SECCHI - Visualization & Analysis Tools for Images from Two Spacecraft

Part 1 - Introduction

STEREO two-spacecraft science opportunities at small and large angles- 2 Classes of Observations

Part 2 - SECCHI Planned Tools for Analysis of Images from Two Viewpoints

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STEREO Science Team Meeting

Boulder, CO March 2004

Classes of Two-Spacecraft STEREO Observations

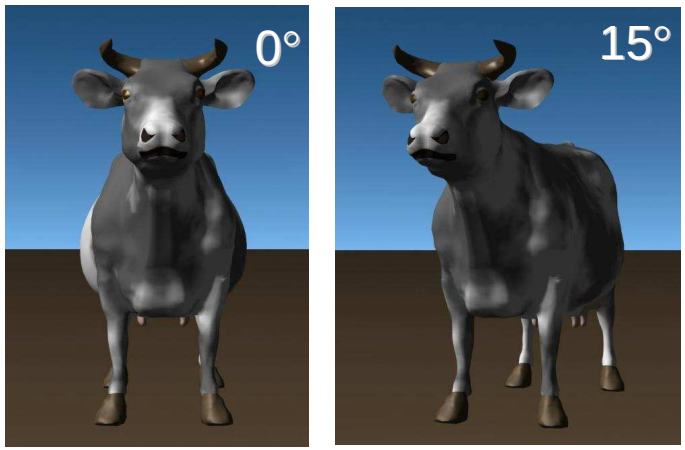
1. Stereoscopic and "Two view points" - *Simultaneous images of same target*

Qualitative or quantitative 3D information from two views

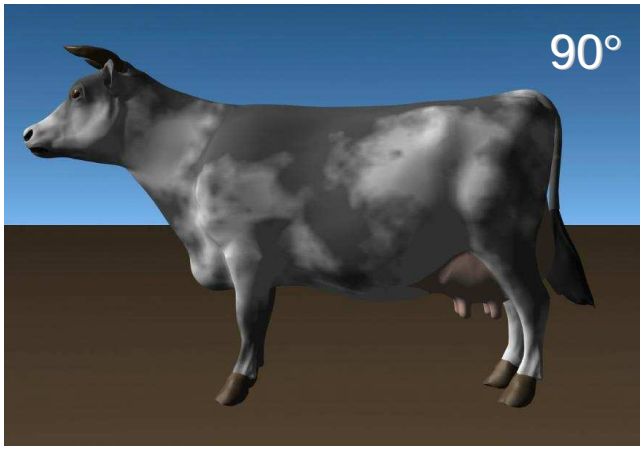
For 3D viewing (goggles, etc.) and quantitative stereoscopy, must see same "features" in both views

- Depends heavily on viewing geometry: stereo angle and overlap of fields-of-view and pointing knowledge
- Probably possible for stereo angles in range 3° - 50°, but best range unknown
- Gary et al. (1998) found ~30° best for simulated soft-X ray loops

Simultaneous views from large angles also provide important 3D information



Stereoscopy for smaller angles, 3° - 50°
Throughout entire 1st year



Additional 3D Information for large angles

Classes of Two-Spacecraft STEREO Observations-
continued

2. Cooperative Observations from Two locations

- Observing different targets

Information from 2 complementary spacecraft locations/vantage points

May be two different wavelengths or SECCHI + in situ F&P

Not necessarily simultaneous

Parts 2 & 3 of this talk discuss visualization & analysis tools for first class only--

1. Stereoscopic and "Two view points" -
Simultaneous images of same target

First Class: Stereoscopic and "Two view point" Science Observations (1 of 3)

Same target from both SC - heavily dependent on viewing geometry

- CME Velocity, Acceleration & Deceleration (CORs & HIs)

  Can determine velocity vs. time when bright leading edge seen from both SC (true stereoscopy)--angular range unknown

  How does solar wind speed effect deceleration? How does CME interact with solar wind structures (CIRS, etc.)?

- CME Structure and Evolution

  Quantitative *3D reconstruction & true stereoscopy for small angles (EUV and white light, probably 3 °-50 °)*

  3D information from two view points (large angles)
  (Analogous to cow viewed with 0° and 90° stereo angles)

  Clues about structure from white light 3D viewing of CME expansion

  What is the spread in longitude of CMEs? (white light, large angles)

Stereoscopic and “Two view point” Science (2 of 3)

- CME Initiation and Evolution - EUVI (*probably 3 °-50 °)*

  Where does prominence lie is relation to magnetic structure as determined from EUVI? Do CMEs result from bipolar or multipolar regions?

  What is the role of reconnection in CMEs?
  Where does reconnection occur?
  High or low? Above or below flux rope ?
  Can we see flux rope form (“pinch off” due to reconnection)?

  Is there always a cavity -- which may be masked by LOS effects?

- Coronal Structure - CORs

  Determine 3D structure of helmet streamers, plumes

  Determine current sheet geometry from stereoscopic analysis of streamers
  (Liewer et al ‘00 did rotational stereoscopy on steady streamers)

  How does current sheet move in response to CMEs?

Stereoscopic and “Two view point” Science (3 of 3)

- Coronal Heating - EUV (*probably 3 °-50 °)*

  Constrain loop heating models better with more accurate loop geometry determination (length,cross section) using stereoscopy

  Map coronal loops accurately to photospheric footpoint using stereoscopy & study relation between photospheric magnetic evolution and coronal response (EUVI)

  Are seemingly interacting loops causing heating or is it a line-of-sight effect?

- Solar Magnetic Activity - EUVI at large angles

  Increased longitudinal coverage of magnetic activity

  (Observe active regions before reaching Sun’s East limb) *

  * *Doesn’t really require two SC*

Second Class: Science from Two SC locations - *Observing different targets*

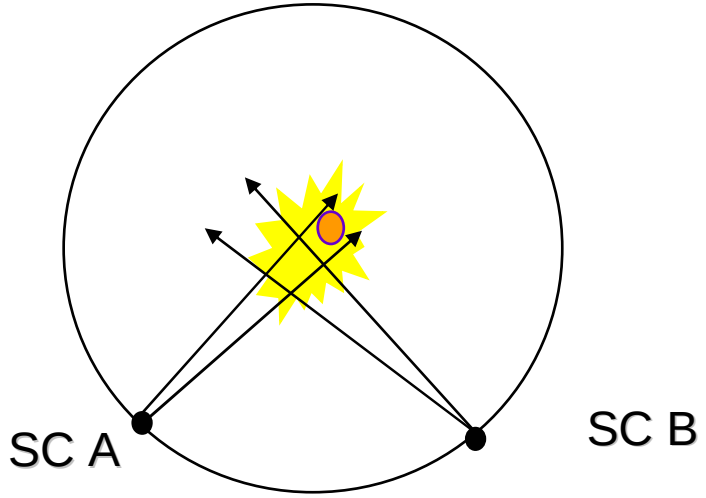
Information from two complementary spacecraft locations and/or vantage points

Physics of CMEs

- EUV/disk observations from SC A - CORs from SC B at large angles

  Determine sequence of event in CME initiation with SC A watching changes in low corona and SC B watching changes in corona (helmet streamer swelling, CME)

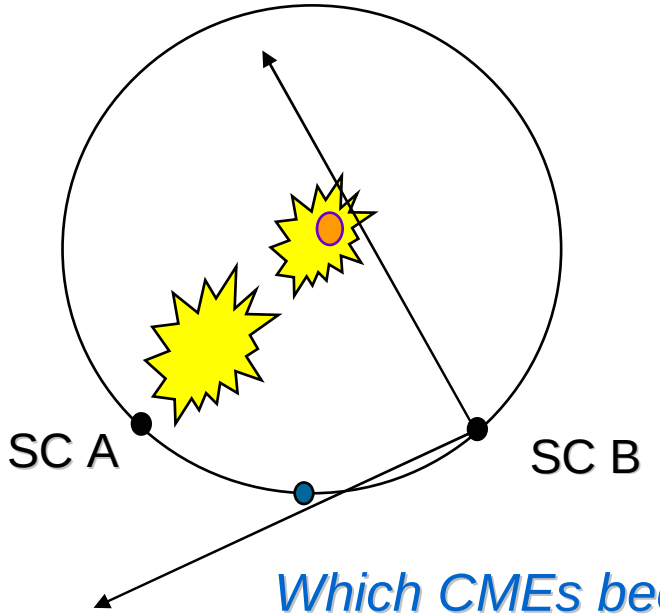
  Determine relationship of white light and EUV CME structures, e.g., what is the EUV counterpart of white-light CME cavity?



Science from Two SC locations *-Observing different targets*

Relate CME in white light to in situ measurements

- Fields and Particles from SC A (and near Earth) + white light observations from SC B at large angles



SC B CORs and Heliospheric Imager (HI) observe CME which passes over SC A (or Earth) for in situ fields and particle measurements

SC A EUVI sees disk signature of CME in EUV

SC A HI-2 also sees CME overhead

SC A CORs may see “halo” CME

Which CMEs become Interplanetary flux ropes?

What is in situ counterpart of bright leading edge of a CME? Shock or pile-up ?

Part 2 -- Overview of SECCHI Planned Tools for Analysis of Images from Two Viewpoints

- SECCHI Team (J. Cook, NRL) is compiling a list of existing and planned software tools for analyzing STEREO images
  - Here, we give an overview of some of the tools, current status and plans

- **3D Reconstruction**
  - 3D Reconstruction for SECCHI/EUVE (LMSAL)
  - Stereoscopy & Stereoscopic Visualization for all instruments (JPL)
  - Tomography for SECCHI White Light images (NRL)
  - Constrained Tomography & Magnetic Field Reconstruction (MPAE)
  - Self-Similar Modeling of Structured CMEs (MPAE aka MPS)
- **Related Tools (List)**

- **3D Visualization for EPO (JPL & MPAE aka MPS)**

3D Reconstruction for SECCHI/EUVE

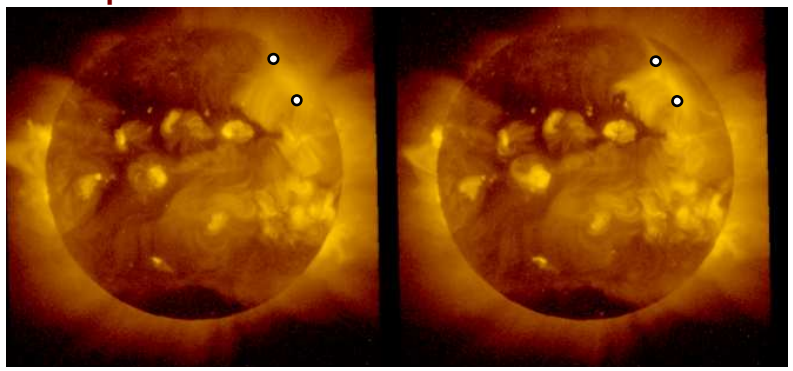
- **Comprehensive Suite of Tools & Techniques for 3D Reconstruction and Visualization of EUV Observations** - M. Aschwanden, J. Lemen, J-P Wuelser, LMSAL & D. Alexander, Rice
  - Software modules available via Solar Software/IDL
    - > Goal is to provide basic software tools to analyze & visualize EUVI data
- **Existing work** documented at http://secchi.lmsal.com/Science
  - Includes
    - > Static & dynamic STEREO data simulations
    - > IDL/STEREO packages for stereoscopy of loops & samples
    - > Bibliography on 3D tomography & stereoscopy
- **Future Plans:** Explore constrained reconstruction, e.g., Reconstruction with a minimum of number of structures (similar to CLEAN)

Simulated Bastille Day Event

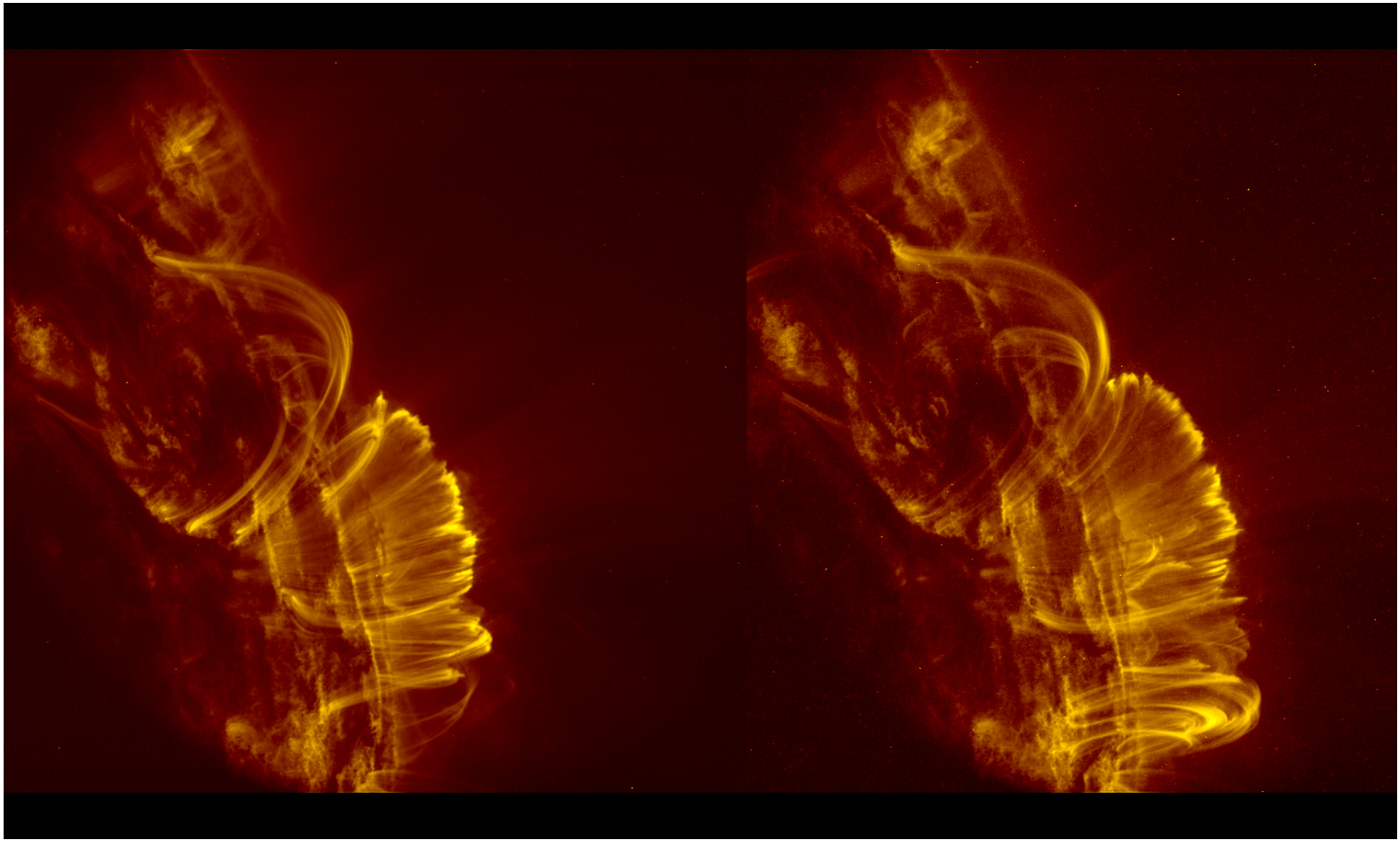
Stereoscopy: Tie Point Tool & Visualization

Classical Stereoscopy: Determine 3D location of a "Feature" identified in both images of a stereo pair using triangulation

- Tie Point Tool under development at JPL (Liewer & De Jong)
  - **Minimum platform-independent tool:** Manual placement of tie points in displayed stereo image pair and computation of 3D location of feature in heliographic coordinate system ***(Exists)***
  - **Under development:** Couple tool to stereo visualization software/hardware (shuttered goggles) to allow 3D cursor placement on a feature (Platform: WindowsXP/2000, LINUX PC, Solaris with NVIDIA graphics card with Quadro4 chip)
  - **Enhancement:** Couple to automatic feature identification



Can be used to trace out loops (EUVE) and to compute 3D velocities of features from time series of stereo images, e.g., CME velocities (CORs and HIs)



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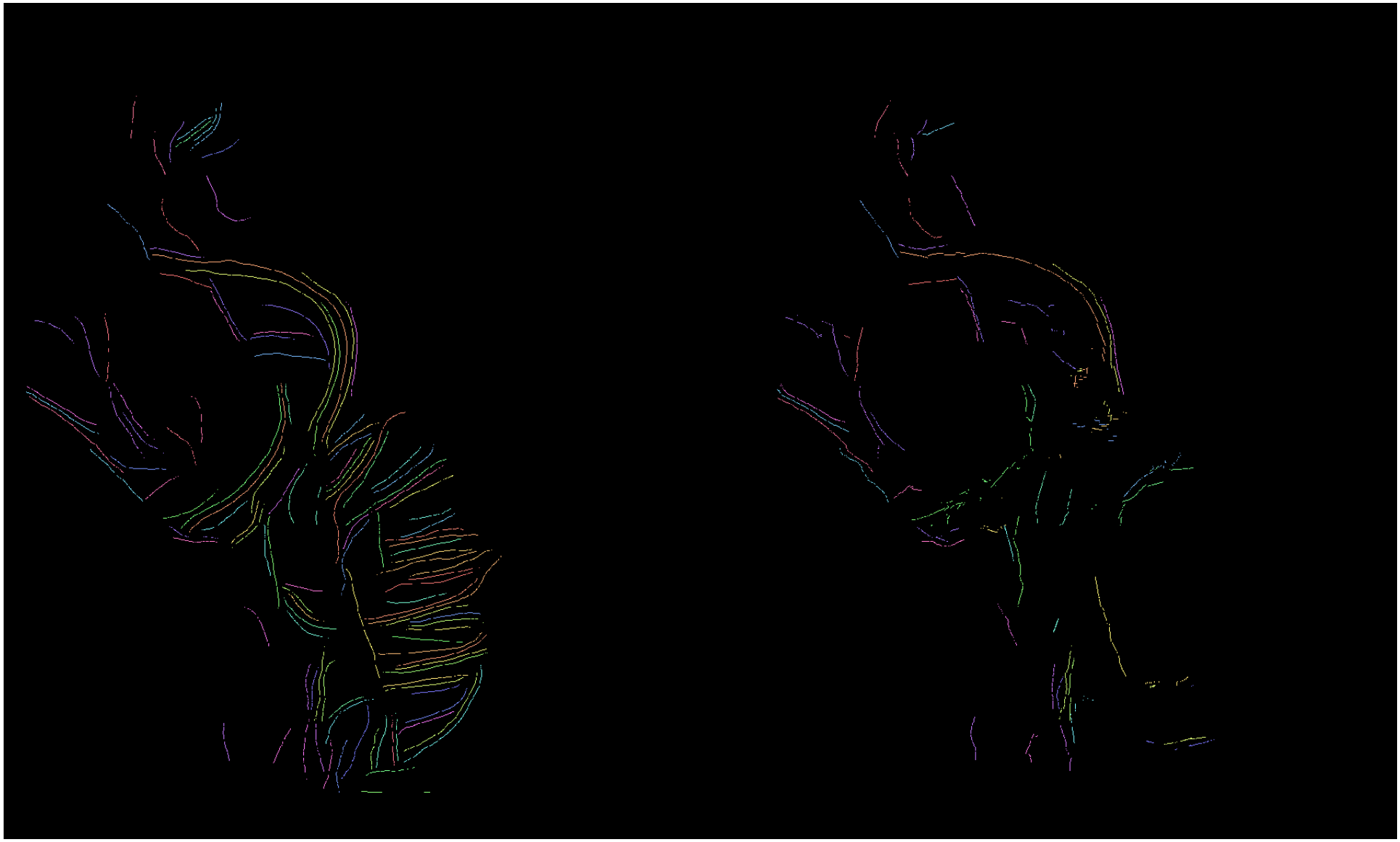
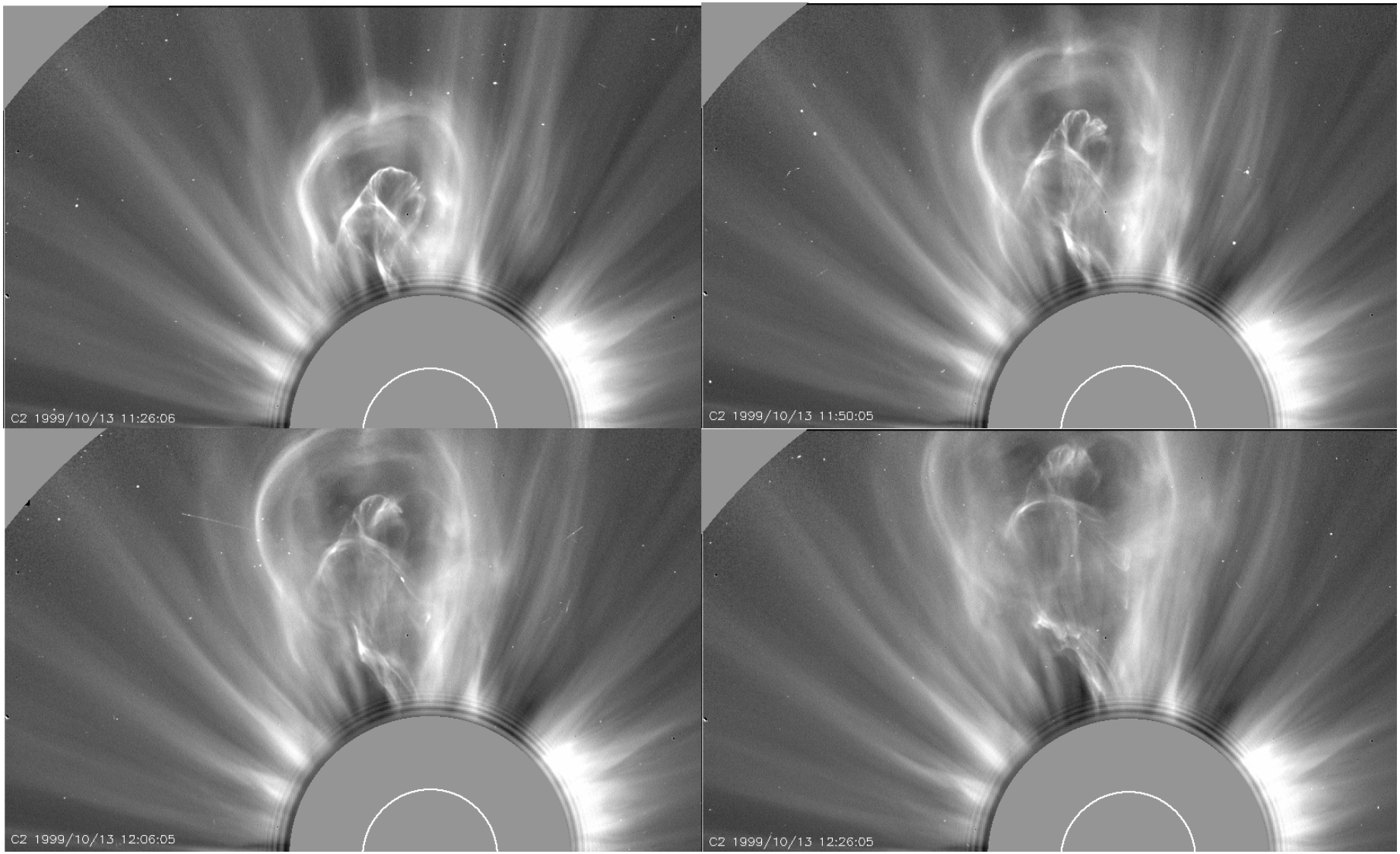
Original TRACE Image Pair - 1 hour separation



Left: Traced Segments (Image 1) **Right: Correlated Segments (Image 2)**

LASCO/C2 Lightbulb CME 13Oct99

Note bright features suitable for stereoscopy

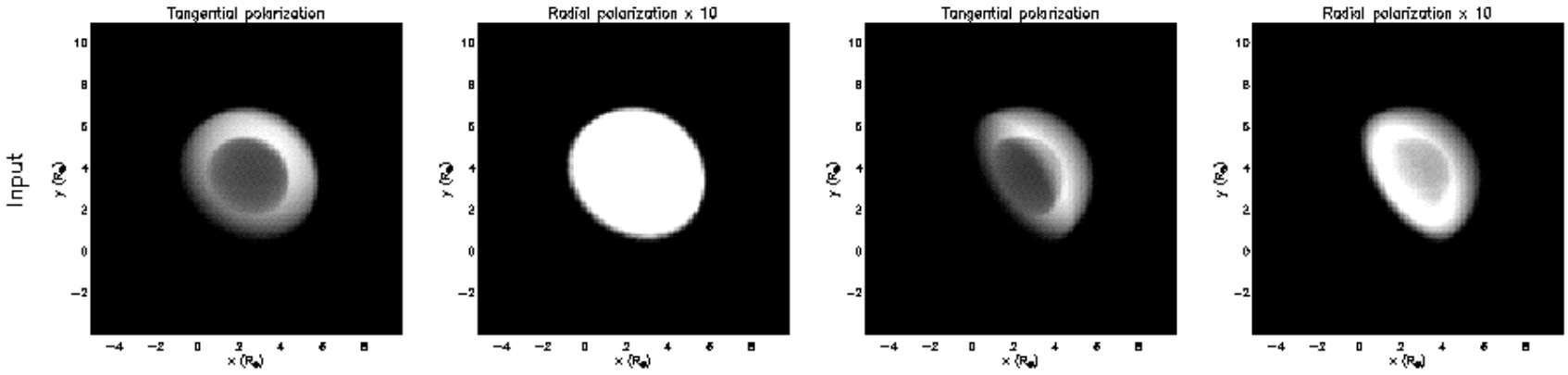


Tomography for SECCHI White Light (CORs&HIs)

- **Tomographic reconstruction of electron density from multiple viewpoints images using commercial PIXON software - J. Cook, J. Newmark, P. Reiser (NRL) & A. Yahil (PIXON)**
  - **PIXON method:** minimize the number of "voxons" needed to reproduce input data *(white light Thomson scattered from electrons)*
- **Current Status:** Tested with synthetic images from **3 input views**, each with 2 polarizations (SECCHI white light + SOHO/LASCO)

TEST CASE- Input from 3 views

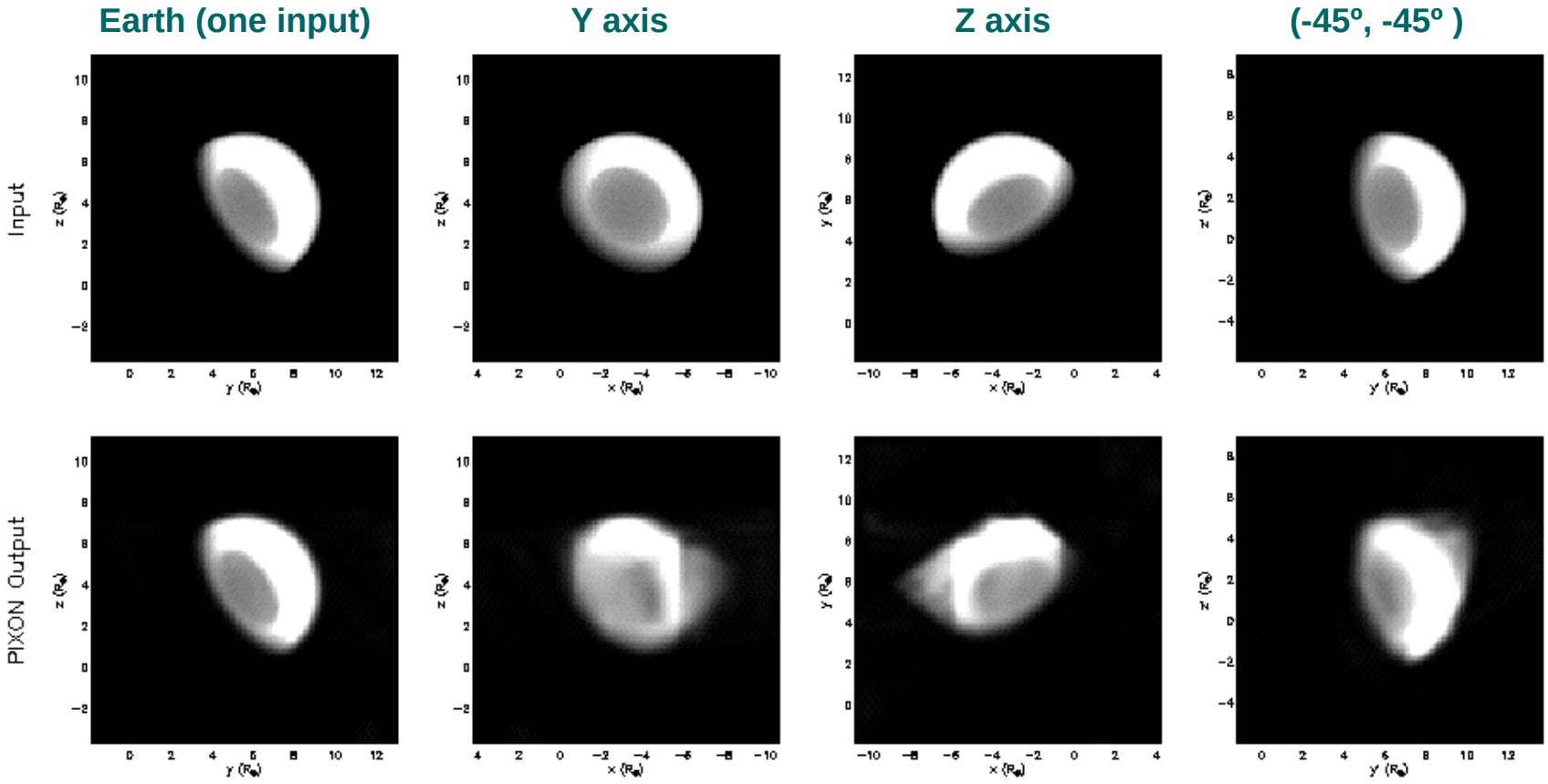
Spacecraft B (-37º) - 2 polarizations | **Earth (0º) - 2 polarizations**



+ Spacecraft A (37º) - 2 polarizations

Tomography for SECCHI White Light (CORs&HIs)

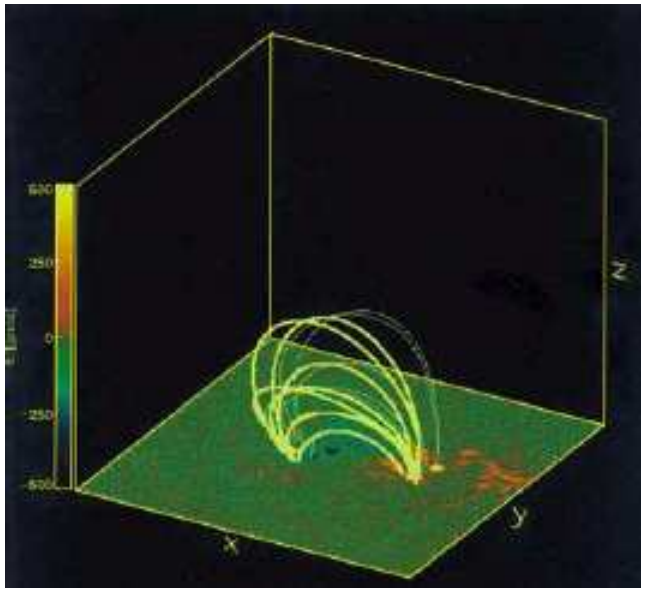
- **Results from PIXON Reconstruction**
  - **TOP Row:** WL Observation computed from input 3D density
  - **Bottom Row:** WL Observation computed from reconstructed 3D density



More information: http://stereo.nrl.navy.mil/ and follow link to "3D R & V"

Finite-Element Tomography & Magnetic Field Reconstruction

- **Classical Inversion code under development at Max Planck MPAE (B. Inhester)**
  - Designed to determine 3D electron density or emissivity from multiple views of the corona
  - Uses a finite element grid & conjugate gradient iteration
  - Can be constrained with corona magnetic field models
  - Basic code has been tested with simulated data
- **Reconstruction of Coronal Magnetic Fields (Wiegelmann & Inhester, MPAE)**
  - Developed method to include stereoscopic EUV information in the reconstruction of coronal magnetic fields from photospheric magnetic fields (using linear and non-linear force free field techniques) *Ref: Wiegelmann & Neukirch, Solar Physics **208**, 2002.*
  - Developing code to align 2D projection of 3D field model with observed coronal features- tested with SOHO/EIT data



Self-Similar Modeling of "Structured" CMEs

- **Self-Similar Model of Origin, Internal Magnetic Field Configuration and Near-Sun Evolution of "Structured" (Flux-Rope) CMEs**

  V. Bothmer, H. Cremades and D. K. Tripathi (MPAE aka MPS)

- **Status:** Analysis of LASCO data from "structured" CMEs shows relationship between LASCO observations, orientation of underlying bi-polar magnetic field source region, and post-eruptive arcades

- **Hypothesis**: "Structured" CMEs arise in a self-similar manner from pre-existing structures overlying neutral lines in bipolar magnetic field regions *(submitted for publication)*
  - Projected white-light topology depends on orientation and position of neutral line on solar disk at time of eruption

- **Goal: 3D forward-modeling as animation of evolution of structured CMEs to compare 2D projections with observations**

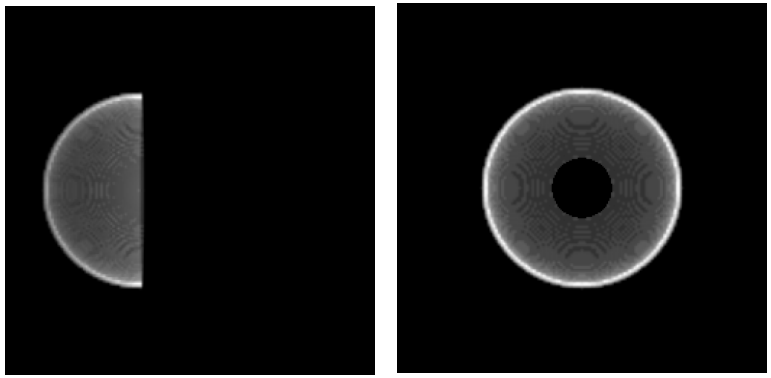
Synthetic SECCHI White Light Images from Simple Structures

- **Tools to compute synthetic SECCHI white light images from known electrons distribution**
  - Synthetic images computed from LOS integration of Thomson scattering from specified 3D density distribution
- **Uses:** Plan and interpret SECCHI white observations & creatae simulated data for testing reconstruction, science planning, etc.

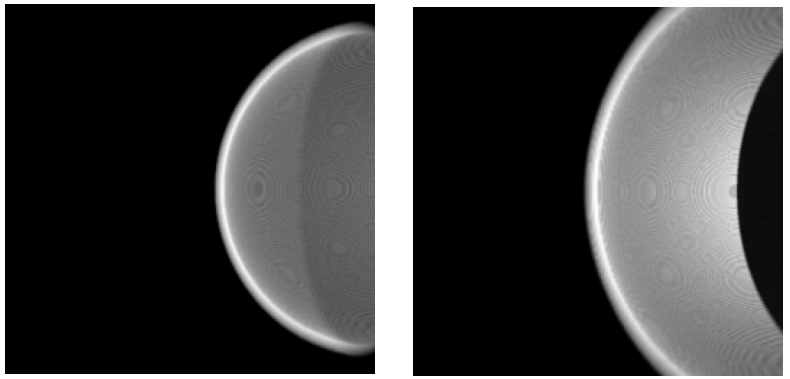
Two Versions:

- **synLOS - Liewer & NRL**
- **Streamer Simulation - Vourlidas & Marque, NRL**

COR2 - CME at 8 R_{sun}, 0 & 90°



HI2 - CME at 120 R_{sun}, 0 & 45°



Other Tools for Analysis of SECCHI images

(from compiled list - not complete)

- **Automatic Solar Feature Recognition and Classification**
  - > D. Rust, P. Bernasconi, B. Labonte, JHU/APL
  - > Further develop automatic tools for sigmoid & filament recognition
- **Combining Nancay Radio Heliograph with SECCHI & SWAVES**
  - > M. Pick, D. Maia, A. Kerdraon, Obervatoire de Paris
  - > Compare radio & SECCHI to identify features emitting in radio
- **CME Mass & Energetics Toolbox**
  - > A. Vourlidas, NRL
  - > Set of IDL routines to derive mass, energy and CM height of CMEs.Goal: create user friendly interface
- **Differential Emission Meassure (DEM) Tool for EUVI**
  - > J. Cook & J. Newmark, NRL
  - > Uses images at various EUV wavelength to computre differential emission measure. Tool now exists for SOHO/EIT and will be modified for EUVI passbands
- **Stereoscopy of EUV Loops**
  - > F. Portier-Fozzani & B. Inhester

Conclusions

- Important science very early in mission when stereo angles are small
  - > ***Need to be ready at launch (February 2006)***
  - > ***Separation of 15° by October 2006***

- Good Start on Analysis Tools
  - Further testing needed

- Observation planning is needed
  - Synthetic data is needed for planning