PRIFYSGOL ABERYSTWYTH UNIVERSITY

STEREO SWG21, Dublin, Ireland

Selected CMEs around the Current Solar Minimum and their 3-D Reconstruction: Comparison with STEREO Results

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Outline

- Solar Mass Ejection Imager (SMEI)
- Interplanetary Scintillation (IPS)

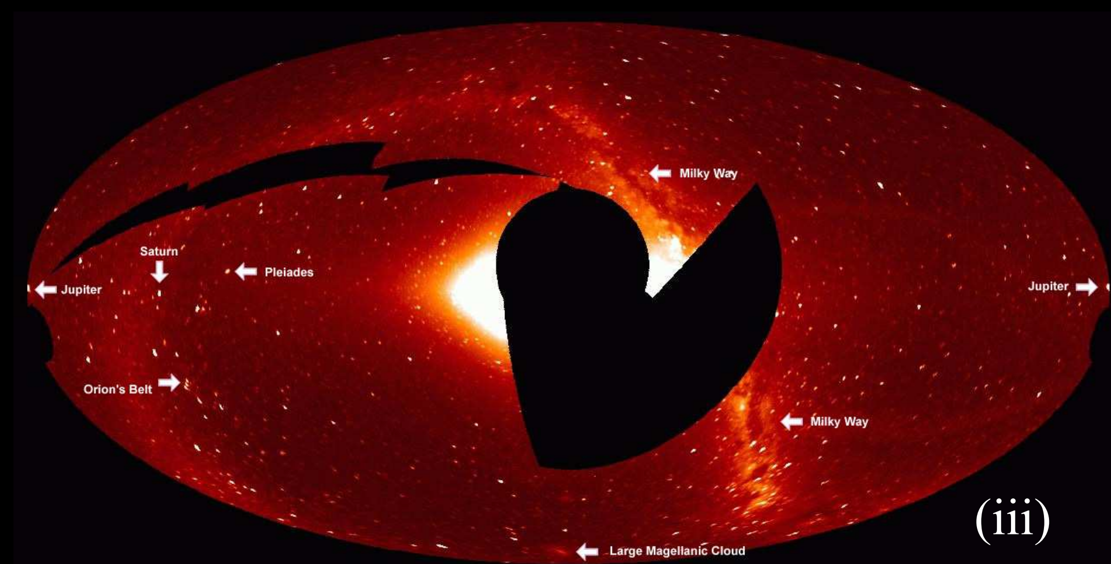
- 3-D Reconstructions of Coronal Mass Ejections (CMEs) and their comparison with STEREO results:
  - 26 April 2008 CME (SMEI)
  - 02 June 2008 CME (IPS)

- Overall Summary and Future Prospects

Solar Mass Ejection Imager (SMEI)

(i)

(ii)



(iii)

Launched in a Titan II from Vandenberg AFB on 6 January 2003: (i) Artist impression; (ii) Simultaneous images from the three SMEI cameras; (iii) First-light - composite all-sky map 2 February 2003 from the three SMEI cameras

Interplanetary Scintillation (IPS) System Used

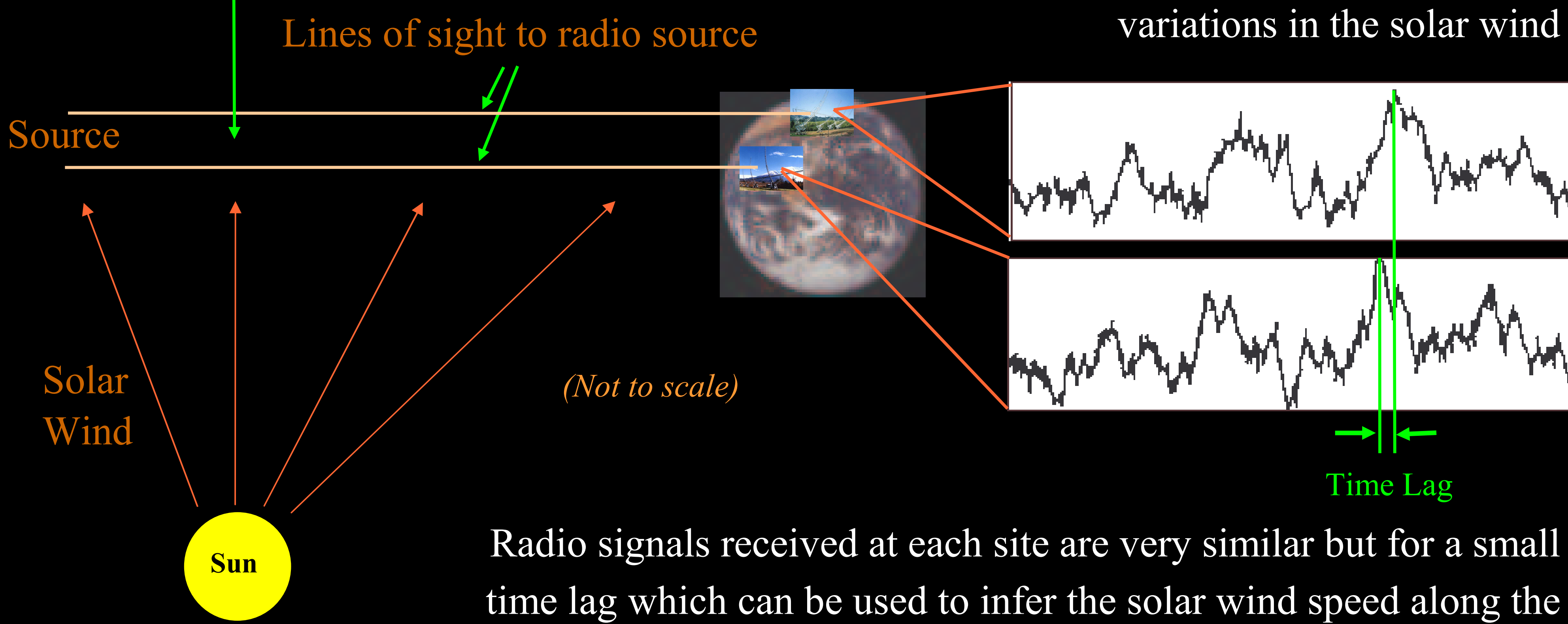
The STELab antennas from left-to-right: Fuji, Sugadaira, Toyokawa (old), and Kiso.
(Courtesy of http://stesun5.stelab.nagoya-u.ac.jp/uhf_ant-e.html)

New STELab Toyokawa IPS array – now partially operational…

Interplanetary Scintillation (1)

P-Point (point of closest-approach of the line-of-sight raypath to the Sun) and point of IPS maximum sensitivity

Radio signal scintillates due to density variations in the solar wind



Radio signals received at each site are very similar but for a small time lag which can be used to infer the solar wind speed along the lines of sight for multi-site IPS observations

IPS is only sensitive to the component of flow that is perpendicular to the line-of-sight

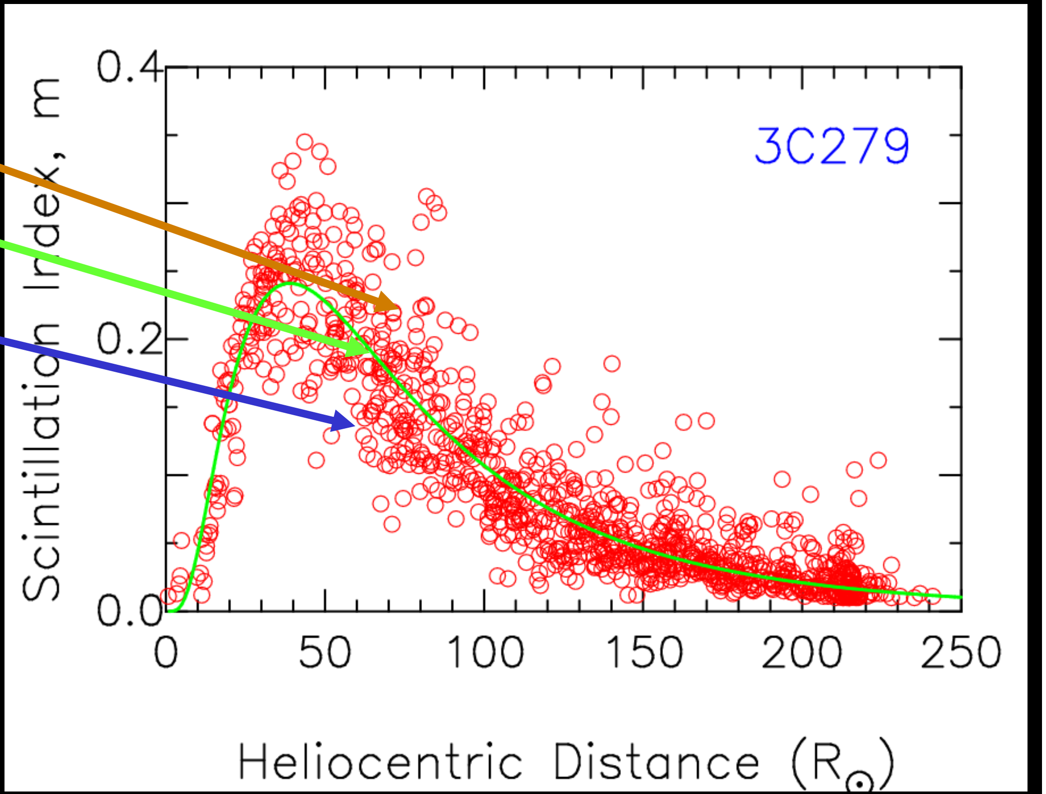
By suitably transforming and calibrating the intensity scintillation time series, the solar wind speed can also be obtained from the spectrum of a single-site IPS observation

Interplanetary Scintillation (2)

Density Turbulence

- Scintillation index, m, is a measure of level of turbulence
- Normalised Scintillation index, g = m(R) / <m(R)>

- **g > 1 → enhancement in δNe**
- **g ≈ 1 → ambient level of δNe**
- **g < 1 → rarefaction in δNe**

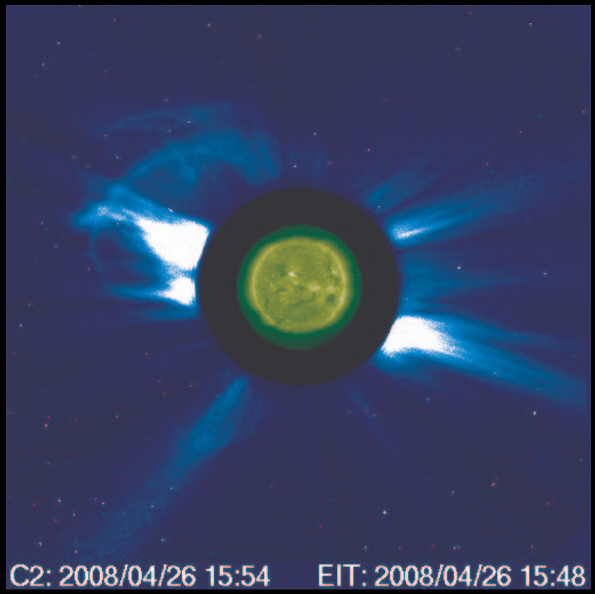


(Courtesy of
P.K. Manoharan)

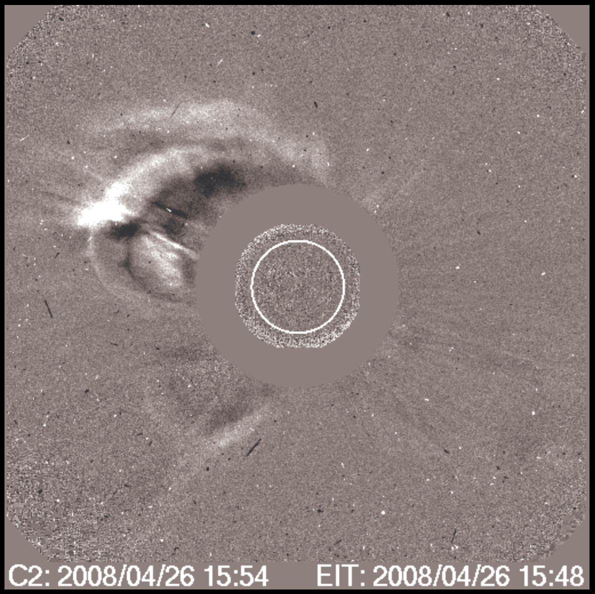
Scintillation enhancement with respect to the ambient wind identifies the presence of a region of increased turbulence/density and possible CME along the line of sight to the radio source

SMEI – LASCO – SECCHI:
26 April 2008 CME –
First seen by SOHO|LASCO C2
at around 14:30 UT

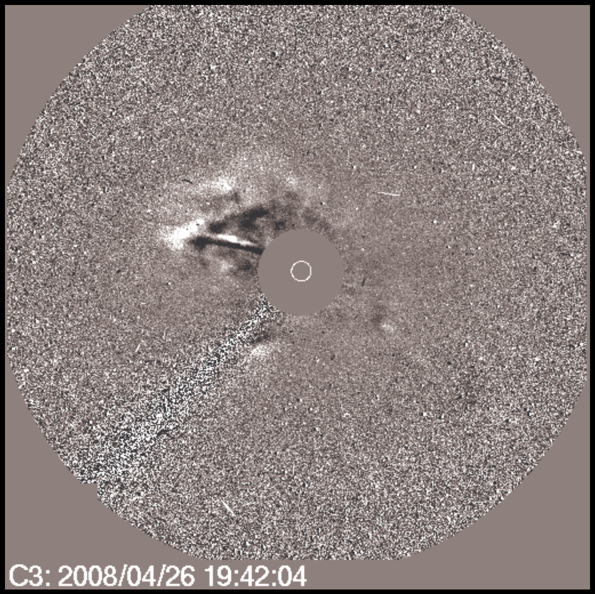
SOHO EIT and LASCO Images



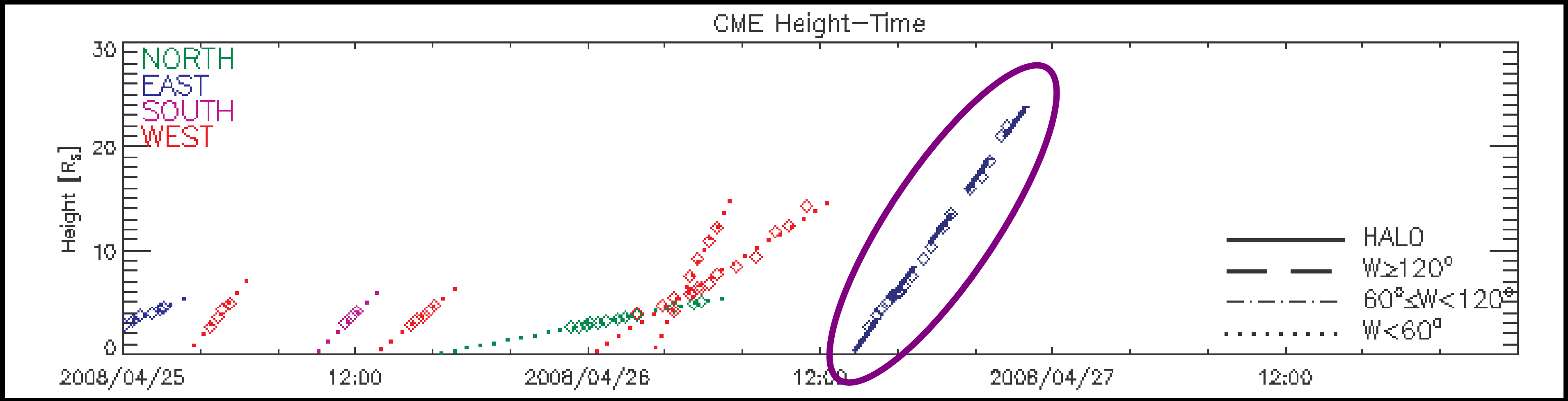
SOHO|EIT/LASCO C2
Composite Images



SOHO|LASCO C2
Difference Image

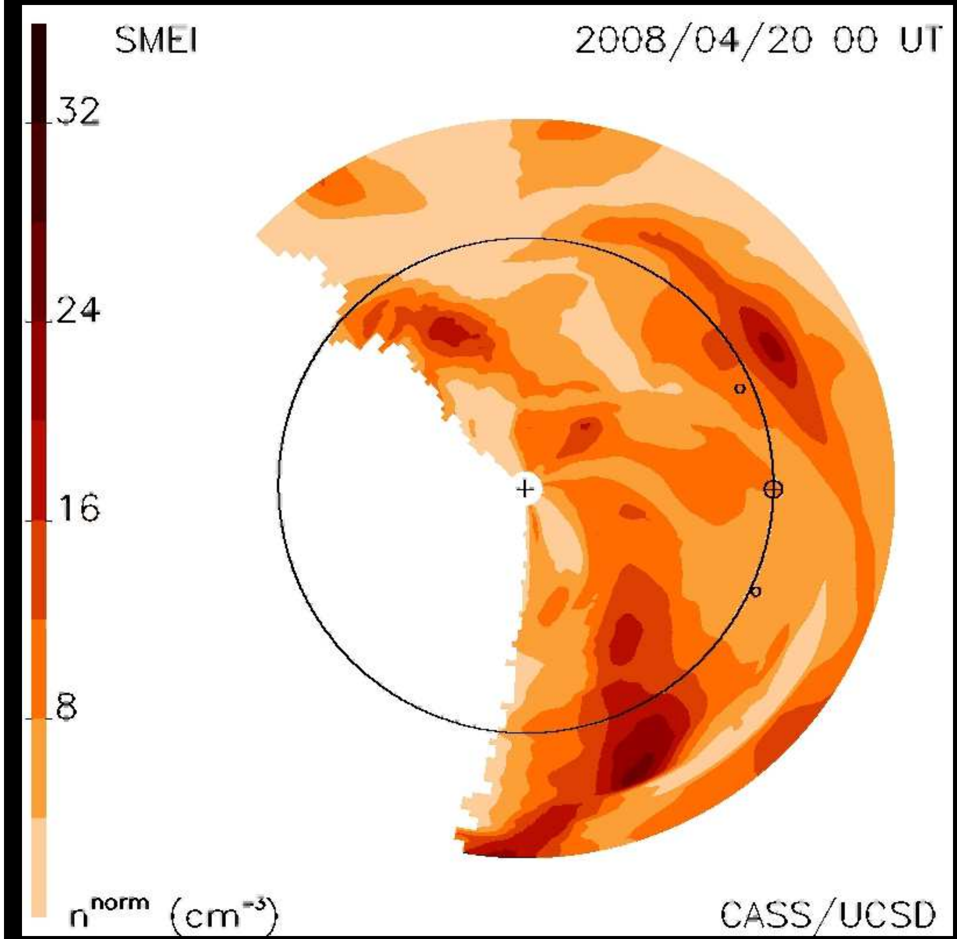


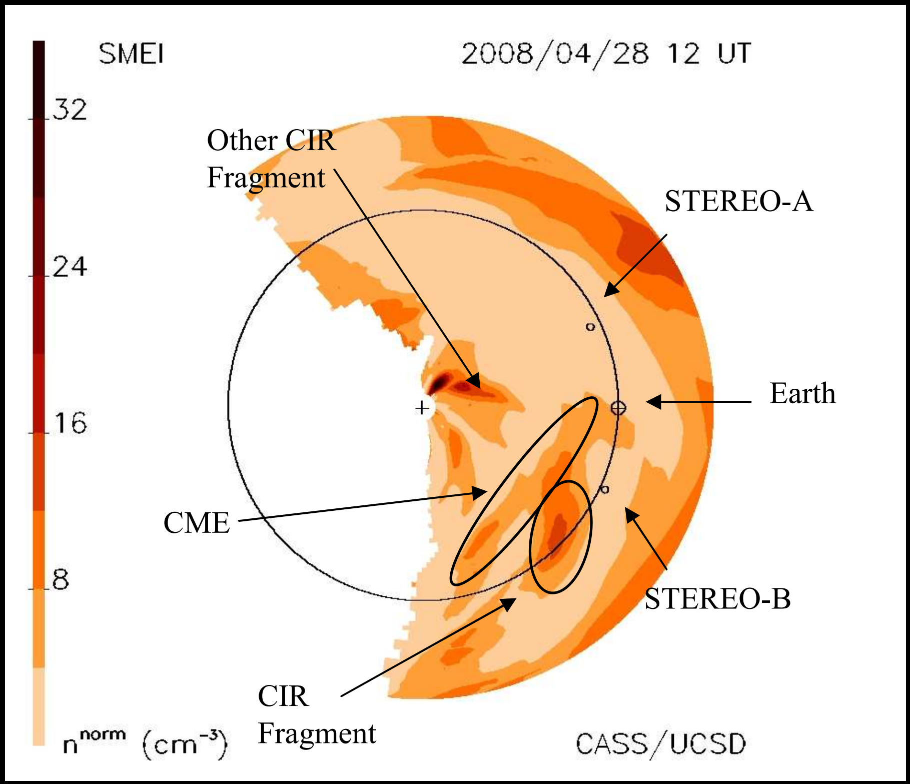
SOHO|LASCO C3
Difference Image

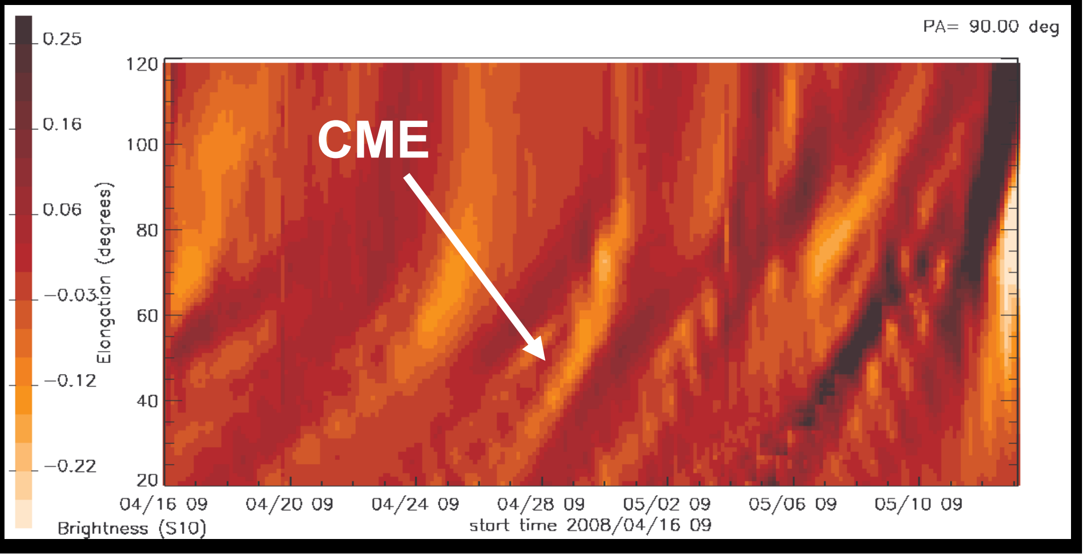


SOHO|LASCO Height-Time Plot (bottom) – All images Courtesy of CDAW CME Catalogue

SMEI 3-D Reconstruction (1)







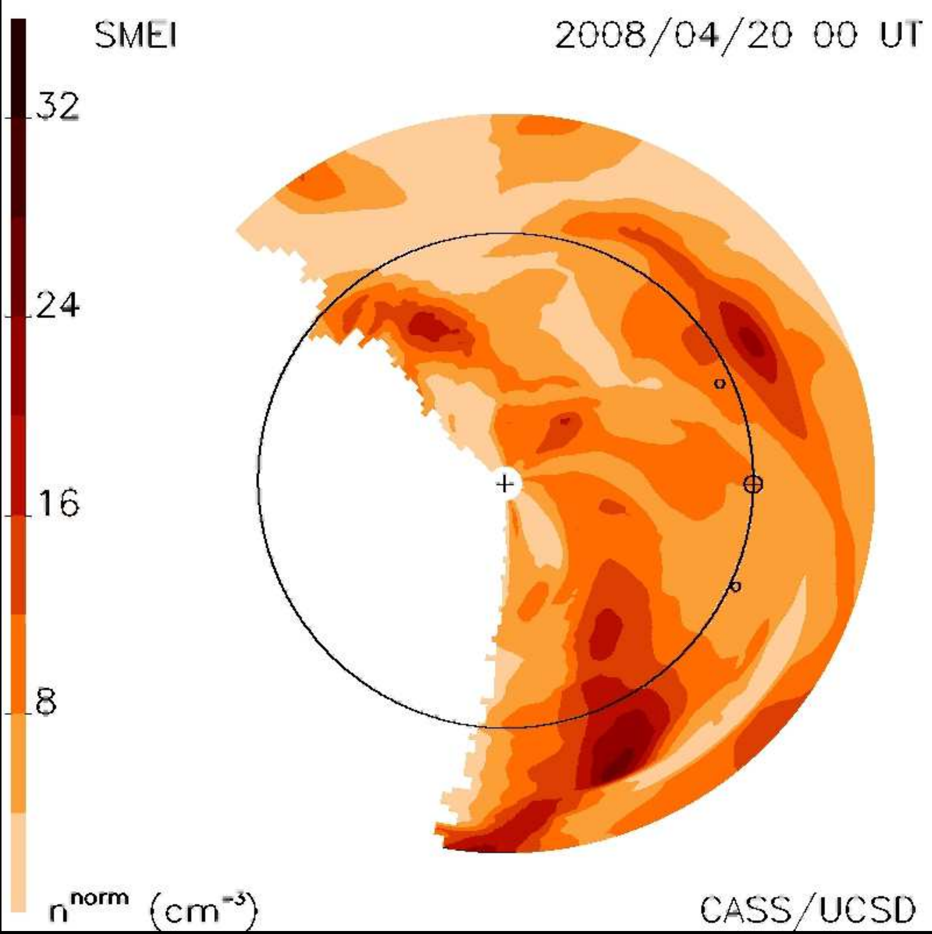
SMEI 3-D reconstructions:

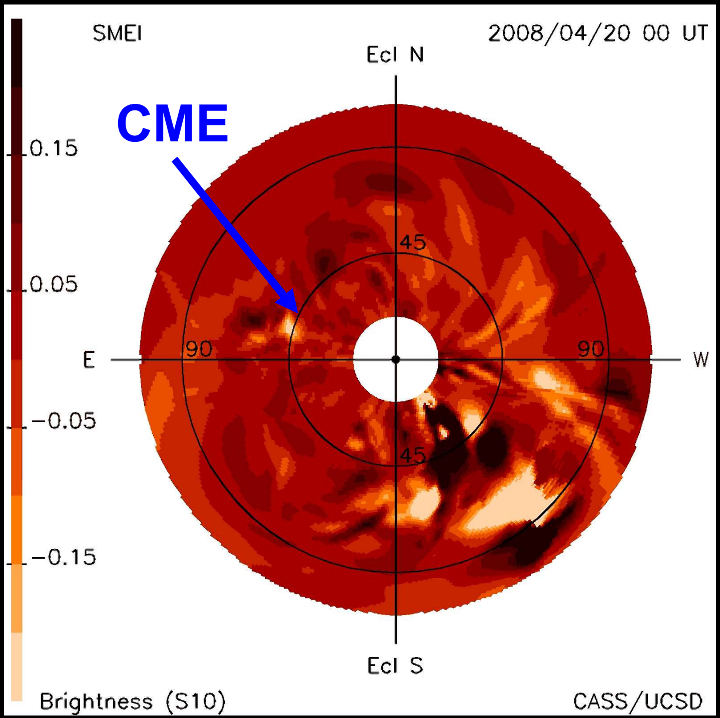
ecliptic-cut movie (above);

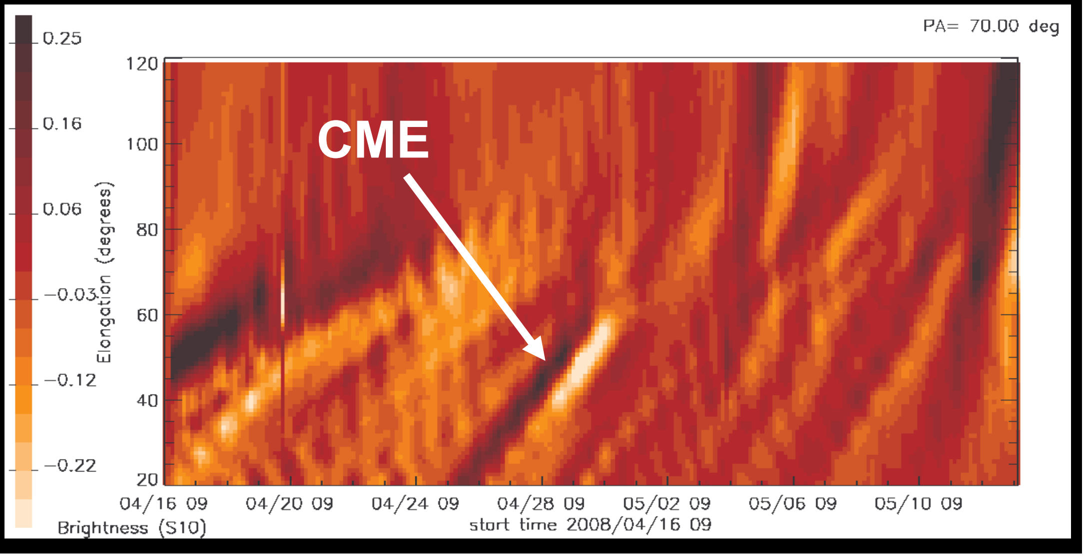
ecliptic-cut snapshot (above right);

and 12-hour differenced 90° PA J-map (right).

SMEI 3-D Reconstruction (2)



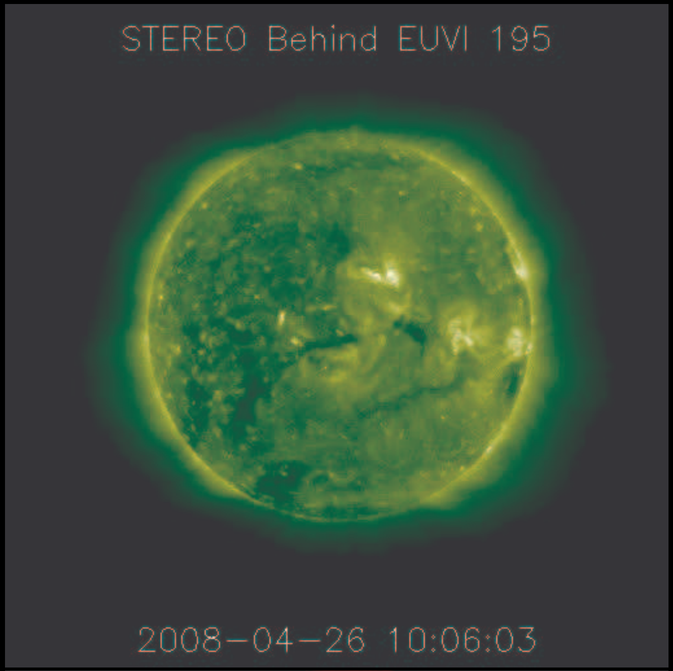




Now a 12-hour differenced 70° PA J-map (right) which shows the CME "track" more clearly.

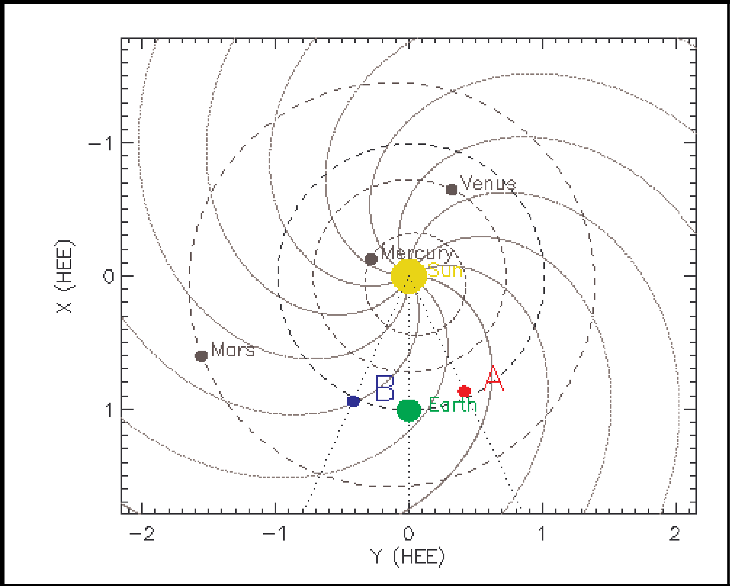
Timing consistent with *in-situ* signatures at STEREO-B

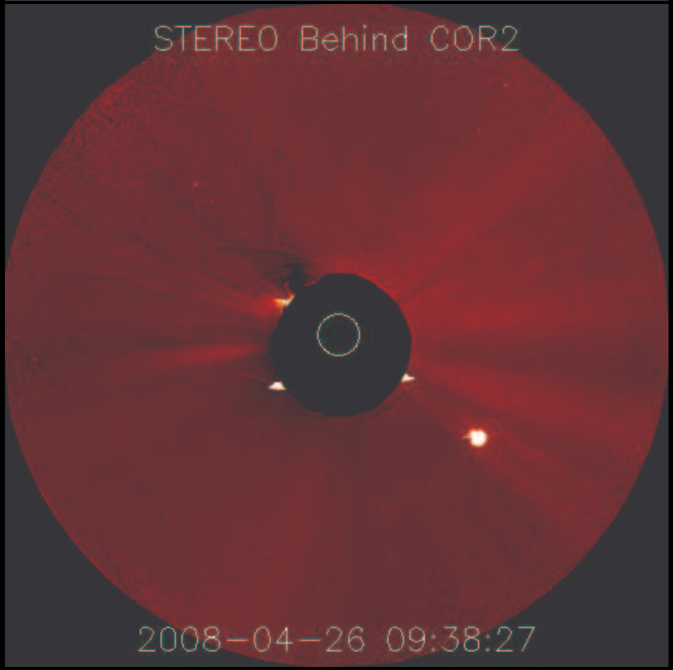
STEREO SECCHI Movies

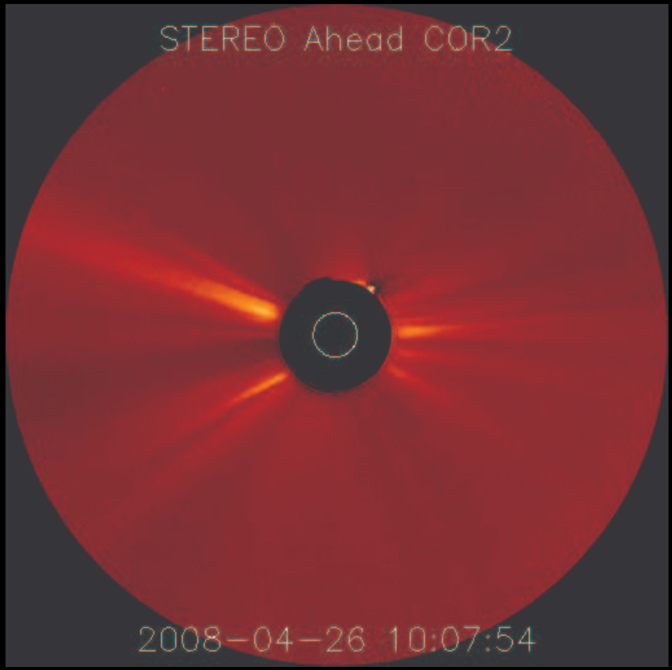


- Arcade, dimming, EIT wave, Type-II burst, faint halo CME from STEREO-B.

- Near Sun-center for STEREO-B & the Earth.



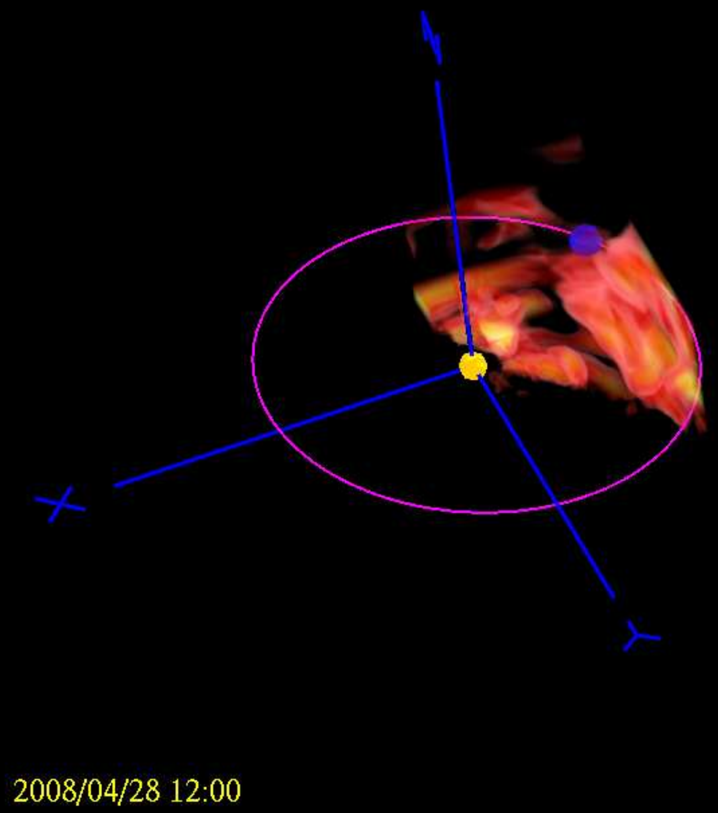


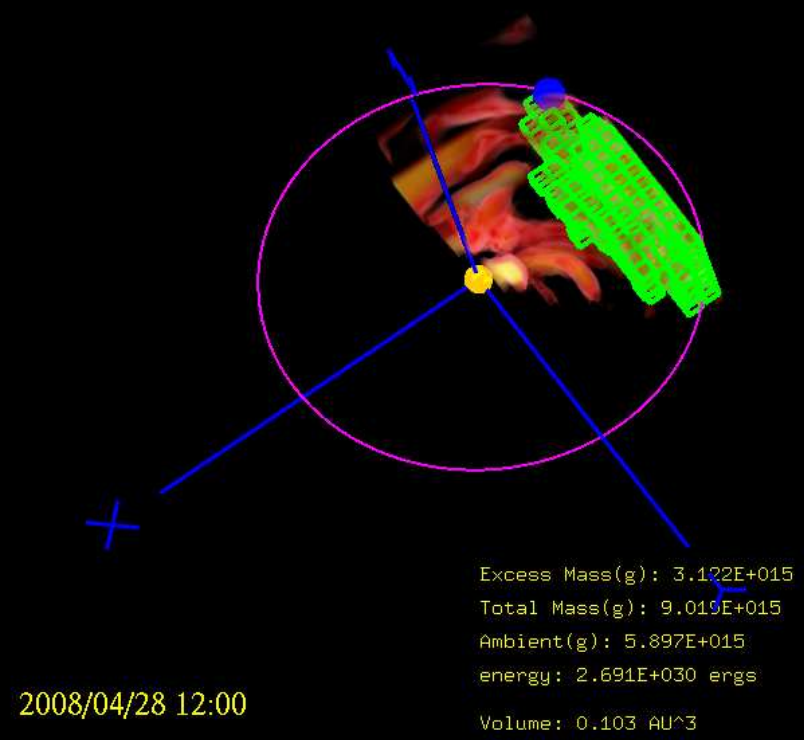


- Majority of mass seen in STEREO-A is in the ecliptic and just North of the ecliptic (as with the SMEI density reconstruction).

Movies are courtesy of Dave Webb.

SMEI 3-D Reconstruction (3)





SMEI reconstructed volume (left) and SMEI reconstructed isolated CME portion (right)

Mass of CME from CDAW CME List (LASCO) = 3.4×10^{15} g (CDAW)
Mass of CME from the SMEI 3-D reconstruction = 3.122×10^{15} g

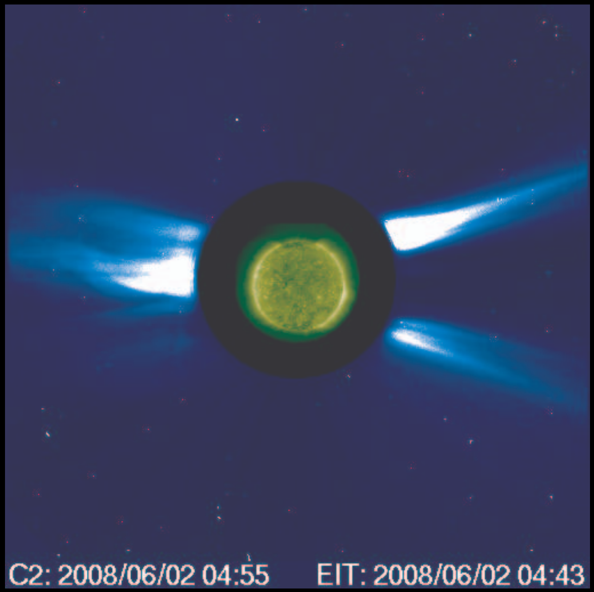
The excess mass above the ambient is what is being shown as the CME mass

STELab – LASCO - CORs: 02 June 2008 CME – First seen by SOHO|LASCO C3 at around 04:17 UT

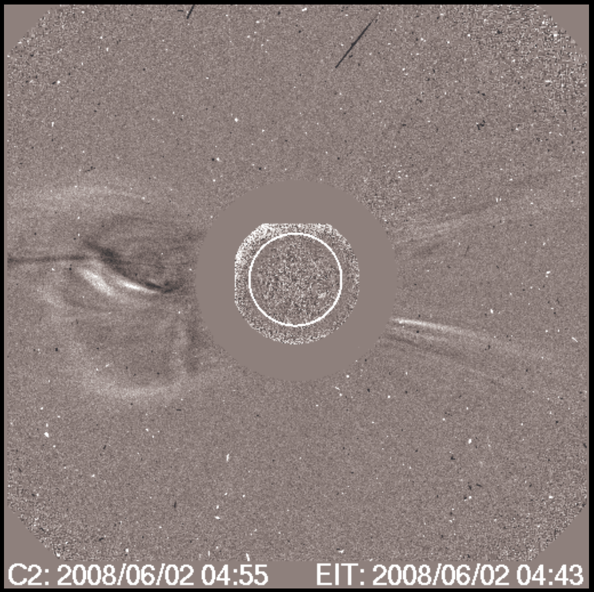
Bisi *et al*., Solar Wind 12 Proceedings, AIP Publishing, 2009

Bisi *et al*., Ap.J.Lett. (submitted), 2009

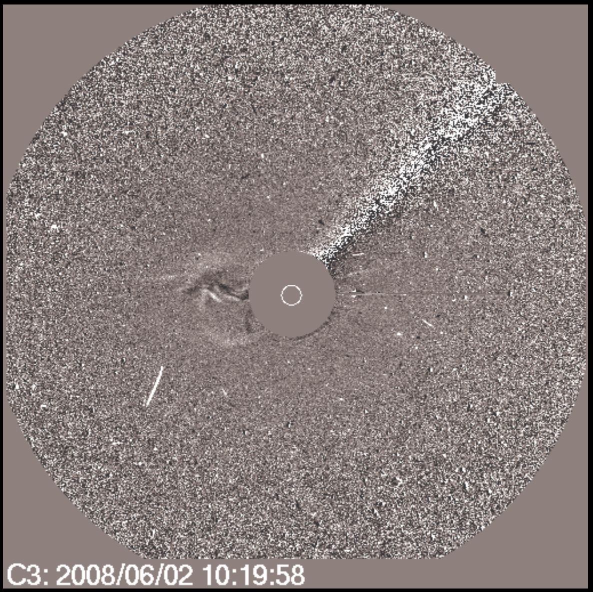
SOHO EIT and LASCO Images



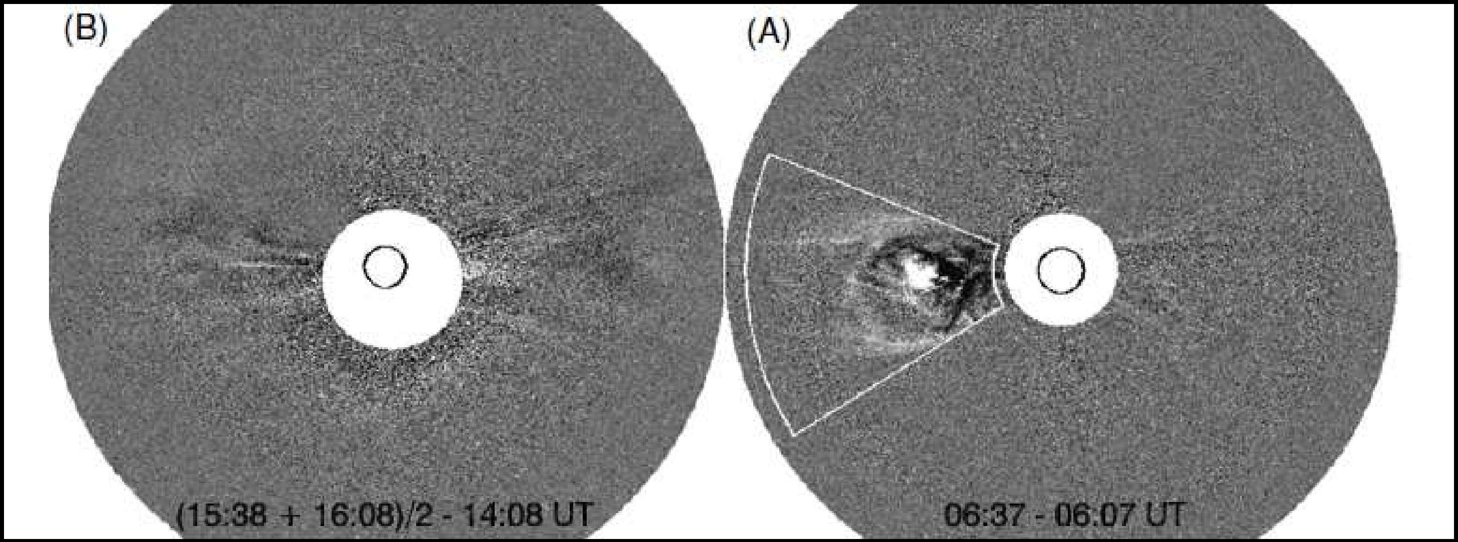
SOHO|EIT/LASCO C2
Composite Images



SOHO|LASCO C2
Difference Image



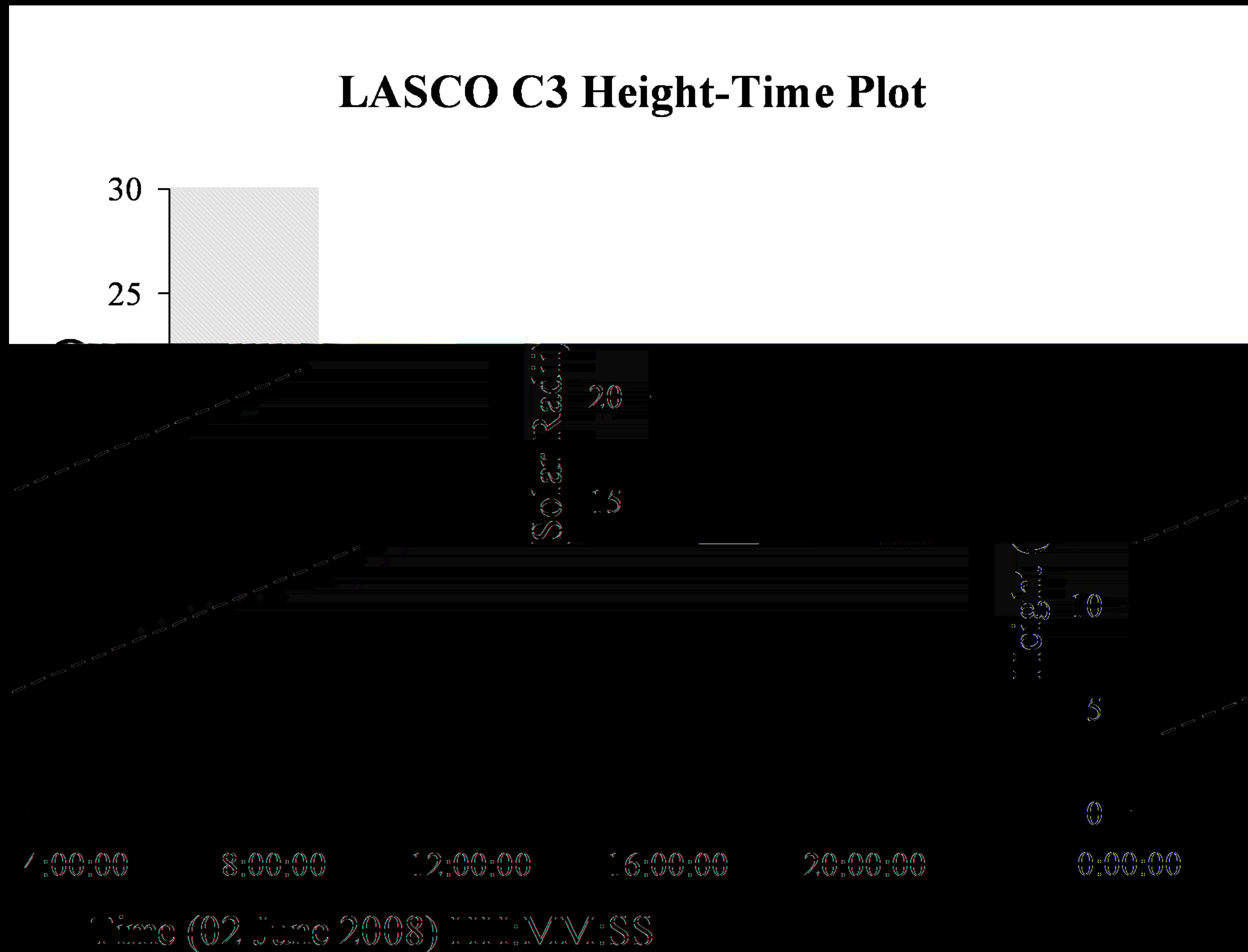
SOHO|LASCO C3
Difference Image



STEREO (B and A) COR2 difference images (from Robbrecht *et al*., Ap.J., 2009)

LASCO Height-Time Plot

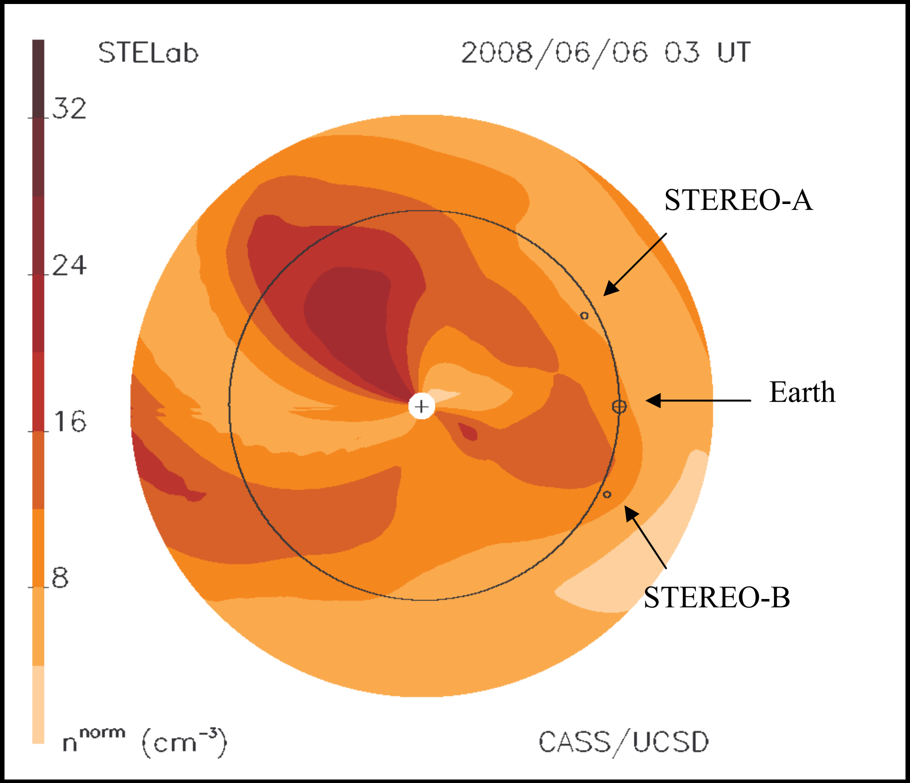
The LASCO C3 height-time (elongation-time) plot of the 02 June 2008 CME using data taken from the CDAW CME catalog. The diagonal-hashed/grey area represents the time when LASCO was down until early on 02 June 2008; thus measurements of the CME within the C3 field of view were only taken from a height of around $8R_{\odot}$.

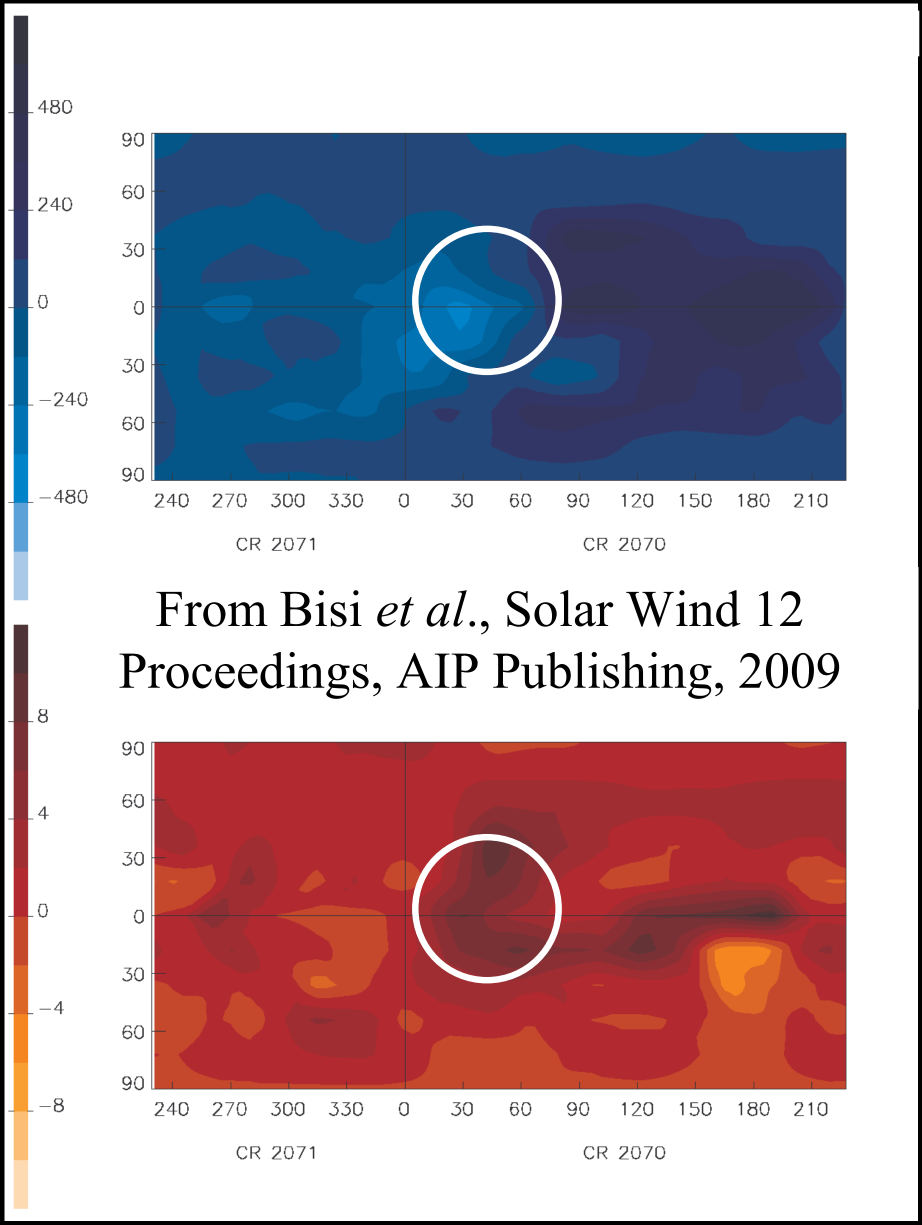


From Bisi *et al*., Ap.J.Lett. (submitted), 2009

STELab IPS 3-D Reconstruction (1)

The slow CME (LASCO plane-of-sky speed of 192 km s^{-1}) from C3 measurements

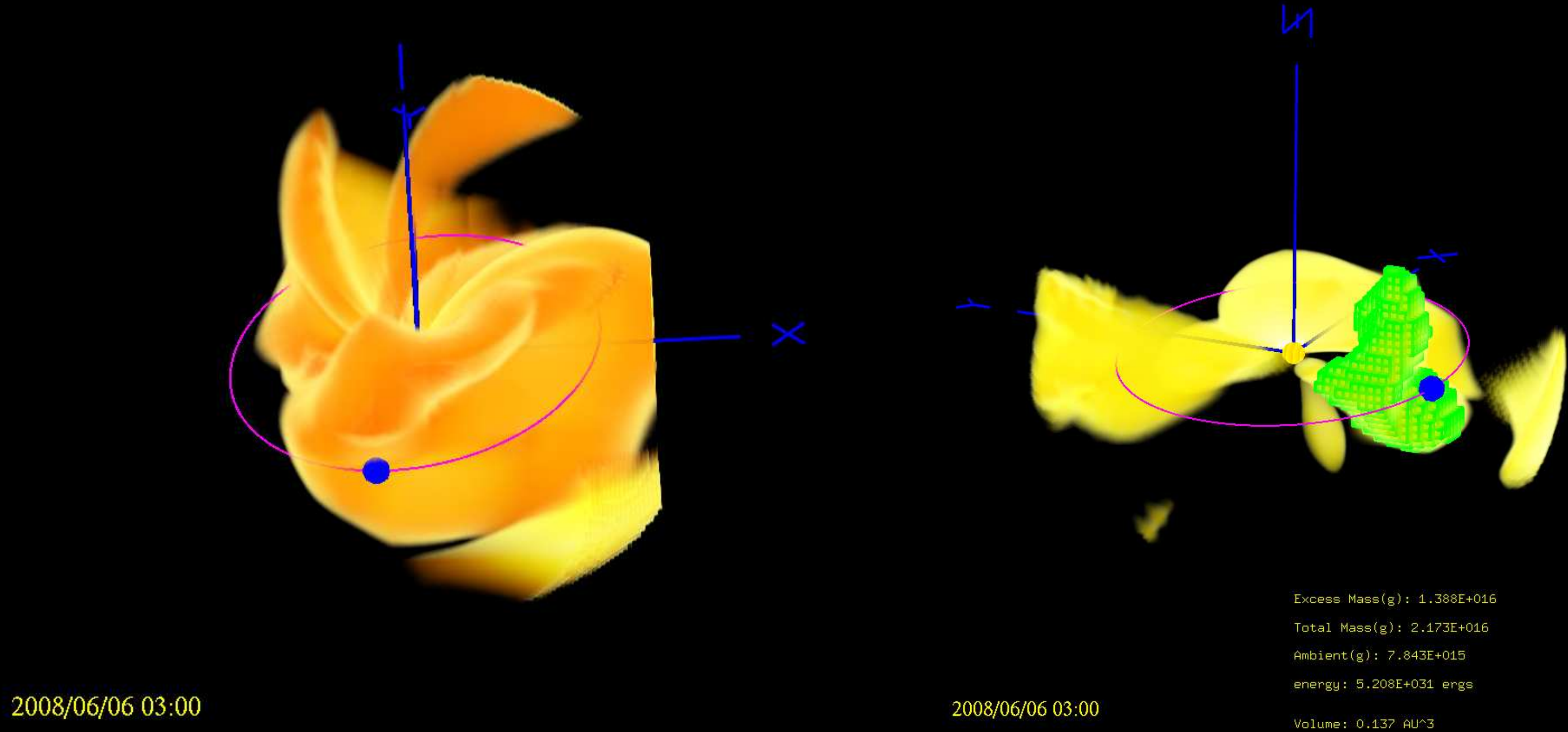




From Bisi *et al*., Solar Wind 12 Proceedings, AIP Publishing, 2009

STELab reconstructed ecliptic cut (left) – STELab reconstructed CR map differences (right)

STELab IPS 3-D Reconstruction (2)



STELab reconstructed volume (left) and STELab reconstructed isolated CME portion (right)

Source:	Excess Mass/CME Mass:	Reference:
CDAW CME Catalog (LASCO C3)	4.7×10^{14} g	CDAW CME Catalog
STEREO COR1-A	7.5×10^{14} g	Robbrecht et al. (2009)
STEREO COR2-A	3.5×10^{15} g	Robbrecht et al. (2009)
STELab IPS	1.4×10^{16} g	Our 3D Reconstruction

The excess mass above the ambient is what is being shown as the CME mass – taken from Bisi *et al*., Ap.J.Lett. (submitted), 2009

Summary and Conclusions

- The mass for the 26 April 2008 CME from the SMEI 3-D reconstructions matches well to the SOHO|LASCO mass obtained from the CDAW CME List; difficult to isolate in the 3-D reconstruction due to the presence of the CIR.

- 02 June 2008 preliminary use of differenced Carrington maps shows the CME signature at 1 AU which compares with SOHO|LASCO images plus an ecliptic cut in density shows weak interaction with STEREO-B.

- The masses for the 02 June 2008 are somewhat different from each instrument/technique; larger masses further out from the Sun may reflect mass load behind the slow-moving CME or possibly highlights differences of the two observation types.

Future Prospects and References

- There are a wealth of "tools" to understand and analyse the reconstructed observations, and to ascertain how well the IPS and SMEI 3-D reconstructions work; of primary importance here is the comparison with further spacecraft measurements and observations.

- Bisi, M.M., B.V. Jackson, P.P. Hick, J.M. Clover, S. Hamilton, M. Tokumaru, and K. Fujiki, "Large-Scale Heliospheric Structure during Solar-Minimum Conditions using a 3D Time-Dependent Reconstruction Solar-Wind Model and STELab IPS Observations", Solar Wind 12 Proceedings, AIP Publishing, 2009

- Bisi, M. M., B. V. Jackson, P. P. Hick, A. Buffington, J. M. Clover, M. Tokumaru, and K. Fujiki, "Three-Dimensional Reconstructions and Mass Determination of the 02 June 2008 LASCO Coronal Mass Ejection using STELab IPS Observations", The Astrophysical Journal Letters (Submitted), 2009

- Robbrecht, E., S. Patsourakos, and A. Vourlidas, "No Trace Left Behind: STEREO Observations of a Coronal Mass Ejection Without Low Coronal Signatures", The Astrophysical Journal, 701:283–291, 2009

http://stesun5.stelab.nagoya-u.ac.jp/uhf_ant-e.html

http://cdaw.gsfc.nasa.gov/CME_list/

Final Acknowledgements

Thanks to CDAW for making their data available on the web: "This CME catalog is generated and maintained at the CDAW Data Center by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA".

Thanks to the NSF (grant ATM0852246) and NASA (grant NNG05GM58G) for their general funding while working on these analyses, and additional funding through the NSF SHINE Postdoctoral Fellowship Program (grant ATM0925023) to M.M. Bisi. In addition, thanks to STFC (in the UK) for funding while working on continued analyses of these events at Aberystwyth University.

The STELab IPS observations were carried out under the solar wind program of the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University.

Further Info…

IPS: *http://ips.ucsd.edu/*

SMEI: *http://smei.ucsd.edu/*

Thanks for listening!