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Physics of Solar Coronal Mass Ejections (CMEs): Theory and Observation[1]

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Coronal mass ejections (CMEs) represent acceleration of magnetized coronal structures to a few thousand km/s in tens of minutes. A recent succession of Sun-observing satellite missions together with a suite of instruments measuring solar wind (SW) plasmas at the L1 Lagrange point have dramatically improved our observational understanding of CME properties from the Sun to 1 AU. The traditional models, which envision releasing magnetic energy stored in the corona via reconnection (accomplished by specified and/or numerical dissipation in these models), have not produced quantitative agreement with the observed CME acceleration and propagation to 1 AU. In this talk, I will present a new concept that does not require reconnection and yields model CME dynamics in good quantitative agreement with data. The underlying magnetic structure is a flux rope, and the basic driving force is the toroidal Lorentz hoop force acting on a flux rope with two legs anchored in the Sun. The force equations were originally derived for axisymmetric toroidal tokamak equilibria by Shafranov, but the basic physics can be adapted to the dynamics of nonaxisymmetric solar flux ropes. The initial flux rope is driven out of equilibrium by increasing its poloidal flux. The calculated acceleration and subsequent propagation of model CMEs have been shown to correctly replicate the observed CME dynamics from the Sun to 1 AU, with the computed plasma and magnetic field parameters at 1 AU in close agreement with the in situ SW data. The increasing poloidal flux produces an electromotive force (EMF) that is sufficient to accelerate particles to X-ray energies. The predicted temporal profile of the EMF given by the best-fit solution to the observed CME trajectory is found to closely coincide with that of the observed associated solar flare X-ray intensity.

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