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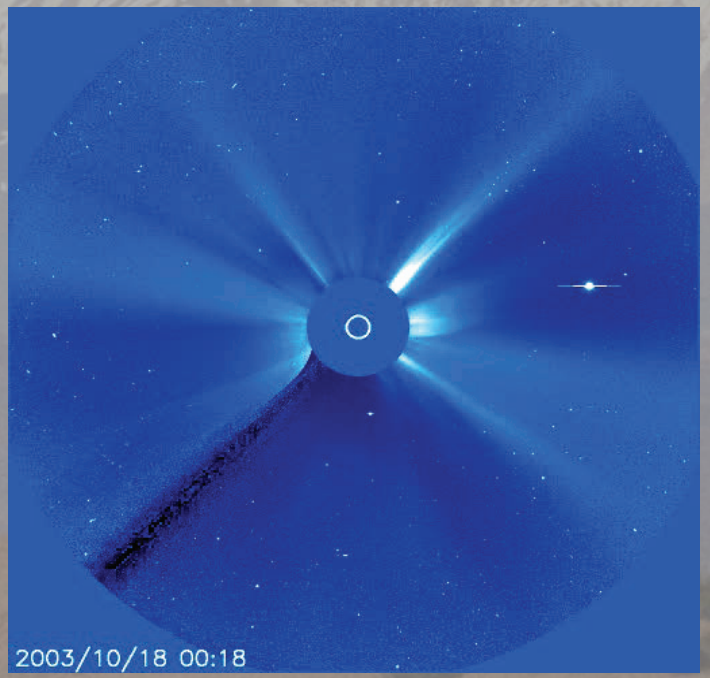

Lecture on June 21, by Rainer Schwenn

a) Coronal mass ejections (CMEs)

- History, examples, definition of terms
- Balloon type CMEs and halos
- Typical CME properties during the activity cycle
- The relationship between CMEs and flares
- Where is the shock in coronagraph data?
- CMEs, shocks, ejecta clouds: a strange metamorphosis!

b) Rainer's catalog of ignorance

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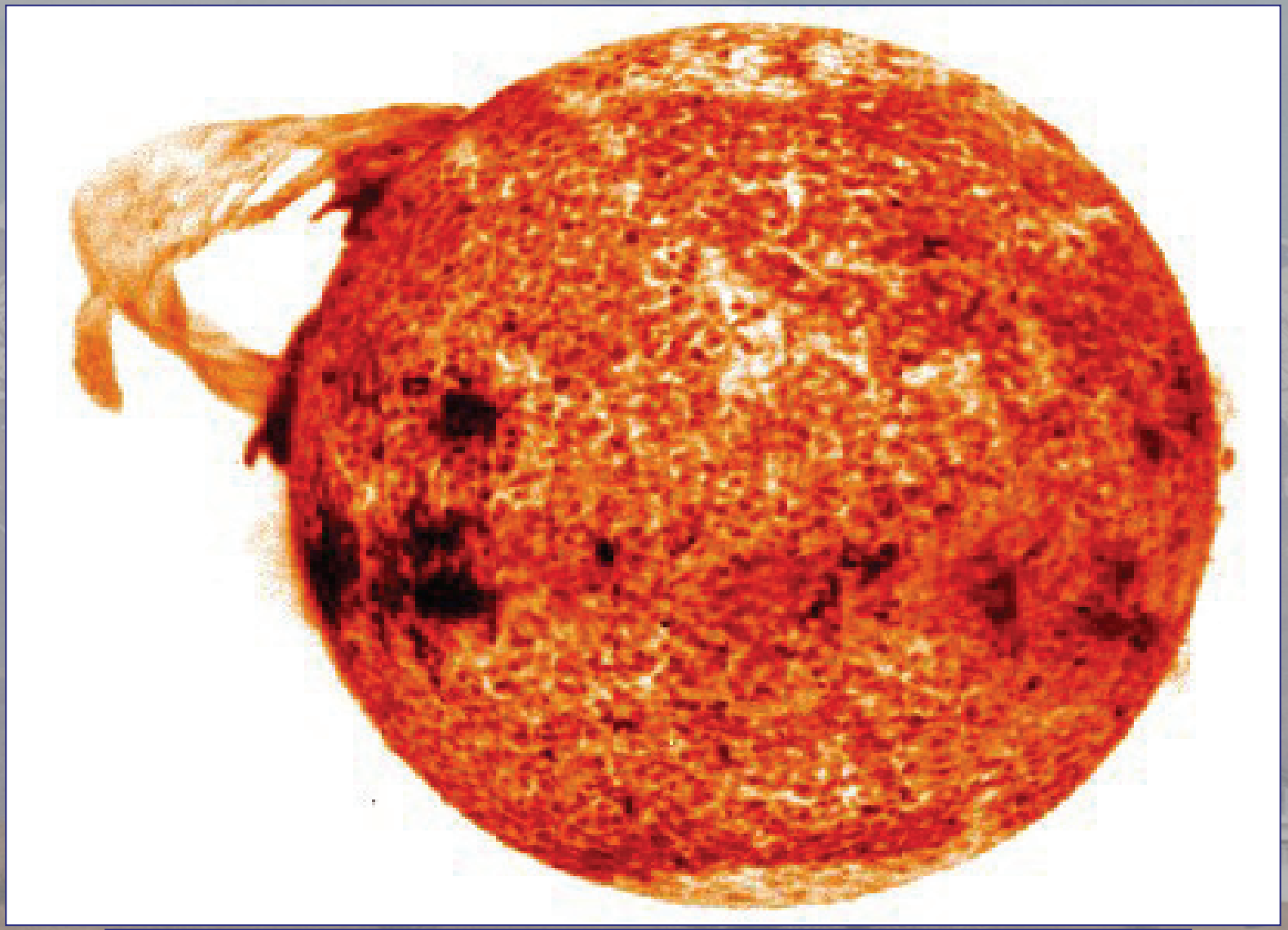
Skylab in 1973 initiated CME research



The most popular astronomical picture in history:
a huge eruptive prominence, seen in the He^{+} line (30.4 nm)

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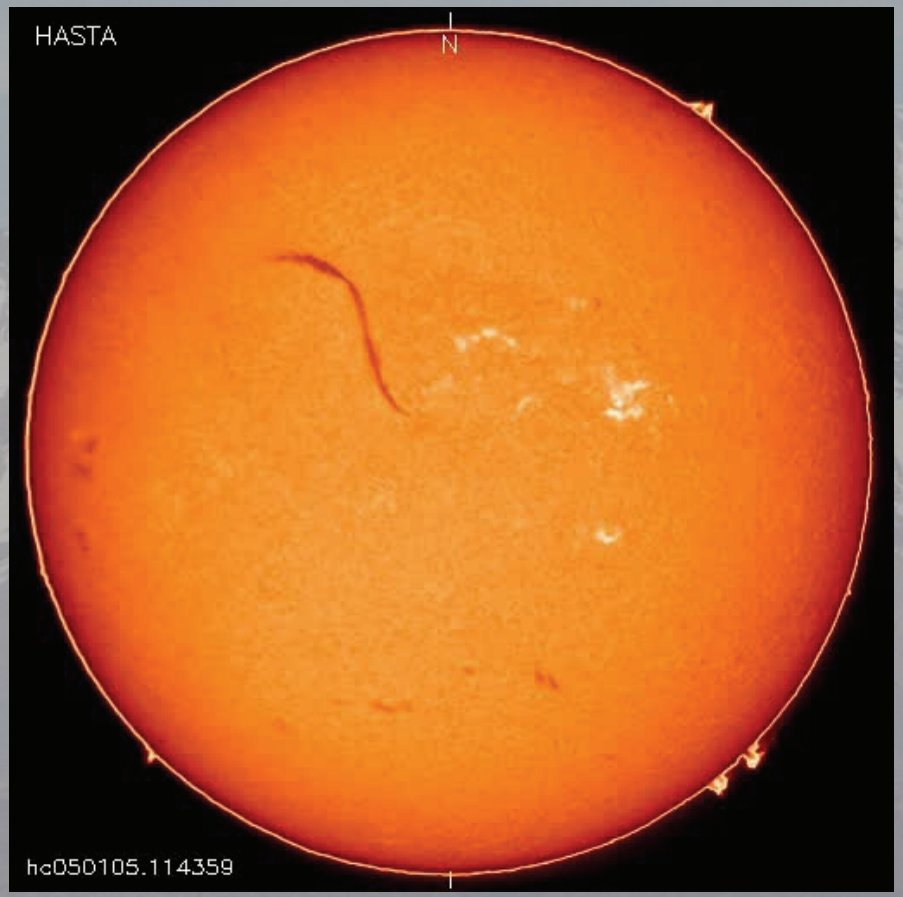
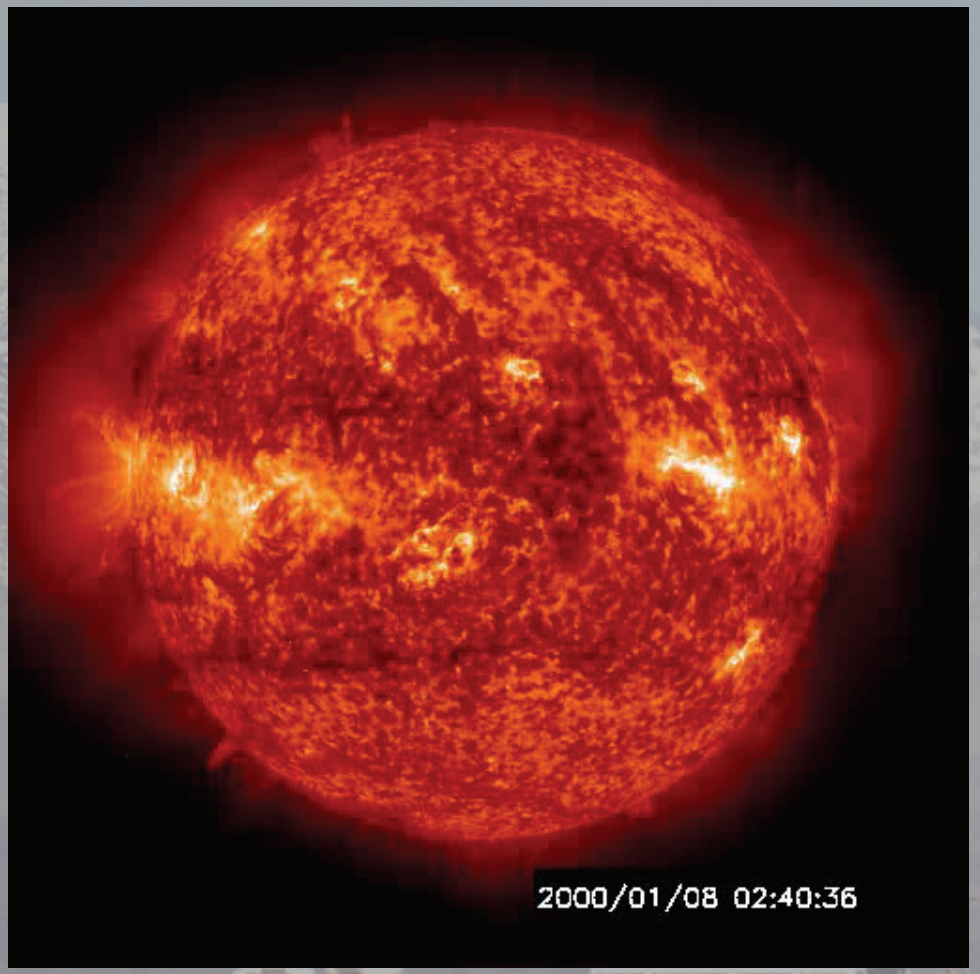
Eruptive prominences and disappearing filaments



A disappearing filament, seen in H-alpha by HASTA



Prominences/filaments: best visible in the He^+ line (30.4 nm), by EIT on SOHO

They are the same: just eruptive prominences!

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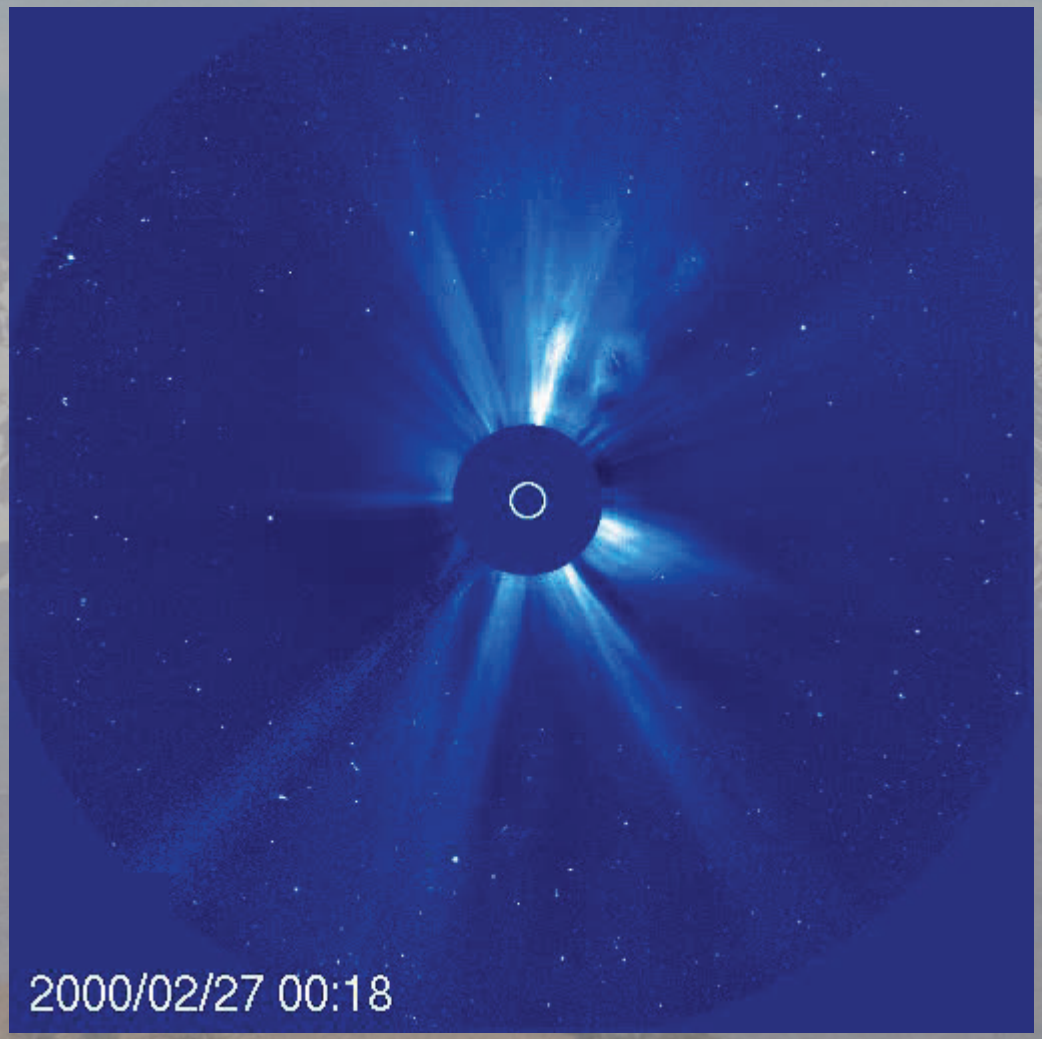
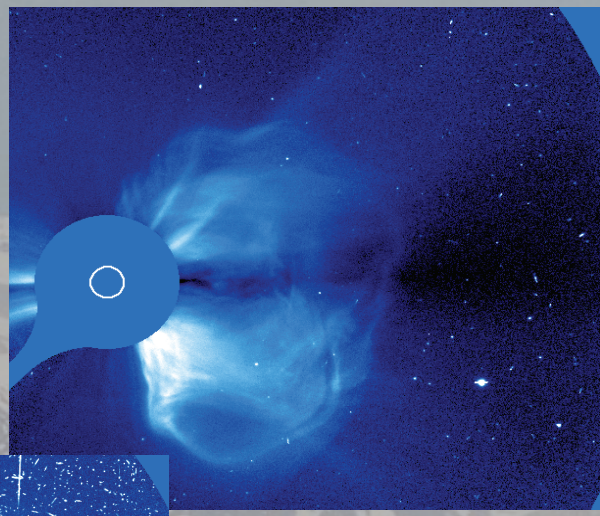
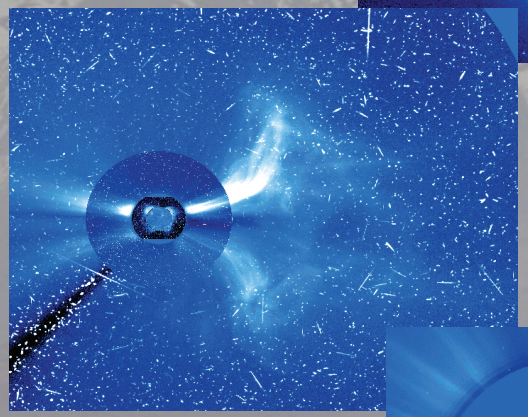
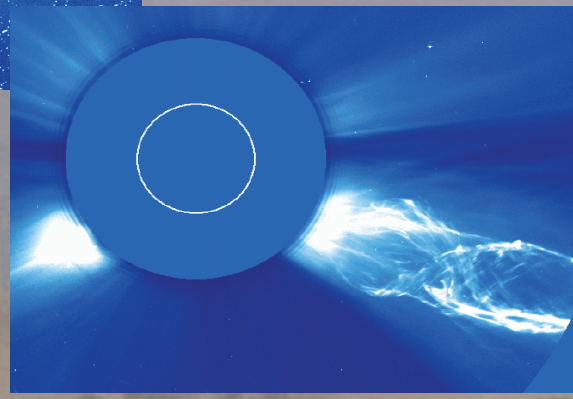
CMEs are spectacular!









Gigantic "Coronal Mass Ejections" (CMEs) drive shock waves out that literally shatter the whole solar system!

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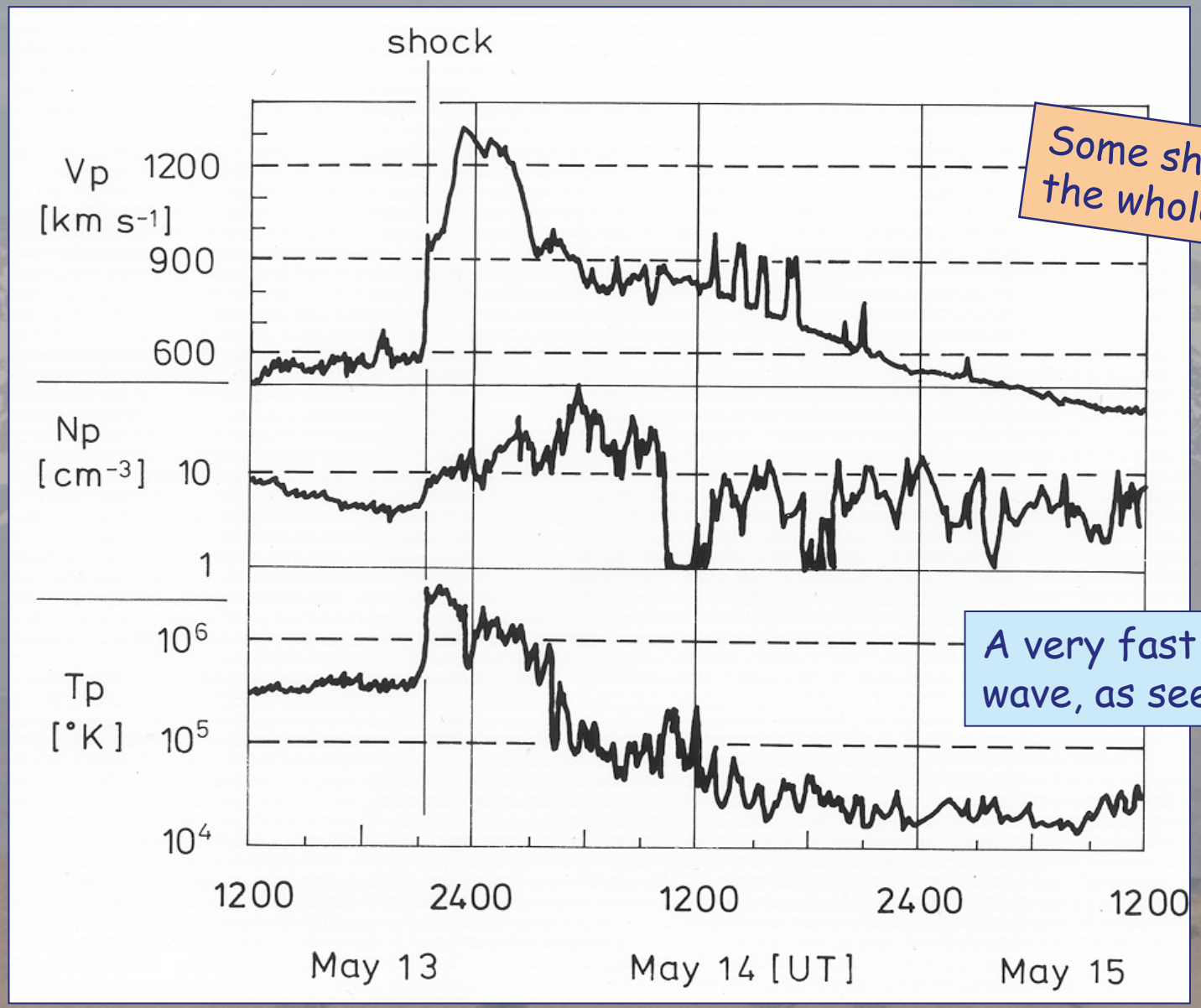
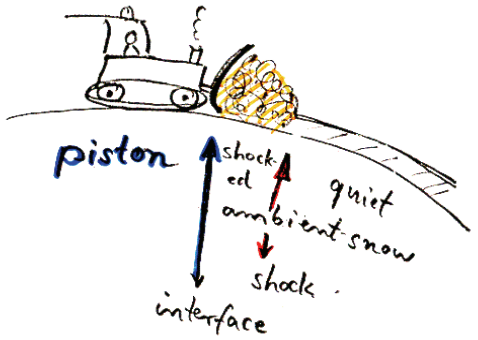
Fast CMEs drive interplanetary shock waves



Some shocks literally shake up the whole heliosphere!

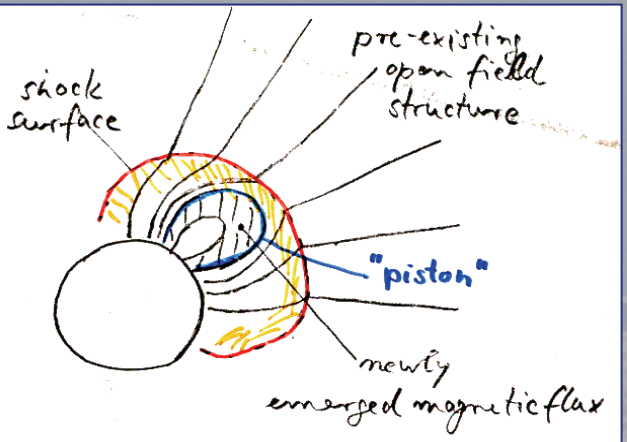
A very fast interplanetary shock wave, as seen by **Helios** in 1978

„Collisionless" shocks in the heliosphere?

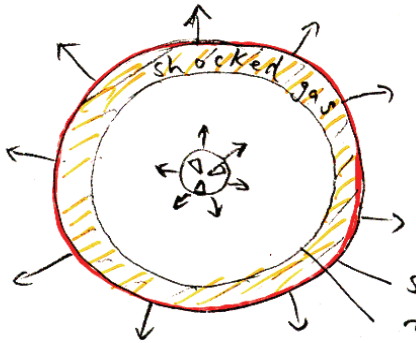


"driven" shockwave

Gold was right!

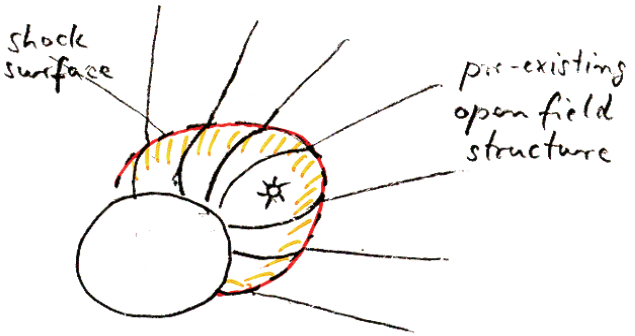


(Gold, 1959)



blast wave

shock front (fast forward)
reverse shock



(Parker, 1959)

The famous battle Gold vs Parker about shocks in the heliosphere:
piston driven shocks vs blast waves?
It began in the late 1950s, i.e. 3 years before the experimental proof of the existence of a solar wind!

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A look into the history of some terms:

Morrison, 1954	diffuse **clouds** of ionized hydrogen bearing a turbulent magnetic field
Piddington, 1958	ejected **magnetic clouds**
Gold, 1959	magnetized clouds, "Gold's bottles"
Parker, 1959	plasma clouds
Schatten, 1970	coronal magnetic bottle
Brueckner et al., 1972	bright plasma clouds (**from OSO 7**) coronagraph
Pinter, 1973	dense plasma cloud within a closed magnetic loop
Tousey, 1973	electron clouds leaving 10 Rs
Stewart et al., 1974	white light cloud
MacQueen, 1974	**coronal transient** phenomena (from **Skylab** coronagraph)
Gosling et al., 1974	mass ejections from the sun
Gosling et al., 1975	coronagraph observed mass ejections, **coronal mass ejection events**
Hildner et al., 1975	mass ejection coronal transients
Gosling, 1976	**solar mass ejection events**
Burlaga et al., 1978	CME for Cold Magnetic Enhancement **(!)**
Munro et al., 1979	mass ejection events
Michels et al., 1980	solar mass ejections
Burlaga et al, 1981	magnetic loop, magnetic cloud
Burlaga et al., 1982	**CME for Coronal Mass Ejection**
Hundhausen et al., 1984	definition of coronal mass ejection

The term "CME" was not introduced until 10 years after their discovery!

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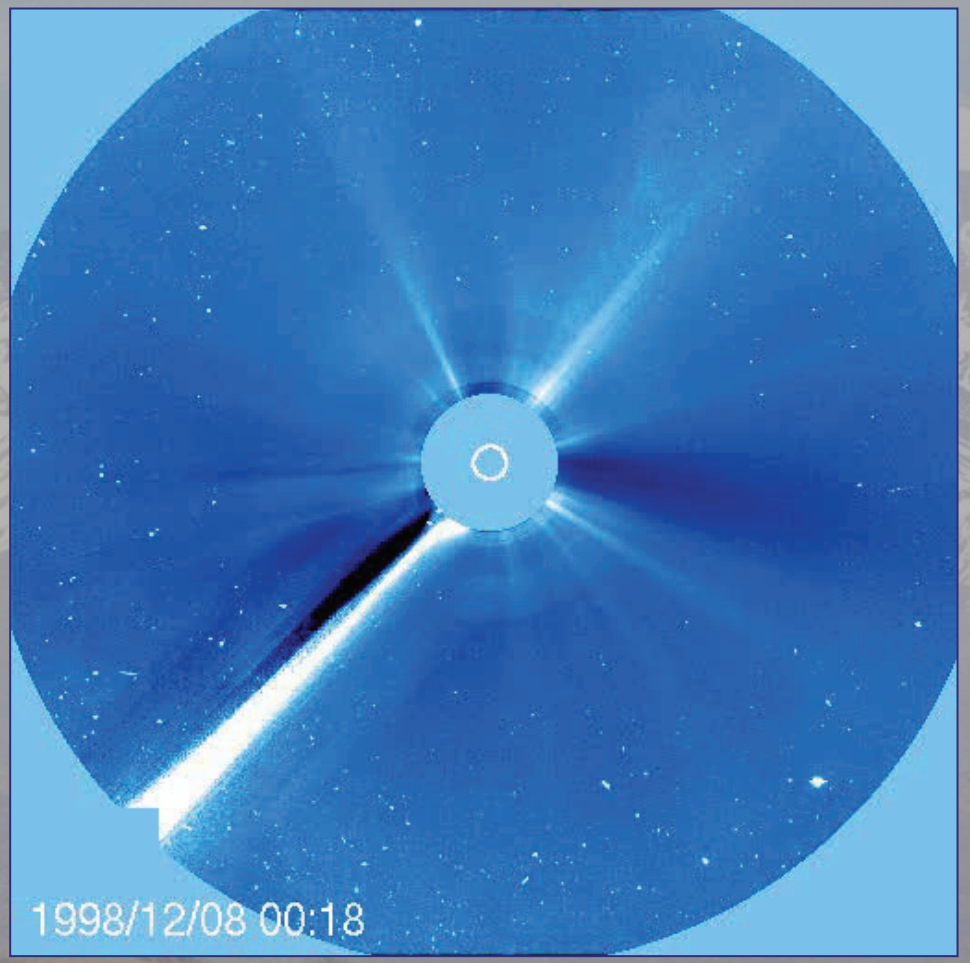
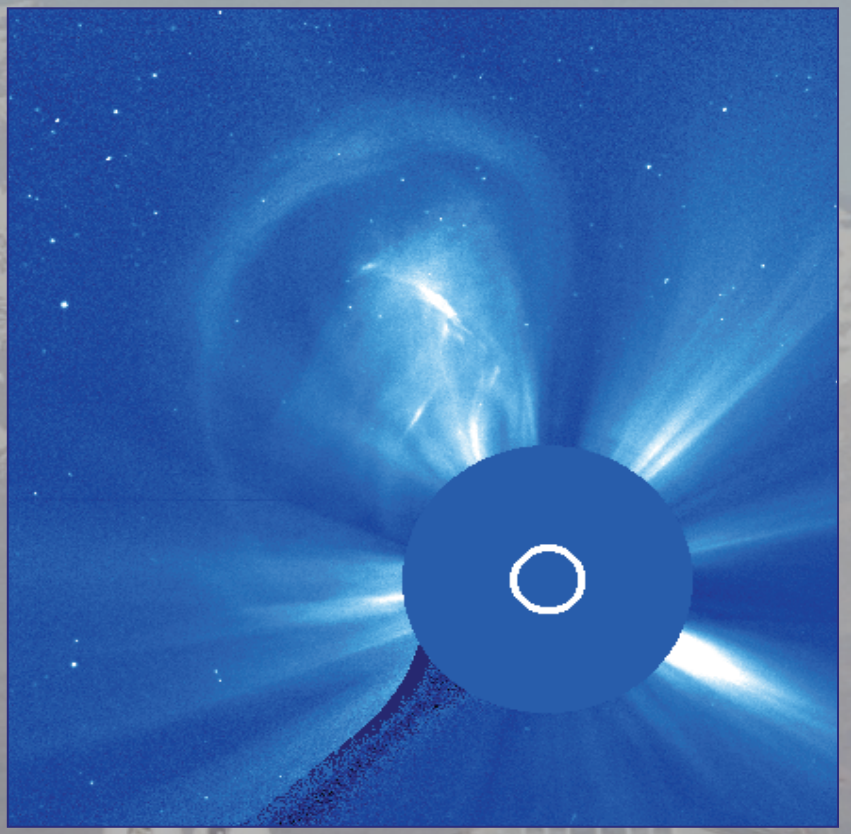
Very common: 3-part structure of CMEs





Most big CMEs show this characteristic 3-part structure:

- bright outer loop,
- dark void
- bright inner kernel

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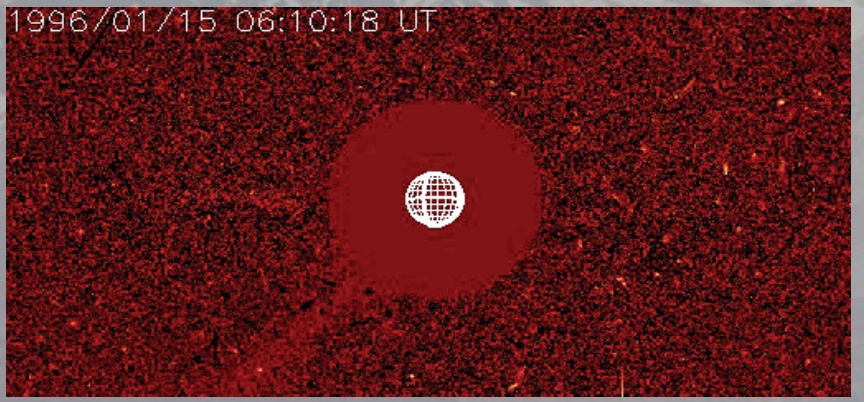
The definition of a CME

"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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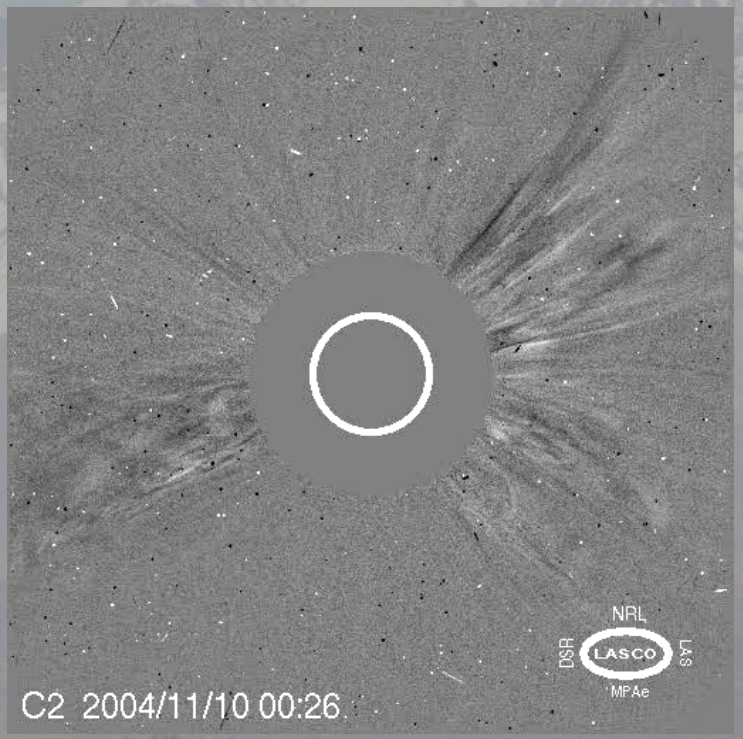
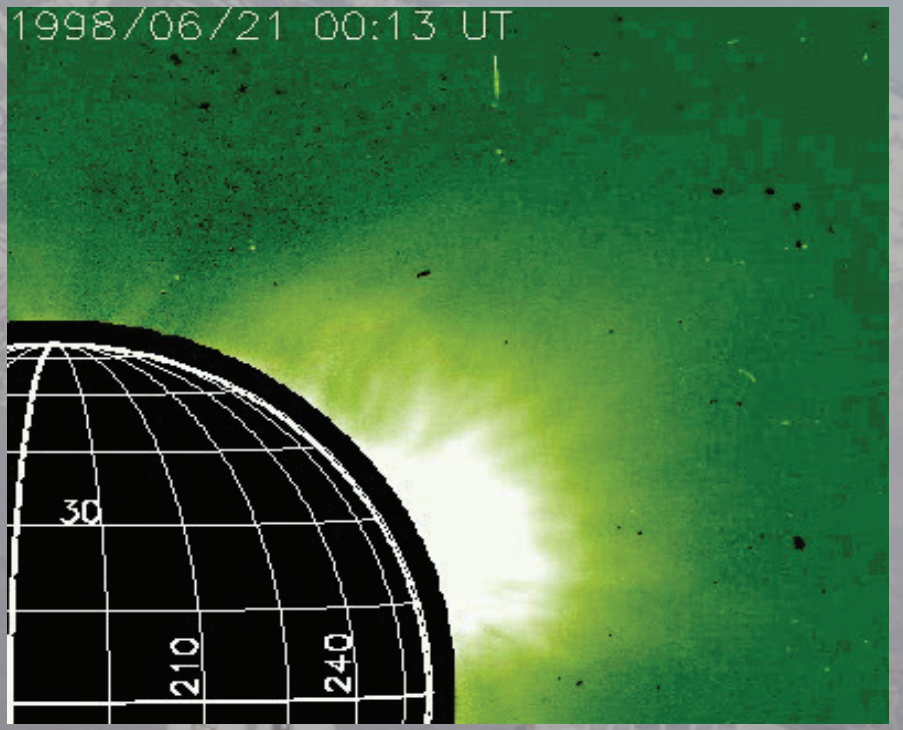
Different types of CMEs ?

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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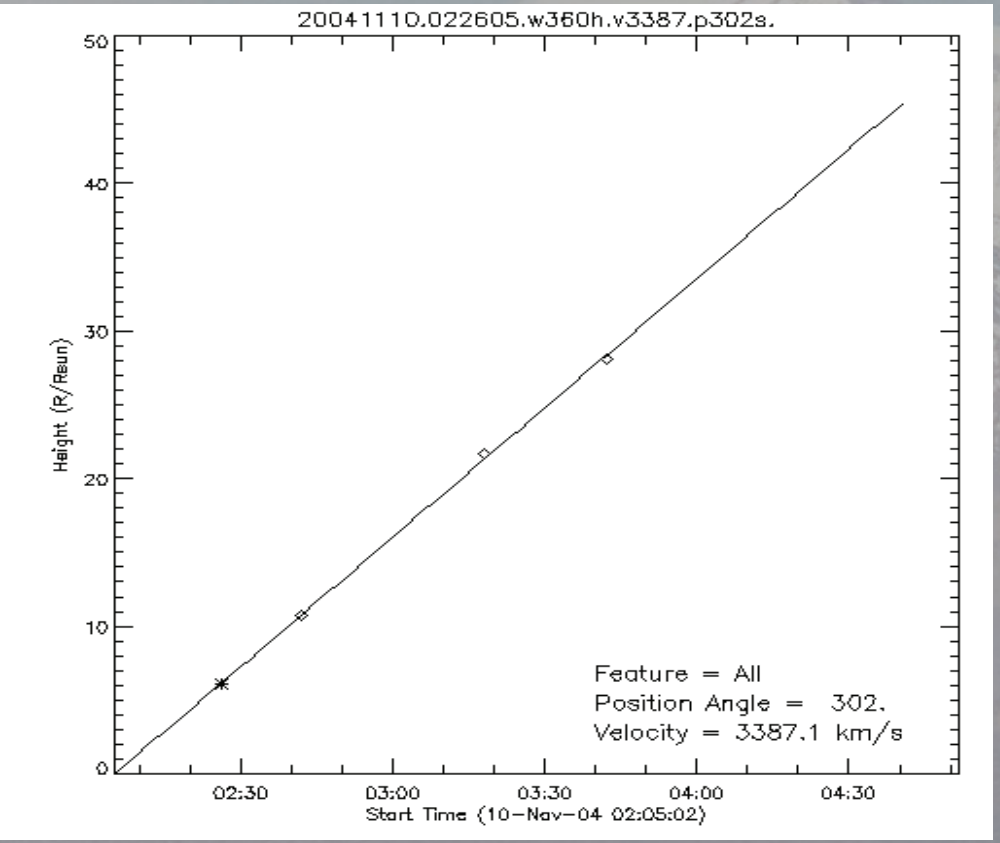
Different types of CMEs ?



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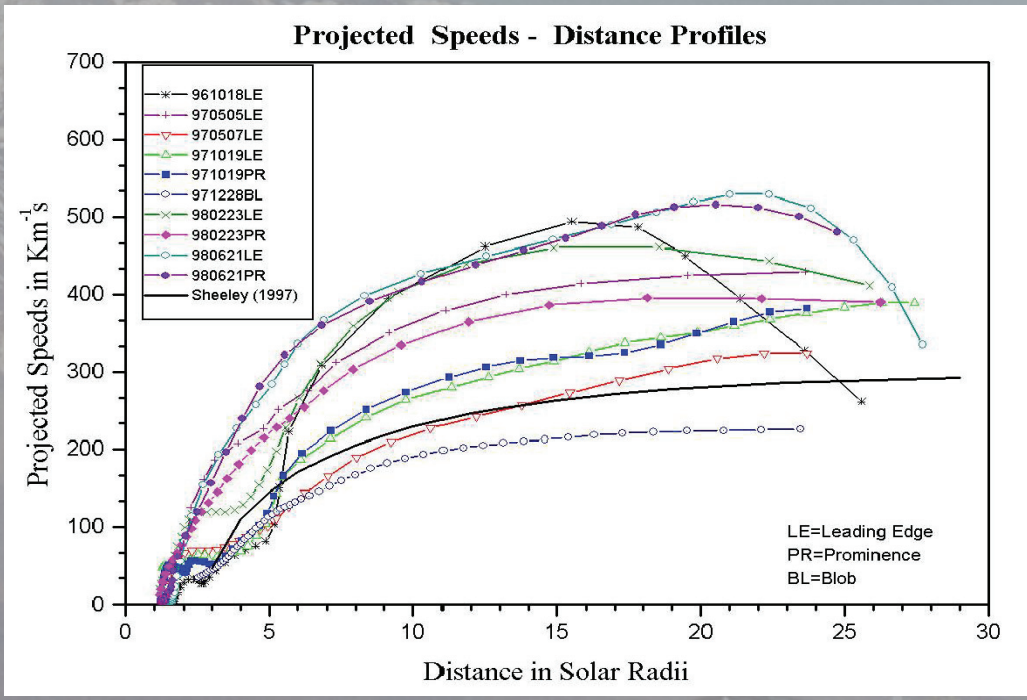
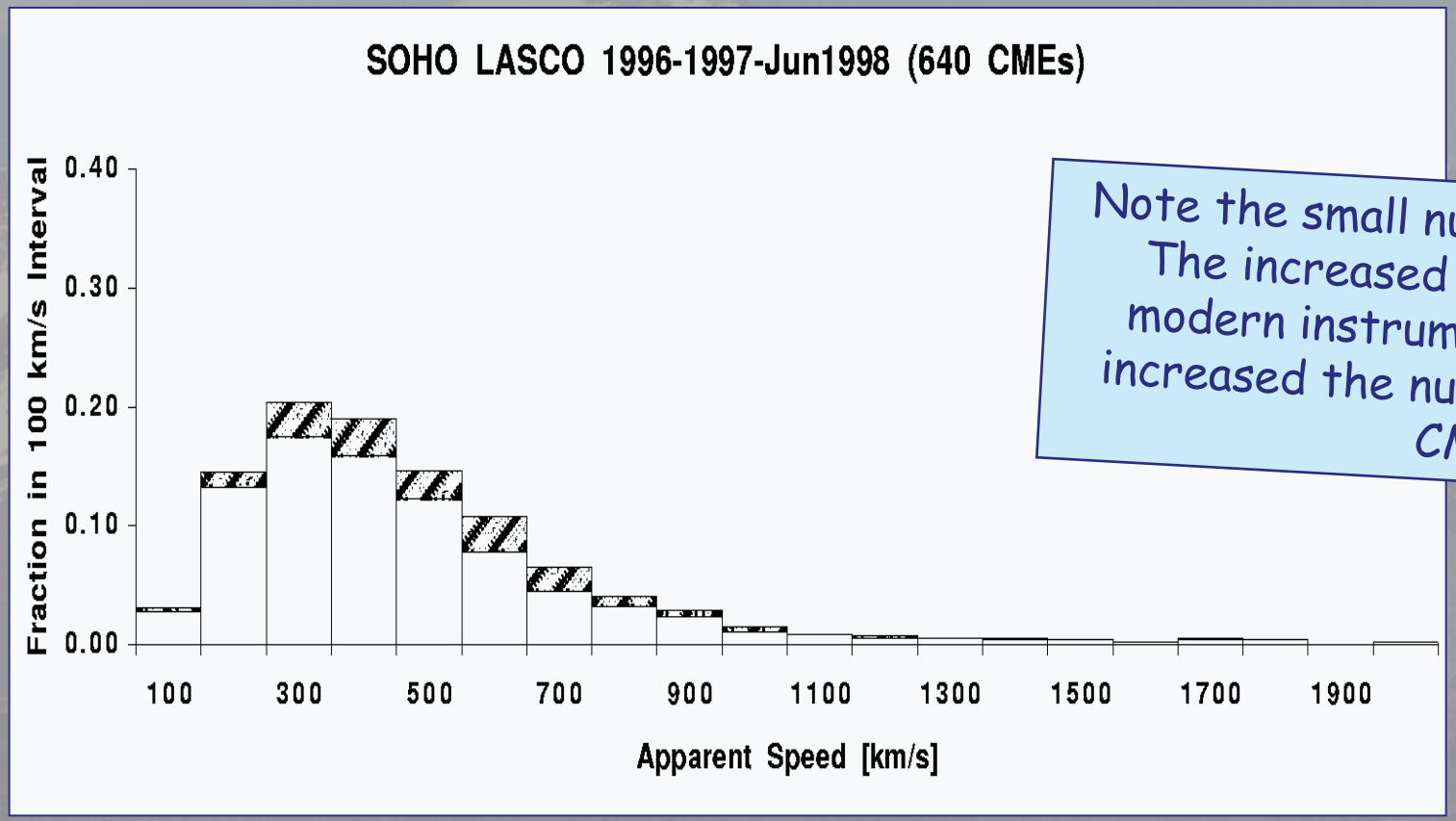


These balloons took some 30 hours to finally take off! They are offsprings of eruptive prominences.

Different types of CMEs ?



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**

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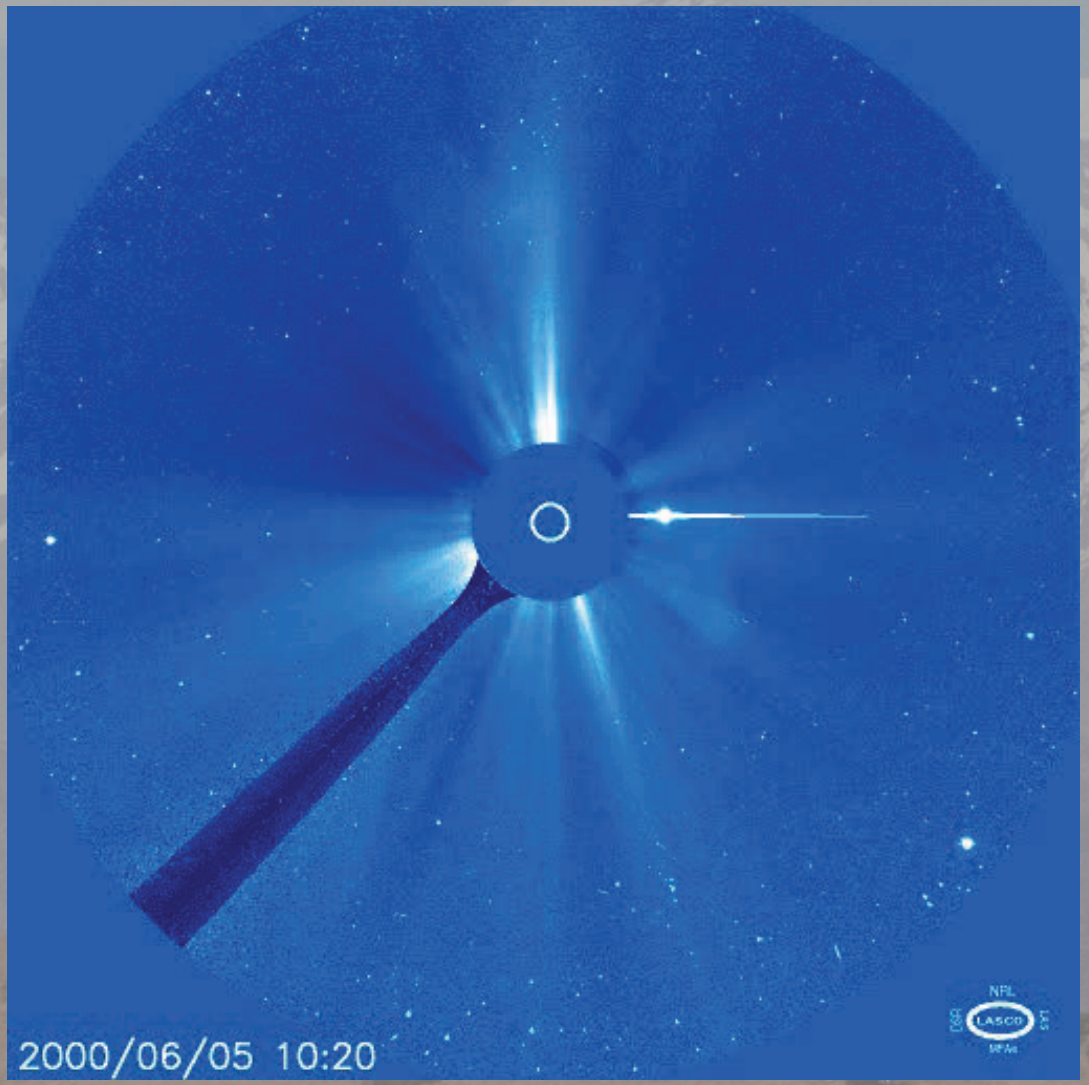
Limb CMEs and „halo" CMEs



A series of dramatic CMEs observed by LASCO C3 on SOHO

Halo CMEs, if pointed towards (not away from!) the Earth, may cause disturbances of the Earth's geomagnetism: Geomagnetic Storms,
Space Weather.

Towards or away from Earth?
That can only be decided using simultaneous disk observations

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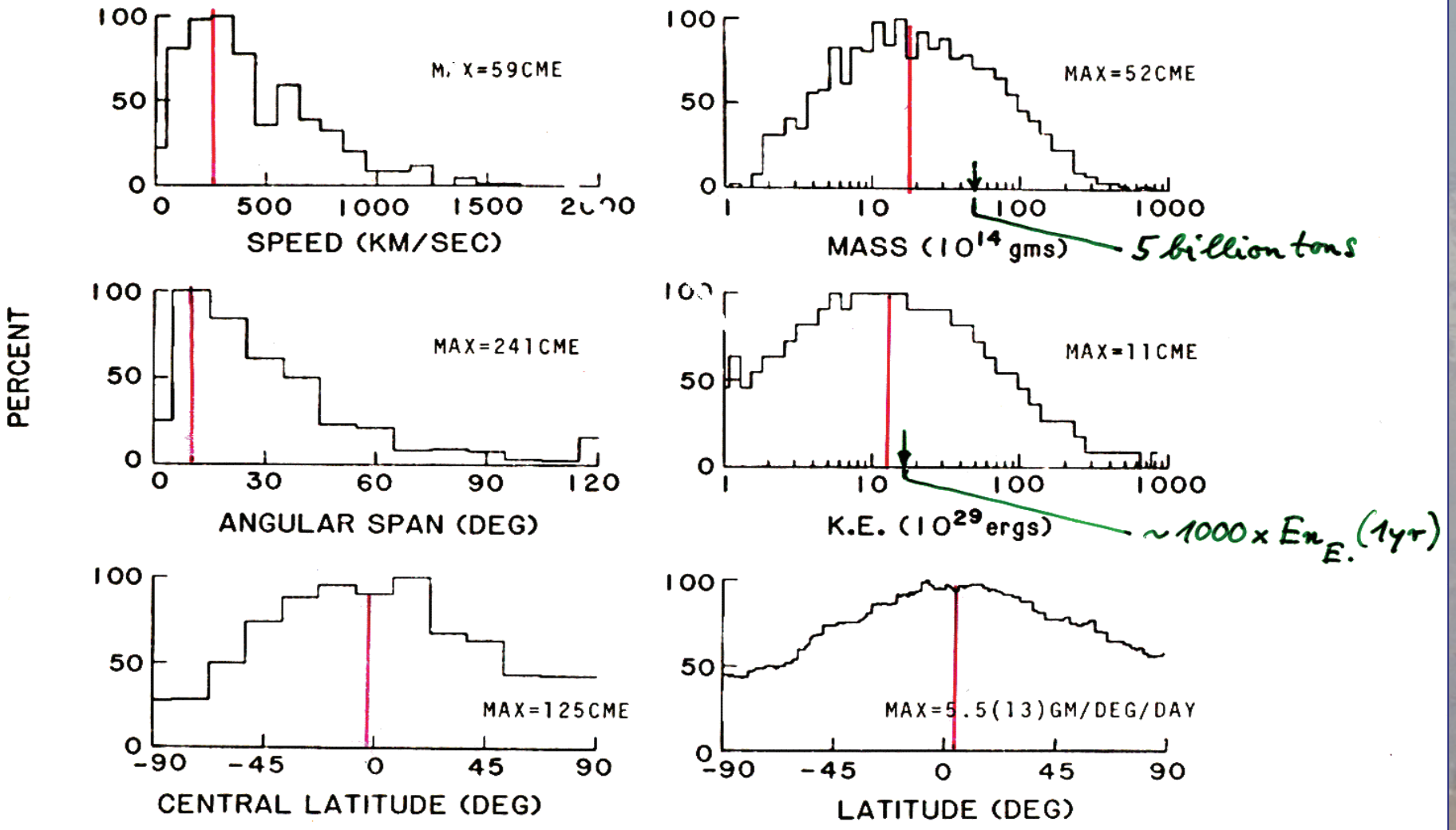
Properties of CMEs, 1979 to 1981



Statistical analysis of about 1000 CMEs observed by **SOLWIND**

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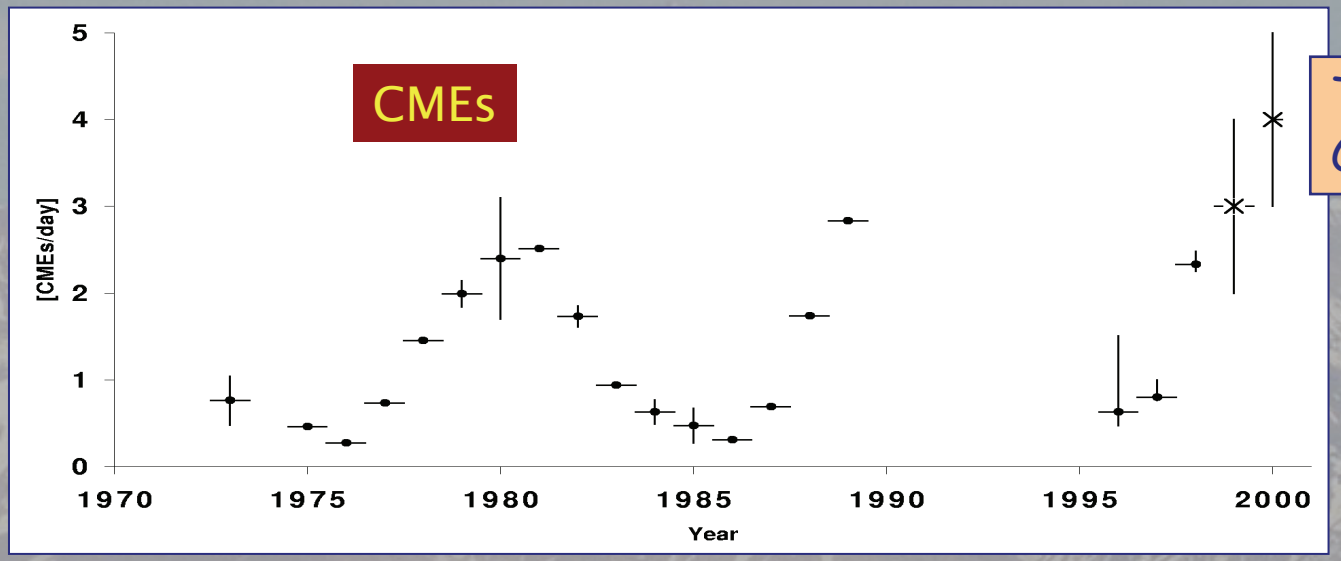
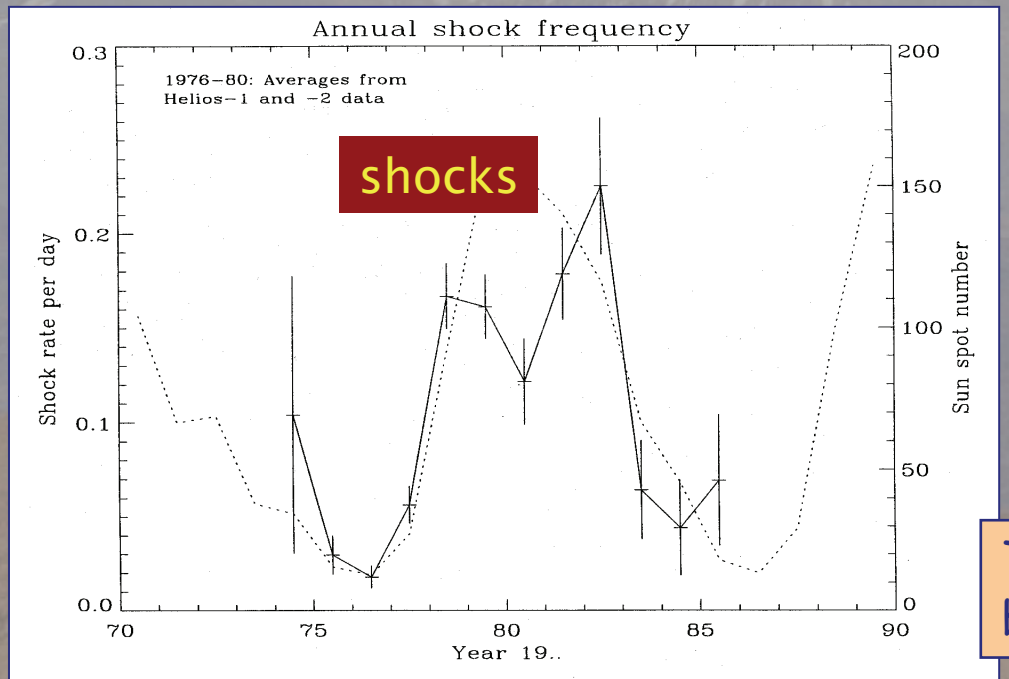
CMEs and shock rates during 2 solar cycles



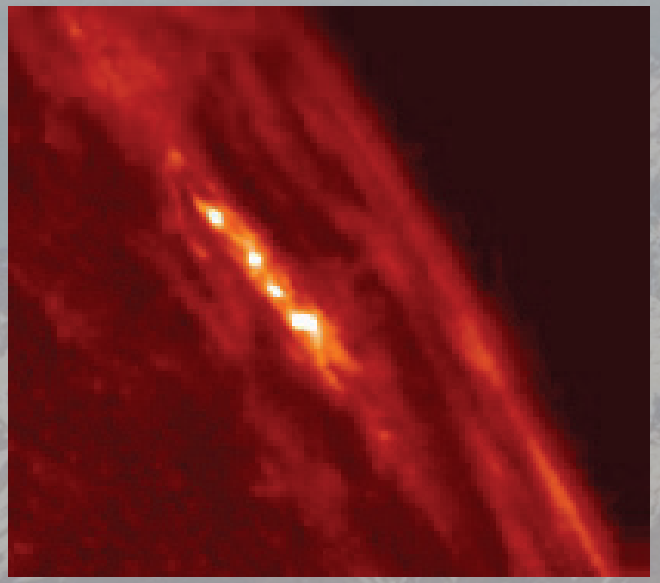
The daily rate of all CMEs

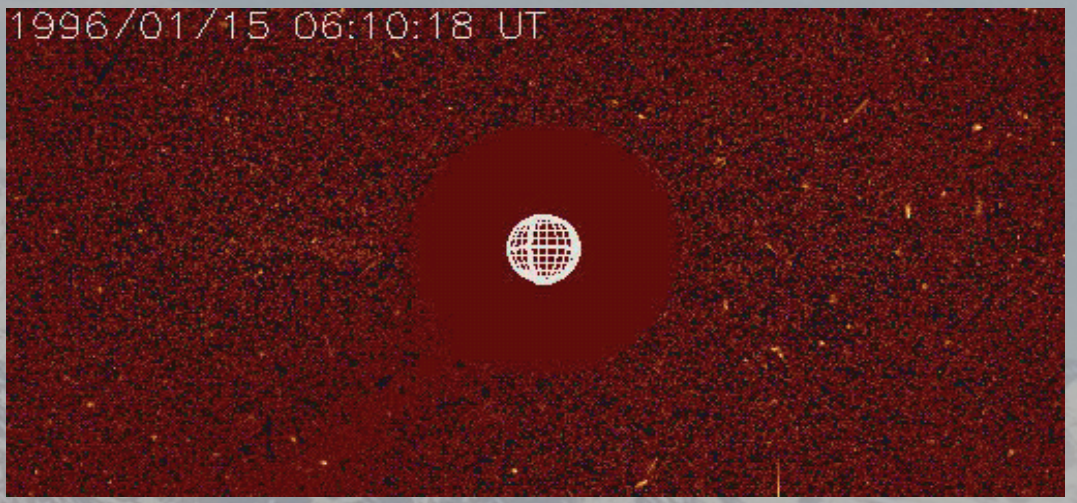
- There is a clear maximum of CME and shock occurrence at maximum acticivty.
- Between minimum and maximum, the rates of both: shocks and CMEs vary by a factor of 10.
- The shock rate shows a double peak: maximum occurrence before and after the maximum.
- The ratio between CME and shock rates is 10.



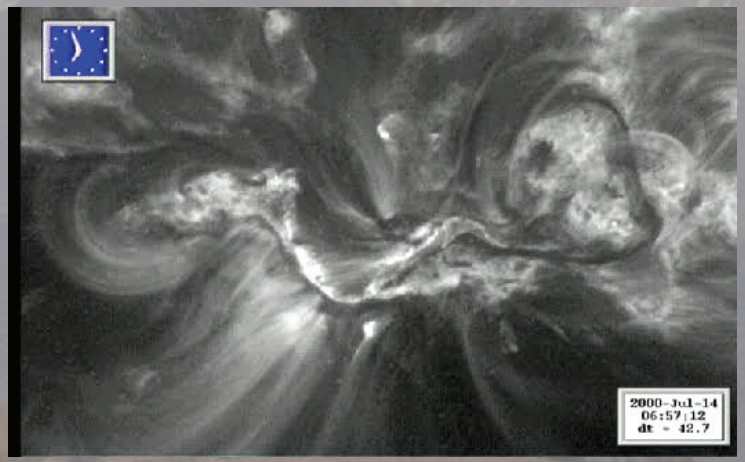
The daily rate of shocks seen by an *in-situ* observer

The relationship between flares and CMEs





The CME of Jan 15, 1996, as seen by LASCO-**C3** on **SOHO**



The „Bastille" flare, on July 14, 2000

- 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.

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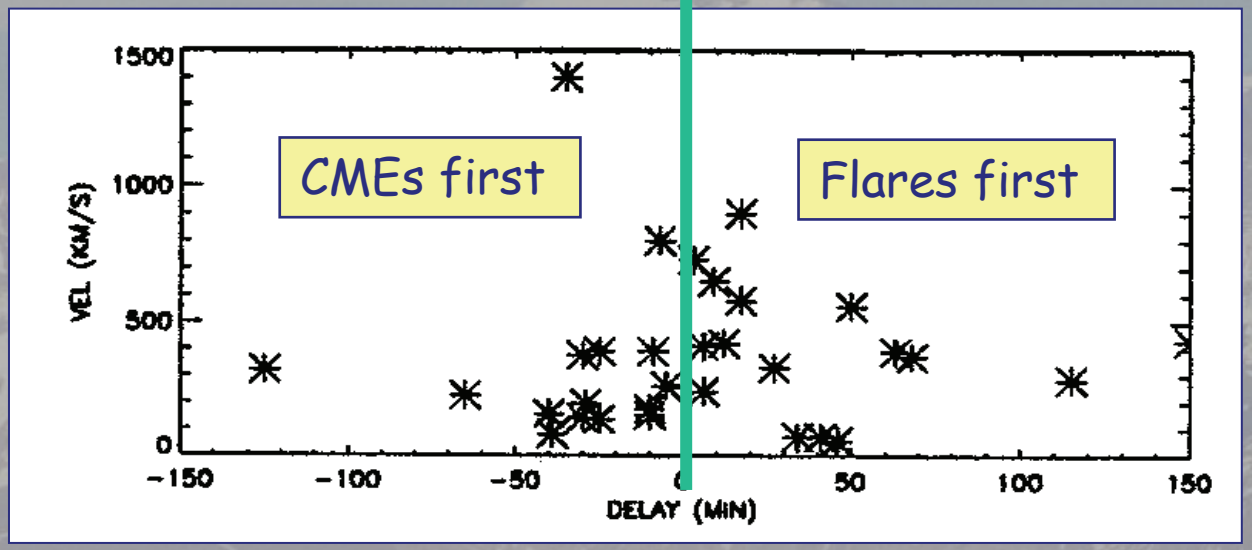
CME-flare relation, a hen-and-egg situation?



Time separation between flares and correlated CMEs

The simple but important conclusions from these studies:

Flares occurring after their associated CMEs cannot be their cause, quite logically.

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

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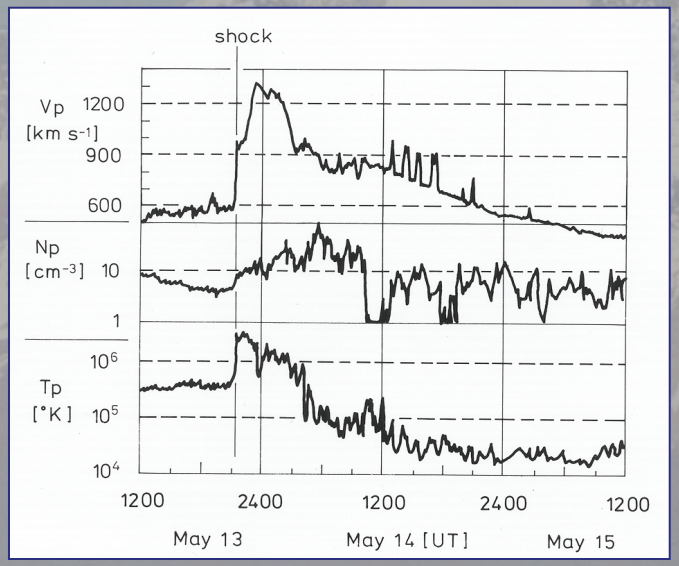
The flares vs CMEs controversy,

problematic for space weather predictions

Since Skylab/Helios times we learned to look for CMEs/shocks/ejecta rather than for flares as has been common for the past 130 years.



Results from correlations between CMEs and interplanetary shocks:

- an observer within the angular span of a fast >400 km/s) CME has a 100% chance to be hit by a fast shock wave,
- every shock (except at CIRs) can be traced back to a fast CME.

These shocks and the driver gases following them have a near 100% chance of becoming geo-effective, if ejected towards Earth.

Note: no such statement applies to flares!

Indeed: there are flares without CMEs (and geo-effects) and there are CMEs (and geo-effects) without flares.

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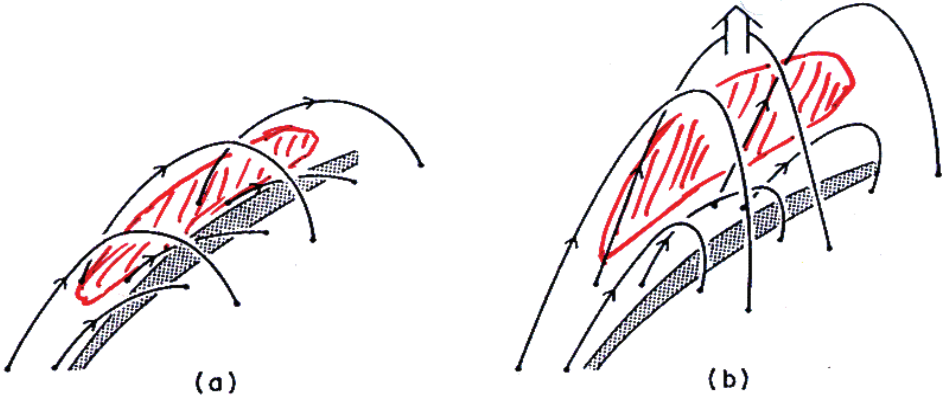
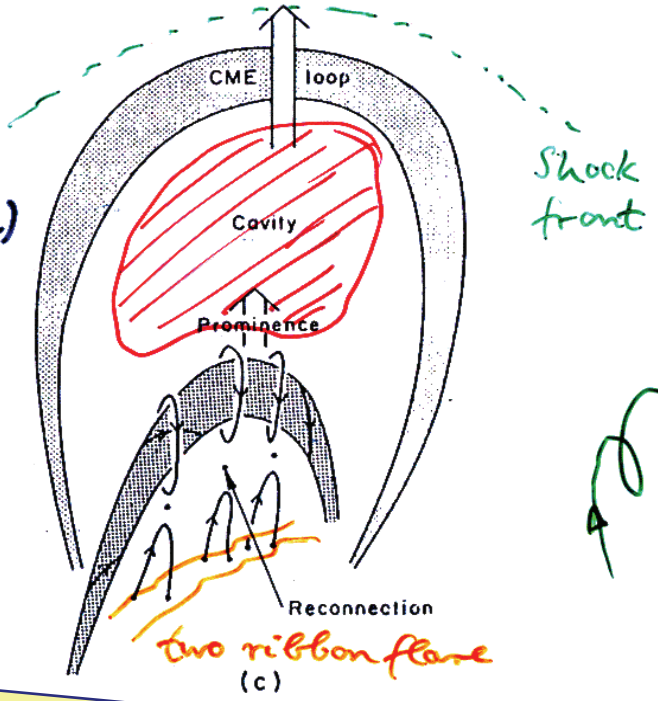
Models, sketches, ideas on CME onset...



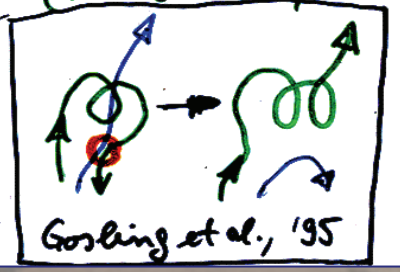
Three-part structure:

1. CME loop (coronal plasma)
2. Prominence cavity
3. Cold prominence mat.



Note:
Filament orientation allows prediction of cloud orientation at earth's orbit!

alternative:
flux rope model
(Marubashi, '86)



Note: CME science is also a field for creative artists...

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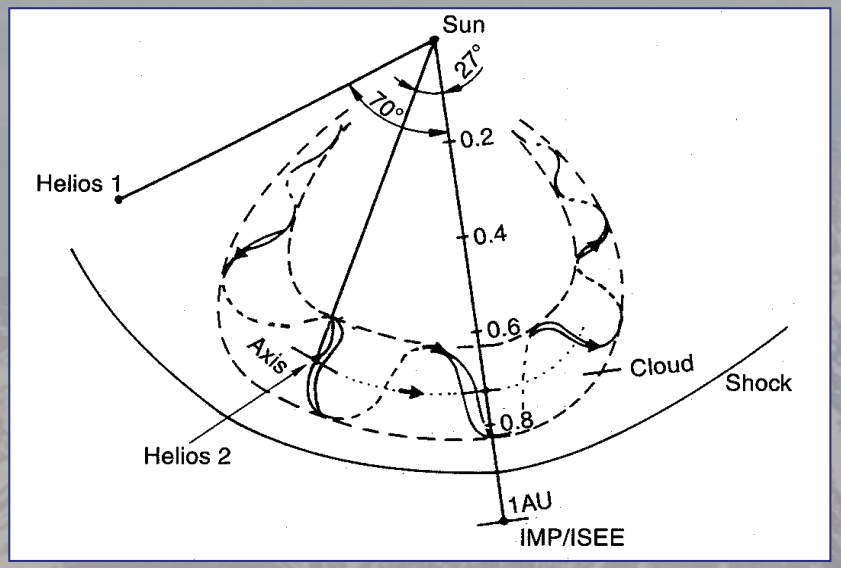
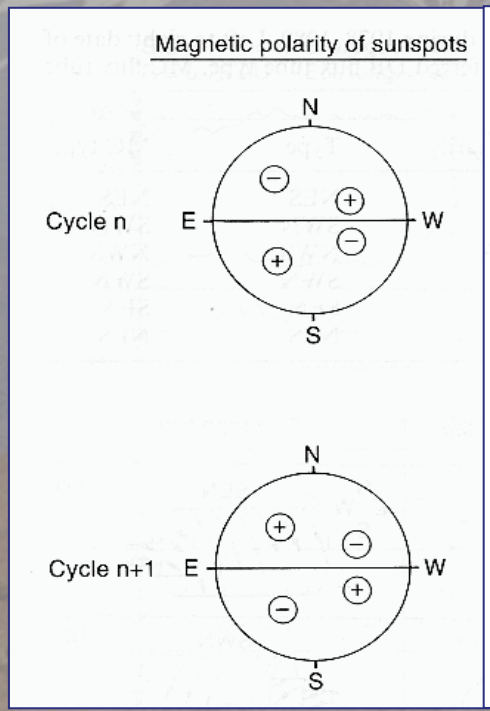
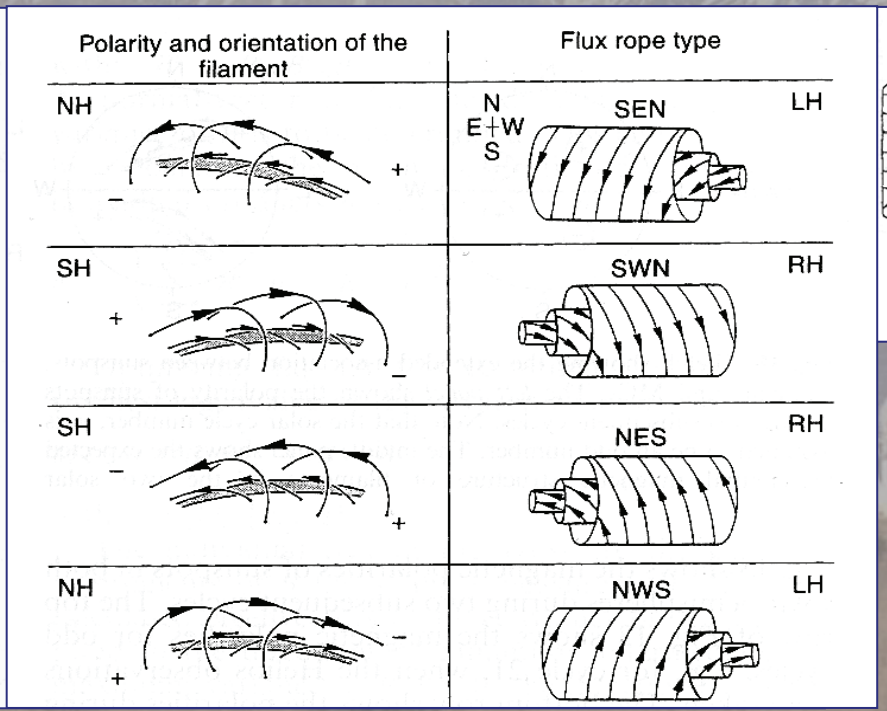
Ejected plasma clouds in space

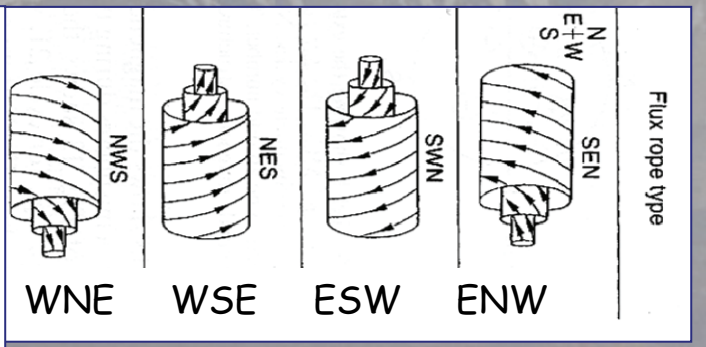


Magnetic clouds imply large-scale rotations of the magnetic field vector

Also possible at times

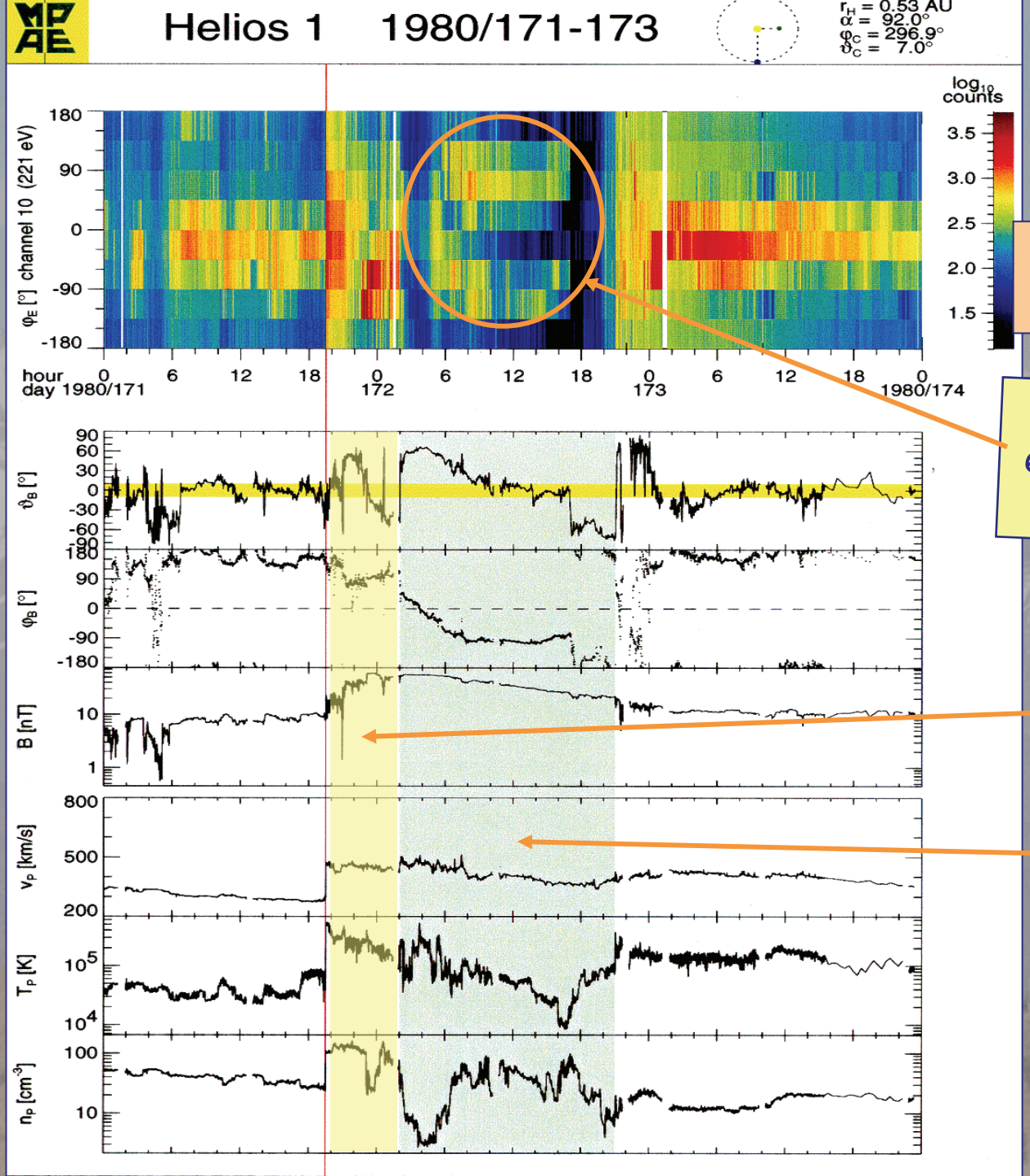






Note: No S in WNE and ENW clouds!

Ejected plasma clouds in space



A typical "magnetic cloud", following a fast shock wave

This cloud contains "bidirectional electrons", evidence for magnetic cut-off

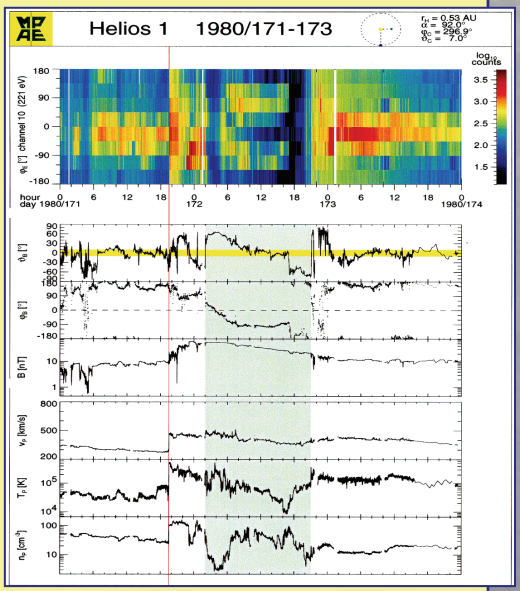
Typical CME products in the interplanetary medium:

- just shocked "sheath" plasma (compressed and heated),
- and sometimes "driver gas", incl. magnetic clouds,
- no more signs of 3-part structure, in general!

Ejected plasma clouds in space

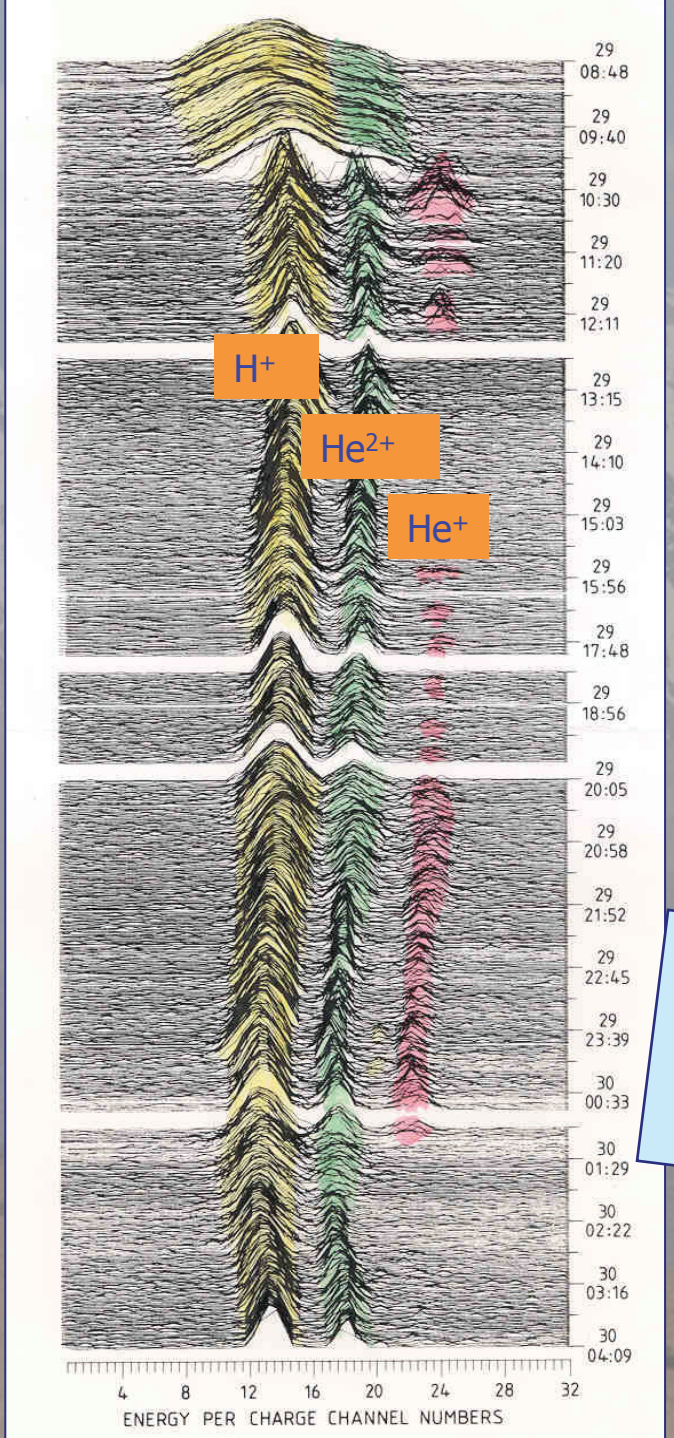
The signatures of plasma clouds/driver gas with respect to the ambient solar wind:

- ion and electron temperature depressions,
- tangential discontinuities in density, temperatures, and field,
- helium abundance enhancements (up to 30 %!),
- unusual ionization states (Fe^{16+}, He^{+}, etc),
- counterstreaming of energetic electrons and protons,
- counterstreaming of suprathermal electrons (BDEs),
- magnetic cloud signatures:
  - anomalous field rotation,
  - strong magnetic field,
  - very low plasma beta,
  - low variance of the magnetic field.



Usually, only a subset of these signatures is observed.

Ejected plasma clouds in space



Discovery of singly ionized Helium ions in the driver gas following an interplanetary shock wave by **Helios 1** in January 1977:
remnants of cold prominence material.

There was only one more such event in July 1977. The next one occurred not earlier than in January 1997, following the halo event on Jan. 6th.

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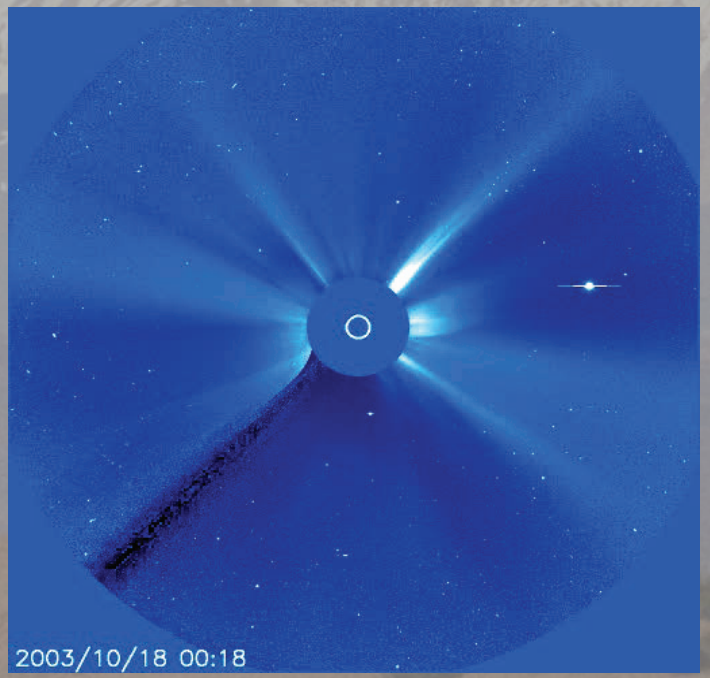

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