On 3D Reconstruction of Coronal Mass Ejections: Study of 31 August 2007 Event

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Contents

- Introduction
- 31 August 2007 CME
- LCT + Triangulation Method – description
  – constraints
- Longitudinal Extension of the CME
- Summary

Introduction

Since the launch of STEREO spacecraft in October 2006, several reconstruction techniques were successfully used to derive **the direction of propagation and the true speed of coronal mass ejections** (CMEs) at distances close to the Sun (coronagraphs fields of view - see the review by Mierla et al. 2010).

Attempts to reconstruct the CME 3D configuration (**full geometric shape**) have been done by:

- Using forward modelling (e.g. Thernisien et al. 2009)
  (a priori known shape of the CME)
- Polarized ratio method (Moran et al. 2010, Mierla et al. 2009)
  (weighted mean distance of the CME plasma density along each line of sight)

Introduction

The aim of this study:

Getting the full 3D geometry of a CME by using local correlation tracking method (to identify the same feature in STEREO/COR images) plus triangulation (to derive its 3D location).

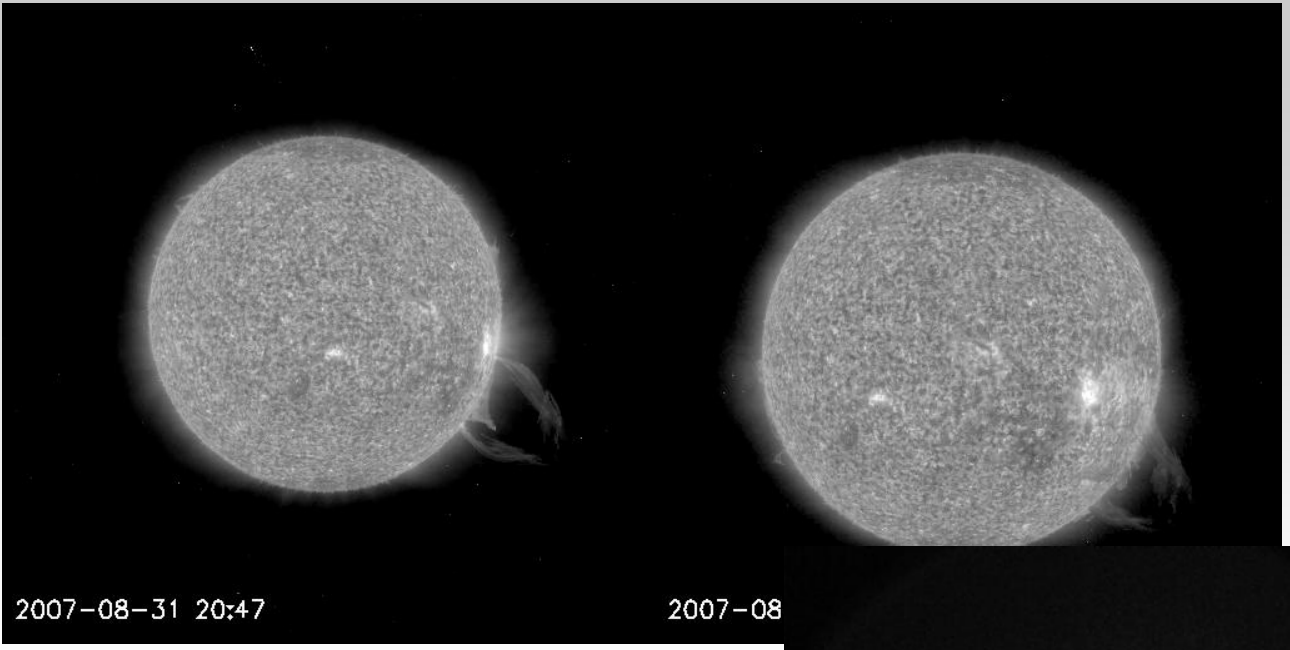
Constraints:

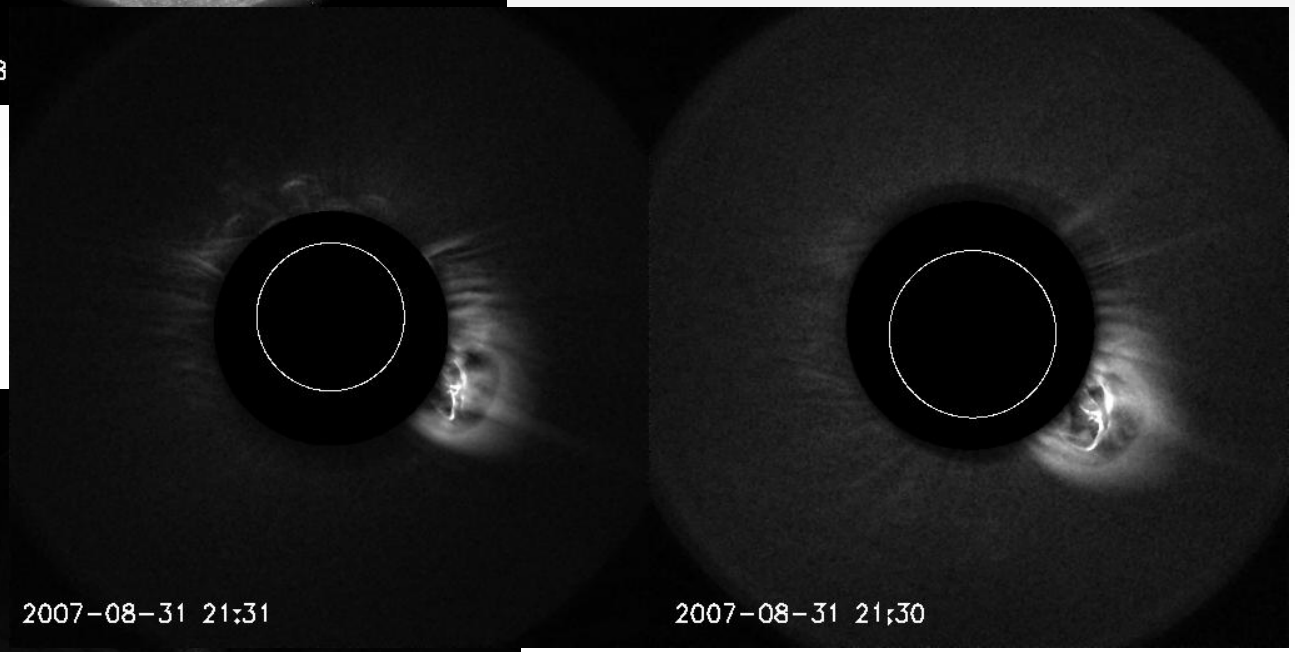
1) the complexity of the CMEs morphologies (bubble-like shapes, twisted flux-ropes etc.);

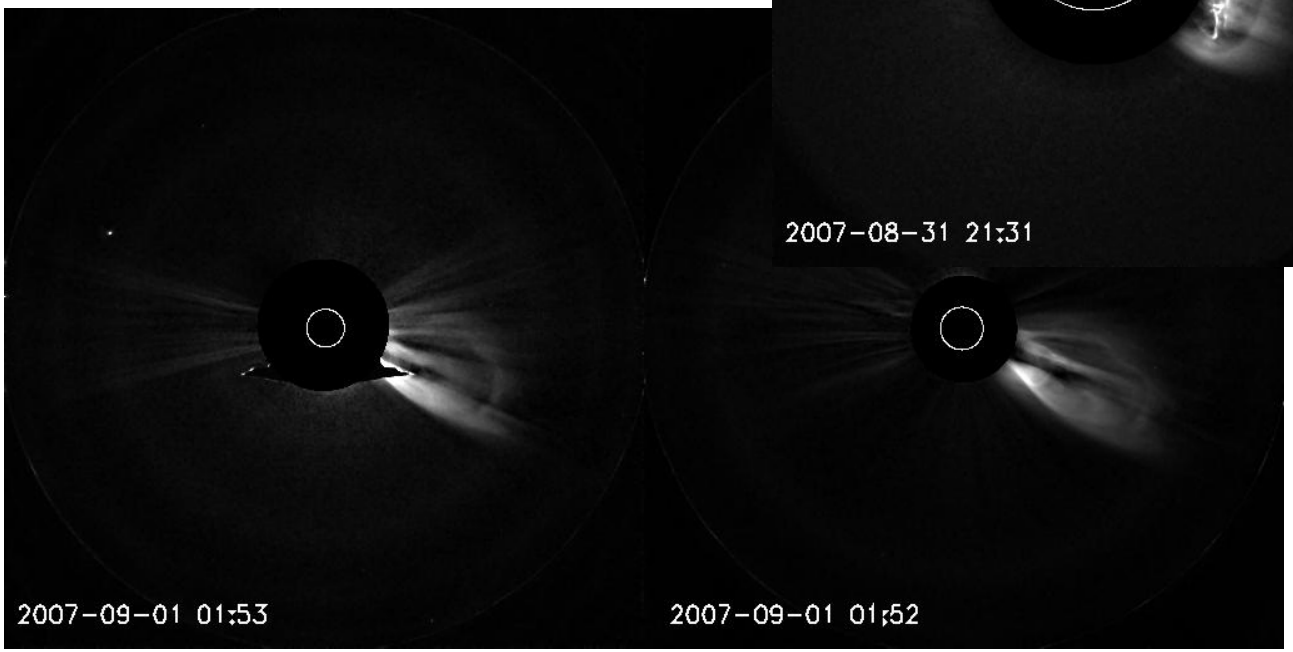
2) the correct identification of the same feature in the two images;

3) optically thin plasma.

31 August 2007 CME



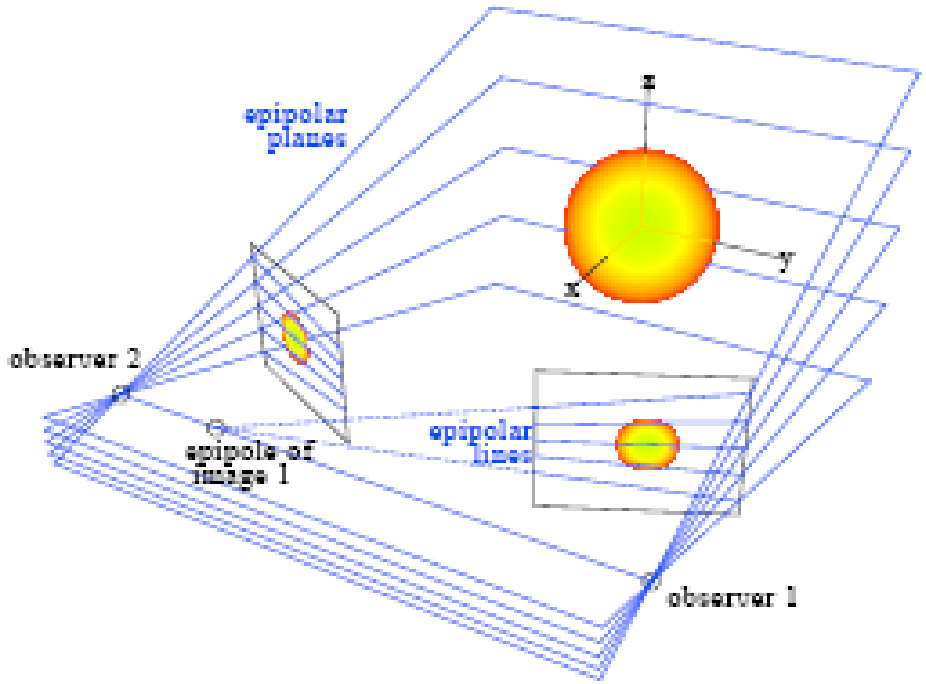




Data pre-processing

Co-align the images in STEREO mission plane:

- same Sun center,
- same pixel resolution
- they are rotated such that epipolar north is at the top of the image



Inhester, 2006

Correlation Technique

The correlation coefficient $\rho_{X,Y}$ between two random variables X and Y with expected values μ_X and μ_Y and standard deviations σ_X and σ_Y is defined as:

$$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_X \sigma_Y},$$

where E is the expected value operator and cov means covariance.

The standard deviation is a measure of the dispersion of a collection of values:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

Covariance provides a measure of the strength of the correlation between two or more sets of random variates:

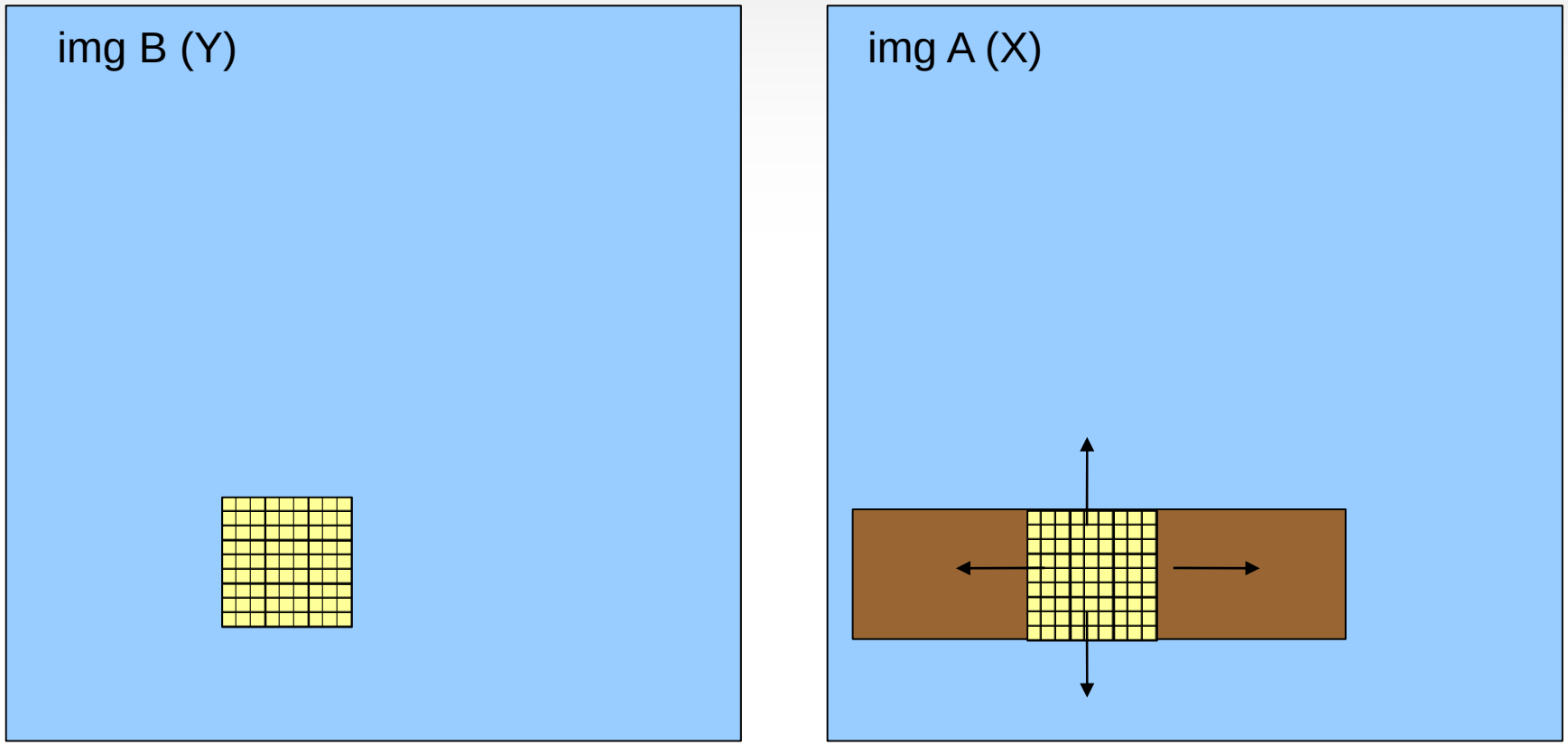
$$\operatorname{cov}(X, Y) \equiv \sum_{i=1}^{N} \frac{(x_i - \overline{x})(y_i - \overline{y})}{N}.$$

Correlation Technique

Note that the images are co-aligned in STEREO mission plane

Program (Sam): bm_flow, imgA, imgB, neigh, lag_window, result_x, result_y, result

$\rho_{X,Y} < 0$: anti-correlation; $\rho_{X,Y} \sim 0$: no correlated; $\rho_{X,Y} > 0.9$: high correlation



= lag or search window (for e.g. 256 x 3 pixels)

= area where correlation is calculated (for e.g 11 x 11 pixels)

Correlation – constraints

1. The technique finds high correlation coefficients for noisy data (low intensity or low signal-to-noise pixels).

Solution: remove the noise

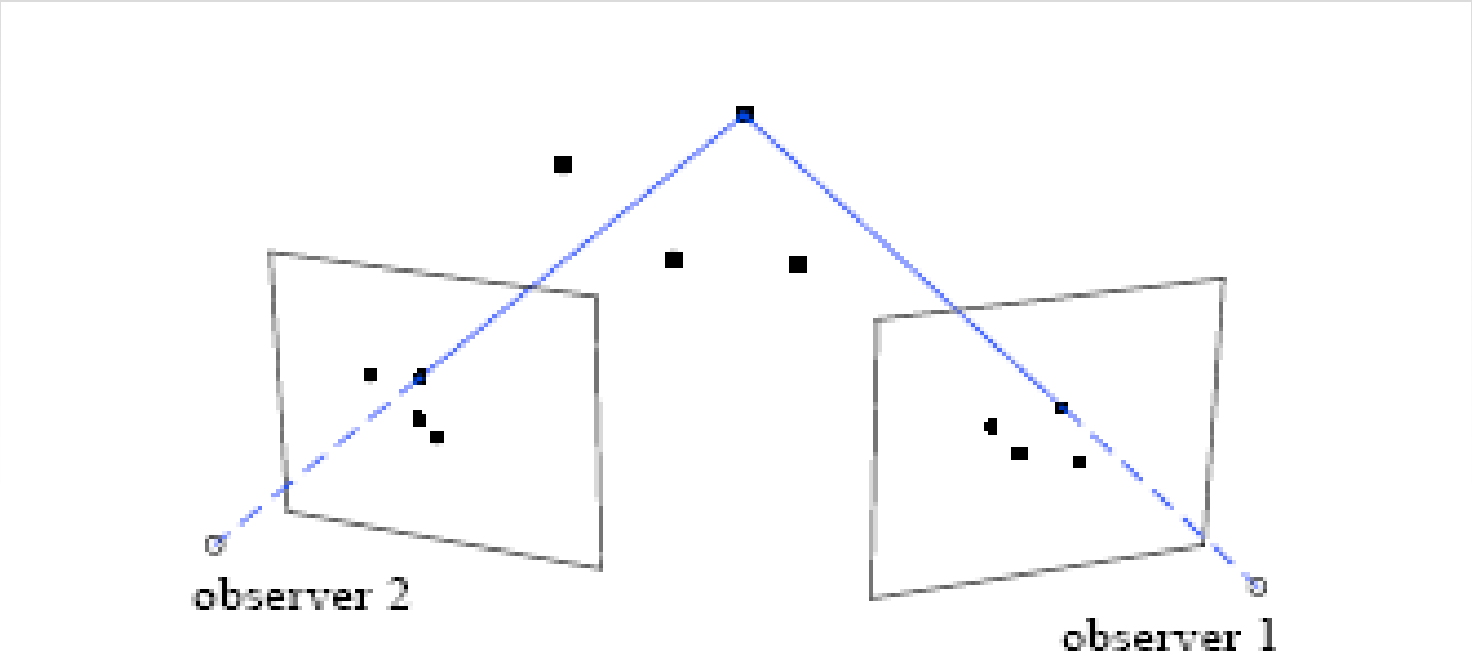
How?

Setting a threshold for each image.

2. For a smooth feature (along the epipolar line) the method finds more than a maxima in a search window

Solution: take the point in the search window closest to the center of mass.

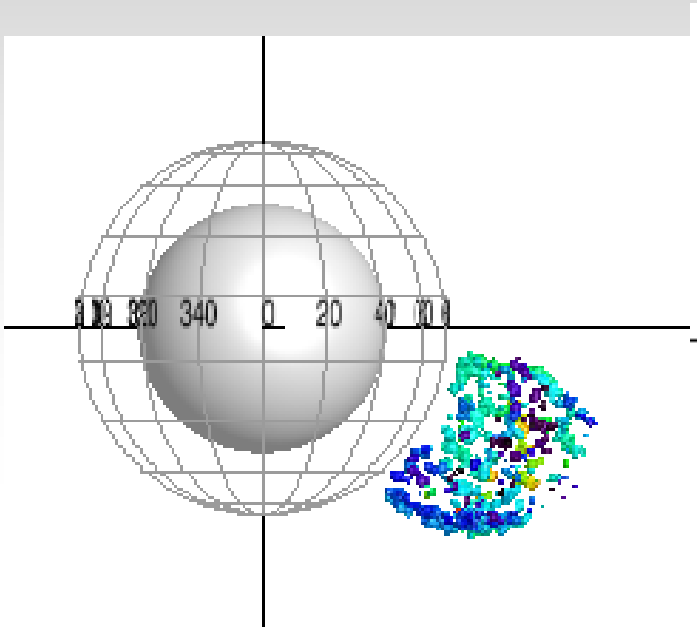
Tie-point reconstruction

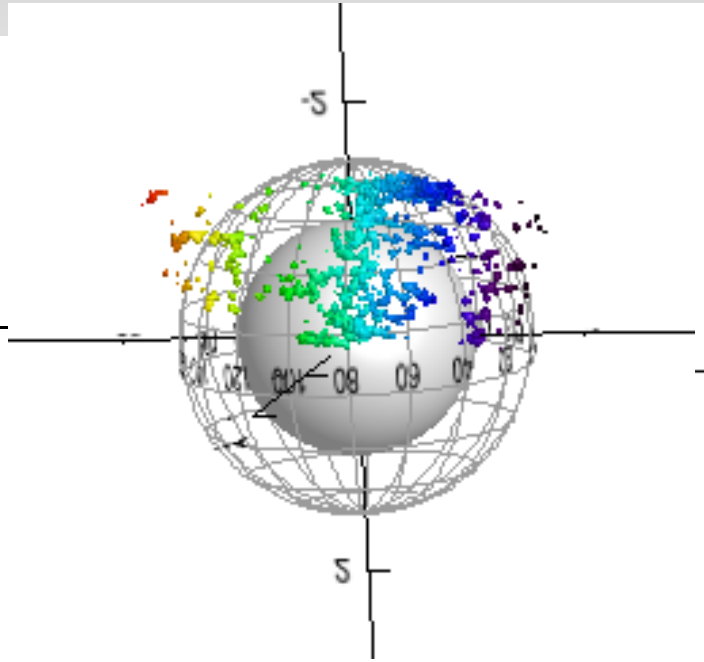


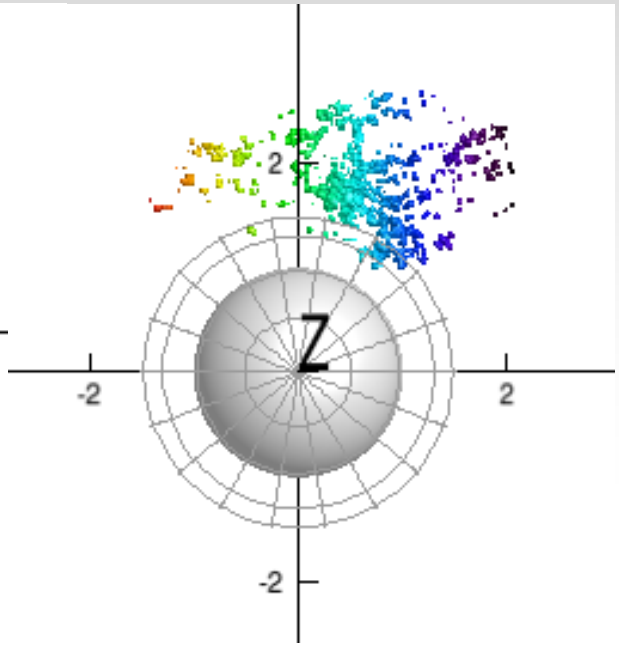
Inhester, 2006

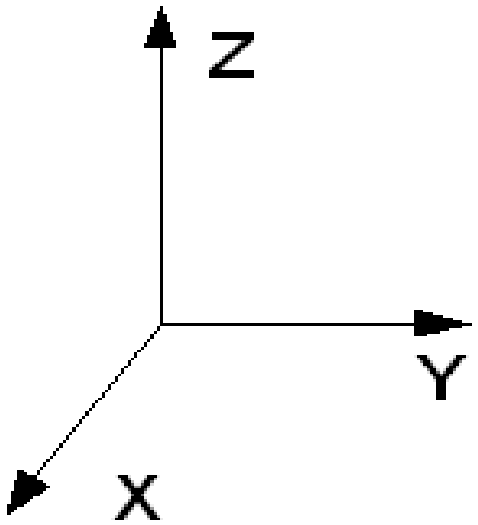
use the program from solar soft (Bill): scc_measure.pro
or depth_reconstruction.pro (Sam)

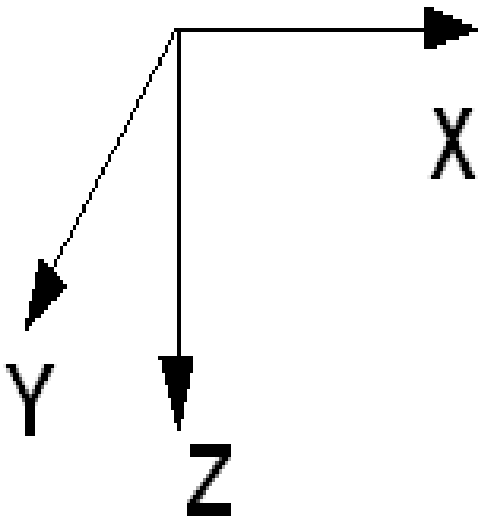
Longitudinal Extension of the CME (COR1)

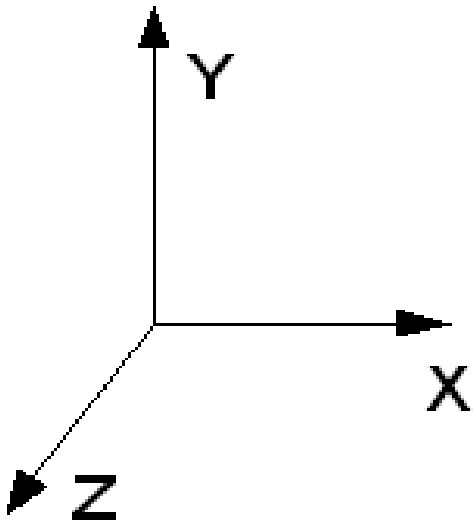




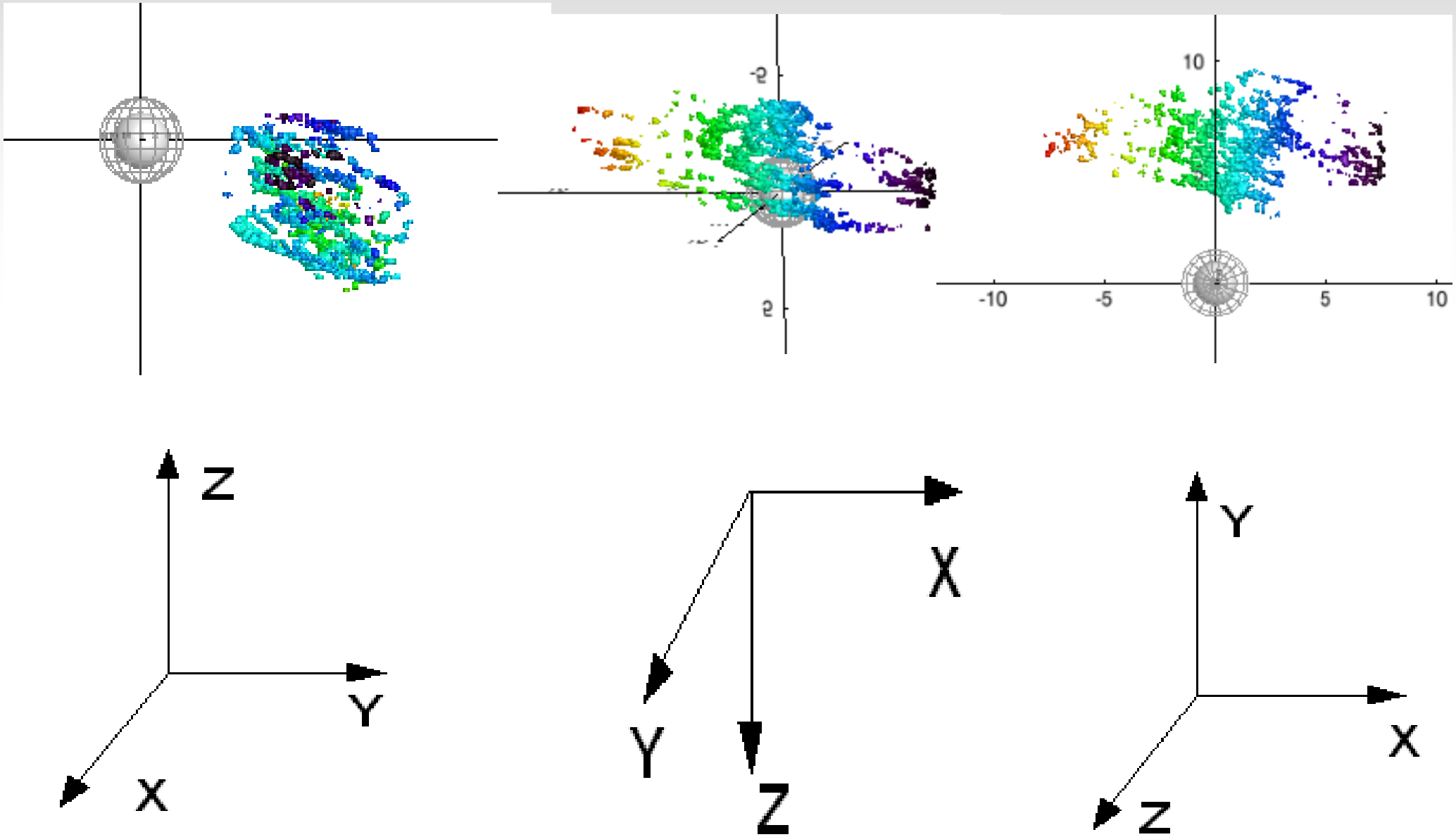




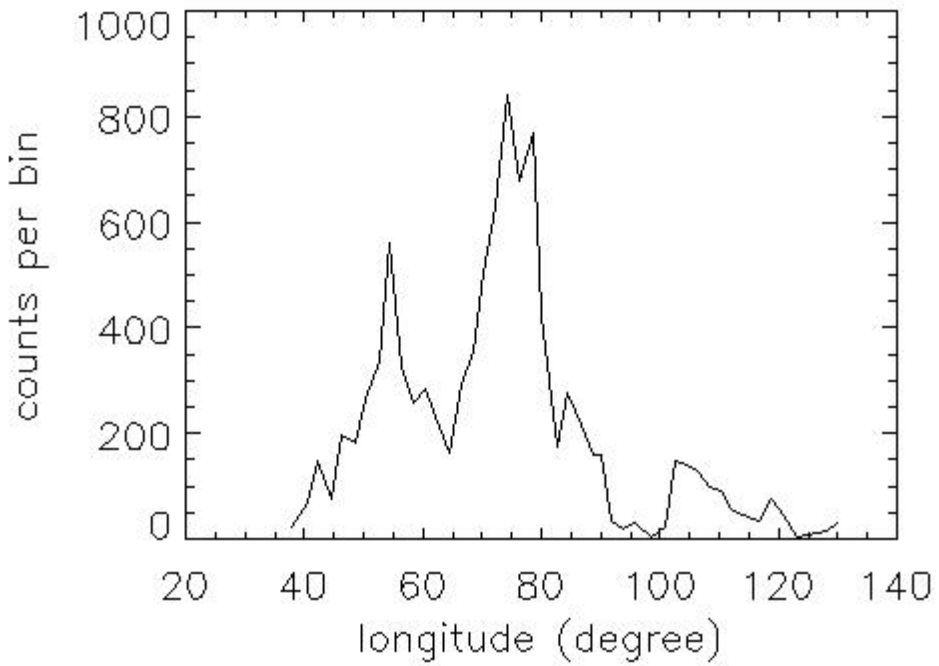




Longitudinal Extension of the CME (COR2)

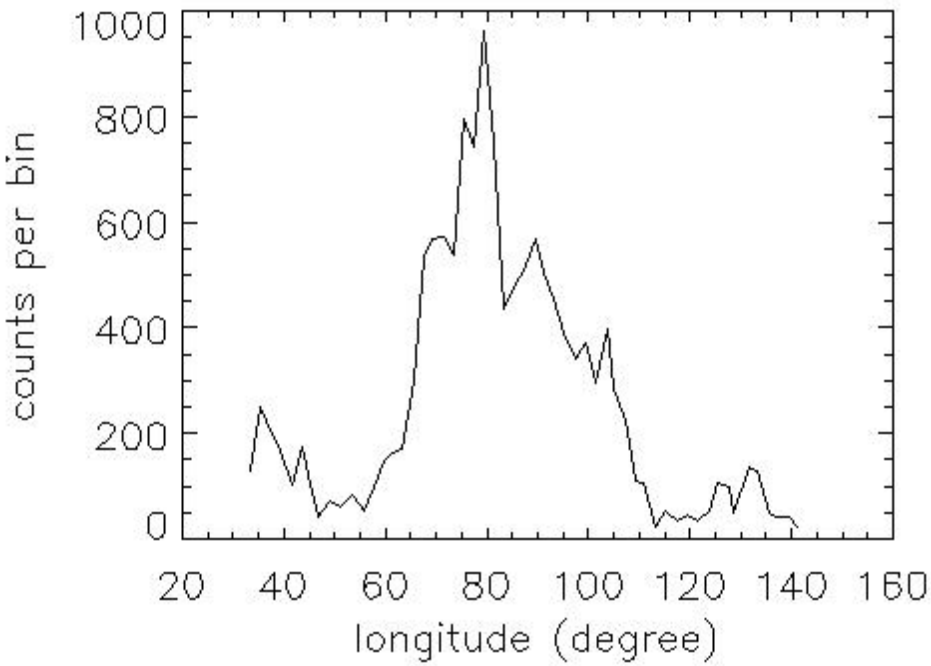


Longitudinal Extension of the CME



COR1

(31 August 2007, 21:30 UT)



COR2

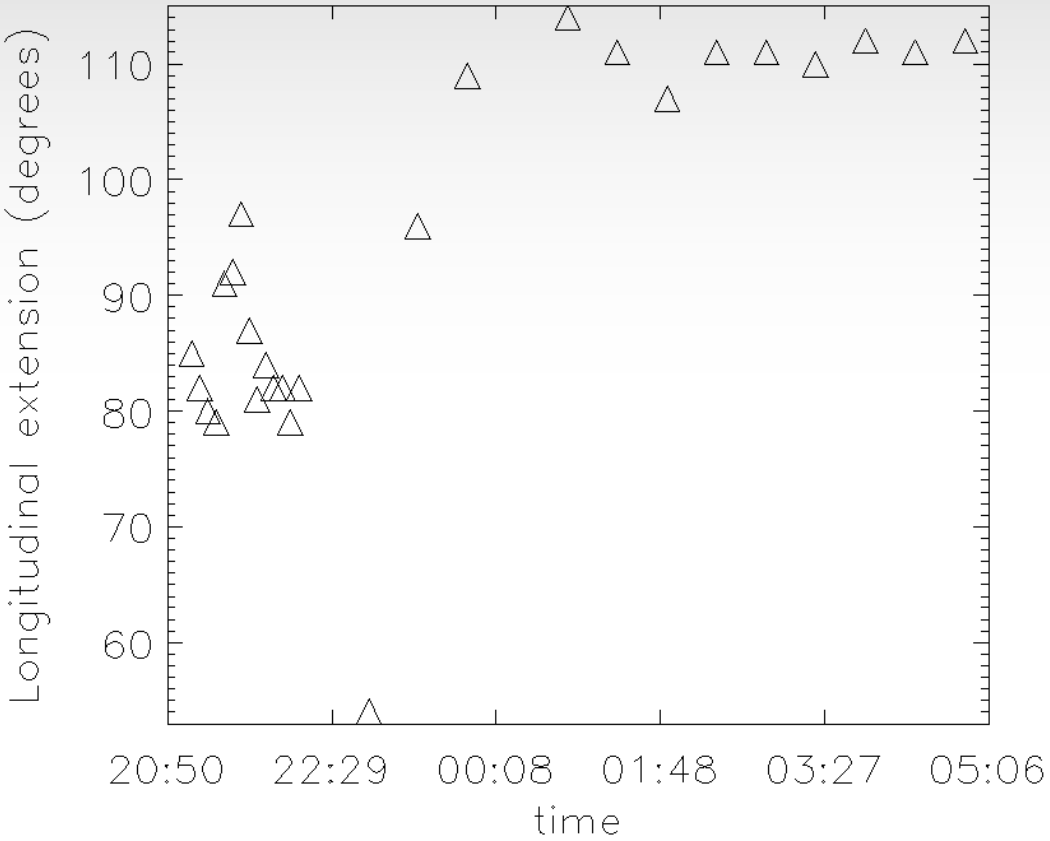
(1 September 2007, 01:52 UT)

Date	Hour	x_heeq	y_heeq	z_heeq	R	lat	longit
31-08-2007	21:05 (COR1)	0.53	1.66	-0.92	1.97	-28	72
31-08-2007	21:10 (COR1)	0.55	1.66	-0.92	1.98	-28	72
31-08-2007	21:15 (COR1)	0.52	1.68	-0.94	2.00	-28	73
31-08-2007	21:20 (COR1)	0.56	1.73	-0.97	2.06	-28	72
31-08-2007	21:25 (COR1)	0.53	1.73	-0.95	2.04	-28	73
31-08-2007	21:30 (COR1)	0.55	1.78	-1.03	2.13	-29	73
31-08-2007	21:35 (COR1)	0.60	1.77	-0.92	2.08	-26	71
31-08-2007	21:40 (COR1)	0.59	1.79	-0.92	2.10	-26	72
31-08-2007	21:45 (COR1)	0.66	1.80	-0.90	2.12	-25	70
31-08-2007	21:50 (COR1)	0.63	1.79	-0.84	2.08	-24	71
31-08-2007	21:55 (COR1)	0.55	1.75	-0.90	2.04	-26	73
31-08-2007	22:00 (COR1)	0.61	1.78	-0.95	2.11	-27	71
31-08-2007	22:05 (COR1)	0.68	1.89	-0.92	2.21	-25	70
31-08-2007	22:10 (COR1)	0.68	1.80	-1.05	2.20	-29	69
31-08-2007	22:52 (COR2)	0.99	3.95	-1.40	4.31	-19	76
31-08-2007	23:22 (COR2)	1.20	4.32	-1.79	4.83	-22	74
31-08-2007	23:52 (COR2)	1.11	4.80	-1.65	5.19	-18	77
01-09-2007	00:52 (COR2)	1.06	5.38	-1.77	5.76	-18	79
01-09-2007	01:22 (COR2)	1.20	5.77	-1.97	6.21	-18	78
01-09-2007	01:52 (COR2)	0.89	6.05	-2.37	6.56	-21	82
01-09-2007	02:22 (COR2)	0.97	6.38	-2.22	6.82	-19	81
01-09-2007	02:52 (COR2)	0.92	6.52	-2.53	7.05	-21	82
01-09-2007	03:22 (COR2)	0.87	6.28	-2.47	6.80	-21	82
01-09-2007	03:52 (COR2)	0.95	6.56	-2.45	7.06	-20	82
01-09-2007	04:22 (COR2)	1.00	6.66	-2.59	7.22	-21	81
01-09-2007	04:52 (COR2)	0.39	6.61	-2.35	7.02	-20	87

Mean value of all reconstructed points obtained from LCT-TP method, in HEEQ coordinate system.

Summary

- The LCT-TP results show some scatter in the direction parallel to the line-of-sight.
- The spread should indicate the depth extent of the CME, if the correlation maxima are due to identical plasma fluctuations inside the CME.
- But, as it is a statistical approach some noise and scatter must be expected.
- Unfortunately, we have no means to check what the real spread of the CME is.
- We can check how good the LCT-TP method is by applying it to a model CME.


Longitudinal extension (degrees)
110
100
90
80
70
60
20:50
22:29
00:08
01:48
03:27
05:06
time