The 3D Heliosphere: What can we learn from STEREO?

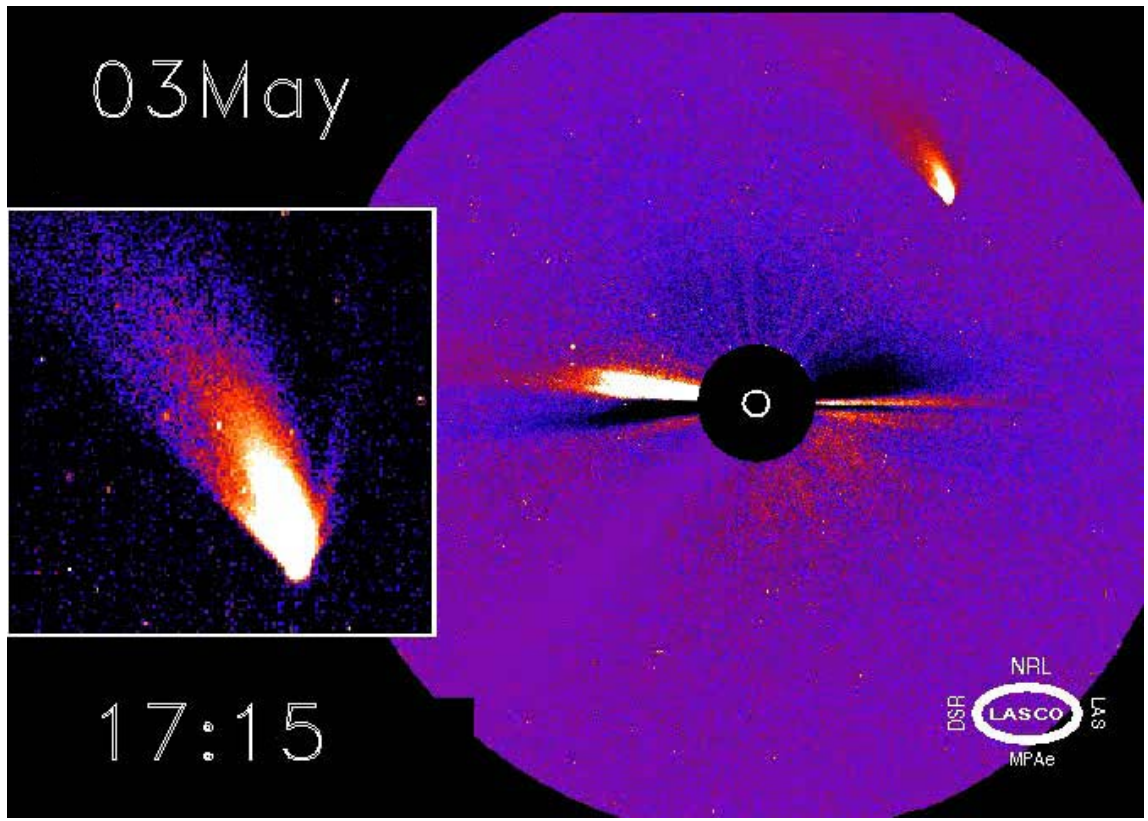
S. T. Suess
NASA - MSFC
National Space Science & Technology Center

Outline:

I. Introduction
- A sparse overview of what is known

II. Two STEREO scenarios:
- II.1. The 'self-realization' scenario
- II.2. The 'new discoveries' scenario

III. Summary



The Skylab coronagraph and x-ray imager:

(i) Defined coronal holes to be the source of CIRs

(i) Revealed the importance of CMEs

A "particulary unexpected result"

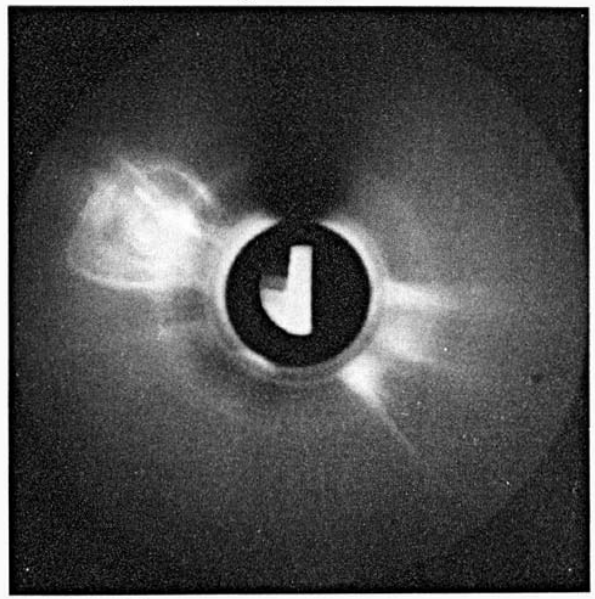
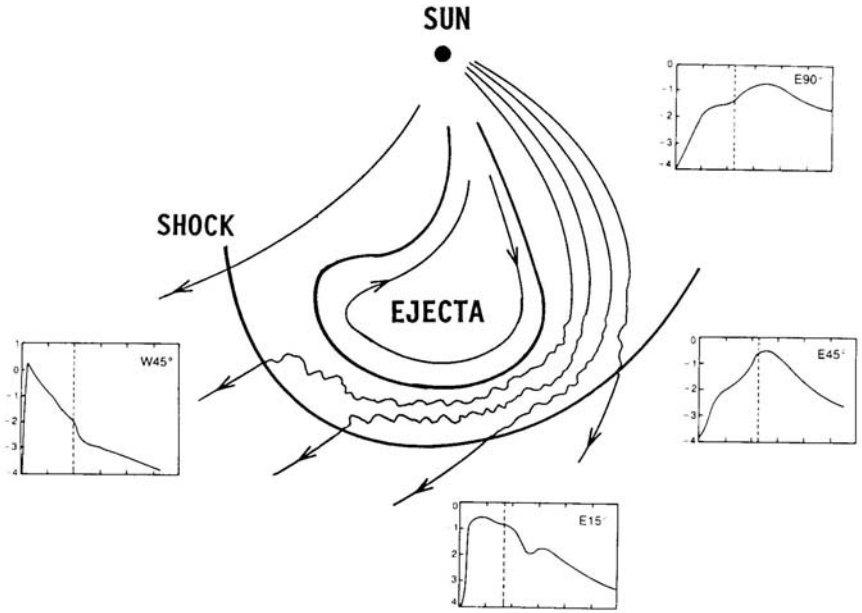


FIG. 2.—A coronal transient, 0943 GMT, 1973 June 10, in a 9-s unpolarized exposure

Multi-point observations:

(i) The discovery of the asymmetric shape of CMEs, shocks, and energetic particle fluxes.



(ii) The discovery of magnetic clouds – which thereafter could be detected with single-point measurements.

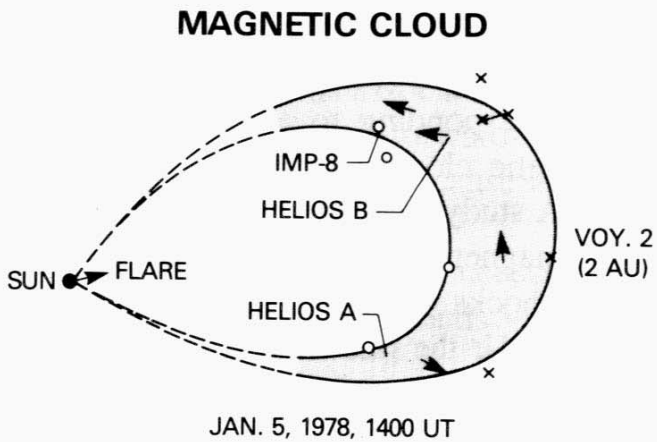


Fig. 6.8. The large-scale geometry of a magnetic cloud determined by multispacecraft measurements. The orientation of the axis of the magnetic cloud, shown by the arrows, was obtained from fits of the data to the solution for a cylindrically symmetric constant-α force-free magnetic field

Quadratures:

Helios – P78-1 quadratures showed that essentially all CMEs on the limb produce interplanetary shocks

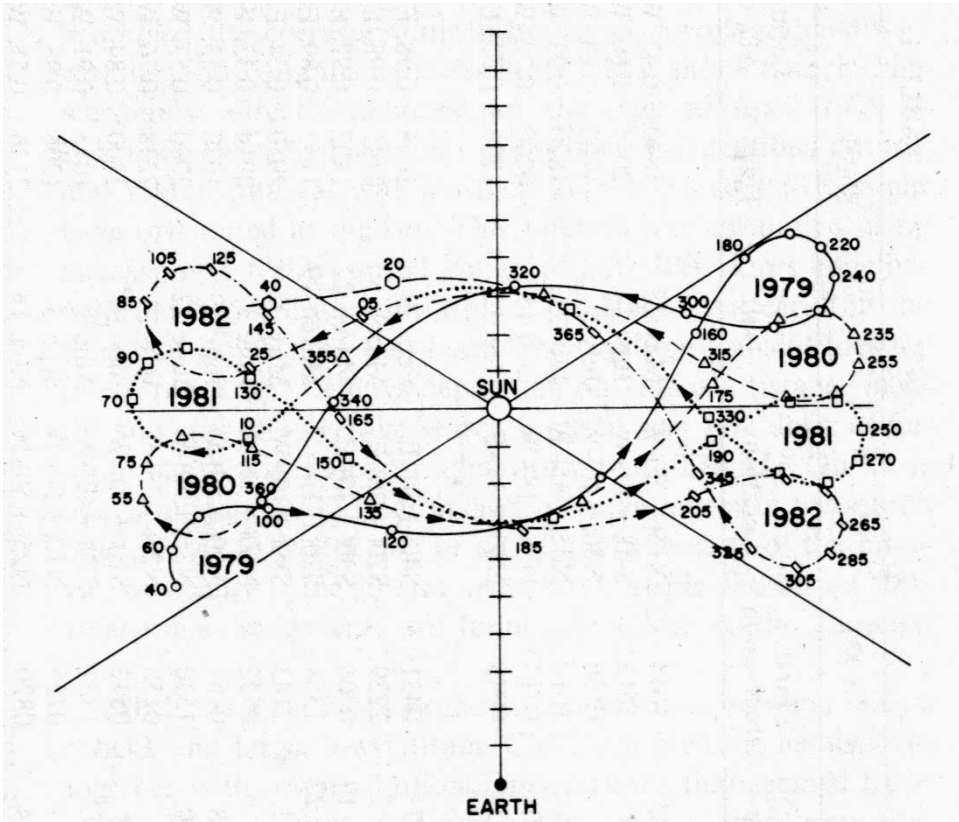
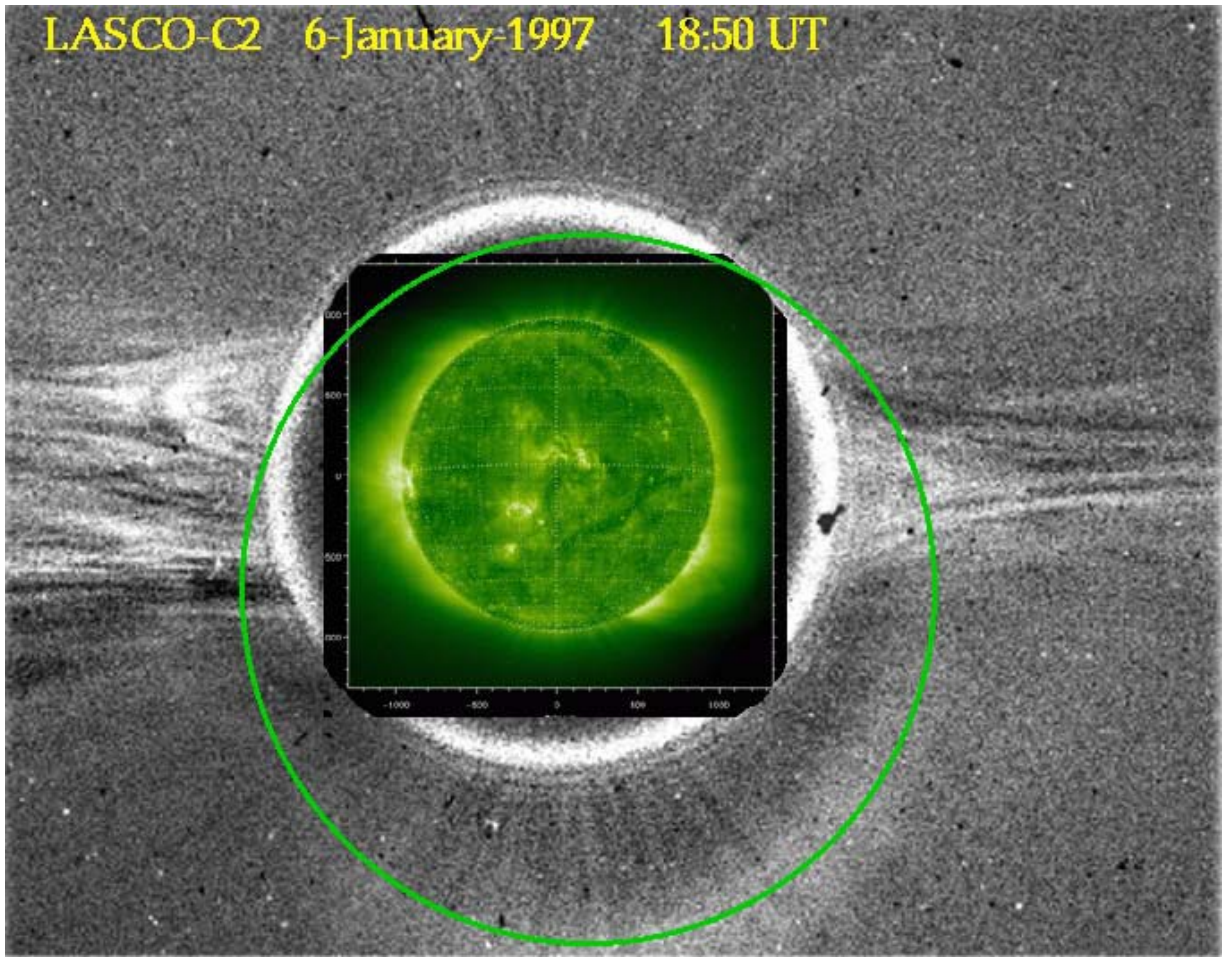


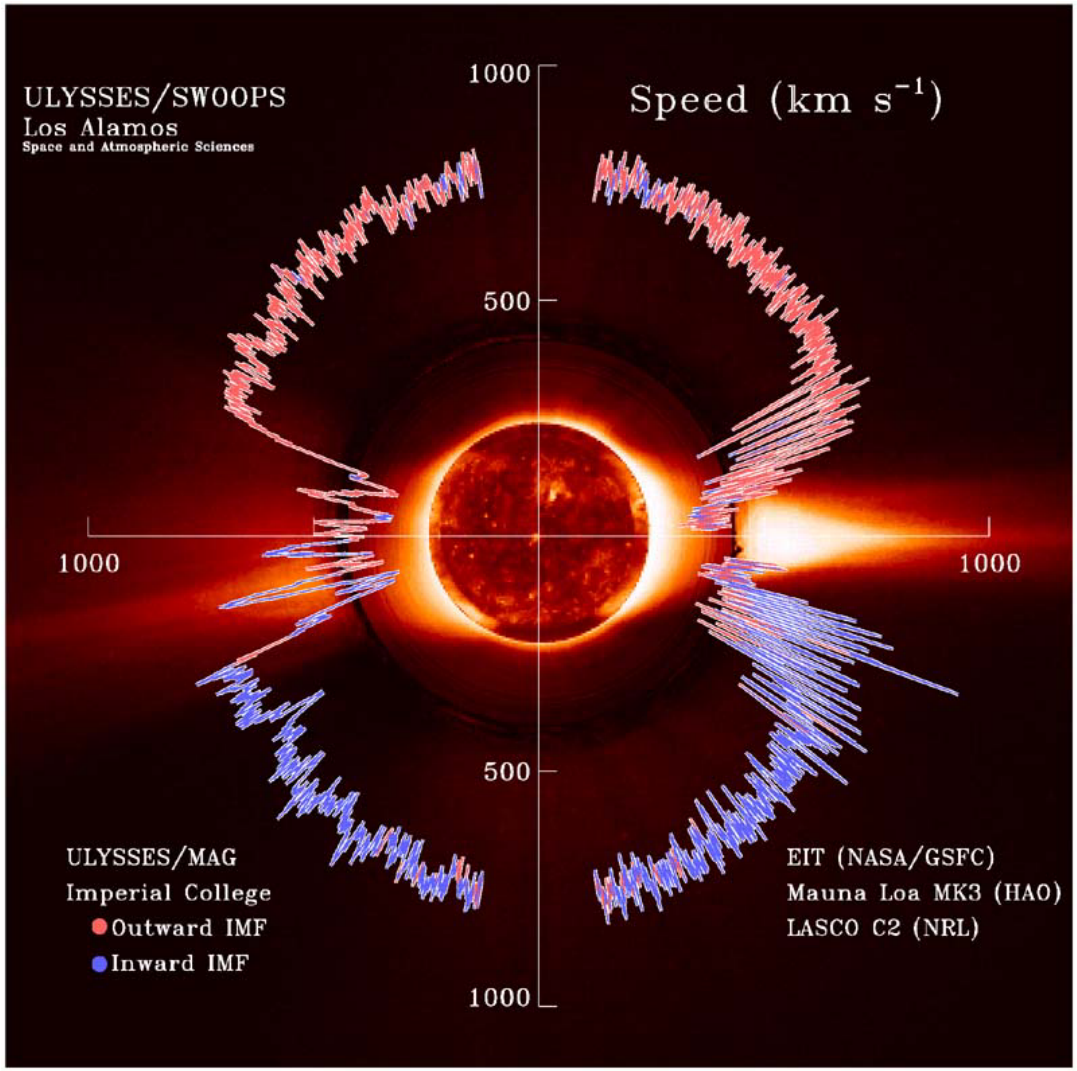
Fig. 1. The Helios 1 orbit in a fixed sun-earth system during 1979–1982. Annually coded tick marks are placed at 20-day intervals, and reference lines are drawn at 32° angles to the east-west direction.

Halo events were discovered with P78-1

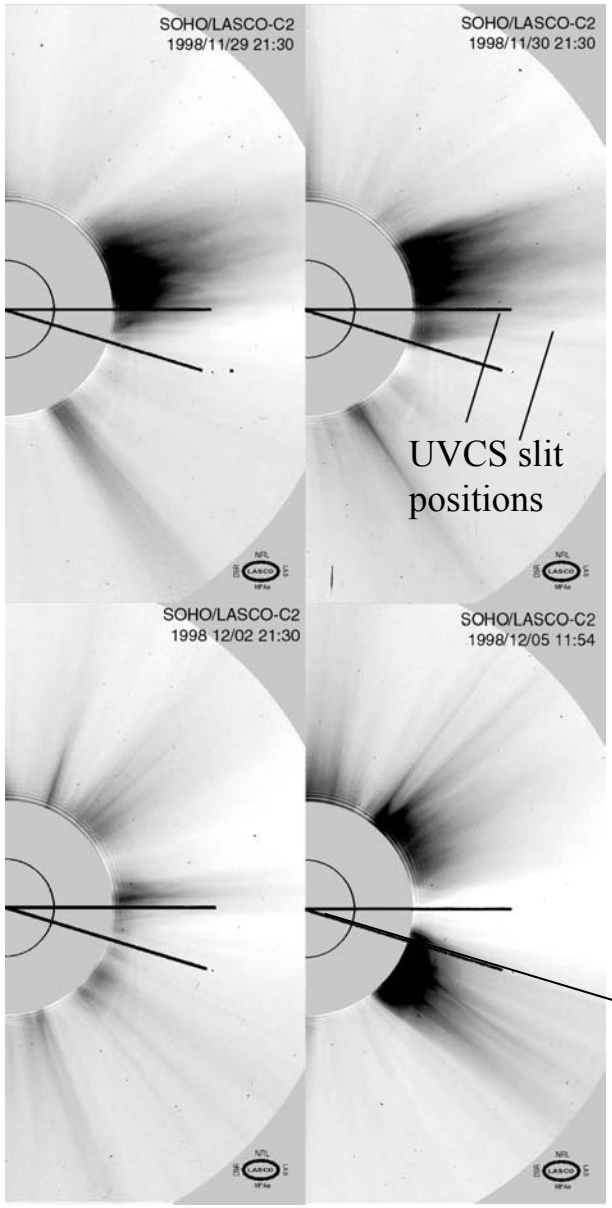
SMM defined the three part structure of CMEs

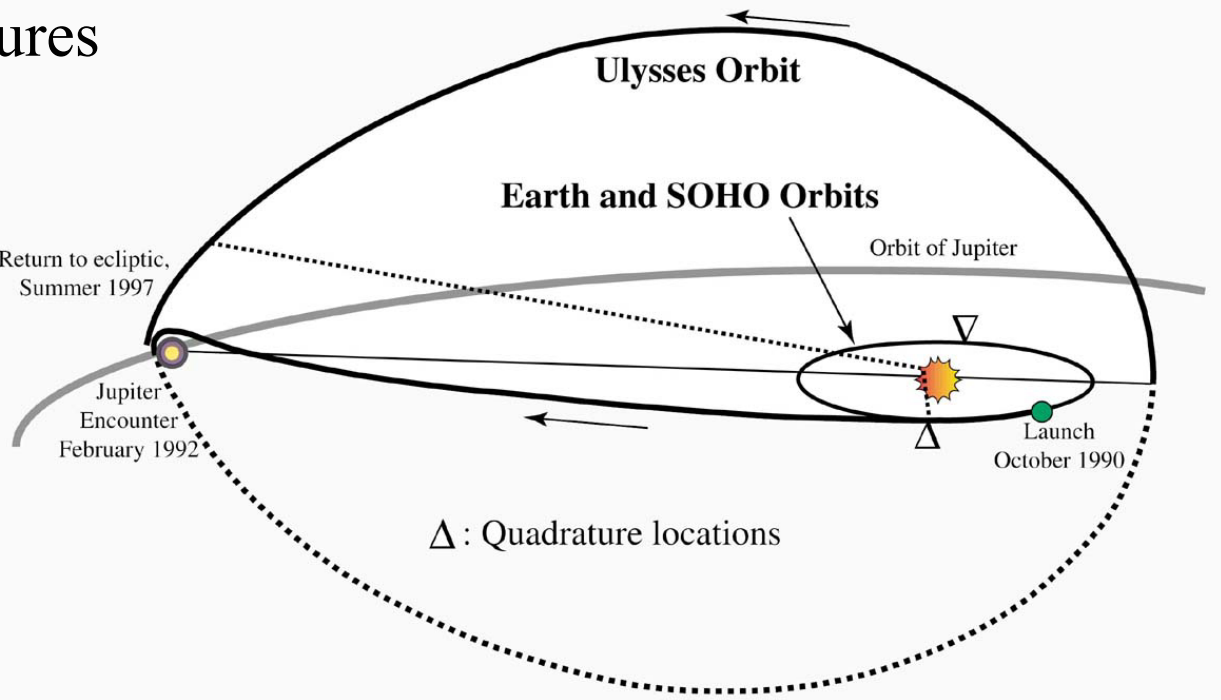


A global picture of the minimum (and, now, maximum) solar wind with Ulysses (dial plot) - the “bimodal solar wind”:



SOHO-Ulysses quadratures





These are confirming the <u>composition solar source-*in situ* plasma</u> identifications suggested from single-point Ulysses and ACE measurements.

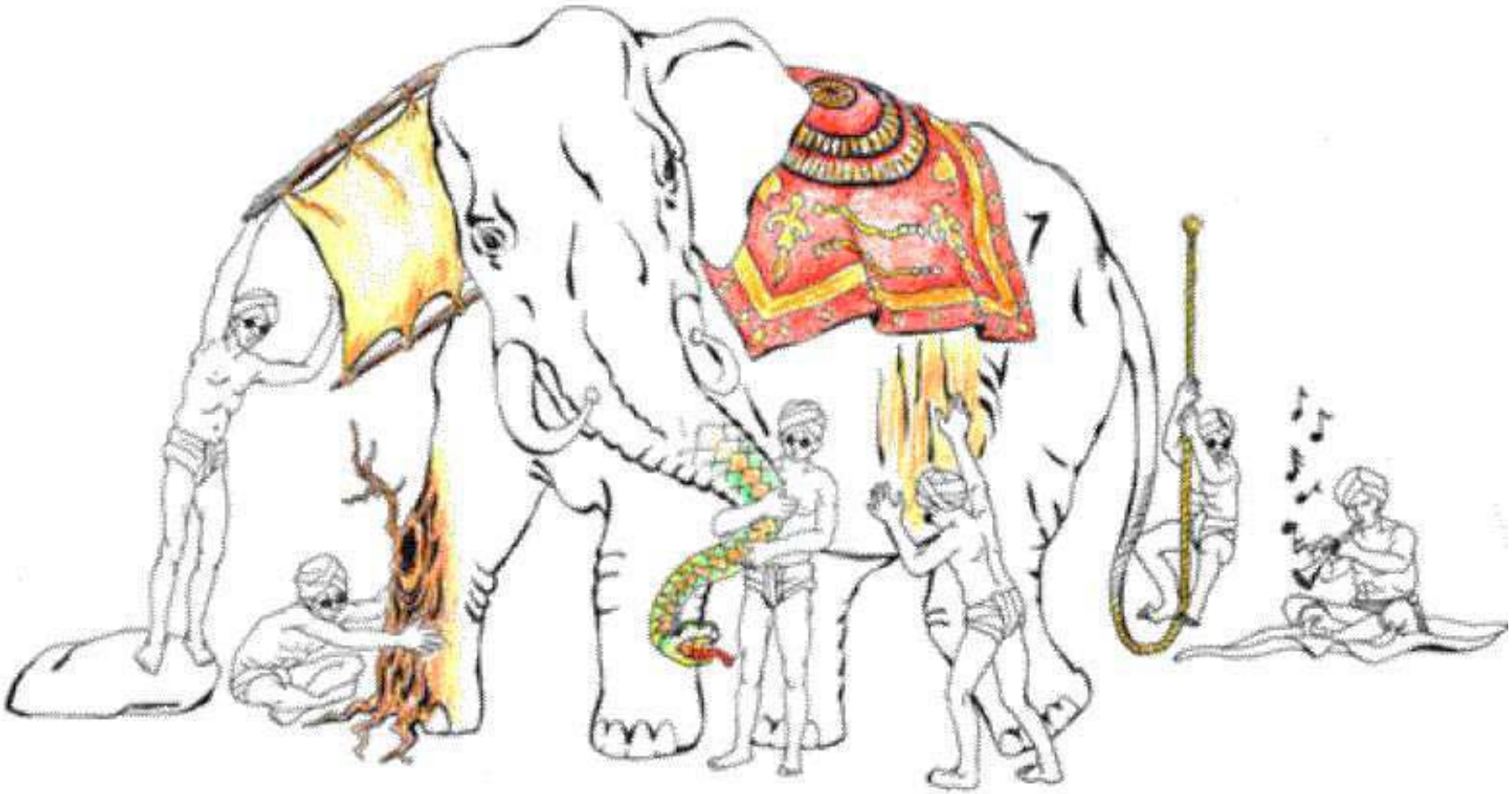
<u>Direction to Ulysses</u> - changing conditions at the footpoint due to solar rotation.

Berdichevsky et al. (2002) - H-α, EUV, radio, EP, coronagraph (LASCO), IP shocks, composition, IMF:

12 ***halo*** events in 1997

- Filament eruptions were behind all the events
  - 7 AR events, 5 non- or decayed ARs
- All started <40 degrees or so from disk center
- EP / Type II events 50% of the time
- Ejecta signatures in 11 of 12 events
- Saw apparent ejecta ***without a halo event*** twice
- 7 or less events had magnetic clouds
- Some confusion about: transit time vs. deceleration vs. acceleration vs. shock speeds

- ***Only 7 of 12 events had a driven shock at 1 AU***



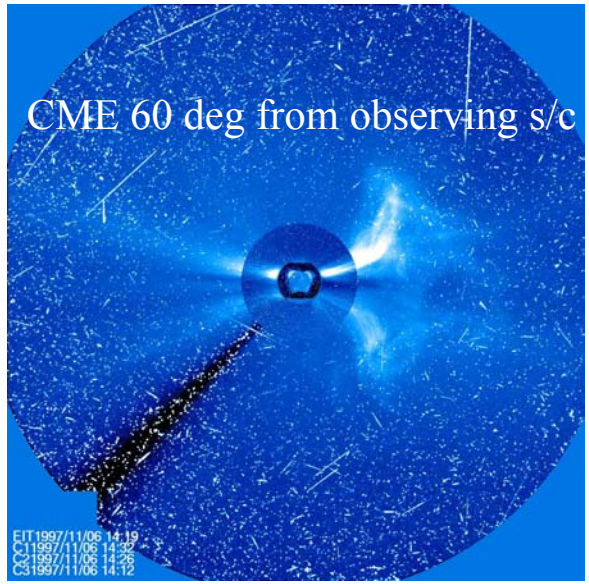
Synopsis:

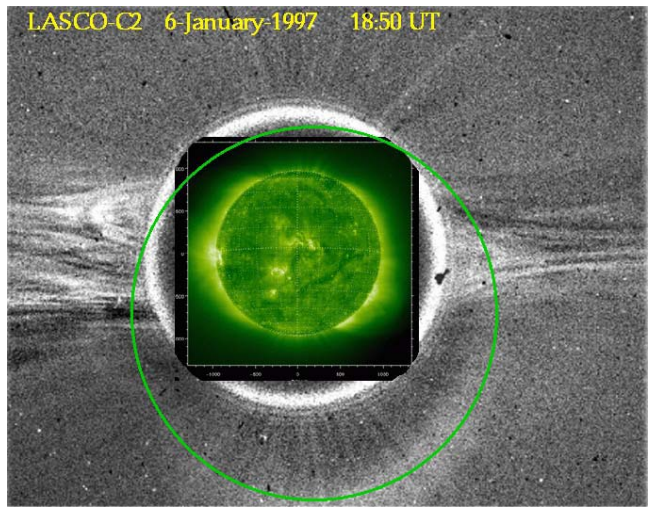
- Limb CMEs produce IP shocks
- Making use of this, the separation of STEREO spacecraft >60 (or 30?) degrees should allow most CMEs to be clearly seen that head towards the opposite of the s/c pair
- The pair should therefore be able to often resolve “what is going where”
- Composition signatures will show when the ejecta is actually encountered
- Modeling - to sort out interaction of H-CMEs with CIRs and predict transit times - although probably much more needs to be done in this area

One question I have:
- Will STEREO really be able to sort out coronal structure?

The “self-realization” scenario:

- Erupting filament in EUV
- Fast (here 1500 km/s) CME
- Directed towards opposite of STEREO pair
- Prompt solar energetic particles
  - - from flare site, blast wave, and driven shock



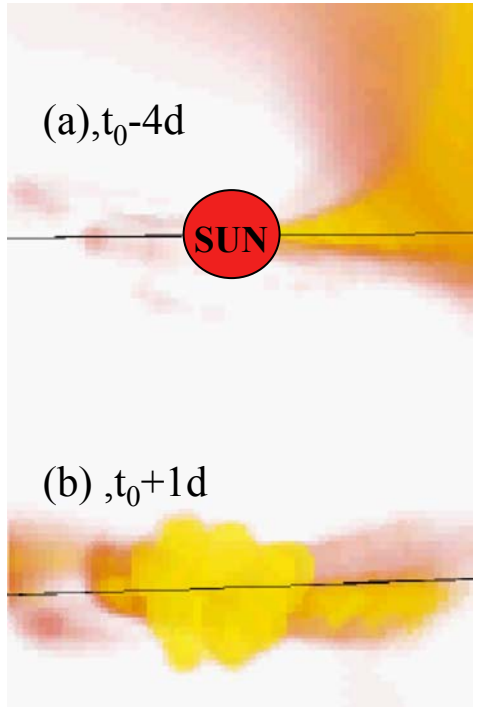


- Strong halo event at “target” s/c

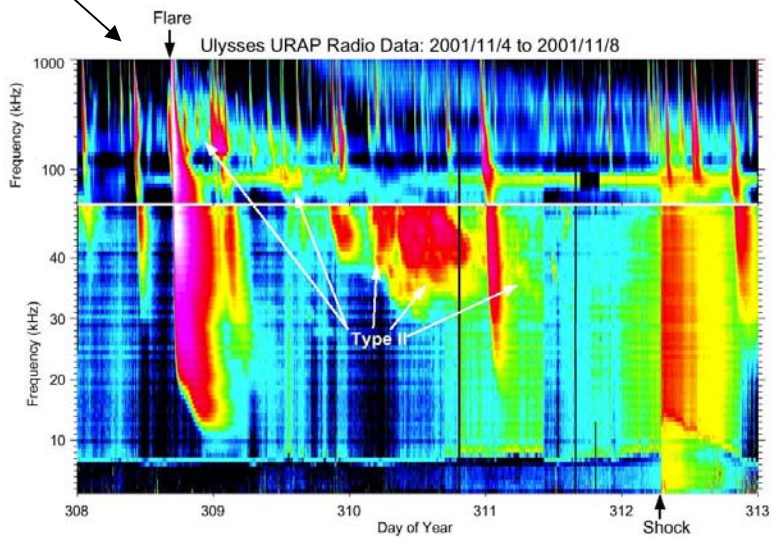
The self-realization scenario continued

•Imaged with HI at both s/c

- - followed until it overtakes ‘target’ s/c
- - followed from the side with the opposite s/c

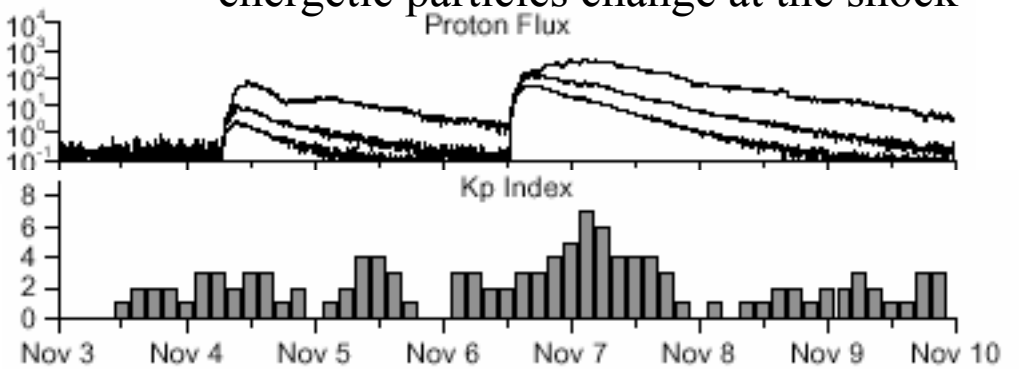


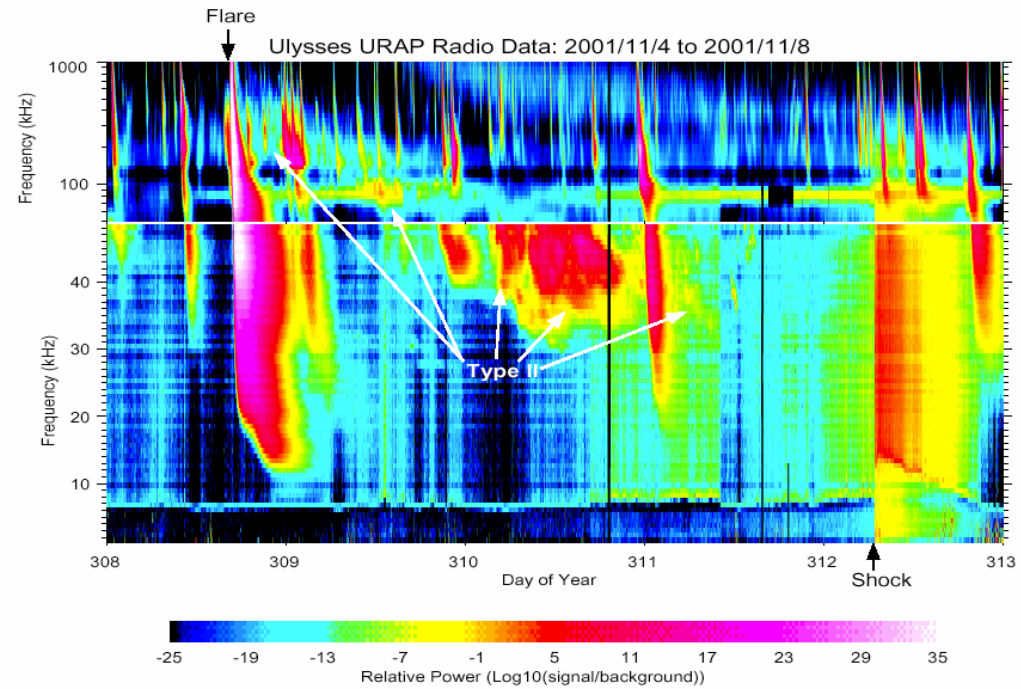
Type II (and III) radio bursts followed with both s/c from the Sun out past the s/c

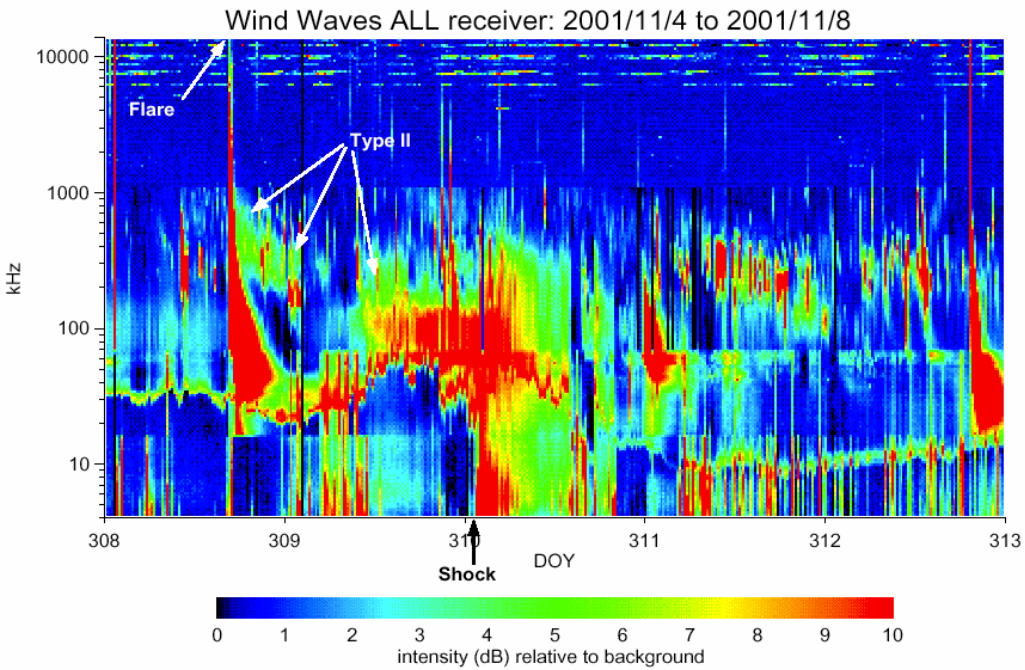


In situ: - shock detection (driven)

- magnetic cloud
- composition change in ‘driver/ejecta’
- bi-direction 100 eV electrons in cloud
- energetic particles change at the shock







The example shown here of radio triangulation of Type II bursts ***from two spacecraft*** is for the eruption/CME/magnetic storm in November 2001.

Ulysses is at top, WIND is at the bottom.

Ulysses ***was over the north pole of the Sun*** at the time.

WIND was near Earth.

Ejecta was seen at both s/c.

(this gives a hint of what might be possible with *more* than two viewpoints in radio)

This “self-realization” scenario is the realization of basic expectations for STEREO. It confirms that it is possible to follow a CME from its origin in an erupting prominence at the sun, out through the corona and solar wind, and to the Earth.

What this scenario fails to do is address the many open questions about:

- the influence of the corona (which had no influence here since it was just shredded by the ejection)

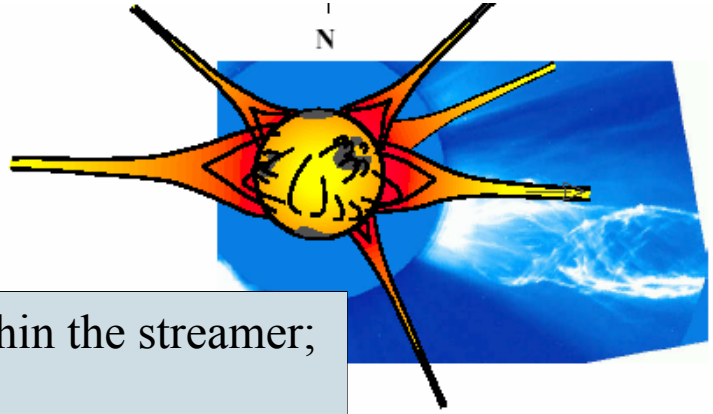
- the influence of CIRs in the solar wind (they were just swept up).

- where driven shocks form (it was effectively there from the start)

- the predictability of CMEs and their terrestrial effects (this one was too easy)

- the very real issue of why only 50% of H-CMEs are found to produce driven shocks (is this a question of detectability or of where a halo event is really pointed?)

The "new discoveries" scenario:



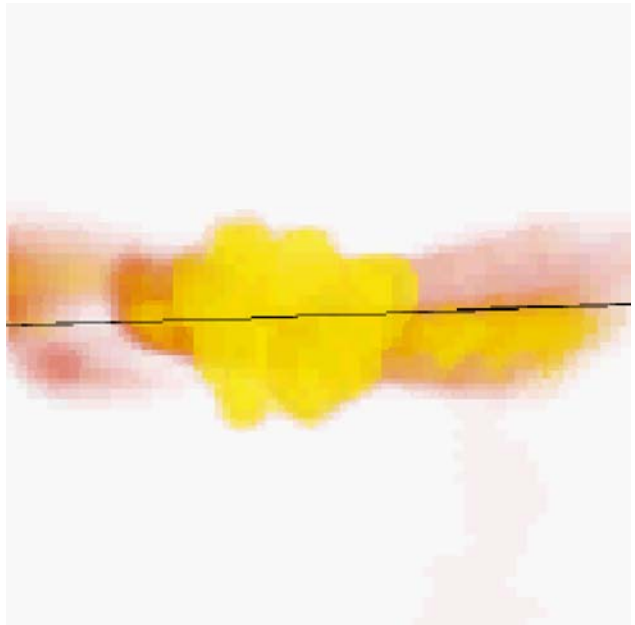
Most likely scenario goes *down*:

A prominence erupts → Confined within the streamer; no CME.

A slow CME → Halo event, Type II emission, Energetic Particles (EPs)

No Type II radio emission or EPs

At best, a weak, off-center, lopsided H-CME directed at one of the two STEREO S/C (the 'target s/c')



ICME followed by Heliospheric Imager at the non-target s/c, to 1AU (I don't think it's really known how well these will perform)

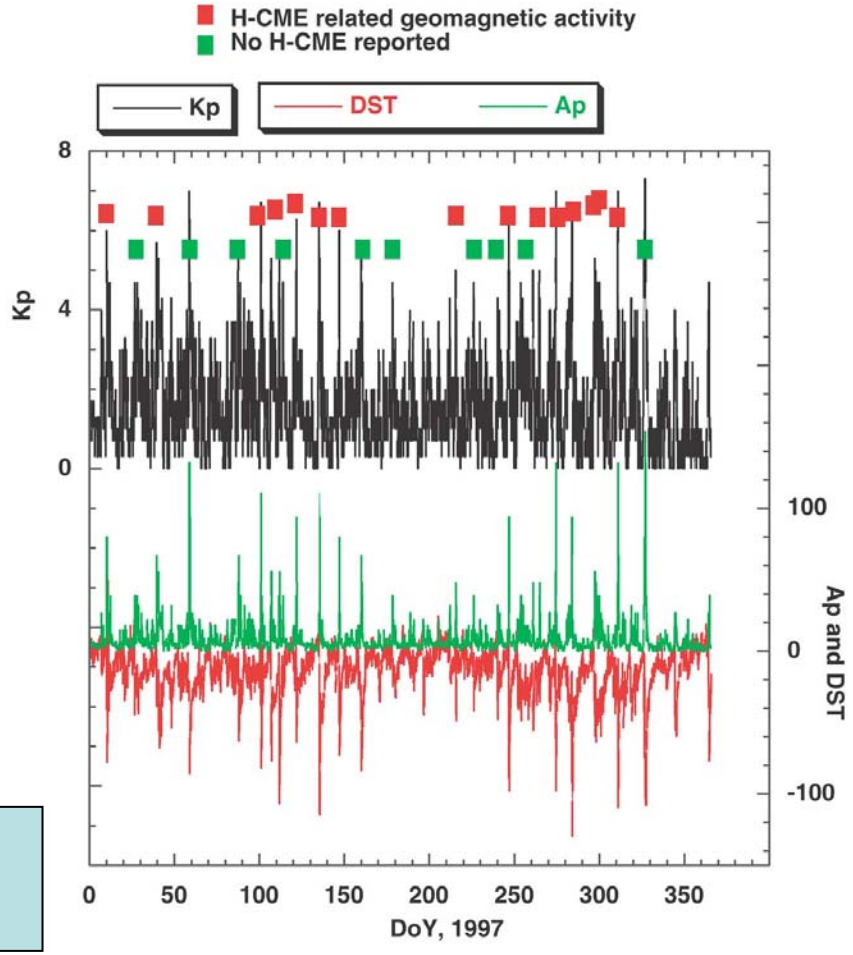
Followed by Heliospheric Imager at the non-target s/c, to 1AU

The ICME is sheared and smoothed by CIRs and other solar wind structure

In situ: Weak shock at 1 AU at one s/c. One (not necessarily the same) or neither s/c sees a magnetic cloud, bidirectional 100eV electrons, or composition signature.

Substantial magnetic storm

No magnetic storm



Why (if no storm)??? - did the ICME *miss* the Earth?

- did the ICME propagate into a high speed stream and *fade*?

Why (if there ***was*** a storm)???- did the ICME have B_z *southward*?

These questions ***can be answered*** with STEREOs' special capabilities.

What, then, do we ***learn*** from STEREO about the 3-D heliosphere and CMEs?

After "enough" examples of the new discoveries scenario have occurred and the two S/C are separated by ≥60° (≥30°?) we may learn:

1. The effect *of*, deflection *by*, and confinement *by* ***coronal structure*** and how much of a streamer gets carried away in a CME.
2. Shock formation criteria, location, and strength, and blast wave fate.
3. Better ways to ***interpret a halo CME***: -directivity / -partial halos / -off-center halos / -lopsided halos / -halos without Type II bursts or EPs.
   - why only some halos are geoeffective.
4. The deformation, weakening, or strengthening of an I-CME by the ***ambient solar wind***.
5. More about *in situ* signatures of ejecta.
6. The relationships between what SECCHI, WAVES, PLASTIC, and IMPACT detect and the ***terrestrial response***.
7. What, in an ICME, causes a magnetic storm.