Lessons Learned from SOHO: The Role of SOHO in STEREO and Solar-B Mission Science

Simon P. Plunkett
Naval Research Laboratory
STEREO/Solar-B Science Planning Workshop
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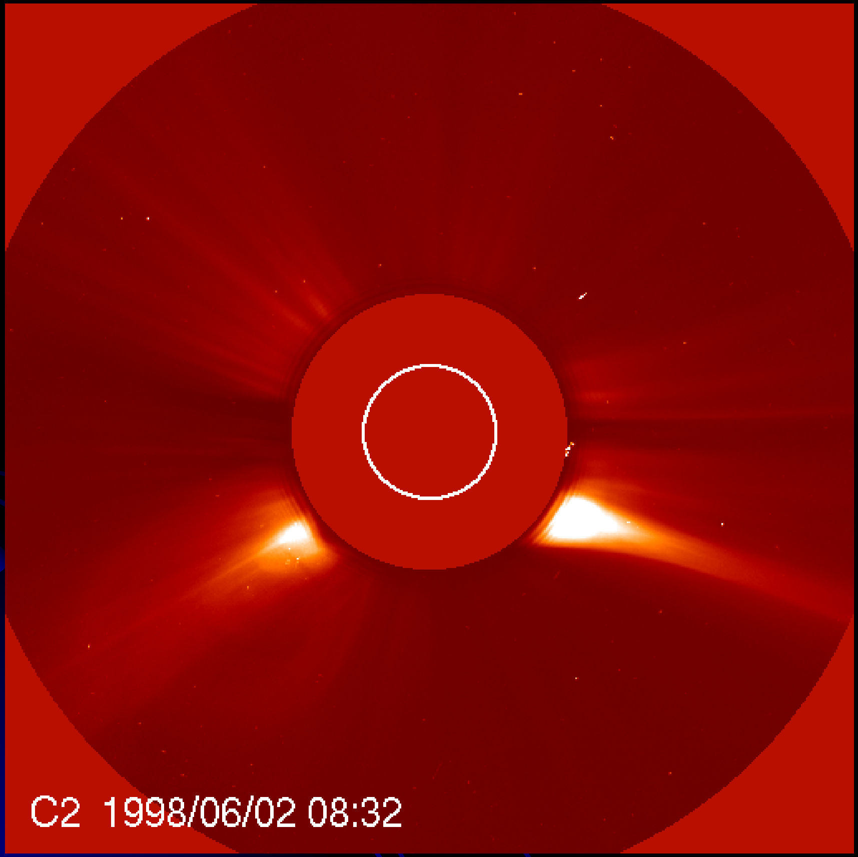
Topics

- Selected science highlights from SOHO relevant to STEREO and Solar-B mission objectives.
- Lessons learned from scientific planning and operations of SOHO instruments.
- Contributions of SOHO to science objectives of STEREO and Solar-B.
- Focus on scientific objectives related to CMEs.

CME Observations with SOHO

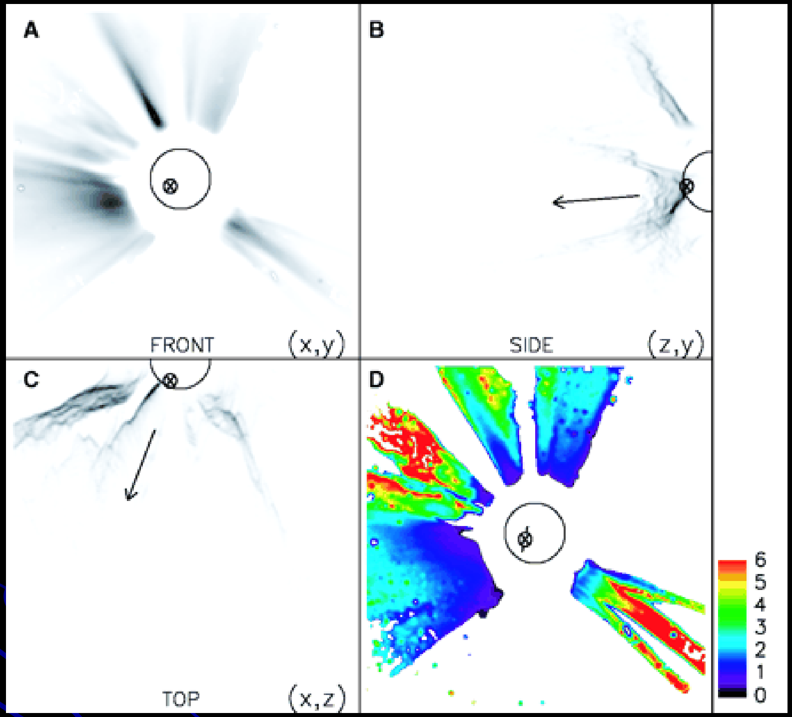
- Over 8,000 CMEs documented in LASCO CME catalog from 1996 to 2005, including speed, width, and position angle measurements:
  - http://cdaw.gsfc.nasa.gov/CME_list
- Masses have been calculated for more than 4,000 CMEs.
- Solar cycle variation of CME properties has been studied in detail.
- Internal structure and dynamics of CMEs has be studied in much greater detail than previously possible.
- Halo CMEs constitute ~11% of the total population of CMEs.
- Many CMEs can now be detected automatically using CACTUS algorithm (Robbrecht and Berghmans 2004).

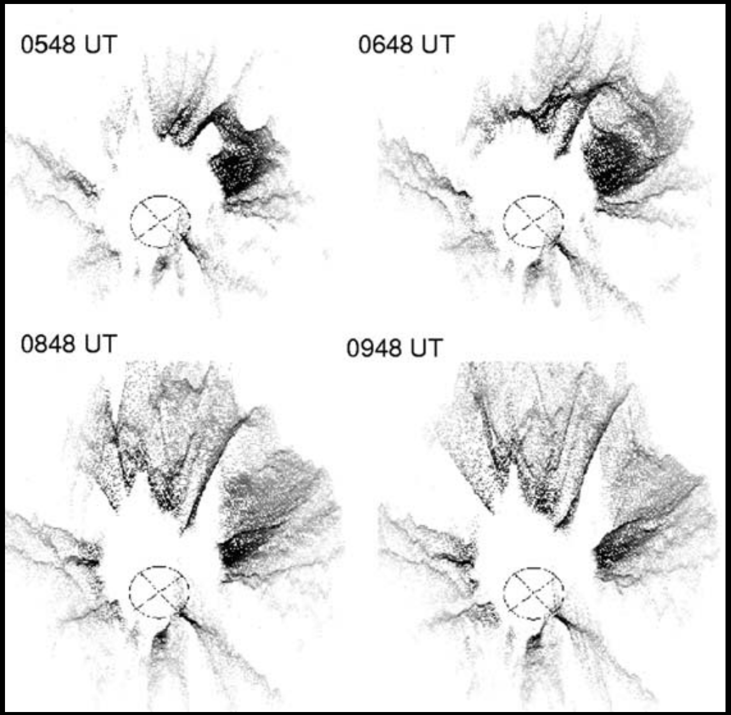
Internal Structure of CMEs



- Movie shows a CME with the classic 'three-part' structure.
- Does this CME structure include a flux rope?
- How does this structure correspond to interplanetary measurements?

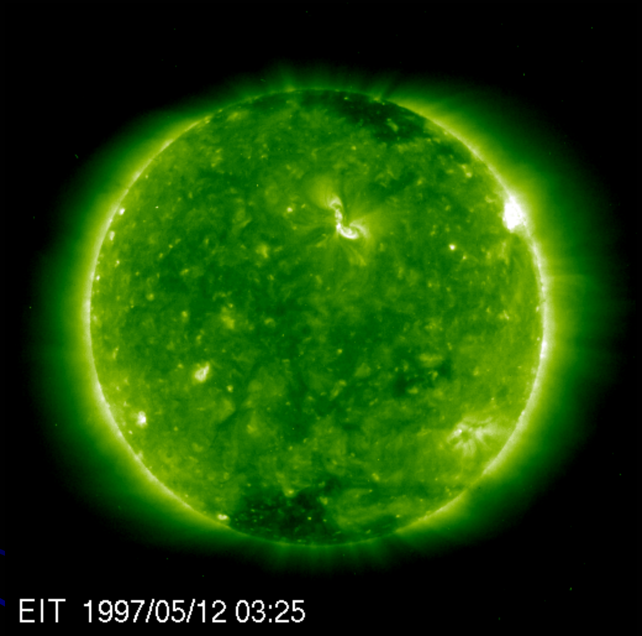
Three-Dimensional Structure of CMEs

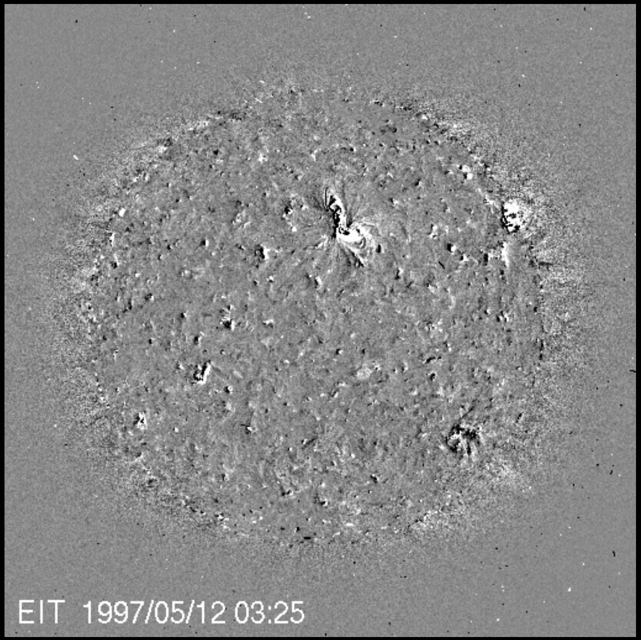




- Visualizations of the three dimensional structure of two CMEs reconstructed from white-light polarization measurements (Moran and Davila 2004, Dere et al 2005).

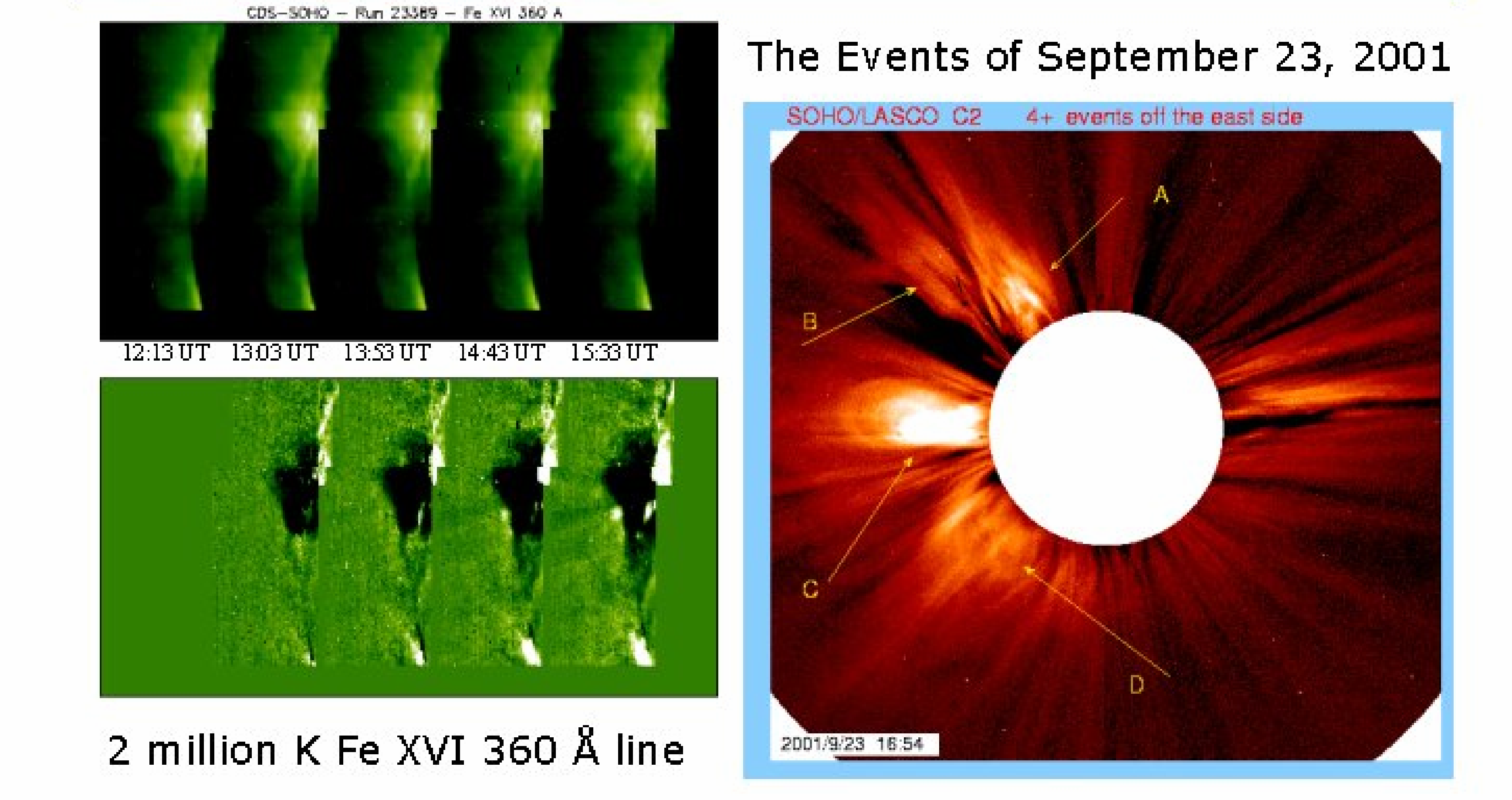
CME Initiation: Waves and Dimming in the Solar Atmosphere





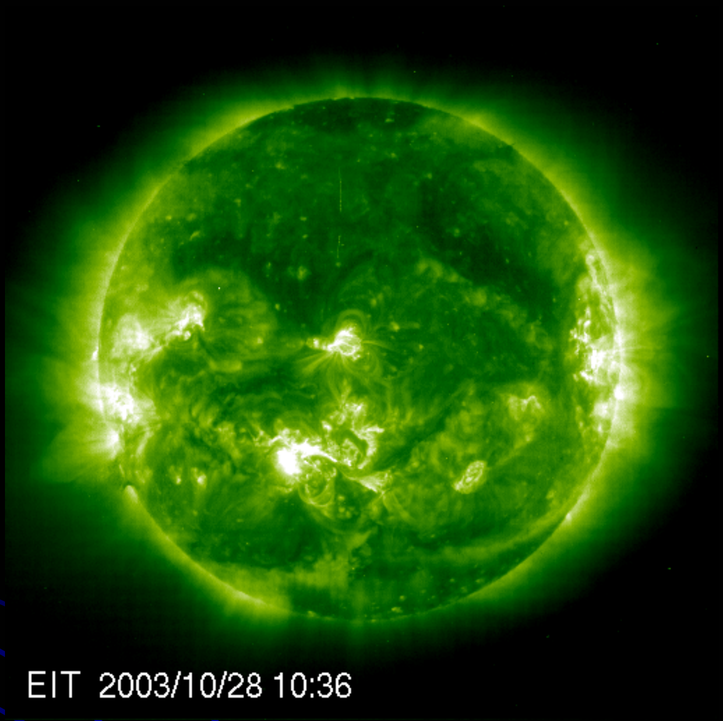
- EIT waves identified as a diffuse emission enhancement propagating radially outward from eruption site, followed by expanding 'dimming regions' (Thompson et al 1998).
- Very strong correlation between EIT waves and CMEs (Biesecker et al 2002).
- Usually observed in Fe XII 195 Å images, but recently observed in Fe XV 284 Å (Zhukov and Auchere 2004).
- Identified as a fast-mode MHD wave dominated by the acoustic mode (Wu et al 2001).

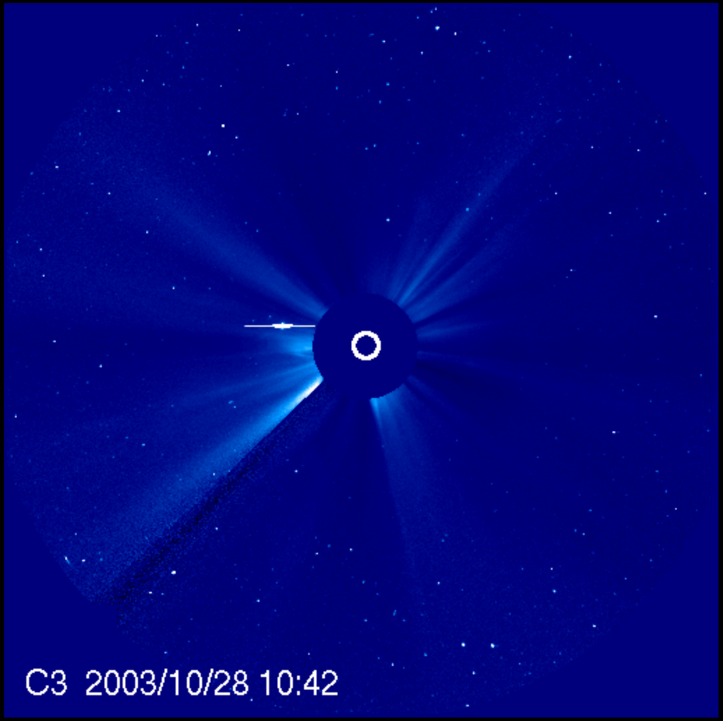
EUV Spectroscopy of CME Onset



- CDS limb scans in several emission lines revealed coronal dimming in the low corona under CMEs observed with LASCO (Harrison and Lyons 2000, Harrison et al 2003).

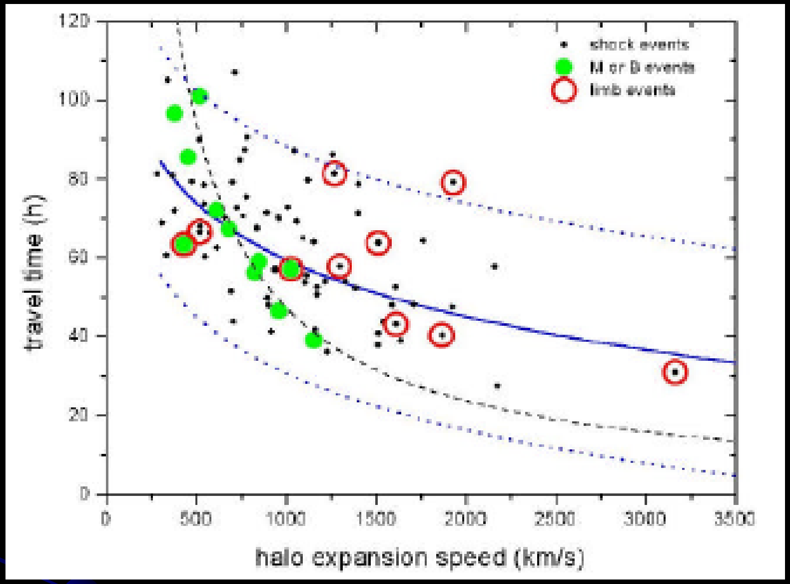
Space Weather Effects (1 of 3)



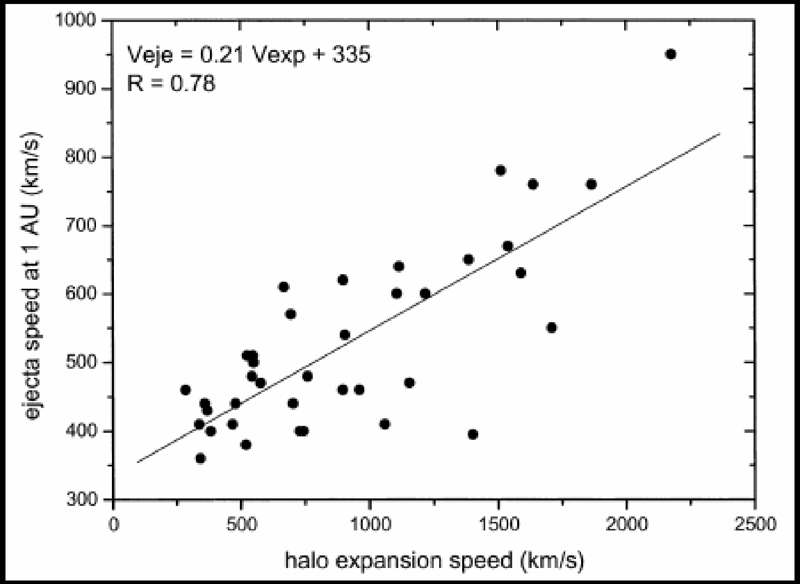


- Firmly established that CMEs are the major solar drivers of non-recurrent geomagnetic storms and solar energetic particle events.
- ~11% of all CMEs detected by LASCO are classified as ‘halo’ CMEs (but note recent caveats by St. Cyr et al 2005).
- Combination of LASCO and EIT images allows events directed towards Earth (frontside) to be distinguished from those directed away from Earth (backside).

Space Weather Effects (2 of 3)



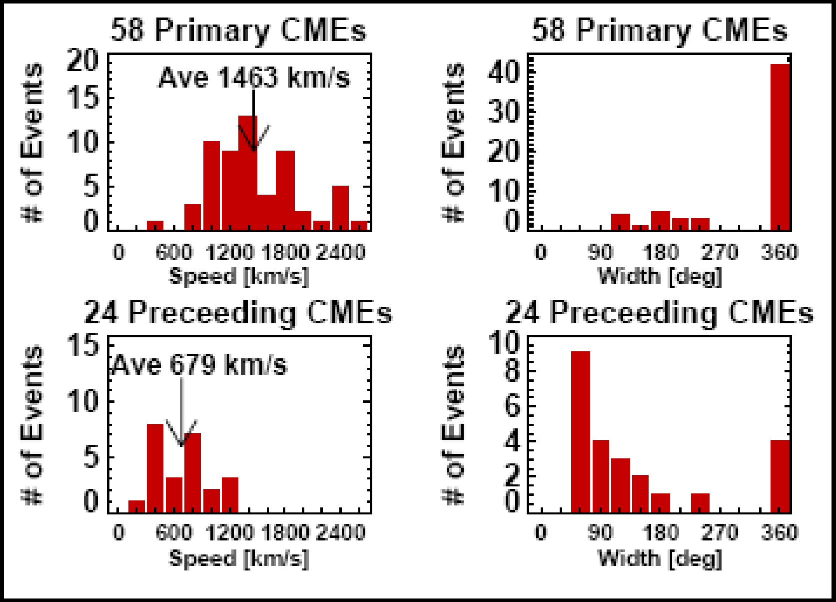
$$Ttr = 203 – 20.77 \times \ln(Vexp)$$



$$Veje = 335 + 0.21 \times Vexp$$

- Halo expansion speed can be used to infer both the travel time to 1 AU, and the peak speed of the ejecta at 1 AU (Schwenn et al 2005, Dal Lago et al 2004).

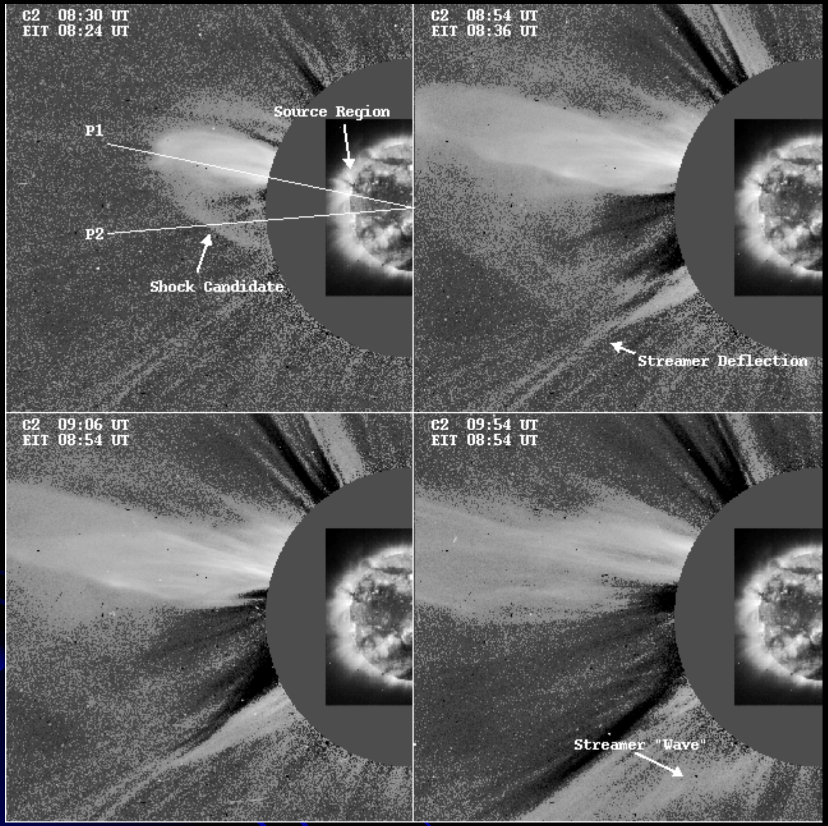
CMEs and Solar Energetic Particles

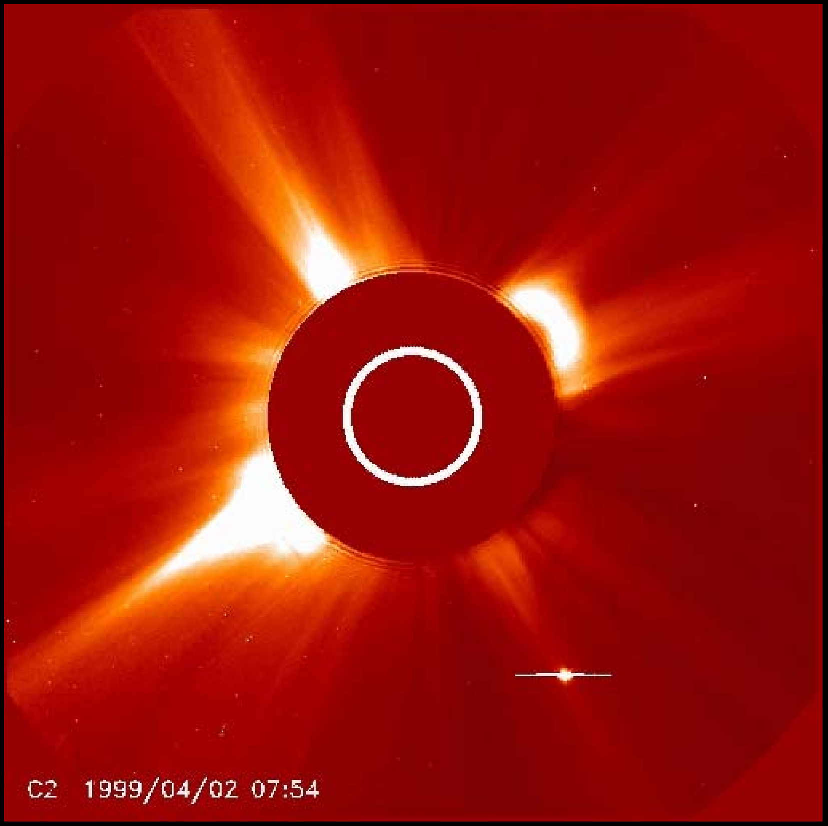


Apparent speeds and widths of CMEs associated with large solar energetic particle (SEP) events from 1997-2002 (Gopalswamy et al 2003).

- Large SEP events are caused by shocks driven by fast (>900 km/s), wide (>90°) CMEs, usually originating in the western hemisphere.
- High intensity SEP events are often preceded by other wide (>60°) CMEs from the same region, suggesting ‘preconditioning’ of the eruption region for the later CME.

Shock Detection: Coronal Imaging

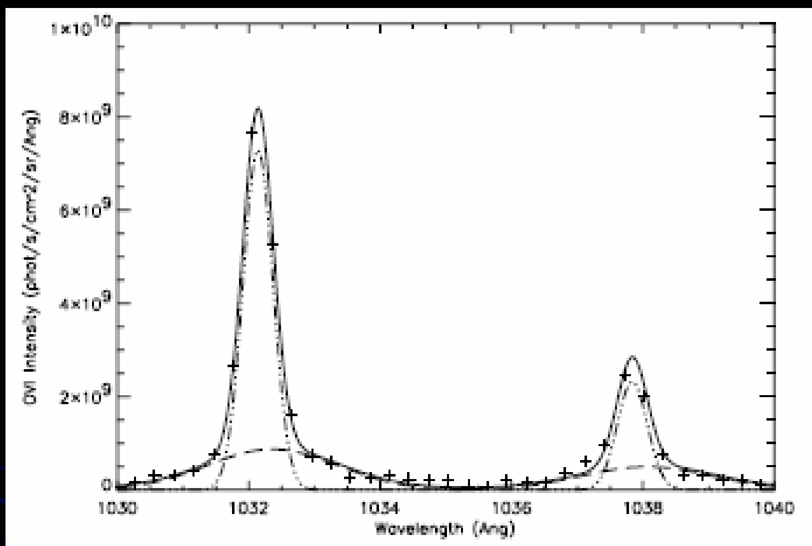




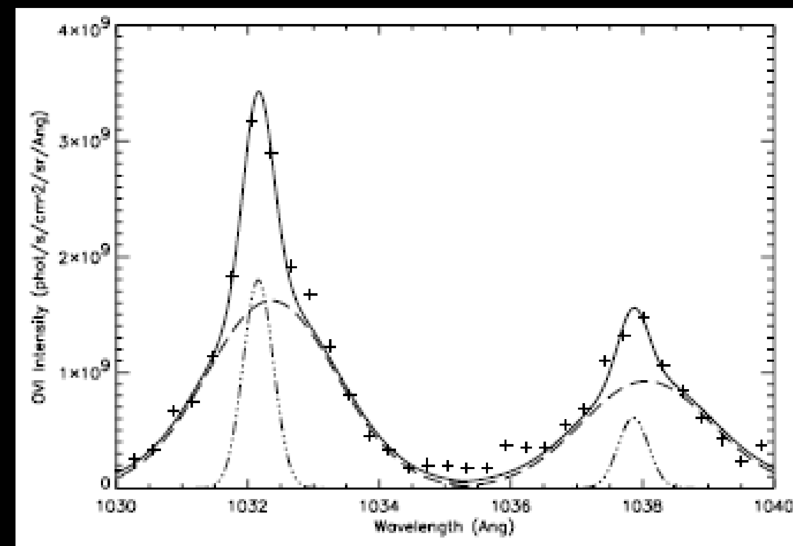
The movie shows a filament CME off the east limb on April 2, 1999. The sharp feature along the southern flank of the CME is seen hitting and deflecting the SE streamer (as a wave should). The sharpness and speed (800 km/s) of the feature indicate that it is very likely a shock. Further analysis demonstrated that this is indeed the case (Vourlidas et al 2003).

Shock Detection: Coronal Spectroscopy

Pre-shock



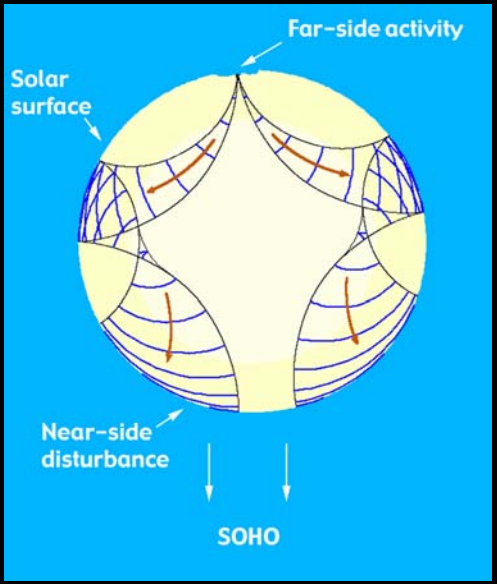
Post-shock

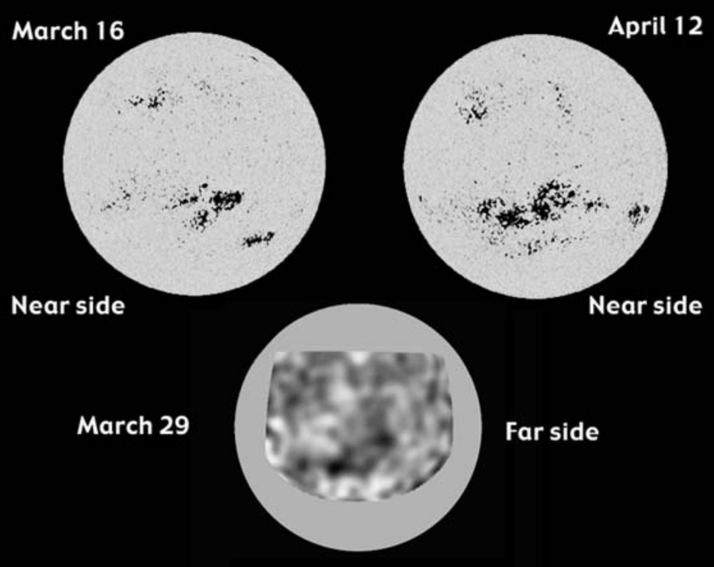


UVCS observations of O VI λ1032 and λ1037 profiles at 1.7 Rs showing the passage of a CME-driven shock wave on March 3, 2000 (Mancuso et al 2002).

- Doppler dimming of line intensities and broadening of the line profiles are evidence of shocked plasma along the line of sight.
- UV spectroscopy can be used to determine plasma parameters such as shock compression ratio, electron and ion temperatures and heating mechanisms.

Far-Side Imaging: Long-Term Forecasting?

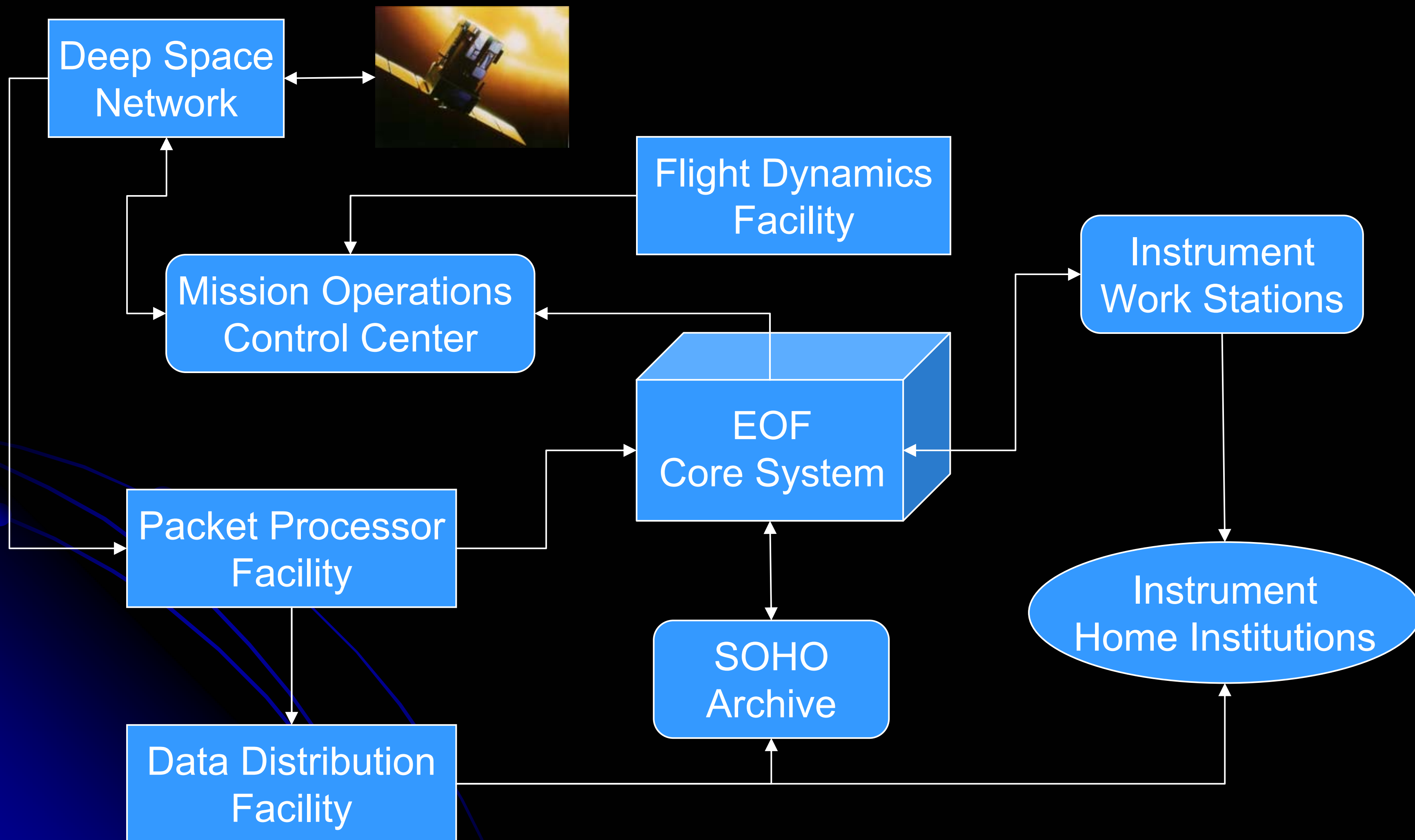




Click to view movie

Imaging of active regions on the far side of the Sun using helioseismic holography (Lindsey and Braun 2000).

SOHO Mission Operations Overview



SOHO Planning Cycle

Meeting	Operational Period	Output
Quarterly SWT	3 months starting in 1 month	Overall priorities, general plan
Monthly SPWG	Month starting in 2 weeks	Refine observational priorities, schedule specific programs
Weekly	Week starting in 3 days Week starting in 10 days	Detailed timeline Revised monthly plan
Daily	Current Day Next Day Day After Next	Optimize pointing targets Select pointing targets Revised weekly plan

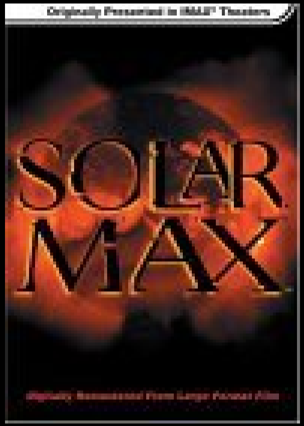
Joint Observing Programs

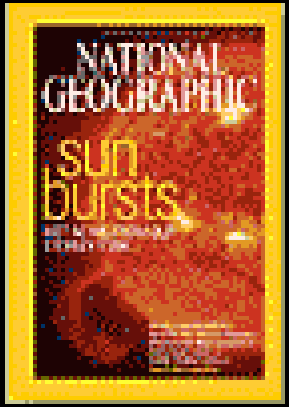
- Joint Observing Programs (JOPs) are coordinated plans for the study of specific solar phenomena using multiple instruments.
  - Many JOPs involve collaborations with other space-based or ground-based observatories.
  - 183 science JOPs and 13 intercalibration JOPs on SOHO web site as of September 2005.
- Individual investigator submits a JOP proposal, which is reviewed and scheduled by the SPWG following discussion with the relevant instrument teams.
- JOP leader is responsible for coordinating the observations (e.g. target selection) and data analysis.
- Important that investigators be aware of the capabilities of instruments when developing JOP proposals.

Public Access to Data

- Open and easy access to data and analysis software via Internet or hard media leads to widespread use of data and increased exposure for mission science by the solar and heliospheric physics communities.
  - Analysis software made available through widely-used IDL-based Solarsoft system.
  - Almost 100% of active researchers in solar physics around the world have published papers using or interpreting SOHO data.
  - Large number of publications using SOHO data (4161 publications in SOHO database through September 2005).
- Involvement of amateurs leads to science that might not get done by the 'establishment' community.
  - ~90% of SOHO comets discovered by amateurs.

Education and Public Outreach

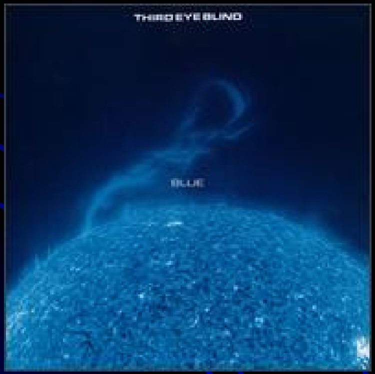




The Washington Post

SPIEGEL ONLINE

CNN.com



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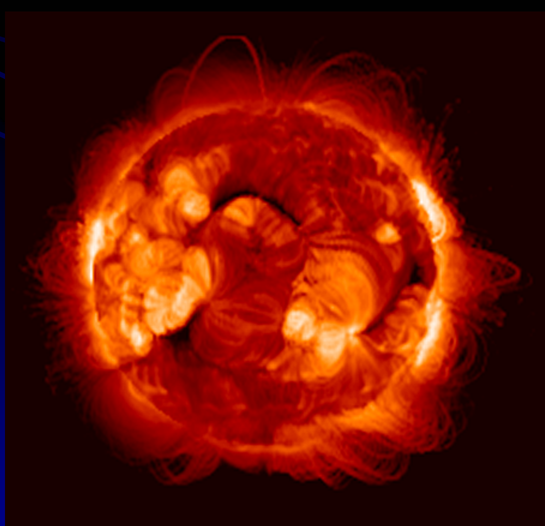
SOHO Contributions to STEREO Mission Science

- Third eye for image reconstruction, stereoscopy (tie points), visualization from multiple views, measurement of solar wind parameters at multiple locations within large-scale structures.
- Head-on view from Sun-Earth line of events seen broadside by STEREO at larger separation angles.
- In-situ measurements of Earth-directed events observed by HIs and SWAVES.
- UV and EUV spectroscopy on-disk and above limb (source regions, shocks, current sheets).
- Line-of-sight magnetograms, particularly for Earth-directed events.
- Imaging and spectroscopy of solar wind in streamers and coronal holes.
- Cross-calibration of coronagraphs and EUV imagers early in mission when STEREO spacecraft are near Earth.

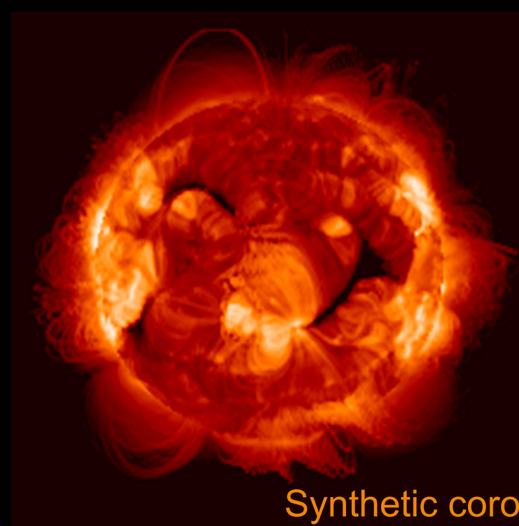
Stereoscopy of Coronal Loops

- SECCHI will use triangulation to determine the 3D structure of loops based on knowledge of the viewing geometry and common features in both images that are identified by the user (‘tie points’).
- Reconstruction errors are smaller with larger separation angles, but it is more difficult to identify the same loop in both images at larger separation angles.
- Third eye in the middle of the two STEREO views will help to identify the same loop in STEREO A and B.

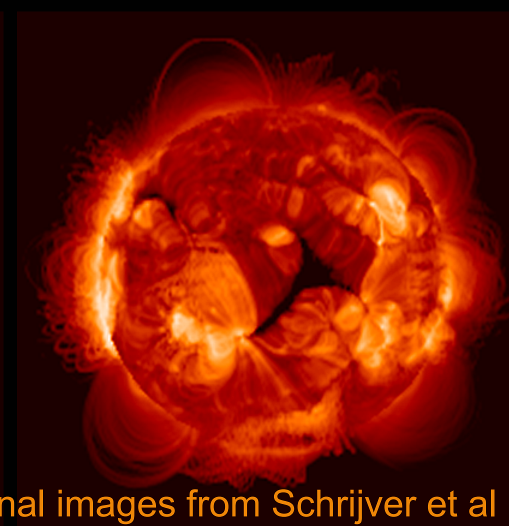
STEREO B at -22º



SOHO at 0º



STEREO A at 22º

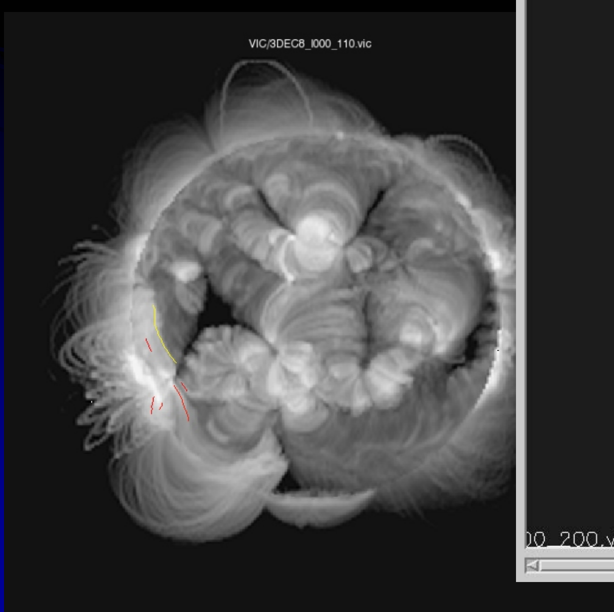


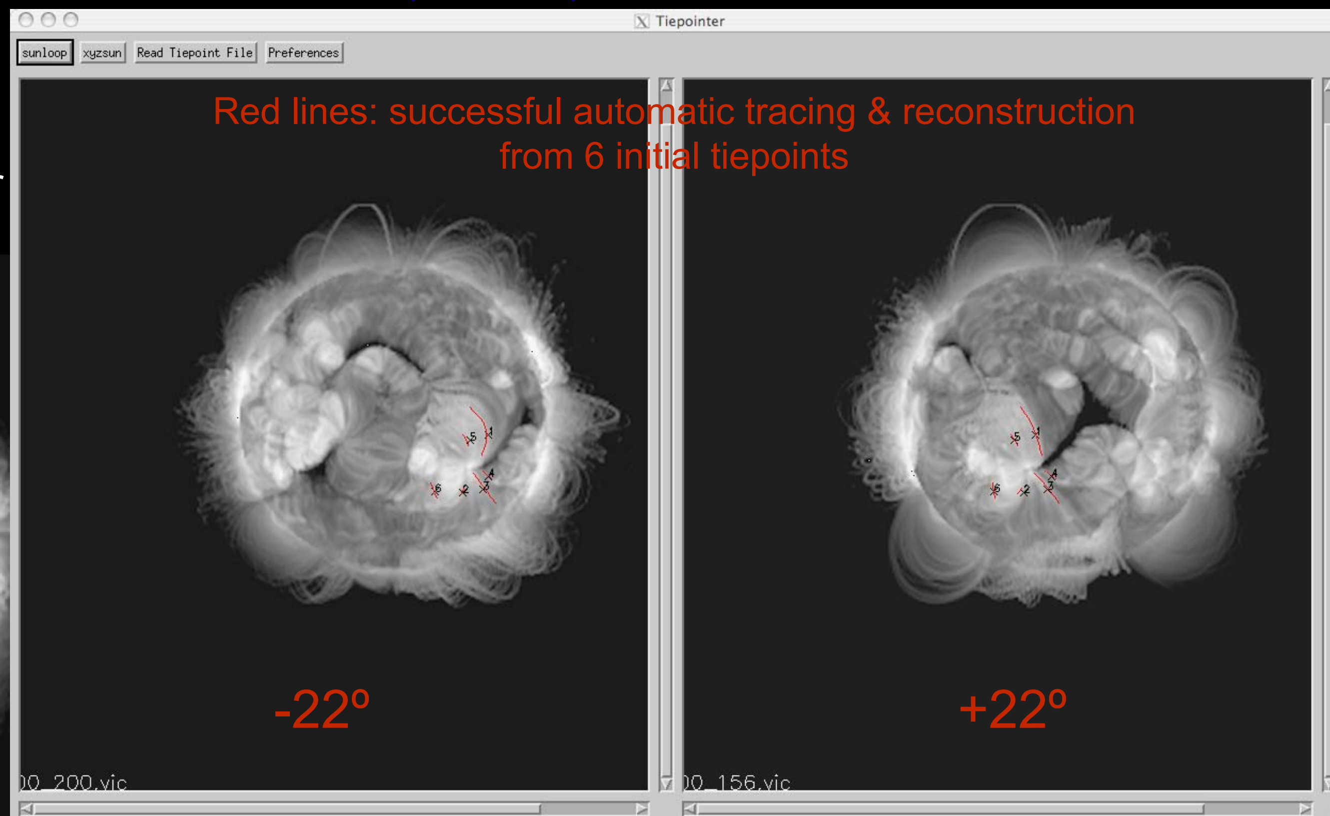
Synthetic coronal images from Schrijver et al

Stereoscopy with JPL Tiepointer Tool

- Reconstruction from synthetic STEREO views with 44° separation.
- Middle (Earth) view is only used to help identify the same loops in both STEREO images.
- 6 loop segments could be identified, traced, and reconstructed.

Below: Side view of reconstructed loops used for verification





Three-Dimensional Reconstruction of a CME (1 of 3)

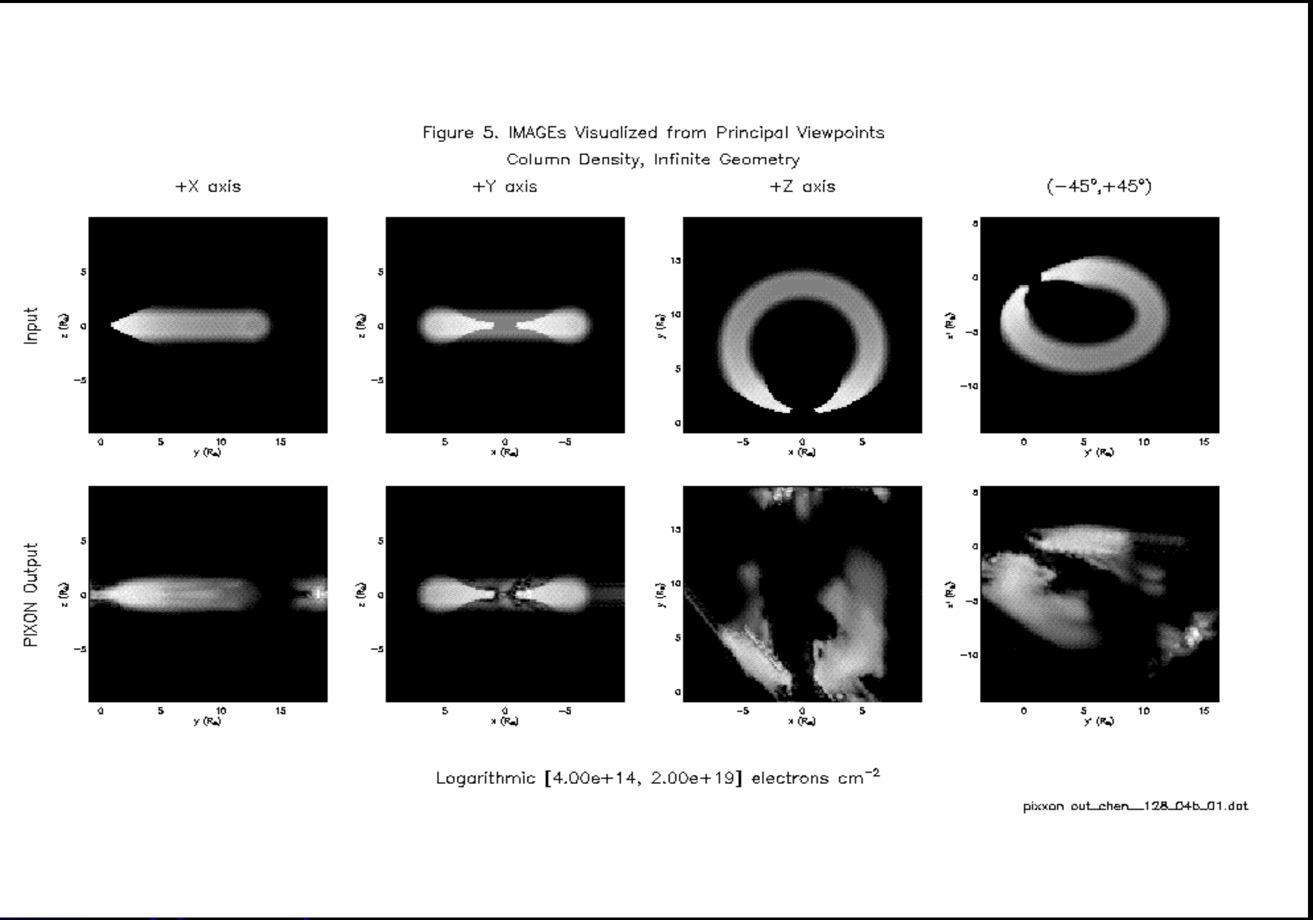


Image visualization of a flux-rope model of a CME (model courtesy of J. Chen).
Top row: Input model data.
Bottom row: Reconstruction from two viewpoints at ± 37° from the flux rope axis.

Three-Dimensional Reconstruction of a CME (2 of 3)

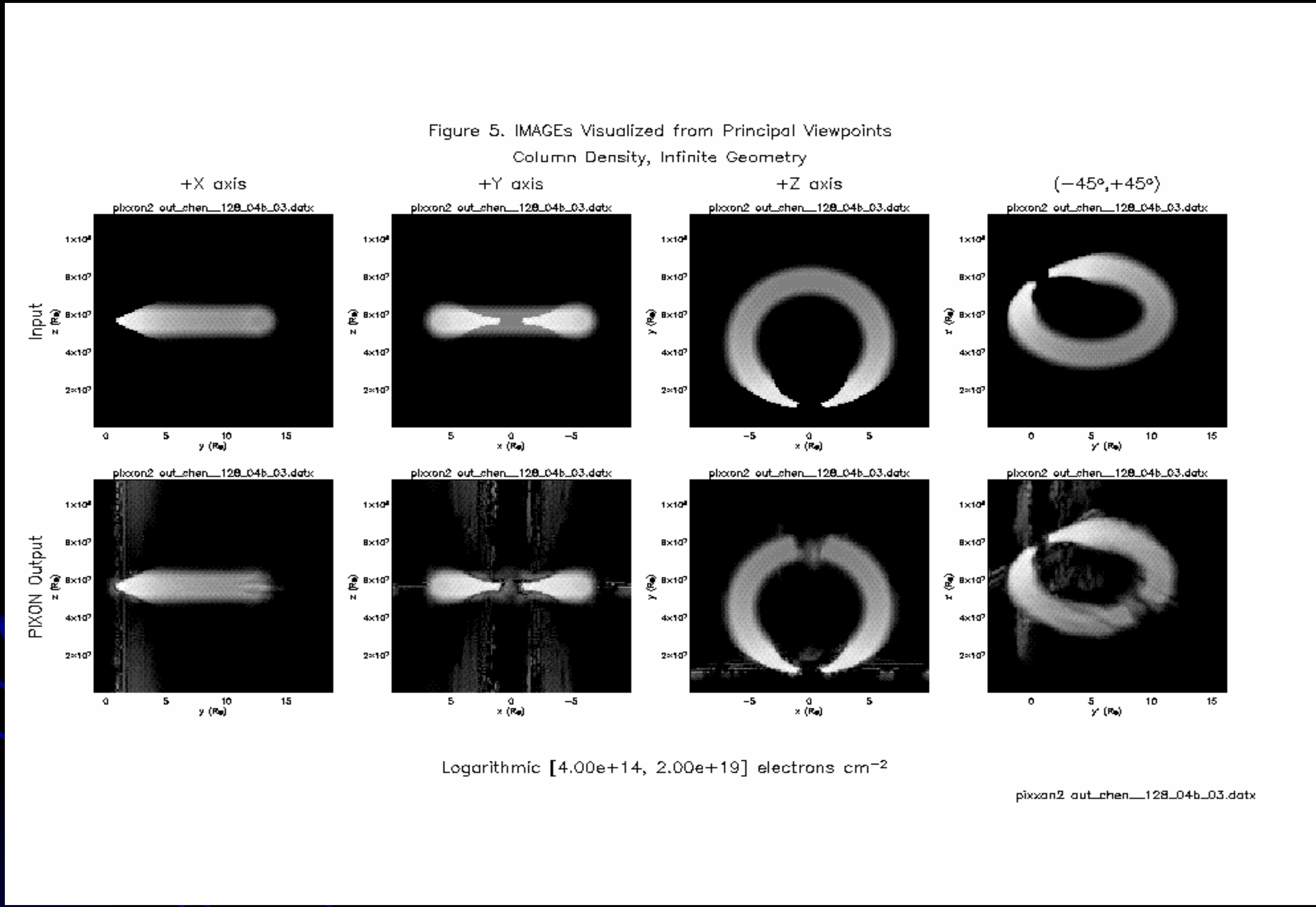


Image visualization of a flux-rope model of a CME (model courtesy of J. Chen).
Top row: Input model data.
Bottom row: Reconstruction from three orthogonal viewpoints.

Three-Dimensional Reconstruction of a CME (3 of 3)

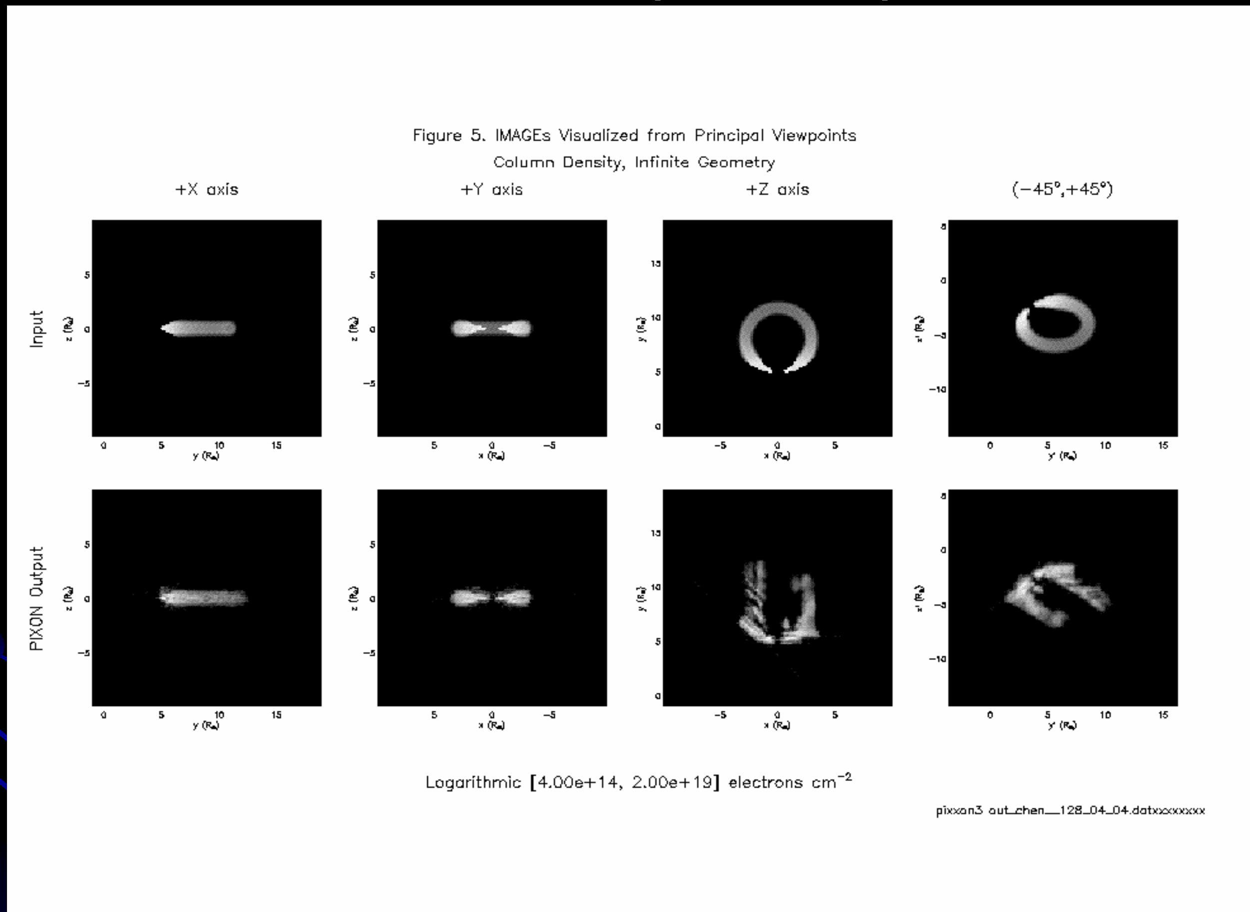


Image visualization of a flux-rope model of a CME (model courtesy of J. Chen).
Top row: Input model data.
Bottom row: Reconstruction from three viewpoints at ± 37° and 0° from the flux rope axis.

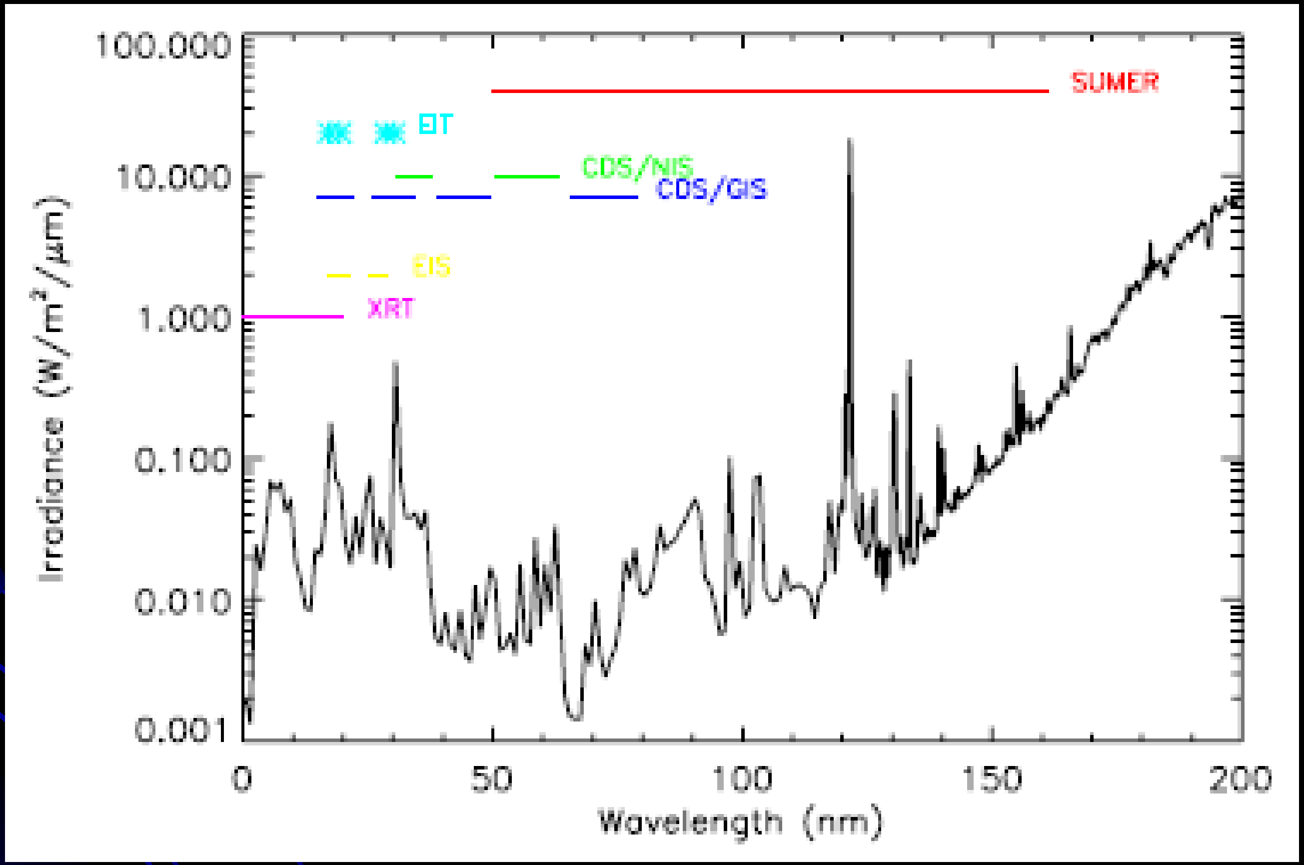
Multipoint Views of CMEs

- CMEs observed near disk center with EIT, and detected as halo events by LASCO, are viewed broadside by SECCHI CORs and HI from STEREO.
  - Determine sequence of events in CME initiation.
  - Determine relationship of white-light and EUV structures (e.g. EUV counterpart of white-light CME cavity).
  - Determine 3D structure of Earth-directed CMEs.
  - Distinguish Earth-directed from anti-Earth-directed CMEs.
- CMEs detected in-situ by SOHO will be observed in visible light by HIs in STEREO.
  - How does the visible structure of CMEs correspond to the in-situ signatures and composition variations within ICMEs?
  - Identify sites of particle acceleration and/or storage.
  - Identify shocks in visible light images.

SOHO Contributions to Solar-B Mission Science

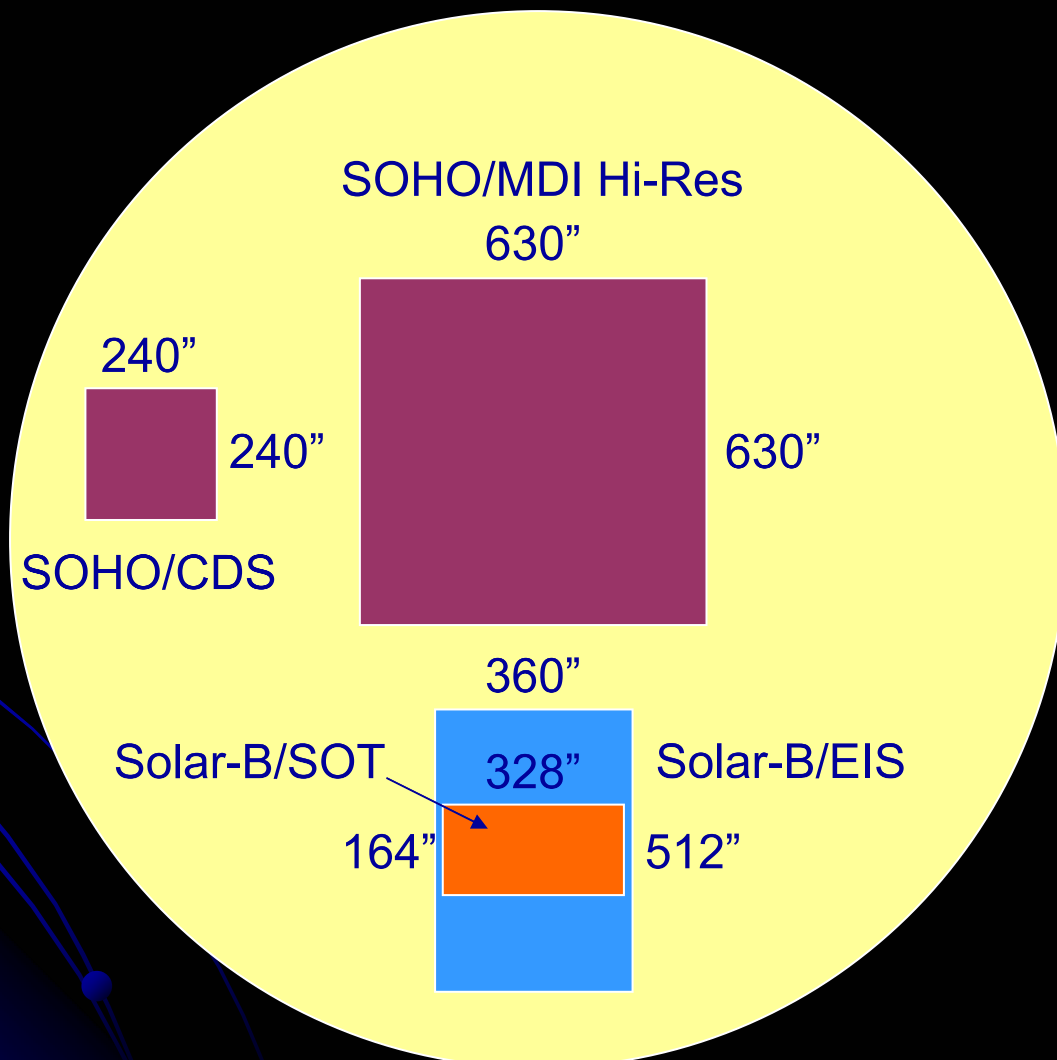
- Full-disk and high-resolution line-of-sight magnetograms and filtergrams from MDI to complement SOT vector field and filtergram measurements.
  - Role of vector field in CME initiation.
- Imaging (EIT and LASCO) and spectroscopy (CDS and UVCS) of CMEs associated with high-temperature plasma observed by XRT.
- EUV spectroscopy (CDS and SUMER) and imaging (EIT and LASCO) to complement EIS.
  - Plasma flows, density and temperature diagnostics in the early stages of CMEs.
- Irradiance and luminosity measurements in visible (VIRGO) and EUV (SEM, CDS and EIT) wavelengths.

Spectral Response Comparison



Reference solar spectrum from Thuillier et al (2004).

Fields of View Comparison



JOP on Filament Eruptions and CMEs

- Target is a magnetic neutral line containing a filament within an active region.
- Objective is to understand the physics of filament evolution and eruption and the initiation of CMEs.
- Solar-B provides high spectral and spatial resolution observations of the filament and the active region, including measurements of the photospheric vector magnetic field, and the overlying coronal plasma.
- SOHO provides global context EUV and visible-light coronal imaging and spectral diagnostics that are complementary to the Solar-B measurements.
- STEREO provides additional views away from the Sun-Earth line, revealing the three-dimensional spatial and velocity structure of the filament and CME.

JOP Instrument Observing Plans

- Solar-B observations:
  - EIS provides fast (coarse resolution) and slow (fine resolution) rasters of the active region in multiple spectral lines.
  - SOT provides high-cadence Hα Dopplergrams and spectropolarimetric maps of the active region.
  - XRT provides high-resolution, high-cadence partial field images and lower cadence full-disk images in multiple channels.
- STEREO observations:
  - SECCHI/EUVI full-disk or partial field images at high cadence in two wavelengths (195Å and 304Å).
  - SECCHI/COR1 and COR2 visible-light polarization brightness images at synoptic cadence.
- SOHO observations:
  - EIT full-disk or partial field images at high cadence in one wavelength (195Å or 304Å).
  - LASCO visible-light coronal brightness images at synoptic cadence.
  - MDI Dopplergrams and line-of-sight magnetic field mages in high-resolution mode (if active region is suitably located).
  - CDS rasters of the active region and surroundings in multiple spectral lines.

Summary

- SOHO has changed many aspects of our understanding of the Sun-Earth system in 10 years of observations.
- SOHO is expected to remain operational during the prime mission phases of both STEREO and Solar-B.
- Science operations of the STEREO and Solar-B missions can benefit from the experience gained with SOHO (JOPs, free and open availability of data etc).
- Some key differences exist in concept of operations for each of the missions.
- SOHO can contribute in significant and unique ways to achieving the science objectives of both STEREO and Solar-B.