

Initiation of Coronal Mass Ejections: Implications for Forecasting Solar Energetic Particle Storms

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We present a synopsis of the initiation of the strong-field solar magnetic explosions that become large, fast coronal mass ejections (CMEs) and thereby produce the intense, days-long particle storms that could kill astronauts and spacecraft in interplanetary space. Based on observations, physical reasoning, and modeling studies, the inferred basic processes that trigger and drive the explosion are described and illustrated with cartoons. The magnetic field that explodes is a sheared-core bipole that may or may not be embedded in strong surrounding magnetic field, and may or may not contain a flux rope before it starts to explode. Beginning at or soon after the explosion onset, tether-cutting reconnection in the sheared core field unleashes a growing, erupting flux rope. Using a simple model flux rope, we demonstrate that the explosion can be driven by the magnetic pressure of the expanding flux rope, provided the shape of the expansion is fat enough. Depending on the details of the pre-eruption configuration and evolution of the magnetic field, the explosion is triggered by one or a combination of three different mechanisms: (1) runaway internal tether-cutting reconnection, (2) runaway external tether-cutting reconnection (a.k.a. breakout reconnection), and (3) ideal MHD instability or loss of equilibrium. No matter how the explosion is triggered, its further growth is driven in basically the same way, by expansion of the growing flux rope erupting from the core of the bipole.

The above characteristics suggest that once the free magnetic energy (shear and twist in the core field) in the bipole exceeds some limit, an explosion will soon (few hours) be triggered. This, in turn, suggests that the critical factor determining whether a bipole will soon explode is the ratio of the free magnetic energy in the bipole to the magnetic energy content that the bipole would have in its relaxed potential-field configuration (which has no free energy). We expect that when the free-energy buildup increases this ratio to some characteristic critical value (of order 1), the bipole will soon find a way to explode.

For an isolated closed solar magnetic field, such as a sunspot active region, the total magnetic energy (the sum of the potential-field energy and the free magnetic energy) and the potential-field energy can be computed from a vector magnetogram of a surface layer of the region, provided the field in and above that layer is in a force-free state (a good approximation above the photosphere in strong-field regions). This is the only plausible way to measure the free/potential energy ratio in solar magnetic fields. So, to test our hypothesis that this ratio is a reliable predictor for strong-field CME explosions, we need highly accurate vector magnetograms of a layer above the photosphere. Obtaining such chromospheric vector magnetograms with enough accuracy to measure the free/potential energy ratio to $\sim 10\%$ or better, requires an advanced solar vector magnetograph mission such as the Magnetic Transition Region Probe (MTRAP) now being considered in the SSSC Roadmap.