

CMEs Observed in the Heliosphere by the Solar Mass Ejection Imager (SMEI)

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Boston College



<http://www.vs.afrl.af.mil/Division/VSBX/SMEI.html>

<http://smei.nso.edu>

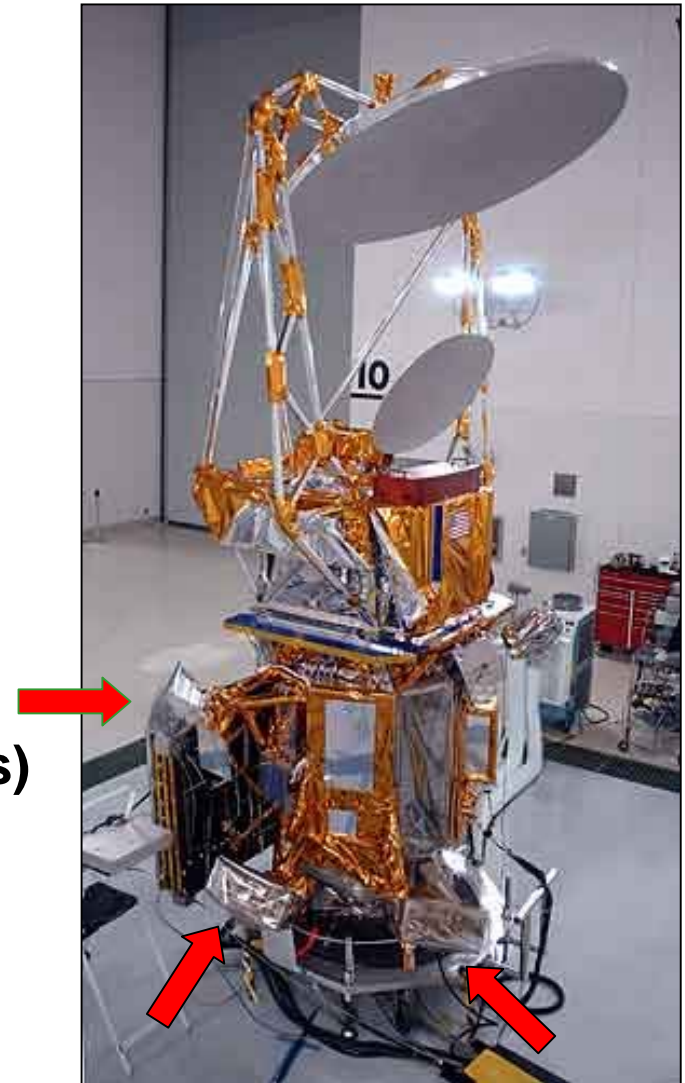
Financial support provided by the Air Force, the University of Birmingham and NASA.

Outline

- **SMEI Goals re CMEs**
 - Space Weather Forecasting**
 - Understanding Physics**
- **How All-sky Maps Constructed**
- **Examples of CMEs:**
 - Limb, Halo, Multiple**
 - Solar Origins; Distance-Time plots**
- **First-Year Statistical Results on CMEs:**
 - Rates, Brightnesses, Spans, Speeds, Distances**
- **Future Data Analyses & Collaborations**

Solar Mass Ejection Imager (SMEI)

- **Proof-of-concept AF experiment**
- **To track CMEs from Sun to Earth**
- **Launched by AF STP**
- **First-ever capability**
- **All-sky view, updated every orbit**
- **Need to detect signal at 1% of background (zodiacal light & stars)**



SMEI on Coriolis Mission

Launched 6 Jan 2003

Now 1 full year of data

Since launch SMEI has observed:

- 100 CMEs; ~5 were Earthward (halo) CMEs**
- 1 comet (Neat)**
- 1 asteroid (Vesta)**
- Auroral light when $K_p > 4$**



Experiment Schedule

- YEAR 1 – Calibration, data processing, develop techniques for tracking CMEs & predicting storms

Data Latency (photon → CCD → AFRL) 24 hours

- YEAR 2 – Validate forecasting techniques (post hoc and real-time tests)

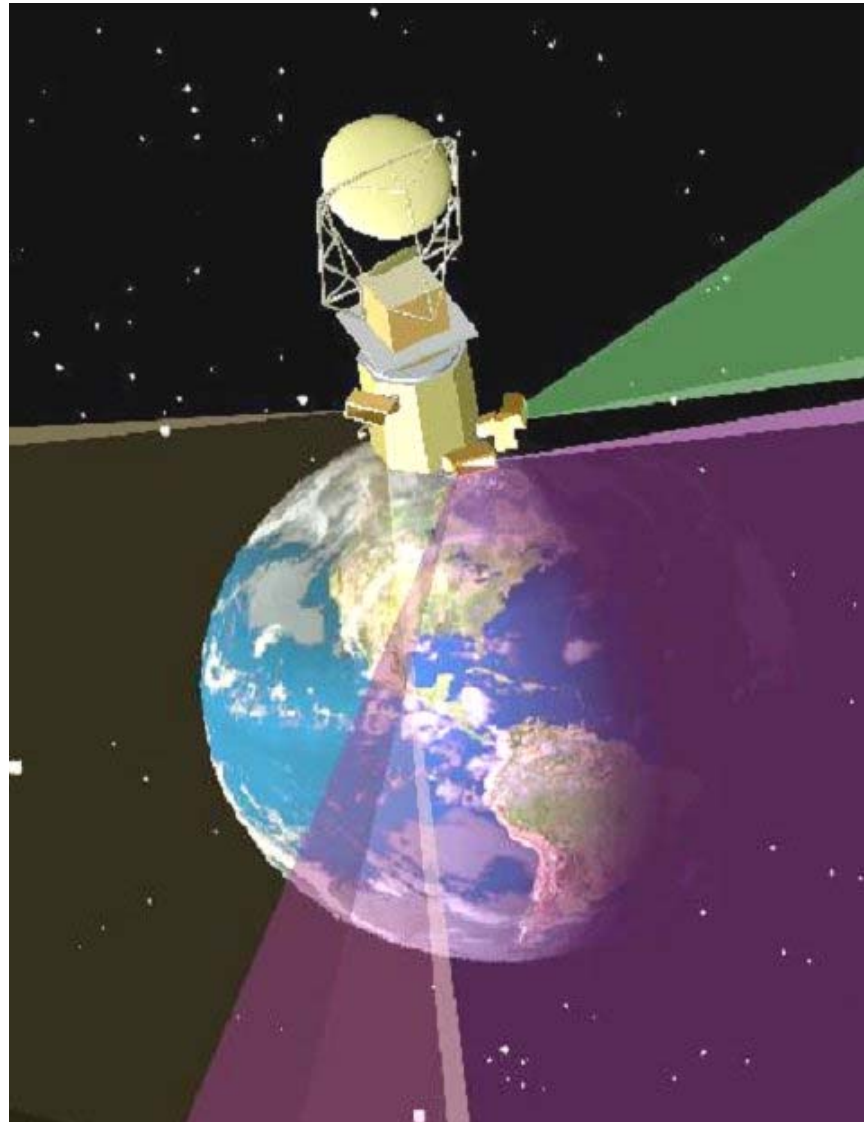
Data Latency (original) 6 hours in Years 2 - 5

- YEARS 3 - 5 – Contribute to operational forecasts?

- Challenges:

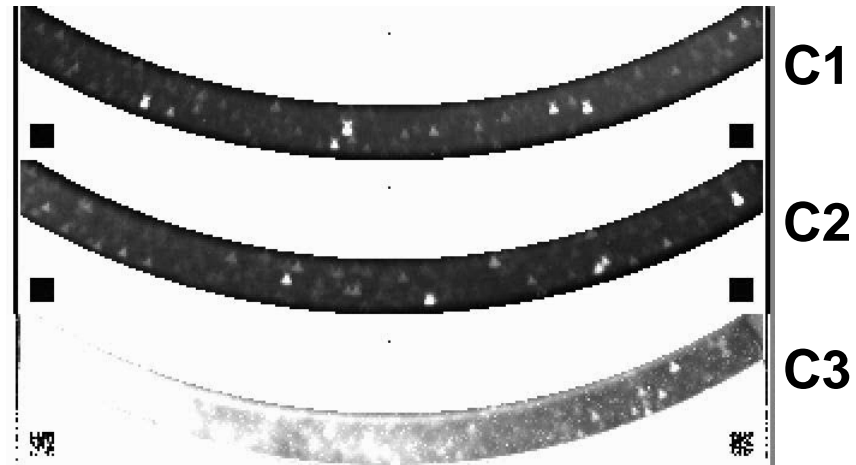
*Camera pointing nearest Sun is 20° warmer than expected.
Particle hits (& aurora) obscure large regions of the sky.
Fewer T/M contacts than required for operational forecasts.*

SMEI Fields of View



Cam
3

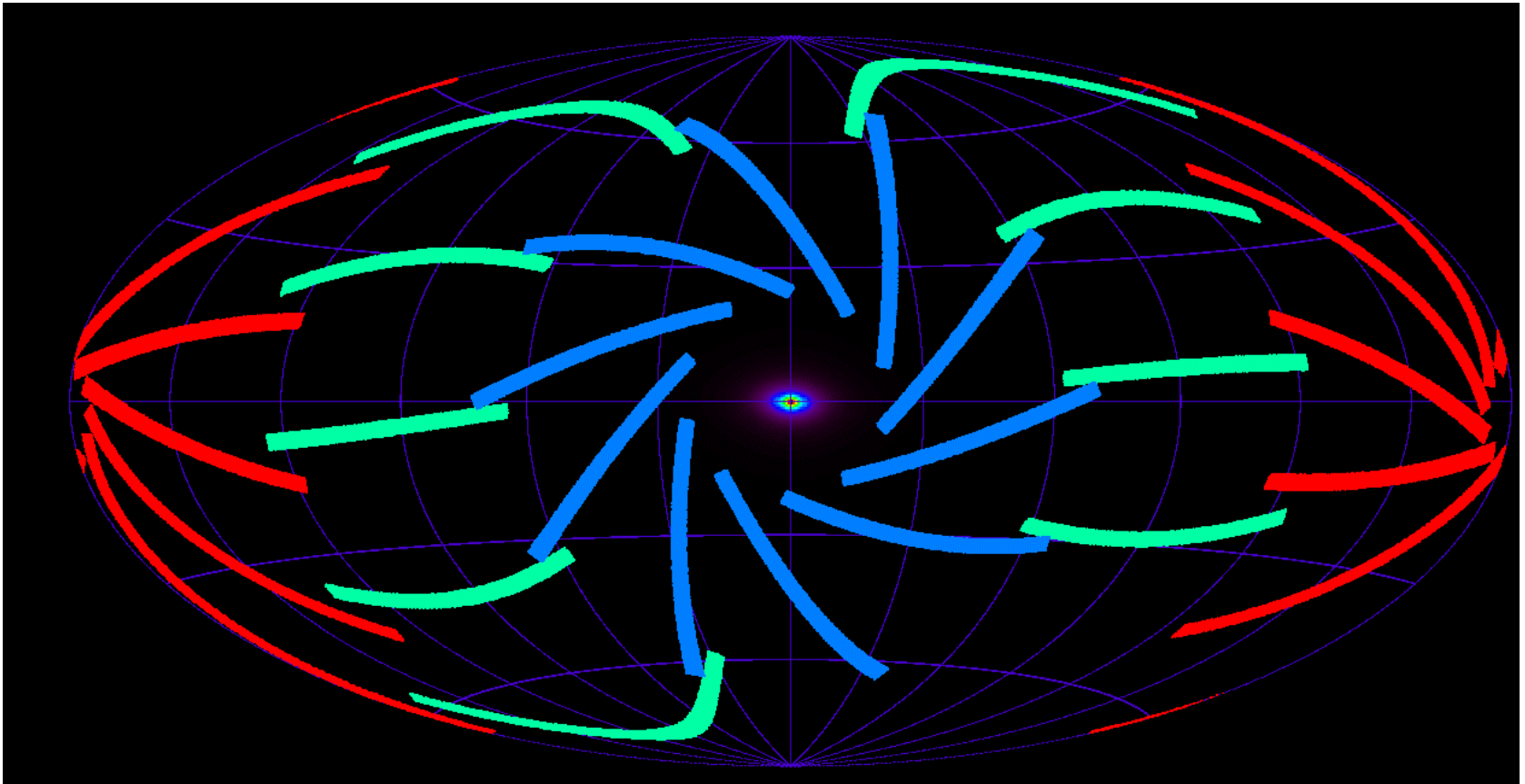
Cam1



Cam2

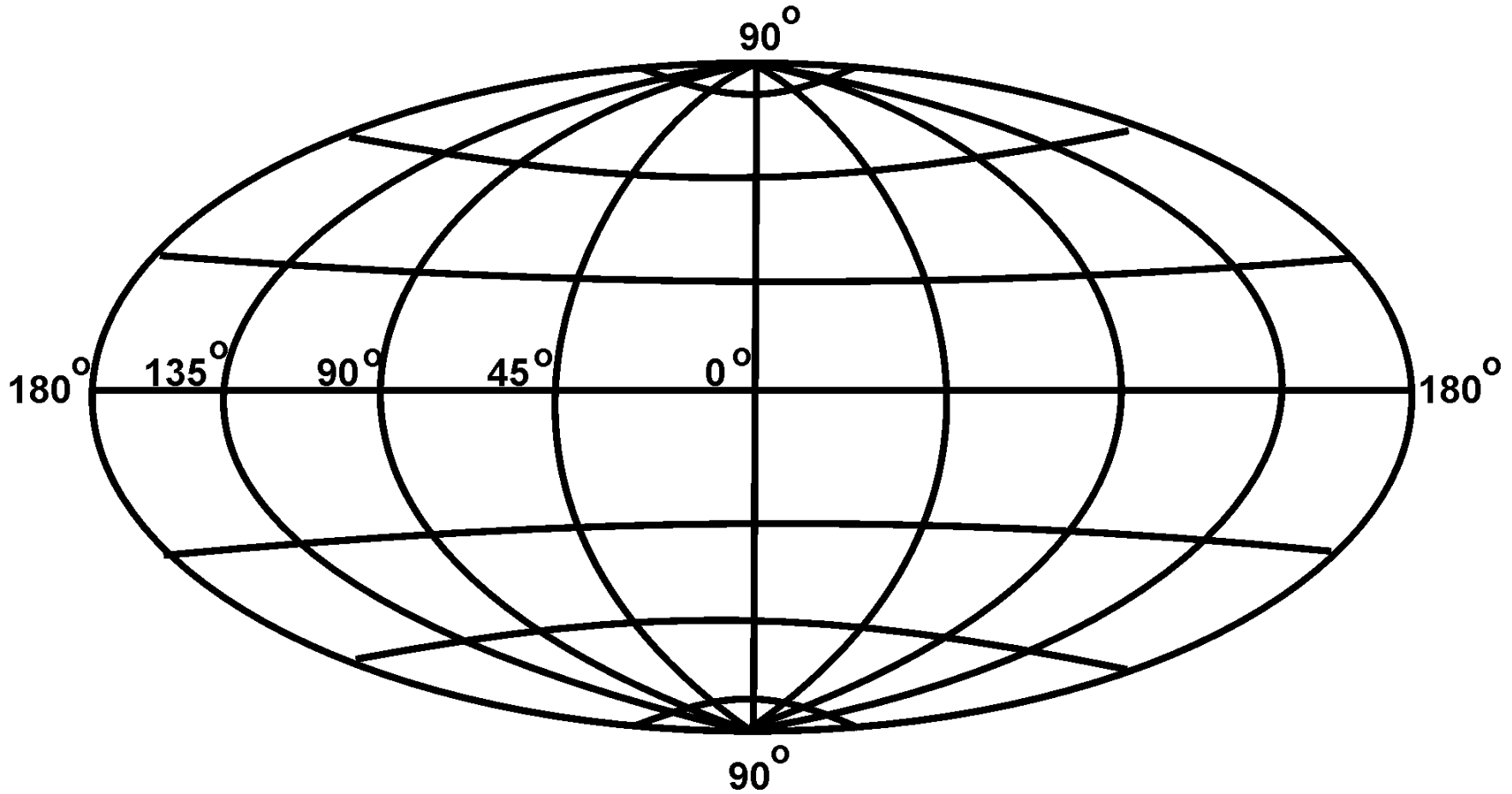
Frame Composite for Aitoff Map

Blue = Cam3; *Green* = Cam2; *Red* = Cam1

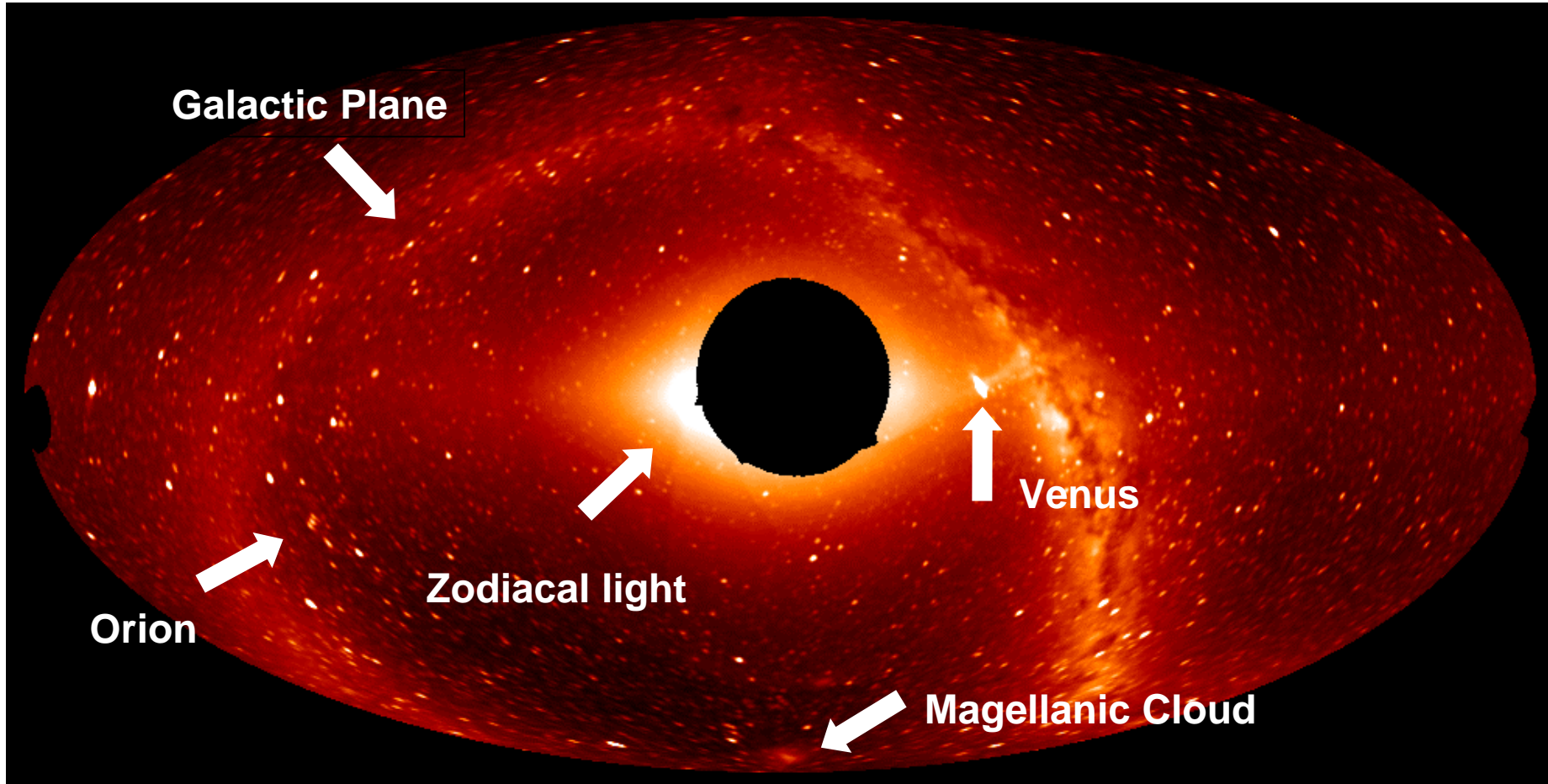


D290; 17 October 2003

Hammer-Aitoff Projection: “Standard” SMEI View

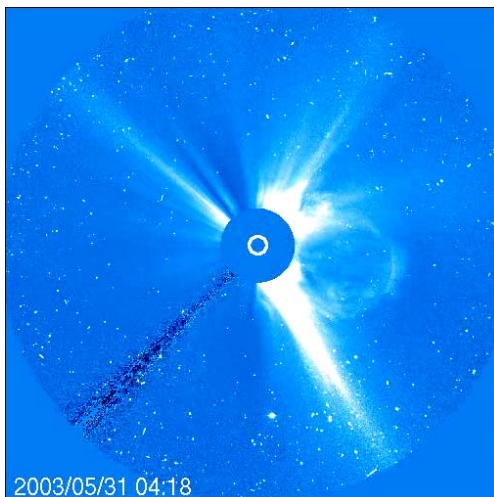
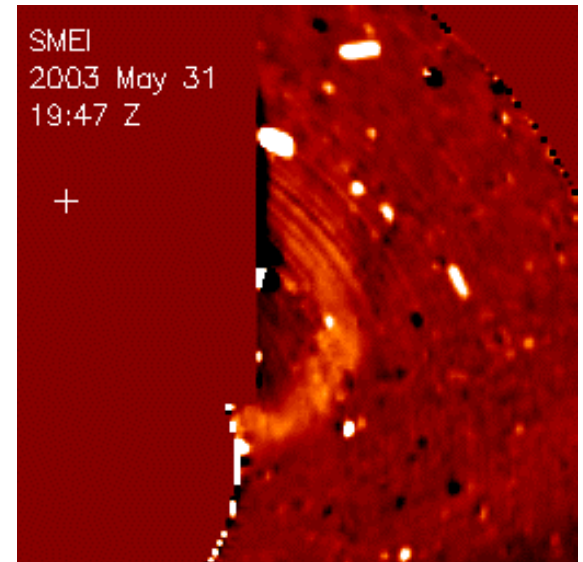
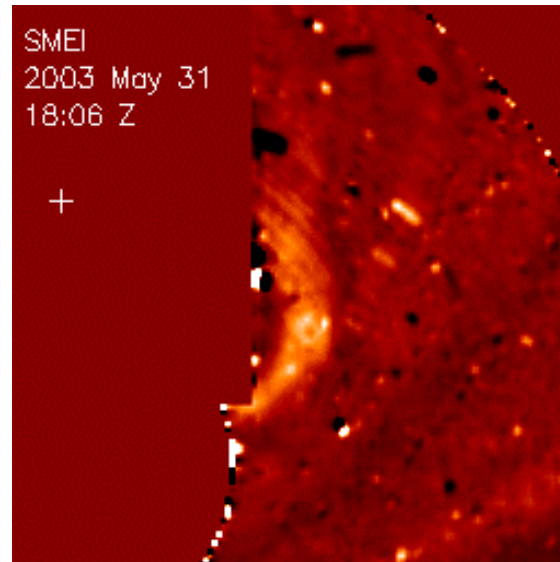
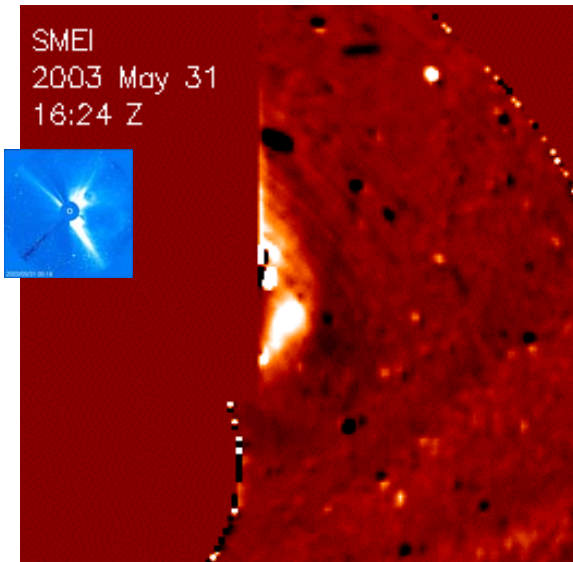


SMEI Composite All-Sky Image



March 2003

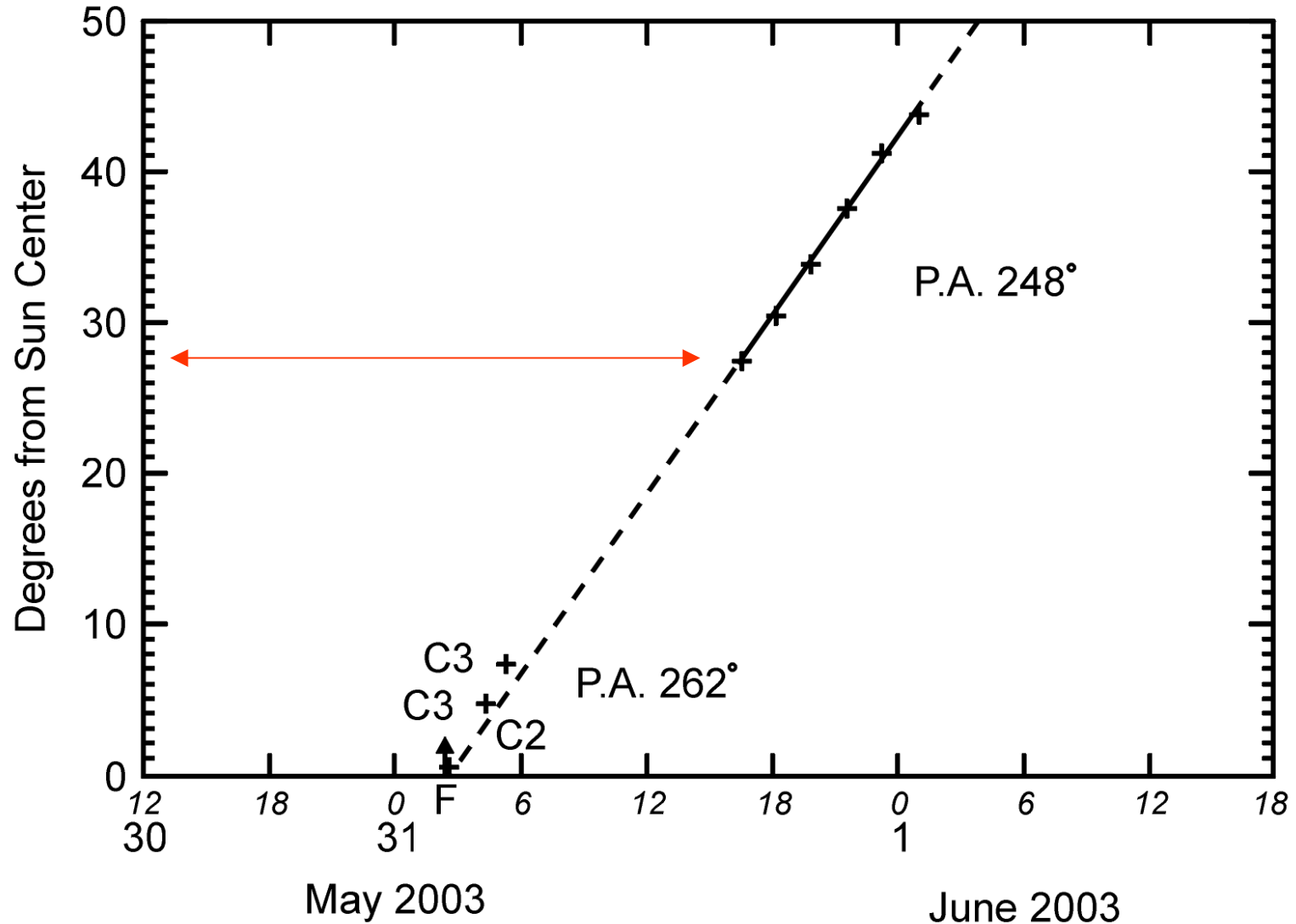
A Fast Limb CME



31 May 2003

**Speed: LASCO C3 → 1765 km/sec.
SMEI → ~1450 km/sec.**

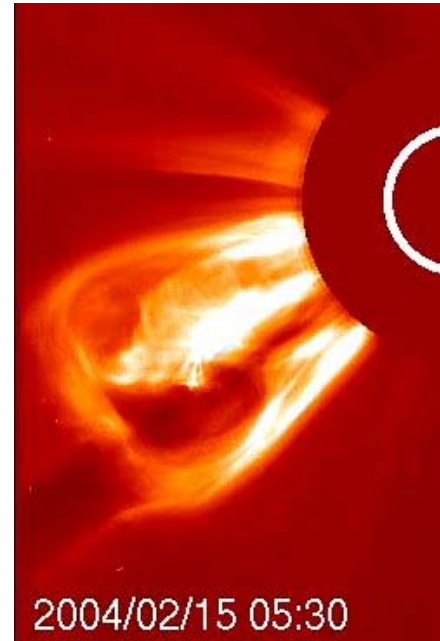
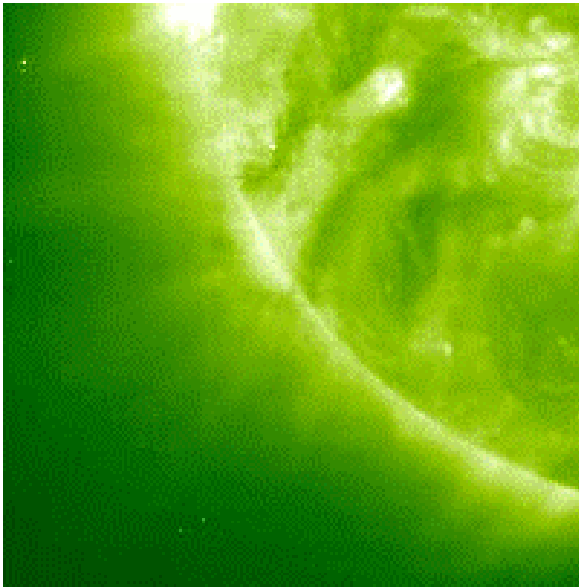
Distance-Time Plot of 31 May Limb CME



EPL/CME: Sun Surface to 35° Elongation

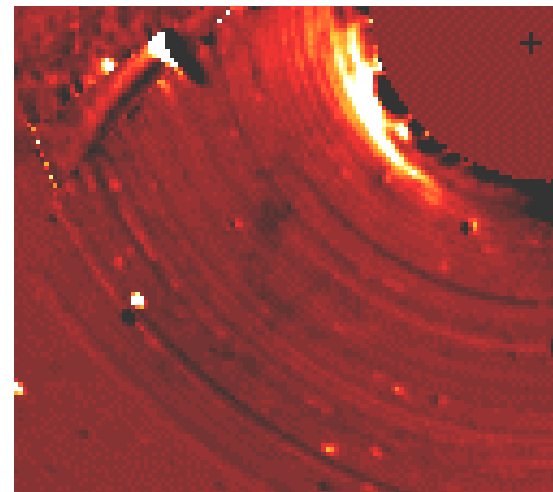
February 2004

EIT
15,00:00 –
10:00



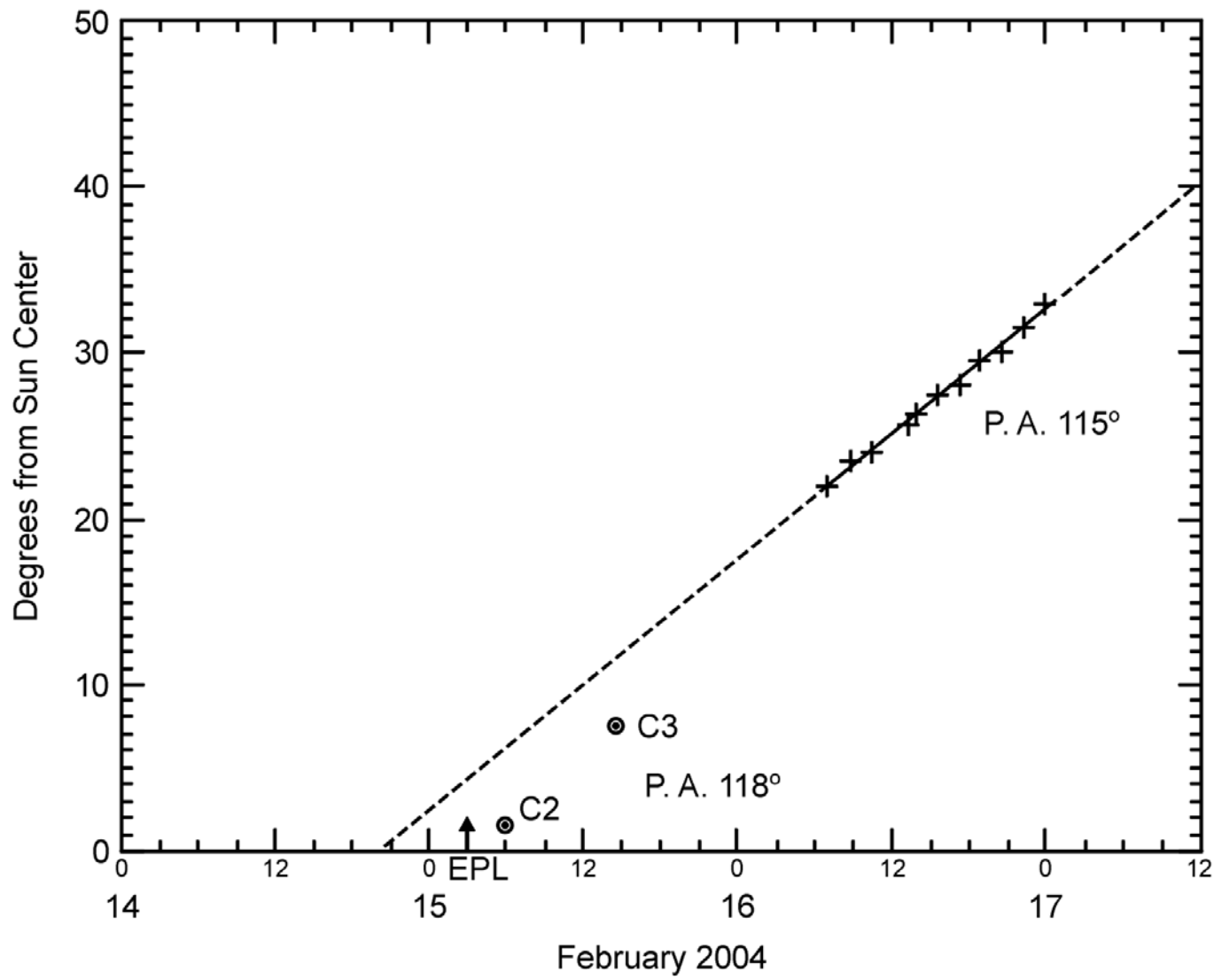
LASCO C2
15, 05:30

LASCO C3
15, 11:42

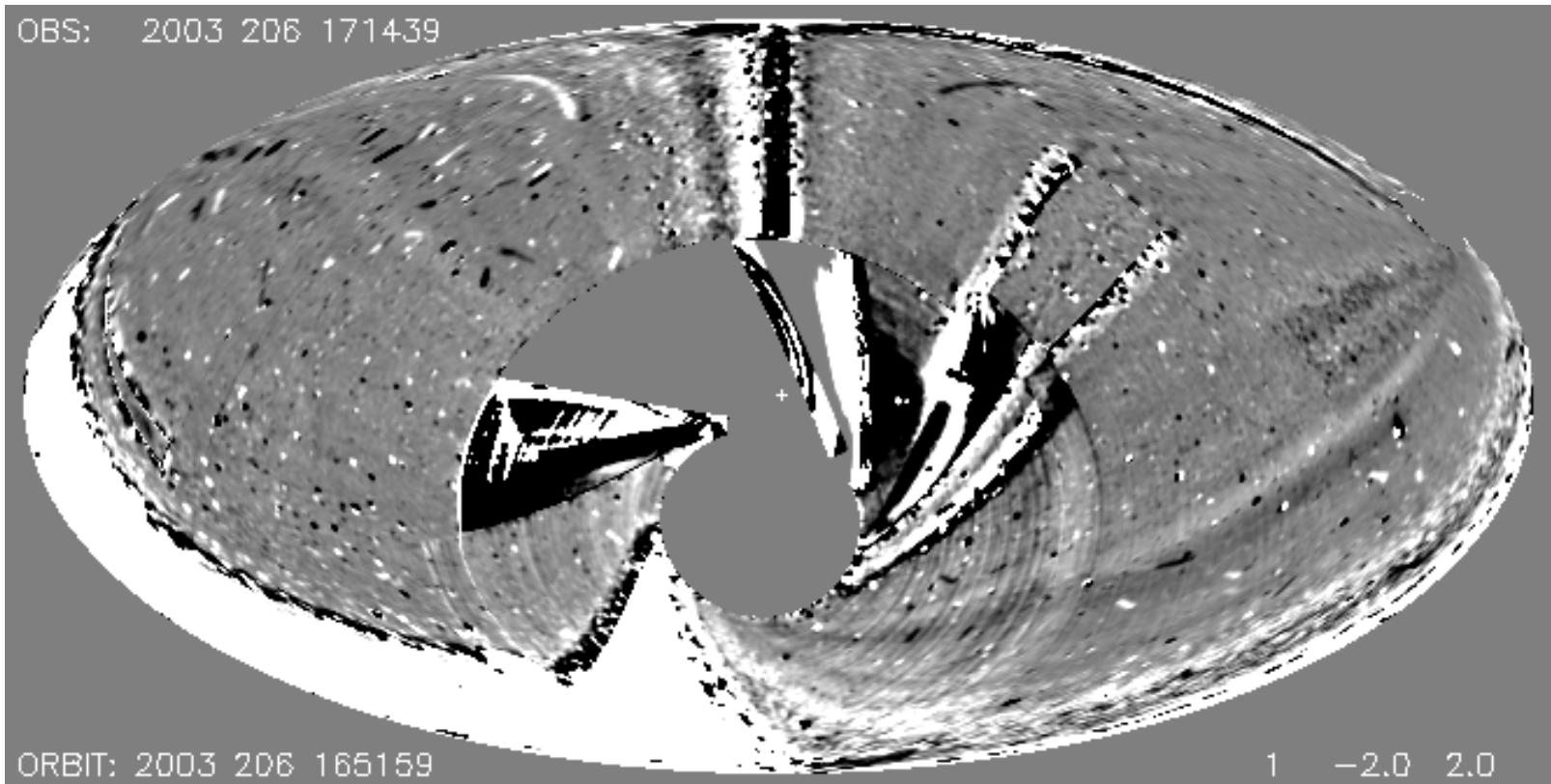


SMEI
16, 07:00 –
24:00

Distance-Time Plot of 15 Feb. 2004 Limb CME



Example Movie of SMEI CMEs



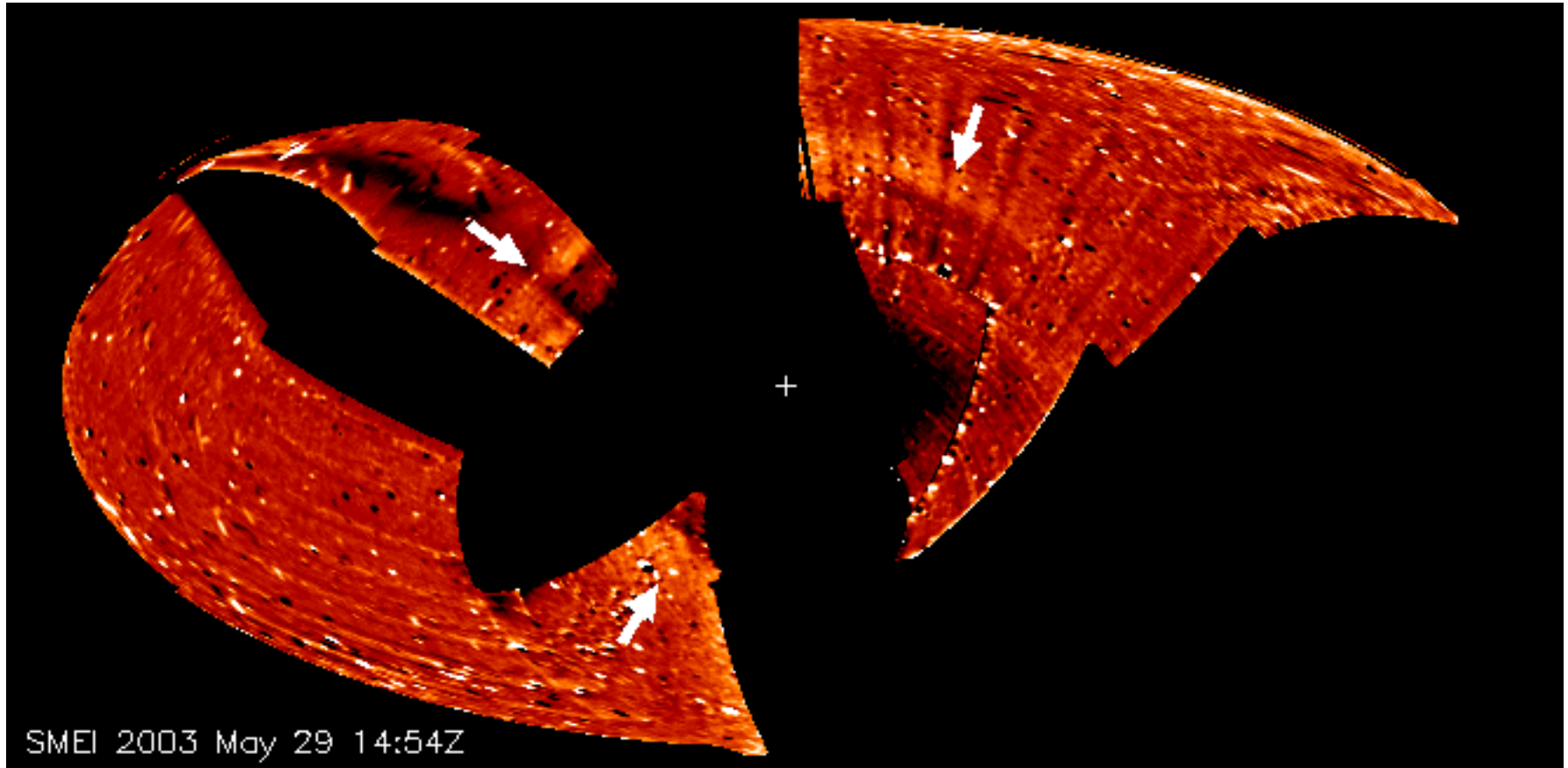
At least 4 separate CMEs!

Slow, bright, bent arc to NW (Cam 3 into 2; lasts 2 days!)

Faint, wide arc over NP

2 wide arcs to E & NW (NOT Halos! Cam 2 into 1)

First Earth-Directed CME Seen by SMEI 28-29 May 2003



Tappin et al., GRL, 31, 2004

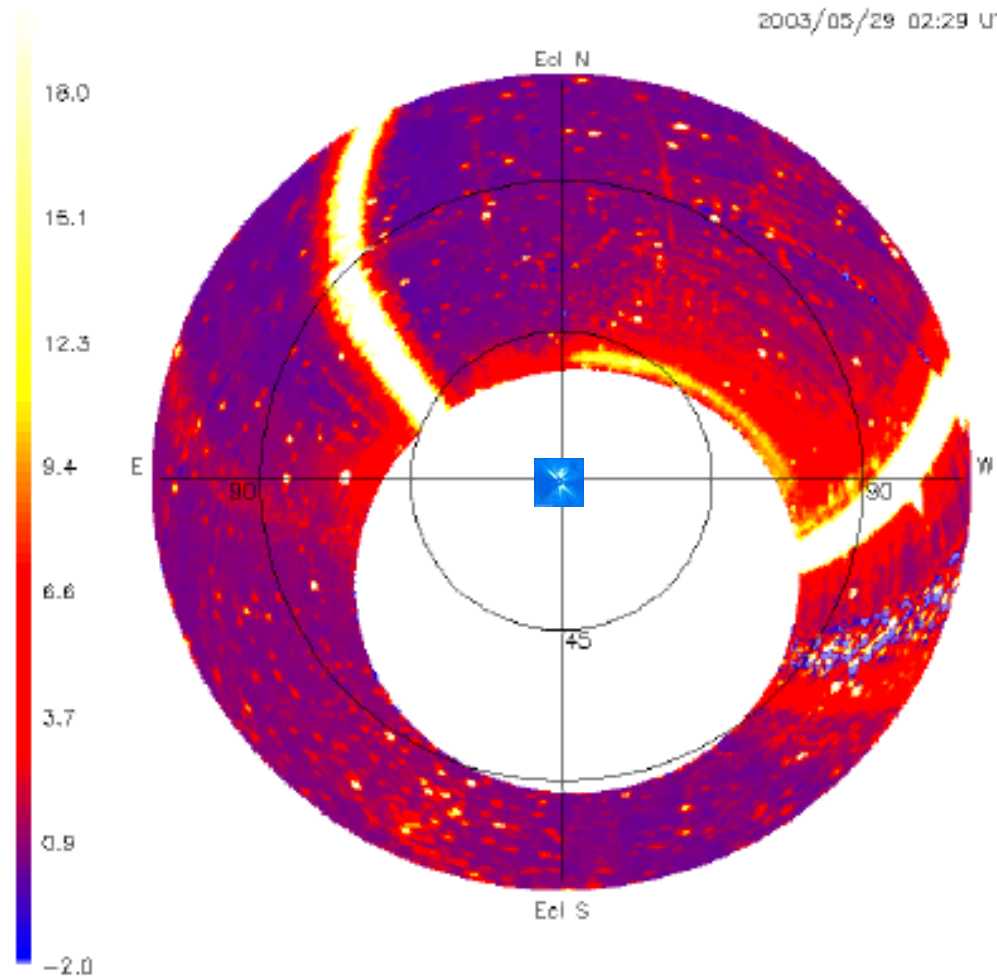
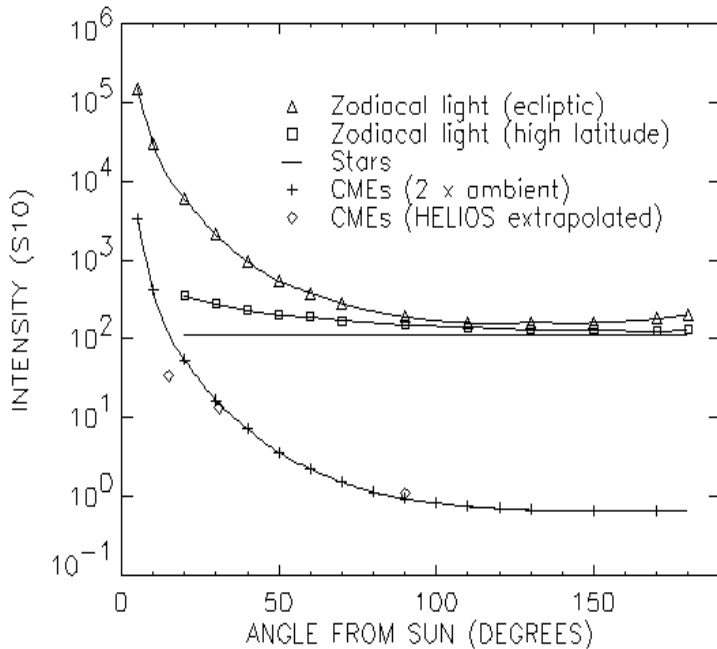
First Halo CME: The Movie



May 28-29 Halo CME hits Earth, causes Aurora & drives a Major Storm

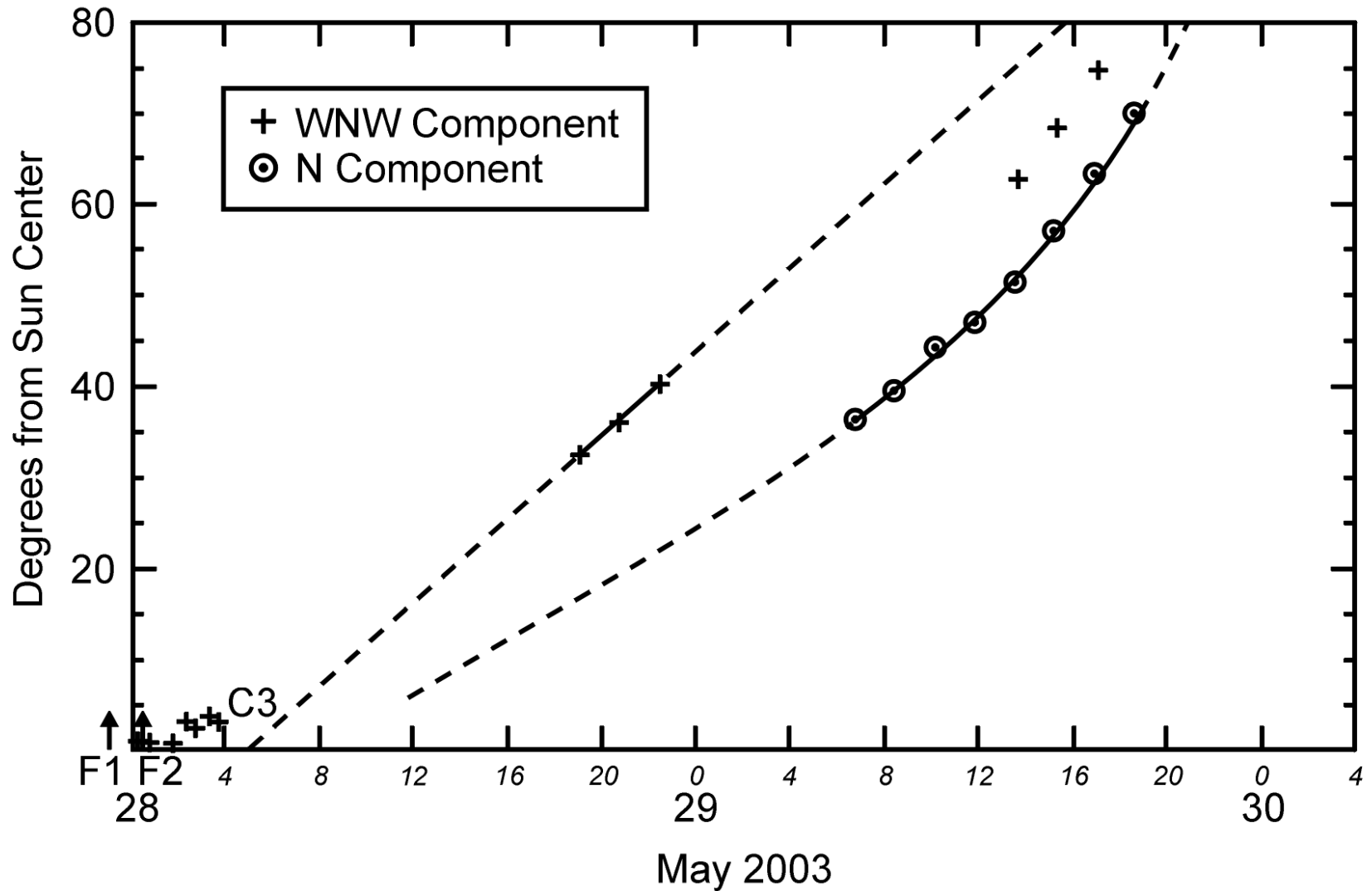
2003/05/29 02:29 UT

1 ADU \approx 0.55 S10



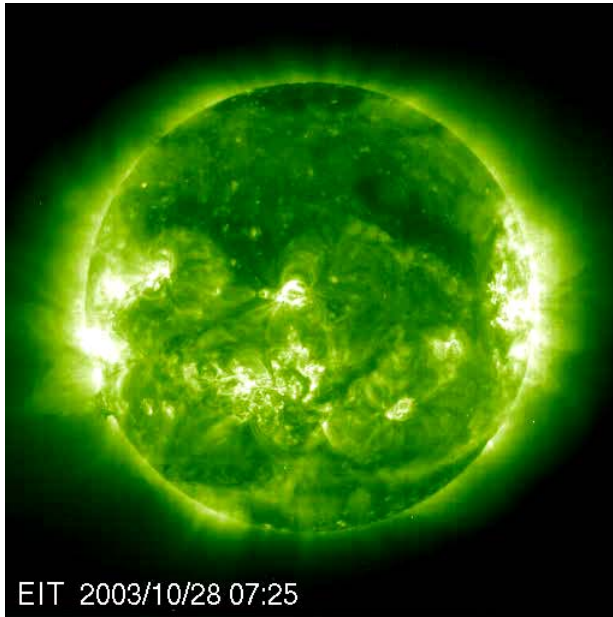
SMEI – inner camera; difference from an average base image.

Distance-Time Plot of May Halo CME

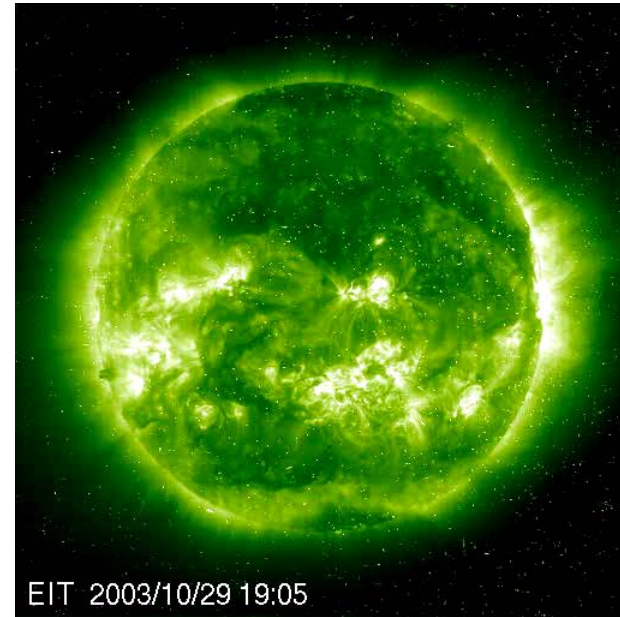


X17 Flare/CMEs X10

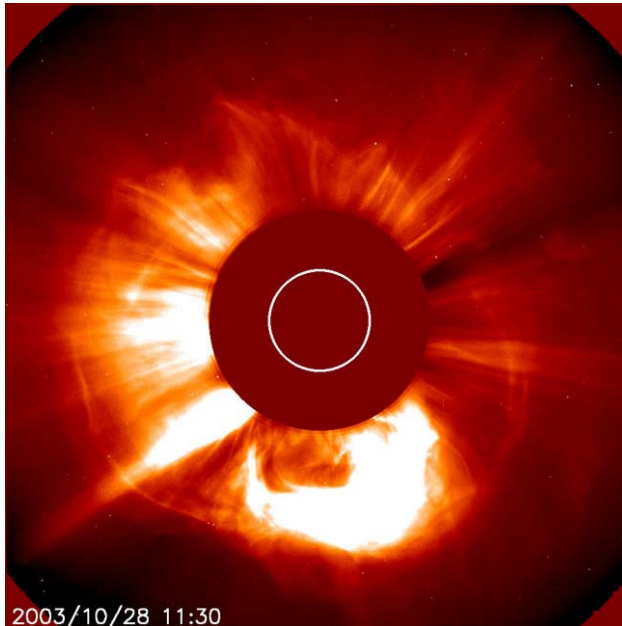
**Oct. 28
EIT 195A**



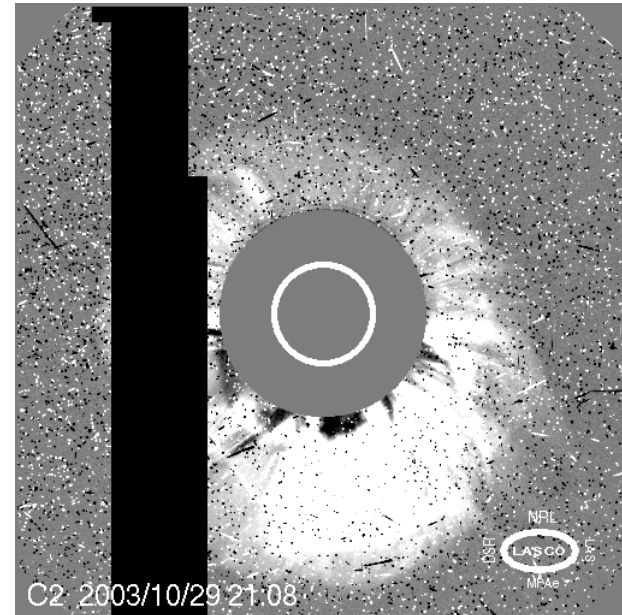
**Oct. 29
EIT 195A**



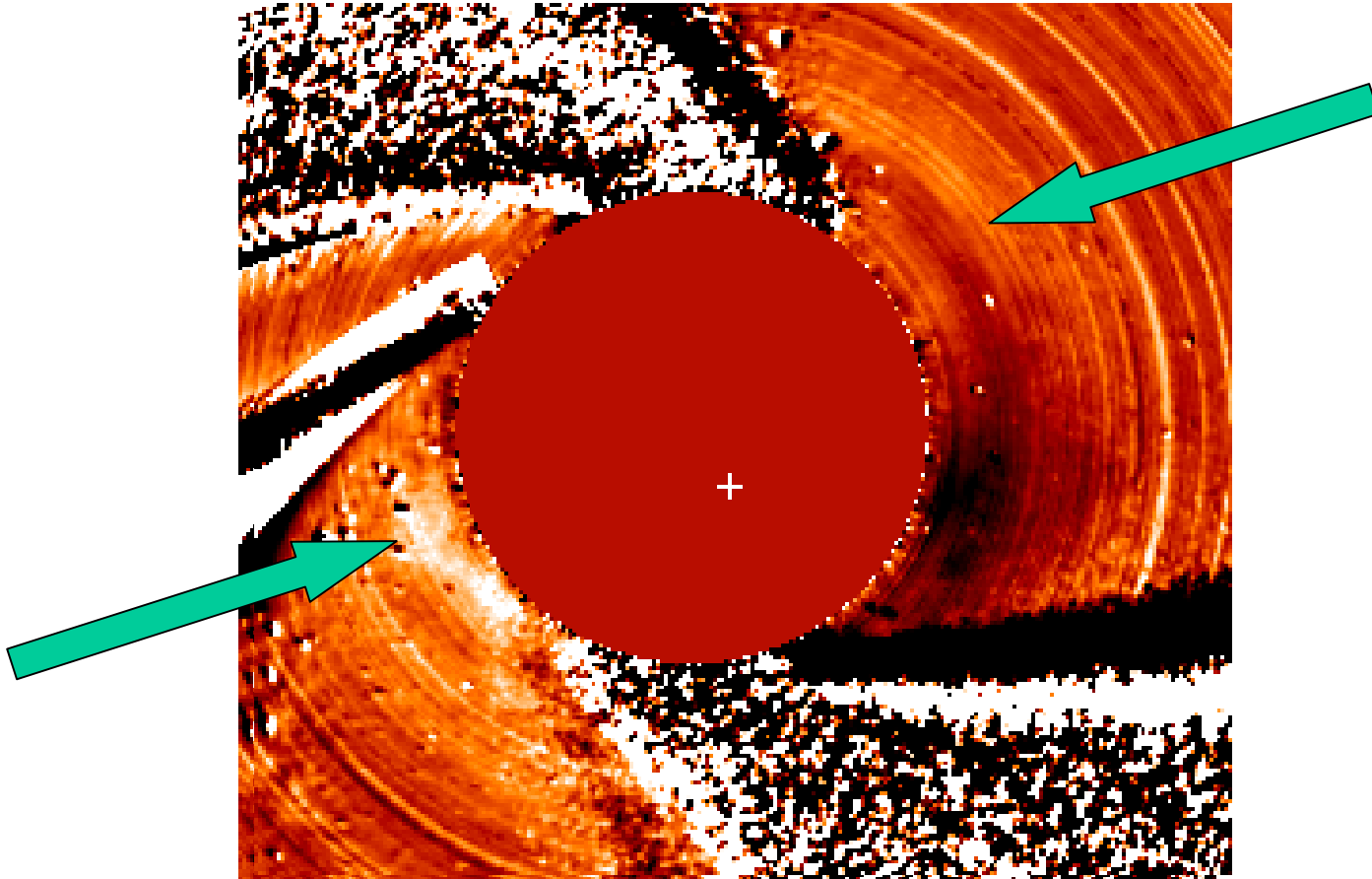
**Oct. 28
LASCO
C2**



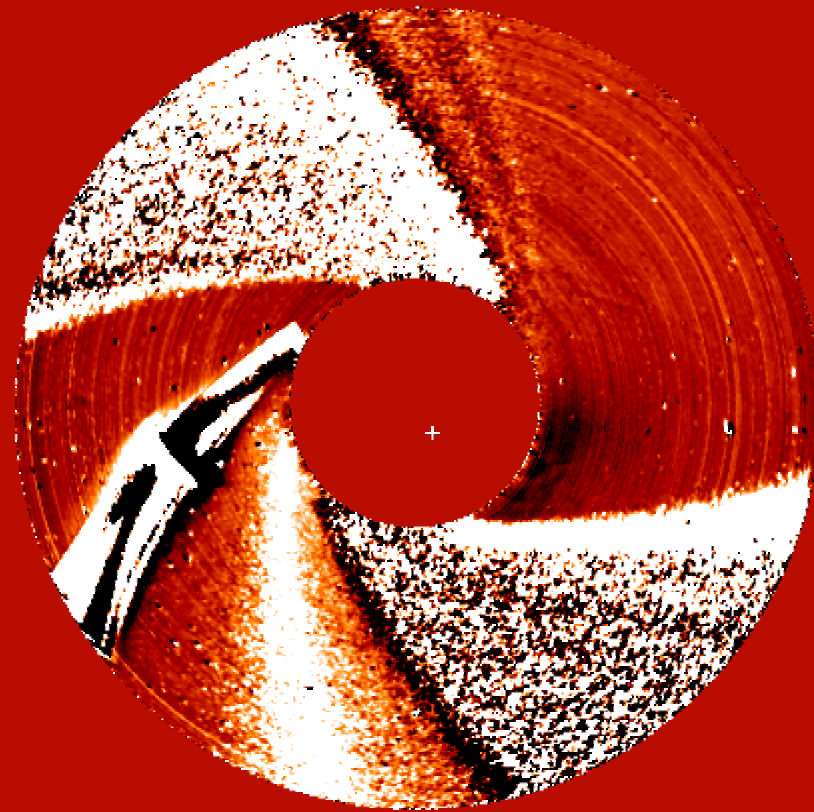
**Oct. 29
LASCO
C2
(Diff.)**



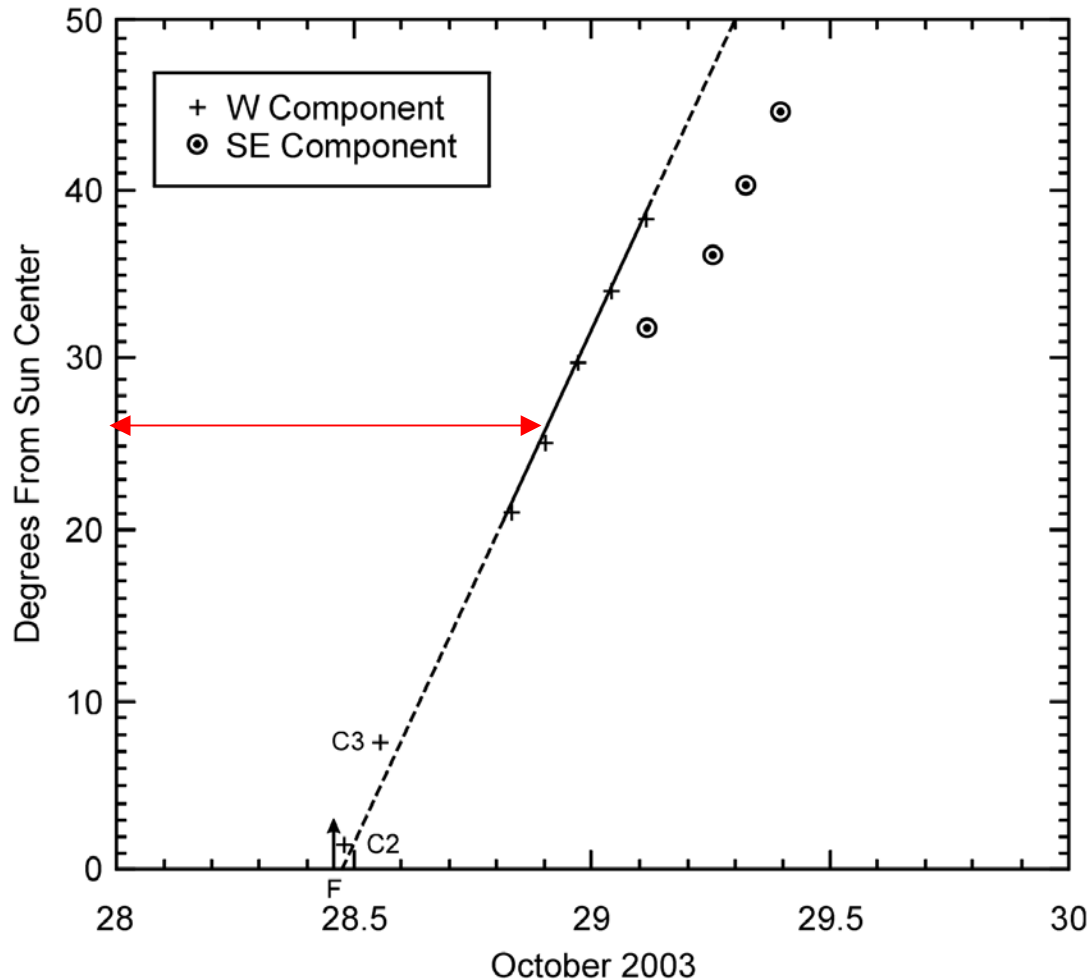
Oct. 28 Fast Halo CME seen by SMEI



Difference image of 2 parts of halo on Oct. 29, 02:10 UT.



Angular Distance vs Time of 28-29 Oct. Halo CME obs. by SMEI



Distance vs time plot of 2 parts of Oct. 28 CME in SMEI; F = flare onset, C2 & C3 = top of CME in SOHO LASCO coronagraphs.

Travel Times of 3 Geoeff. Halo CMEs

Date/Event 2003	Flare Onset at Sun (UT)	1 st SMEI Obs. (hours)	Shock at Earth (hr.)	Shock- SMEI (hr.)
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May 27-28 - X1, X4

23, 00 +19,31 +42 +23,+11

Oct. 22 - M4 >05:00 +37 +58 +21

Oct. 28 - X17 11:00 +9 +19 +10

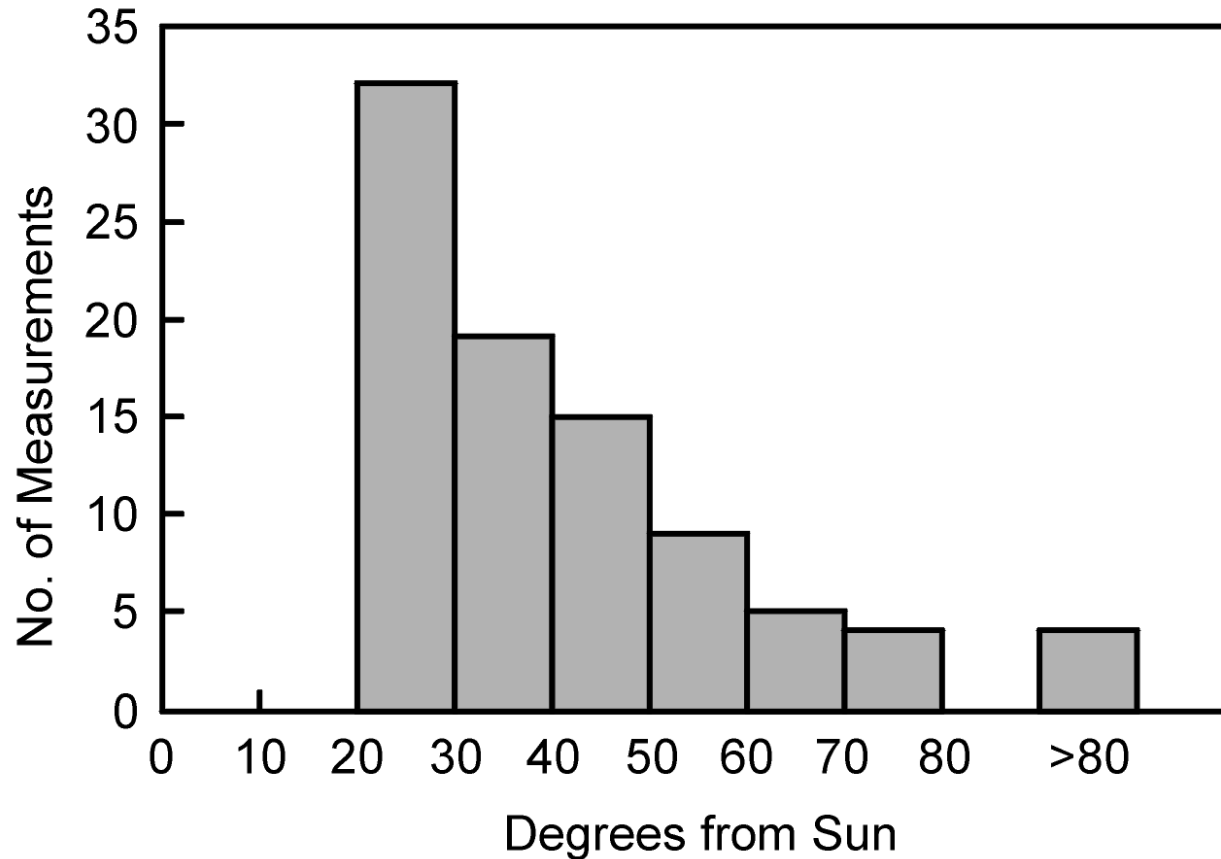
Oct. 29 - X10 21:00 (no data) +19.5 ----

Conclusion: SMEI first detected 3 Earthward CMEs 10 – 23 hr. before shock arrivals at 1 AU.

Summary of Early Results: SMEI CMEs

- ~100 CMEs Observed During First Full Year
375 total days – 62.5 no obs. days = 312.5 obs. days
Est. Occurrence Rate = **0.31 CMEs/day**
- Morphology: More structured nearer Sun (Cam 3) & broad arcs far from Sun (Cams 2 & 1)
- SMEI vs LASCO: ~ half of SMEI CMEs likely assoc. with LASCO CMEs. Detailed comparison to come.
- Brightness: Mean = 1.25 adu; Range = 0.2 - 6.0
Equiv. to **0.6 S10** units (Range **0.1 - 3.0**)
- Spans (detected): Mean **> 42°**; Range = 7 - 107
- Angular Speeds: Mean = **1.1°/hr.**; Range = 0.3 - 4.9
P-approx. Speeds: Mean = **482 km/sec**; Range = 51 - 1611

Angular Distance when CMEs First Detected by SMEI



So, most CMEs are first observed 20-50° from Sun.

SMEI Data

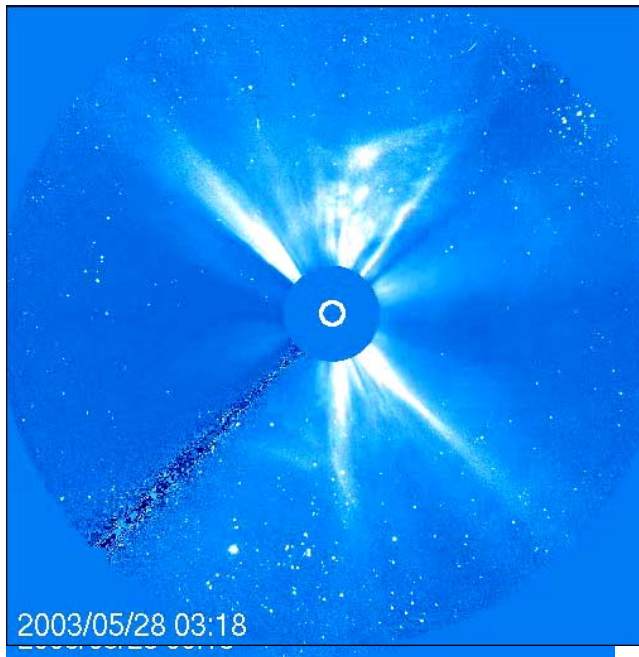
Required Processing

- Remove cosmic rays & hot CCD pixels
- Remove stars: 2 methods being used
- Remove a zodiacal cloud model
- Normalize radial brightness

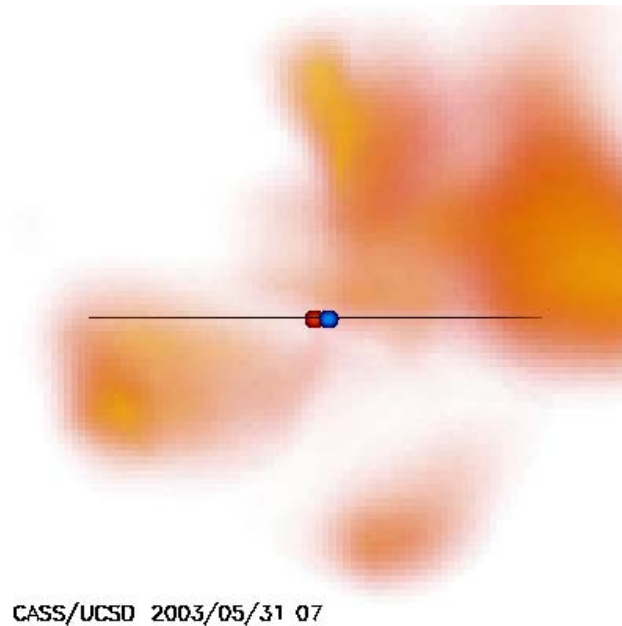
Final Archives; End Products

- Heliospheric Sky Maps
- 3-D Model Reconstructions
- Zodiacal Cloud
- Stellar Time Series: Novae, Variable stars,
- Planetary transits
- Comets & Near-Earth Objects

IPS Modeling: 25 May – 3 June 2003



LASCO C3



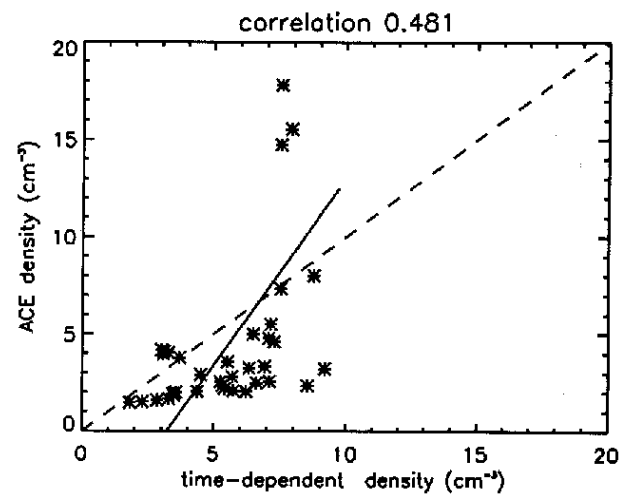
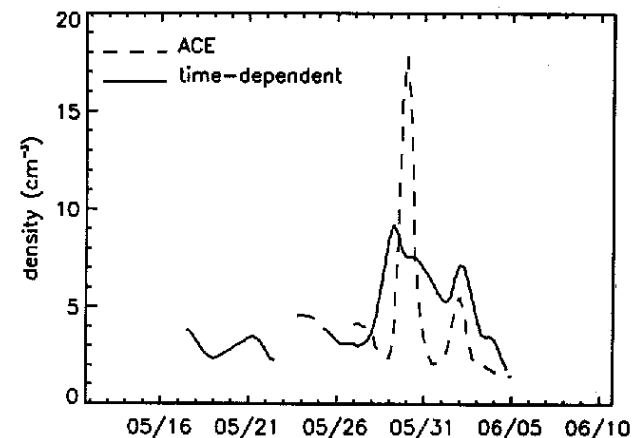
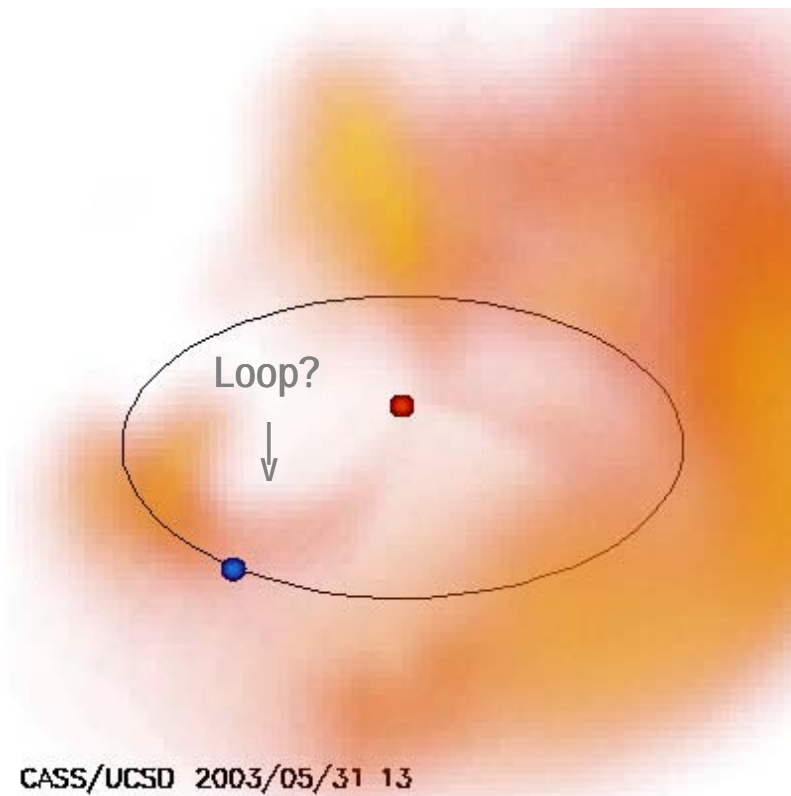
3D Reconstruction IPS

Left: Halo CME observed in LASCO C3 on May 28

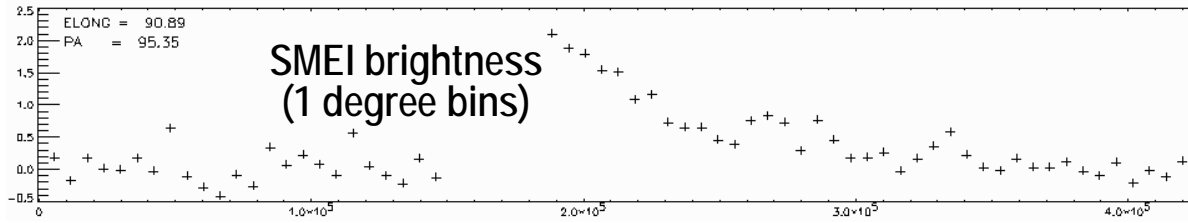
Right: As "observed" in IPS reconst. image on May 31 from 3 AU behind Earth

IPS Modeling: 25 May – 3 June 2003

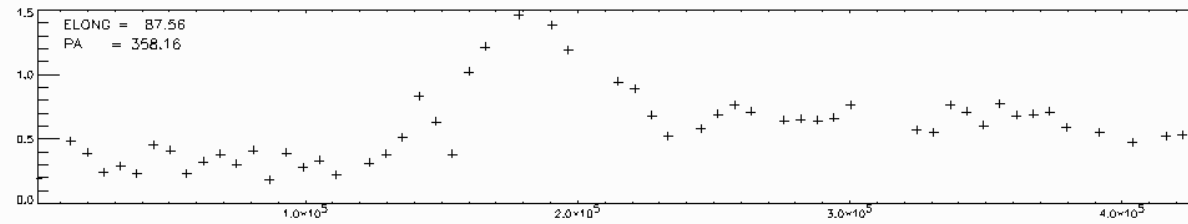
Time-Dependent Heliospheric 3D Reconstruction Analysis



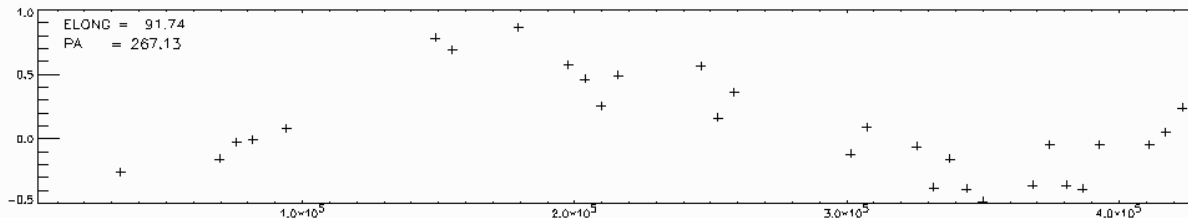
May 28-31 SMEI Brightness Time Series



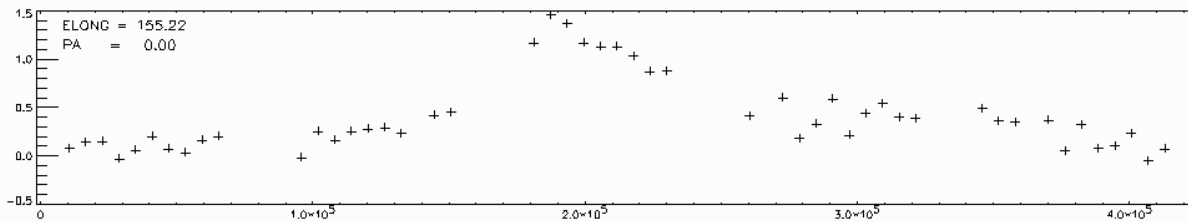
Elong. = 91°



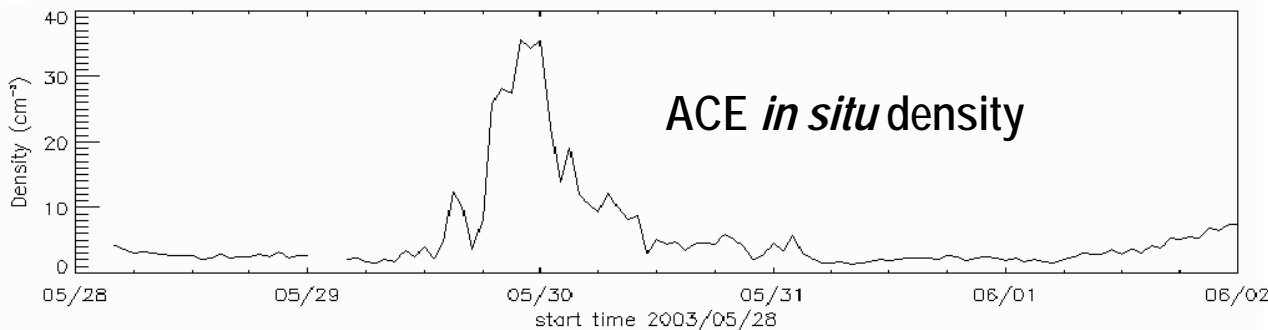
Elong. = 87°



Elong. = 92°



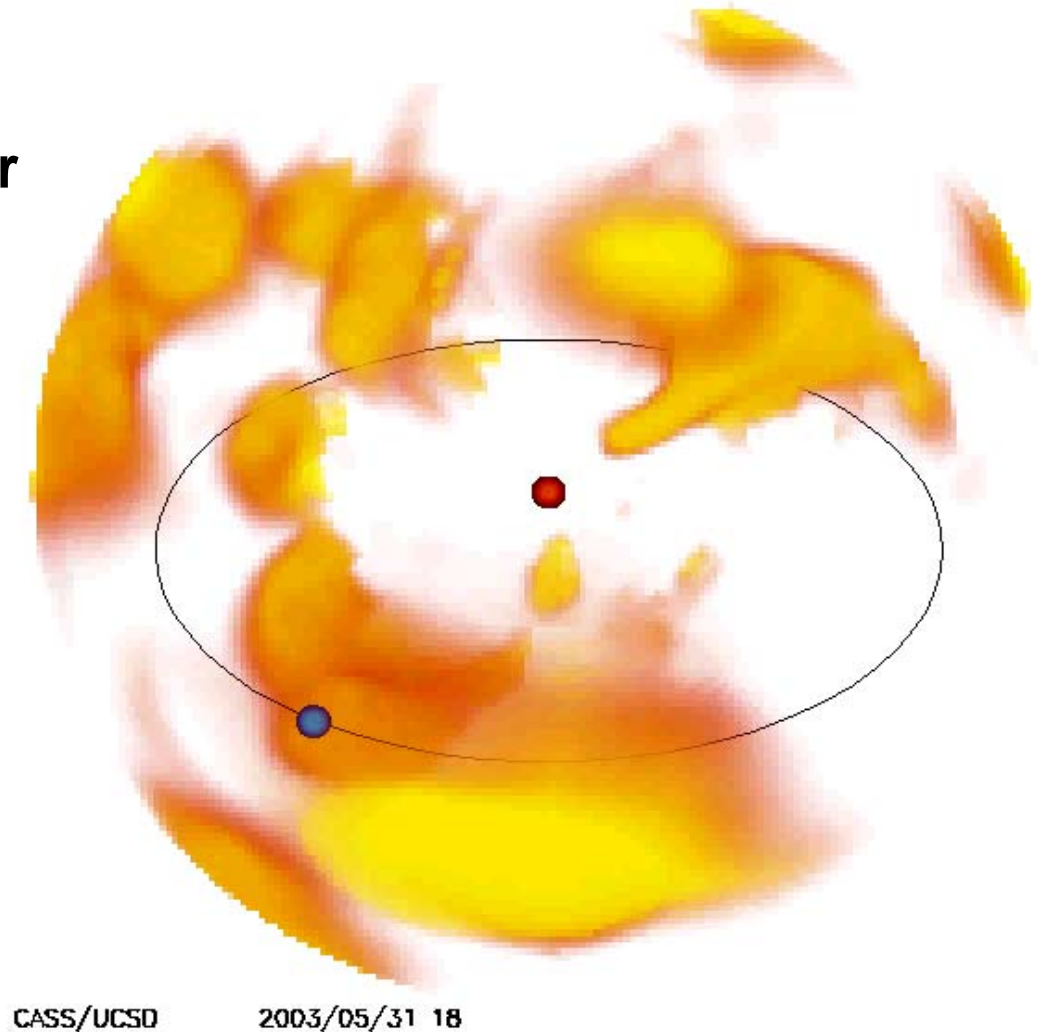
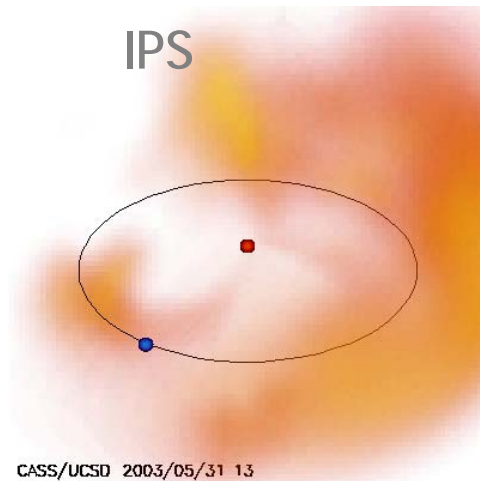
Elong. = 155°



CMEs in 3D using Reconstruction

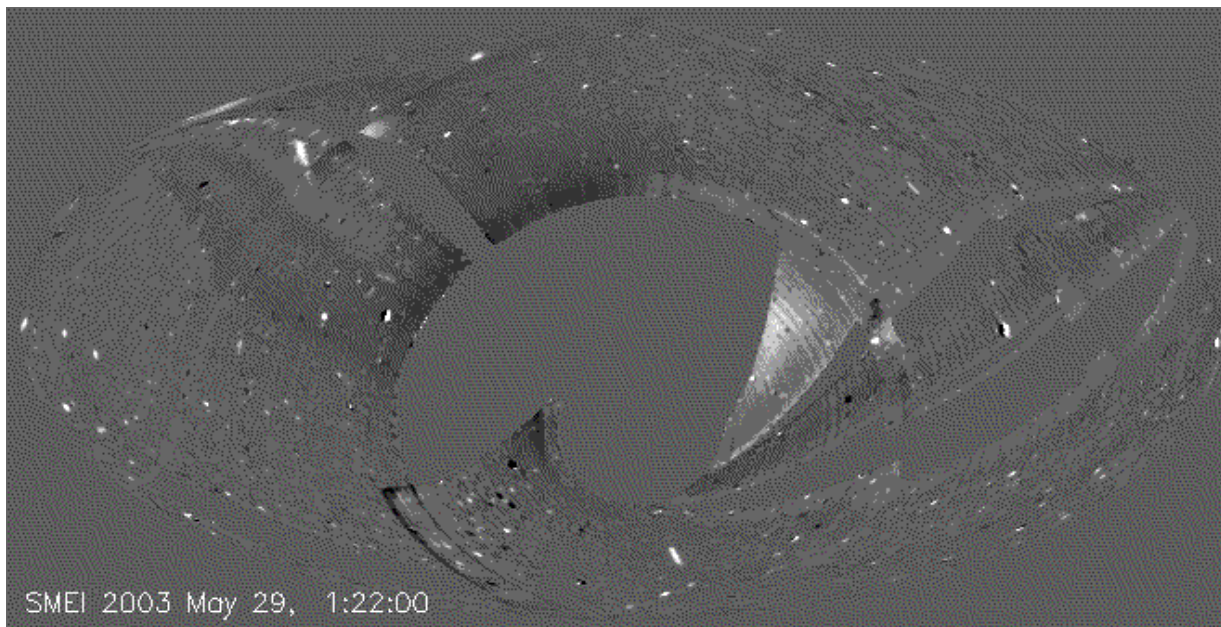
SMEI

SMEI data with model of solar wind kinematics used to reconstruct 3D structure of CMEs & other regions of enhanced density.

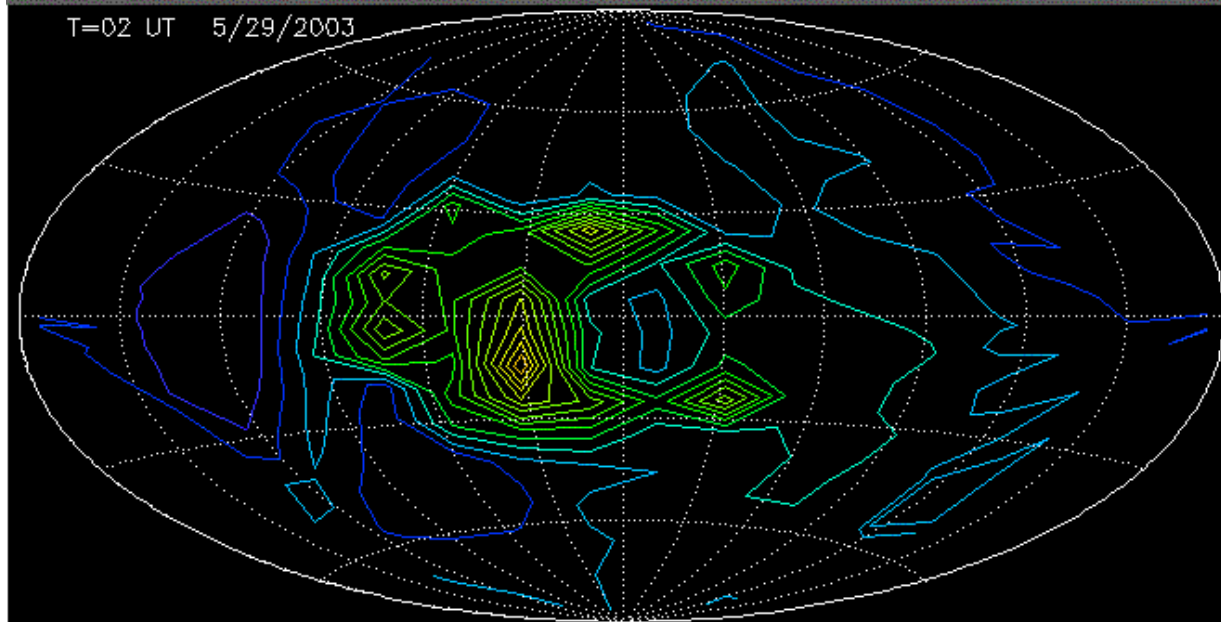


Comparison SMEI & HAF Model: 29 May 03

SMEI



**HAF
Model**



*Courtesy:
Deehr, Sun
& Fry*



Conclusions



- **SMEI has observed ~100 CMEs in 1 year.**
Rate: 0.3/day; Brightness: ~1 S10; Spans: >42°;
Angular speed: 1.1°/hr.; P-speed: 482 km/sec.
- **CMEs more structured near Sun (like in LASCO);
broad & arc-like far from Sun.**
- **SMEI detected 3 geoeffective halo CMEs at ~1/3 of
Sun to Earth distance.**
 - Proof of principal that SMEI can detect even fast
Earthward CMEs < 1 day before arrival.
 - New tool for early warning of storms.
- **SMEI also has detected a comet, asteroids & auroral light**
- **Future Analyses & Collaborations:**
Improved Calibrations & Reprocessing
Comparisons: LASCO, SWAN, WAVES, Ulysses, etc.
3D Reconstructions of CMEs & Corotating Structures
Space Weather modeling