

# Coronal Magnetic Implosions

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## 1 History

This paper summarizes material presented in two published papers (Hudson, 1999; Hudson, 2000), which make the case that disruptions of the solar corona (flares and/or CMEs) must involve *implosions*. This requirement results in a conjecture with observable consequences, as detailed below. Historically, this line of thinking predates *Yohkoh* and has the following intuitive underpinning. When we see a coronal event, we observe many phenomena that require energy inputs: radiation, particle acceleration, material acceleration, levitation of material against gravity, and the expansion of the magnetic field. We do not observe the other side of the equation, namely phenomena that release energy, rather than absorb it. *Yohkoh* has provided some of the best data with which to search for the missing energy supply, but thus far to no avail.

The coronal magnetic field serves two roles during a transient event such as a flare or a coronal mass ejection. The field physically contains the energy, and it also imposes geometrical structure on it because of the frozen-field condition. The restructuring necessary to provide energy for an event should therefore happen visibly as the event develops, so long as we can ignore other forces (gravitation and the acceleration of the solar wind).

## 2 Conjecture

We can capture the intuitive problem stated above in a well-defined conjecture:

*During a transient, the coronal field lines must contract in such a way as to reduce  $\int_V (B^2/8\pi)dV$ .*

Where the integral covers the entire corona. We list three conditions needed for this conjecture to hold:

1. The event must happen rapidly;
2. Gravitational energy must be negligible;
3. Magnetic pressure should dominate gas pressure.

The first of these conditions simply states the requirement that no driver supplies energy across the boundary during the event evolution. The long Alfvén transit time across the photosphere makes this reasonable. The second condition excludes suspended filament mass, for example, as a source of flare energy. We probably don't really need the low- $\beta$  assumption, but it seems reasonable in any case.

The conjecture envisions the contraction of the field lines. In other words, at least some coronal field lines connecting their two conjugate points in the photosphere, where line-tying anchors them (condition 1), must decrease in length during the evolution of the event. The behavior of the volume integral of  $B^2$  determines which field lines must shrink. The field-line shrinkage results from the decrease of coronal magnetic pressure as the instability extracts energy from the field.

### 3 Observable consequences

The need for shrinkage implies that the field lines connecting given footpoints must jump to shorter paths at the time of energy release. This could occur either with or without reconnection, depending upon the nature of the instability. In principle a full model of the coronal magnetic field before and after an event could show the results of this re-mapping. In practice we should also see the flow field, as the shrinking field lines drag the coronal plasma around. In the context of the classical large-scale reconnection model, one should see the inflow towards the reconnection point, and the outflow from it. In the normally favored geometry the post-reconnection shrinkage (Švestka et al., 1987; Forbes and Acton, 1996) provides the bulk of the energy release.

For this reason the recent *Yohkoh* observations of the flow field above certain arcade flares (McKenzie and Hudson, 1999) seem extremely interesting. These data show that we can use naturally-occurring tracers to define the flow field, if we have movie-type coronal observations of adequate spatial and temporal resolution.

## 4 Frequently asked questions

### 4.1 Why is this important?

The *Yohkoh* data show us many kinds of ejection, often involving flows apparently perpendicular to the field. These almost invariably take the form of expansion (but see Yokoyama, 2000, for an exception). Expansion means inflation of the magnetic field and therefore an increase in its energy. Thus the commonest observations show us restructuring that should not happen unstably, because they result in a growth of the coronal magnetic energy.

### 4.2 But I can show analytically that an expanding field releases energy!

Such arguments (*e.g.* Moore *et al.*, 1999) rely upon considering only a part of the problem. Full numerical treatments invariably show that stressing the field (adding energy to it) causes it to inflate (*e.g.* Sturrock *et al.*, 1994).

### 4.3 Isn't your "implosion" the same thing as magnetic reconnection?

No, because an ideal MHD instability should also result from an implosion in the same sense. Locally, the annihilation of the magnetic field (reconnection) certainly reduces the magnetic pressure, but at least in a Petschek-type geometry this would not provide much energy. One needs to look at the global process in any case.

### 4.4 I thought we understood flare loops pretty well....

Yes, the indirect evidence (and now the "supra-arcade downflows" observed by McKenzie and Hudson, 1999) certainly support some form of the standard opening-closing model, *in the gradual phase*. But the impulsive phase may be quite different.

## 4.5 Where should we look for implosions?

I think the TRACE data, with high time resolution and excellent spatial resolution, offer the best chance for the detection of implosion flows during the impulsive phase. These could occur on small spatial scales in strong-field regions. The gradual-phase flow fields, presumably on large spatial scales, have to compete with the large-scale expanding motions often seen during a CME launch. Possibly here one has a highly anisotropic flow field, outwards in some directions but inwards in other directions.

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