Solar Flares Project

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On September 1, 1859, British astronomer Richard Carrington noticed something peculiar in the sky from his observatory; a large cluster of sunspots were surrounding the sun.

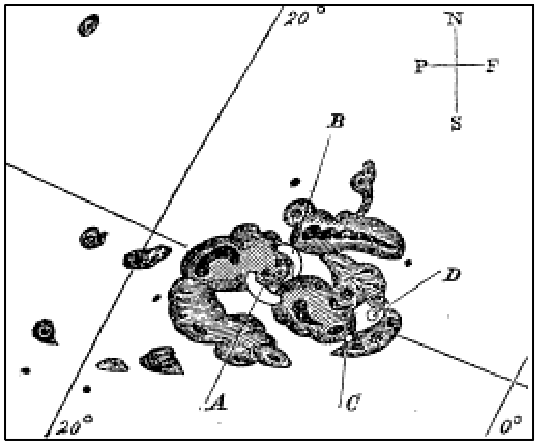

Figure 1. Carrington's drawing courtesy of NASA ("Solar Superstorm-NASA Science")

Carrington claims that after he drew the sunspots, they flashed a white light. After that, he regrettably went to get a second observer to see the peculiarity, but when he returned, the light had dimmed quite a bit. He watched while the white spots faded away and eventually disappeared. The next day the skies across the world were filled with red, green, and purple auroras. At the same time, telegraphs around the world began to malfunction. For example, sparks were shooting from the telegraphs to their operators and telegraph paper was catching on fire. Even when the telegraph operator cut off the telegraph's power supply, the telegraph continued to receive messages because of the induced electrical current from the auroras. (Bell). If this event were to occur in today's society, what kind of devastation would it bring to a world dependent on electronic technology? If such an event were strong enough to shut down the electronic technology of the entire world, how long until the next massive solar flare occurs? For the past half of a century, this question has been the basis for many researchers' work; however, prediction of the time a solar flare will occur and its magnitude still lies outside the range of human insight. The purpose of this paper is to delve into the characteristics of solar flares and their potential impact on humanity.

The Sun

First of all, solar flares cannot form without massive amounts of energy. Of course, the most abundant amount of energy in the solar system rests within the sun and is released every second of every day as a result of fusion. In the center of the sun, hydrogen atoms undergo fusion with other hydrogen atoms until helium atoms are created. Every time a helium atom is formed, 4.48×10^{-12} Joules of energy are created. The sun has a mass of 1.989×10^{30} kilograms. Using Einstein's equation, $E = mc^2$, the potential energy that can be derived from the mass of the sun is 1.79×10^{49} Joules, which has been enough to keep the sun shining for over four billion years and is easily enough to form solar flares with incredible magnitudes (Benestad 27-32).

The sun has four layers and three main boundaries that separate these layers. The center of the sun is called the Core, which does not have a boundary with the second layer, called the Radiative Zone. The third layer is called the Convective Zone, which is separated from the Radiative Zone by the shell called the tachocline. The Convective Zone is separated from the fourth layer of the sun, the Chromosphere, by the photosphere. And the Chromosphere is bounded by the thin layer of gas called the Solar Corona (Benestad 29-32).

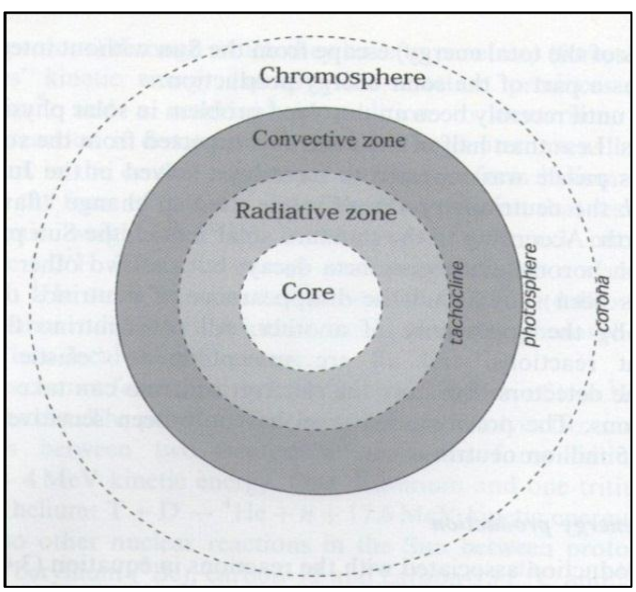

Figure 2. Layers of the Sun courtesy of *Solar Activity and Earth's Climate* (Benestad 32)

The Solar Corona is a massive sphere that circles the sun and consists of plasma. Plasma of this outside layer of the sun is the result of superheated gases. All of the atoms of these superheated gases are ionize and any forces between the atoms will be primarily electromagnetic (Tandberg-Hanssen 78). The Solar Corona is composed of Hydrogen and Helium atoms. It moves constantly around the sun and can be seen in the picture below.

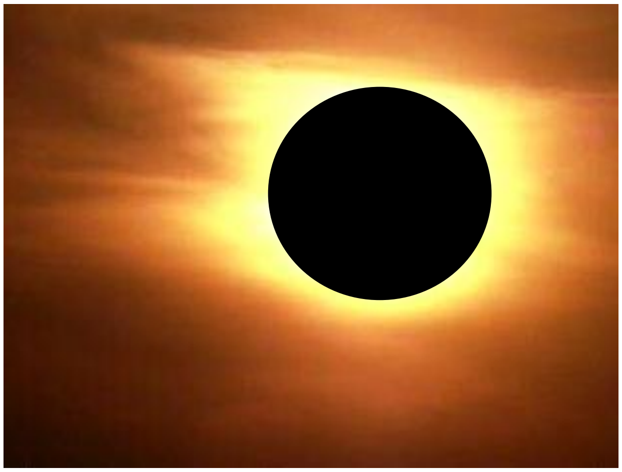

Figure 3. Picture of a Darkened Sun, surrounded by the Solar Corona

Over the years, scientists have compiled what they think is evidence of magnetic fields in the solar corona surrounding the sun. As professor Donald E. Billings stated, the

> loop structure of coronal material could not maintain its observed stability without the intervention of magnetic forces… The simplest and most obvious [appearance of a magnetic field in the solar corona] is the distribution of coronal material. Loops that are hotter than the surrounding coronal material and several times as dense would expand with explosive violence if they were not magnetically constrained [by magnetic forces of the sun] (Billings 262).

These magnetic fields are caused by the movement of gases inside the sun. However, even though the magnetic field of the sun is very powerful, breaks sometimes occur in these magnetic fields, allowing the formation of sunspots.

Sunspots are dark, cold areas in the photosphere of the sun. They are strong magnetic fields that are able to cut through the surface of the sun but must occur in pairs because a magnetic field extends from one sunspot to another, forming a loop. The number of these sunspots on the sun reaches a maximum or a minimum over a period of time, which usually occurs once during the sun's 11-year-cycle. Also, the magnetic energy of the sun reaches a maximum every 22 years (Hough).

Sunspots are believed to form due to the "magnetic interaction with turbulent flow and electric conduction." Researchers explain the formation of sunspots with the mean field dynamo theory. This theory basically means that sunspots form on a region of the sun where the magnetic flux has just increased phenomenally due to the rotation of the sun. These regions on the sun are more commonly known as bipolar active regions. If these loops of magnetic field lines experience a "magnetic reconnection" by coming in contact with each other, then "there is a rapid shift as contorted field lines snap back like rubber bands, accelerating a giant bubble of plasma and magnetic loops into space at speeds up to 2000 km/s" (Coradetti). These active regions have constantly changing magnetic fields and an increase in microwave and radio wave bursts, which can help scientists predict whether or not a place on the sun could potentially create a solar flare (Svestka 244-7).

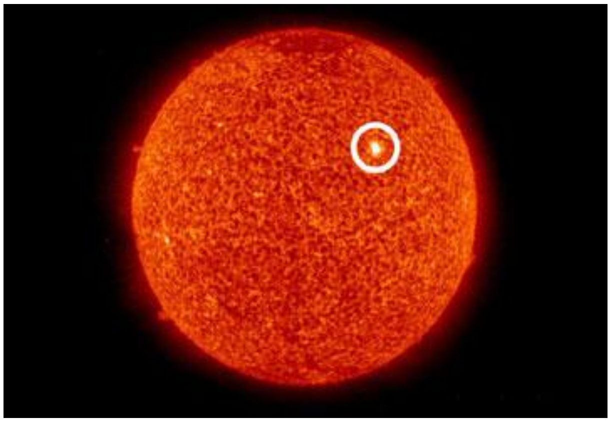

Figure 4. Picture of a Sunspot in 2008 courtesy of the How Stuff Works Website (Layton)

The Formation of Solar Flares

The reason why solar flares can obtain so much energy is due to the process of Magnetic Shear, which refers to the "energized state of the magnetic field in the solar corona." The magnetic field of the sun is energized when it is warped due to the sun's rotation. An electric current is formed when the magnetic field of the sun is warped, creating enough energy during a solar burst to form solar flares. This twist of the magnetic field occurs during the process of photospheric flows. This process involves the "convective flows in the dense photosphere… [that] tend to move the footprints of the magnetic field lines that penetrate it through the effect of line tying", which is called photospheric shearing. These twists can also be the result of the burst of warped fields underneath the sun's photosphere. Magnetic shear refers to "the twist that energizes the magnetic field above the potential state" (Crooker et al, 58).

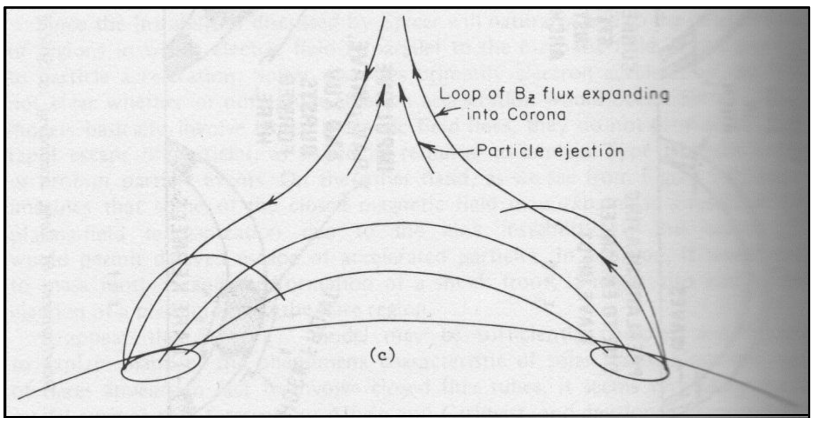

Figure 5. Break in magnetic field lines courtesy of *Solar flares: a monograph…* (Sturrock 446)

Once the sun has gone through its 11-year-cycle and stored a massive amount of energy in its magnetic field, then the energy of the magnetic field is released in a very violent and instantaneous way, which results in the formation of solar flares. This formation involves a three stage process. The first stage is the precursor stage, where the magnetic energy that has been building up in a solar flare is released. The second stage is the impulsive stage whereby the protons and electrons of the sun are accelerated to produce energies of over a million electron volts. During this stage, "radio waves, hard x-rays, and gamma rays are emitted." Finally, during the third stage, more commonly known as the decay stage, there is a steady increase and decrease of x-rays. These stages can vary in length from a few seconds to an hour ("Solar Flares").

The Physical Properties of Solar Flares

Solar flares can best be described as a release of magnetic energy that has built up in the atmosphere of the sun. During solar flares, the brightness of the sun becomes much more intense. The energy released from the sun during these massive events “is emitted across virtually the entire electromagnetic spectrum, from radio waves at the long wavelength end, through optical emission to x-rays and gamma rays at the short wavelength end” ("Solar Flares"). The temperatures inside a solar flare can reach as high as 100 million degrees Kelvin, but usually stay in the 10 to 20 million degrees Kelvin range. The quantity of the energy that is emitted during a solar flare is gargantuan; an average solar flare will emit 100 Exawatts (10^{20} Watts) of energy. This is equivalent to “millions of 100-megaton hydrogen bombs exploding at the same time!” ("Solar Flares")

Solar flares emit a gargantuan amount of radiation in a variety of different wavelengths. In some cases, they can vary from 2×10^{-13} meters to 10 kilometers. However, most of the radiation is in the form of radio waves and x-rays. Radio and x-ray bursts come out of the sun in primarily three different types of developments: the Bremsstrahlung, Gyro-Synchrotron, and Plasma emissions. The Bremsstrahlung process is a result of electromagnetic radiation that comes from the electrons ricocheting off the sun. Gyro-Synchrotron Radiation is an electromagnetic radiation that is formed from electrons rotating in the sun’s immense magnetic field. And Plasma Wave Radiation occurs as a result of a single plasma wave that has been influenced by flowing electrons, but the electromagnetic waves are only emitted once the plasma wave has been converted to radio waves and x-rays (AAS-NASA Symposium on the Physics of solar flares 349-52).

The Space Environment Services Center (SESC) in Boulder, Colorado, forecast the x-ray flux continuously throughout the day on their website. Below is a plot of X-ray emissions for three days in October. The plots provided by the SESC, part of the National Oceanic and Atmospheric Administration (NOAA), in Boulder, Colorado represent solar x-ray flux values of three days.

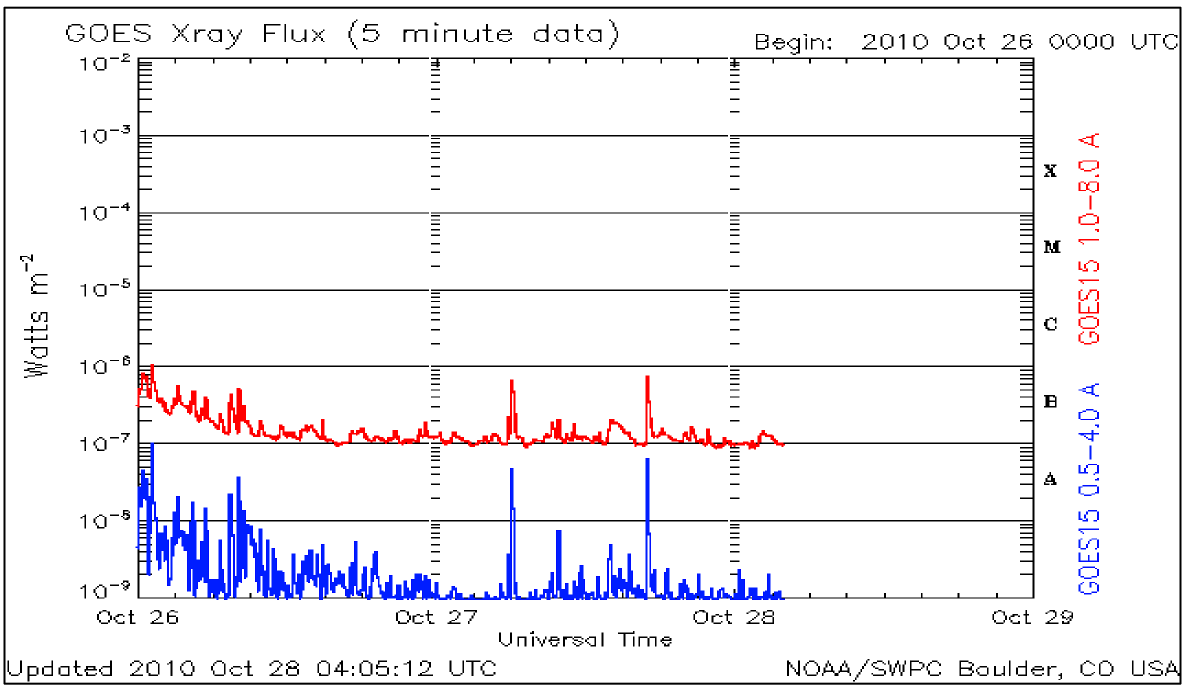

Figure 6. Solar X-ray Flux courtesy of NOAA ("Today's Space Weather")

Solar Flare's Effects on Human Technology

Since September 1, 1859, solar flares have been regarded as dangerous to human technology. There are three main components of solar flares that can make them unsafe to humans. The first are x-rays, which increase the concentration of electrons in the sky, blocking radio transmission on Earth by absorbing or deflecting radio waves based on their frequency. This loss in radio communication can occur for an hour or more during a solar flare. The second element of solar flares that could affect humans on Earth is the energetic protons. These protons could potentially harm satellite components, such as computers, detectors, and transducers. They also jeopardize the lives of humans in Space. The third affect that Solar flares could have is their effect on the geomagnetic field, which can instantaneously change from the difference in the solar flare's magnetic field and the momentum of the solar wind, coming in contact with the Earth's magnetosphere (Sawyer et al, 1-2).

> This disturbs the ionosphere, and affects measurements used in geophysical exploration. Induced currents can disrupt electric power transmission and cable communications and affect oil pipelines. Heating of the upper atmosphere associated with geomagnetic disturbances changes its density structure, increases atmospheric drag on satellites, and thwarts efforts to predict satellite orbits (Sawyer et al, 1-2).

Solar flares occur continuously on the sun; however, when several sunspots group together in one place on the surface of the sun, they form lots of magnetic field loops that can make each other stretch out into space and eventually come in contact with each other causing a large Solar Wind. This incredible release of magnetic energy from the sun is more commonly known as a Coronal Mass Ejection (CME) (Crooker et al, 9-13). CMEs occur most of the time during the peak of sunspot activity on the sun every 11 years during which the magnetic field of the sun changes from the north pole to the south pole or vice-versa, like it did in 2001 (Benestad 38).

CMEs can have a much larger impact on the Earth's magnetic field than solar flares. They can be much more harmful to the Earth; however, because of the magnetic field formed around the Earth, which is only a thousandth the size of the magnetic fields formed by CMEs, they are relatively harmless to earthlings (Coradetti). As seen during the 1859 CME, however, technology on Earth was affected by a CME when its magnetic field was strong enough to overwhelm the protective force of the Earth's magnetic field.

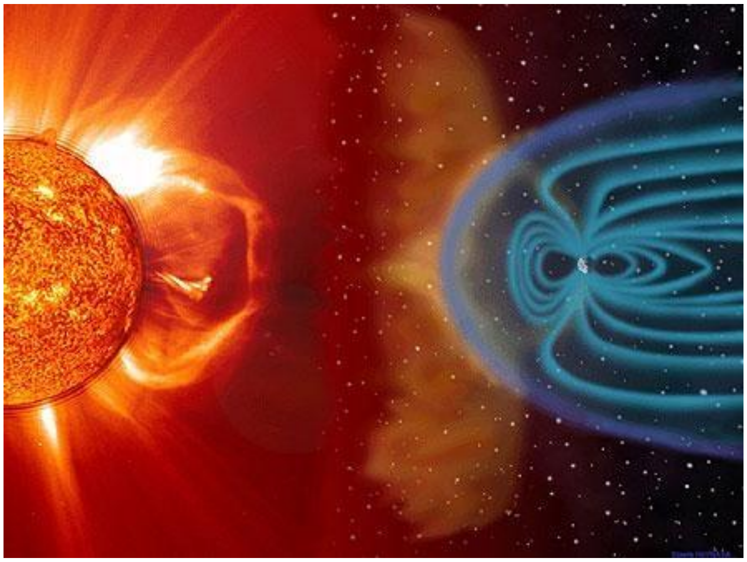

Figure 7. Earth's Magnetic Field against CME courtesy of MSU Solar Physics (Coradetti)

Solar Flare Forecast

The recurring maximum of solar flare activity suggests that there might be a way to forecast them. The Sun's fluctuating bursts of microwave energy could be a possible predictor of solar flares. During these bursts, "Immense clouds of radiation and charged particles erupt from the sun's surface." A physicist, Pierre Kaufmann, and his coworker, Rodney V. Souza, "noticed that the sun emitted burst of microwave energy during or before each [CME]." The microwave burst of three of the CMEs coincided with the eruption of the flares on the sun's surface, but the microwave bursts for the other seven occurred about 5 to 15 minutes later (Perkins).

No successful methods for solar flare prediction have been developed yet, but there are numerous forecast centers around the world that try to detect an increase in Solar Flare activity every day in different regions of the world. They include the SESC, which is part of the NOAA, the Observatoire de Meudon in Paris France, the Institute of Applied Geophysics in Moscow, USSR, Radio Research Laboratories, Ministry of Post and Telecommunications in Tokyo, Japan, the Ionospheric Prediction Service near Sydney, Australia, and the Forschungsinstitut der

Deutsche Bundespost in Darmstadt, Germany. The forecast most commonly used by these warning centers is determined by solar and geophysical data; however, only the SESC and the Radio Research Laboratories issue an alert if there is solar flare emission observed (Sawyer et al, 99).

NASA has forecast that a large solar flare will hit the Earth in the year 2013, and that efforts to lessen the devastation must be taken right now. Dr. Richard Fisher, who is NASA's Heliographics Director, states that

> [NASA] know[s] it is coming but [they] don't know how bad it's going to be… It will disrupt communication devices such as satellites and car navigations, air travel, the banking system, [people's] computers, everything that is electronic. It will cause major problems for the world. Large areas will be without electricity power and to repair that damage will be hard… Systems will just not work (Hough).

However, although some predictions of the 2013 solar flare state that it could be more devastating to mankind than previous solar flares, some recent predictions are beginning to show that this solar flare may just be average. Basically, scientists have no real clue as to when the next massive solar flare will hit; all they know is that one is likely to happen within the next one to five hundred years, leaving a considerable gap for prediction (Kennedy).

Also, knowing that the modern world has become so globalized that it is dependent on technology worries a number of scientists. In 1859, the solar flare ruined only telegraph machines around the world because that was all that mankind had created of any electronic use. There is no way of knowing if solar flares will affect all of the modern day appliances that humans use from day-to-day, such as cell phones, computers, televisions, etc.

In conclusion, solar flares have proven that they can be harmful to human technology with the countless forms of radiation that they emit on a daily basis. However, the Earth's magnetic field has acted as a shield to these solar flares for ages, which is one of the reasons why life is possible on Earth. Nevertheless, one day a CME with the same or greater magnitude as the one in 1859 will come toward Earth and alter the Earth's magnetic field. Will humans focus their time and attention on preparing for this certain future occurrence? Only, time will tell, but until that time, solar flares should continue to be researched and respected for their massive and unpredictable behavior.

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