Lessons for STEREO - learned from Helios

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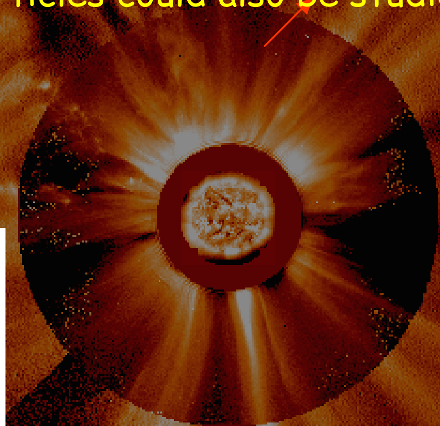
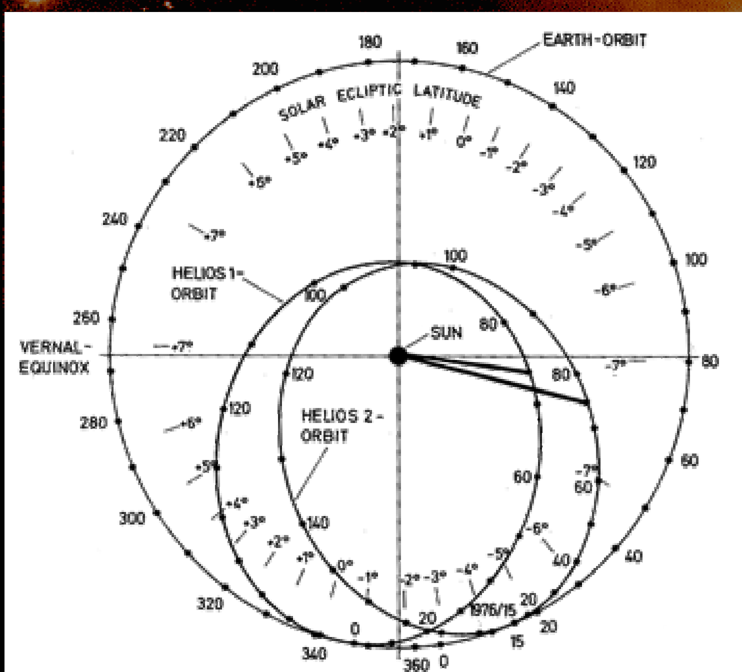
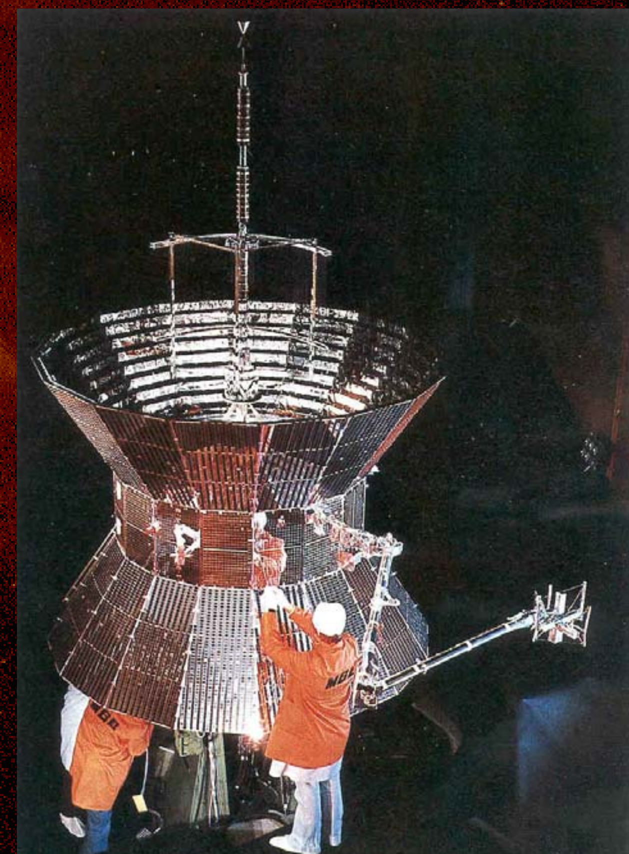
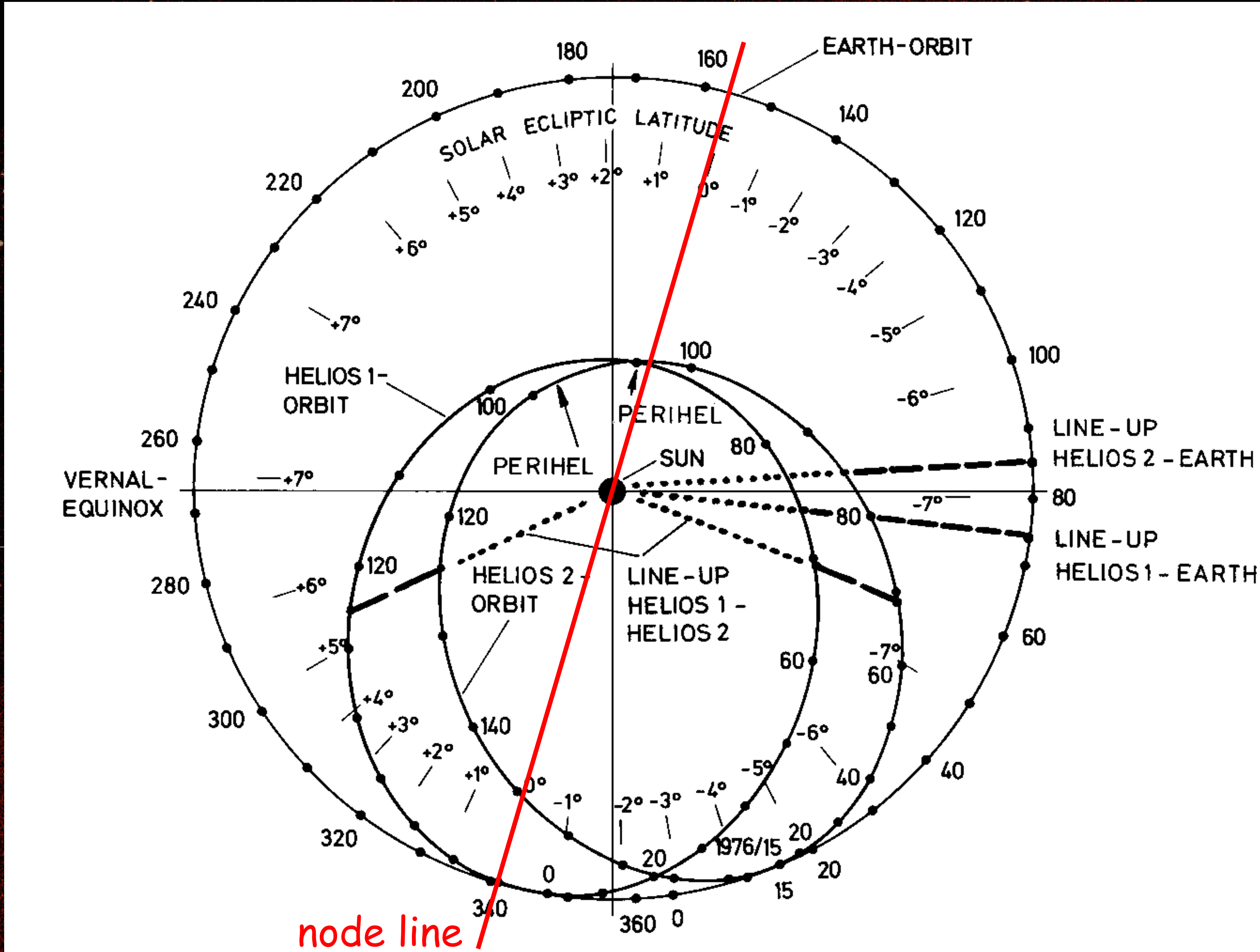
Rainer Schwenn, MPS Lindau
schwenn@mps.mpg.de

The Helios mission resembled the upcoming STEREO mission in several respects. Helios could reveal details about the longitudinal and latitudinal stream structure, it allowed unique associations between limb CMEs and their radial propagation towards an in-situ observer, and the large-scale propagation of solar energetic particles could also be studied.







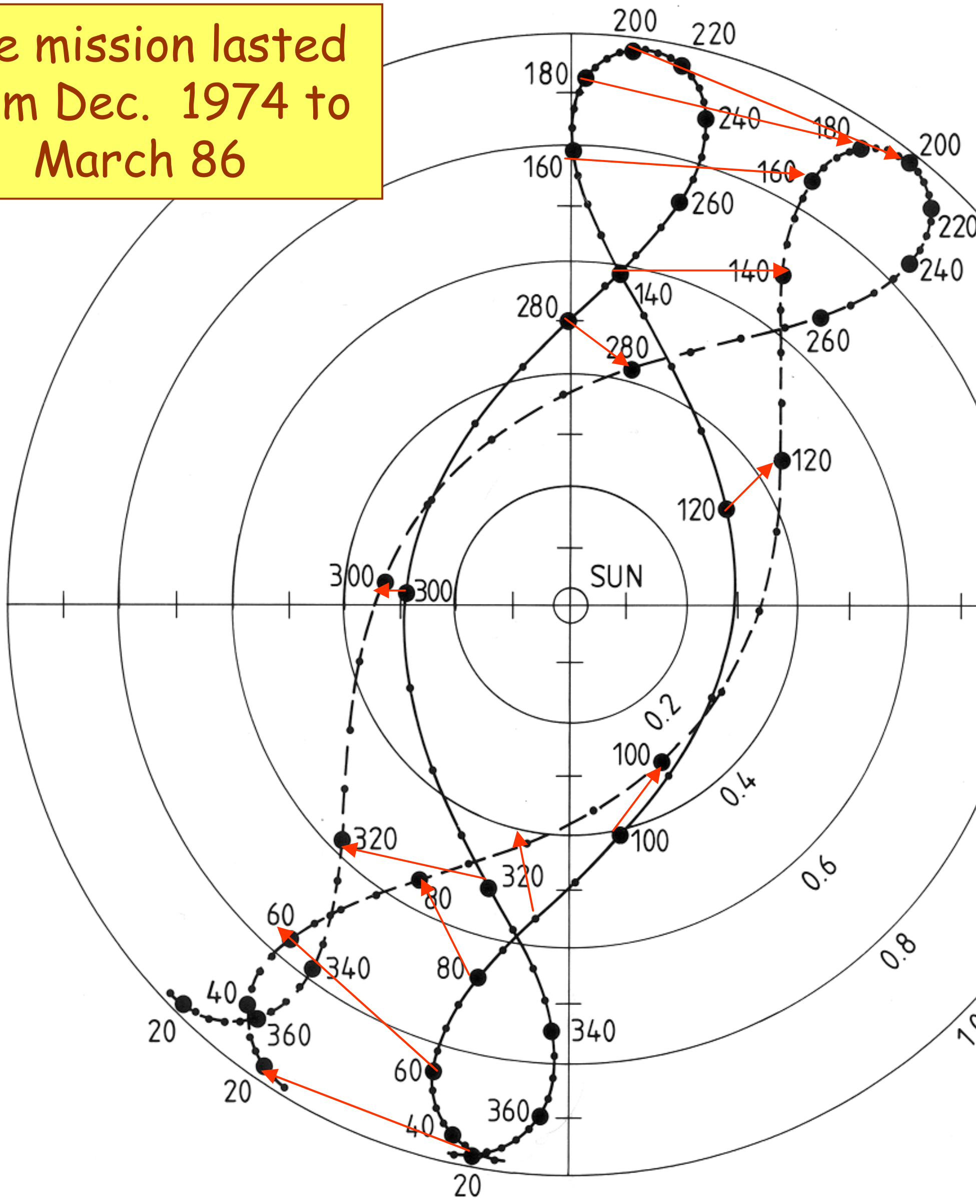


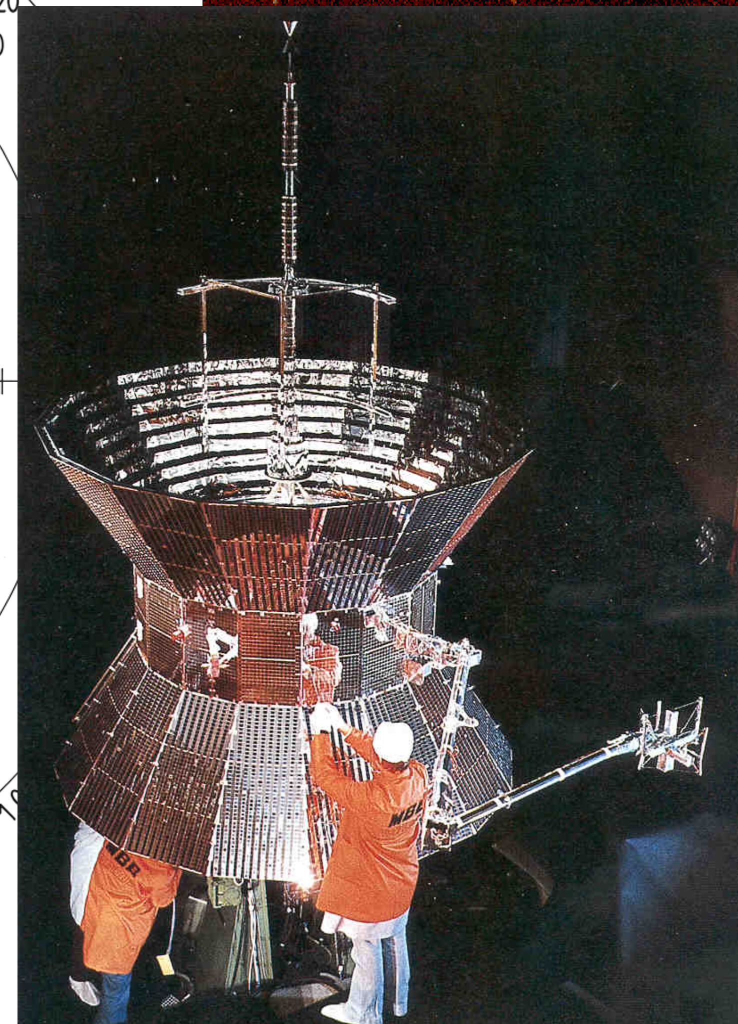
The orbits of the Helios 1&2 solar probes in 1976

The mission lasted from Dec. 1974 to March 86

Helios 1&2

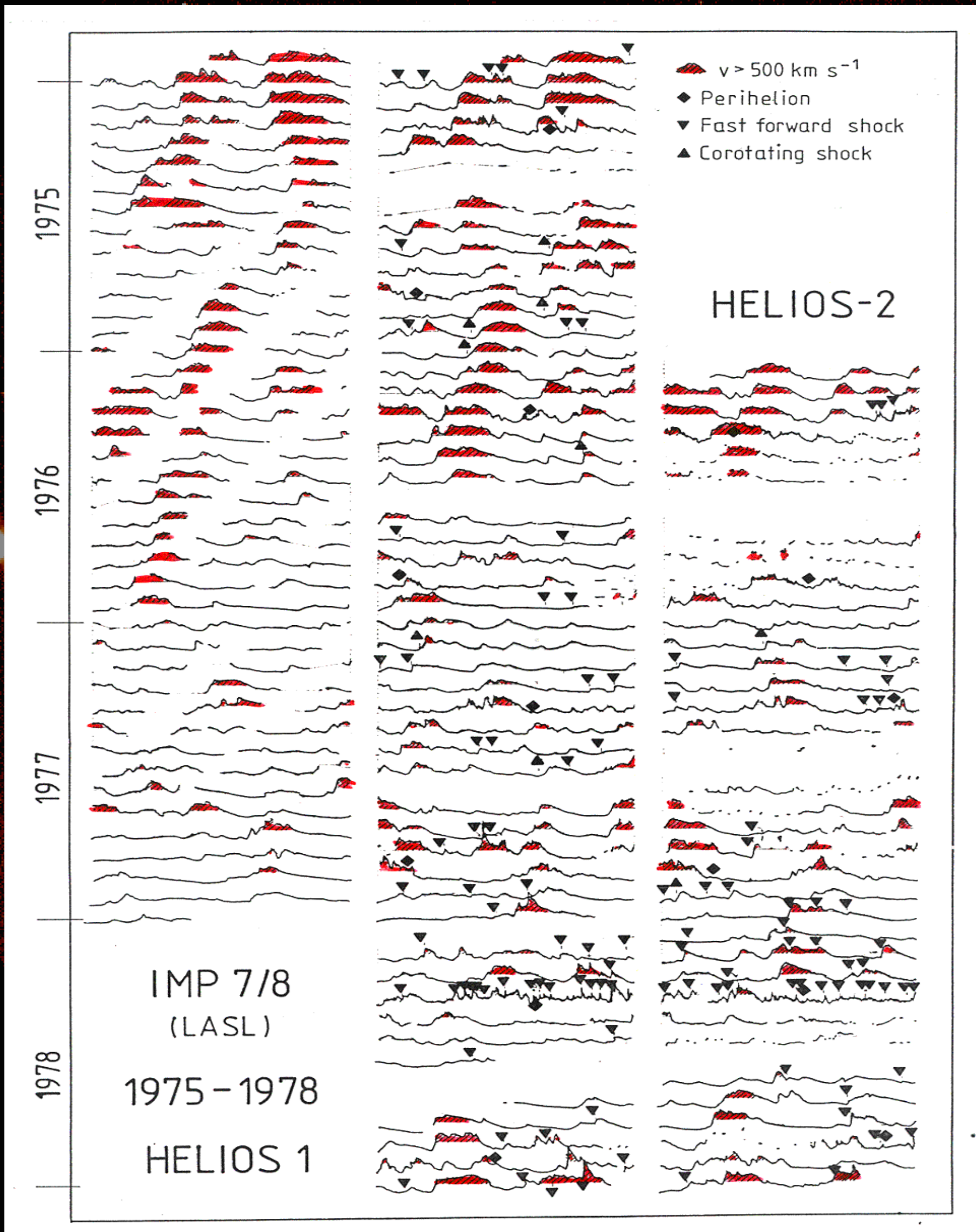
a stereo-mission, but no imagers on board !





A variety of stereo and radial line-up constellations!

Solar wind stream structure 1974 to 1978



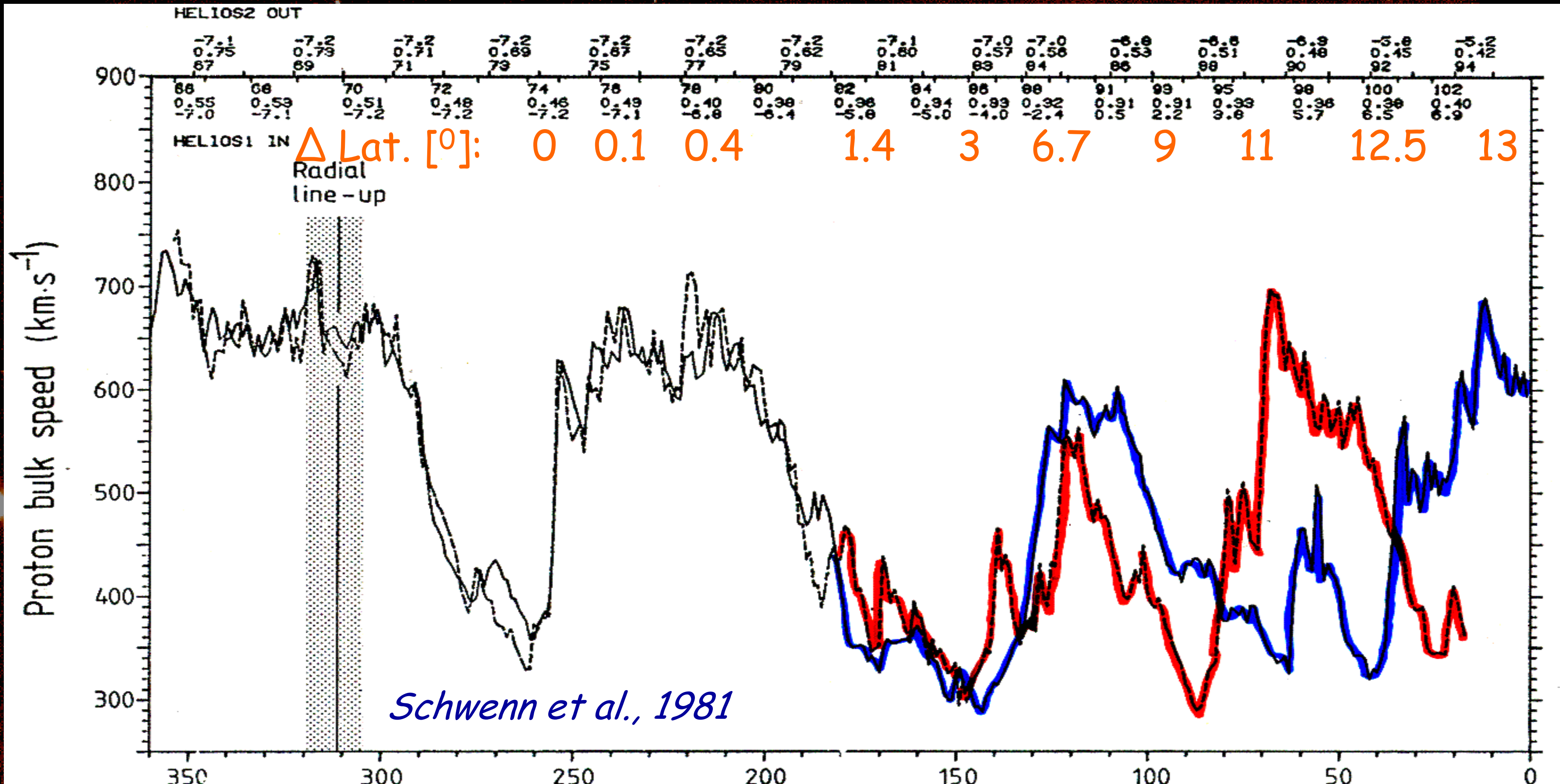
Minimum

The solar wind stream structure, observed by the Helios 1&2 and IMP spacecraft from activity minimum in 1975/76 onward.

With increasing solar activity (in 1978), many transient events destroyed any regular solar wind structure

Maximum

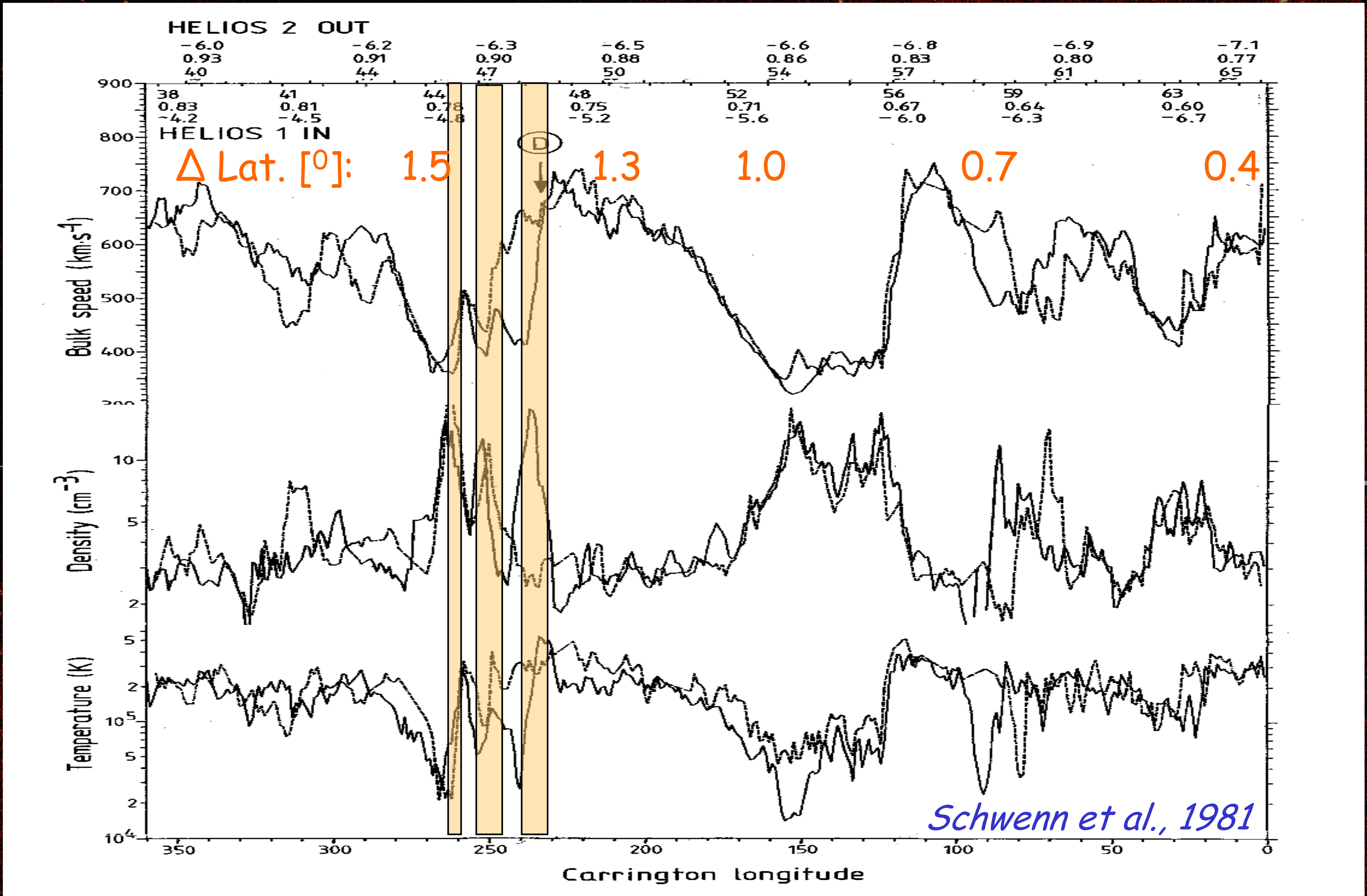
Latitudinal stream boundaries



The line-up between Helios 1 and Helios 2 in 1976, and the succeeding divergence in latitude

It is the latitude that makes stream structures differ, rather than radial distance or time!

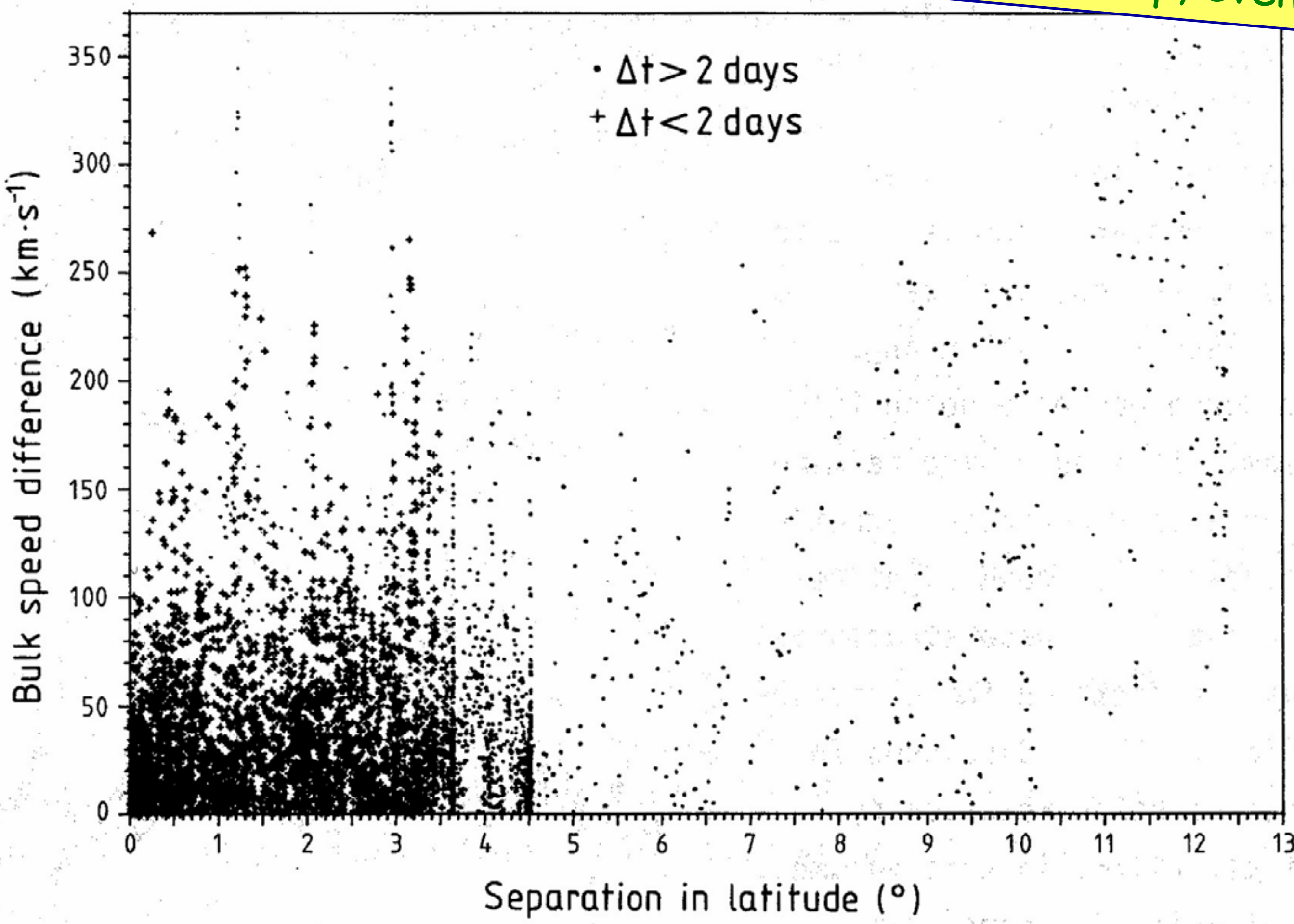
Latitudinal stream boundaries



Entry into a high-speed stream in 2 or even 3 steps,
a mere latitude effect!

Latitudinal stream boundaries

They remain sharp, even beyond 1 AU!

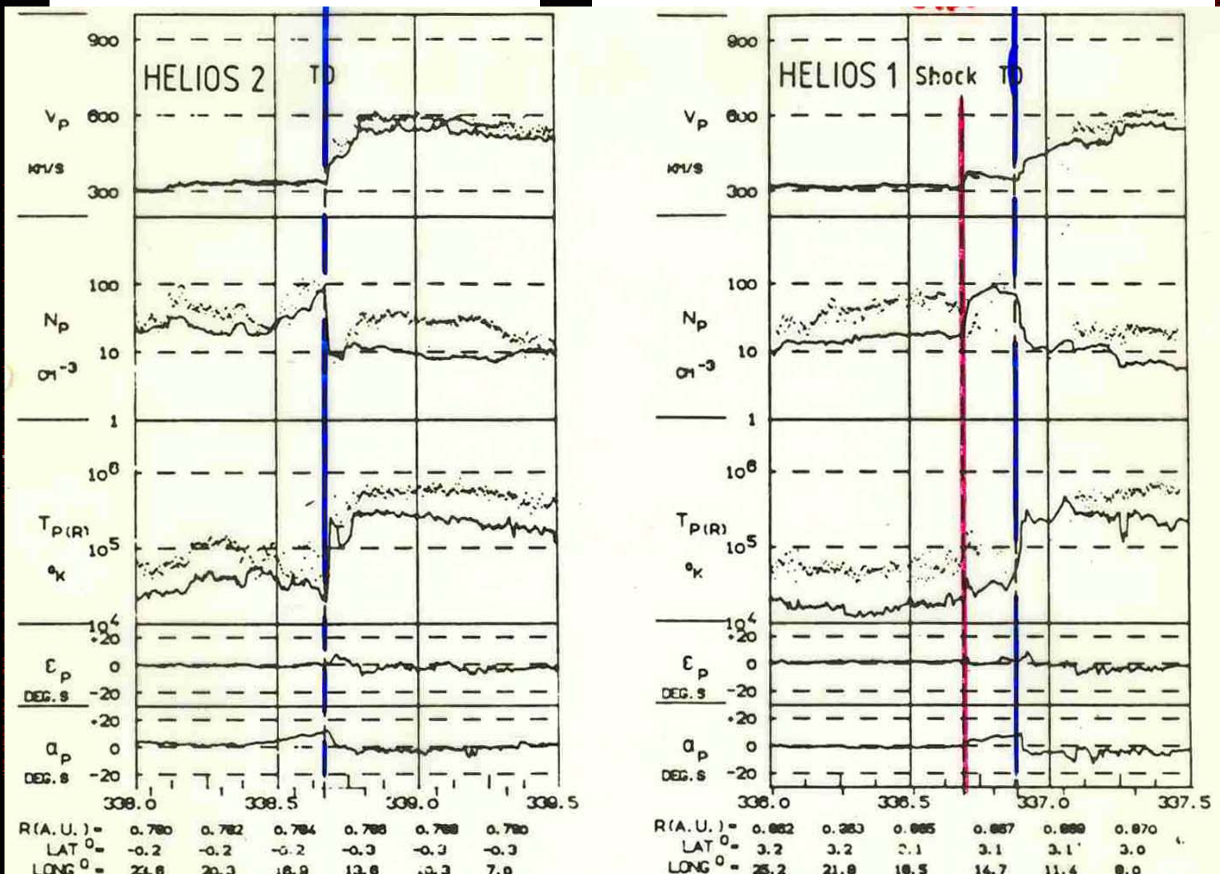


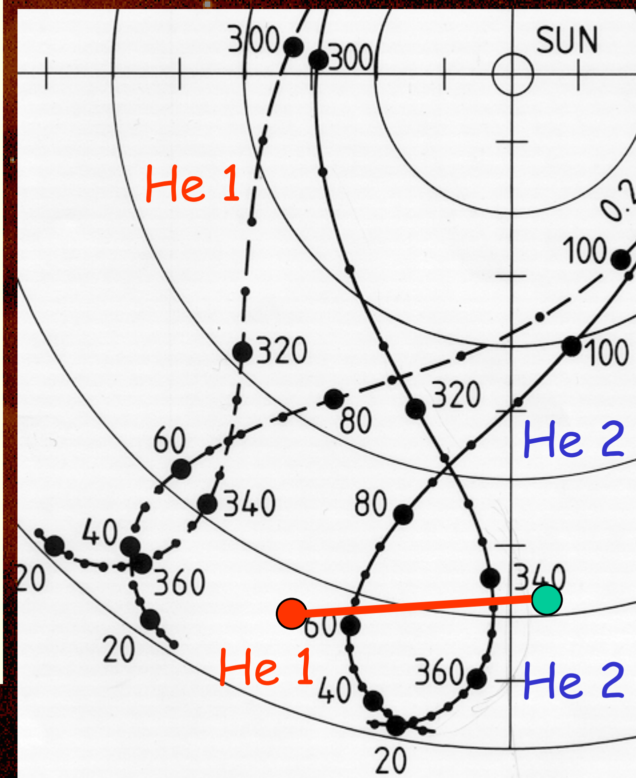
The difference ΔV in proton bulk speed measured by the two HELIOS probes as a function of their separation in heliographic latitude Δε. Each point represents an average over 1° in solar longitude. The crosses denote cases with corotation times of less than two days.

CIRs at high speed stream fronts

can differ substantially with latitude!

No corotating shock | CIR with corotating shock

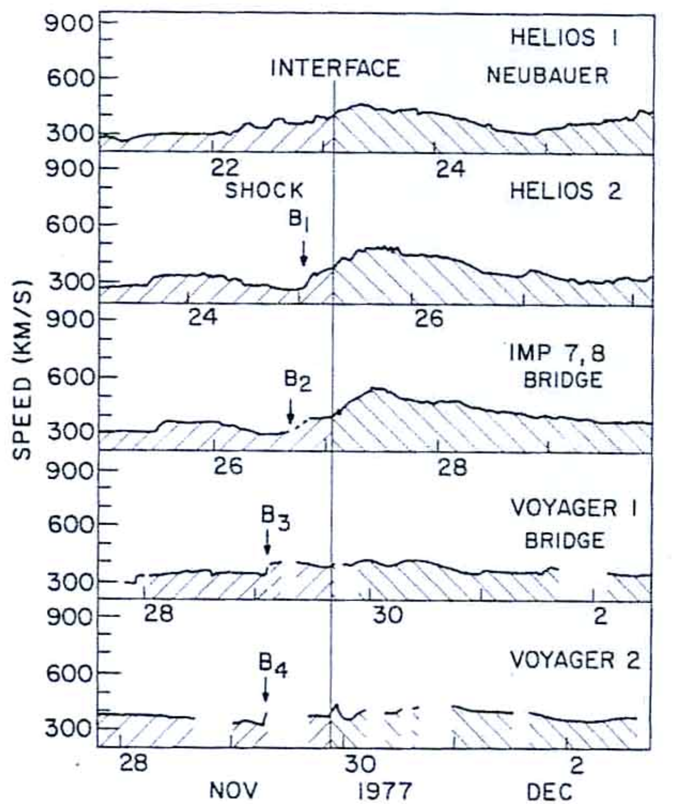




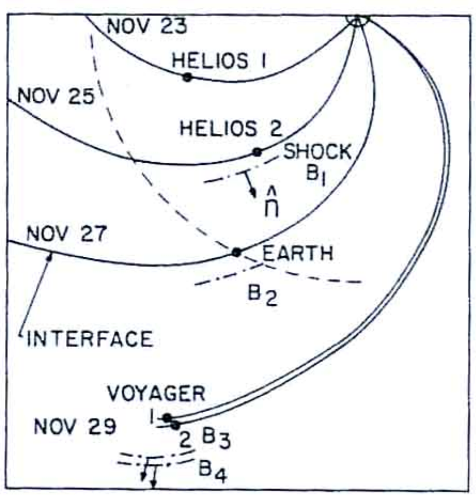
R =	0.78 AU	0.87 AU
Lat =	-0.2^0	$+3.2^0$
Clong =	15^0	13^0
Date =	76:338:16:00 UT	76:336:21:00 UT

A CIR

observed by 6 S/C in November 1977



Burlaga et al., 1978

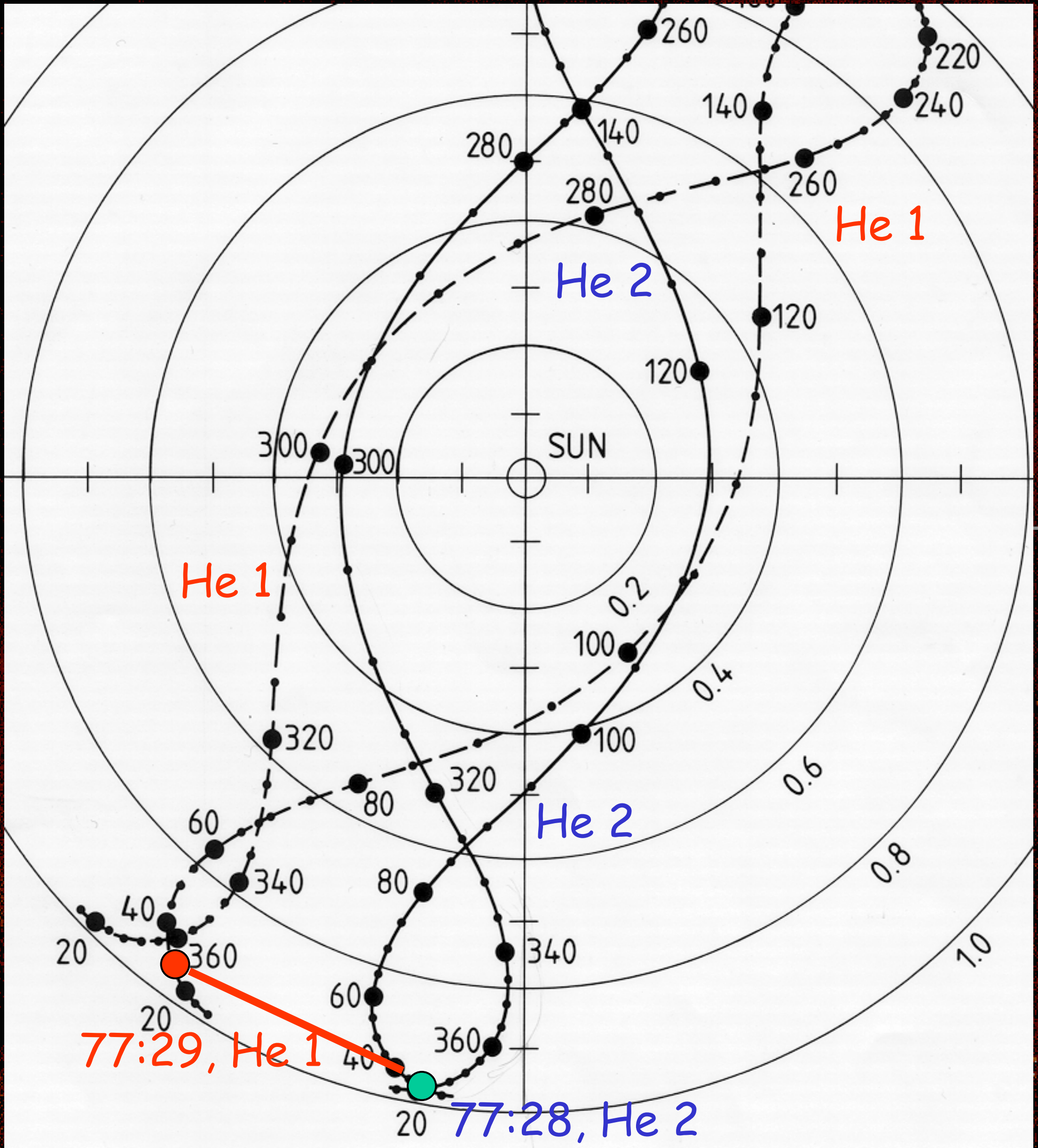


Note:

- the stream interface SI is observed at all S/C,
- He 2 is first to observe a corotating shock,
- the stream is gone at 1.6 AU, but
- the SI is still there, and
- the corotating shock is still there.

A transient shock, seen from Helios 1&2

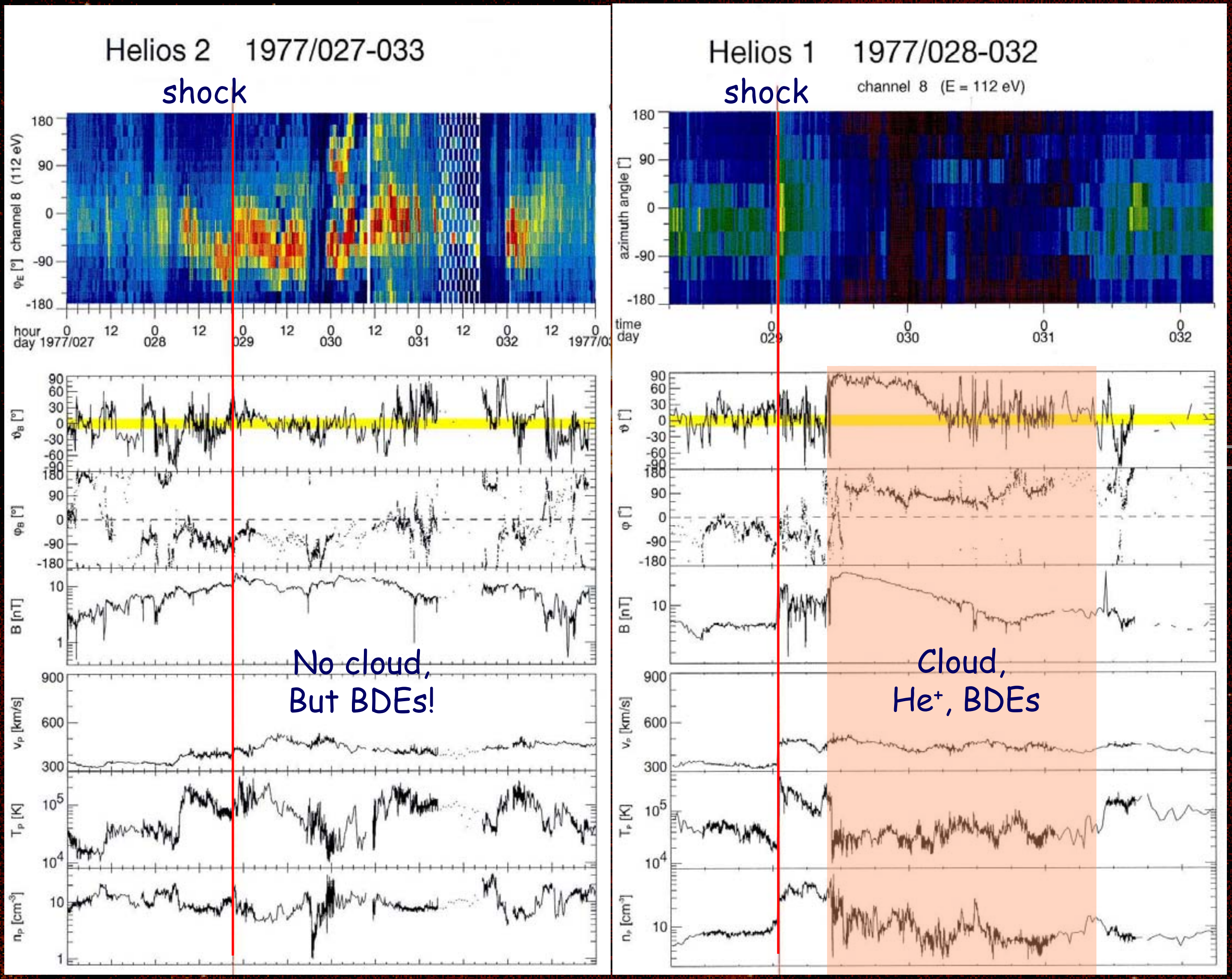
27⁰ apart in longitude



Helios orbits in 1977

A transient shock, seen from Helios 1&2

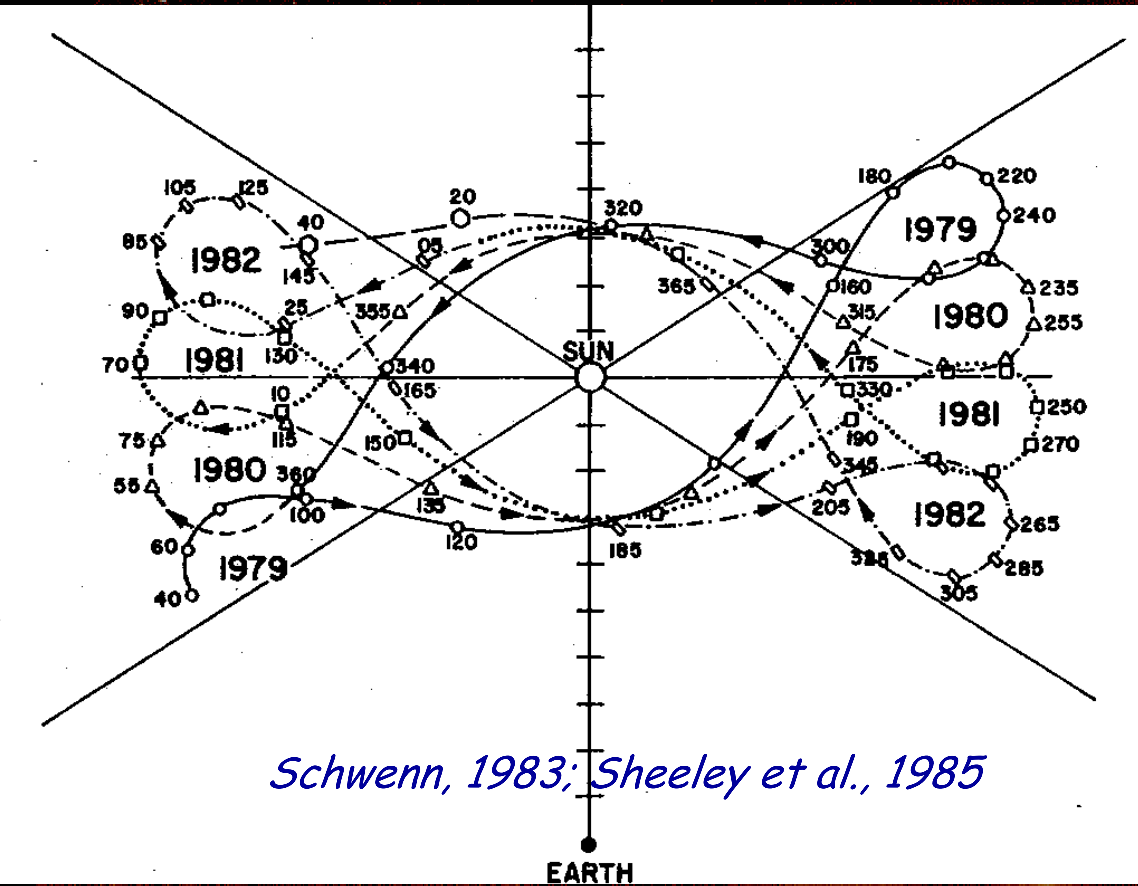
27^0 apart in longitude



0.98 AU
-5.0^0 lat
351^0 HSE

0.952 AU
-2.0^0 lat
323^0 HSE

Predecessors to STEREO-A/B: Helios plus P78-1



Schwenn, 1983; Sheeley et al., 1985

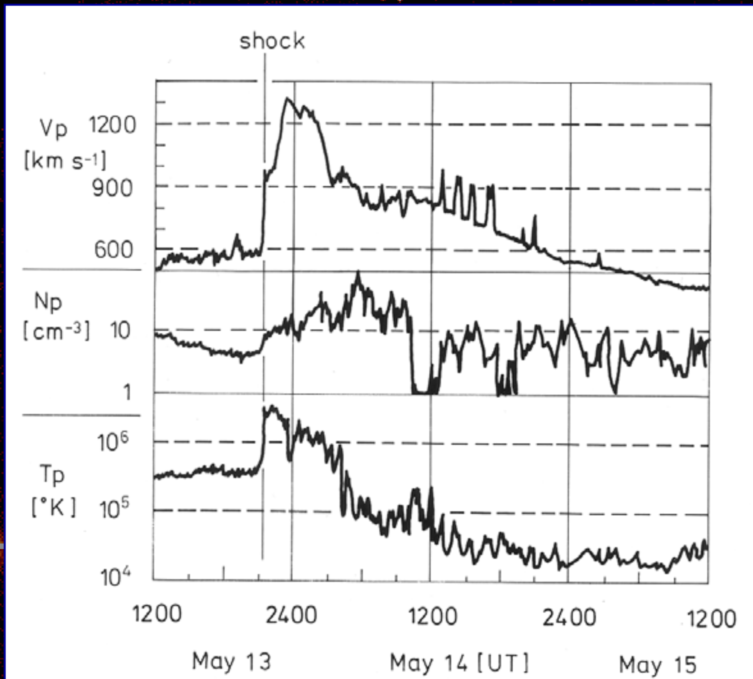
Orbit of Helios 1 with respect to the Sun-Earth line

The coronagraph on P 78-1 recorded CMEs above the limb. The plane-of-the-sky speed (which equals the radial speed for limb CMEs) of several hundred CMEs was measured.

The Helios probes happened to travel above the limb for long time periods and could observe *in-situ* the arrival of ICMEs.

For 49 events in 1979 to 1982 a unique association between CMEs seen at the sun and ICMEs observed *in-situ* (within +/- 30^0 of the sky plane) could be found and the travel time be determined.

Stereo views resolved the flare-CME controversy



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.

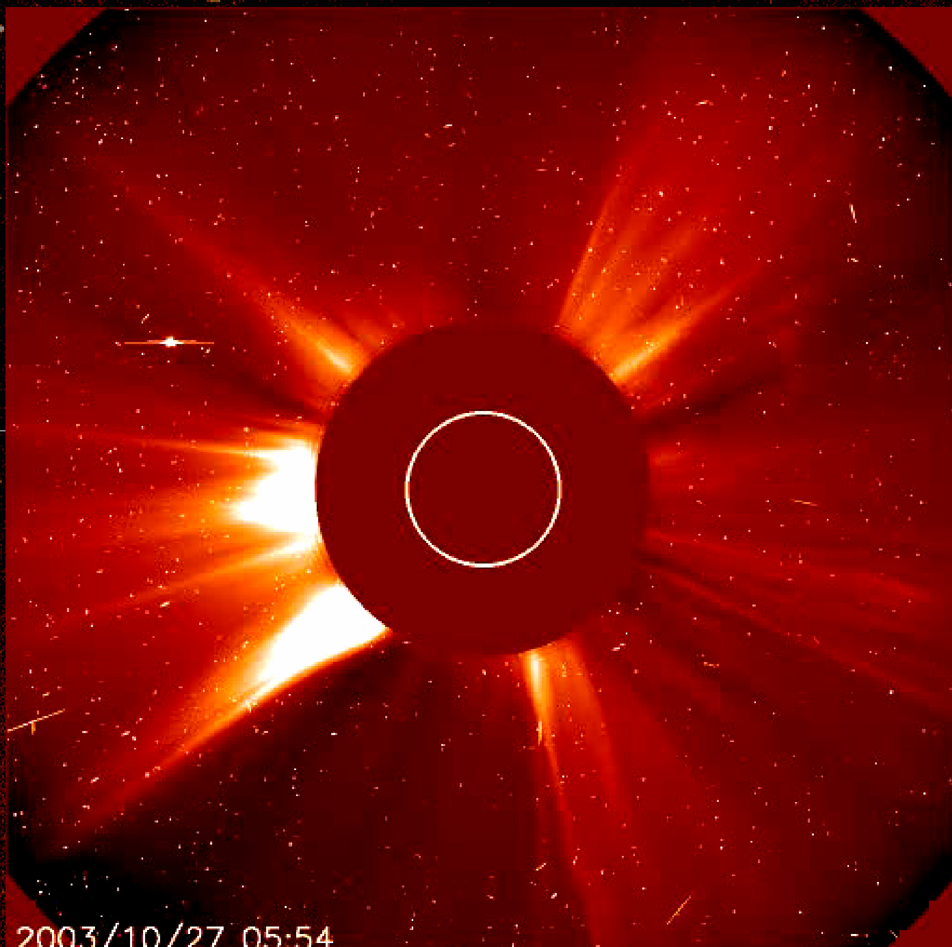
Sheeley et al., 1985

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.

The key problem in space weather forecasting: How to measure the CME's speed component V_{rad} along the LOS?



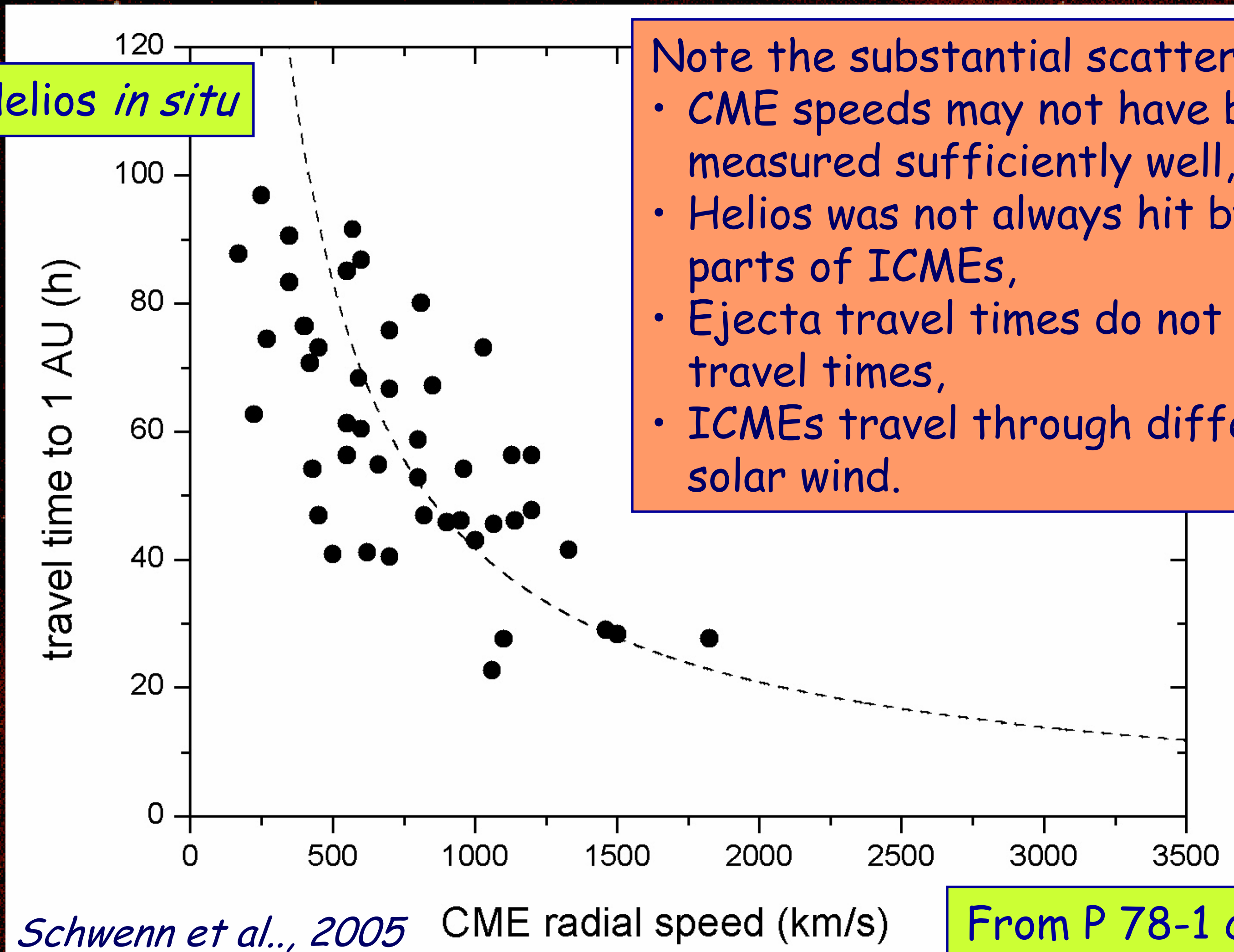
On October 28, 2003, in conjunction with a X13 flare, there occurred a gigantic halo CME .

By the way: 8 hours earlier a little comet had evaporated!
Coincidence?
:
Note: in 10 years mission time, SOHO has seen more than 1000 little comets and some 10000 CMEs...

Even if we could measure V_{rad} near the Sun, we are still in trouble.
That's what we learned from Helios

Unique radial speed measurements of limb CMEs (SOLWIND) and associated ICMEs (Helios)

From Helios *in situ*



Note the substantial scatter! Reasons:

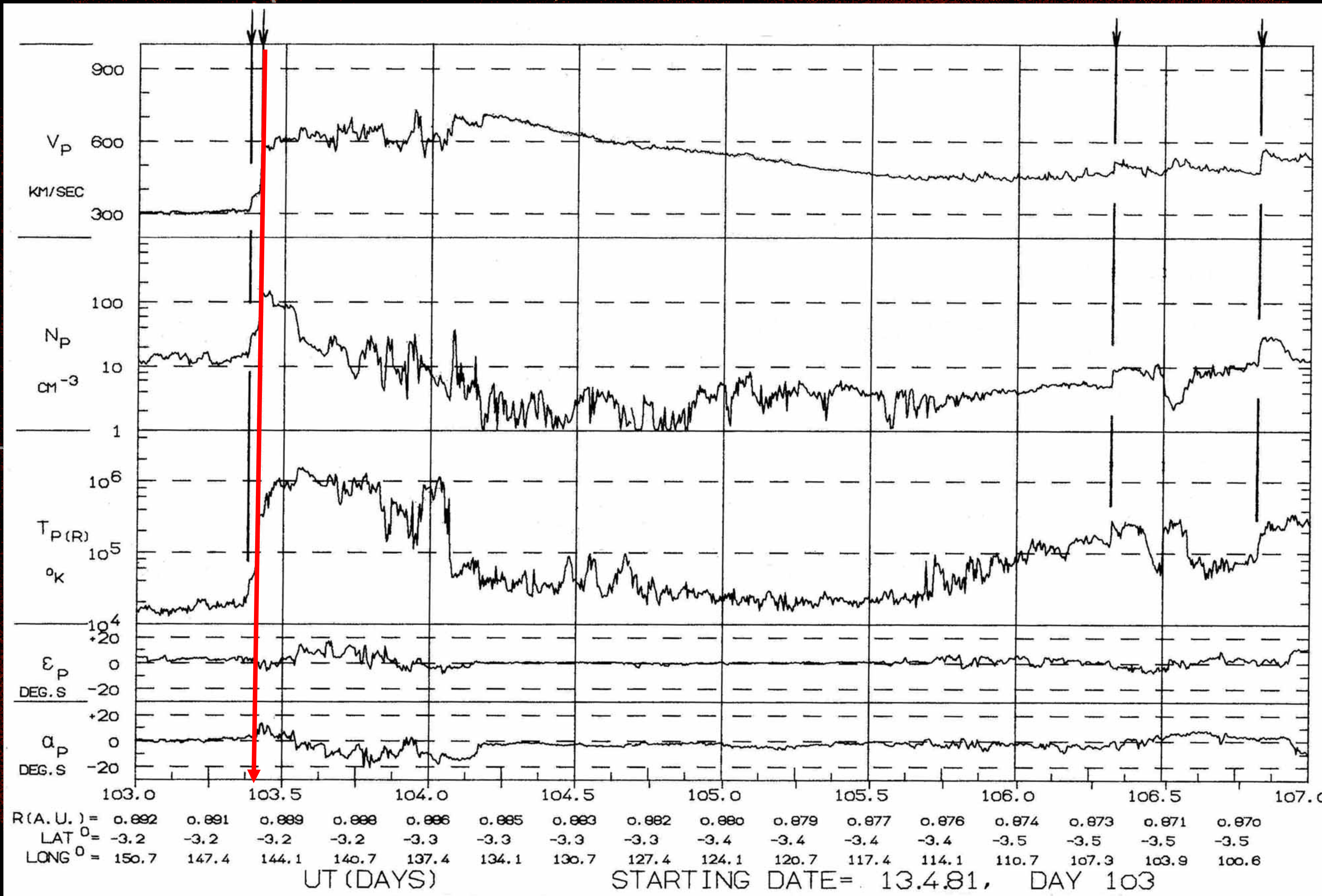
- CME speeds may not have been measured sufficiently well,
- Helios was not always hit by the fastest parts of ICMEs,
- Ejecta travel times do not equal shock travel times,
- ICMEs travel through different ambient solar wind.

Schwenn et al.., 2005

From P 78-1 coronagraph

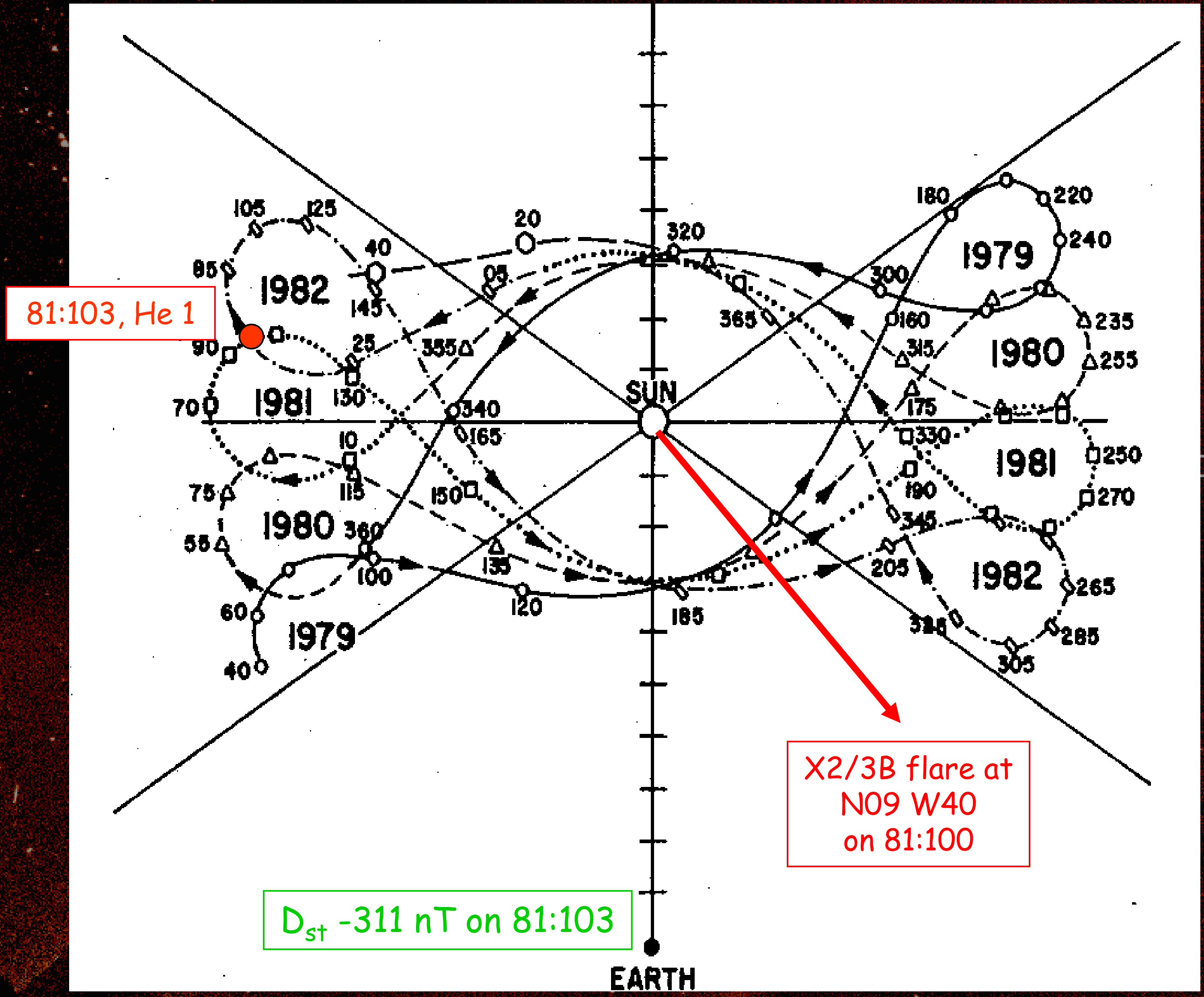
The travel time of ICME driven shock fronts from the Sun to the location of Helios 1 vs the CME radial speed V_{rad}.

Shock fronts may extend far around the Sun

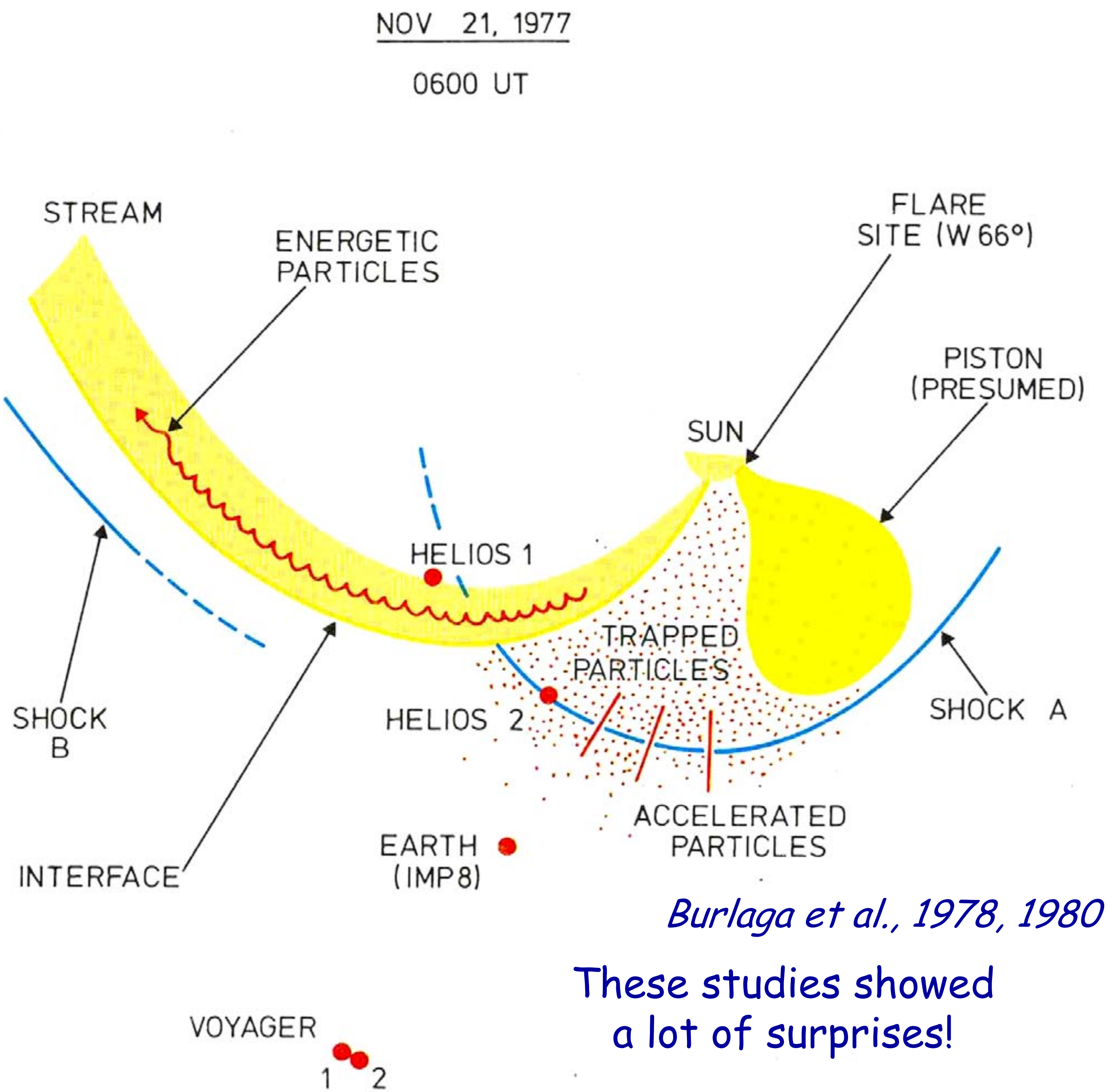


The CME center was 140° in longitude off the Helios 1 position

Shock fronts may extend far around the Sun



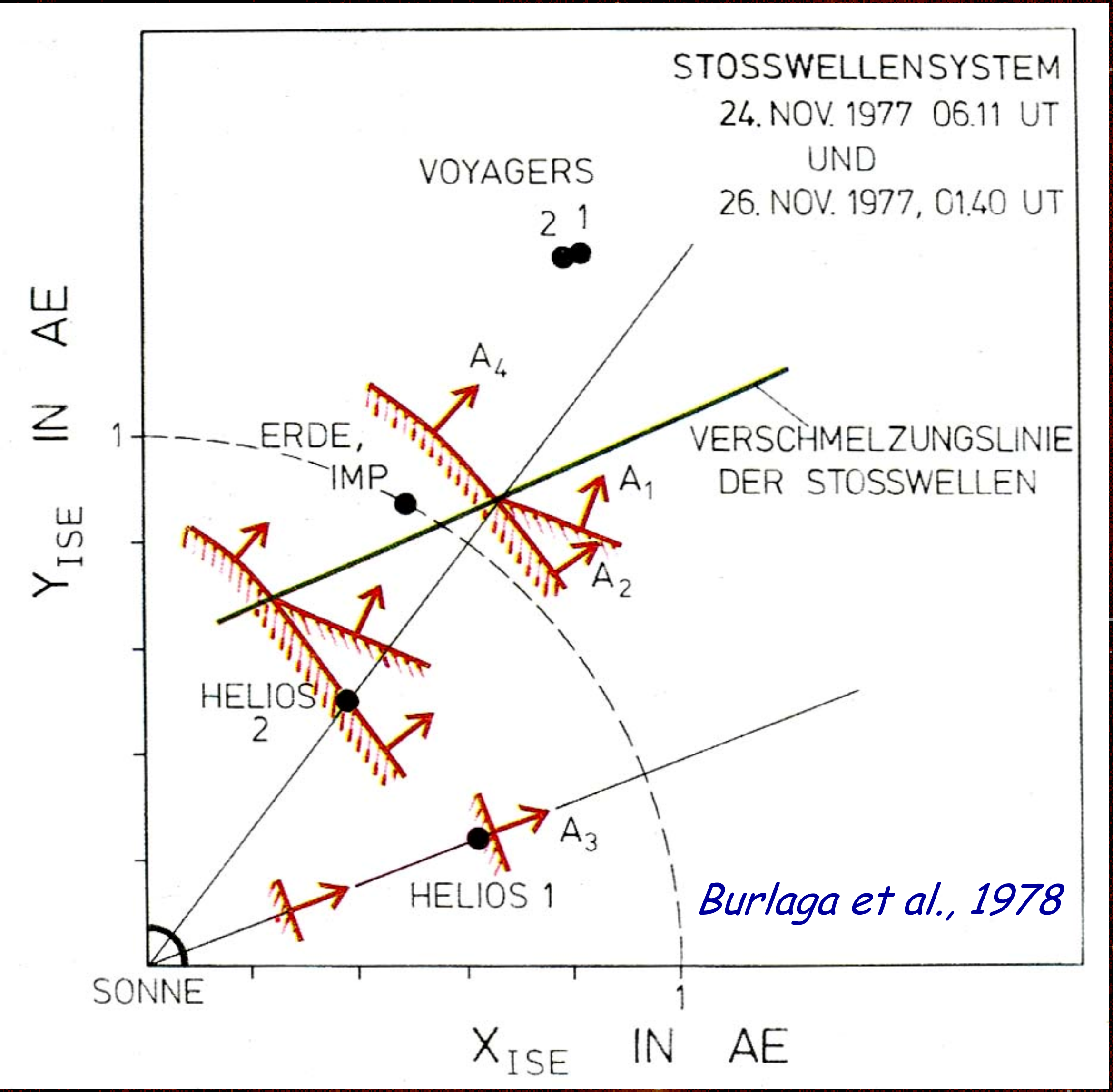
Multipoint study of shock propagation and extent



Burlaga et al., 1978, 1980

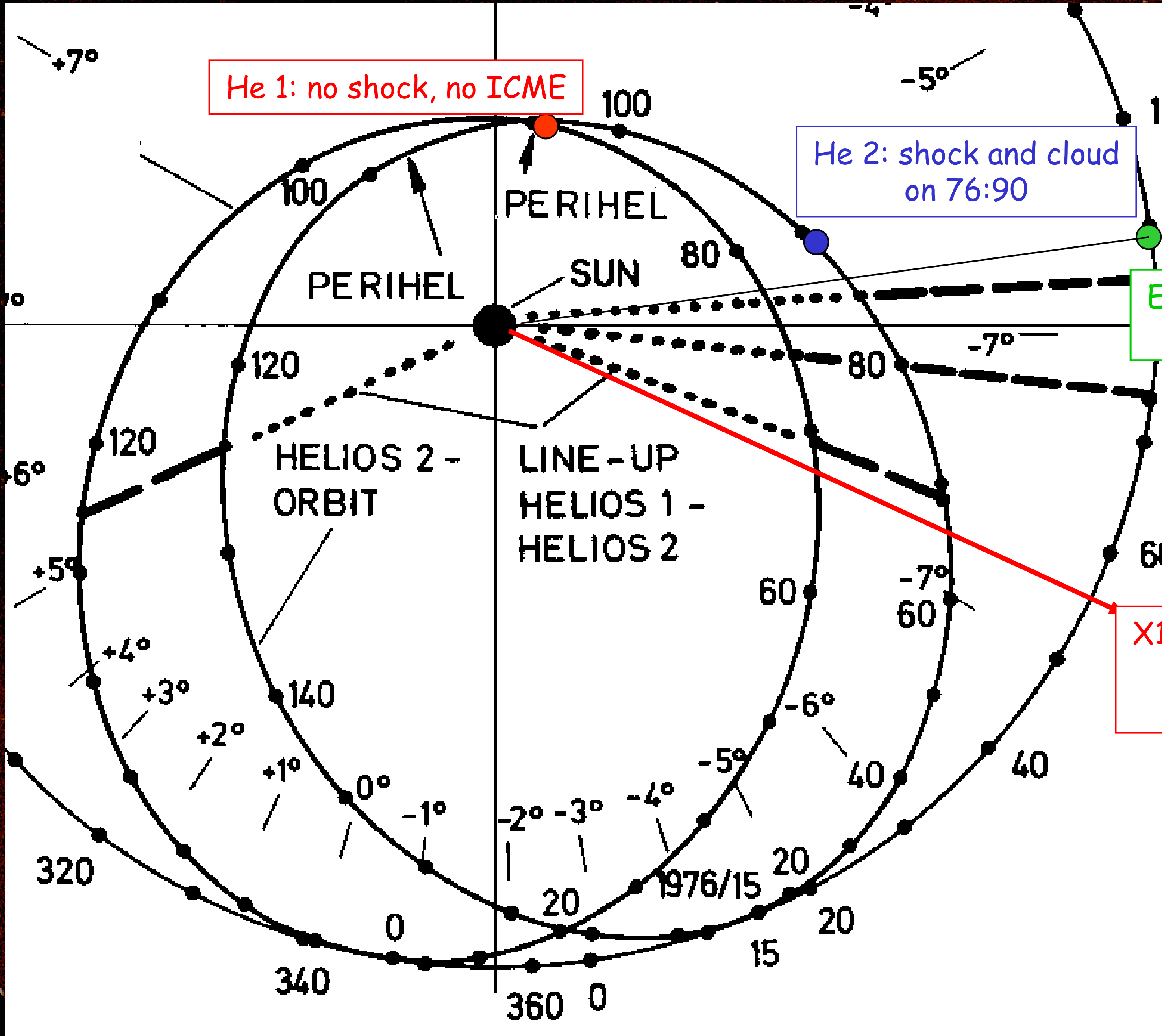
These studies showed a lot of surprises!

Shock fronts may extend far around the Sun

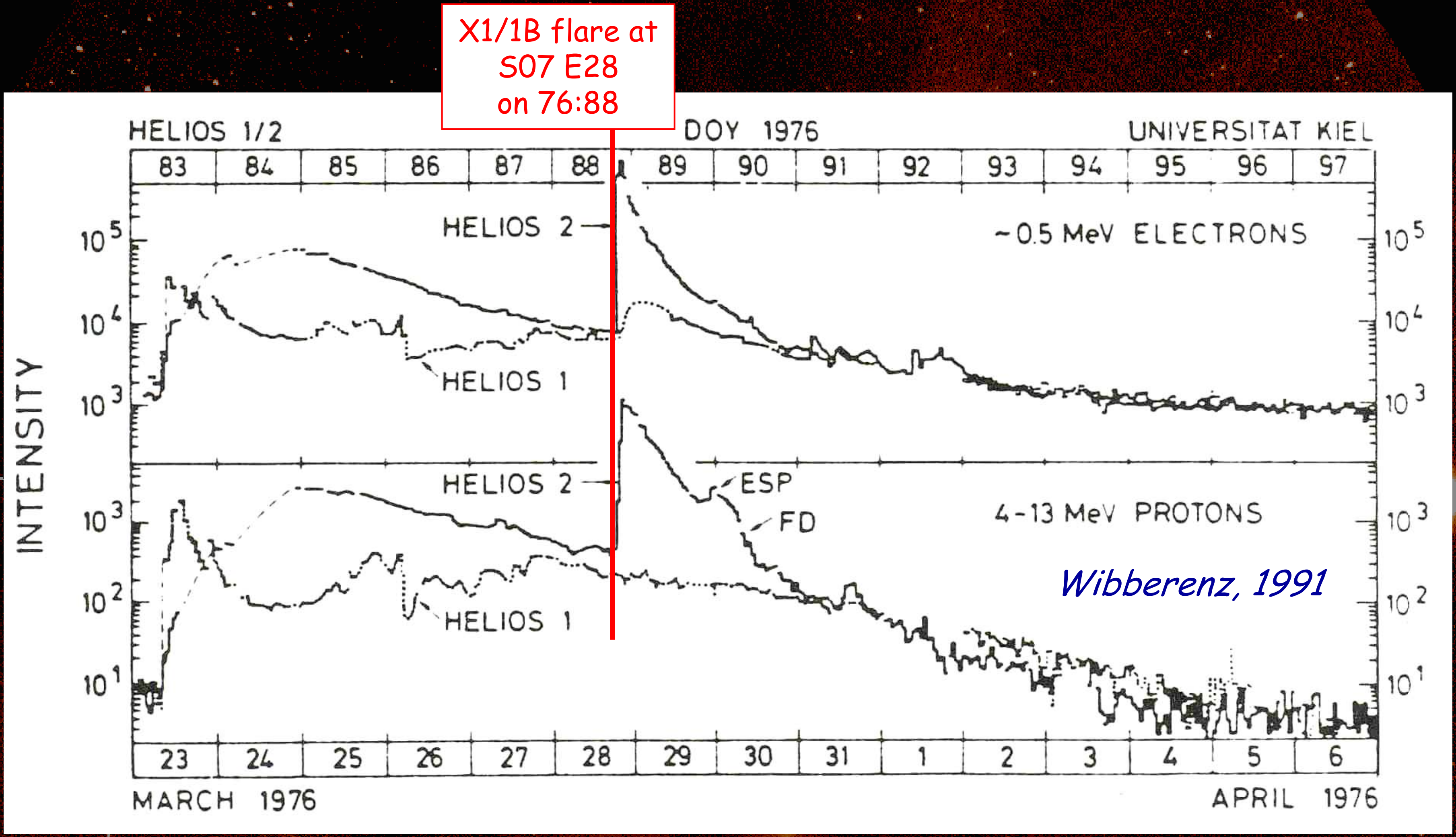


The shocks A1 and A2 seen by He 2 merged,
and at Earth and at the Voyagers one single shock arrived.

Stereo-constellation at the events in March 1976

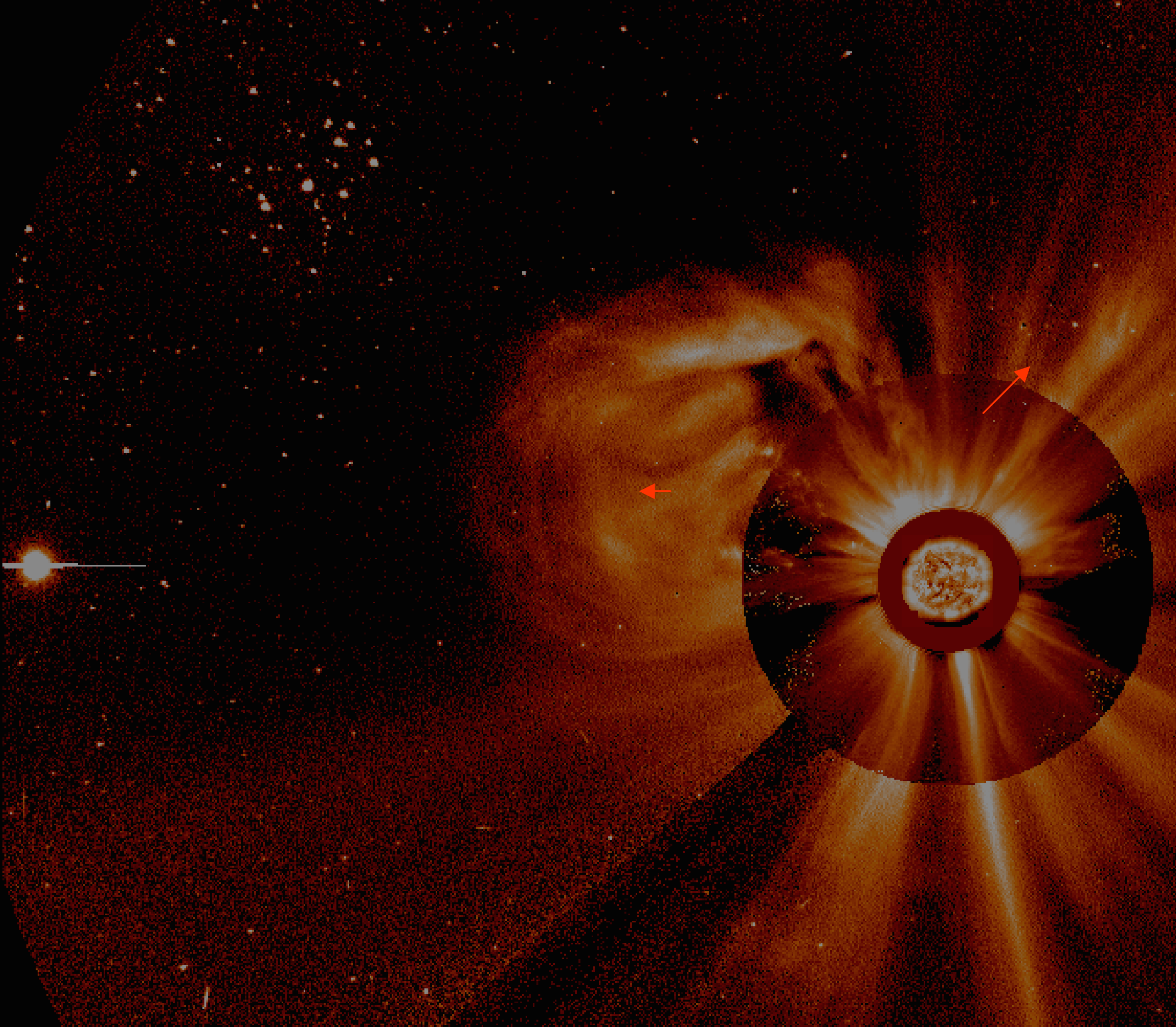


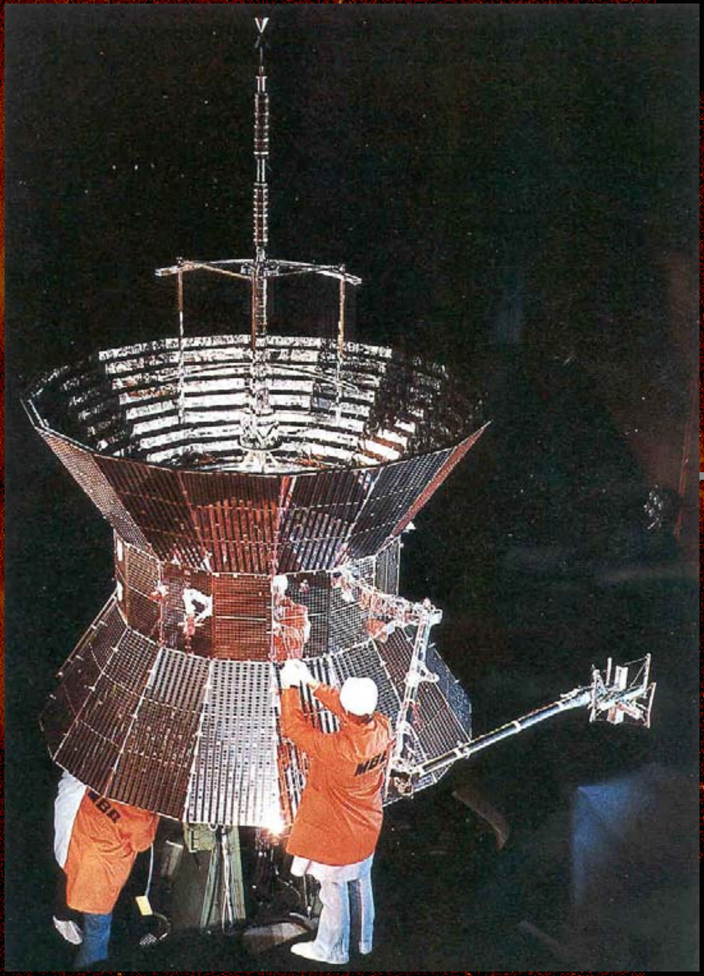
Multipoint study of particle propagation



Relativistic solar electrons made it to He 1, some 90^0 west of the flare site, but no protons!

Preparing for STEREO - revisit Helios!





The Helios plasma data are available, on line,
Thanks to Peter Schroeder, SSL Berkeley!
http://sprg.ssl.berkeley.edu/htbin/impact/HeliosData.pl