CMEs, solar wind and Sun-Earth connections: unresolved issues

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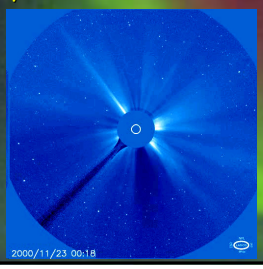
In recent years, an unprecedented amount of high-quality data from various spaceprobes (Yohkoh, WIND, SOHO, ACE, TRACE, Ulysses) has been piled up that exhibit the enormous variety of CME properties and their effects on the whole heliosphere. Journals and books abound with new findings on this most exciting subject. However, major problems could still not be solved. In this Reporter Talk I will try to describe these unresolved issues in context with our present knowledge.



My very personal
Catalog of ignorance,
Updated version (see SW8)
IAGA Scientific Assembly in Toulouse,
18-29 July 2005

MPRS seminar on January 18, 2006

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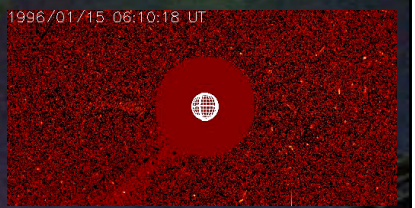
The definition of a CME

"We define a coronal mass ejection (CME) to be an observable change in coronal structure that occurs on a time scale of a few minutes and several hours and involves the appearance (and outward motion, RS) of a new, discrete, bright, white-light feature in the coronagraph field of view." (Hundhausen et al., 1984, similar to the definition of "mass ejection events" by Munro et al., 1979).

CME: coronal -------- mass ejection,
not: coronal mass -------- ejection!



In particular, a CME is NOT an
Ejección de Masa Coronal (EMC),
Ejectie de Maså Coronalå,
Eiezione di Massa Coronale
Éjection de Masse Coronale

The community has chosen to keep the name "CME", although the more precise term "solar mass ejection" appears to be more appropriate.

An ICME is the interplanetry counterpart of a CME

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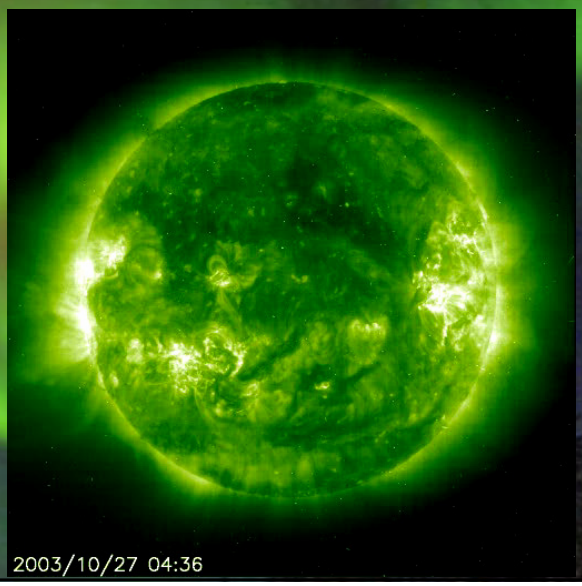
1. The onset of coronal mass ejections

1.1. Which pre-event signature signals an impending CME ?



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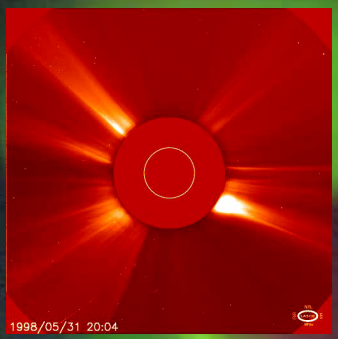
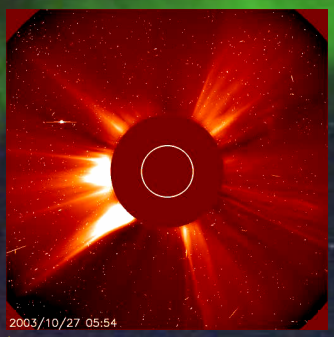
1. The onset of coronal mass ejections

1.2. What is the actual trigger of a CME?



Two small comets were evaporating near the Sun. A few hours later a huge ejection occurred. Coincidence? No! Says Dan Baker...



On October 28, 2003, in conjunction with a X13 flare, there occurred a gigantic CME . 8 hours earlier a little comet had evaporated! **Coincidence?**

By the way: In 10 years mission time, SOHO has seen more than 1000 little comets and some 10,000 CMEs...

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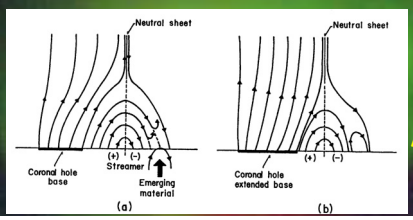
1. The onset of coronal mass ejections

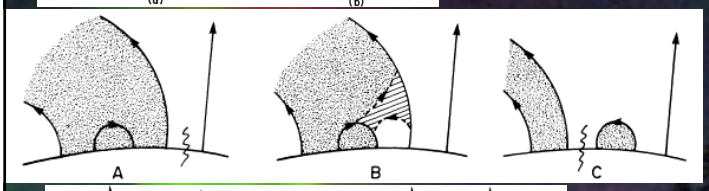
1.3. Is proximity of coronal hole boundary stimulating CME?



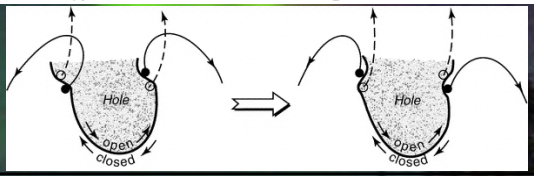
Bravo 1995

The idea:
Emerging loop near CH boundary reconnects with CH open field line and thus shifts CH boundary.

(Remnant of Hewish's idea:
CHs -> „eruptive streams" -> CMEs)



Kahler & Moses, 1990



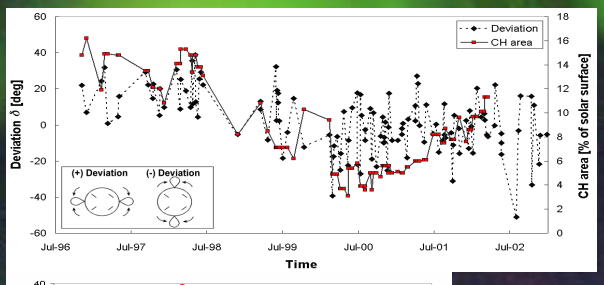
Maintenance of rigid rotation by „footpoint switching

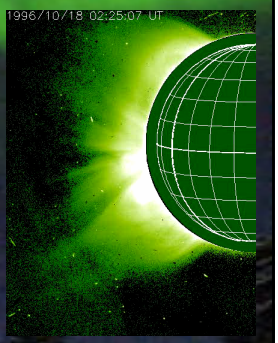
Wang & Sheeley, 2004

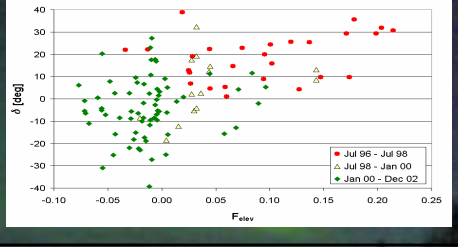
1. The onset of coronal mass ejections

1.3. Is proximity of coronal hole boundary stimulating CME?

At least, coronal holes do deflect CMEs towards solar equator!





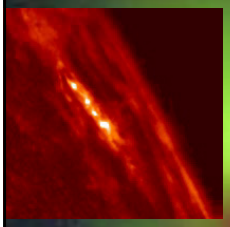


Conclusion:
The larger coronal holes are, the more they can deflect CMEs

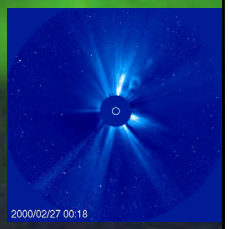
Cremades, 2005

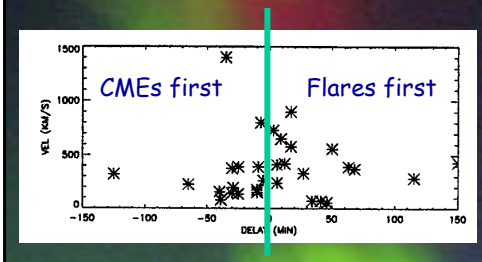
1. The onset of coronal mass ejections

1.4. Which role do flares play for CMEs' onset and further fate?



- Flares are localized short-duration explosions in the solar atmosphere, seen in visible light, EUV, X- and Gamma-rays.
- CMEs are large-scale expulsions of huge plasma clouds that may drive shock waves.
- Flares and CMEs often occur in close temporal context.





Time separation between flares and correlated CMEs

Harrison, 199?

The simple but important conclusions: flares occurring after their associated CMEs cannot be their cause, quite logically.

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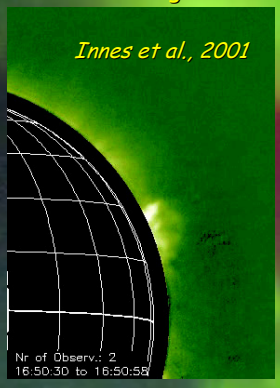
1. The onset of coronal mass ejections

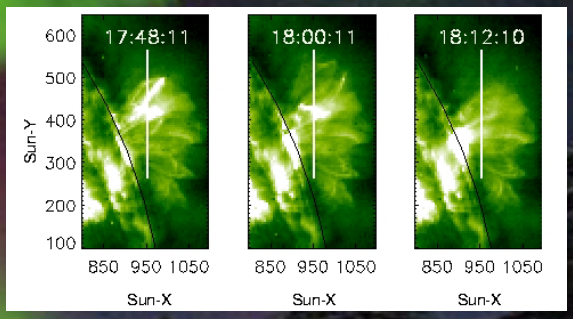
1.4. Which role do flares play for CMEs' onset and further fate?

For illustration: the explosive onset of a CME, in close context with a flare:

For this CME on May 8, 1999 we were lucky to observe the onset in great detail, using data from several instruments: MICA, SUMER, EIT



The MICA coronagraph took an image every half minute!



EIT images, taken every 12 minutes

The SUMER slit happened to be in the "right" location.

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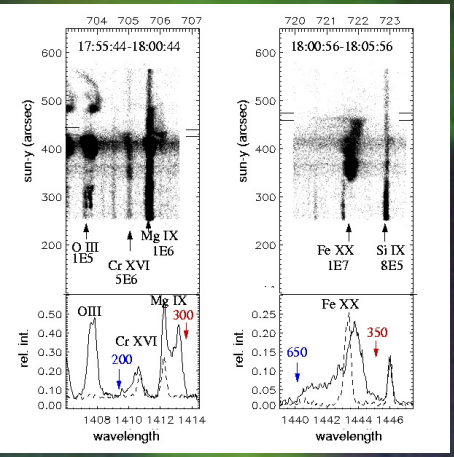
1. The onset of coronal mass ejections

1.4. Which role do flares play for CMEs' onset and further fate?



Line-of-sight plasma speeds from SUMER spectra, and MICA radial speed data fit together:

Expansion speeds up to 600 km/s in all directions were measured. That indicates 3-D explosive reconnection at a site in the corona!

Innes et al., 2001

Flares and CMEs are probably symptoms of a more basic "magnetic disease" of the sun.

Harrison, private communication, 2000

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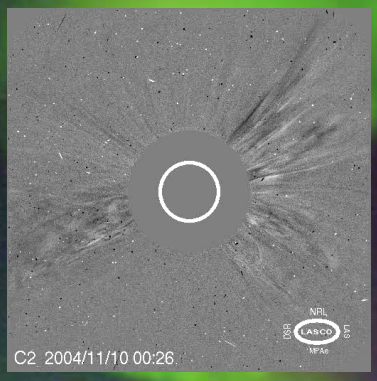
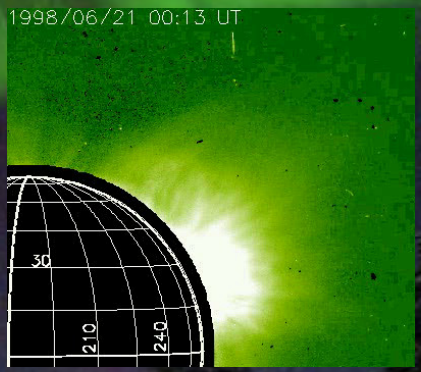
2. Different types of CMEs?

The bandwidth of CME properties (speed, acceleration profiles, sizes, event associations, etc) is enormous. It is hard to conceive that they are all due to the same release and acceleration mechanisms.



This extremely fast limb CME of Nov. 10, 2004, went to 30 Rs in 2 hours!



This balloon took some 30 hours to finally take off! It was the offspring of an eruptive prominence.

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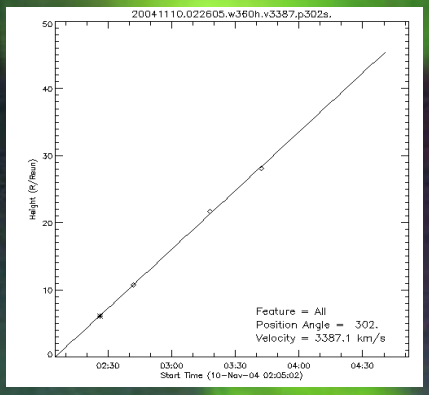
2. Different types of CMEs?

2.1. Are there different acceleration mechanisms at work?

2.2. How small are the smallest CMEs?

2.3. How are the ejected plasma clouds integrated into the solar wind?



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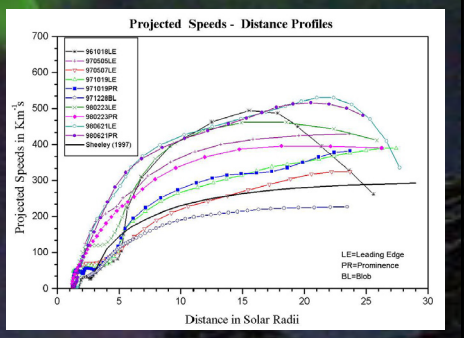

"Balloon"-type CMEs take up speed slowly, like the ambient slow solar wind

Srivastava, 1999

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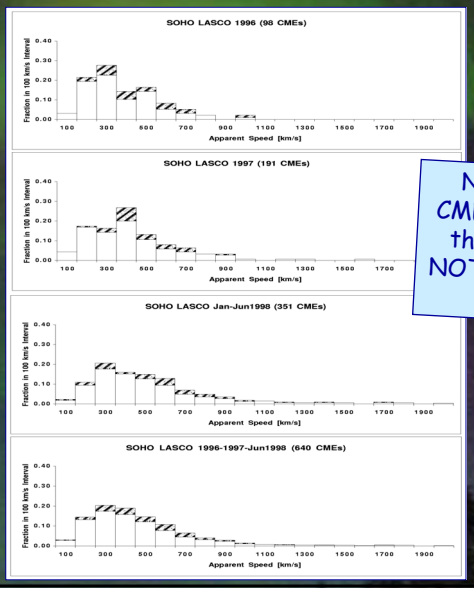
2. Different types of CMEs?

2.4. Is there a continuous spectrum of CME properties?



Note the small number of slow CMEs! The increased sensitivity of the modern instrumentation has NOT increased the number of slow, faint CMEs.

Histogram of apparent front speeds of 640 CMEs, observed by **LASCO** on **SOHO**

St.Cyr et al., 2000

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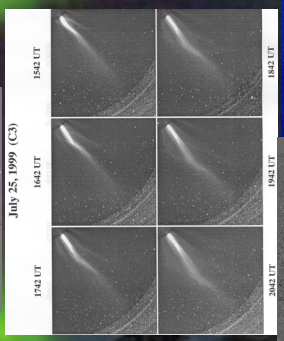
3. What is the topology of CMEs?

3.1. How to interpret the various commonly observed features of CMEs?

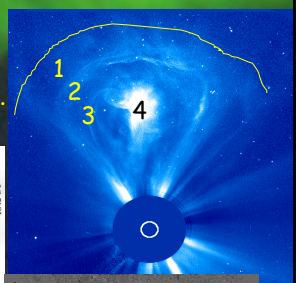
3.2. Where would a shock front be in coronagraph images? How far ahead of the bright loop and how far extended?

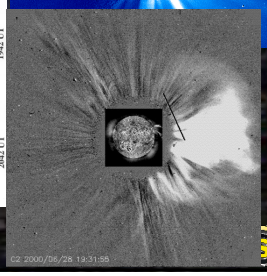
The majority of CMEs has a clearly discernible 4-part structure. Str.1 and the shock itself remain invisible, but...

Vourlidas, 2003
Ciaravella, 2005



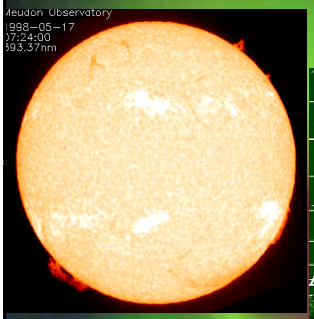
Sheeley,2000

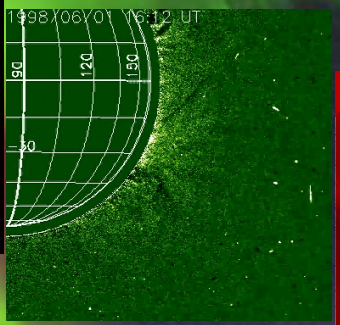


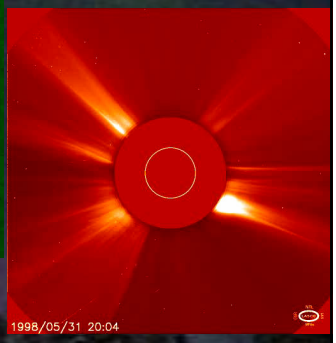


3. What is the topology of CMEs?

3.3. How long before a CME eruption is the big loop formed? Does it hold the stuff down until it erupts or is it formed as part of the eruption process?







A CME with an erupting prominence, observed on June 2nd, 1998.

3. What is the topology of CMEs?

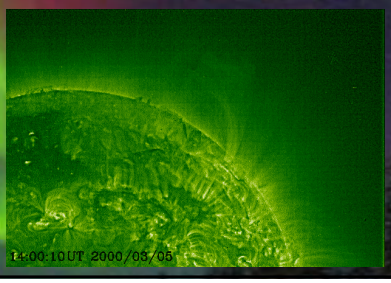
3.4. Is the bright white loop part of the ejecta, i.e., does it act as driver or is it driven itself?

3.5. Where and when are the loop legs ever disconnected?

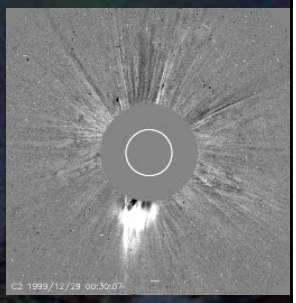
3.6. Are the cavity and the bright kernel separate entities or are they both parts of one big flux rope?

3.7. Do all erupting streamers have cavities?

3.8. What do the downflow events and collapsing loops mean?



Tripathi, 2005

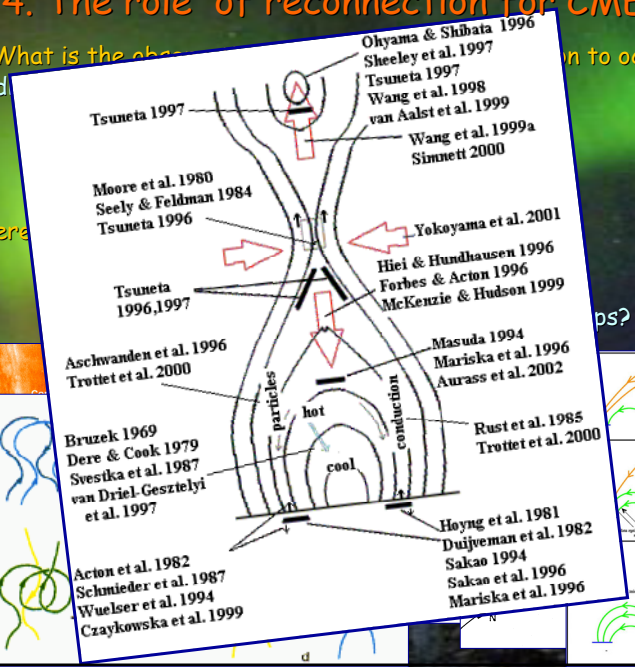


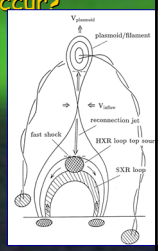
Wang and Sheeley, 1999 ff

4. The role of reconnection for CMEs

4.1. What is the ch… …n to occur?
Cand…

4.2. Where… …ps?



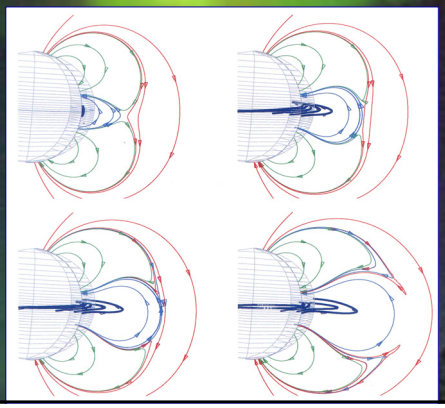


4. The role of reconnection for CMEs

4.3. When does reconnection occur in the CME process?

4.4. What exactly is the role of reconnection: trigger, driver, or mere sequel?

4.5. How, where and on which time scales is the new flux opened by a CME compensated by appropriate reconnection?



The „breakout model" for CMEs

Antiochos, 1998

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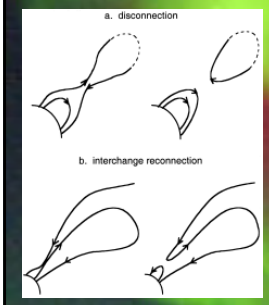
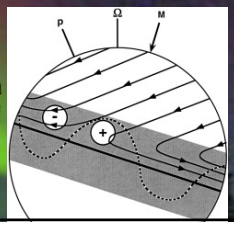
4. The role of reconnection for CMEs

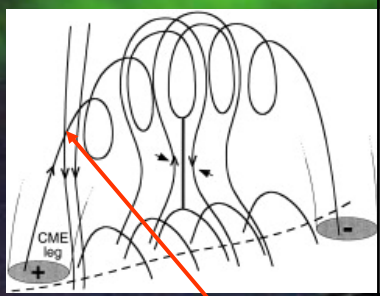
4.6. How is the „flux catastrophy" avoided?

The problem: Emerging bipolar loops break open in CMEs and keep adding flux to the IMF. How is that ever compensated?



Interchange reconnection might help to maintain CH rigid rotation above the differentially rotating photosphere





Interchange reconnection might happen here!

Crooker et al., 2002

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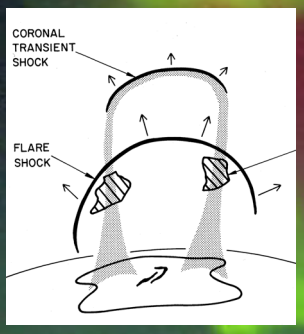
5. Shock waves from flares and CMEs

5.1. Where are shock waves actually being formed?

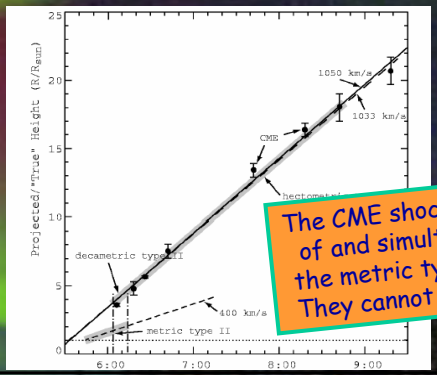
5.2. Are shocks from flares blast waves, qualitatively different from driven CME shocks?

5.3. Do flare shocks eventually die out, and where?

5.4. Do flare shocks catch up with ejecta and CME shocks?



Wagner&McQueen, 1983



Klassen, 1999

The CME shock runs ahead of and simultaneously to the metric type II shock. They cannot be the same!

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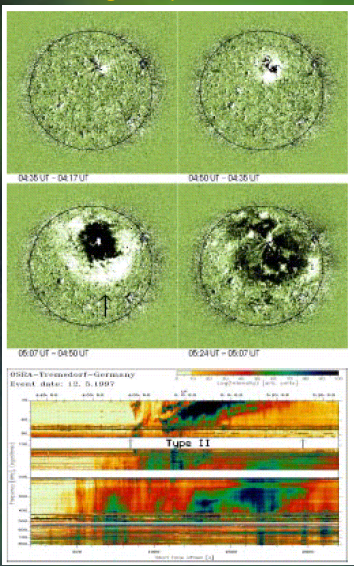
5. Shock waves from flares and CMEs

5.5. Moreton- and EIT waves, coronal dimmings, radio type II&III bursts, energetic particles – is there a consistent scenario?



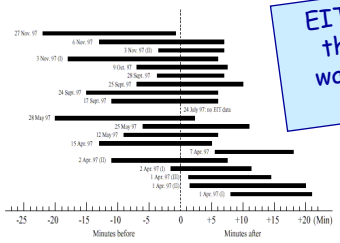


Fig. 2. EIT wave onset related with the start of associated type III bursts (indicating the start of the impulsive flare phase). The start time of the type III bursts is zero on the time axis

EIT waves are NOT the coronal shock waves causing radio bursts

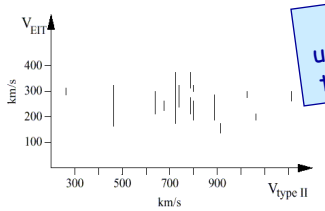


Fig. 3. The speed relation between EIT waves and type II bursts

EIT waves are usually much slower than type II waves

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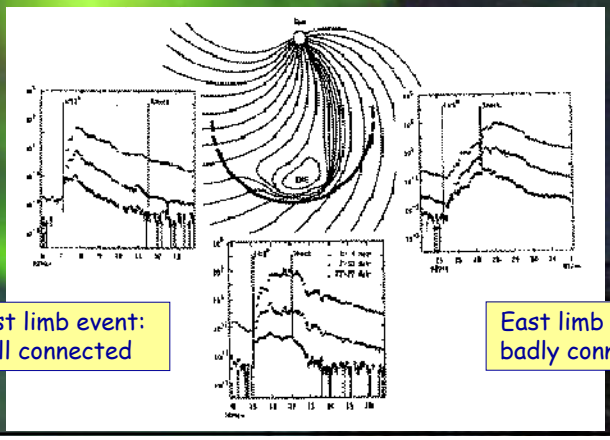
6. Particle acceleration (SEPs)

6.1. Where, when and how are particles accelerated?

6.2. Are there two (or even more) classes of SEPs?

6.3. Injection of SEPs on far distant field lines: transport or local acceleration?



West limb event: well connected

East limb event: badly connected

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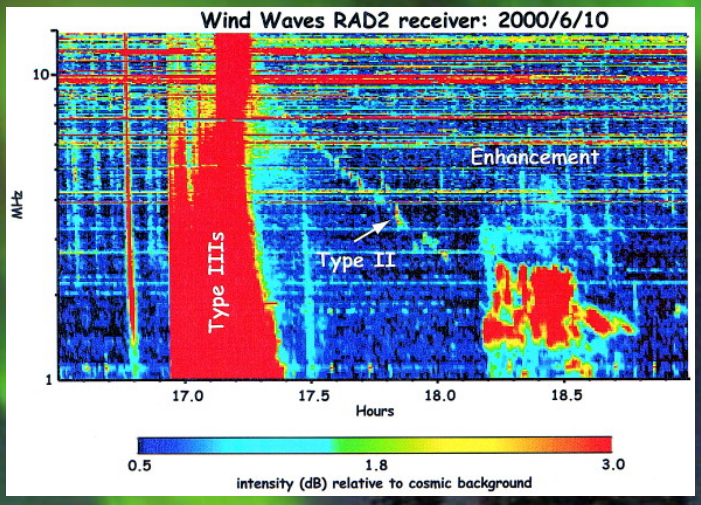
6. Particle acceleration (SEPs)

6.4. What is the seed population for SEPs?



Cannibal CMEs?

Gopalswamy, 2000?

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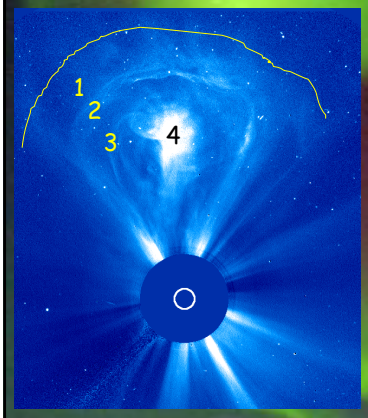
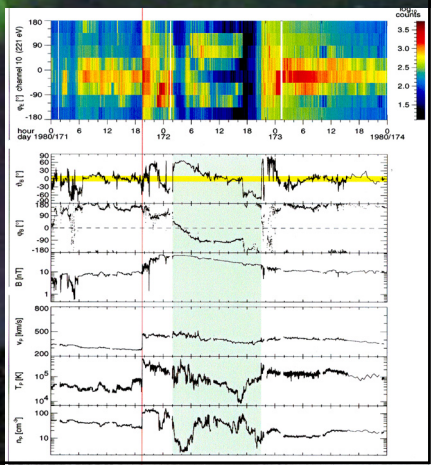
7. The transformation of CMEs into ICMEs

The majority of CMEs has a clearly discernible multi-part structure. But most ICMEs exhibit a very different two-part structure: a shock-compressed sheath layer followed by a rather homogeneous low beta plasma, with several other characteristic signatures („driver gas", „piston").

7.1. How is the CME structure transformed into the ICME structure?



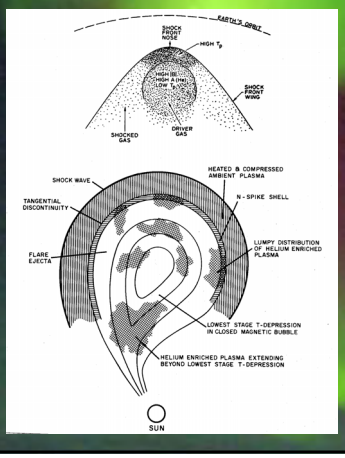


7. The transformation of CMEs into ICMEs

7.1. How big in extent are shock fronts compared to ICMEs?

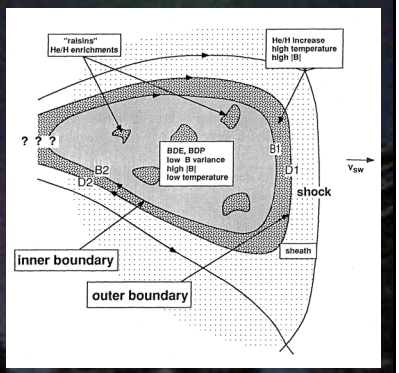
7.2. Why are not all ejecta clouds also magnetic clouds?

7.3. Where and how long do ICMEs act as shock drivers?



Borrini, 1982

Bame, 1979

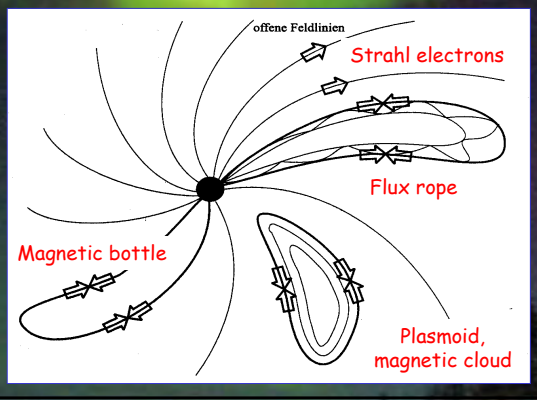


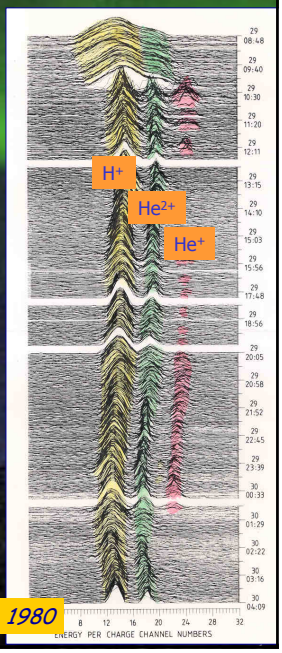
7. The transformation of CMEs into ICMEs

7.4 Why do we find He^+ enhancements so rarely in ICMEs?

7.5. What do abundance and ionization state mesurements tell us about the ICMEs' origin?

7.6. What does bi-directional streaming really mean?





Schwenn, 1980

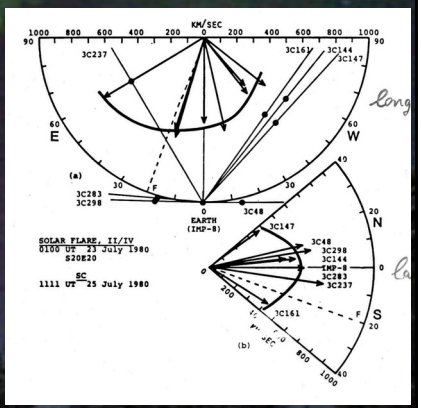
8.The extent of shock fronts, ejecta, and SEP fluxes

8.1. How far around the Sun do ICMEs and SEP fluxes extend?

8.2. How irregular are the shockfronts due to local shock speed differences?

8.3. Are shock fronts continuous surfaces all around?

8.4. Acceleration & deceleration processes throughout the heliosphere?



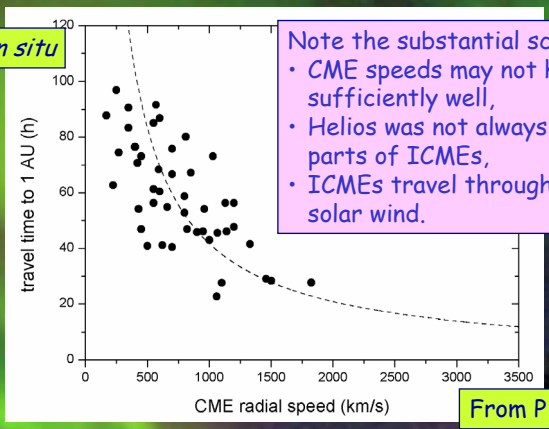
Watanabe, 199?

MPS

8. The extent of shock fronts, ejecta, and SEP fluxes

8.4. Acceleration & deceleration processes throughout the heliosphere?

From Helios *in situ*



Note the substantial scatter!
- CME speeds may not have been measured sufficiently well,
- Helios was not always hit by the fastest parts of ICMEs,
- ICMEs travel through different ambient solar wind.

Schwenn et al., 2005

From P 78-1 coronagraph

The travel time of ICME driven shock fronts from the Sun to the location of Helios 1 vs the CME radial speed V_{rad}.

This is why forecasting ICME arrival times is inherently uncertain, even if we could exactly measure the radial CME speed near the Sun!

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CMEs, solar wind and Sun-Earth connections: unresolved issues

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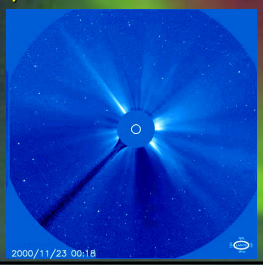
In recent years, an unprecedented amount of high-quality data from various spaceprobes (Yohkoh, WIND, SOHO, ACE, TRACE, Ulysses) has been piled up that exhibit the enormous variety of CME properties and their effects on the whole heliosphere. Journals and books abound with new findings on this most exciting subject. However, major problems could still not be solved. In this Reporter Talk I will try to describe these unresolved issues in context with our present knowledge.



My very personal
Catalog of ignorance,
Updated version (see SW8)

IAGA Scientific Assembly in Toulouse,
18-29 July 2005

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