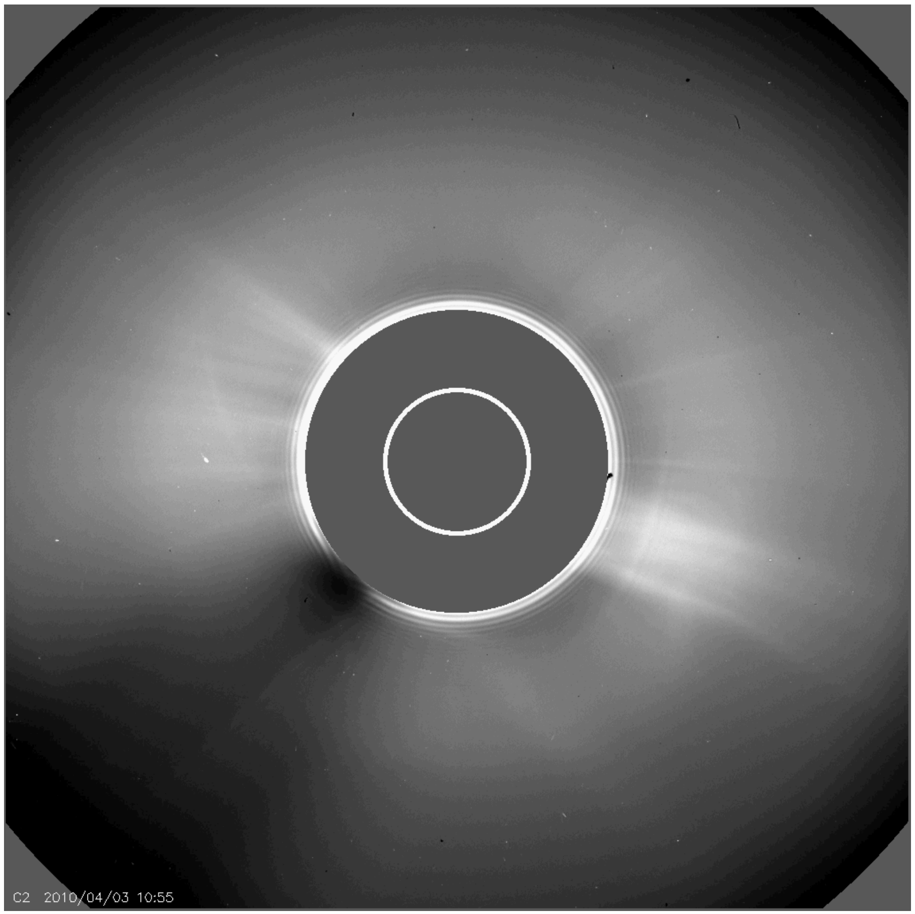
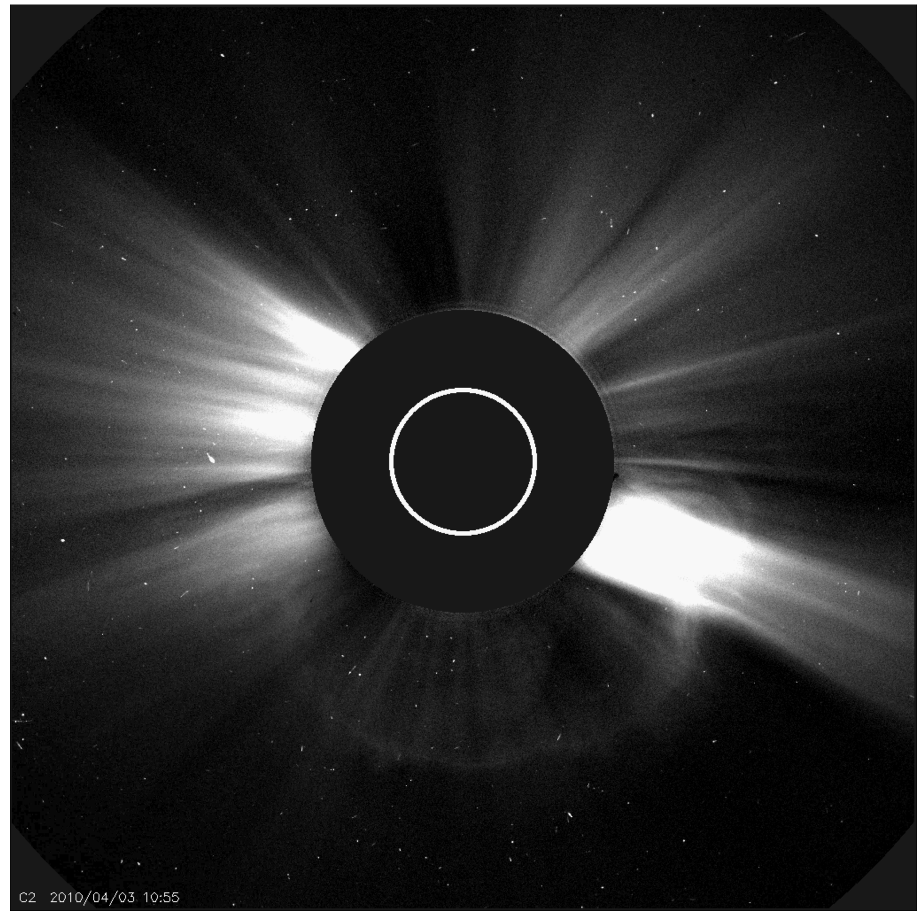
How to do 3D reconstruction of CMEs

Marilena Mierla

- **Getting the data**
- **Data processing**
- **3D reconstruction methods**



Raw image



Monthly background subtracted

White-light coronagraph images (LASCO) – getting the data

LASCO-C2 and LASCO-C3 on-board SoHO

- externally occulted coronagraphs

- get the data (level 0.5, fits files):

  http://sharpp.nrl.navy.mil/cgi-bin/swdbi/lasco/images/form

- get monthly background images:

  http://lasco-www.nrl.navy.mil/content/retrieve/monthly/

Data available also on our server - IBLIS

LASCO data pre-processing

- Subtract bias
- Divide by exposure time
- Replace missing blocks
- Multiply by calibration factor (optional)
- Multiply by (inverse) vignetting function/array (divide the flat-field)
- Subtract stray light
- Distortion correction
- Rectify image to solar north up, if SOHO in upside-down position

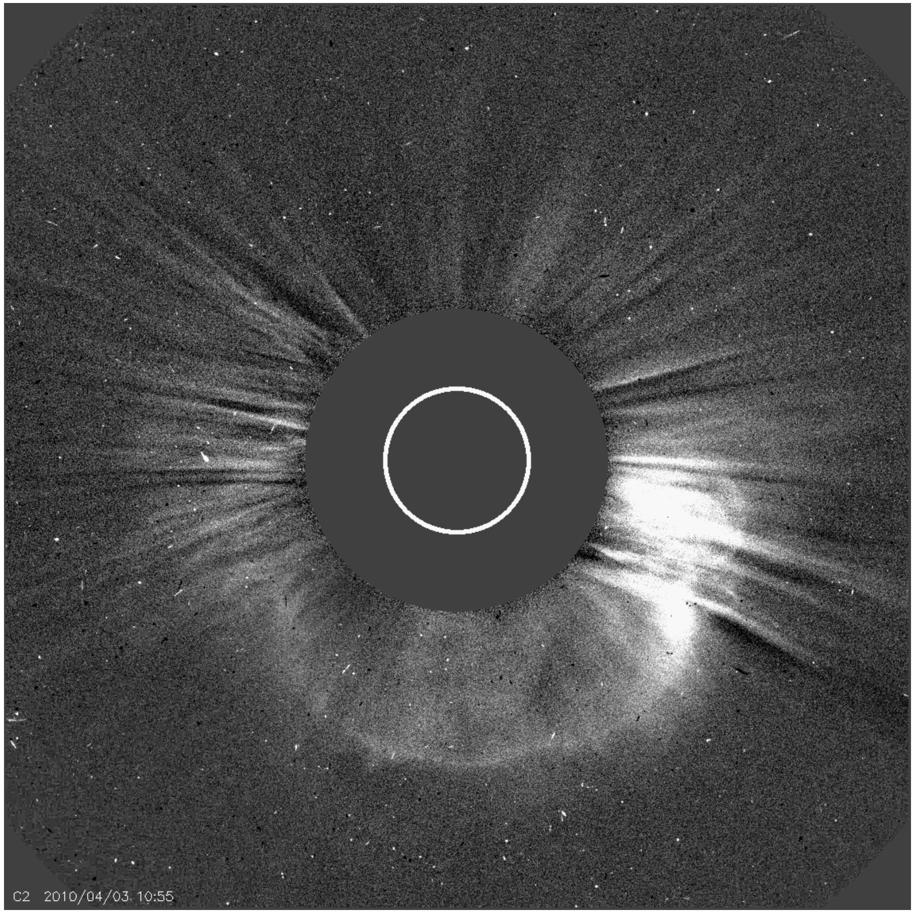
```
IDL> image = LASCO_READFITS ('filename', header)

IDL> REDUCE_LEVEL_1, 'filename'
```

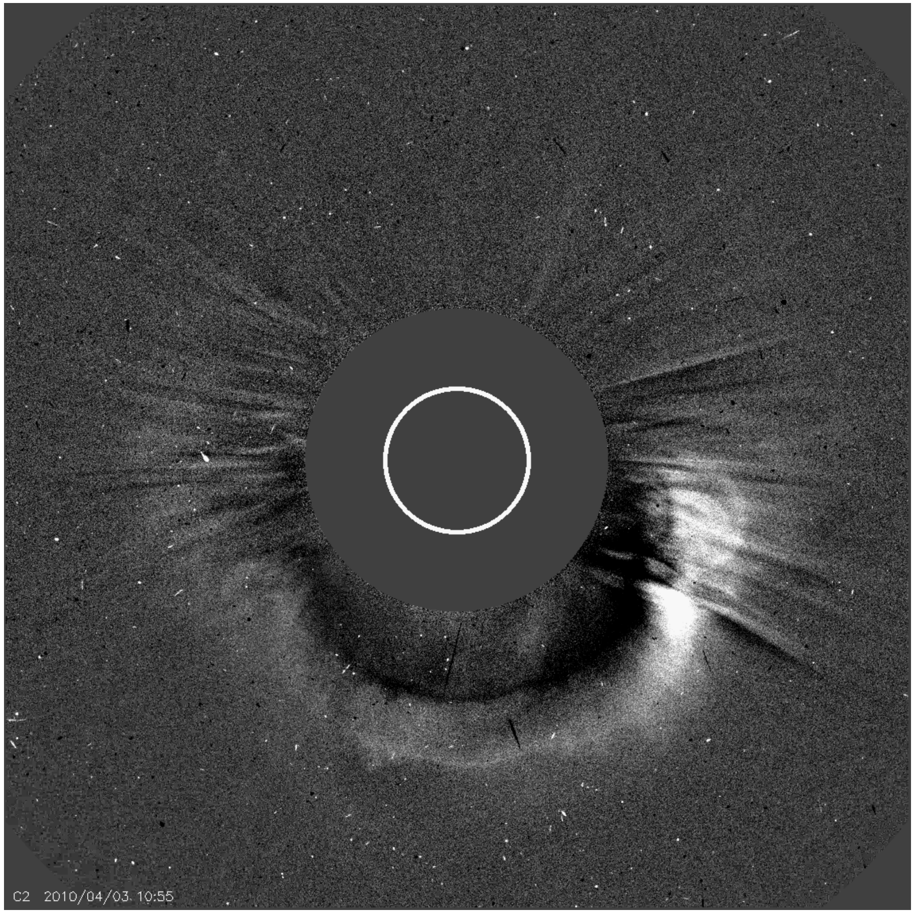
where filename is name of FITS file (level 0.5) to process, including path

LASCO-C2 data processing: Visualize the CMEs

Base difference
Img(i) – Img(0)

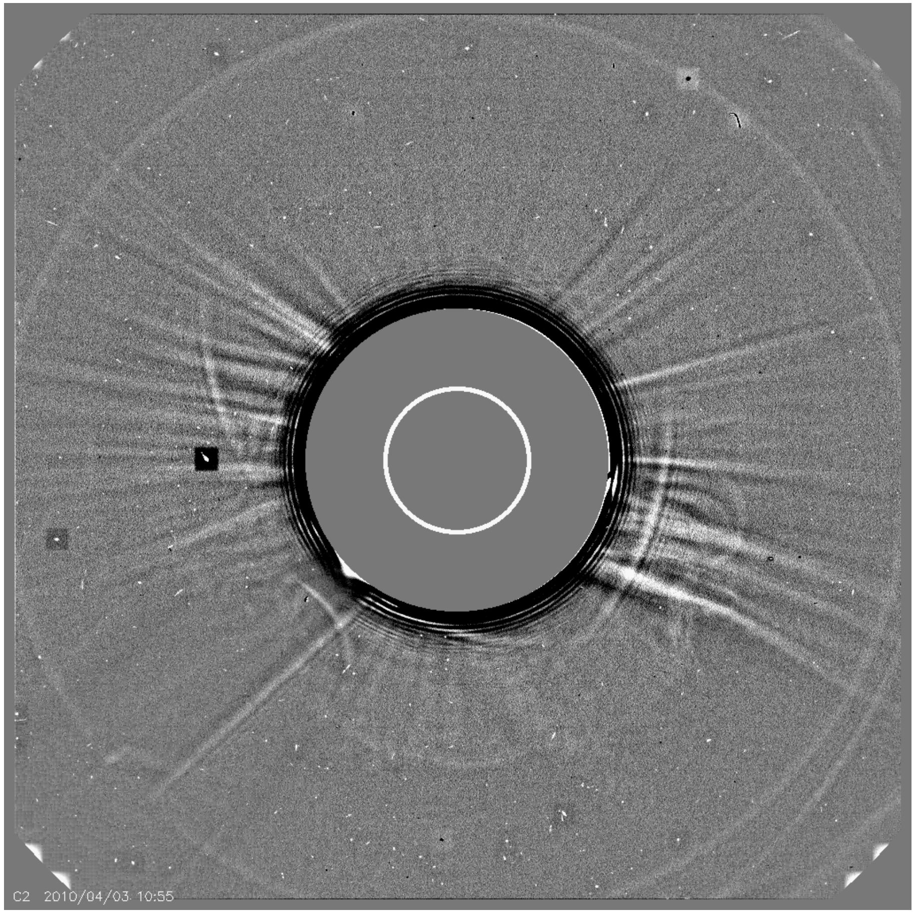


- running difference
Img(i+1) – Img(i)

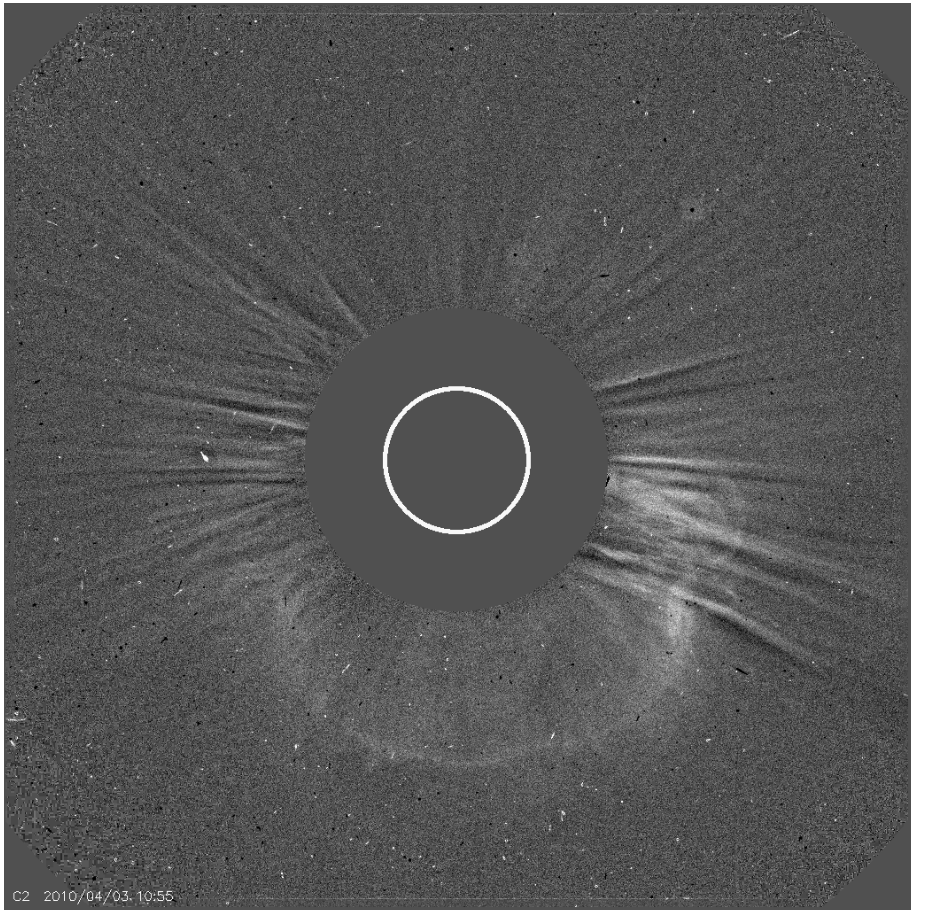


Visualize the CMEs

Unsharp mask

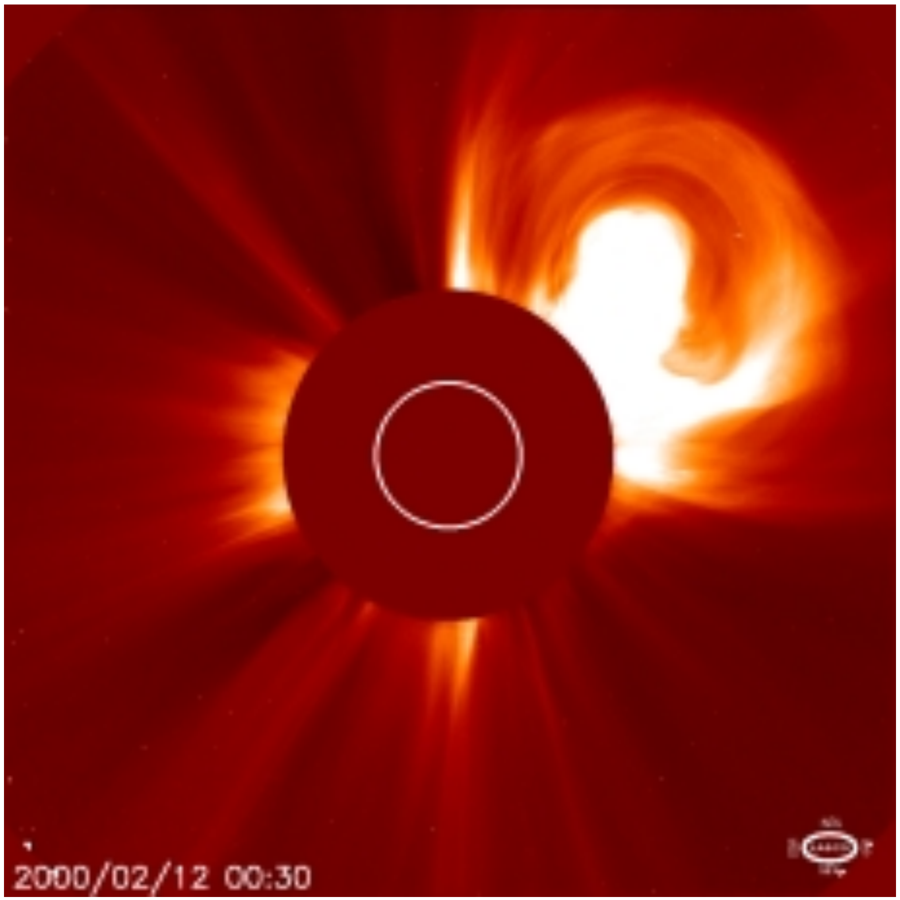


Sharpen ratio

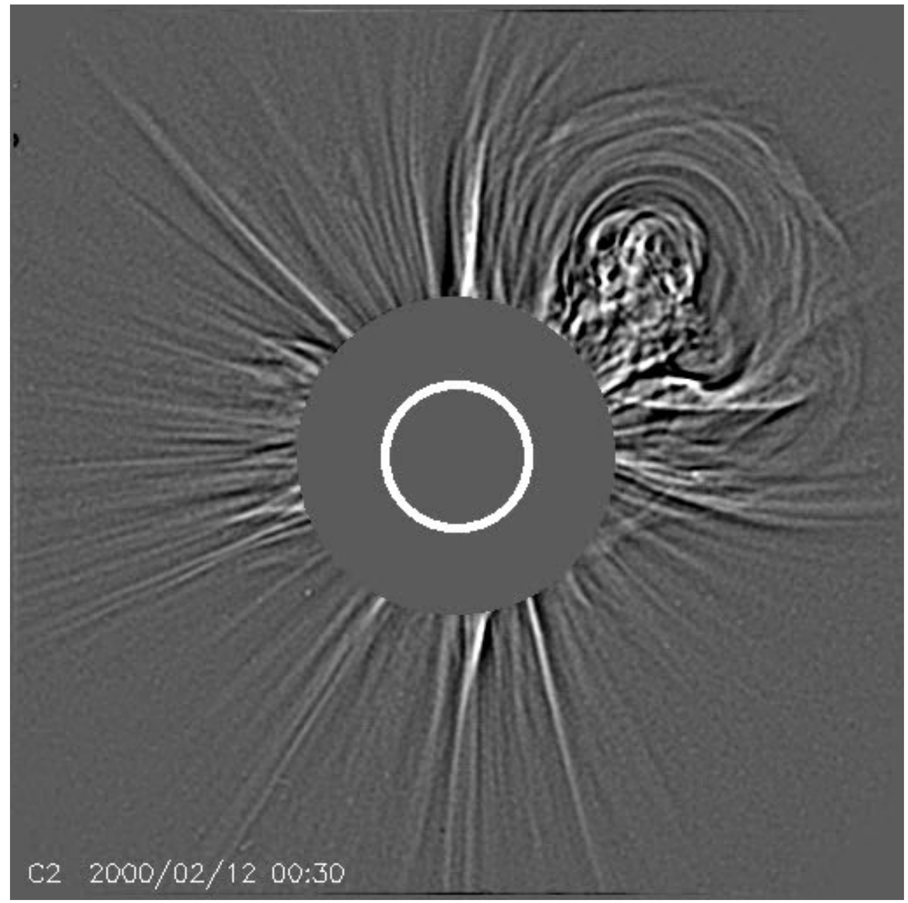


LASCO wavelet enhanced movies

http://lasco-www.nrl.navy.mil/index.php?p=content/wavelet



Before wavelet

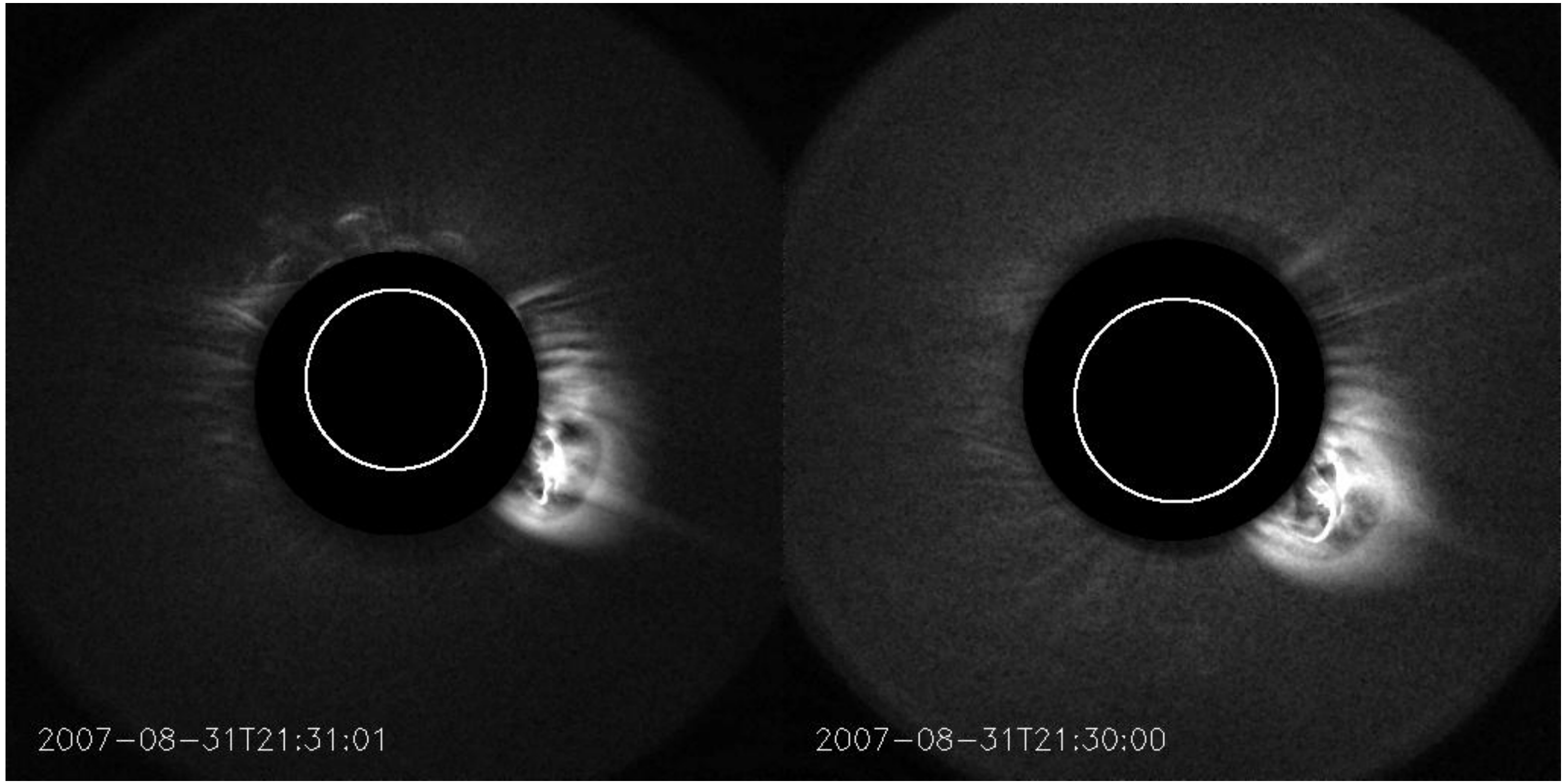


After wavelet

Stenborg and Cobelli 2003

COR1 data

COR1 observes in a white-light waveband 22.5 nm wide centred at the Hα line at 656 nm.



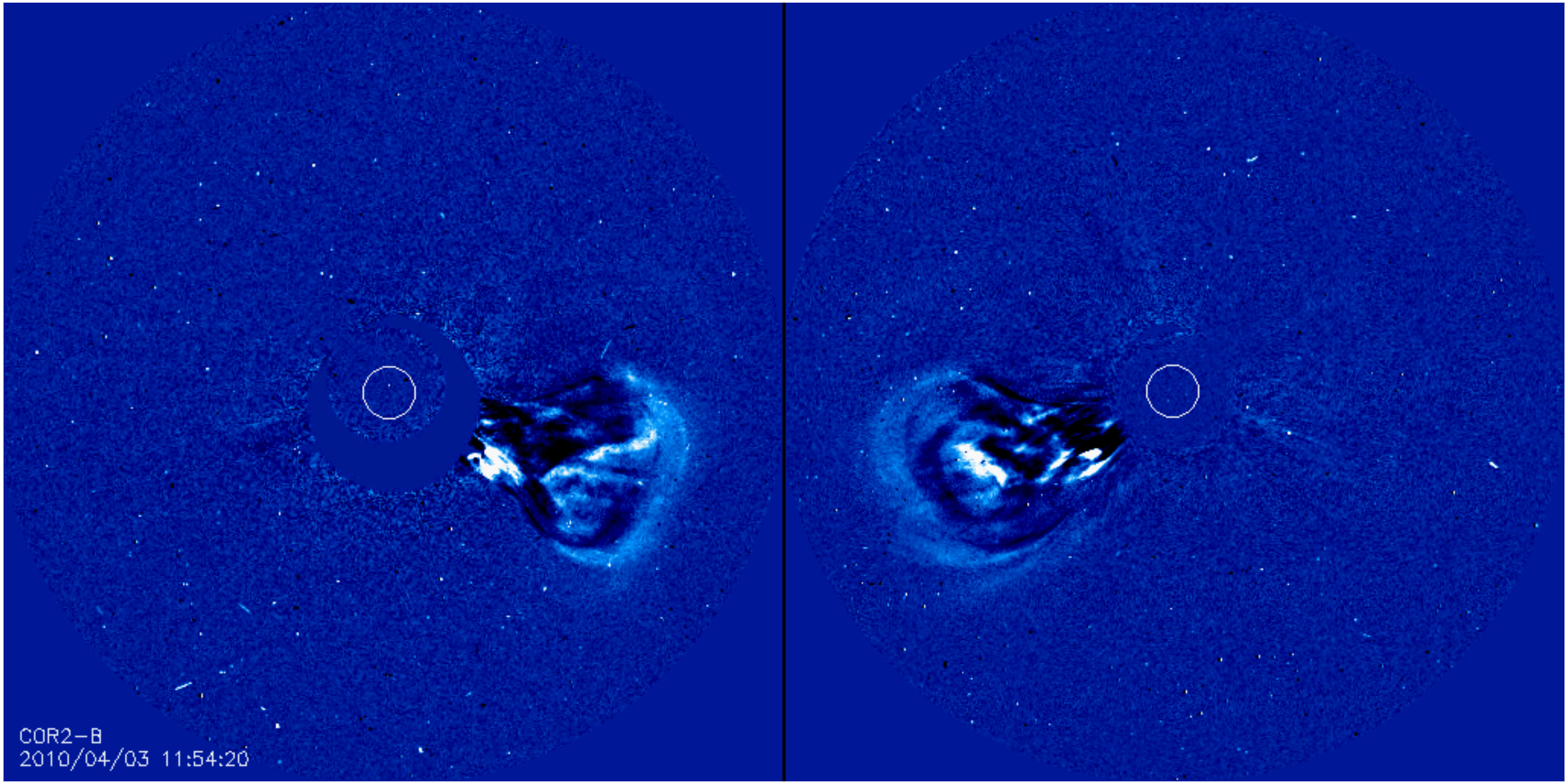
It takes polarised images at three different polarisation angles: 0 (I_0), 120 (I_{120}), and 240 (I_{240}) degrees from where total brightness (B) and polarised brightness (pB) images are derived:

$$B = \frac{2}{3}(I_0 + I_{120} + I_{240}), \tag{1}$$

$$pB = \frac{4}{3}\sqrt{(I_0 + I_{120} + I_{240})^2 - 3(I_0 I_{120} + I_0 I_{240} + I_{120} I_{240})}, \tag{2}$$

(Thompson & Reginald 2008)

COR2 data



The SECCHI-COR2 is an externally occulted Lyot coronagraph which observes the coronal emission in visible light, having a field of view from 2.5 to 15 $R_\odot$.

The COR2 coronagraphs take polarised images at three different polarisation angles at 0, 120, and 240 degrees.

White-light coronagraph images (COR) – get the data

COR1 and COR2 on-board STEREO.

- get the data (level 0.5, fits files, polarized):

  http://secchi.nrl.navy.mil/cgi-bin/swdbi/secchi_flight/images/form

- get monthly background images:

  http://www.darts.isas.ac.jp/pub/solar/sswdb/stereo/secchi/backgrounds/

Data available also on our server - IBLIS

Reading and preparing COR1 data:

The primary routine for reading and preparing SECCHI data for analysis is secchi_prep.pro
http://secchi.nrl.navy.mil/wiki/pmwiki.php?n=Main.SecchiPrep

secchi_prep reads in the filename of a secchi pre-flight level 0.5 data and process data to level 1.0.

Information about the calibration status of COR1 can be found at:
http://secchi-ical.wikidot.com

See also Thompson and Reginald 2008.

Background subtraction: Thompson et al. 2010.

http://cor1.gsfc.nasa.gov/guide/

Reading and preparing COR1 data:

Create pB (polarised brightness) images with monthly background subtracted:

IDL> secchi_prep, filename, hdr, img, /polariz_on, /pb

Create totB (total brightness) images with monthly background subtracted:

IDL> secchi_prep, filename, hdr, img, /polariz_on

Create pB images without subtracting the background:

IDL> secchi_prep, filename, hdr, img, /polariz_on, /pb, /bkgimg_off

filename = array of COR1 filenames (level 0.5, polarized images) including path

Reading and preparing COR2 data:

Get B (total brightness), not calibrated images created on-board

```
IDL> secchi_prep, filename, hdr, img, /calfac_off, /calimg_off, $
        /rotate_on
```

Create pB (polarised brightness) images:

```
IDL> secchi_prep, filename, hdr, img, /polariz_on, /pb
```

Create B (total brightness) images:

```
IDL> secchi_prep, filename, hdr, img, /polariz_on
```

filename = array of COR2 filenames (level 0.5 images) including path

Reconstruction Methods

1) tie-pointing or triangulation (two view directions) *(Inhester 2006)*

Program in Solar Soft (William Thompson):
IDL> scc_measure, imga, imgb, hdra, hdrb, outfile=fileout, /append

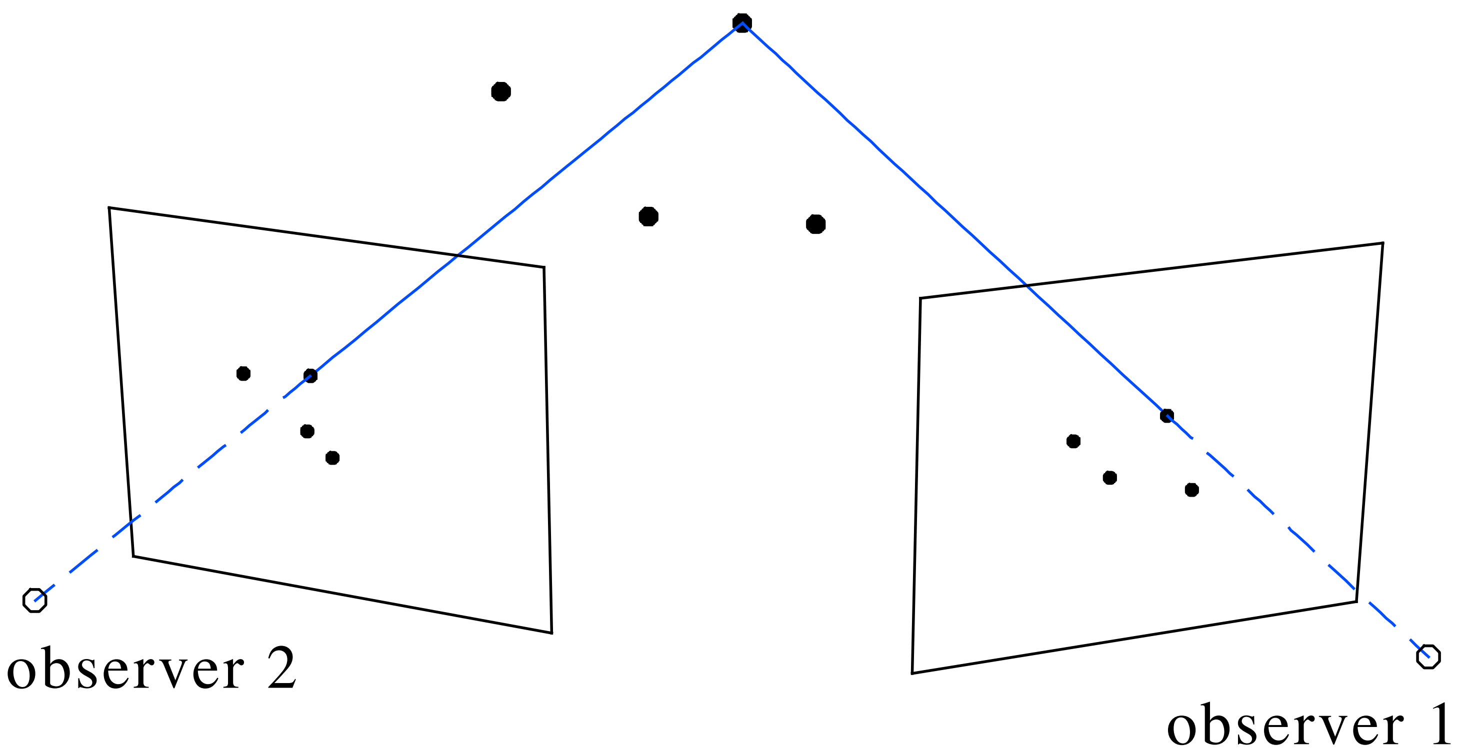
3) forward modeling (one or more view directions) *(Thernisien et al. 2006, 2009)*

Program in Solar Soft (Arnaud Thernisien):
IDL> rtsccguicloud, imga, imgb, hdra, hdrb, ssim = ssimout, sgui = sguiout

2) polarization ratio method (one view direction, pB and B images) *(Moran and Davila 2004, 2010)*

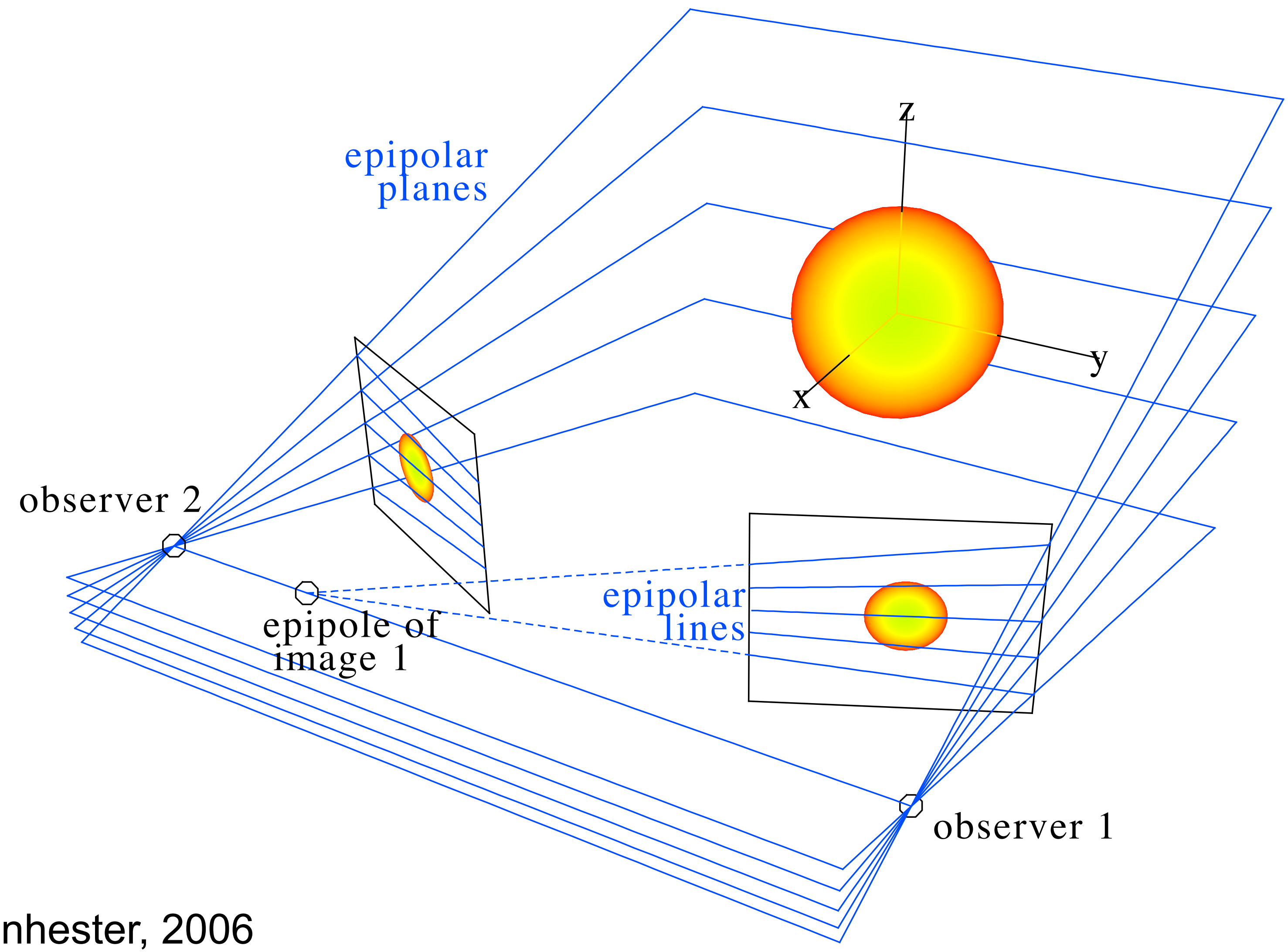
IDL program on my IBLIS folder (/home/marilena/idl_prog/secchi/3d/)
IDL> get3d_cme_polariz

Tie-point reconstruction (triangulation)



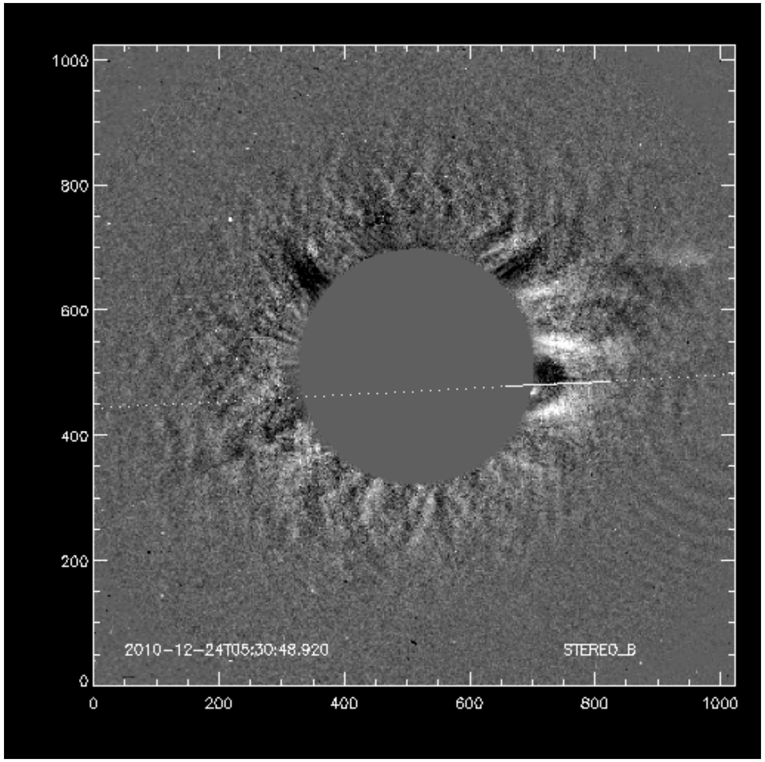
Inhester, 2006

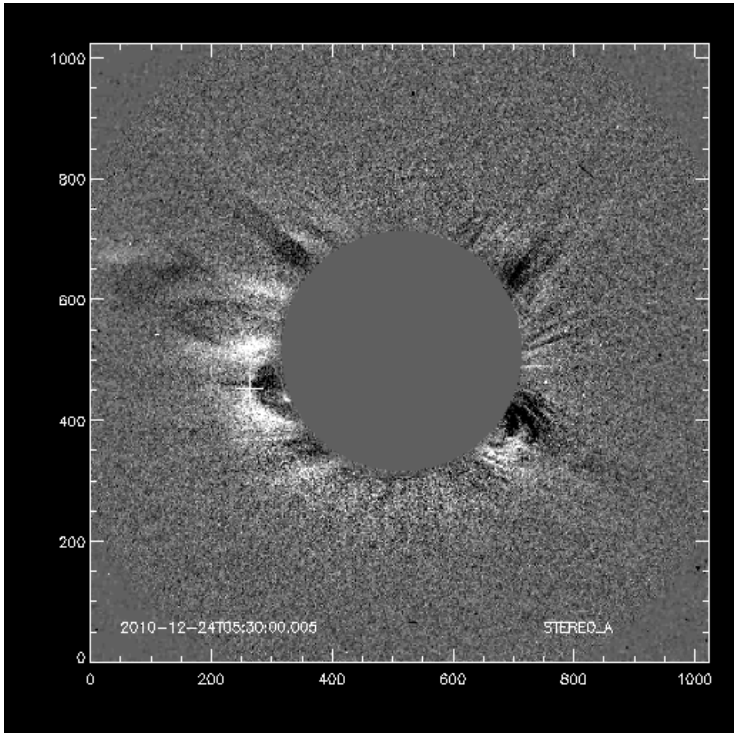
Epipolar geometry

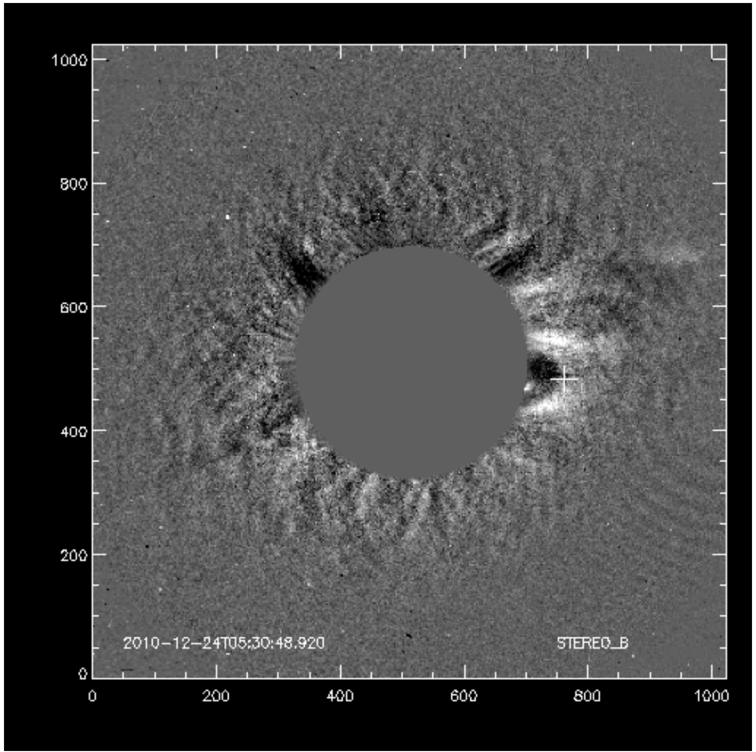


Inhester, 2006

A, B

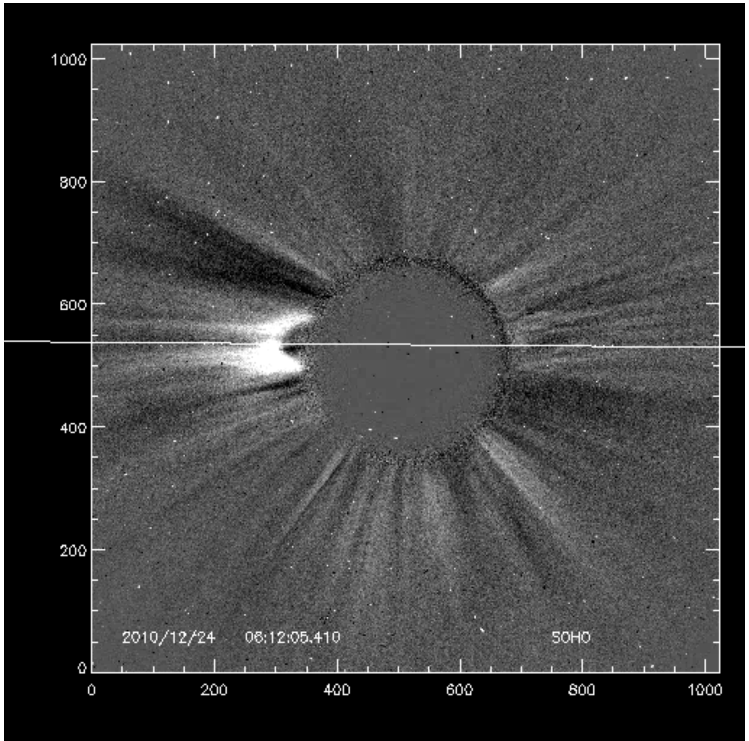




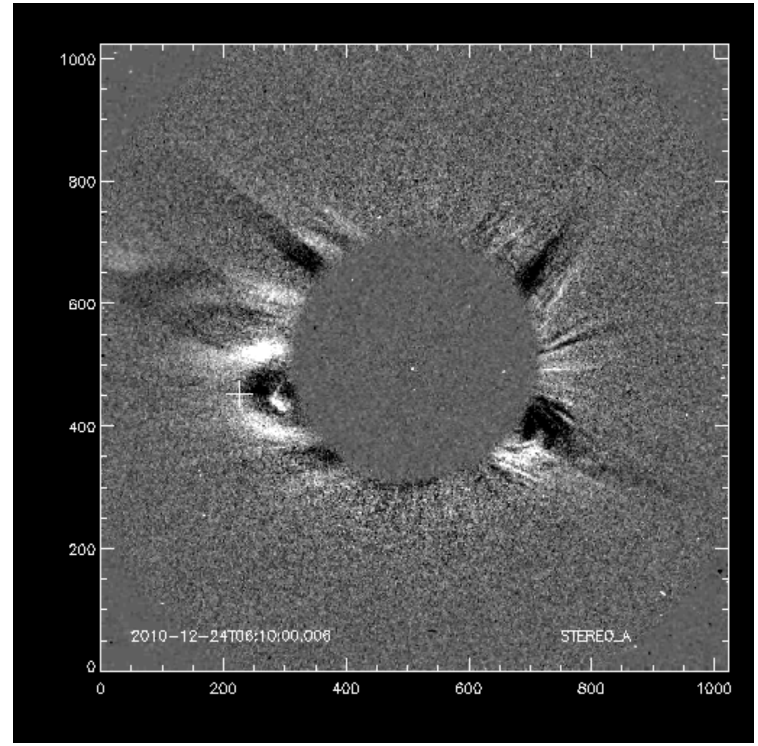


Rad = 2.26 Rs
Lon = 37^o
Lat = -18^o

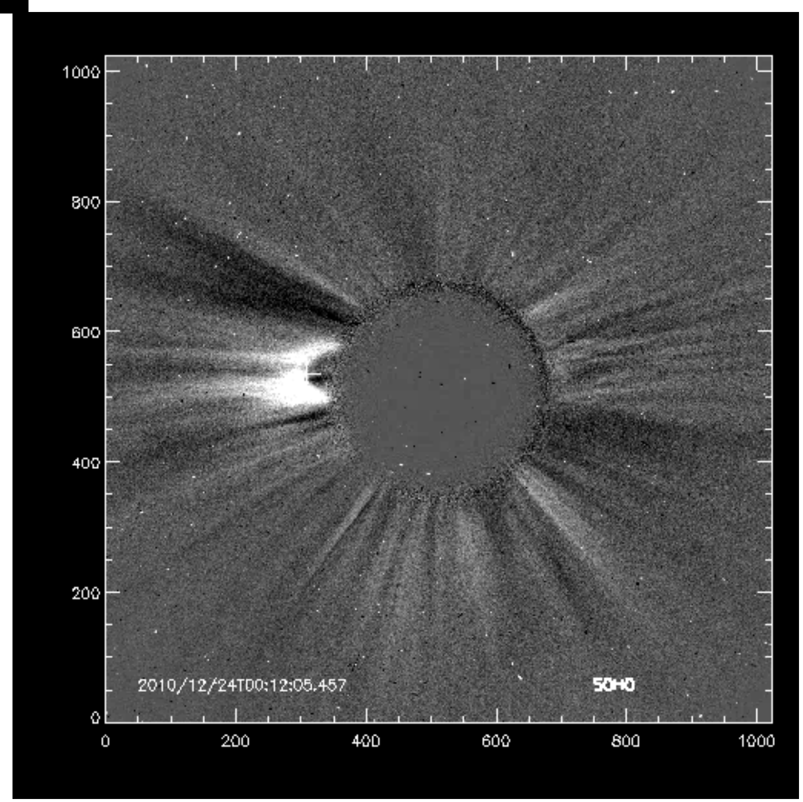
Images courtesy Vaibhav Pant



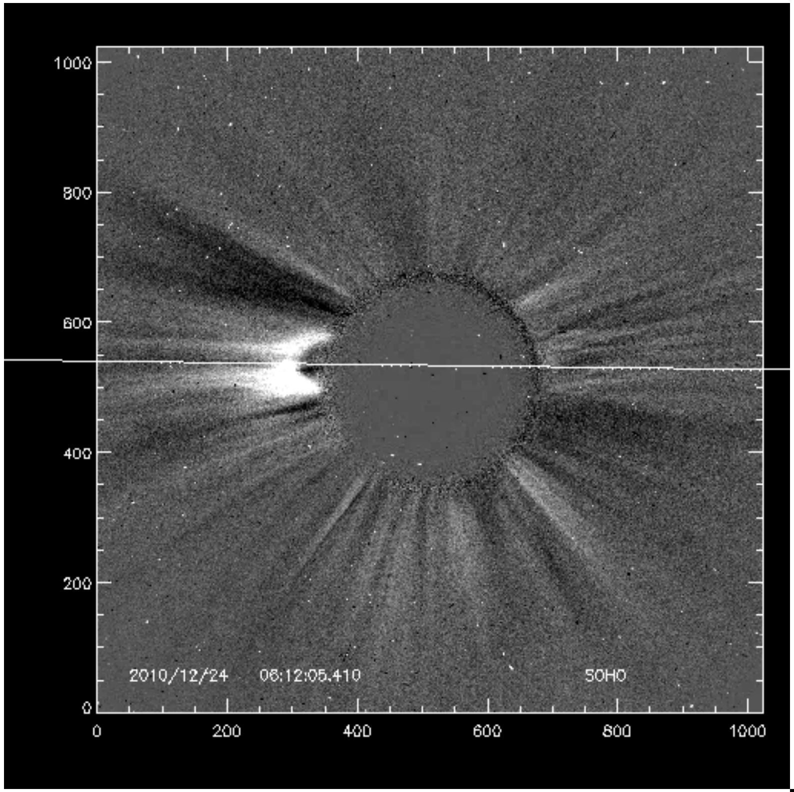
A, LASCO



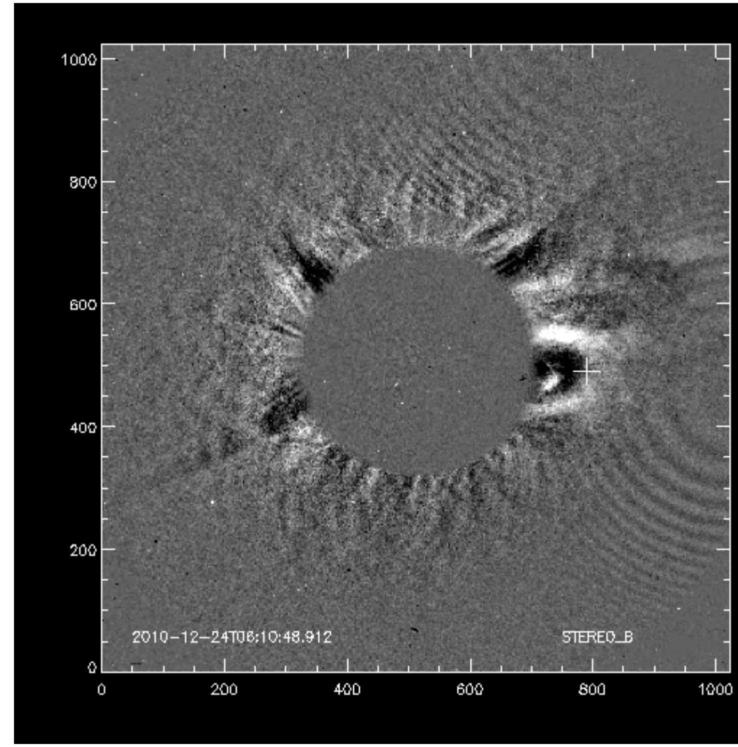
Rad = 3.39 Rs
Lon = 45^{o}
Lat = -12^{o}



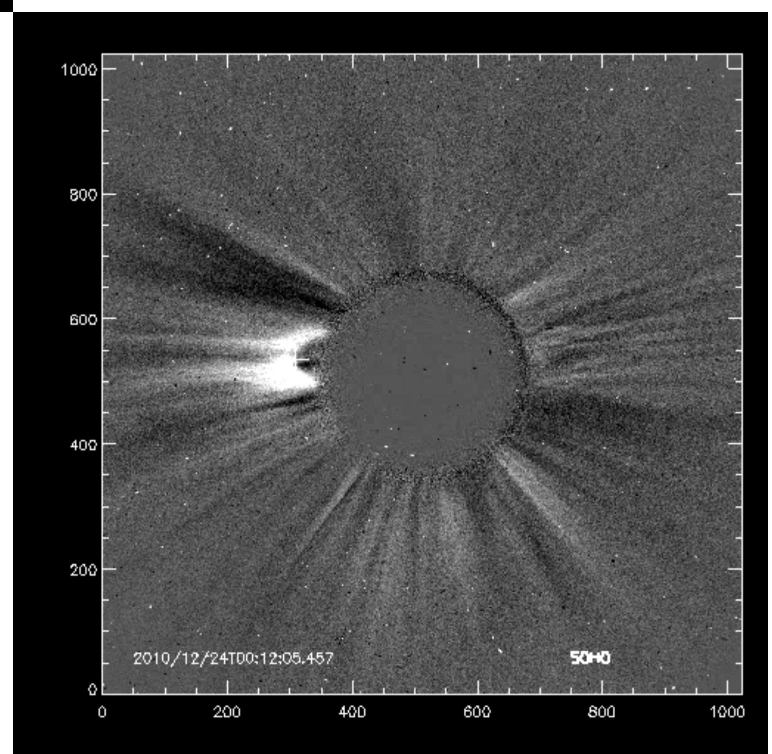
Images courtesy Vaibhav Pant



B, LASCO



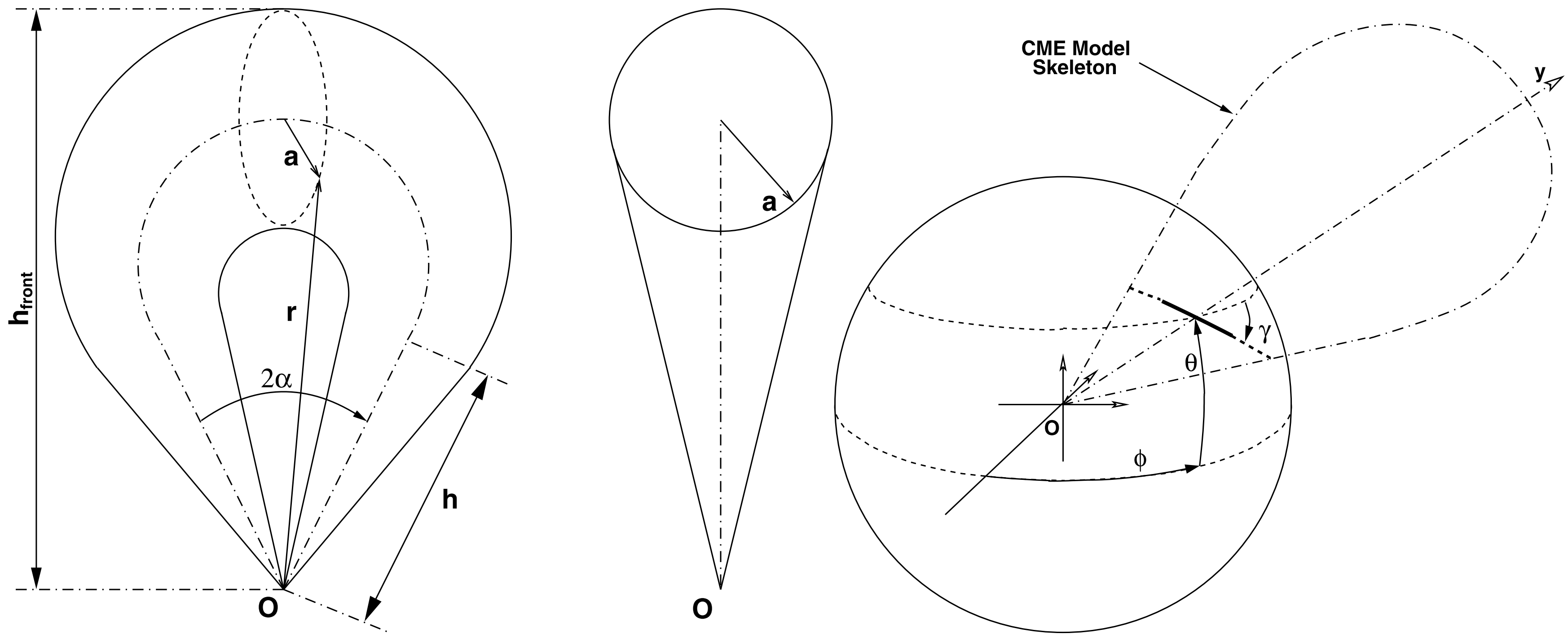
Rad = 3.32 Rs
Lon = 46^{o}
Lat = -12^{o}



Images courtesy Vaibhav Pant

A Geometric Flux Rope Model: The Hollow Croissant Model

Thernisien et al., 2006, 2009, 2011

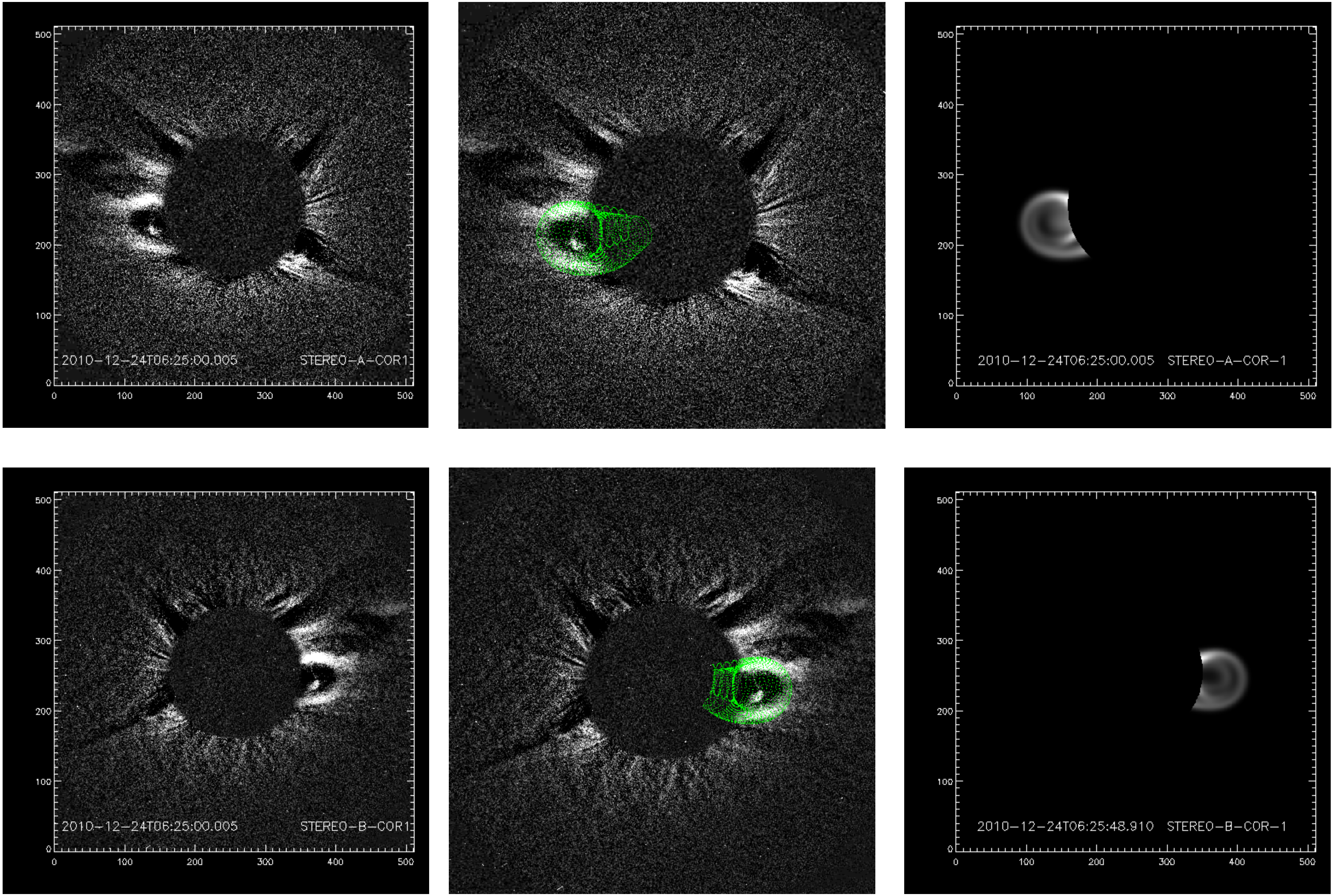


(a) (b) (c)

Include LASCO image also:

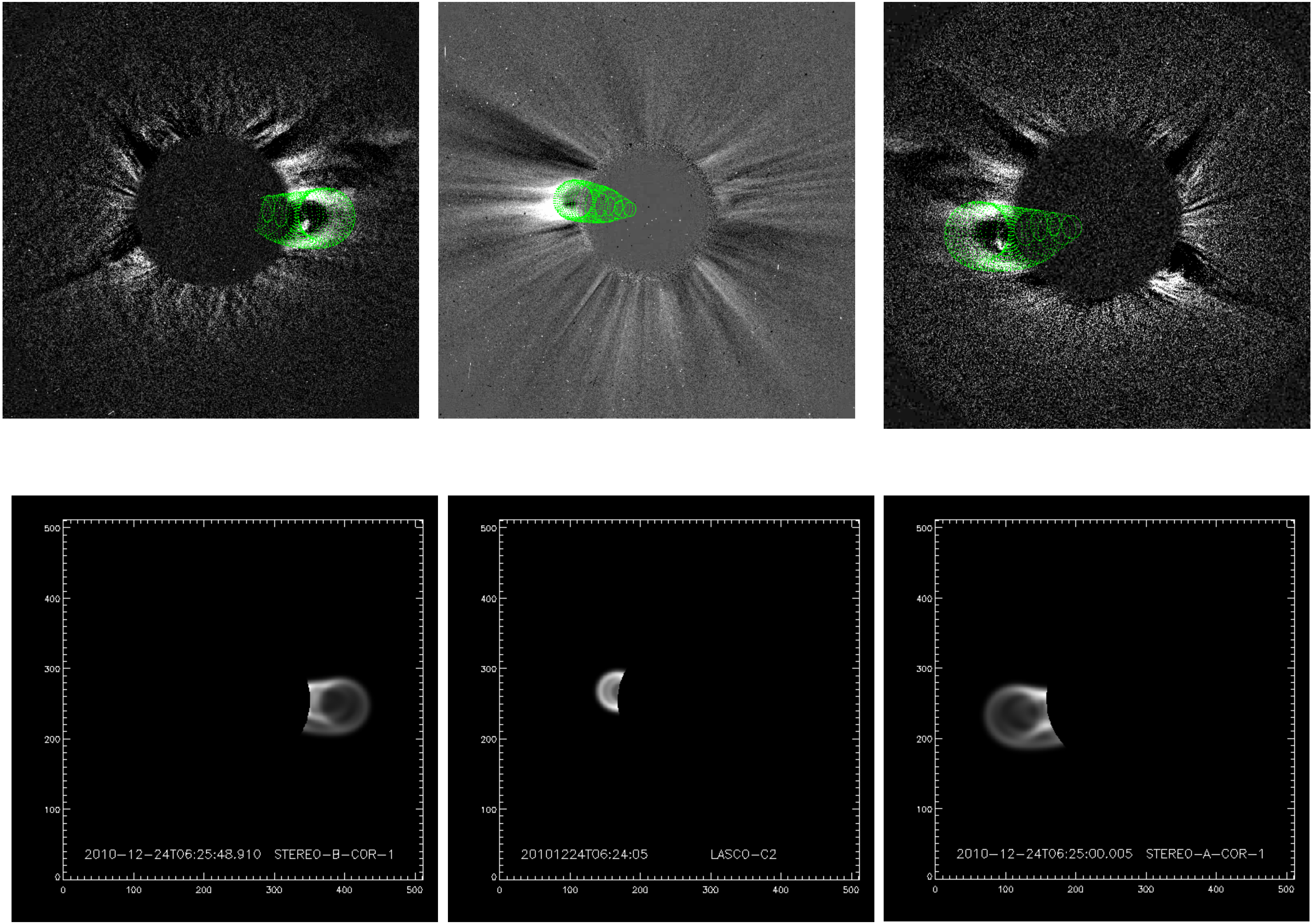
```
IDL> rtsccguicloud, ima, imb, hdra, hdrb, $
ssim = ssimout, sgui = sguiout, swire = swire, ocout = oc, $
imeuvia = ima_euvi, hdreuvia = hdra_euvi, imeuvib = imb_euvi, $
hdreuvib = hdrb_euvi, imlasco = imlasco, hdrlasco = hdrlasco
```

COR1-A



COR1-B

Images courtesy Vaibhav Pant

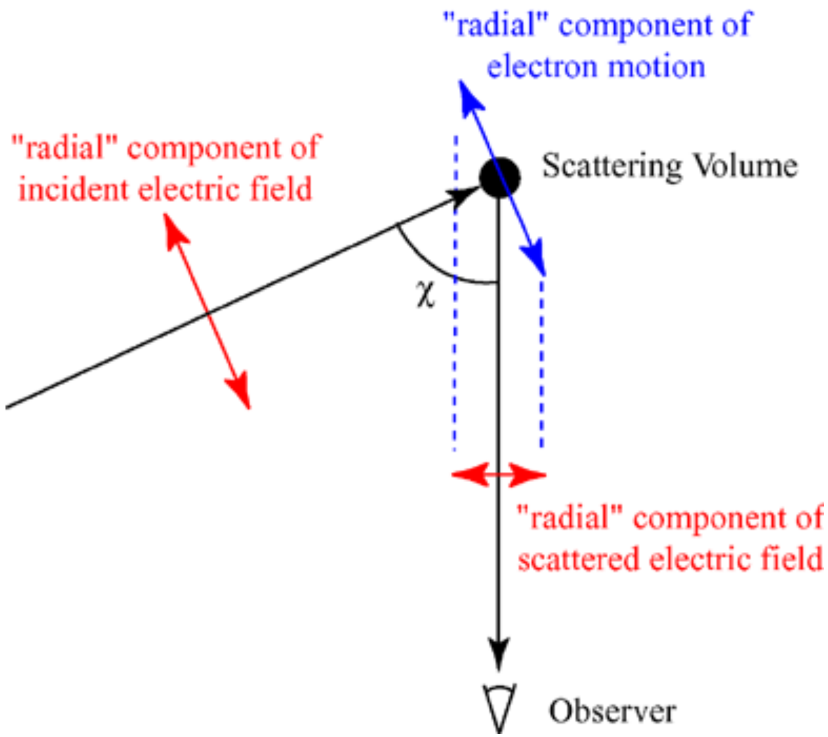


Images courtesy Vaibhav Pant

FM parameters A, B	**FM parameters A, B, C2**
Longitude= 30.18	Longitude=41
Latitude=-14.5	latitude=-12
tilt angle=-19.6	tilt=-10.6
height=3.2	height=3.5
ratio=0.27	ratio=0.2
halfangle=14	halfangle=13
time=2010-12-24T06:25	time=2010-12-24T06:25

Polarization ratio method - Theory

Technique based on Thomson scattering properties. (Moran and Davila 2004 , Dere et al. 2005)



$I_t - I_r$ <=> **pB**
$I_t + I_r$ <=> **B**

<u>Theory (Billings 1966):</u>

$$I_t = I_o \frac{N_e \pi \sigma}{2} [(1-u)C + uD]$$

$$I_t - I_r = I_o \frac{N_e \pi \sigma}{2} \sin^2 \chi [(1-u)A + uB]$$

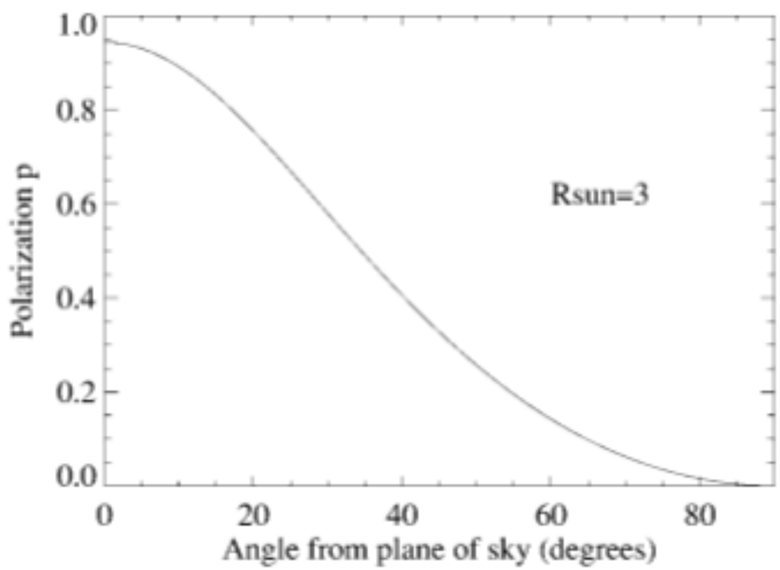


FIG. 1.—Polarization p vs. angle from the plane of the sky at 3 $R_\odot$.

Polarization ratio method - Observations

Technique based on Thomson scattering properties (Moran and Davila 2004 , Dere et al. 2005).

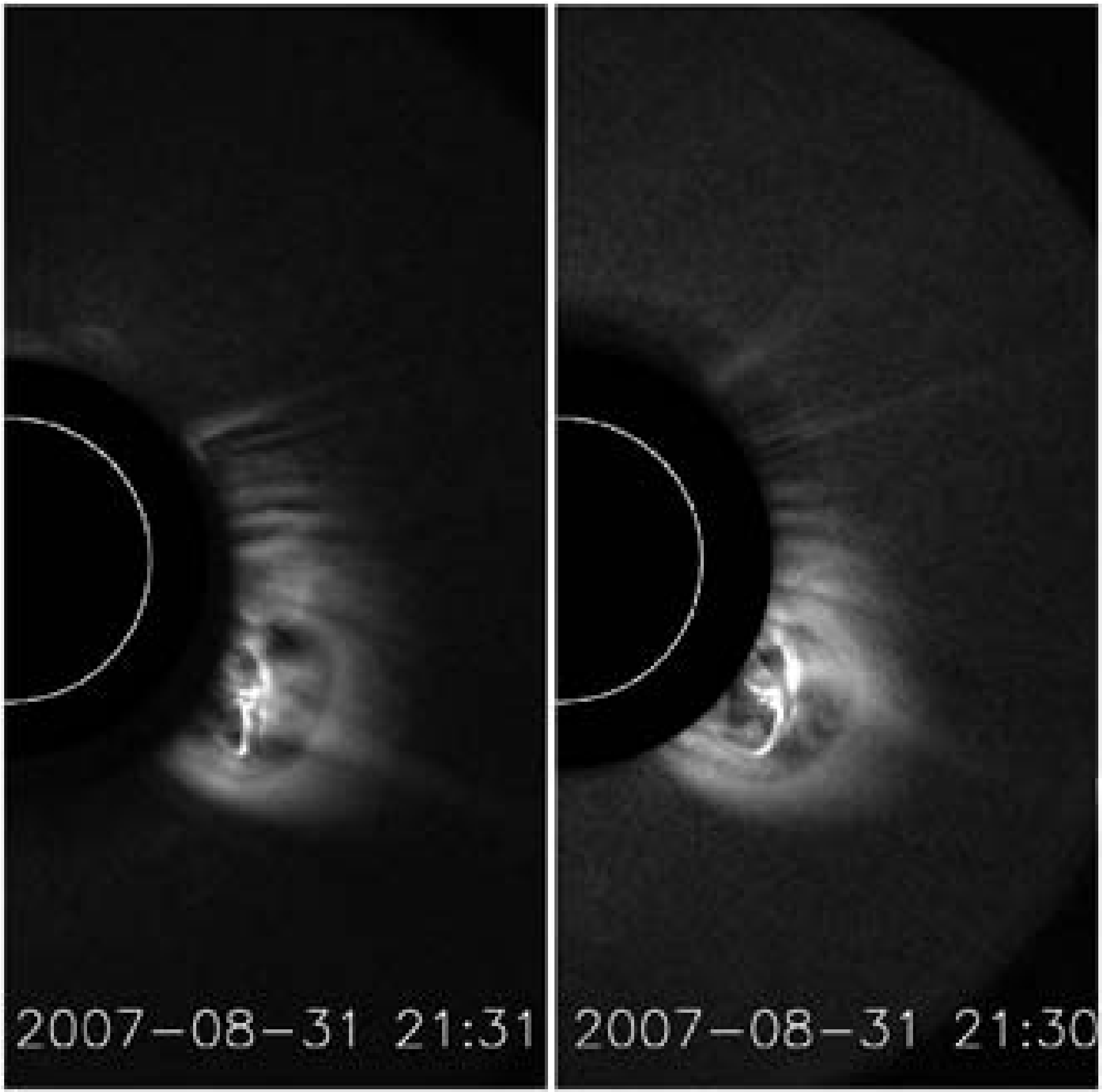
<u>Observations (STEREO/COR):</u>

The ratio of polarized-to-total electron-scattered emissivity (K-corona) is measured by recording coronal images through three polarizers.

$$B = \frac{2}{3}(I_0 + I_{120} + I_{240}),$$

$$pB = \frac{4}{3}\sqrt{(I_0 + I_{120} + I_{240})^2 - 3(I_0 I_{120} + I_0 I_{240} + I_{120} I_{240})},$$

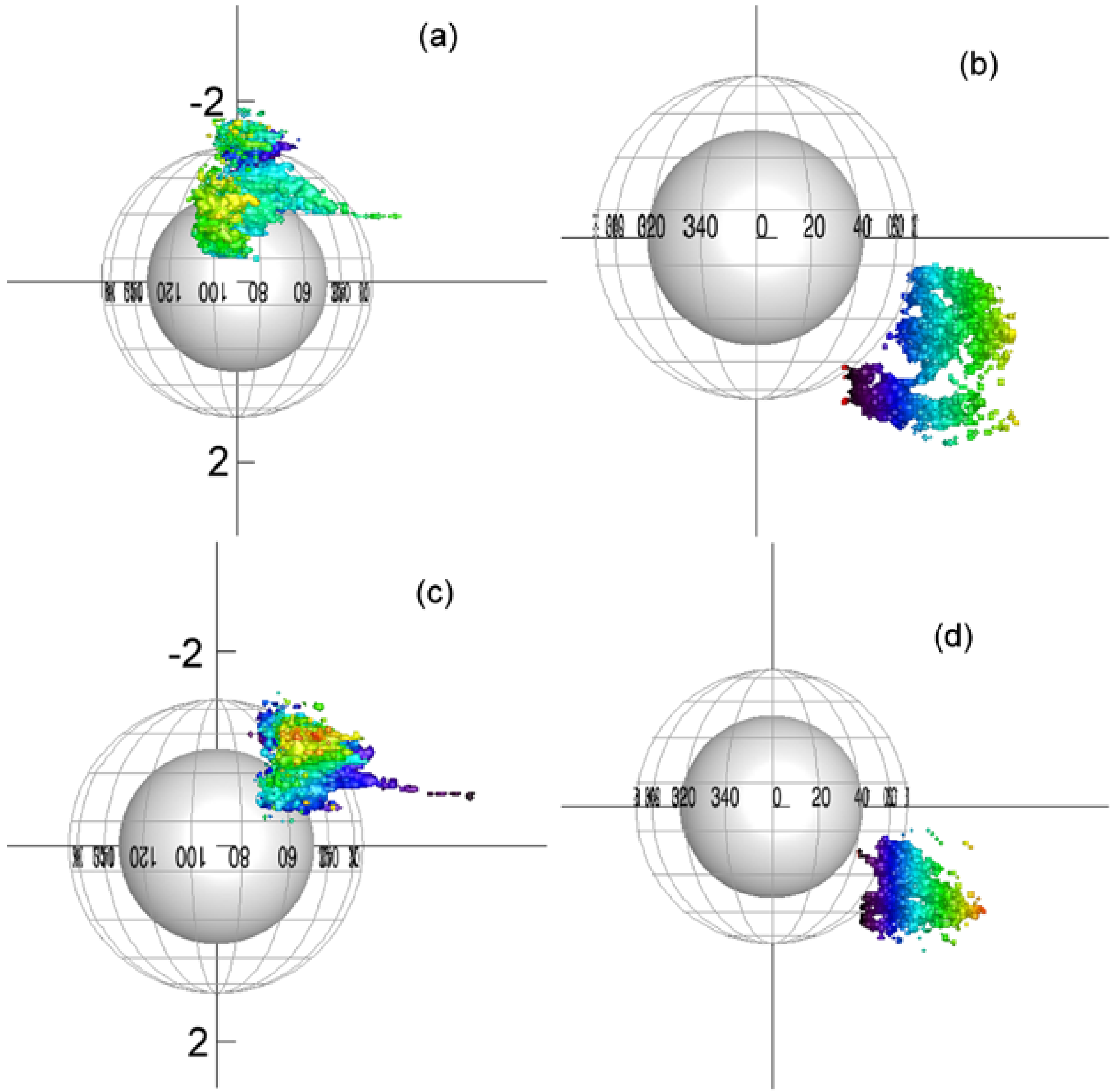
CME seen by COR1 on 31 August 2007, 21:31 UT.



Polarization ratio – application to August 31, 2007 CME

COR1-A

COR1-B



front view

side view

Mierla et al. 2009

Summary

To do 3D reconstruction of CMEs:

- Get the data

- Process the data

- Remove the background in order to be left only with the CME signal

- Apply different reconstruction techniques on the CME signal