures, the most notable of which occurred in Canada in 1989. The Hydro-Québec power failed because of an overloaded transformer.[10]As the grid fell, more than 5 million people lost their electricity, thereby creating an awful economic side effect in that region. As terrible as this seems, there would have been absolutely no preventative measure if a storm comparable to the Carrington Event had occurred. A storm that size would've knocked out power in almost all of eastern North America. Luckily, with the helpful aid of recently discovered technologies and safe uses, much more preventative tactics are being used to help ensure that outcomes like this don't happen again.

Though there are many procedures and systems that can be hindered by the presence of strong solar magnetism, new techniques and planning have been designed with safety and efficiency in mind. These include early detection systems with integrated space weather forecasts and magnetic data monitors that can be watched in case a solar flare is imminent and an operation has to be shut down. Adapting old technology to more advanced solar detection methods allow for the cost-effective use of equipment from a geophysical standpoint. In fact, some magnetic survey equipment integrates “measurement by drilling” technology[11].This is a profound way to use real time data to monitor drilling direction, a tactic that’s vital in the industries of oil and gas production.

Aircraft, as well as spacecraft, have also been taken into account; the development of stronger, less reactive materials have been introduced to the market in order to help dampen the effect of solar magnetism on radio signals and onboard electronics. Specialized flight paths have also been utilized by multiple airlines to greatly increase safety and avoid Polar Regions, known for their increased solar activity. The most proactive of all the countermeasures is the notion of space weather modeling. This is a simple concept in which computer models of space weather systems are created in hopes of creating sets of predictions and seeing how accurate they truly are. While early models seemed too crudely constructed, newer, more precise models have been made and tested with some of the most complex scenarios and have come out with more than reasonable theories/conclusion. These realistic systems all use a method called magnetohydrodynamics[12], or (MHD), which treats plasma in the vacuum of space as a fluid while it interacts with the Earth’s magnetic field. Multifaceted schemes like this can replicate the most detailed means of magnetic particle motion (Fig 8).

The exploration of space dynamics introduces a new and interesting aspect the almost every day interactions between the sun and the rest of the solar system. If it weren’t for the existence of a variable, dynamic magnetosphere, the Earth would be nowhere near sustainable enough for humans. There are far too many factors that go into what sustains the solar system, but at the very heart of it all lay the power of a rather “stellar” magnetic field.

Figures

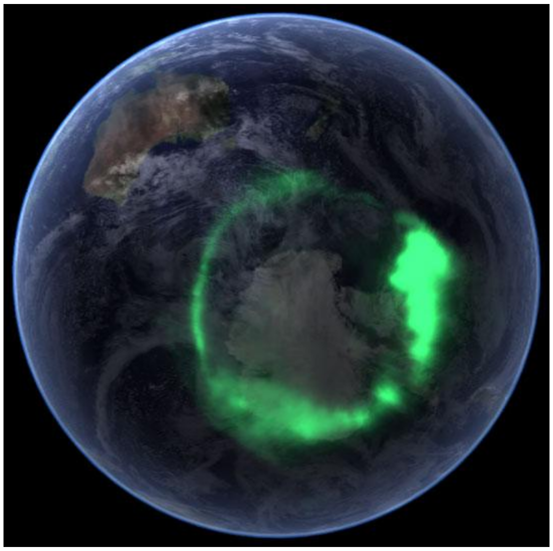


Figure 1: Satellite view of an aurora from space. Courtesy of NASA.gov

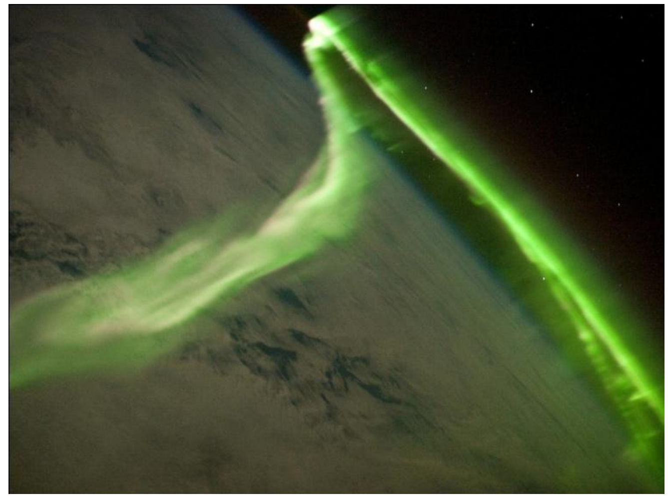
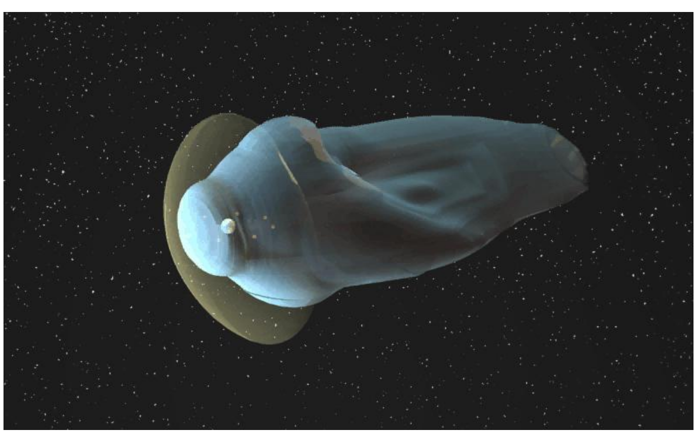


Figure 2: NASA photograph of aurora from space. Courtesy of NASA.gov

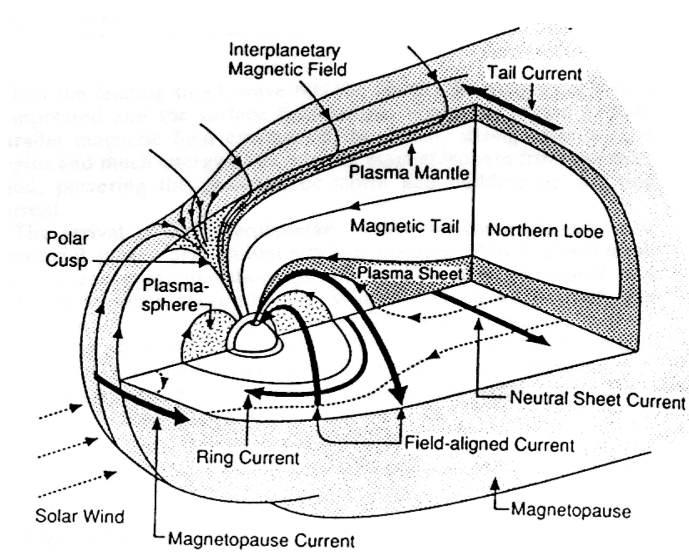
Figure 3: 3-dimensional artist's rendition of magnetosphere. Courtesy of land-of-kain.de



Figures (cont'd)

Figure 4: Cutaway of magnetosphere. Note the location and shape of the Magnetopause

Courtesy of springerimages.com



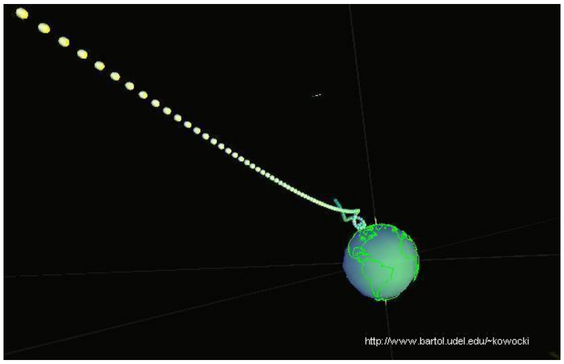


Figure 5: Computer generated trajectory of particle in magnetosphere. Courtesy of Wikipedia.org

Figure 6: Field diagram of interplanetary magnetic field. Courtesy of planetaryexploration.net

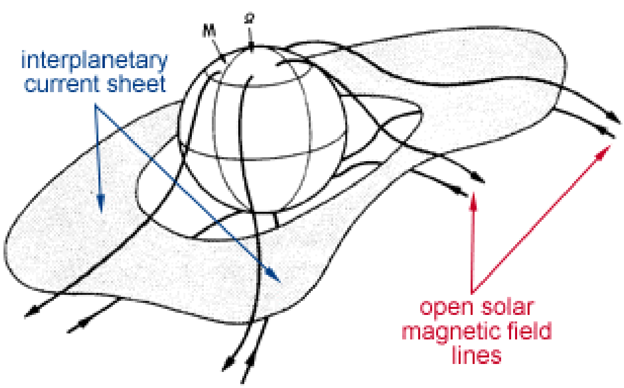


Figure 7: Field diagram of interplanetary magnetic field. Courtesy of Wikipedia.org

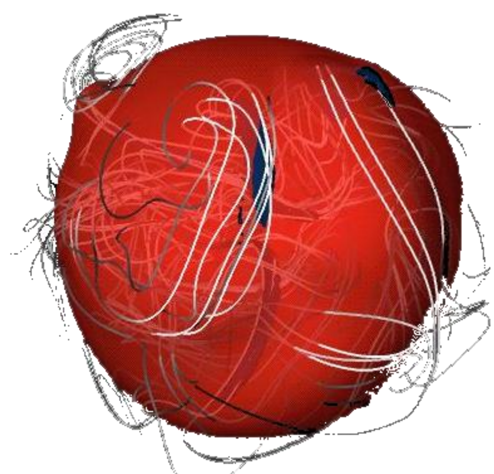


Figure 8: Computer generated image of magnetic field lines of a magnetohydrodynamic

Courtesy of Wikipedia.org

Notes

1. David Stern, ed. "The Sun's Magnetic Cycle." The Great Magnet, the Earth. NASA, n.d. Web. 28 Nov 2011. <http://pwg.gsfc.nasa.gov/earthmag/sunspots.htm>.
2. Ibid.
3. Johns S. Lewis, *Physics and Chemistry of the Solar System*, (Burlington, MA: Elsevier Academic Press, 2004), 88.
4. H Scheffler, and H Elsasser, *Physics of the Galaxy and Interstellar Matter*, (New York: Springer-Verlag, 1982), 204-205.
5. Ibid
6. David Stern, The Great Magnet, the Earth
7. Giuseppe Bertin, *Dynamics of Galaxies*, (Cambridge,UK: Cambridge Publishing Company, 2000), 149-200.
8. David Stern, The Great Magnet, the Earth
9. "Seeing the Invisible."*International Solar-Terrestrial Physics Program*. NASA, n.d. Web. 23 Nov 2011. <http://www-istp.gsfc.nasa.gov/istp/outreach/cmeposter/seeing.html>.
10. Ibid
11. Ibid
12. Dorch, Soren. "http://www.scholarpedia.org/article/Magnetohydrodynamics."*Scholarpedia*. Scholarpedia, 2007. Web. 25 Nov 2011. <http://www.scholarpedia.org/article/Magnetohydrodynamics>.

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