# Gradual SEP Events and the Low Corona

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Based on a small sample of events, we have reported that the low coronal morphology of solar eruptions may correlate with the properties of major SEP events (Nitta, Cliver and Tylka, ApJL, 586, L103, 2003). This can be a combined effect of the magnetic field topology around the CME source region and the physics of the ejection. Using the potential field source surface (PFSS) model, we study the relation between the isotropic shock and the well-connected field lines with some implications to SEP properties.

# Two Classes of Gradual SEP Events

## as suggested by recent ACE measurements

| | Type A | Type B |
|---|---|---|
| O and C Spectra (above 1-3 MeV/nuc) | Power-law with an exponential rollover | Power-law only |
| Fe/O or Fe/C (above 1-3 MeV/nuc) | Suppressed. Decreases with increasing energy | Enhanced. Increases with increasing energy above a few MeV/nuc |
| Fe charge state | 10-14 | ~20 |

What is the role of flares in type B gradual SEP events?

# What makes the different classes of gradual SEP events?

- Contribution from flare particles, either directly or as "seed" particles?

  CMEs may play the role of transporting as well as accelerating particles. What are the seed particles?

- Shock properties, such as quasi-parallel and quasi-perpendicular?

  What are the drivers of the shocks, and their directions with respect to the magnetic field?

# Intense flares without large SEP events

Intense flares, even if they are at longitudes usually thought to be well-connected, are not correlated with gradual SEP events when no energetic CMEs are associated.  Some of the following flares show motions in the low corona but they do not go beyond certain distances and are not associated with fast and extended CMEs.

List of X-class flares (>W30) not associated with large SEPs

| Date | Start | Peak | End | Class | Location |
|---|---|---|---|---|---|
| 27-Nov-1999 | 12:05 | 12:12 | 12:16 | X1.4 | S15 W68 |
| 2-Mar-2000 | 08:20 | 08:28 | 08:31 | X1.1 | S14 W52 |
| 30-Sep-2000 | 23:13 | 23:21 | 23:28 | X1.2 | N07 W90 |
| 2-Apr-2001 | 10:04 | 10:14 | 10:20 | X1.4 | N15 W60 |
| 25-Nov-2001 | 09:45 | 09:51 | 09:54 | X1.1 | S23 W71 |

# Possible correlations between type A/B and coronal signatures (based on a small sample of flares observed primarily in soft X-rays)

## Type A:

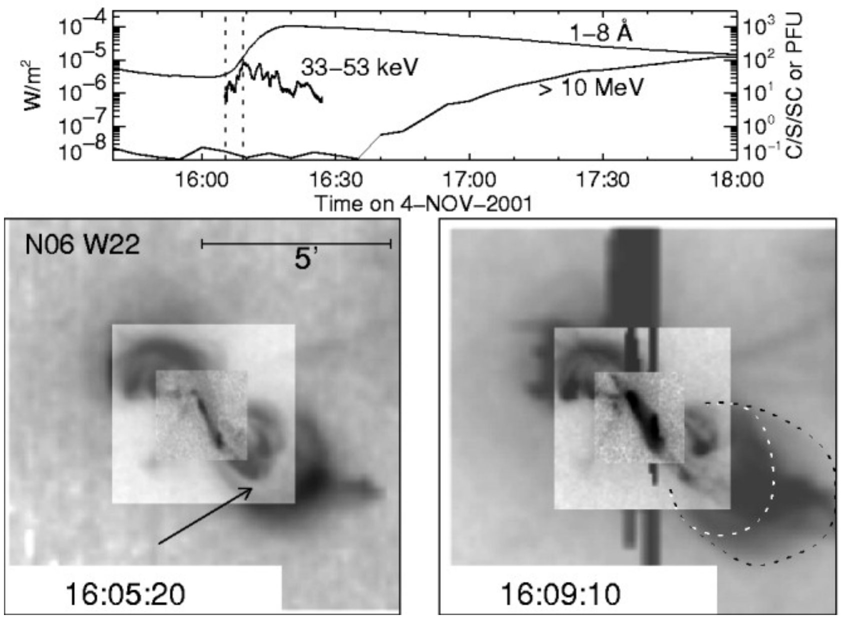
- The flare is preceded by gradual large-scale motions that seem to accelerate to a CME (i.e., the flare is part of the CME process)
- The acceleration seen in X-ray images nearly coincides with the CME height time relation extrapolated linearly to the flare location.

## Type B:

- The flare is an explosive one. The pre-flare motions, if seen, are not on large-scale. The flare could have occurred without a CME.
- The acceleration seen in X-ray images comes after the CME height time relation extrapolated linearly to the flare location (=deceleration very close to the Sun).

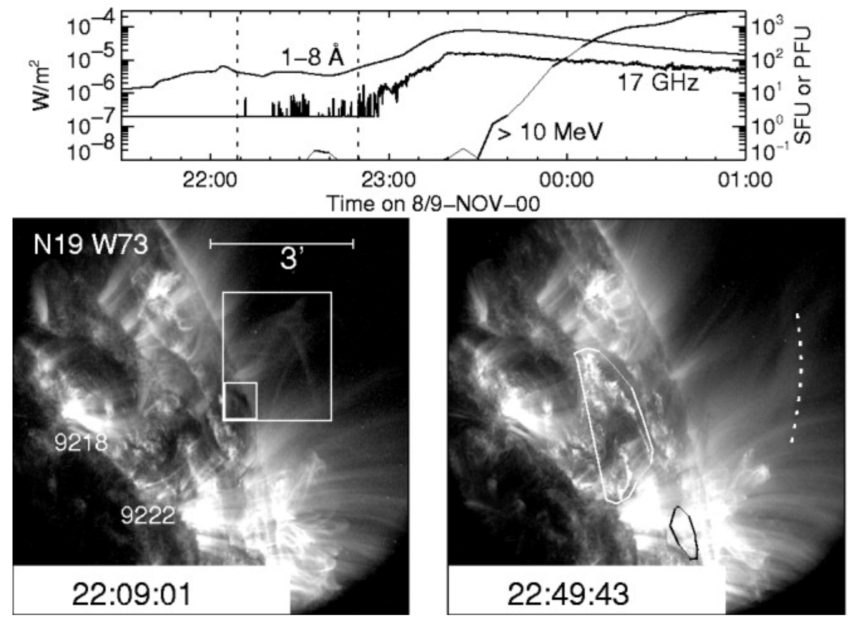
# Flares associated with type-A SEP events

## Eruption from a sigmoid region




Yohkoh/SXT images show that the western part of the sigmoid region erupted following gradual expansion.

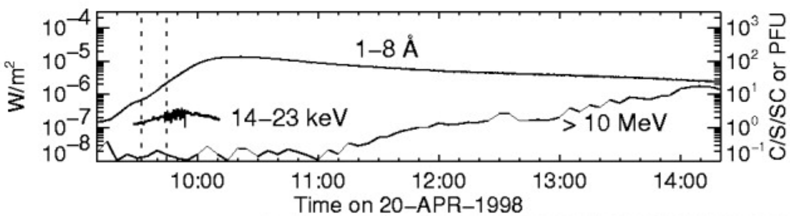
## Eruption of a filament between minor regions.

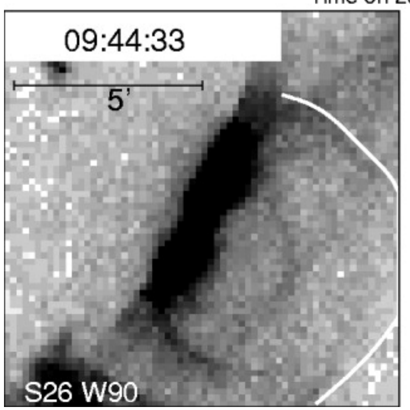


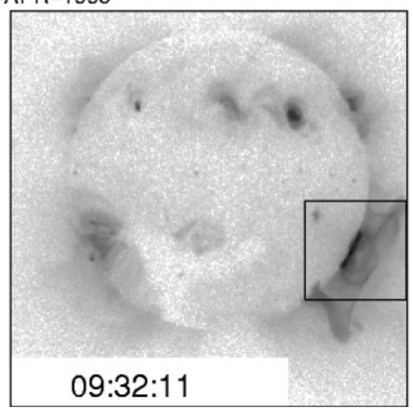

TRACE 171 A images captured a filament eruption from an area between minor active regions.

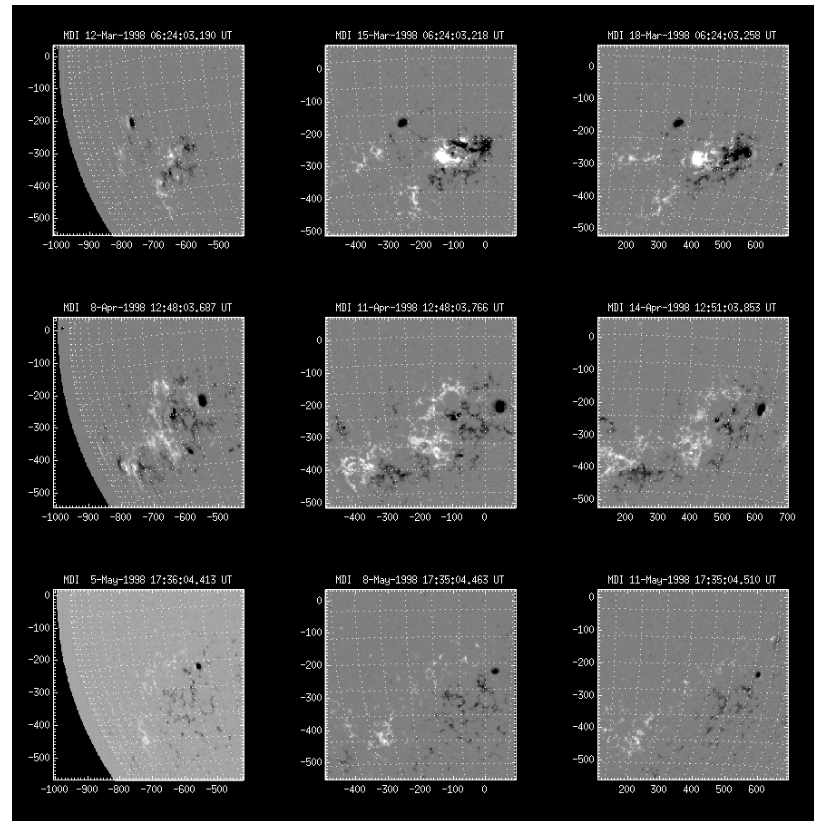
# Flares associated with type-A SEP events

## Filament eruption around a decaying region



8179
800 mil
17-Mar

8194
300 mil
11-Apr

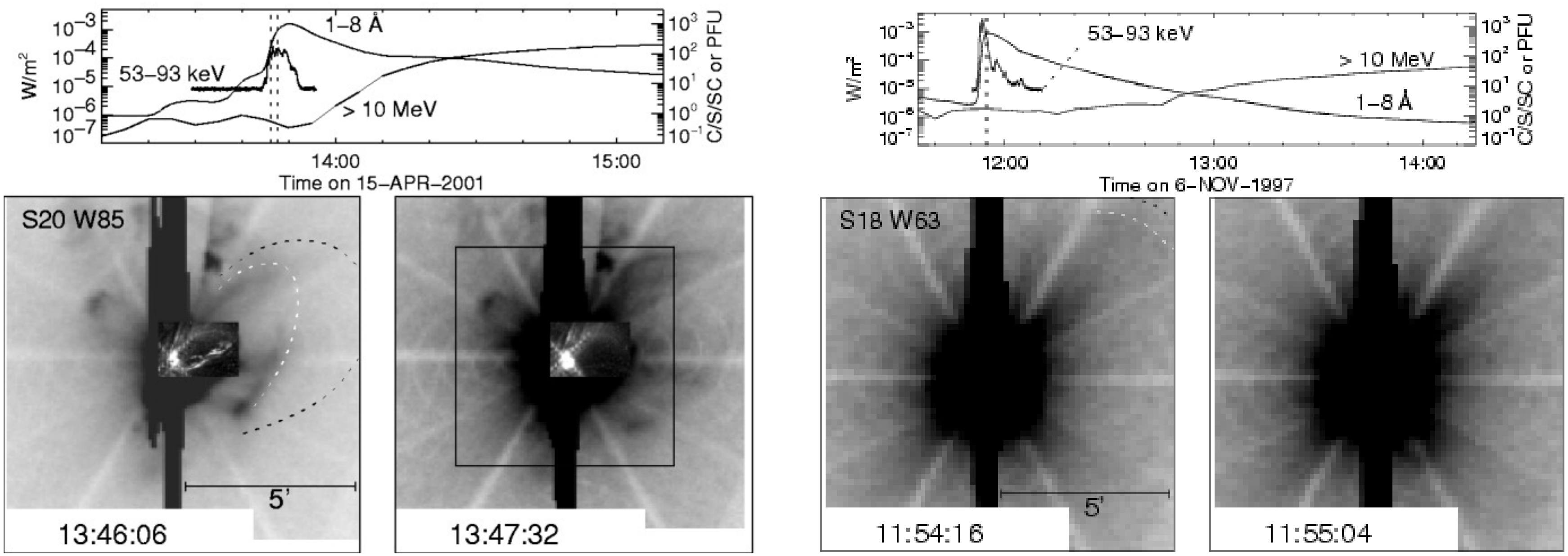
8217
50 mil
8-May

Large-scale motion preceded acceleration. This again did not involve major sunspot groups.

The CME/M1 flare occurred 6 days after the right panel in the middle row (~16 degrees behind the limb).

# Flares associated with type-B SEP events

Sudden appearance of large-scale eruptions during the impulsive phase




In these flares, ejecta in X-rays were diffuse without clear precursors, giving an impression that the motions may represent flare blasts. In the 15 April 2001 flare, TRACE (see insets) did observe motions of a filament-like structure, but it was on a small scale.

# Quasi-parallel and Quasi-perpendicular

In order to test the hypothesis of quasi-parallel (quasi-perpendicular) conditions contributing to type A (type B) SEP events, we need to know the geometrical relation between the shock and the magnetic field. We specifically try to study if these conditions are seen in the low corona.

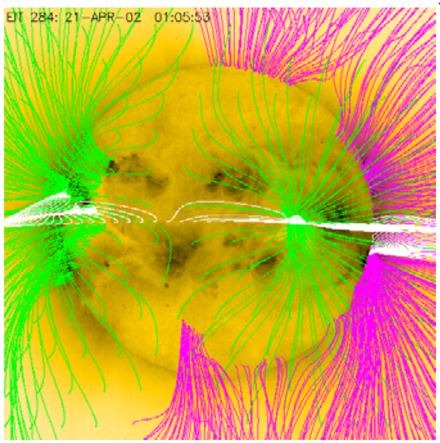
We use the potential field source surface (PFSS) model , with the following assumptions:

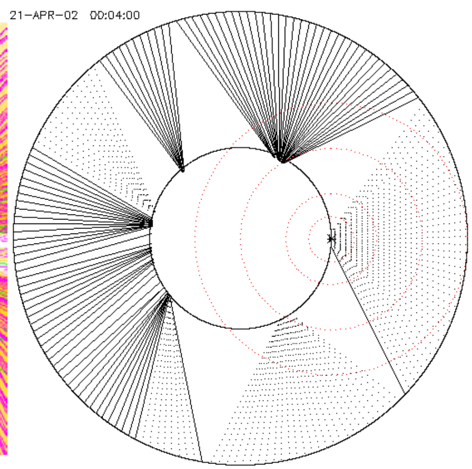
1. The magnetic field above the source surface (at 2.5 $R_{sun}$) follows the Parker spiral.
2. The non-radial behavior of the magnetic field occurs only between the photosphere and the source surface, where the current is assumed to be zero.

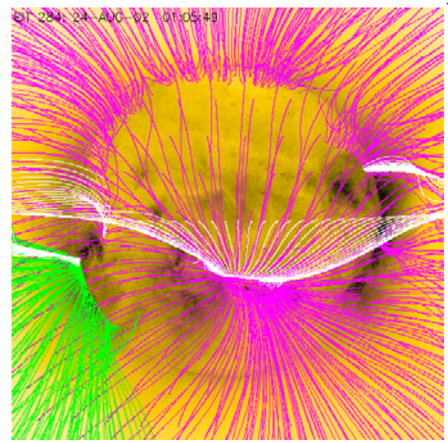
# Campaign Events

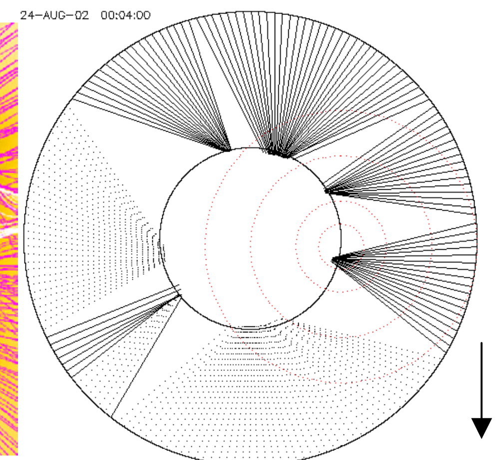
21 April 2002 event: Well-connected field lines within the flaring region (S14 W84).

24 August 2002 event: Well-connected field lines far from the flare region (S02 W81)



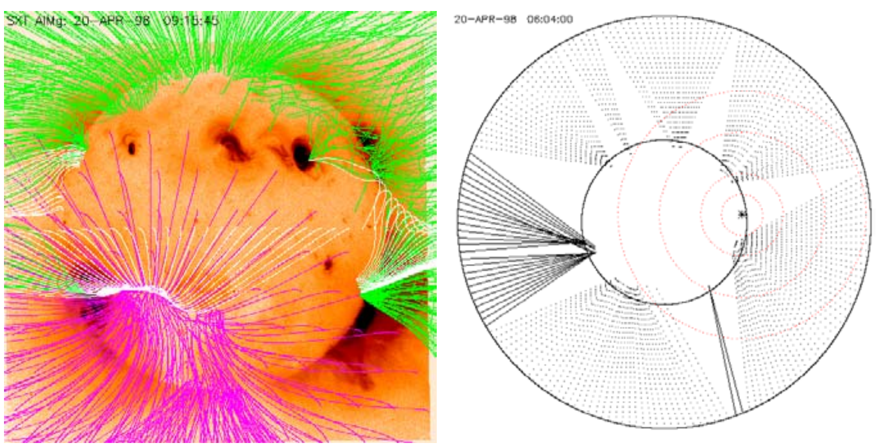



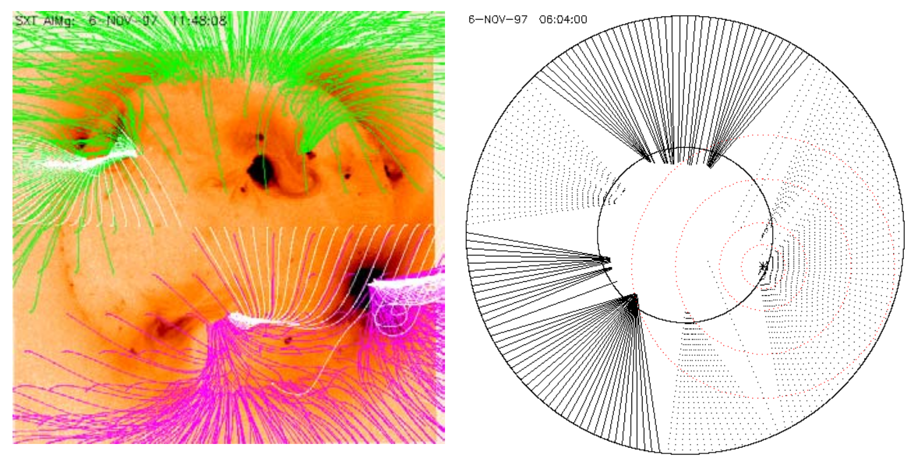

"Yellow" images show open field lines overplotted on EIT 284 A images. Green and pink stand for different polarities at their photospheric foot-points. White lines indicate field lines that reach the source surface at the ecliptic. The simplified polar view of the ecliptic field lines are also shown, with their start and end points connected by straight lines (solit: northern hemisphere, dotted: southern hemisphere). This shows non-radial behaviors (in longitudes) of some field lines. Circles in red indicate isotropic shocks from the flare sites.

# Other Events

Although a more sophisticated approach is needed, we may suggest that regions with well-connected field lines may provide quasi-parallel conditions (→ type A events) in the low corona, whereas those far from well-connected field lines may correspond to quasi-perpendicular (→ type B). But the following examples indicate that this is not always the case.




20 April 1998, type A, S25 W106



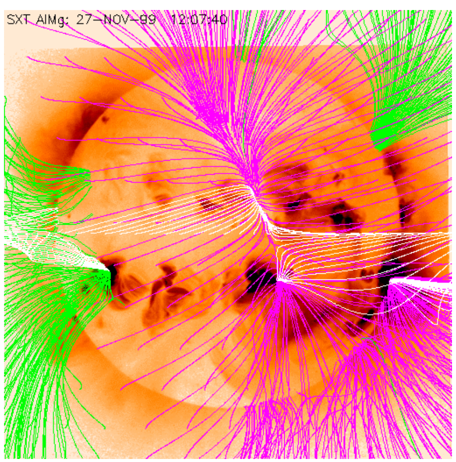

6 November 1997, type B, S18 W63

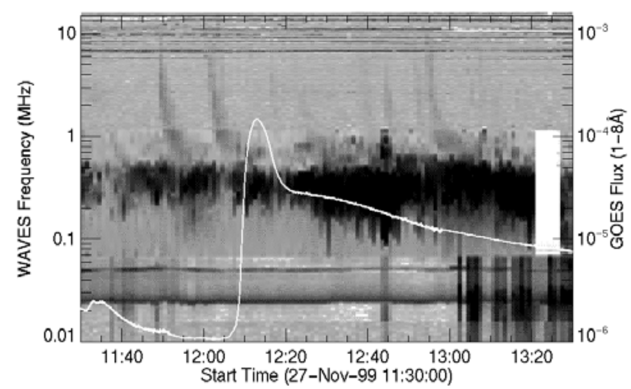
# Various Explanation for the Lack of Persistent Patterns

- SEPs are mainly accelerated farther from the Sun, so their properties do not strongly depend on the low corona.
- CME shocks are not isotropic (unlike blast waves) and they can also propagate non-radially.
- Interplanetary magnetic field can be so messy that the concept of connectivity breaks down for gradual SEPs.
- The PFSS model may not be applicable to regions that are responsible for gradual SEP events (via energetic CMEs).

# Use of the PFSS Model

- We emphasize that the PFSS model successfully reproduced well-connected field lines in several impulsive SEP events, which are thought to come from flares.
- The knowledge of the topological relation between the shock and the magnetic field may be useful for understanding the SEP onset times and peak fluxes.
- The lack of SEPs from big flares well-connected regions (see below) may provide deeper insights into flare processes.




The 27 November 1999 X-class flare occurred in a well-connected active region (S15 W68), as indicated by some white field lines, no SEPs were observed. There was no CME, DH type II burst or metric/DH type III burst but a metric type II burst.

# Conclusions

- There seems to be a correlation between the low coronal manifestations of flare/CME events and properties of gradual SEPs.
- We need to employ simple techniques (such as the PFSS model) to study how the shock propagate in quasi-parallel or quasi-perpendicular conditions.
- 2-d plots suggest that the quasi-parallel (quasi-perpendicular) conditions sometimes correspond to type A (type B) events, but not always.