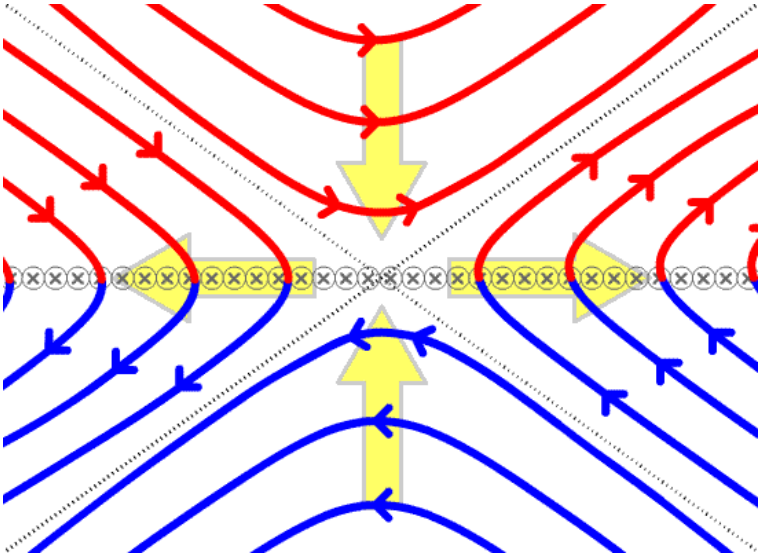
My Observations of How Magnetic Reconnection Occurs

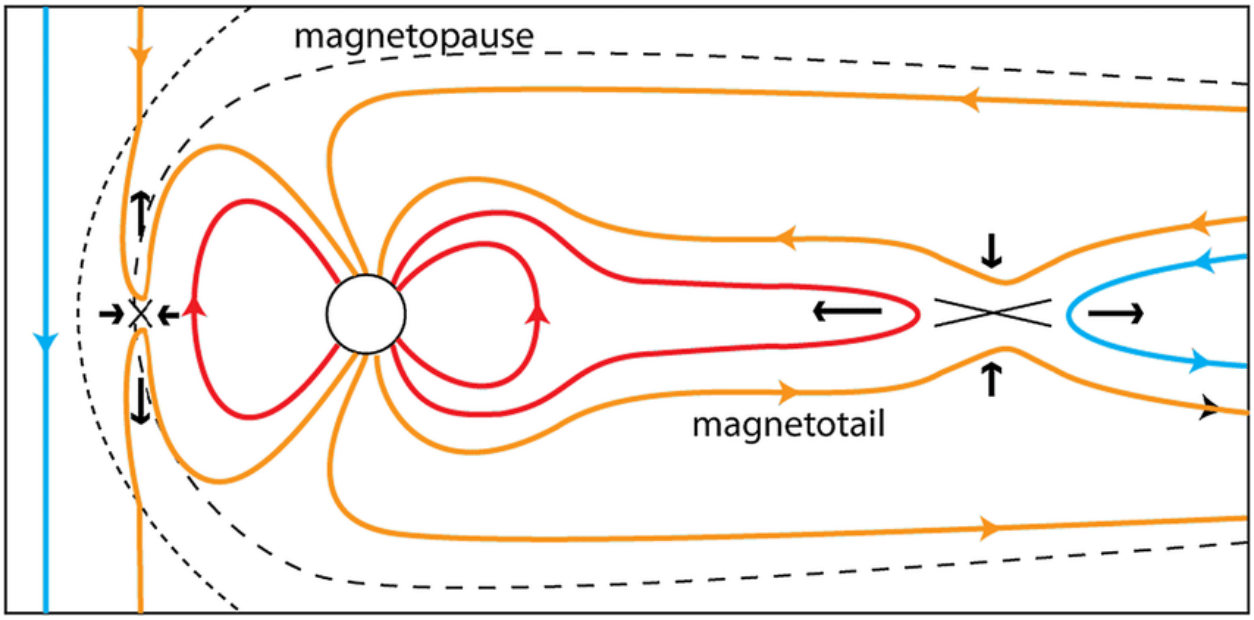
Currently how magnetic reconnection occurs in plasma is not yet fully understood; and since I am not a plasma physicist, I did not try to understand this phenomenon based upon the theories that are taught to those who are in the profession. I first analyzed how this event occurs in our solar system solely focusing to understand this phenomenon based on the proven laws of electromagnetism and induction. In doing so, I have developed my own simple understanding of how this phenomenon occurs in our solar system and related how it occurs tokamak fusion devices.

When I first heard that this was the cause of failure in tokamaks; I had no idea what it was or if there was even a chance that I could understand what it is after studying the phenomenon. For the most part, I learned that no one has yet to fully understand how magnetic reconnection even occurs. Wikipedia describes magnetic reconnection as: *"A physical process occurring in highly conducting plasmas in which the magnetic topology is rearranged and magnetic energy is converted to kinetic energy, thermal energy, and particle acceleration."* Basically theory suggests that oppositely directed magnetic field lines in highly conductive plasmas that flow towards each other will form two newly connected field lines that have a plasma outflow. The image below from the same Wikipedia is basically depicting a magnetic field in red, from the top, being pushed towards an opposing magnetic field in blue, from the bottom. As these fields get closer to each other, they form newly connected field lines that expel massive disruptive energies perpendicularly outward from the inflow from the top and bottom. This is a very simple two-dimensional description of magnetic reconnection.



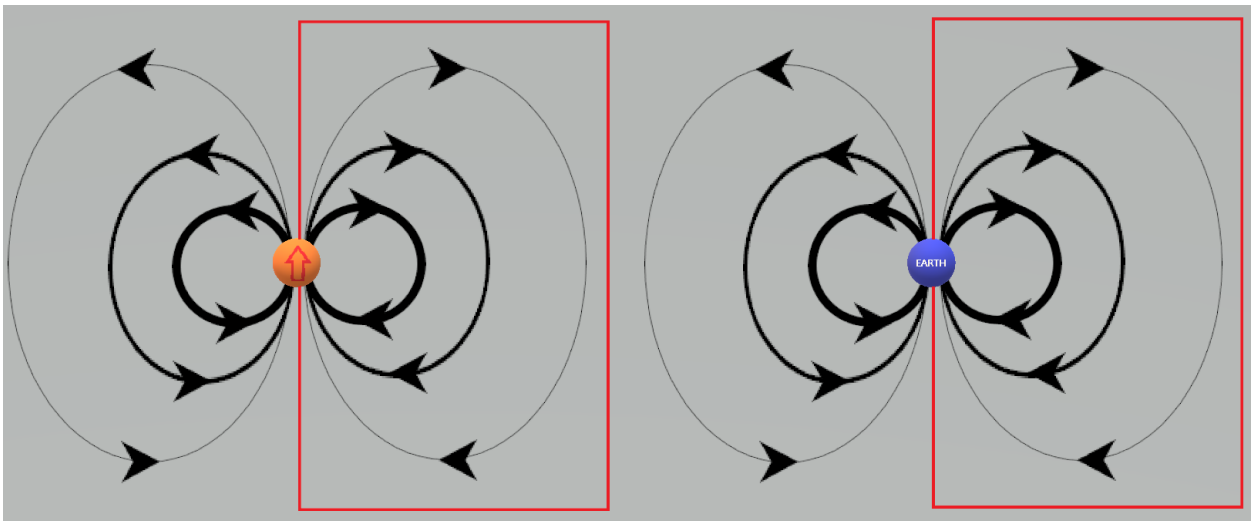
Enormous magnetic reconnection events routinely initiate from our sun during its most active times during its solar cycle before flipping its magnetic poles. This highly energetic event on the Sun is called a coronal mass ejection (CME). CMEs are a massive ejection of charged particles, plasma; which travels with a magnetic field from the solar corona. CMEs will then directly interact with Earth's protective magnetic fields by bombarding the fields with large amounts of charged particles and plasma. The interaction between CMEs and Earth's magnetic fields produces a plurality of magnetic reconnection events. The reconnection events normally occur on the bowshock, front, and tail, back, of Earth's magnetic fields interacting with the CME's flow of charged particles. I found that it was easiest to focus on the reconnections that occur at the tail since these are much more dramatic than the

bowshock, front. Below is a basic diagram from the Space Science Reviews journal on “The Scientific Foundations fo Forecasting Magnetospheric Space Weather”. In this diagram, you can see that the fields in orange and red are stretched and pushed together on the tail end to cause the reconnection event.



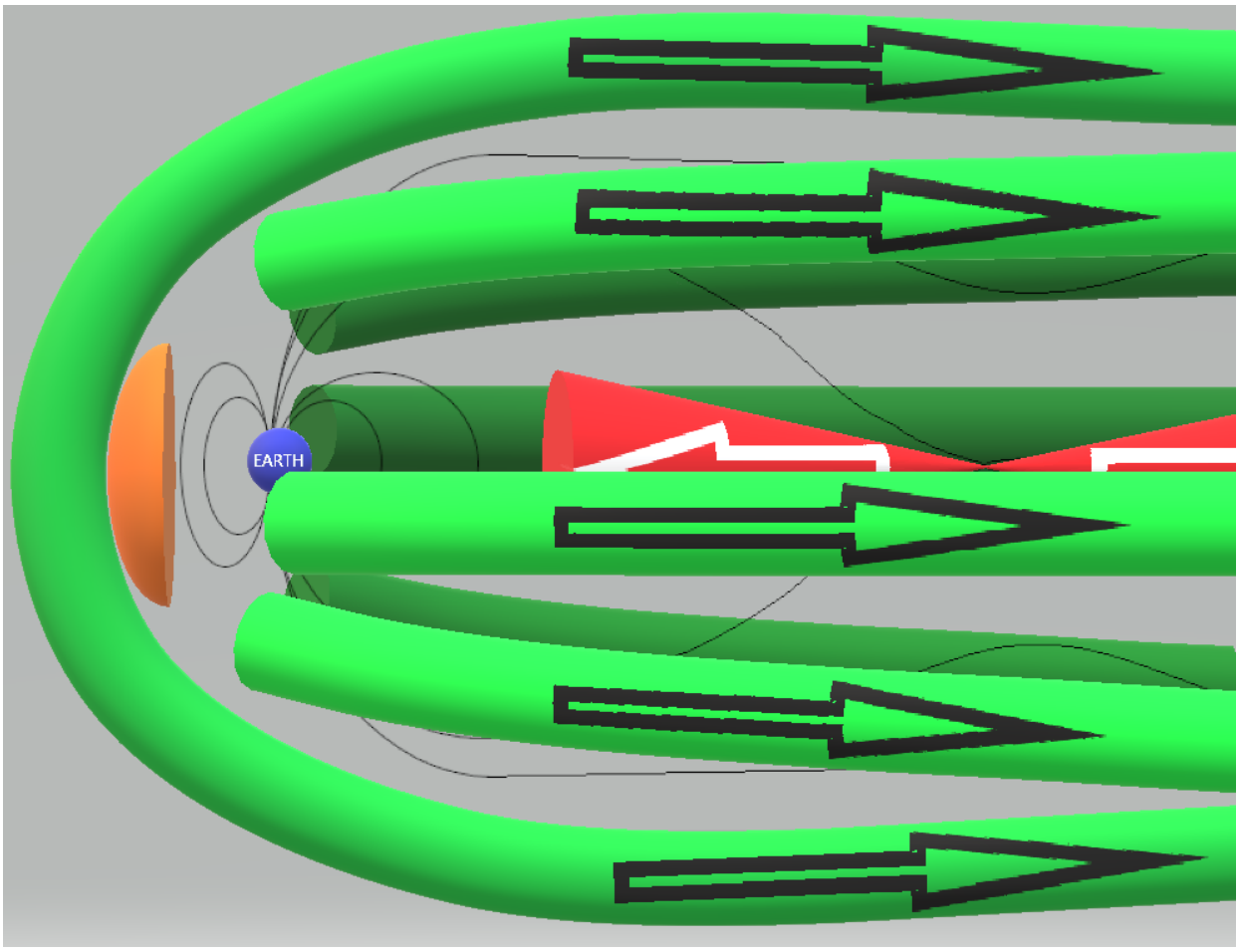
Even though this diagram seems simple to understand how inflows from a CME event can cause powerful reconnecting outflows; there are compounding factors that allow for magnetic reconnection to occur. First of all, the reason that magnetic reconnection is such an amazing phenomenon, is because magnetic field lines were believed to not be able to be broken before the discovery of this phenomenon. The normal behavior of magnetic field lines is not to cross other field lines; which results in them pushing against each other. So after studying the reconnection phenomenon on a stellar magnitude, I realized that reconnection occurred when a closed-loop would collapse and reconnect upon itself, which was a glaring detail that was never realized or stated from my studies on this phenomenon. In the previous diagram, one can see that this closed-loop interaction upon itself is the main cause that initiates the reconnection event on the bowshock, front, and tail, back, of the Earth.

To give a better idea of what I am talking about; depicted in the following diagram on the left is a dipole magnetic field which can be either an electric or magnetic dipole. In the following diagram on the right is the dipole magnetic field that is emitted by Earth. The main thing to observe is that both of these dipoles are made of continuous field loops surrounding the dipole source flowing from north to south. These field loops are closed loops that have no beginning or end. When I am referring to a closed-loop; I am referring to a portion of the dipole, which is the portion of the field enclosed in the red box in the following diagram. Each of these closed-loops are made of countless layers of field lines, and each of these field lines obtains the same amount of strength. The most differentiating factor between these field lines in the closed-loop is that they decrease in density as the field lines increase in distance away from the poles. Basically, the strength of each magnetic field line is proportional to the line density.

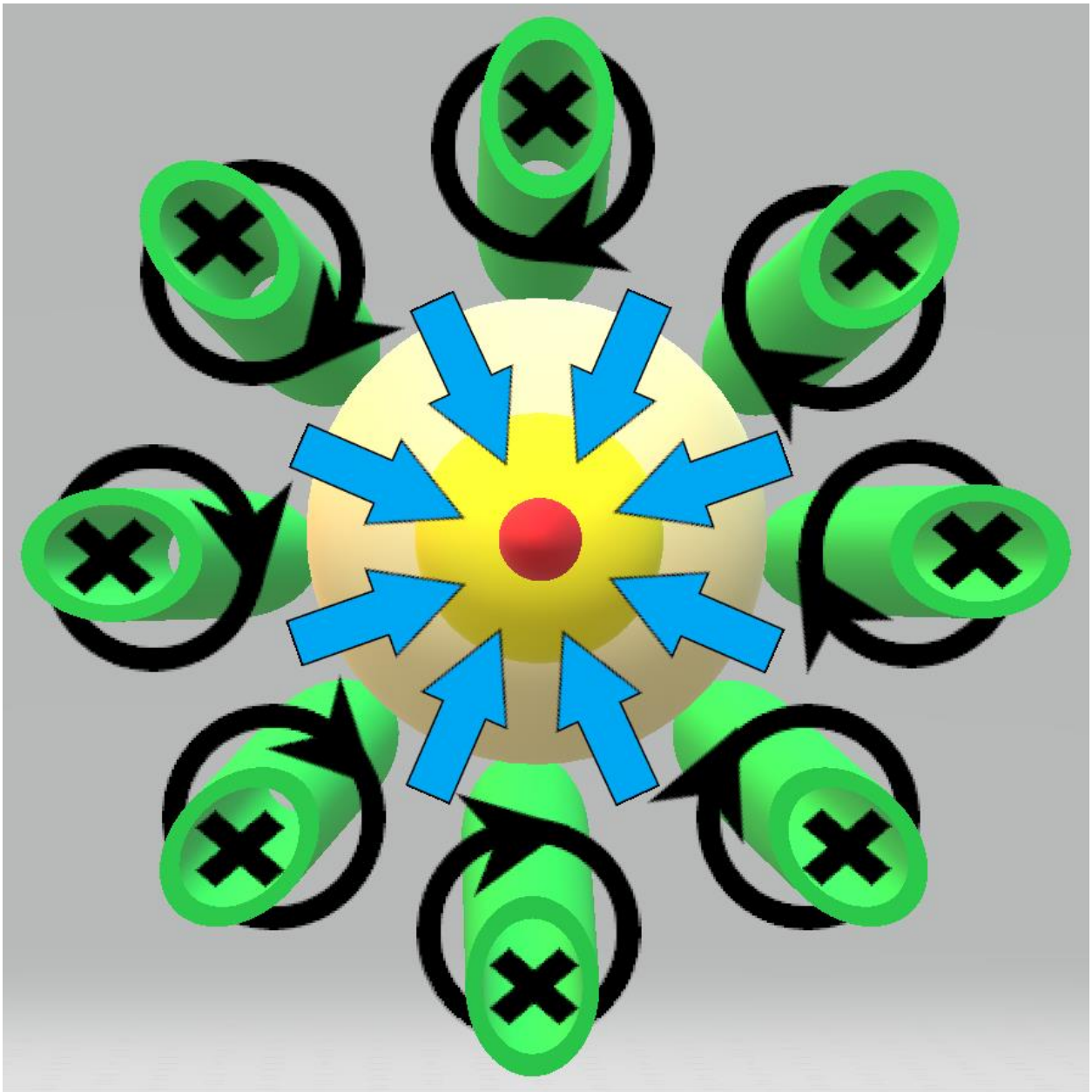


All magnetic fields are made of photons and every field line has a distinctive property that makes them different from each other. This distinctiveness for each field line is what keeps them from merging. If magnetic reconnection is mainly occurring with closed-loop fields collapsing upon themselves; then there is a possible explainable reason why the reconnection of magnetic fields is even able to initiate. When inflows are forcing a closed-loop field upon itself; fields of the same loop perpetuate the same properties and can merge and reconnect. Magnetic field lines will always seek the path of least resistance between opposite magnetic poles. So, when the conditions are met where a field line can interact with itself and shorten the closed-loop distance, it will.

The biggest disagreement that I have with many of those who study the phenomenon of magnetic reconnection is how the inflow force occurs in allowing for the possible pinching of loop fields to even occur. When applying Ampere's Law in studying currents, it is commonly known that two parallel wires carrying a current in the same direction will exert attractive forces upon each other. From my observations, I believe this type of attractive force is the main cause of magnetic reconnection events. These moving charged particles from CMEs and solar winds can be imagined as a countless amount of wires carrying electrical current around Earth's magnetic field from the bowshock to the tail of the magnetic reconnection event. To display how this occurs, I created an illustration that presents how CMEs and solar winds interact with Earth's magnetic field. The bowshock which is where the most dynamic impact occurs in this field interaction is depicted in orange on the following diagram. As these charged particles are forced to move around Earth's magnetic field, they accelerate and move parallel around the Earth's fields. The current of these charged particles are depicted as a green current. As these charged particles are forced to travel more parallel to one another; they create an attractive force amongst each other and create a squeezing, inflow, pressure upon Earth's stretched magnetic field within the created currents on the tail-end of the planet. In the following illustration, Earth's manipulated magnetic fields are depicted by thin black lines. The magnetic reconnection outflow forces are depicted in red.



The following diagram depicts a cross-section perspective of the magnetic reconnection event from Earth towards the tail. The compressing force of the parallel running currents is depicted with blue arrows; and Earth's compressed and pinched magnetic fields are depicted in different shades of yellow. The outward ejection force from the magnetic reconnection is depicted in red.

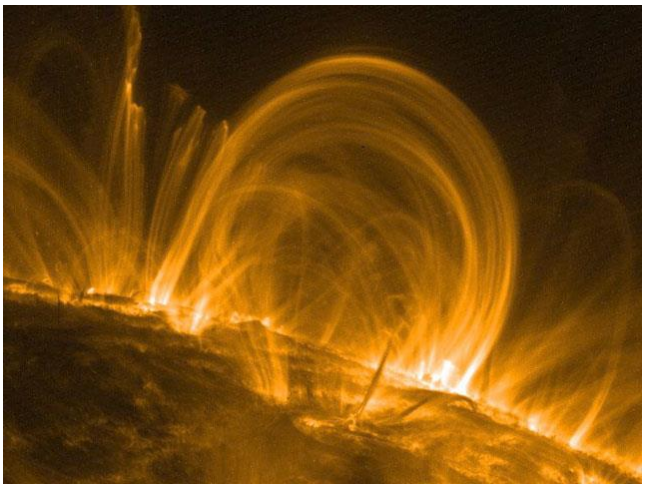


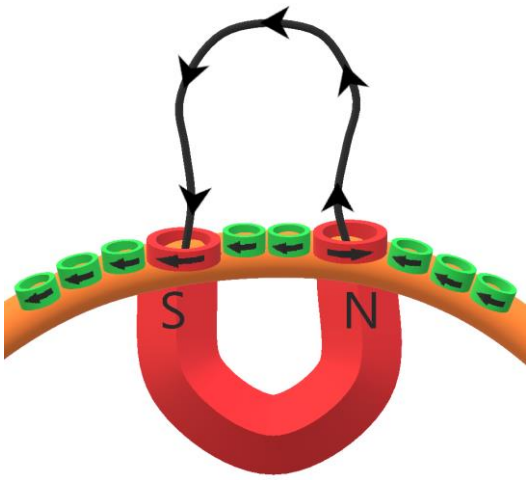
Being a prideful West Virginian from the West Side of Charleston, I find it easiest to explain how magnetic reconnection occurs by relating the event to how coal locomotives transit on railroads. I grew up about 150 yards away from the railroad tracks; and daily I would see powerful locomotives filled with coal rolling through our borough hills. Because of being raised in close proximity to West Virginia's life blood, it is probably why it was natural for me to associate magnetic reconnection to transiting trains. I like to imagine each field line as a rubbery and flexible train track. Each flexible track has a different width and is meant to represent an individual closed-loop. The wider and shorter track for the larger train would be closer to the dipole source than the thinner and longer track for the smaller but equally as powerful train. If each train is pulling a line of hopper cars full of coal that is the length of their field lines, the amount of weight carried by each train would equal the same amount of weight. This weight represents the field strength. Since each track is made specifically for each train they do not merge or

cross, but when the same size track is forced upon itself; a train is able to fit on the newly found track and take the shortcut towards the dipole which is the path of less resistance. This new path breaks the track into two separate looped tracks that are carrying less weight than the other surrounding tracks. Of course, this is a simple way to think about how magnetic reconnection is initiated, but reconnection is not a simple two-dimension interaction. It is more like a bubble, shaped like an innertube, being severed and reconnected.

Previously I presented the definition of magnetic reconnection. In this definition, it was stated, "*magnetic energy is converted to kinetic energy, thermal energy, and particle acceleration".* Once the field line is reconnected a huge amount of energy is expelled, outflow. Keeping the coal train analogy in mind, if one of the tracks is severed and reconnected; there are now two individual tracks that are carrying less weight than the other surrounding tracks, closed-loops. So, the lighter, weaker, track that is still attached to the perfectly balanced dipole system; must be compensated to operate within the laws physics. The law of physics that I am talking about is the law of conservation of energy. This means that the dipole system will shift to balance and convert the loss of weight, magnetic strength, into an energy that is equivalent to the average weight of the other tracks minus the difference held on the newly reconnect track that is still attached to the dipole system. This converted energy is then observed as, "*kinetic energy, thermal energy, and particle acceleration".*This converted energy then ejects the second newly reconnect solitary track away from the dipole system as a whole.

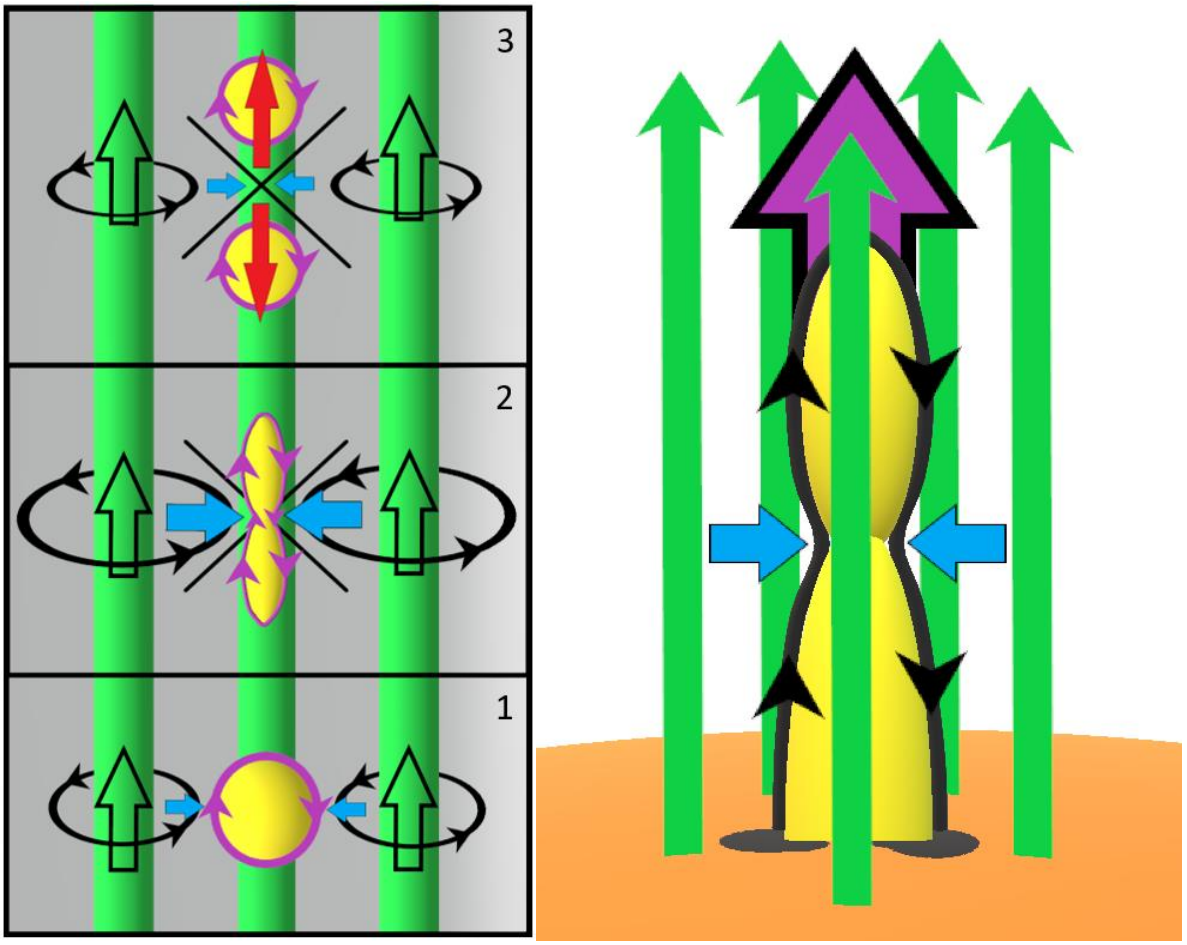
If my assumption about how magnetic reconnection occurs is correct, then there is a simple explanation of how CMEs occur in the first place. Previously I stated that the probability of sunspots being a phenomenon or inefficiency in the sun's system was pretty high; which means that these spots more than likely don't function like the rest of the magnetic confines that allow the sun to function. Sunspots appear in pairs and always interact as if there is a bar magnet underneath the photosphere connecting the two. Below on the left is a picture of the aching fields on the sun's surface, and on the right a diagram depicting this coupled sunspot interaction.





Since this coupled relationship between sunspots is more than likely a phenomenon, it is very likely that the smaller and weaker confining fields that make up the majority of the sun's confinement layer has a charged particle rotation that is clockwise; which causes an inward-directed confinement field. When the sun is at its most active, which occurs every 11 years, the most amount of sunspots are visible. During this highly active period, usually more than 100 sunspots can be seen at once, which accounts for less than one percent of the sun's total confinement surface area.

Due to this sunspot phenomenon, the magnetic fields created by the sun's spicules can interact with sunspots' magnetic fields. Sun spicules are energetic streams of plasma that moves outward from the sun's Chromosphere. As the sun enters its most active cycles every 11 years, these spicules currents are at their greatest strength. Depicted below is the magnetic reconnection event that creates a CME. The spicule currents are depicted as green currents moving away from the sun's surface. These currents will create a plurality of counterclockwise magnetic fields that will attract amongst one another. This attraction results in inflow forces that cause coupled fields created by sunspots to be forced upon themselves. Thus, creating an observable magnetic reconnection known as a CME. Sequentially numbered on the bottom left is the general idea of how this spicule inflow creates a magnetic reconnection. On the bottom right, this general concept is applied to the coupled fields of a sunspot pair.



If the fields of individual spicules get trapped by other surrounding spicules that are attractive to each other, this magnetic reconnection event can also occur amongst spicules. The main difference between a spicule field reconnection compared to a sunspot one is that spicule reconnection is extremely weak in comparison to a sunspot reconnection and would not come close to being as massive as an observed CME. The reason that magnetic reconnection amongst coupled sunspots is such a massively strong event is that the magnetic fields that are tied to sunspots are so much stronger than

the surrounding fields on the surface of the sun. To simply put it, CMEs occur when magnetic reconnection on the sun involves stronger than normal magnetic fields of sunspots that are forced to collapse upon themselves from attractive pinching parallel traveling currents of charged particles.