CMEs OBSERVED IN THE HELIOSPHERE BY THE SOLAR MASS EJECTION IMAGER (SMEI)

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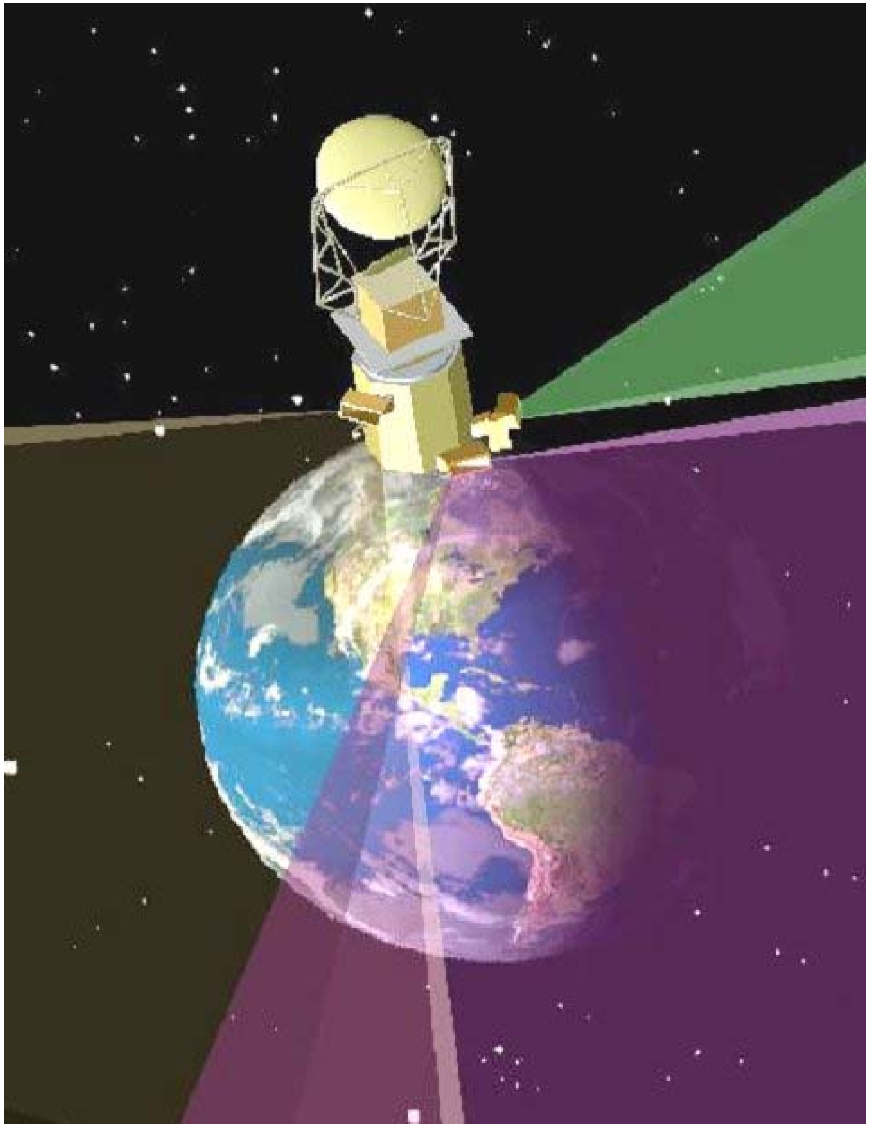
- **Heliospheric Mapping**
- **Search Criteria & Data Products**
- **Types & Characteristics of CMEs**
- **CME Studies & Results Summary**
- **SMEI + STEREO + Solar-B**

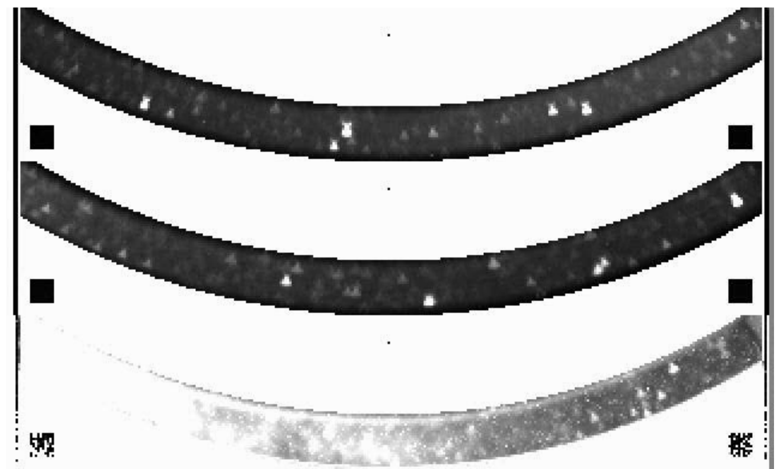
SMEI Fields of View



Cam1

Cam 3

Cam2



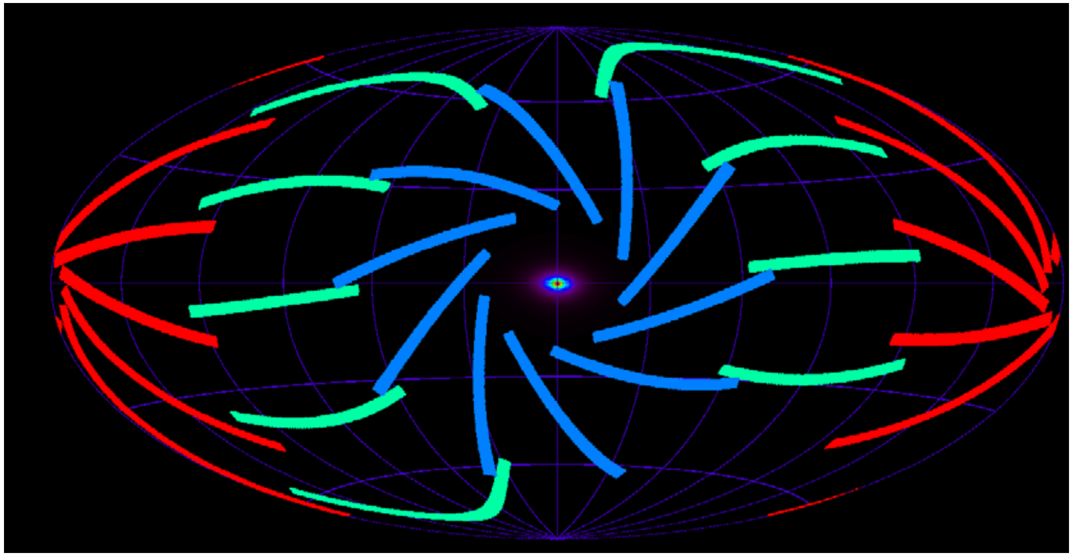
C1

C2

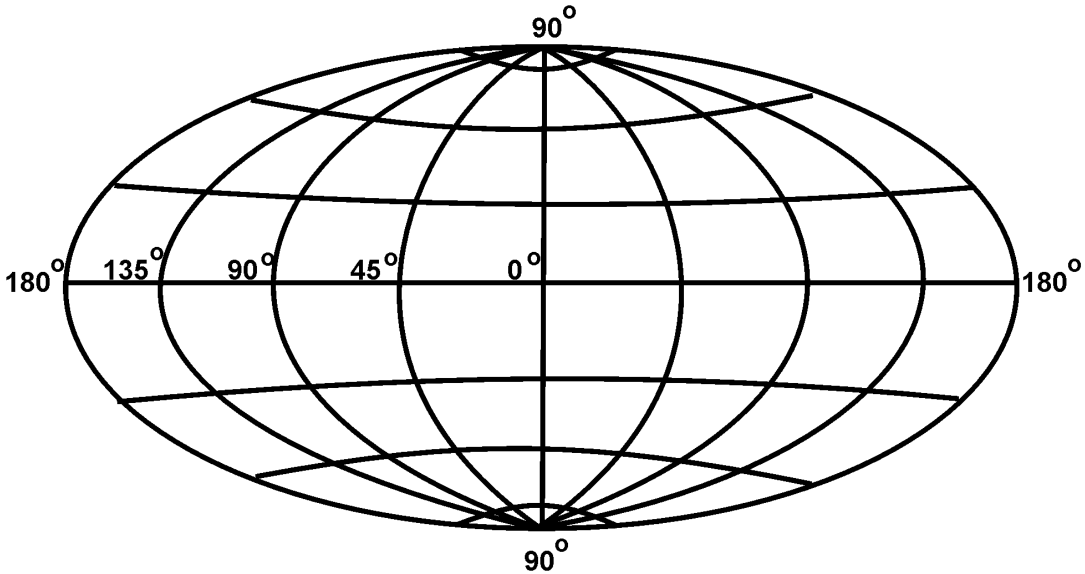
C3

Frame Composite for Hammer-Aitoff Projection: the "Standard" SMEI View

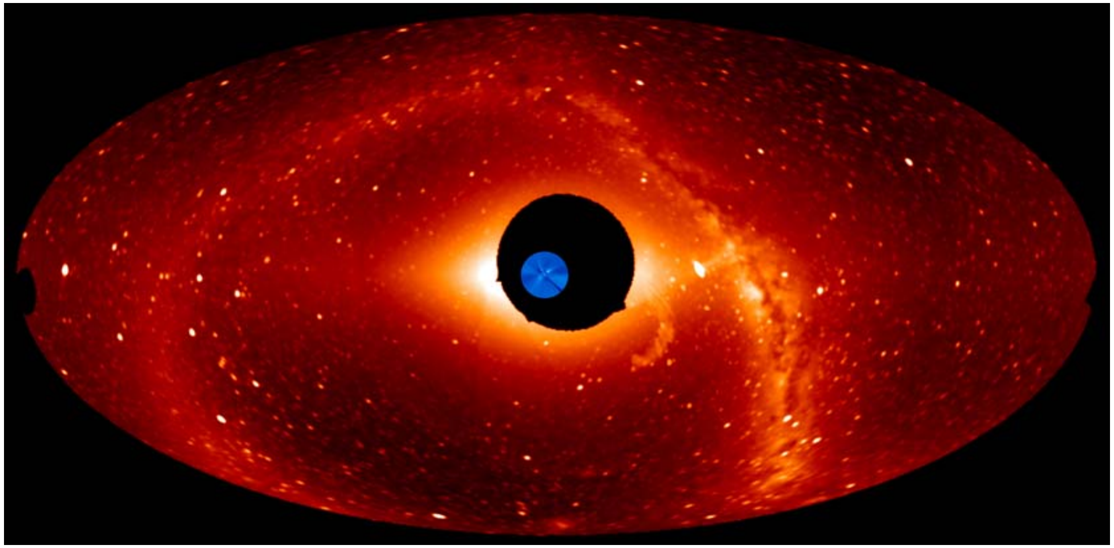
Cam 3
Cam 2
Cam 1

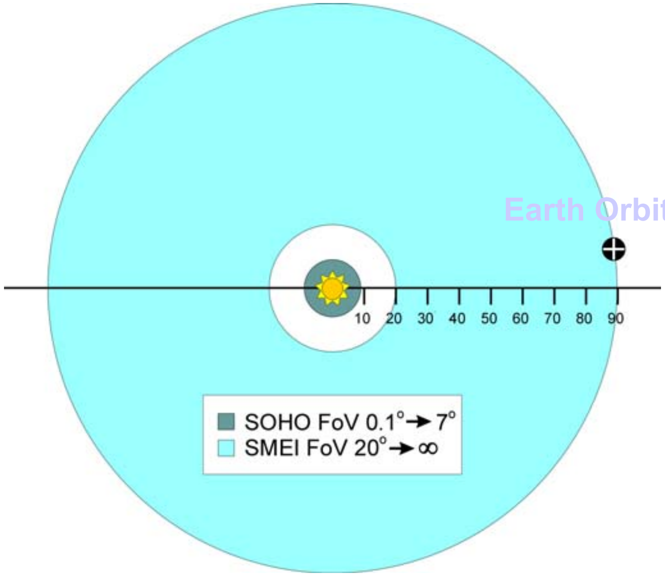


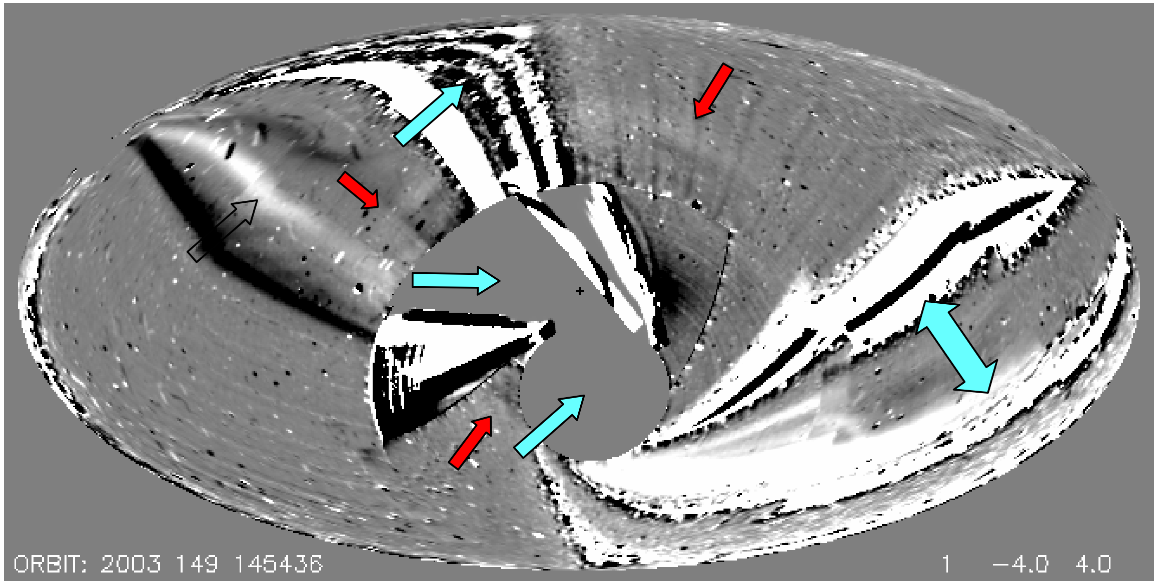
Every 30th camera frame during one orbit shown



SMEI Aitoff View & LASCO Comparison







Left: SMEI composite all-sky image with LASCO coronagraph field (blue) overlaid and CME superimposed. Top: SMEI and LASCO fields overlaid.

Red arrows - Earth-directed CME.

Blue arrows - obscured data from particle enhancements incl. SAA, auroral light, zone of exclusion and shuttered areas.

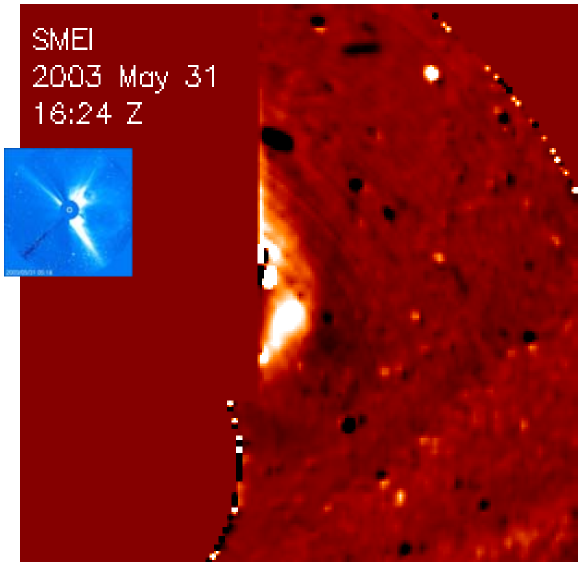
Search Criteria & Data Products: SMEI CMEs

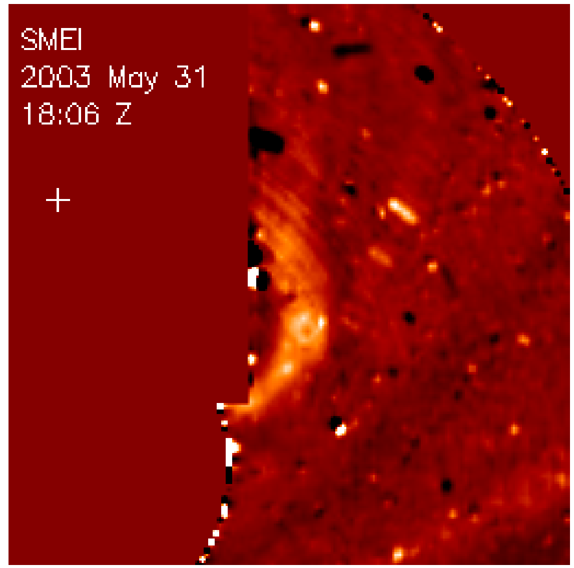
- Search uses near-real time processed Aitoff all-sky maps
  - Orbital difference movies
- Observation period searched:
  - 6 February 2003 – end August 2004
  - Statistical study over first 1.5 years
  - CME list being updated thru present
- Data Products:
  - Event files of images of each CME
  - Movies of each CME
  - File of comments for each CME
  - Summary event list

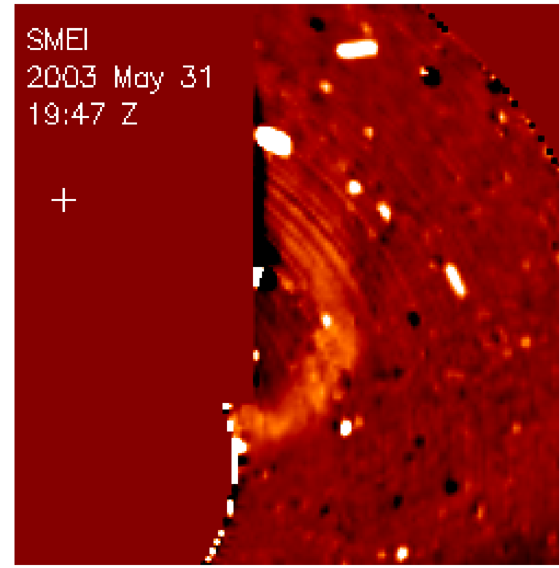
Categories by Fractions of CMEs Observed by SMEI

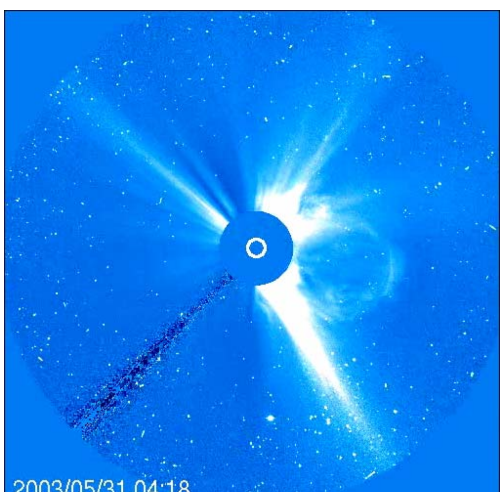
A) Limb CMEs	50%?
B) Erupting prominences with CMEs	>4% (>6)
C) Multiple CMEs	25%
D) Distant wide arcs	~30%
E) Concave-outward V-shaped CMEs	3% (4)
F) Earthward ("halo") CMEs	~30%

(A) A Fast Limb CME







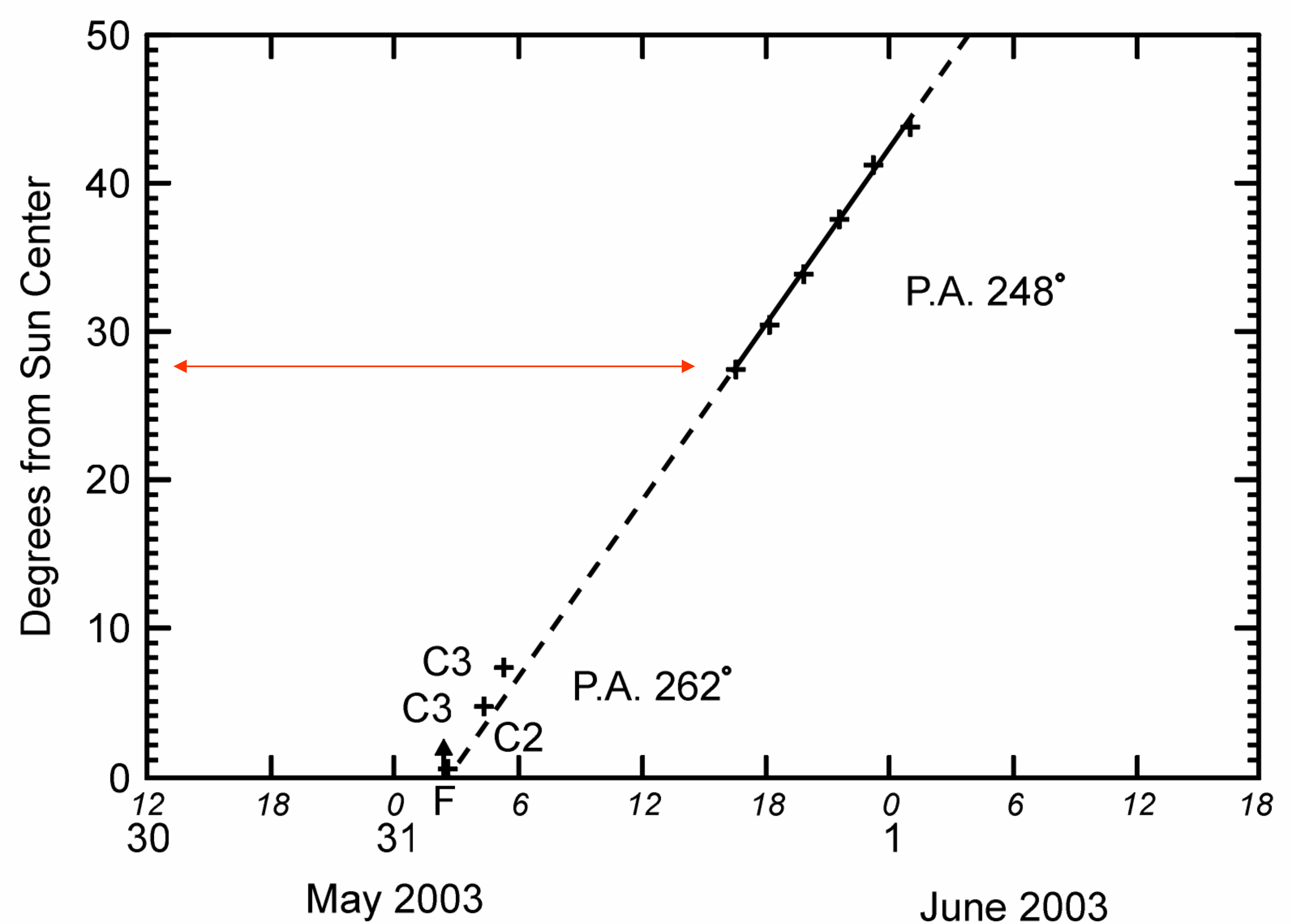


31 May 2003

Speed: LASCO C3: 1765 km/s

SMEI: ~1450 km/s

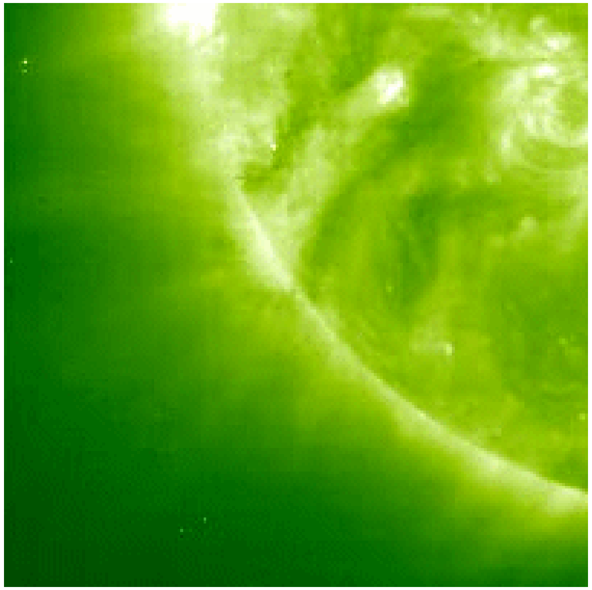
Distance-Time Plot of 31 May Limb CME

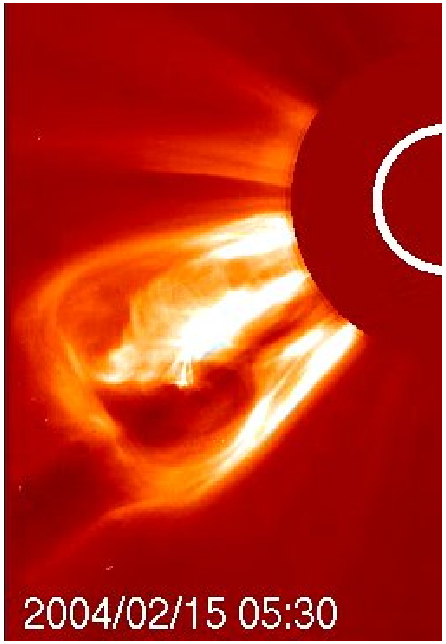


(B) An EPL/CME: Sun Surface to 35° Elongation

February 2004

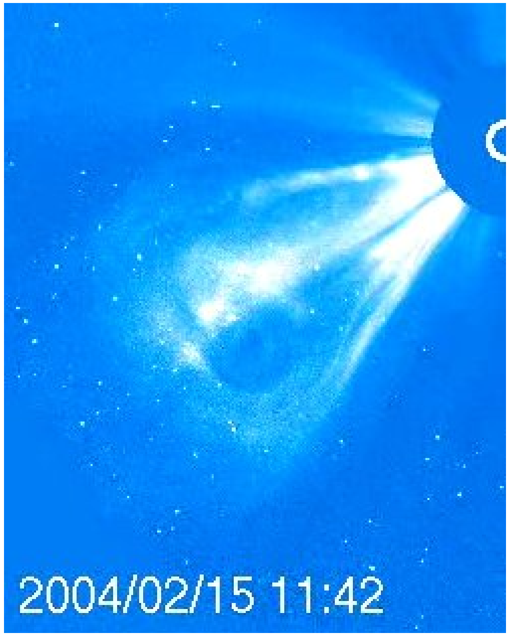
EIT
15, 00 – 10

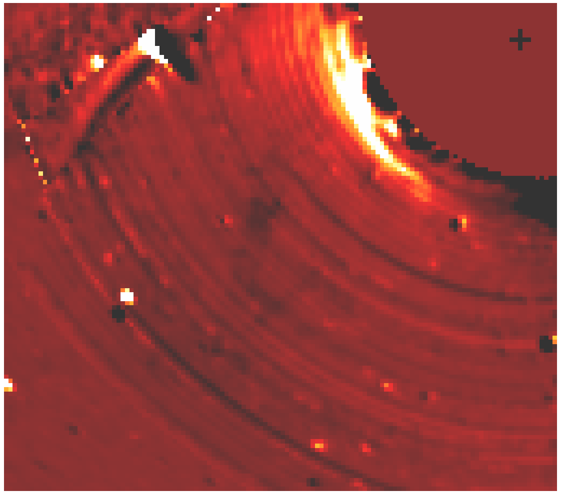




LASCO C2
15, 05:30

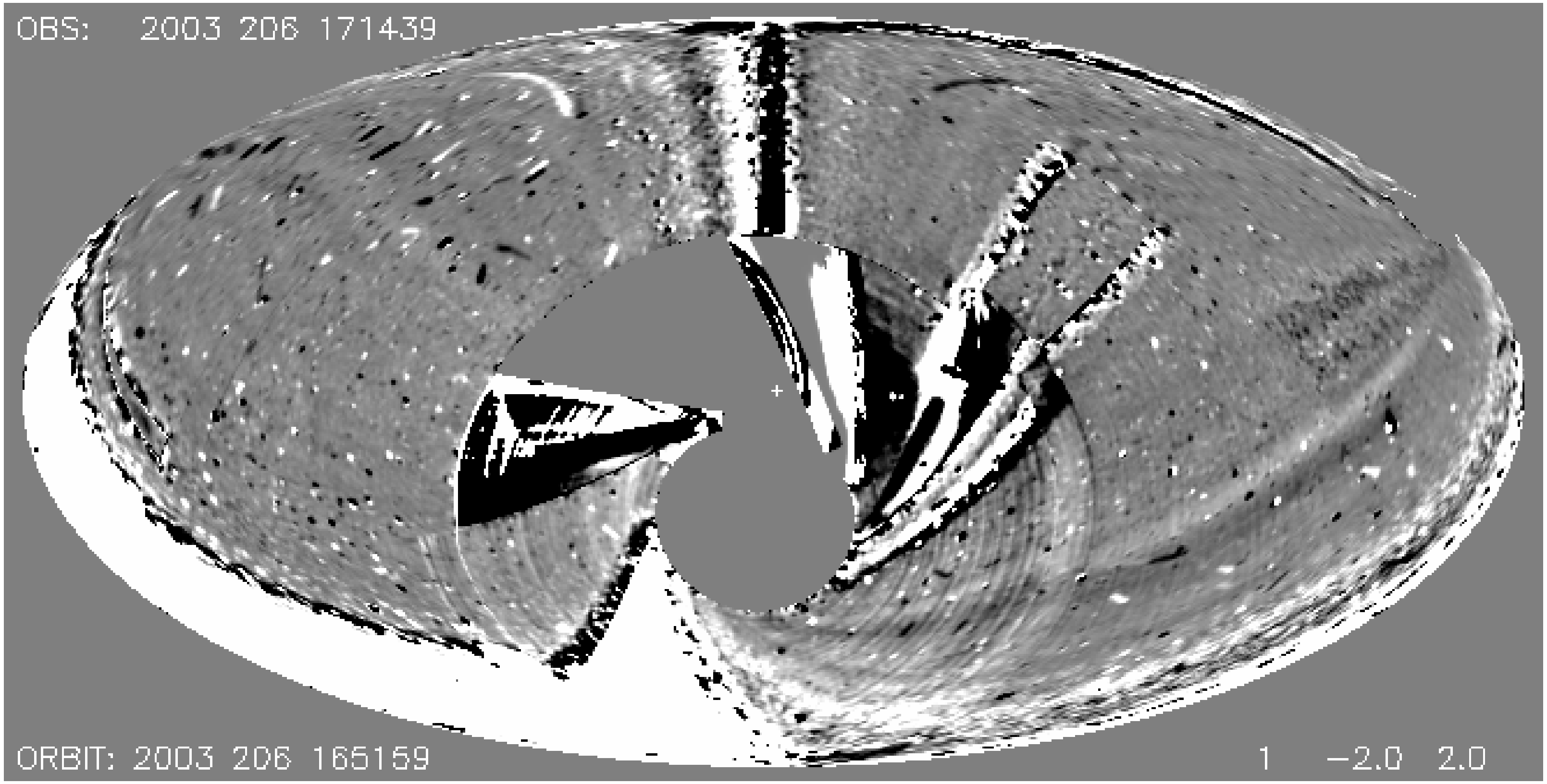
LASCO C3
15, 11:42





SMEI
Orbit diff.
16, 07 – 24

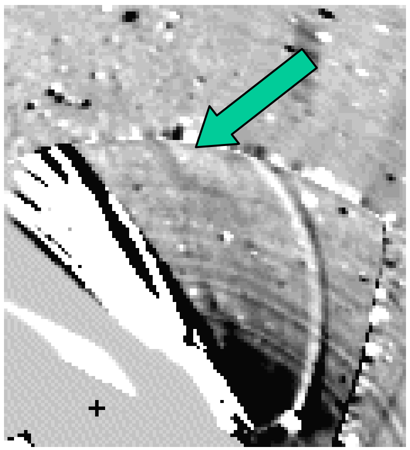
(C) Multiple CMEs & (D) Distant Arcs



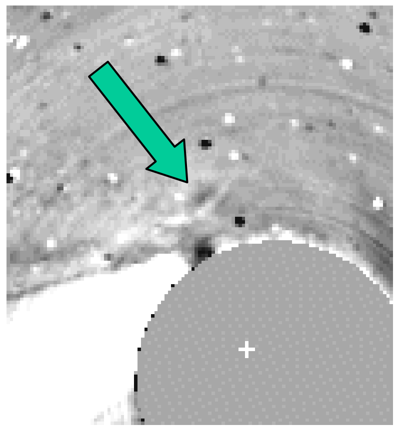
At least 4 separate CMEs!

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)

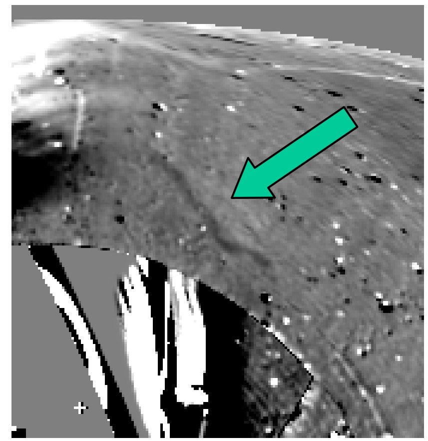
E) Concave-outward CME Structures



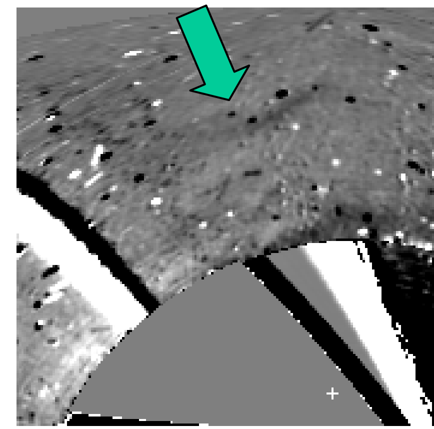
25 April 2003
NNW of Sun



13 March 2003
NNE of Sun



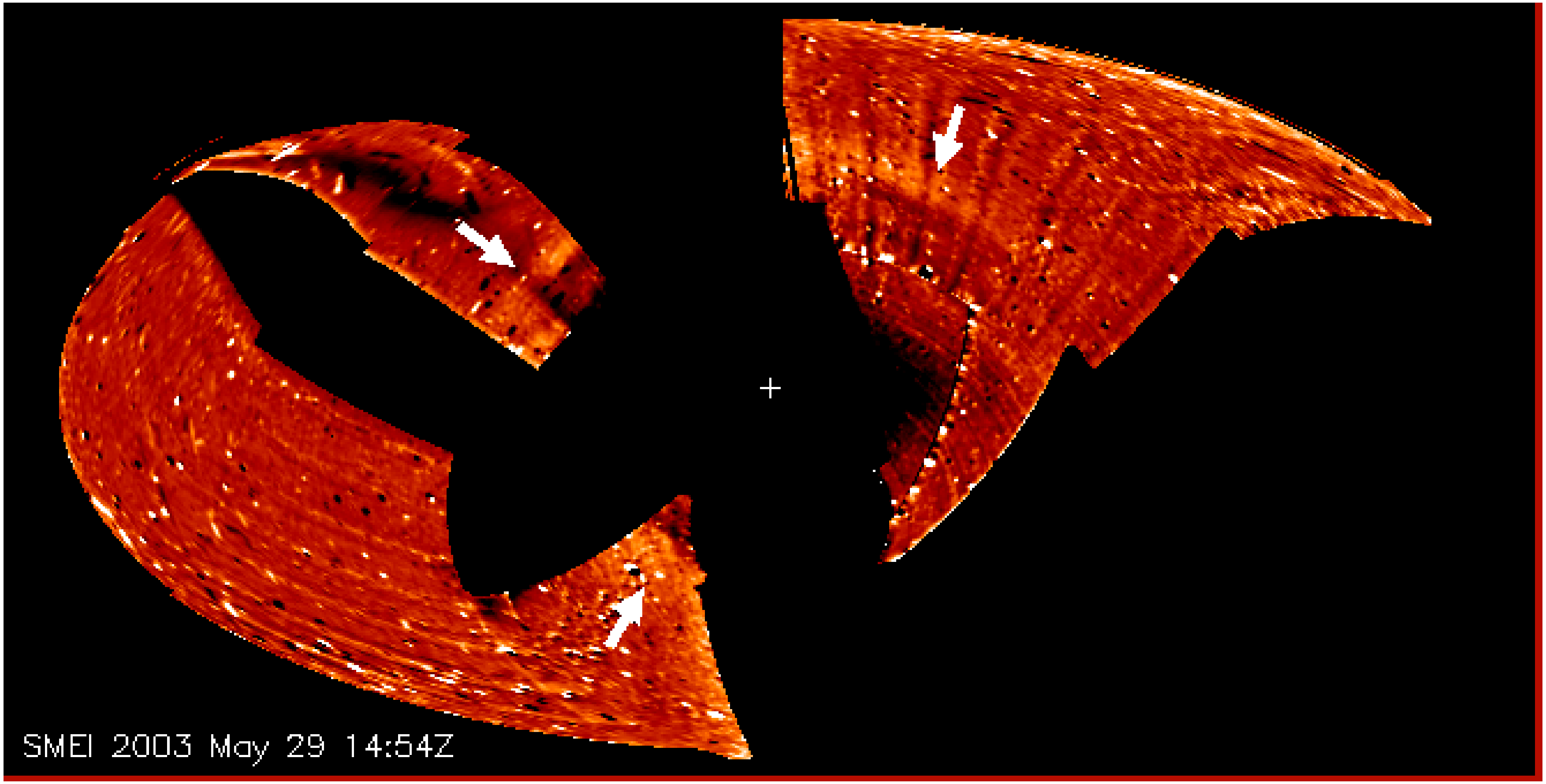
26 July 2003
NW of Sun



28 May 2004
NNE of Sun

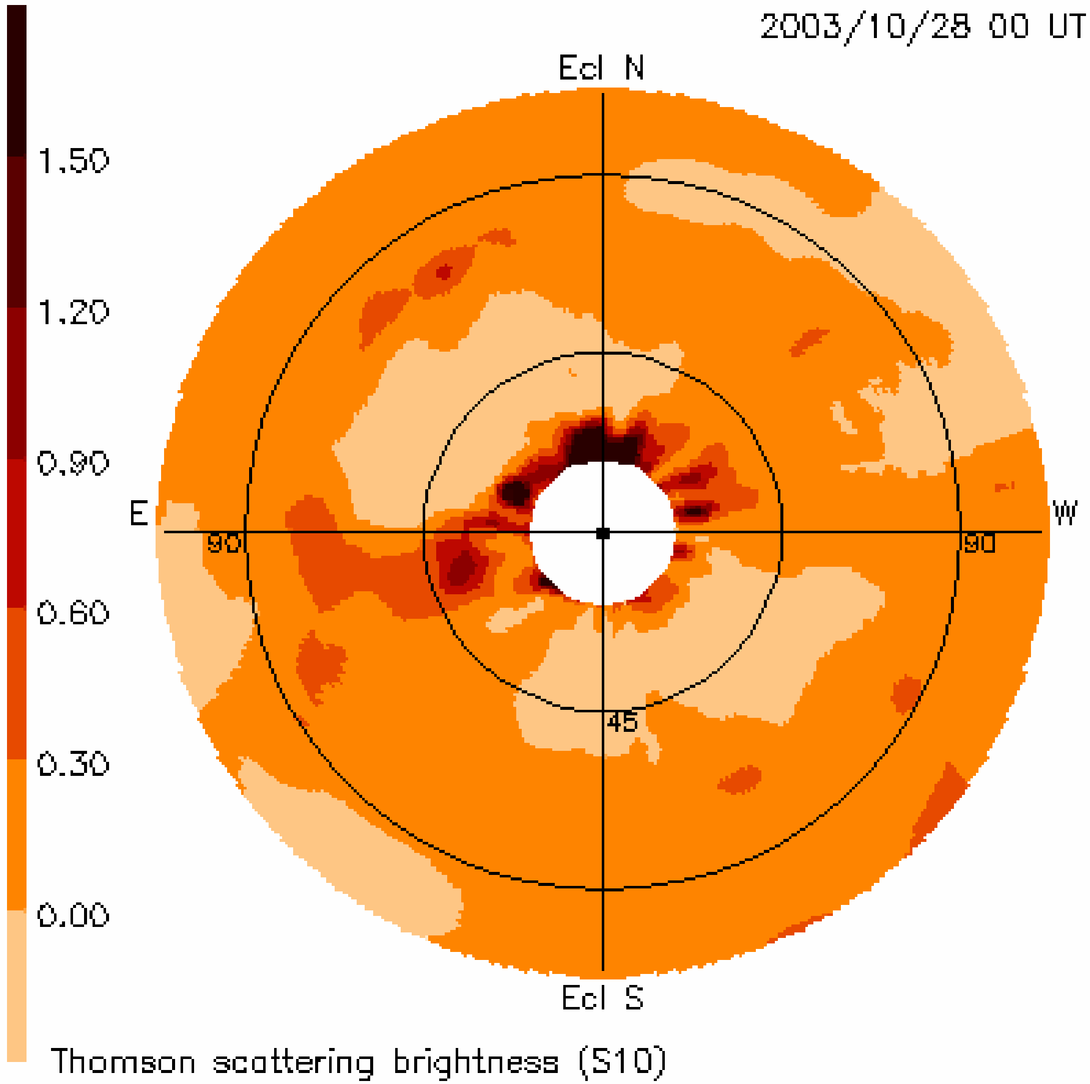
Orbit-to-orbit difference images. Sun located at '+' signs. Exclusion zone circle is 20^{o} in radius.

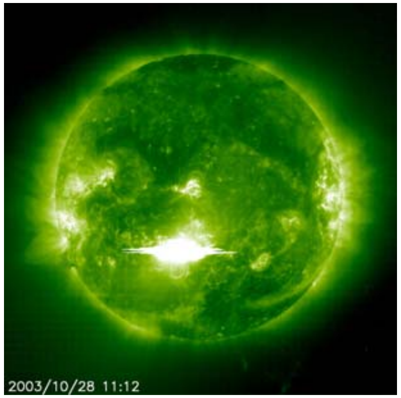
(F) First Earth-Directed CME Seen by SMEI
28-29 May 2003



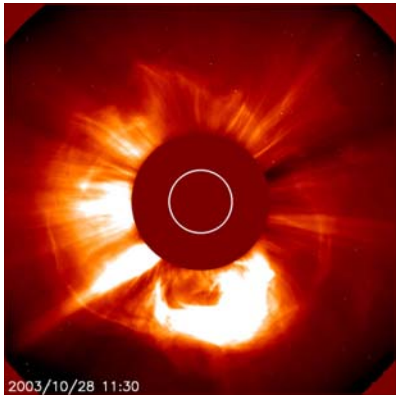
Tappin et al., GRL, 31, 2004

(F) SMEI Ecliptic “fisheye” Maps of Oct. 28-29, 2003 CME



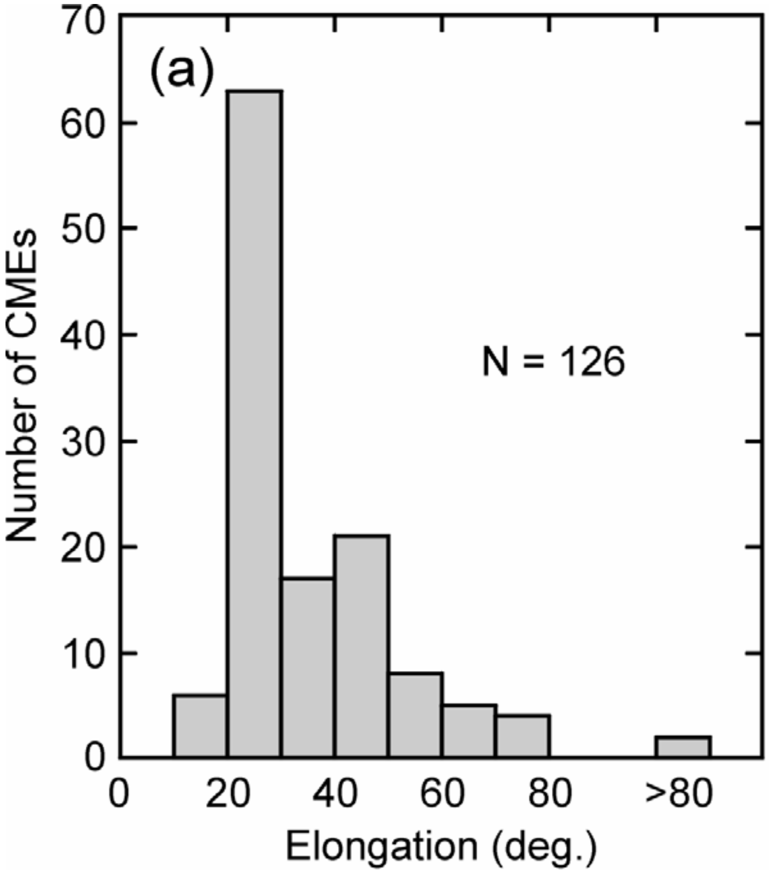


EIT 195A
Oct. 28, 11:12

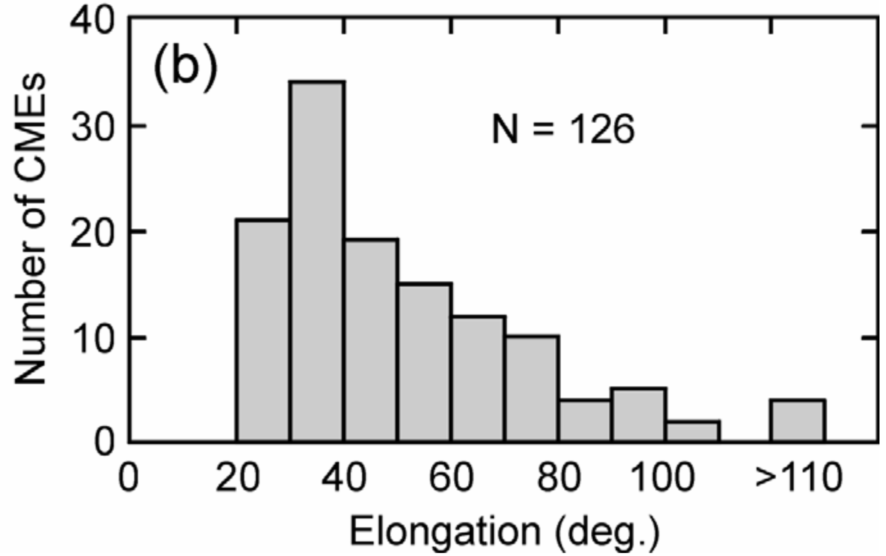


LASCO C2
Oct. 28, 11:30

Elongations Observed for CMEs



First Observed



Last Observed

~ 1/3 of SMEI CMEs can be tracked far from Sun.

Identifying Earthward CMEs in SMEI

- **Large Storms → SMEI CMEs**

  Study of all intense storms (peak *Dst* < - 100nT), Feb. 2003 - Jan. 2005; 2 years

  - Of 21 storms, 3 inadequate SMEI obs., 1 not examined, 1 due to shock sheath;

  - Of 16 remaining, 87.5% (14/16) storms had assoc. SMEI CMEs.
  All CMEs were at large elongations (> 60°) at storm onset.
  All 16 storms had assoc. SMEI aurora.

  - *TIMINGS:*
  ΔT, 1 AU shock arrival - SMEI first obs. = 19.2 hr. (range 9-26 hr.)
  ΔT, onset of storm - SMEI first obs. = 29.2 hr. (range 18-42 hr.)

  Study of all moderate storms (peak *Dst* < - 60nT), Mar. 2003 – Feb. 2005; 2 years

  - For 85% (39 of 46) SMEI saw a CME within 2 days prior.

- **1 AU Shocks → SMEI CMEs**

  Study of 1 AU shocks; ACE, WIND (in-situ) & LASCO (CMEs) 1998 - present

  - Nearly all 1 AU shocks are assoc. with CMEs.
  - 20 shocks assoc. with SMEI CMEs (13 also with storms).
  - But these CMEs not atypical; e.g., elongation, spans.

SMEI - LASCO Comparisons

- **Preliminary SMEI → LASCO Comparison Study**

  - Simnett study: February – December 2003
  - 71% (57/80) of SMEI CMEs associated with obvious LASCO CMEs.
  - 14% (11/80) associated with very faint LASCO CMEs.
  - The remaining 15% (12/80) have no associated LASCO event.

- **Complete LASCO ↔ SMEI Comparison Study**

  - Underway: 3-year NASA grant; SMEI Team with NRL
  - SMEI sees fewer CMEs than LASCO over same period. Why?

    Because of operational down time for tests and calibrations.

    Partial spatial obscurations; particles, aurora, sunlight.

    Some CMEs seen in LASCO close to the Sun fade with height.

    Sequences of events in LASCO manifest as a single feature in SMEI.

Statistical Results Summary: SMEI CMEs

- SMEI has observed 139 CMEs in 1.5 years and 204 CMEs in 2.5 yr.
  Est. occurrence rate = 0.31 CMEs/day

- Brightness: Mean = 1.25 adu; 2.3 S10 units (range = 0.4 - 11 S10)
  (based on preliminary calibration: 1 S10 = 0.55 adu)
  Helios-2*: Mean = 2.3 S10 (1.5 - 2.95; 1976-1979)

- Spans (detected): Mean > 42°; Range = 3 – 107°
  LASCO*: Mean = 60° (median = 42°)
  Helios-2*: Mean = 53° (1976-1979)

- Durations: Mean 15.6 hr.; Range = 3 – 72 hr.
  Helios-2*: Mean = 37 hrs. (1976-1979)

- Speeds: Angular mean = 1.1°/hr. P-approx. mean = 482 km/sec
  LASCO*: Mean = 507 km/sec
  Helios-2*: Mean = ~500 km/sec (1976-1979)

- SMEI detected ~20 halo CMEs at ~1/3 of Sun to Earth distance.
  Can detect CMEs 10 hr. to 1+ days before Earth arrival.

* LASCO results courtesy S. Yashiro & N. Gopalswamy;
Helios-2 results from Webb & Jackson, JGR, 95, 1990.

SMEI Information Sources

References:

- **Instrument paper:** ***Eyles et al., Solar Phys., 217, 319, 2003***
- **"Mission" paper:** ***Jackson et al., Solar Phys., 225, 177, 2004***

- **URL for SMEI instrument description & general information:**

    http://www.vs.afrl.af.mil/ProductLines/SMEI/

- **URL for SMEI images & movies:**

    http://smei.nso.edu/

Possible SMEI-STEREO-Solar-B Joint Science

Overlap of the Missions

SMEI launched on STP Coriolis mission Jan 2003
STEREO launch May/June 2006; Solar-B launch Sept. 2006
SMEI nominal mission 3 years; 5 year design lifetime
Main degradation: Sunward camera signal-to-noise
- Uploading bad-pixel mask

Continuing operations ($2M/year) depend on:
- Success of Navy Windsat experiment
- AFRL finding support if Windsat fails

Space Weather

Onset & source structure; Solar-B provides B-field
Different views of Earthward CME: SMEI - Head-on; STEREO HIs - Side-on
HIs: 3-D images early in mission; Triangulation later
Determine trajectory, time of arrival & strength of CME.
But CME rate low: CME rate at solar minimum 0.5-1/day

SMEI Provides Context of Heliospheric Structures

Movies of corotating structures & CMEs (3D recontructions)
Time-of arrival of structures at STEREOs
- Intercomparison of remote sensing & in-situ meas.
- Tests of heliospheric models

3-Point Measurements of Large-Scale Structures

SMEI + near-Earth/L1spacecraft + 2 STEREOs

- In-situ measurements of plasma & IMF: L1 + STEREO in-situ

- Density/Mass measurements from SMEI + STEREO HIs

Comparison with Solar-B & COR1, COR2 measurements

THE END

SMEI CME Studies & Collaborations

- **Improved calibrations & reprocessing of existing data.**
- **3D reconstruction of IP density enhancements (CMEs & corotating structures) and kinematics**
- **Some collaborations with other data sets:**
  - ***LASCO comparison***
  - ***Ulysses on CME kinematics***
  - ***ICMEs & Forbush decreases***
  - ***IPS comparison***
  - ***Wind/WAVES***
  - ***SOHO SWAN (St. Cyr)***
- **Space Weather modeling: HAF & other IP model comparisons.**

SMEI Presentations/Papers

Published

• "Instrument" paper	*Eyles et al., Solar Phys., 2003*
• May 2003 Halo CME – storm	*Tappin et al., GRL, 2004*
• "Mission" paper	*Jackson et al., Solar Phys., 2004*
• Oct-Nov 2003 period	*Webb & Allen, Space Weather, 2004*

In-press

• 3D reconstr. of Oct-Nov 03 events	*Jackson et al., JGR, 2005*
• Wind/WAVES – SMEI CMEs	*Reiner et al., JGR, 2005*
• Survey of Halo CMEs	T. *Howard et al.*
• CMEs & Ulysses kinematics	*Tappin, Solar Phys., 2005*
• SMEI-IPS; Oct. 2003	*Tokumaru et al., URSI, 2005*

In progress

• First-year CME statistics	*Webb et al.*
• Space weather	*Fry et al.; Webb et al.*
• ICMEs & Forbush decreases	*Simnett, Kahler (ICRC)*
• Comparison SMEI & IPS data	*Jackson, Tokumaru*
• Comet tail disconections	*Kuchar et al.*

>40 talks/abstracts

• 2 AGU Special Sessions

16 popular articles or press releases

Some Speculation

- **CME Morphology:**

  More structured nearer Sun (Cam 3):

  - True limb CMEs show more structure

  - So do CMEs with erupting prominences

  Broad arcs far from Sun (Cams 2 & 1):

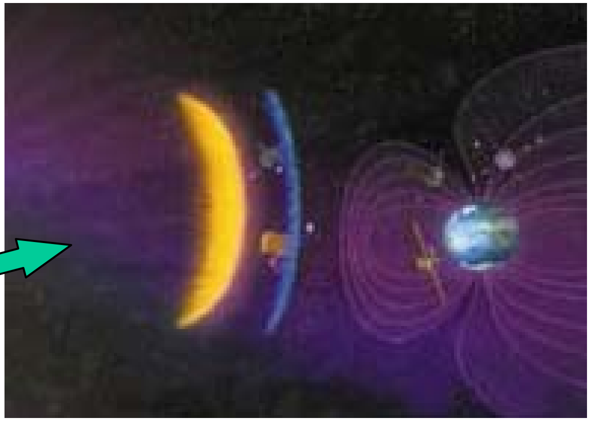
  - Shock or shock sheath?

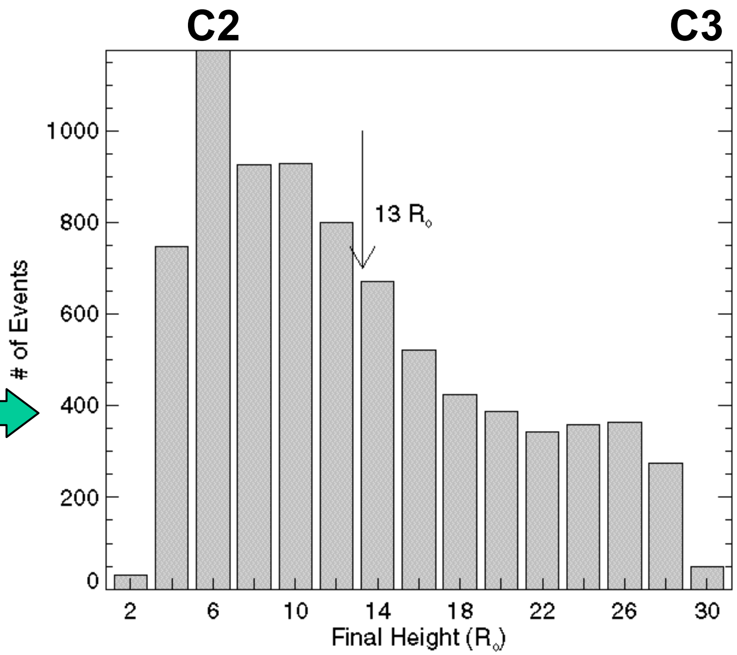
  - Compressed leading edge of ejecta?

  Distant concave-outward structures:

  - Evolved prominence material?

  - CME front encountering gradient in solar wind flows?





- **SMEI vs LASCO: ~half of SMEI CMEs likely assoc. with LASCO CMEs. Detailed comparison to come.**

  - But many LASCO CMEs fade < 10Rs!

  - Why? Density decrease, turbulence, merge with solar wind, propagation direction, other??

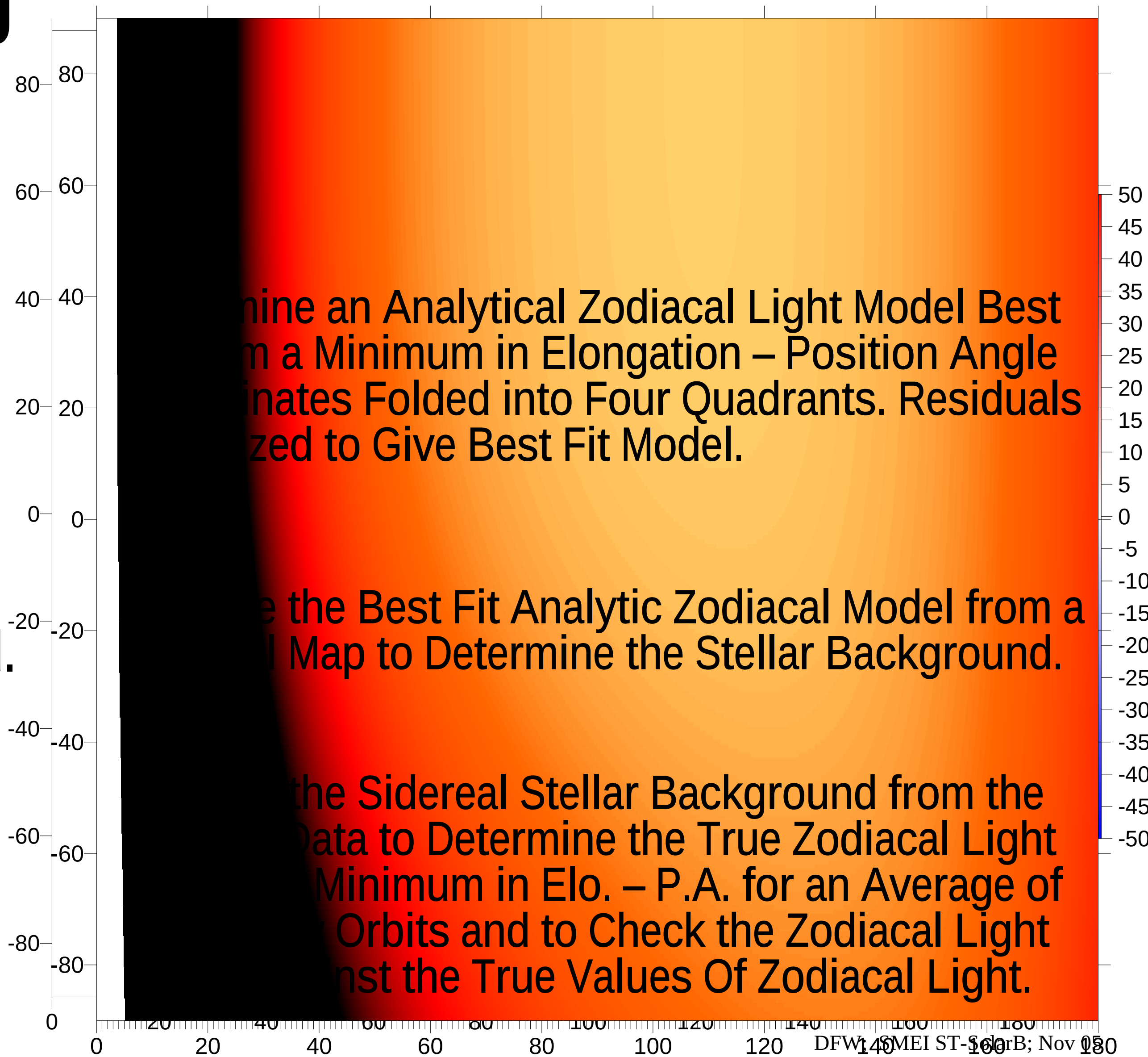
3-D Reconstruction of CMEs Using SMEI

UCSD Editing Sequences for SMEI

SMEI Zodiacal cloud Subtraction from a model fit.

How to determine the zodiacal cloud.

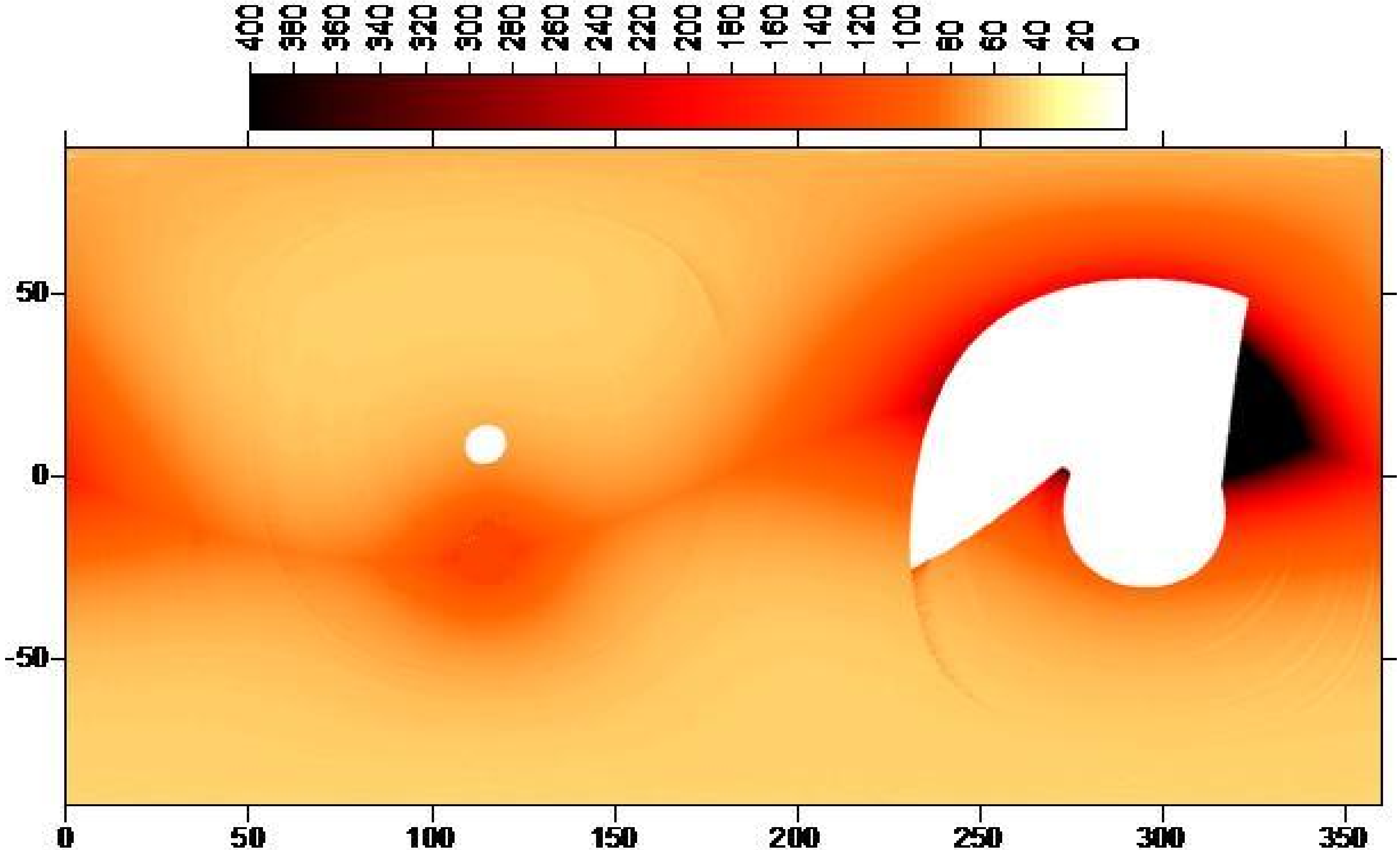
How to remove it.



3-D Reconstruction of CMEs Using SMEI

Zodiacal light and Removal

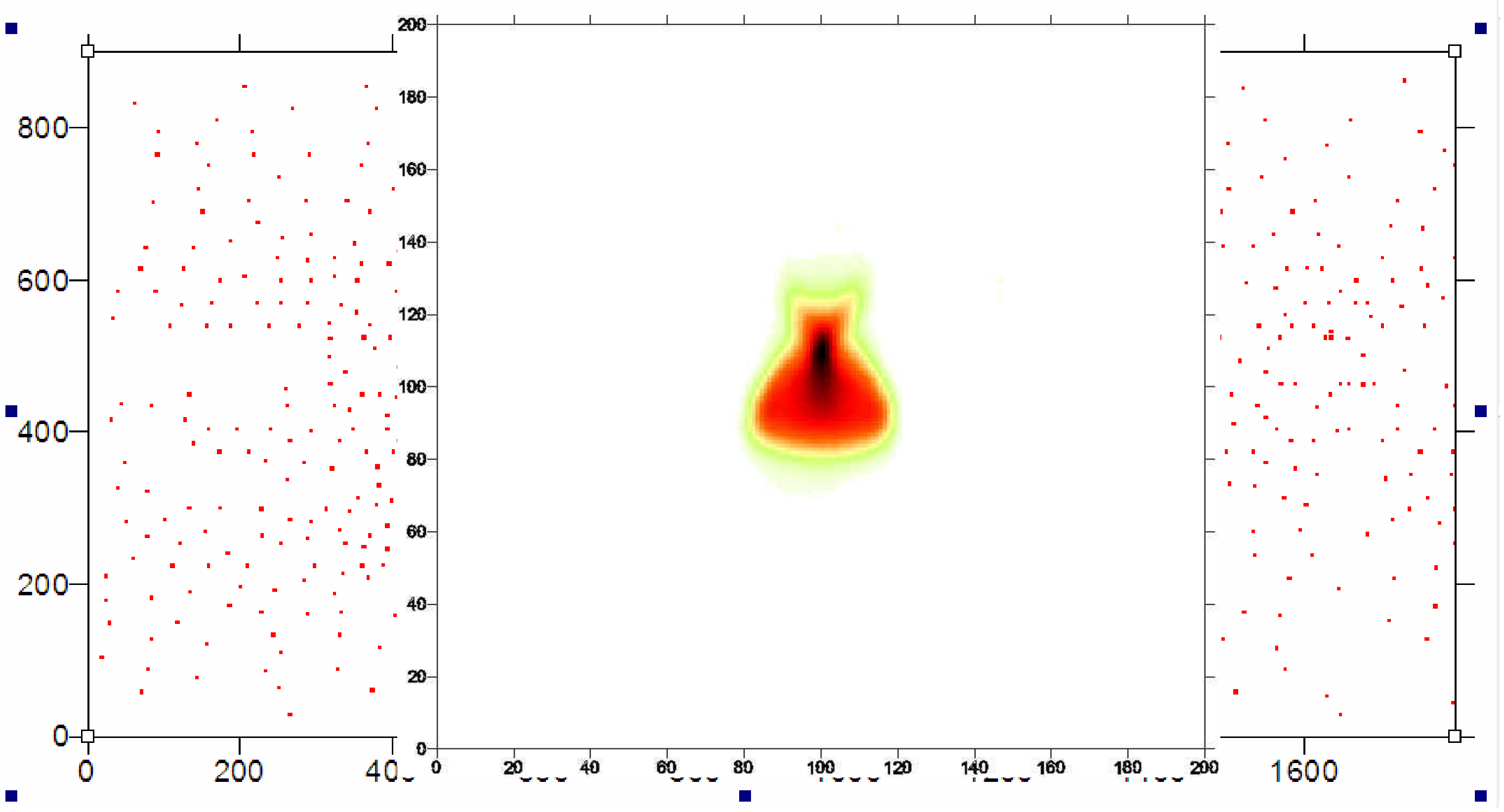
UCSD Editing Sequence



3-D Reconstruction of CMEs Using SMEI

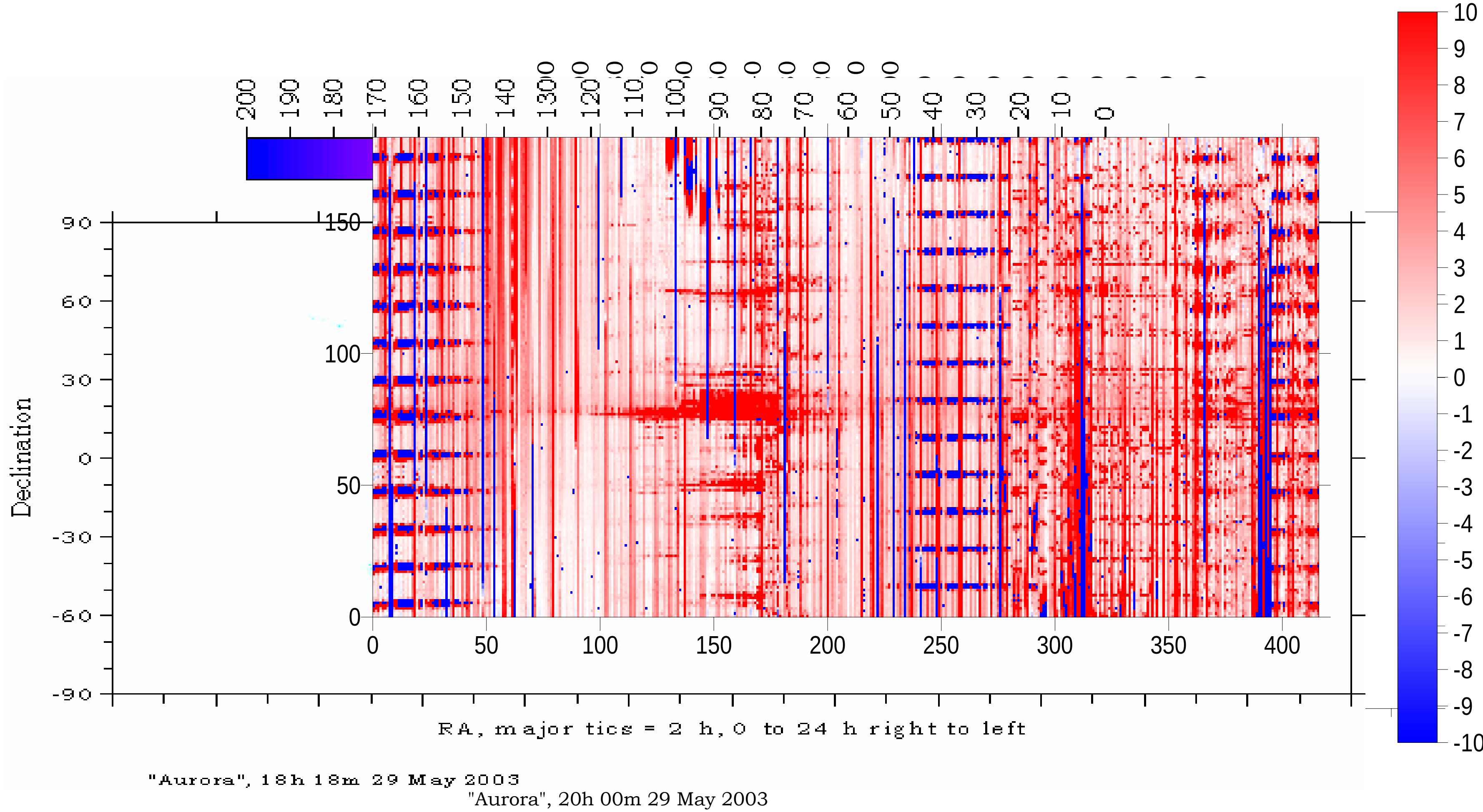
UCSD Editing Sequence

Dealing with time series precisely. (Where stars brighter than 6th magnitude aren't.) Late October, period ~1100 locations shown.



3-D Reconstruction of CMEs Using SMEI

UCSD Editing Sequences

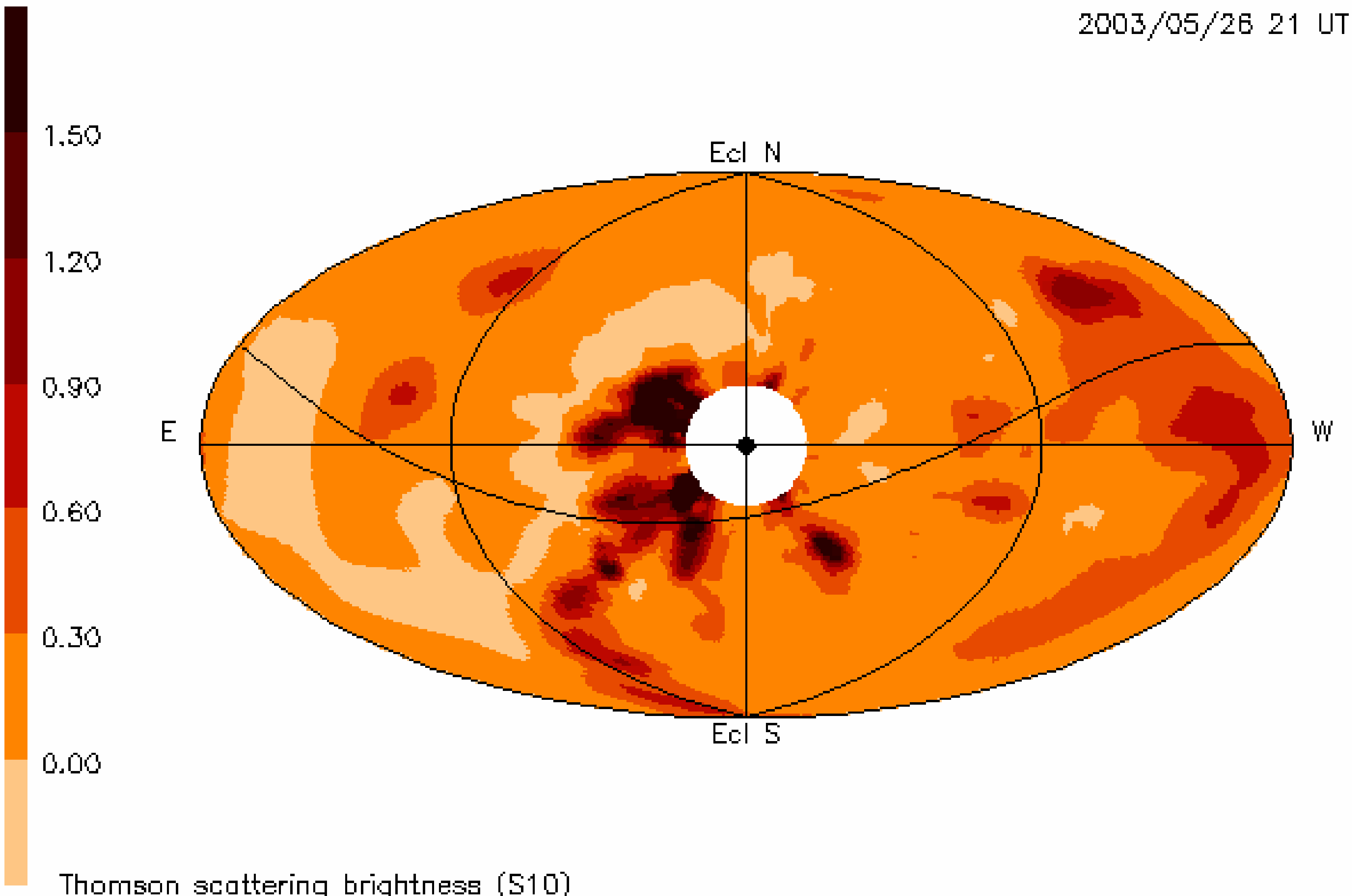


Aurora Removed by Recognition of their Signal on an Orbit – Temporal Sequence Map.

3-D Reconstruction of CMEs Using SMEI

Enhanced Images from Timeseries

26 May – 05 June 2003, (May 28 ‘Halo’ CME)

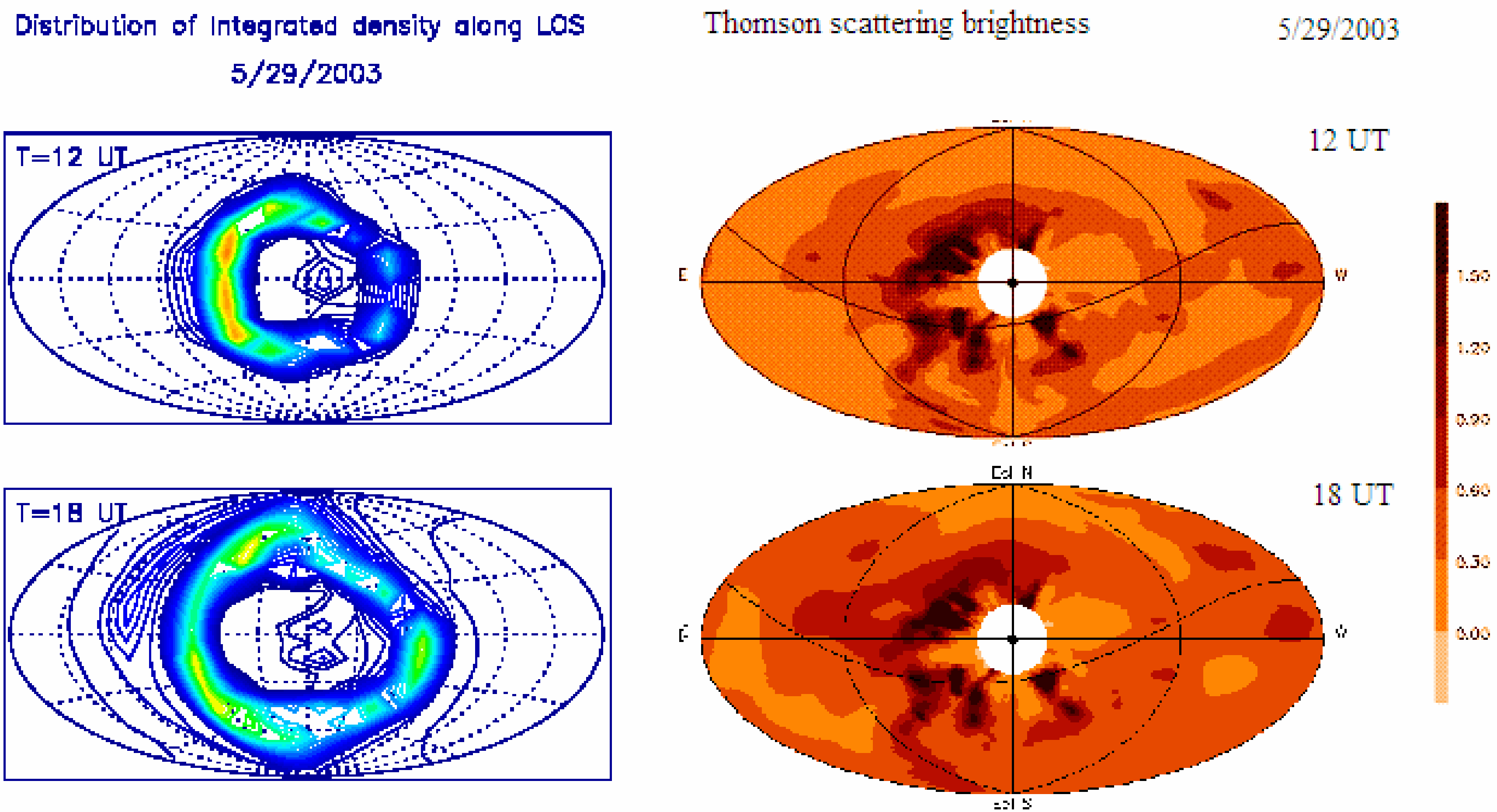


IE_2005

3-D Reconstruction of CMEs Using SMEI

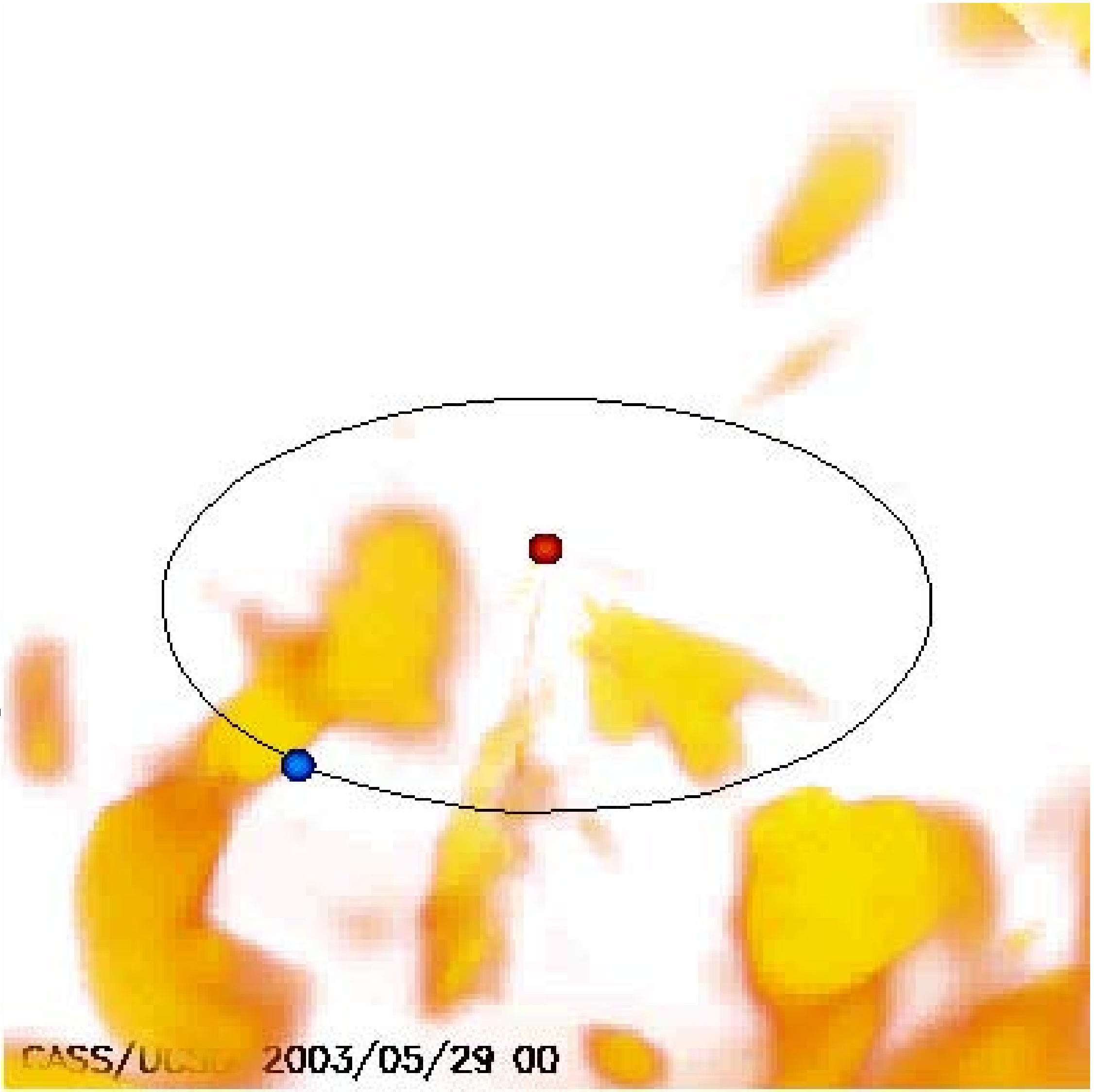
Enhanced Images from Timeseries

Comparison with HAF model



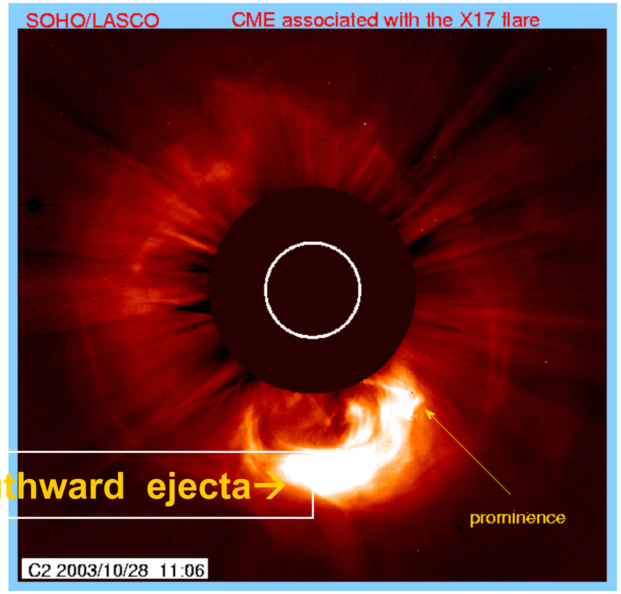
3-D Reconstruction of CMEs Using SMEI

SMEI 3D reconstruction of the 28 May CME.



Electrons are contoured with an R^{-2} density fall-off between 10 - 30 $e^{-}cm^{-3}$.

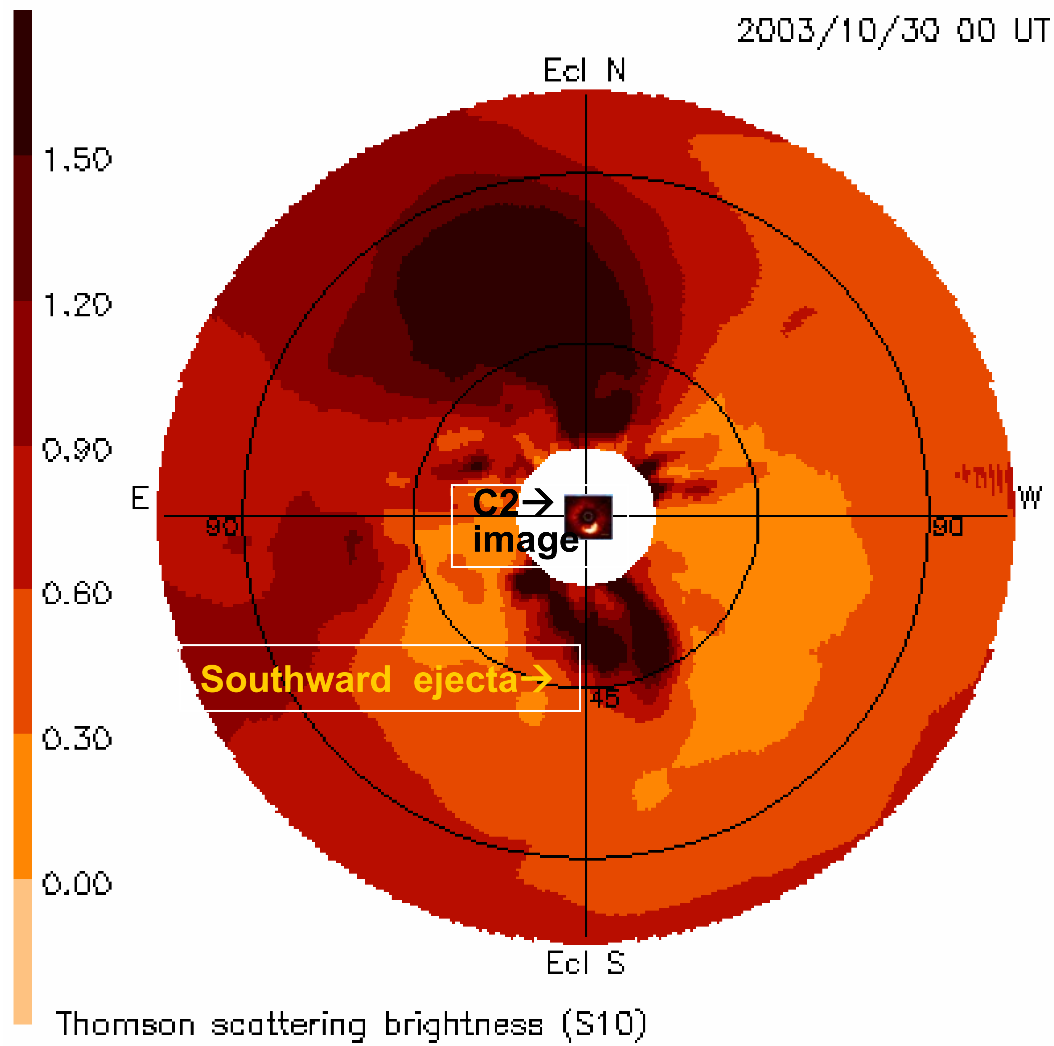
3-D Reconstruction of CMEs Using SMEI



LASCO C2 CME image to 6 Rs.

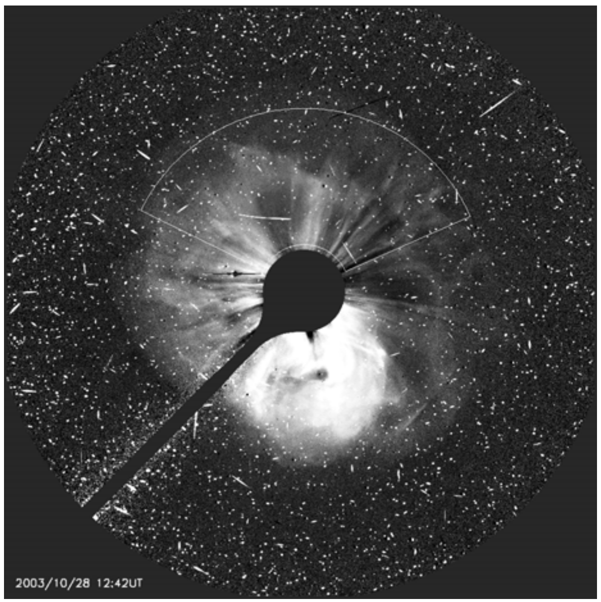
SMEI enhanced Sky Map image and animation to 110º elongation.

Northeast-directed ejecta consistent with IPS g-level observations (Tokumaru *et al*., 2004)



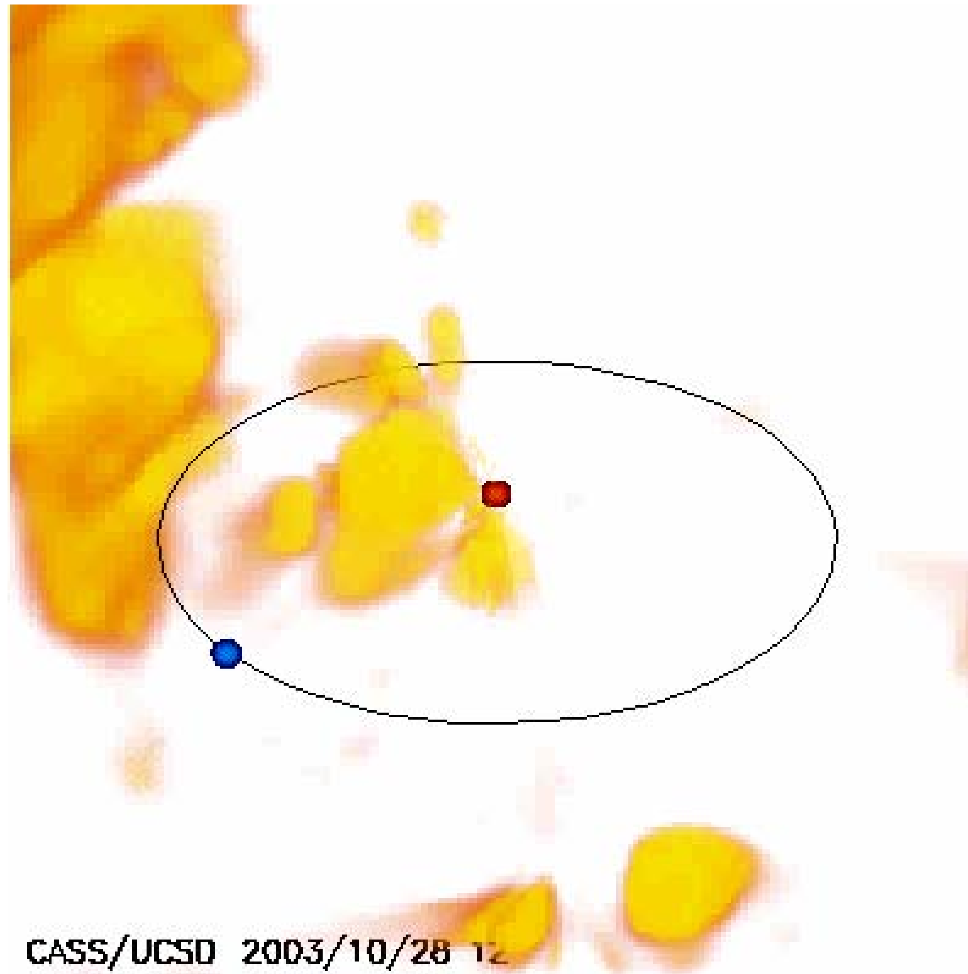
3-D Reconstruction of CMEs Using SMEI

SMEI 3D reconstruction of the October 28 CME.



The above structure has a mass of about 0.5×10^{16}g excess in the sky plane but ~ 2.0×10^{16}g excess at 60° (Vourlidas, private communication, 2004).

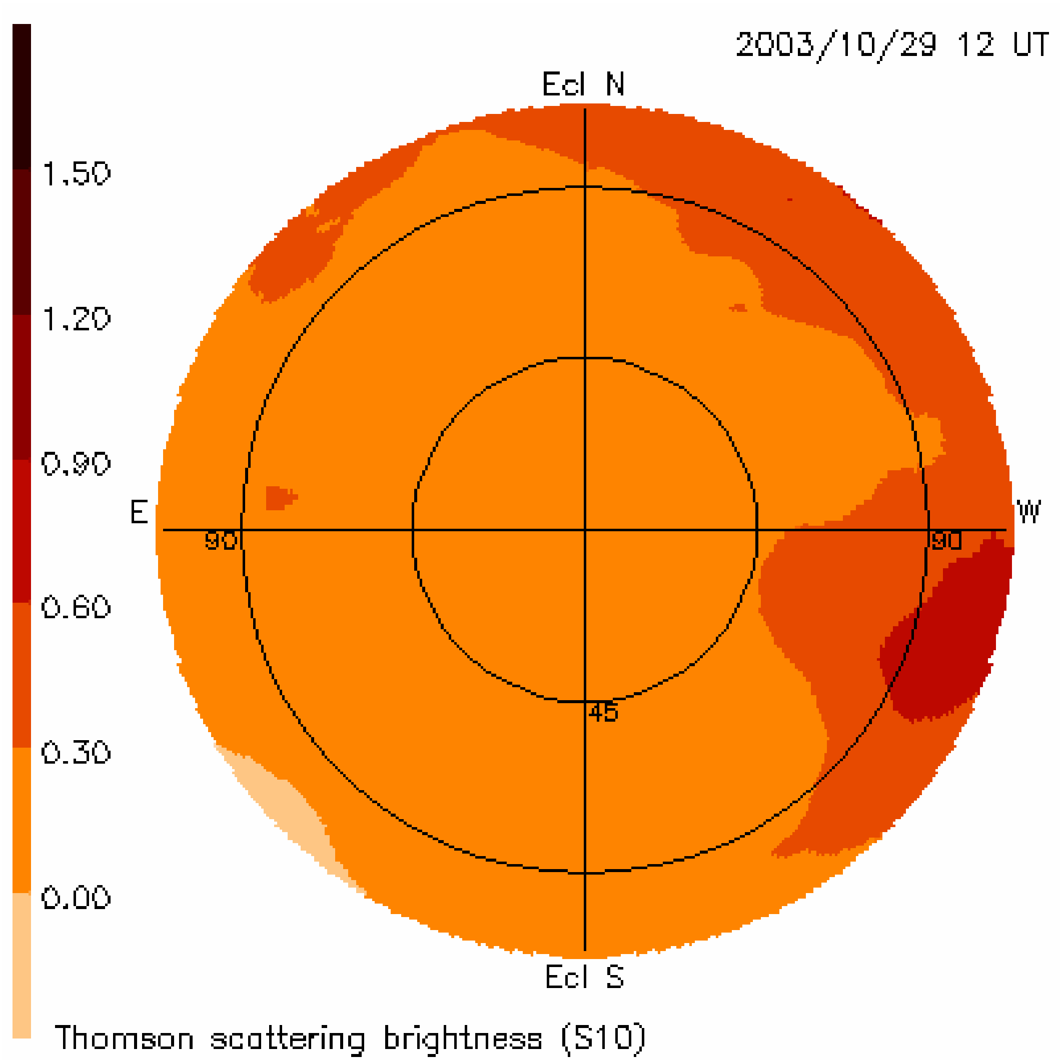
Mass determination ~6.7×10^{16}g excess and 8.3×10^{16}g total for northward directed structure within the 10 $e^{-}cm^{-3}$ contour.



3-D Reconstruction of CMEs Using SMEI

SMEI 3D reconstruction of the October 28, 2003 CME.

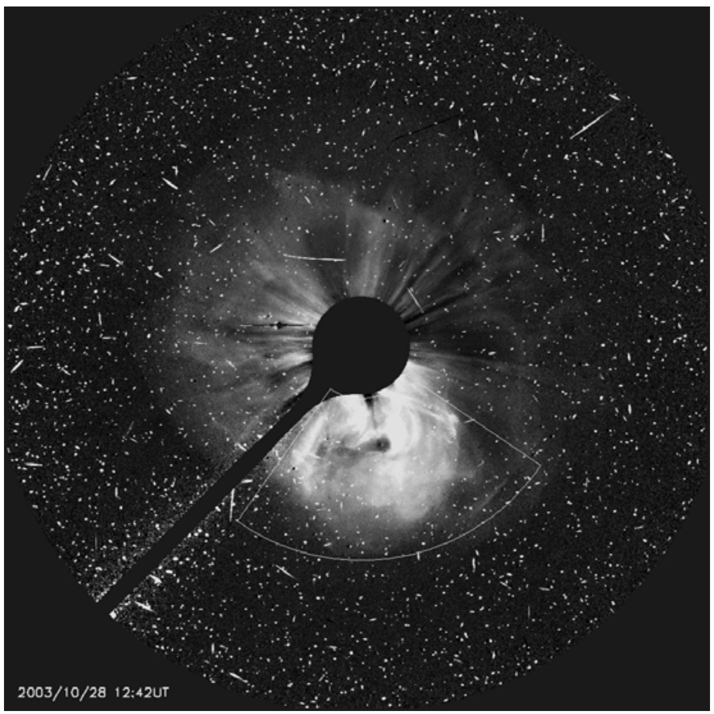
The dominant structure vanishes about 45 from the Sun-Earth line. The arch-shaped structure fades to the south of Earth.



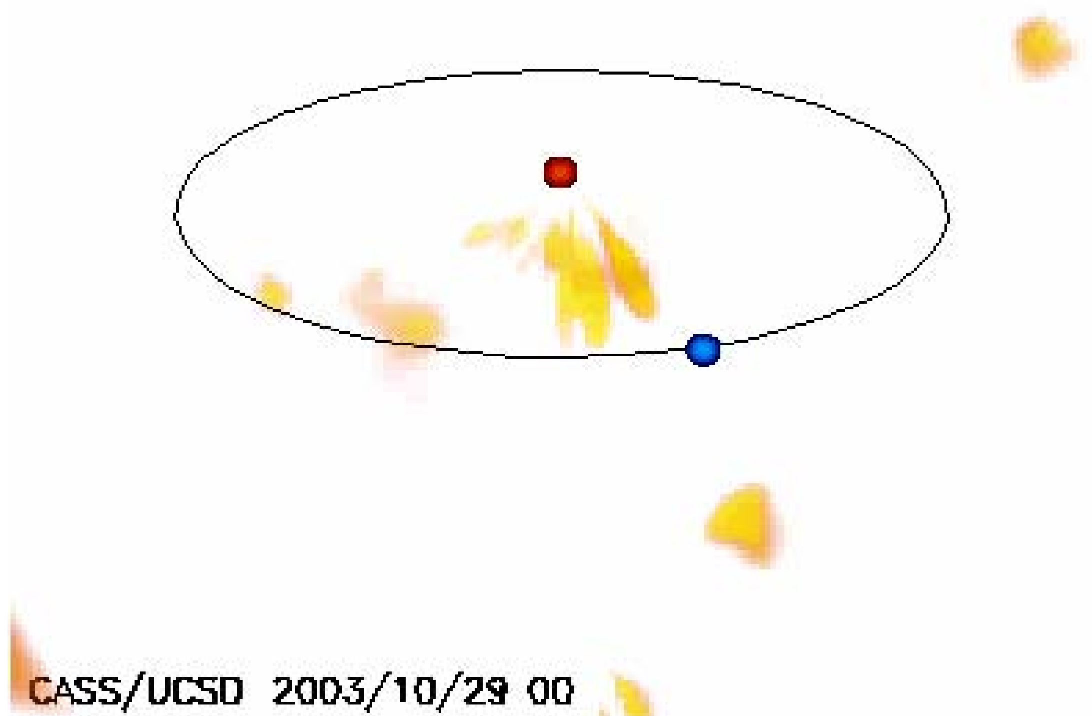
3-D Reconstruction of CMEs Using SMEI

SMEI 3D recon-struction of the October 28 CME.

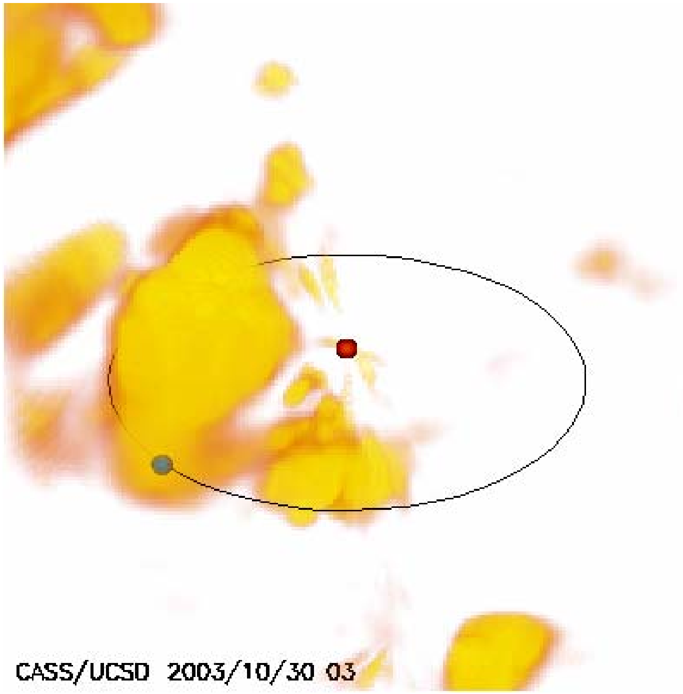
Mass determination ~3.6 × 10^{16}g excess and 4.2 × 10^{16}g total within 20 e^{-}cm^{-3} contour.

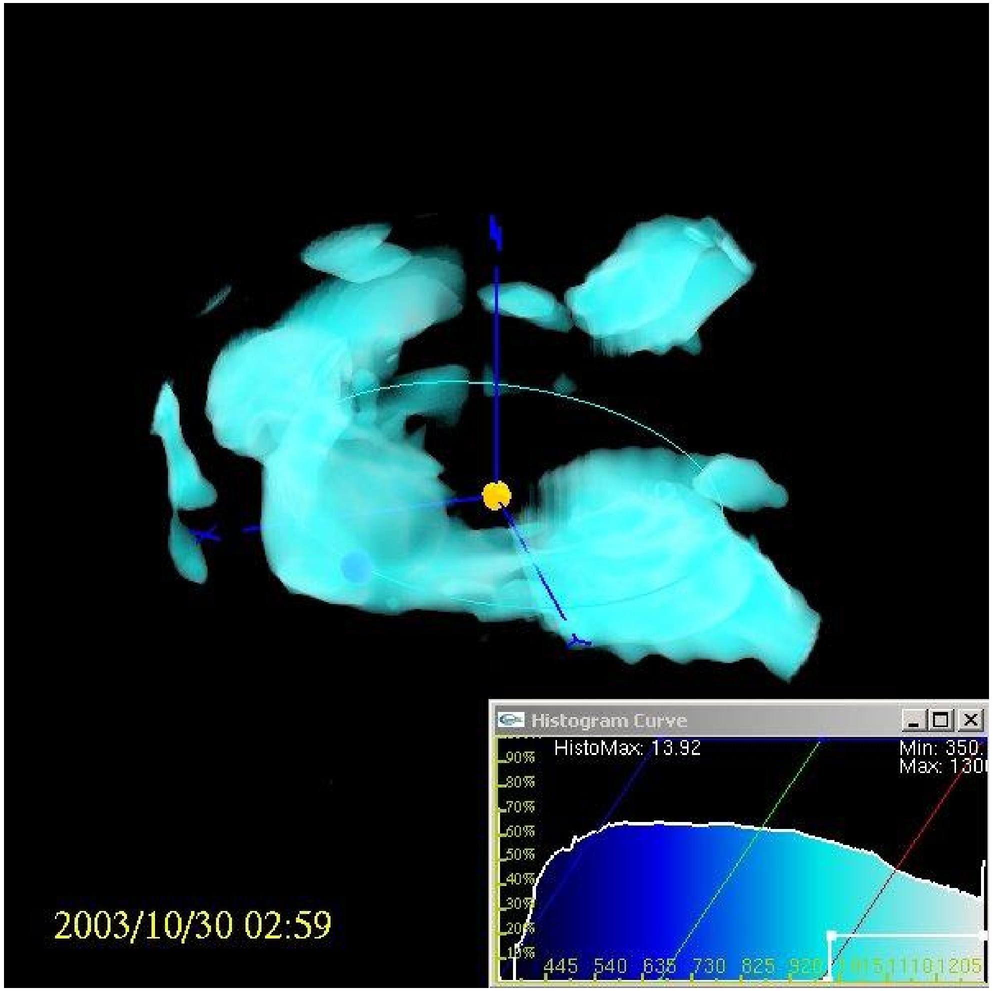


The above structure has a mass of about 1.5 × 10^{16}g excess in the sky plane.



3-D Reconstruction of CMEs Using SMEI





SMEI reconstructed density on October 30 at 03 UT 15 $e^- cm^{-3}$ to 30 $e^- cc^{-3}$.

IPS UCSD reconstructed velocity at 03 UT viewed above 1300 km s^{-1}.

3-D Reconstruction of CMEs Using SMEI

Summary/Work Needed:

a) Modeling: Better heliospheric modeling - incorporation of 3D MHD into the forward-modeling tomographic analysis (Odstrcil *et al*.).

b) Comparisons with STELab IPS results (Tokumaru et al.) & HAF model (Frye et al.)

c) NRT Pipeline Processing of fully calibrated images

d) Restrospective SMEI - 3D reconstruction analysis from the entire time period observed by SMEI and comparison with other CMEs.