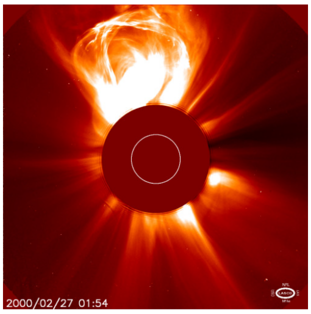
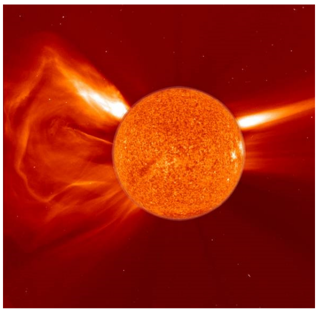
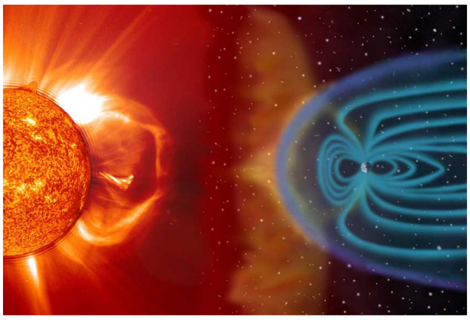
Sun – Part 26 - Coronal mass ejection





Coronal mass ejections



CME threatening Earth

A coronal mass ejection (CME) is a massive burst of gas and magnetic field arising from above the sun's surface either in the corona or further into space (interplanetary CME). The ejected plasma consists mainly of electrons and protons in addition to small quantities of heavier elements, plus the entraining coronal closed magnetic field regions. CMEs are associated with huge changes and disturbances in the coronal magnetic field. Small-scale energetic signatures eg plasma heating observed as compact soft X-ray brightening may be indicative of impending CMEs. CMEs also often follow solar flares. However, they remain difficult to forecast.

Although the solar flare observed during the 1859 Carrington event was probably associated with a CME, the first official detection of a CME, as such, occurred as recently as 1971. R Tousey of the US Naval Research Laboratory made the discovery while using the Orbiting Solar Observatory (OSO) 7 when he noted a very bright area during routine imaging. Once recognised as a discrete phenomenon, it was realised that earlier observations of coronal transients or even those seen visually during solar eclipses were probably also CMEs.

Like solar flares, CMEs have been studied with terrestrial and space-based equipment. There is clear evidence from probes that CMEs increase solar wind speeds and densities, and stimulate rapidly varying magnetic fields. When CMEs reach Earth's atmosphere they cause geomagnetic storms.

They most often originate from active regions on the Sun's surface eg sunspot groupings and are associated with other forms of solar activity eg solar flares, although the link between them is both complex and poorly understood. For example, while CMEs and solar flares are usually closely related, sometimes CMEs occur without an associated flare. Also, most weak flares do not have CMEs, but stronger ones do. Furthermore, even when associated with flares, the two events do not always occur in the same order. These findings undermined the proposal that CMEs are driven by the heat of solar flares.

Despite these anomalies, it is thought that CMEs and solar flares are caused by a common event – large scale restructuring of the magnetic field. The Sun's active regions have closed magnetic field lines, in which the magnetic field strength is large enough to contain the plasma. However, these lines must be broken or weakened for the ejection to escape the Sun. This process is that of magnetic reconnection whereby highly twisted or stretched field lines break, forming a more relaxed system. As for solar flares, CMEs are the result of the accompanying sudden release of energy stored in the original stressed magnetic fields. CMEs are also possible in quiet surface regions, although the latter is often a recently active area. Despite commonality in their cause, study of their behaviour has confirmed that CMEs and solar flares are different solar features.

CME frequency varies with the sunspot cycle. Near solar maximum, there are about 2 CMEs per day (maximum 6) while, near solar minimum one occurs about every 5 days. At solar minimum, CMEs form mainly in the coronal streamer belt near the solar magnetic equator. At solar maximum, they originate from active regions with more homogeneous latitudinal distributions. While CME energy is released into the solar wind at speeds of 10 -3,000 km/sec., this is somewhat slower than the speed of solar flares which can be up to 70% of speed of light. While the energy from flares can reach Earth within 15 minutes, CME travel time to Earth varies from 13 hours up to several weeks, depending on the trajectory they follow. The average travel time is 3.5 days.

A typical CME has 3 features: a cavity of low electron density, a dense core (the prominence, which appears as a bright region embedded in the cavity, and a bright leading edge. Ejection starts with an initial pre-acceleration phase characterised by a slow rising motion. This is followed by a period of rapid acceleration away from the Sun until a near-constant velocity is reached.

Hazards When a CME directed towards Earth is powerful enough to reach it as an interplanetary CME, the shock waves of the travelling mass of solar energetic particles cause a geomagnetic storm that may disrupt Earth's magnetosphere, compressing it on the day side, and extending the night side magnetic tail. When the magnetosphere reconnects on the night side, it releases huge amounts of energy, which are redirected back towards Earth's upper atmosphere. The solar energetic particles can cause extra strong aurorae, disrupt radio transmission, damage satellites and electrical transmission lines, potentially resulting in massive and long-lasting power outages. Humans at high altitudes, in planes or space stations, also risk exposure to relatively intense cosmic rays, which are potentially lethal in high quantities.

Sources: Ridpath, I (Ed) (2012) Oxford dictionary of astronomy 2nd ed rev, www.en.wikipedia.org