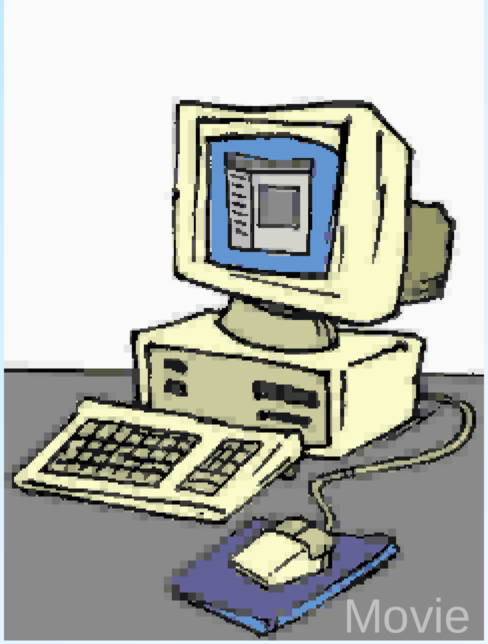
Sur la détermination de la morphologie 3D et des propriétés du plasma solaire de la corona

On Determination of 3D Morphology and Plasma Properties of the Solar Corona

(http://science.nasa.gov/ssl/PAD/SOLAR/papers/garyga/StereoParis.htm)

G. Allen Gary, John M. Davis, and Ronald Moore
Space Science Department
George C. Marshall Space Flight Center/NASA
Huntsville, AL 36812

An earlier analysis performed and published (Solar Physics, 183, 45-76, 1998) is revisited and applied to SECCHI-like observations. Using coronal models and imaging-rendering techniques we investigate several important facts regarding the solar stereographic mission. A synthesized image is presented formed from integrating the emission from the volume elements along the line-of-sight path through a 3-dimensional volume. We used analysis of pairs of these synthesized images with various angular perspectives to investigate the effect of angular separation on mission objectives. The resulting images and analysis provide guidelines for developing a stereographic mission analysis program.



The 3D Sun and Inner Heliosphere: The STEREO View
The First STEREO Workshop (March 18-20, 2002)
Paris, France

*Movie – Click to play movie

Conclusions

$3D^{\lambda}_{(x,y,t)} \longrightarrow 4D^{\lambda}_{(x,y,z,t)} \longrightarrow nD_{(x,y,z,t,\rho,T,v,B,..)}$

Temporal set of stereographic 2D images to a MHD physical model – the challenge (EUVI analysis as per paper but CORs analysis is complex)

A priori information – The all important input

Location of centroid (large-scale structures)

Principal axis of symmetry (origin: near or far-side)

Principal axis of radial expansion (evolutionary track)

Region of origin and footpoints

Temporal history

Global magnetic field

Specific triangularization (location) of point sources (micro-structures)

Physical nature of the object

Observational constraints

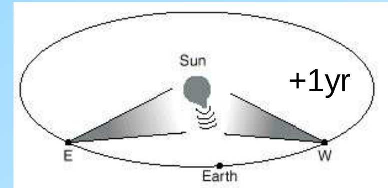
Self-similar modeling

Serendipity – The magic of the mission

STEREO- Solar Terrestrial Relations Observatory

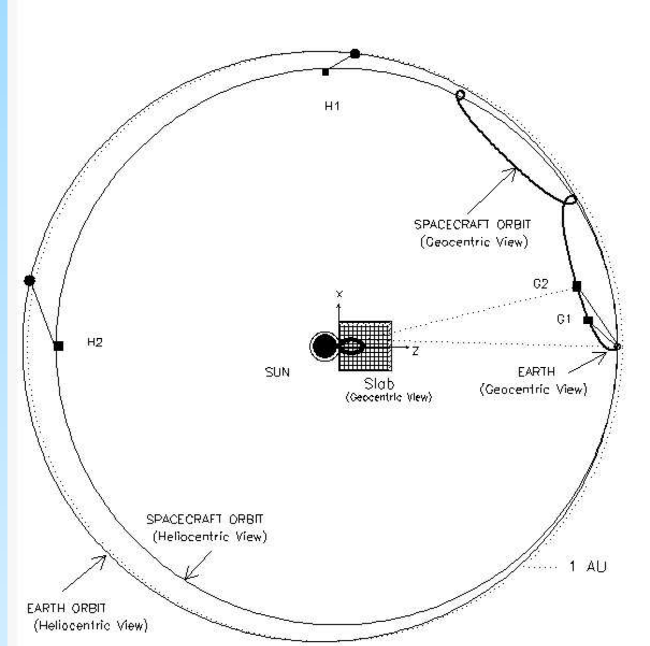
Launch of Dual Spacecrafts: 5 May 2006

Launch Solar-B: 5 OCT 2005



Mission Concept: The STEREO mission will provide a totally new perspective on solar eruptions and their consequences for Earth. Achieving this perspective will require moving away from our customary Earth-bound lookout point. To provide the images for a stereo reconstruction of solar eruptions, one spacecraft will lead Earth in its orbit and one will be lagging. Each will carry a cluster of telescopes. When simultaneous telescopic images are combined with data from observatories on the ground or in low Earth orbit, the buildup of magnetic energy, and the lift off, and the trajectory of Earthward-bound CMEs can all be tracked in three dimensions. When a CME reaches Earth's orbit, magnetometers and plasma sensors on the STEREO spacecraft will sample the material and allow investigators to link the plasmas and magnetic fields unambiguously to their origins on the Sun.

Mission Scientist Davila-GSFC



SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation) is a suite of remote sensing instruments consisting of two **white light coronagraphs** (1.2-3 and 3-15 Rs) and an **EUV imager** (2x EIT), collectively referred to as the Sun Centered Imaging Package, and a **heliospheric imager** (12-84Rs; 66-318Rs). PI Howard-NRL

SWAVES (Stereo Waves) measures interplanetary type II and type III radio bursts, both remotely and in situ. Type II radio bursts are associated with the propagation of CMEs in the corona and interplanetary medium (IPM).

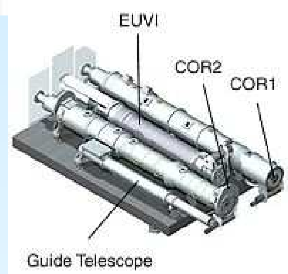
PI Bougert-CNRS,France

IMPACT (In-situ Measurements of Particles and CME Transients) includes a Solar Wind (SW) experiment to measure ~0-100 keV electrons, a magnetometer (MAG) experiment to measure the vector magnetic field, and a Solar Energetic Particle (SEP) experiment to measure electrons and ions.

PI Luhmann-UCB

PLASTIC (PLasma And SupraThermal Ion Composition investigation) measures solar wind protons and alphas, the elemental composition, charge state distribution, kinetic temperature, and velocity of heavy ions, and measures suprathermal ions.

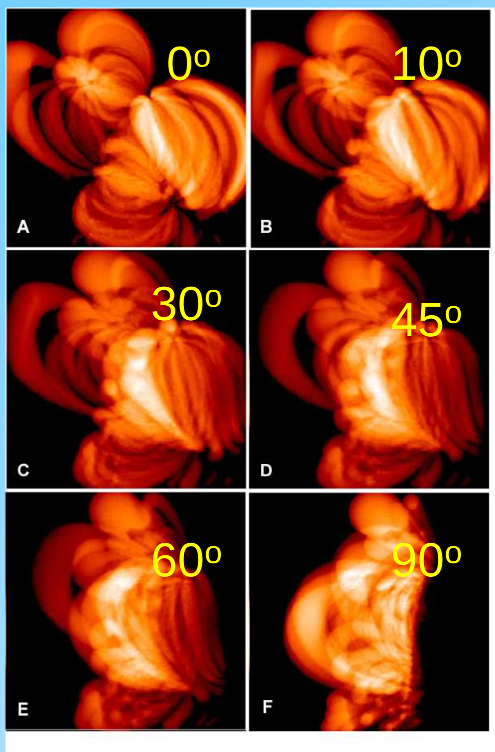
PI Galvin-UNH



Review of Previous Analysis

Gary, Davis, & Moore,1998, Solar Phys. 183, 45

Synthesized coronal loop images of *optical thin flux tubes*



Conclusions of that analysis:

- Maximum information at a specific angular separation
- Benefits of time - differential imaging
- A priori information improves volume reconstruction

Stereographic Pairs

Employing time separated images

Review of Previous Analysis

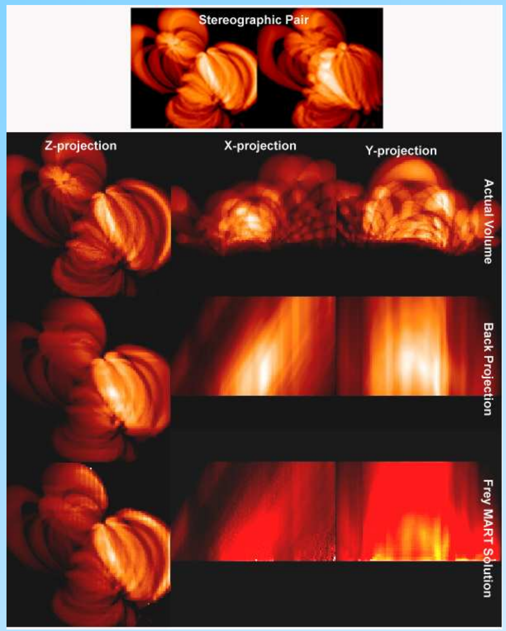
Gary, Davis, & Moore,1998, Solar Phys. 183, 45

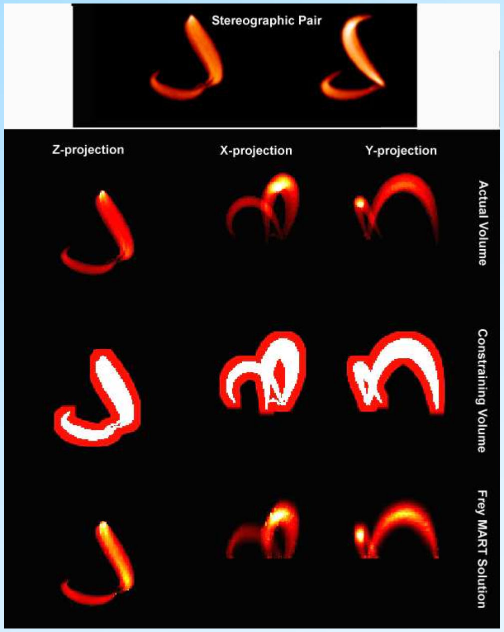
Tomography by Discrete Reconstruction Techniques

(See paper for details)

Frey's Modified Multiplicative Algebraic Reconstruction (MART)

Importance of temporal subtractive techniques and a priori information





Restricted volume based on magnetic field extrapolation

Three-view of the render coronal loops seen along the x, y, and z axes.

(Top triplet: Input model Bottom triplet: Derived model)

Data Analysis Flow of coronal loops:

Triangulation

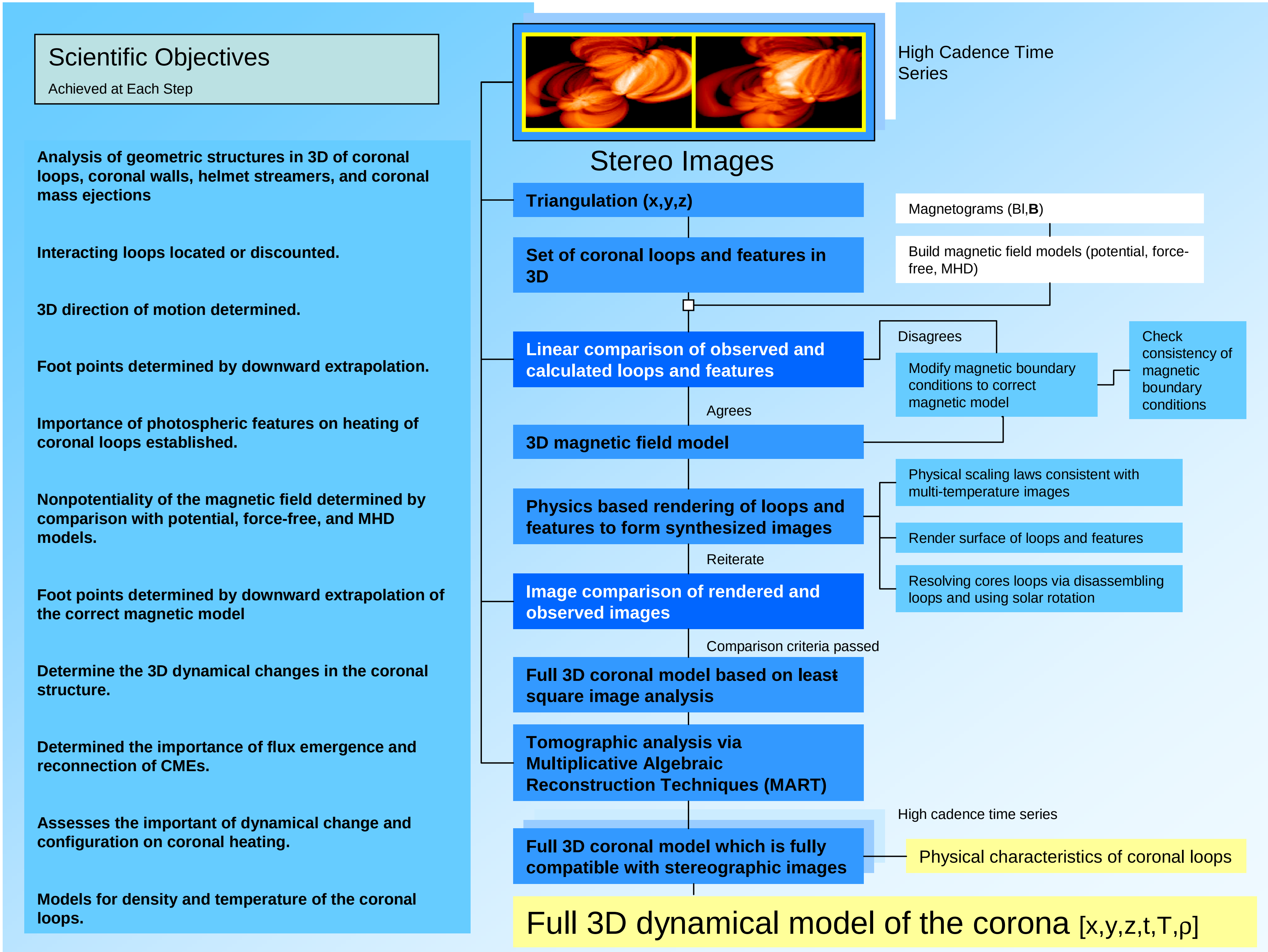
Magnetic Field Extrapolation

Coronal Rendering

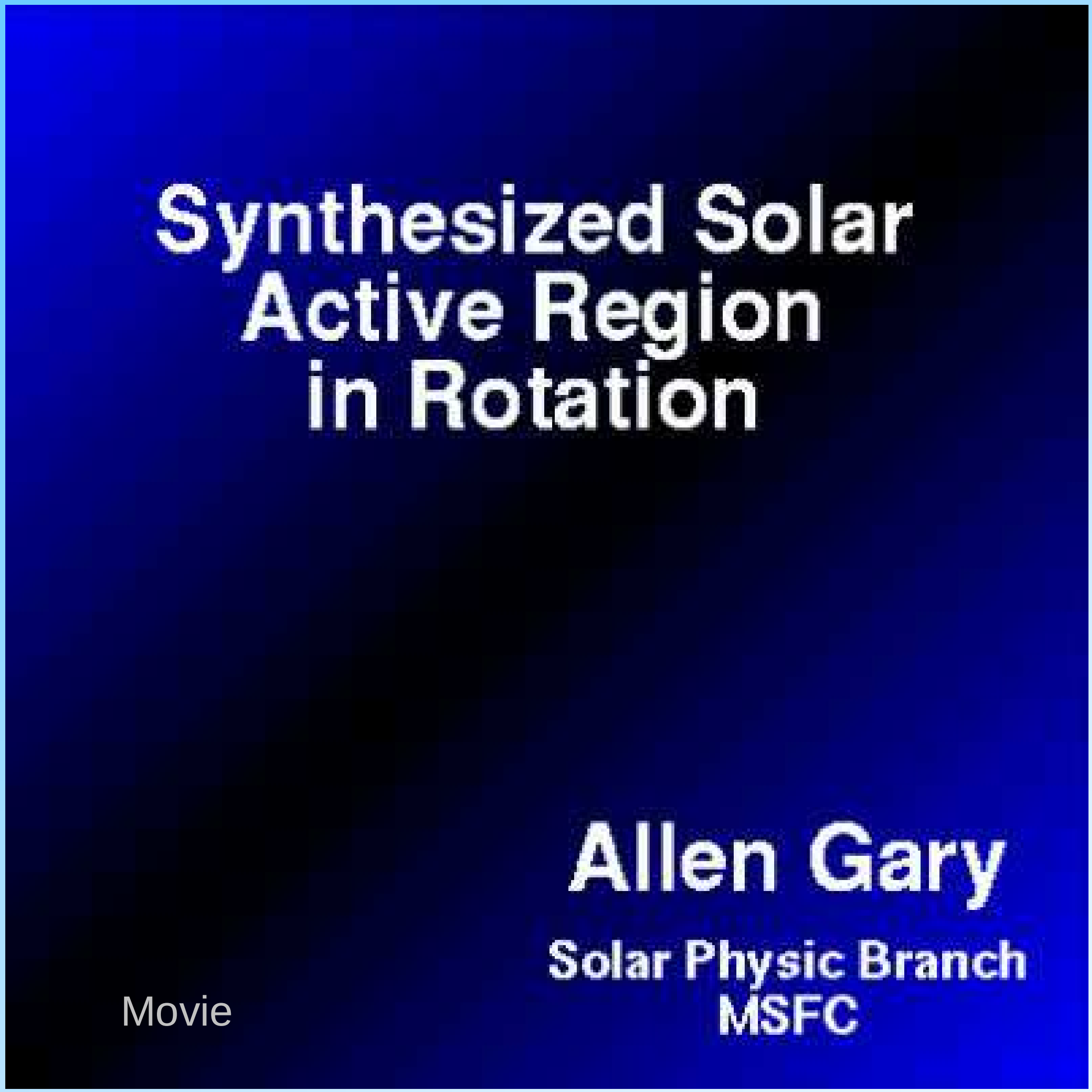
Tomographic analysis

Iteration

- **3D geometric location**
- **Interacting loops located.**
- **3D direction of motion determined.**
- **Importance of photospheric motion.**
- **Nonpotentiality magnetic field determined.**
- **Foot points of coronal loops determined.**
- **Determine the 3D dynamical changes in the coronal structure.**
- **Determined the importance of flux emergence and reconnection of CMEs.**
- **Assesses the important of dynamical change and configuration on coronal heating.**
- **Density and temperature models.**

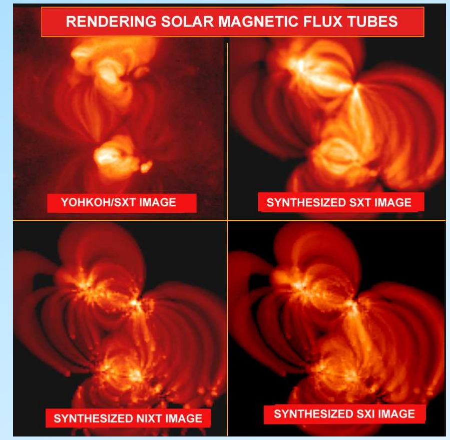


Scientific Objectives
Achieved at Each Step
Analysis of geometric structures in 3D of coronal loops, coronal walls, helmet streamers, and coronal mass ejections
Interacting loops located or discounted.
3D direction of motion determined.
Foot points determined by downward extrapolation.
Importance of photospheric features on heating of coronal loops established.
Nonpotentiality of the magnetic field determined by comparison with potential, force-free, and MHD models.
Foot points determined by downward extrapolation of the correct magnetic model
Determine the 3D dynamical changes in the coronal structure.
Determined the importance of flux emergence and reconnection of CMEs.
Assesses the important of dynamical change and configuration on coronal heating.
Models for density and temperature of the coronal loops.
High Cadence Time Series
Stereo Images
Triangulation (x,y,z)
Magnetograms (Bl,B)
Build magnetic field models (potential, force-free, MHD)
Set of coronal loops and features in 3D
Linear comparison of observed and calculated loops and features
Disagrees
Modify magnetic boundary conditions to correct magnetic model
Check consistency of magnetic boundary conditions
Agrees
3D magnetic field model
Physics based rendering of loops and features to form synthesized images
Physical scaling laws consistent with multi-temperature images
Render surface of loops and features
Resolving cores loops via disassembling loops and using solar rotation
Reiterate
Image comparison of rendered and observed images
Comparison criteria passed
Full 3D coronal model based on least square image analysis
Tomographic analysis via Multiplicative Algebraic Reconstruction Techniques (MART)
High cadence time series
Full 3D coronal model which is fully compatible with stereographic images
Physical characteristics of coronal loops
Full 3D dynamical model of the corona [x,y,z,t,T,ρ]

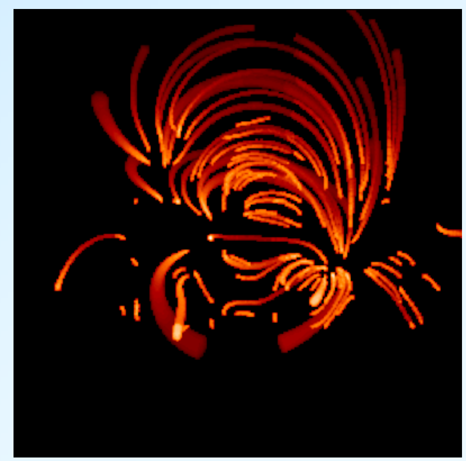


SXT image type

Gary (1997) Solar Physic 174, 241



Various Instrumental Response Functions

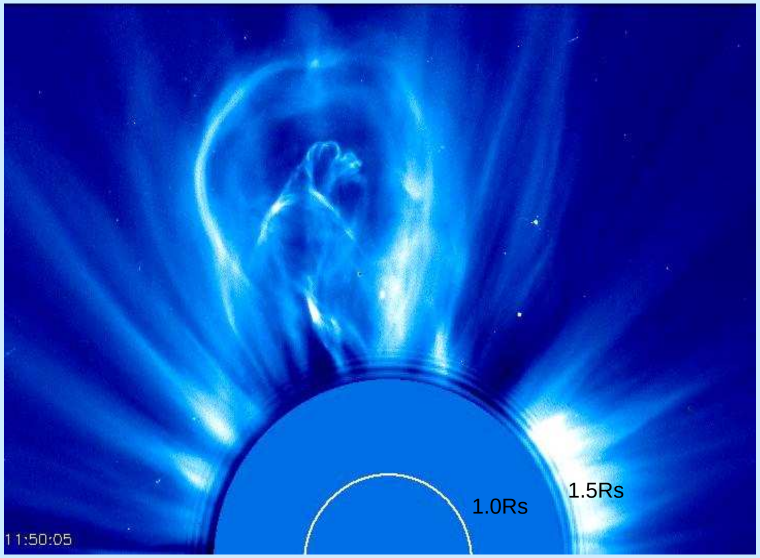


EIT image Type

Large Scale vs. Fine Scale Structure

Solar & Heliospheric Observatory

Large Angle Spectrographic Coronagraph



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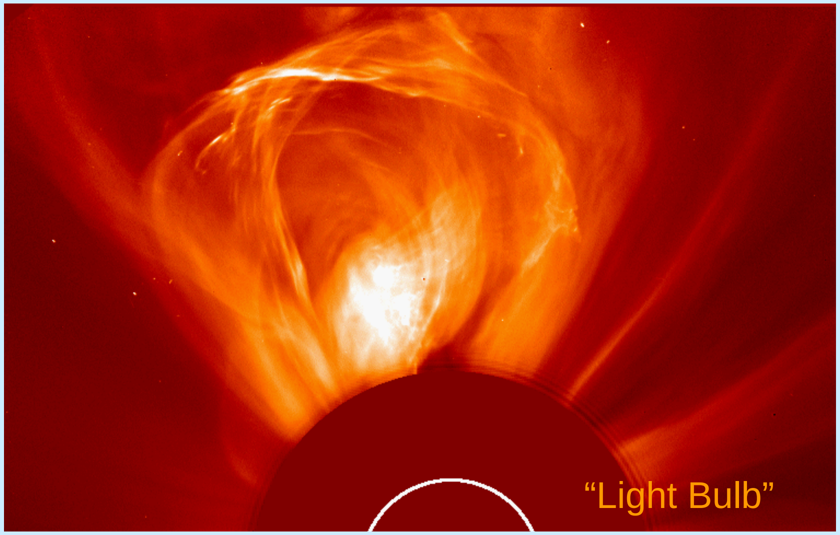

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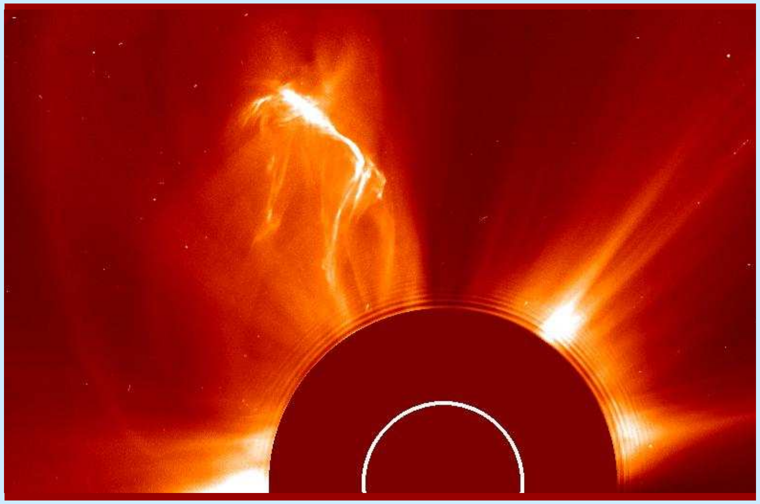

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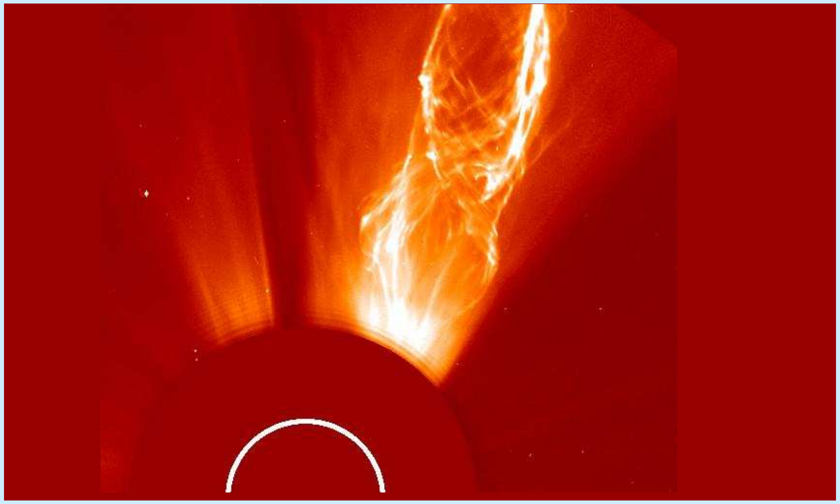

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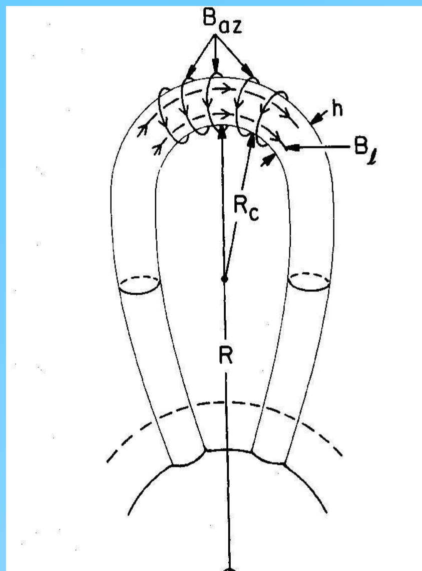
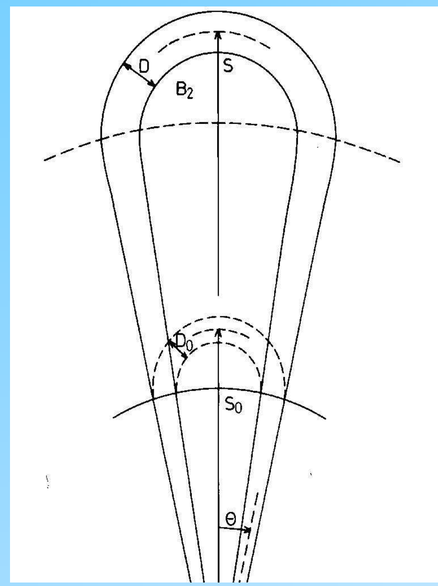
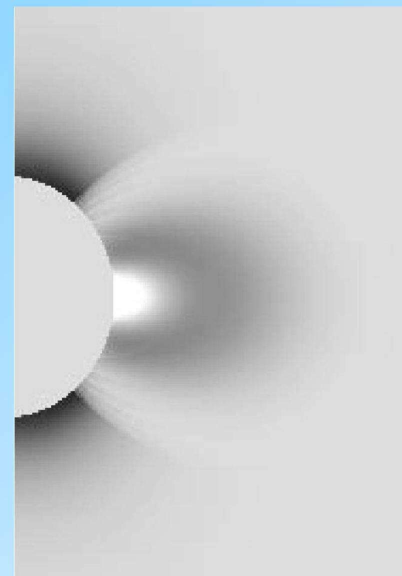
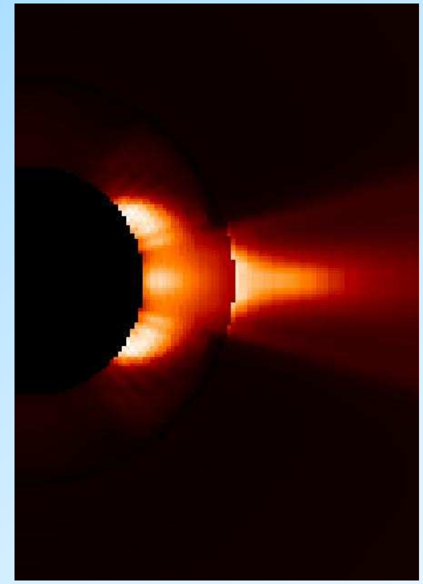
Coronal Transient Models

Deformation models & standardizing against similarity transformations









Mouschovias & Poland (1978,AJ,200,657)
Coronal loop

Pneuman (1980,SP,65,369)
Coronal loop

Gibson & Low (1998,AJ,493,460)
Closed bubble +…

Wu et al. (2000,AJ,545,1101)
Closed bubble+…

CME Ejection Models

Ref: Klimchuk, J. A., 2001, Geophys. Mono. 125, AGU

Subclass I

Storage and Release Models:

1) Mass loading and release
2) Magnetic tether release
3) Magnetic tether straining

Subclass II

Directly Driven Models:

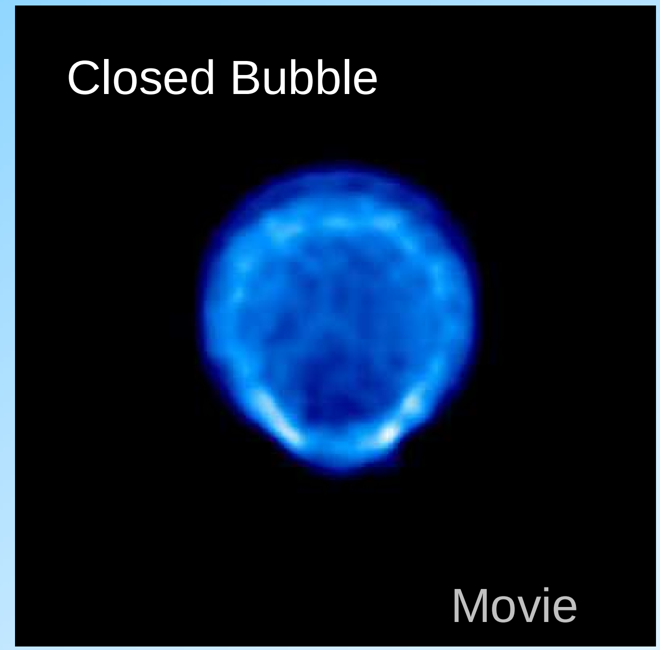
1) Thermal impulsive blast
2) Dynamo inflation

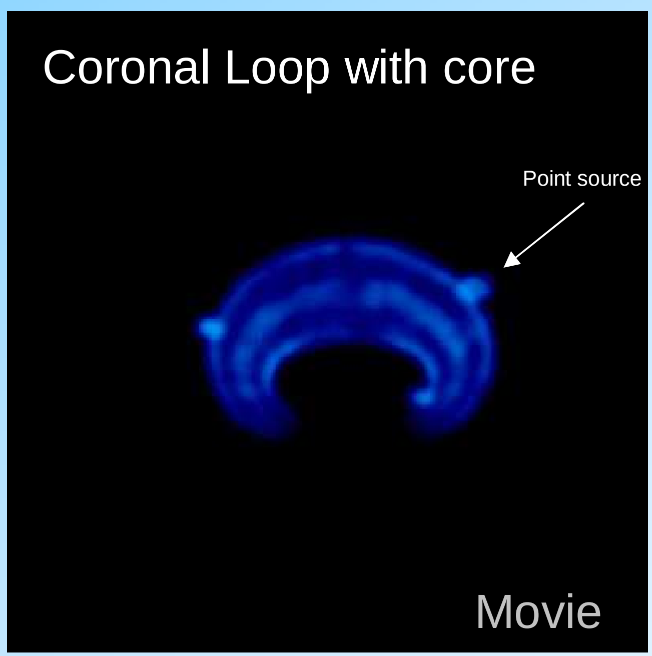
Movies

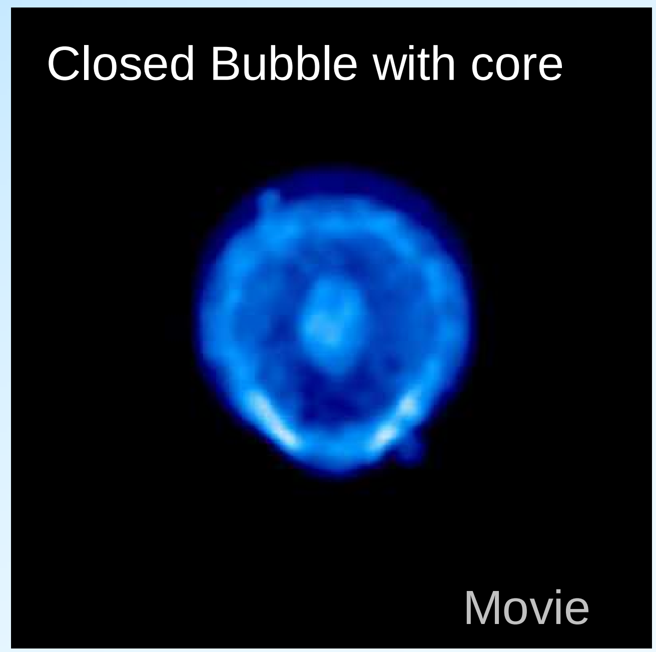
Simple Synthesized Models

- ▸Optically thin
- ▸ Fixed, random fine structure
- ▸ Added point sources

(Large scale vs small scale)







A priori information:

Location of centroid (large-scale structures)

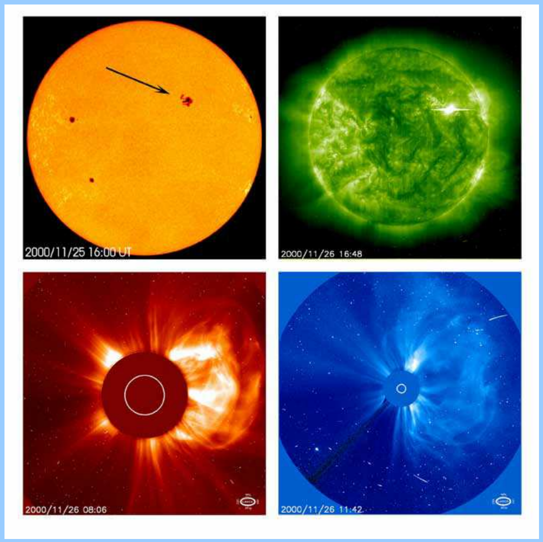
Principal axis of symmetry (origin: near or far-side)

Principal axis of radial expansion (evolutionary track)

Region of origin and footpoints

Temporal history

Velocity Vector



Global magnetic field

Specific triangularization (location) of point sources (micro-structures)

Physical nature of the object

Classification: CME, streamers, plumes

Temporal evolution: Expansion rates

Density constraint (positive definite, maximum density limit)

Continuity – connectivity - cohesiveness of features.

Observational constraints

Limit on micro-structures (spatial resolution)

Density gradients

Self-similar models

The discrete reconstruction problem: Estimate x given y

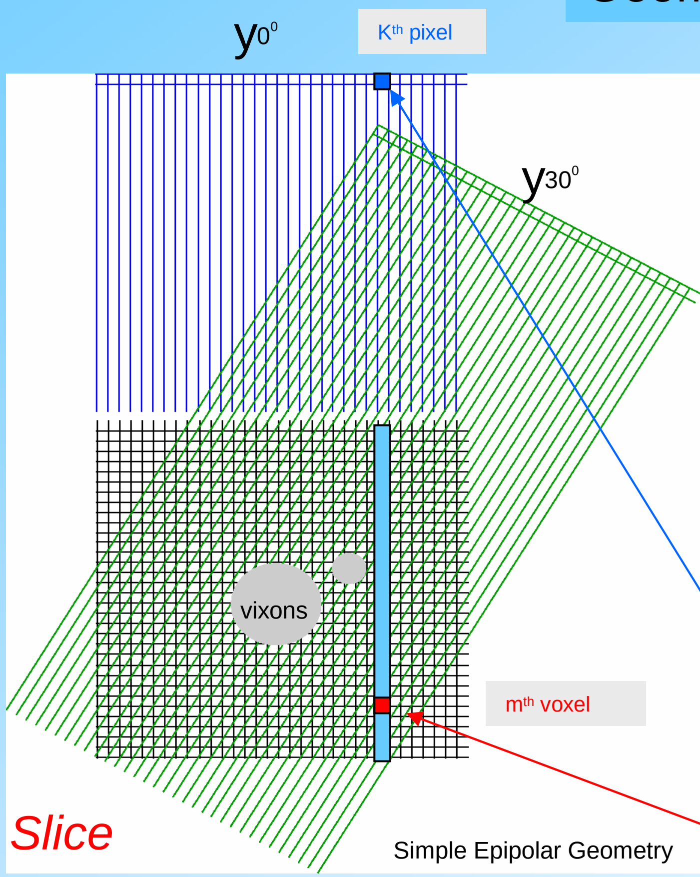
$$\mathbf{y = R\,x + e}$$

Image pixels data

Volume vector

Noise

Geometry projection matrix



$$\text{Min}\ \ \chi^2(\xi) = |\, y - R\,x\,|^2 \quad + \gamma\,|x|^2 + \ldots$$

Regularization

Iterative Solution:

$$x(\lambda+1) = P_\lambda(\,x(\lambda)\,,\,R,\,y)$$

$$\mathbf{y} = y^{0^\circ} \oplus y^{30^\circ}$$

$$y^{0^\circ}{}_k = r_{k1}\,x_1 + r_{k2}\,x_2 + \ldots + r_{nk}\,x_n$$

$\mathbf{x}$: $x_m = x_{ij}$ (N^2 voxels)

The discrete reconstruction problem

$$\mathbf{y = R\, x + e}$$

Penalized Residual Minimization Problem

$$\text{Min}\ \ X^2(x) = |\, y - R\, x\, |^2 + \gamma\, |x\, C^{(p)}\, x| \ \ \ldots.$$

$C^{(p)} = \Delta^{(p)\,T}\, \Delta^{(p)}$ where $\Delta^{(p)}$ is the difference matrix to generate the Pth derivative.

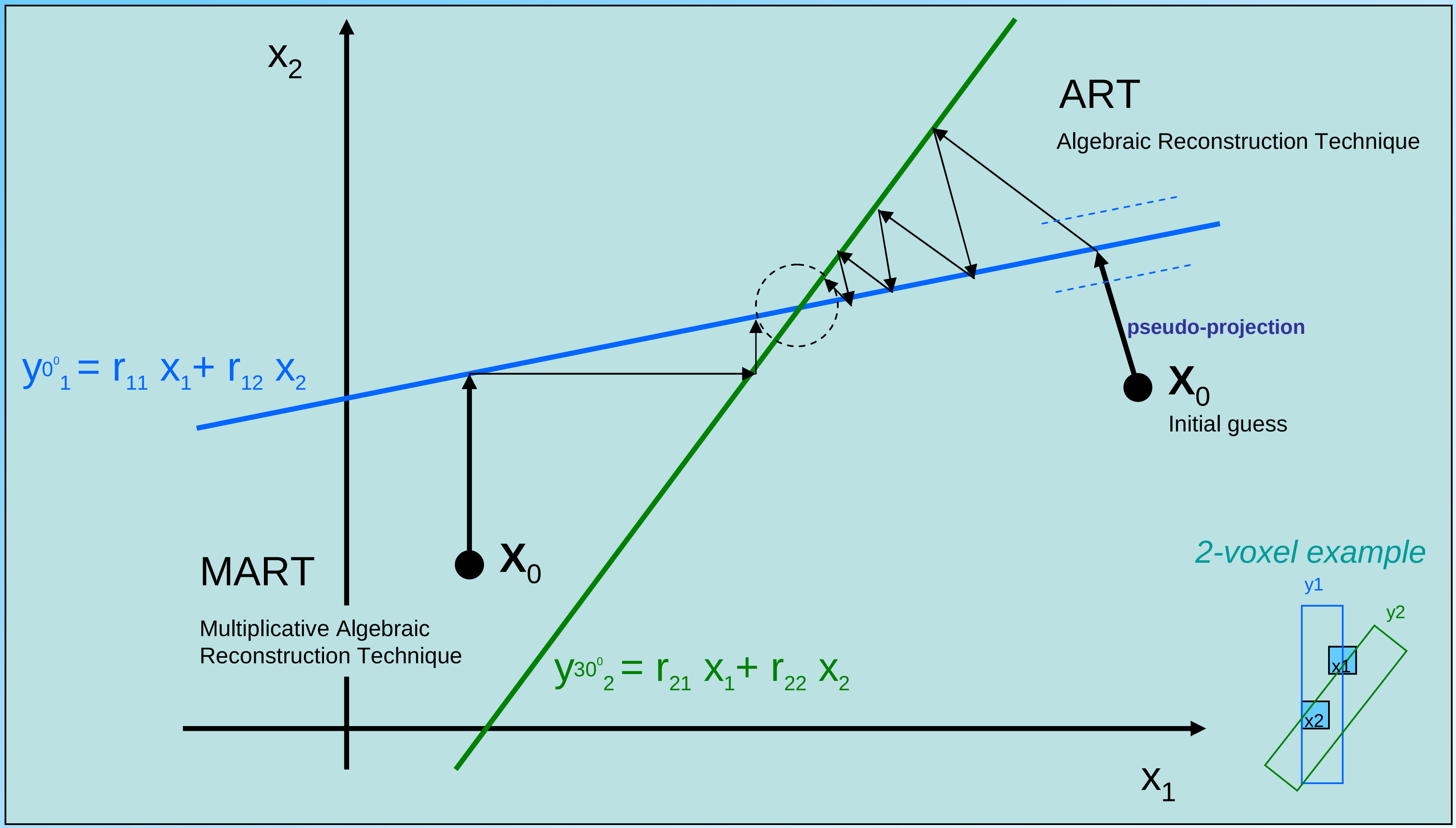
The inverse problem for STEREO: Minimization of the solution space.

How to describe the “Penalized Residual Minimization Problem” taking into account the a priori information?

And

What is the best iterative method to employ to solve for a solution?

Iterative methods



MART:

$x_i(\lambda+1) = x_i(\lambda) \bullet [y_i / (\mathbf{r}_k, \mathbf{x}(\lambda))]^{\gamma}$

cycle k, k=row (projection) , λ =iteration, $0<\gamma<1$

ART:

$\mathbf{x}(\lambda+1) = \mathbf{x}(\lambda) + [y_k - (\mathbf{r}_k, \mathbf{x}(\lambda))]\, \mathbf{r}_k / (\mathbf{r}_k, \mathbf{r}_k)$

cycle k, k=row (projection), λ =iteration

γ=relaxation parameter

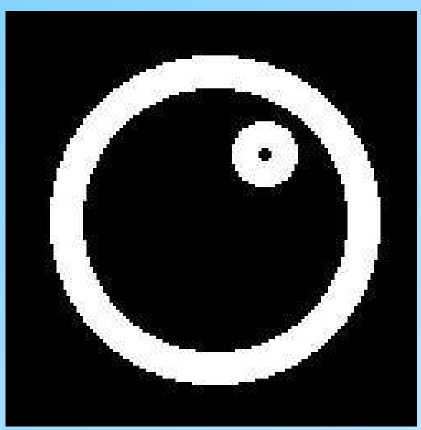
Backward Projection

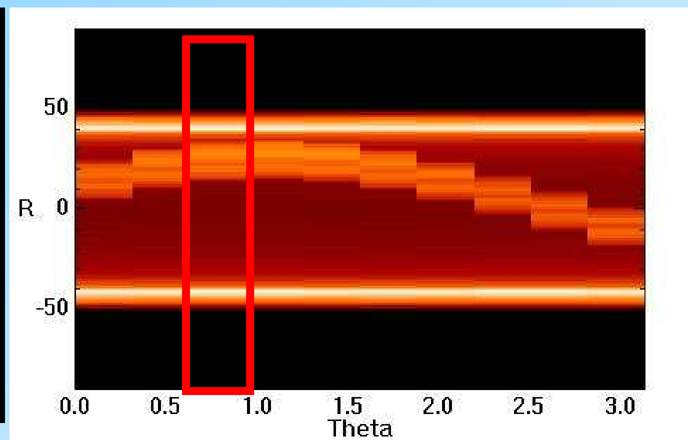
Radon transform: $y(\rho, \theta) = \int_{-\infty}^{\infty} x[\rho \cos\theta + s \sin\theta , \rho \sin\theta + s \cos\theta)]\, d\, s$

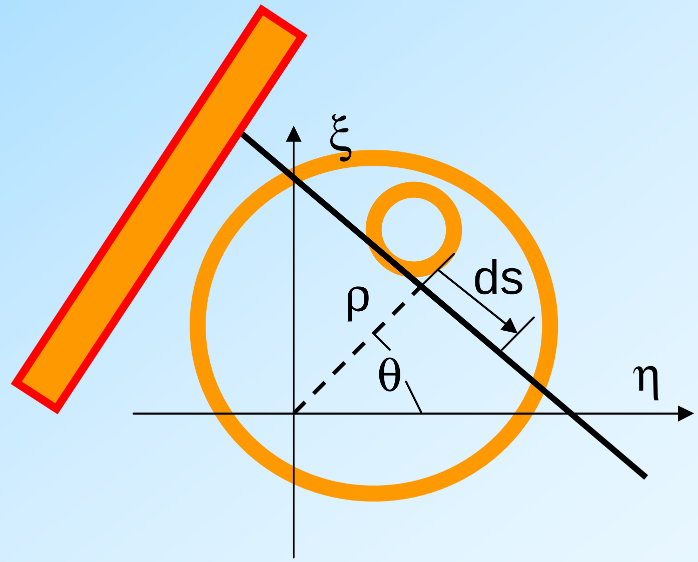
Backward projection: $x_B(\eta, \xi) = \int_{0}^{\pi} y[\theta, \eta \cos\theta + \xi \sin\theta)]\, d\, \theta$

The output x_B is the volume x blurred by the Radon transform.

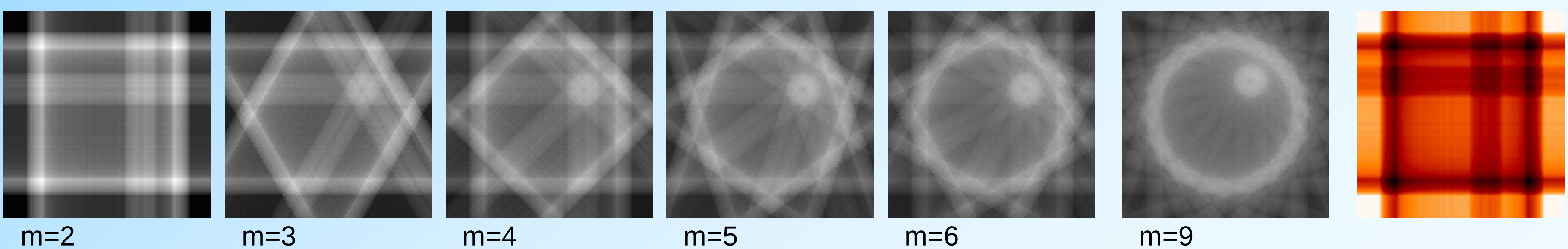
Reference IDL routine: RADON







Movie



MART: Multiplicative Algebraic Reconstruction Technique

►Initial Guess of all the emission values via backward projection

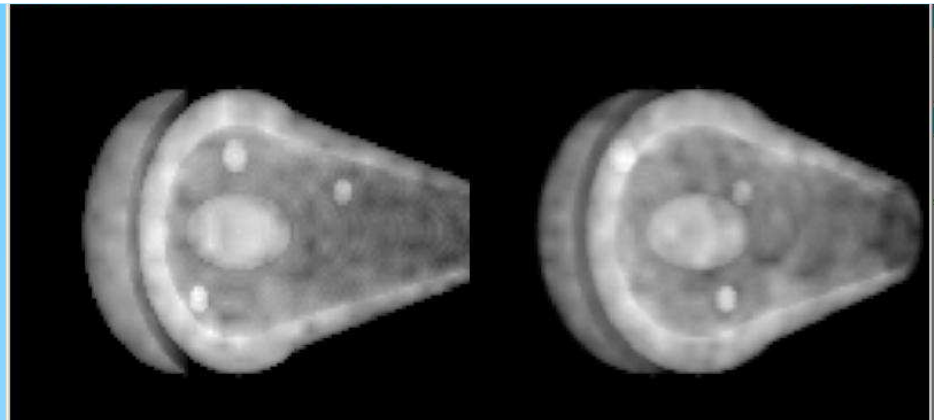
► Updating scheme by modifying elements

► Elements which have zero emission remain void

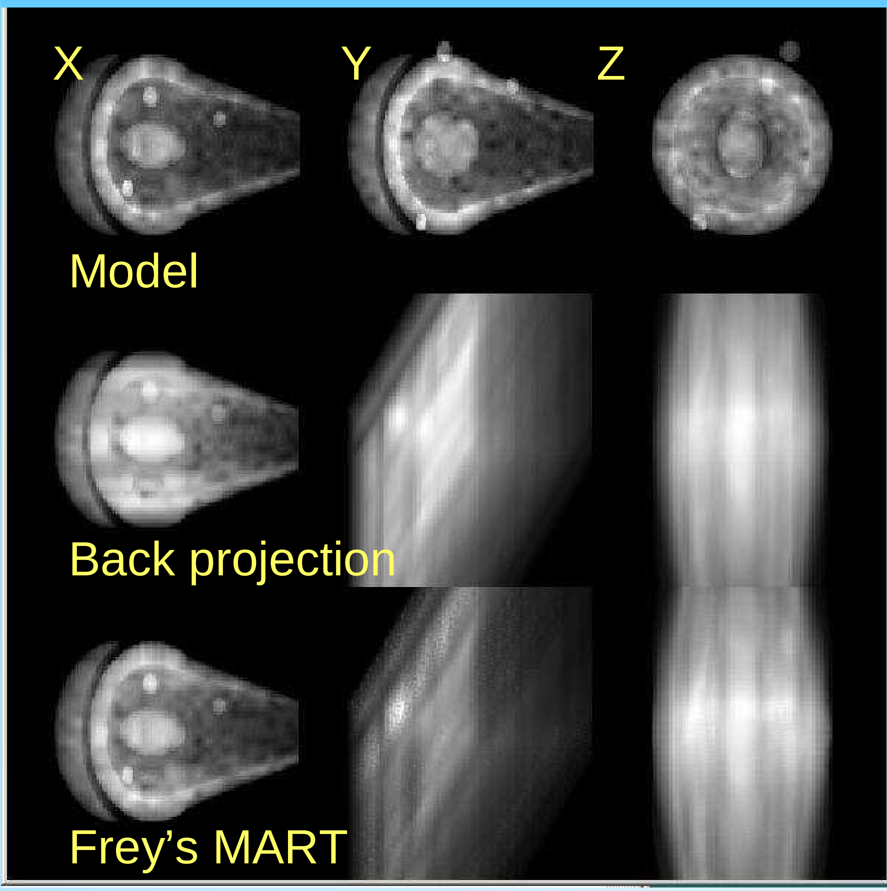
► Result yields reconstruction with lowest information content for the voxels consistent with the given images, i.e., the solution of the maximum-entropy problem.

The desire is to use all the a priori information and the 3D input of a series of time images of an event and reconstruct an 4D representation (e.g., the volume as a function of time) of the coronal transient.

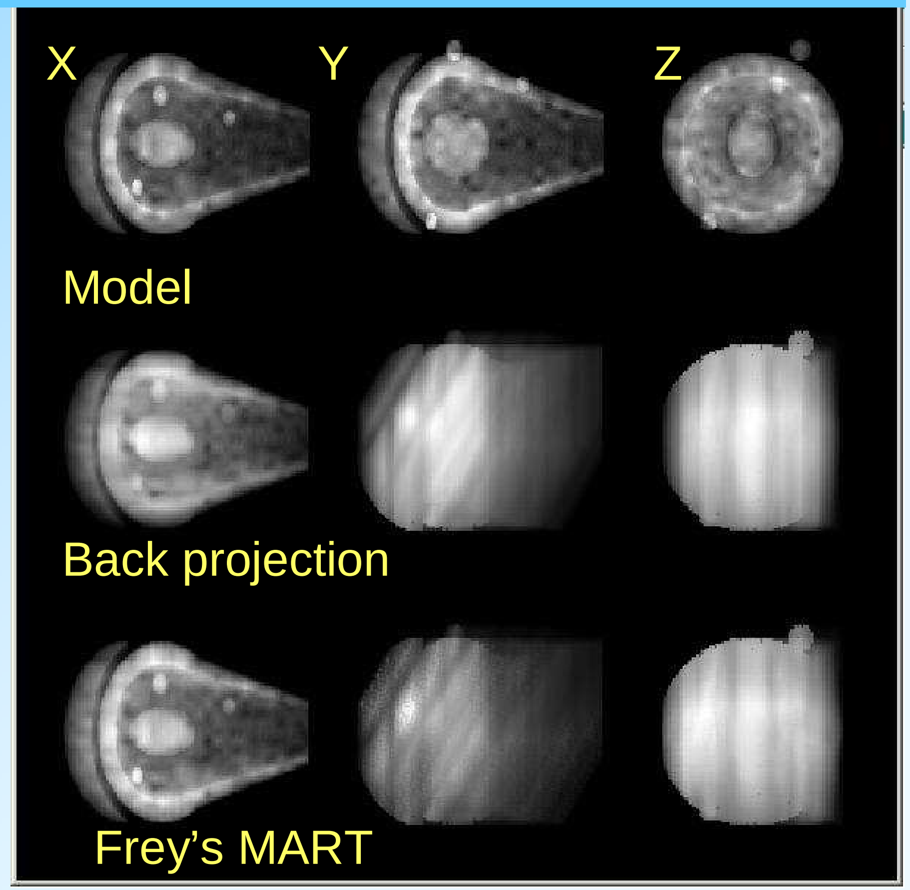
Stereographic Pairs
30^0 Separation



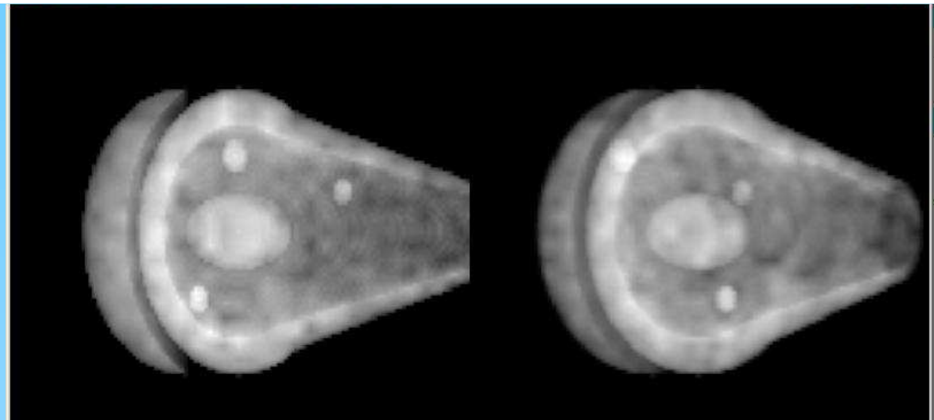
A priori information= none



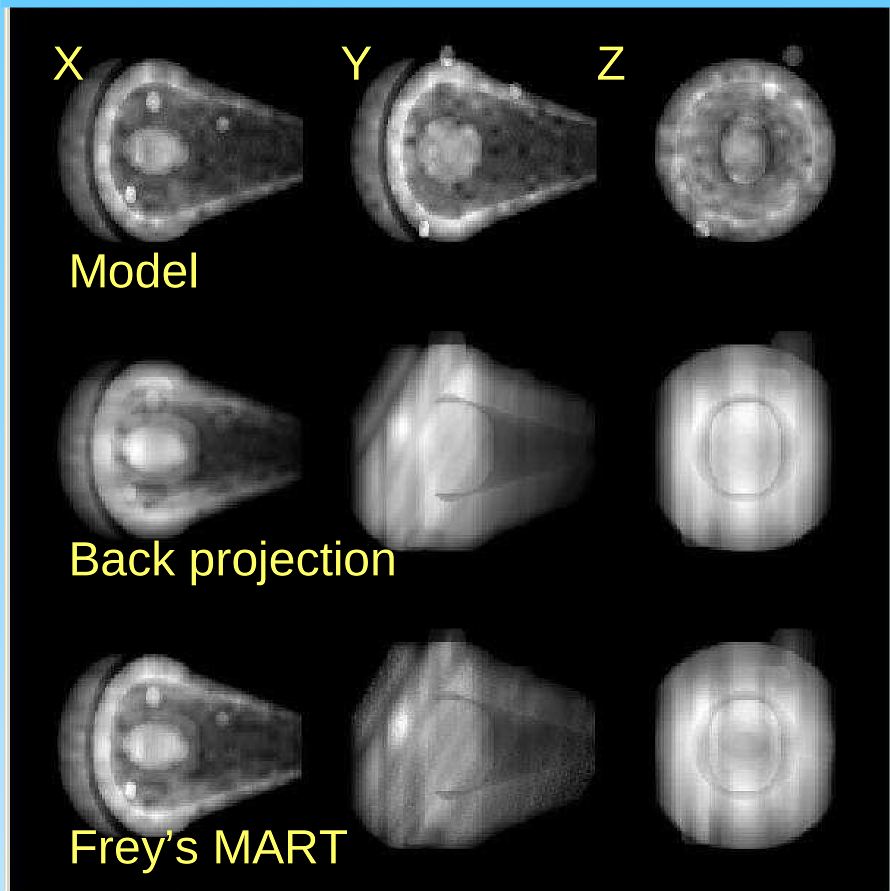
A priori information = Volume



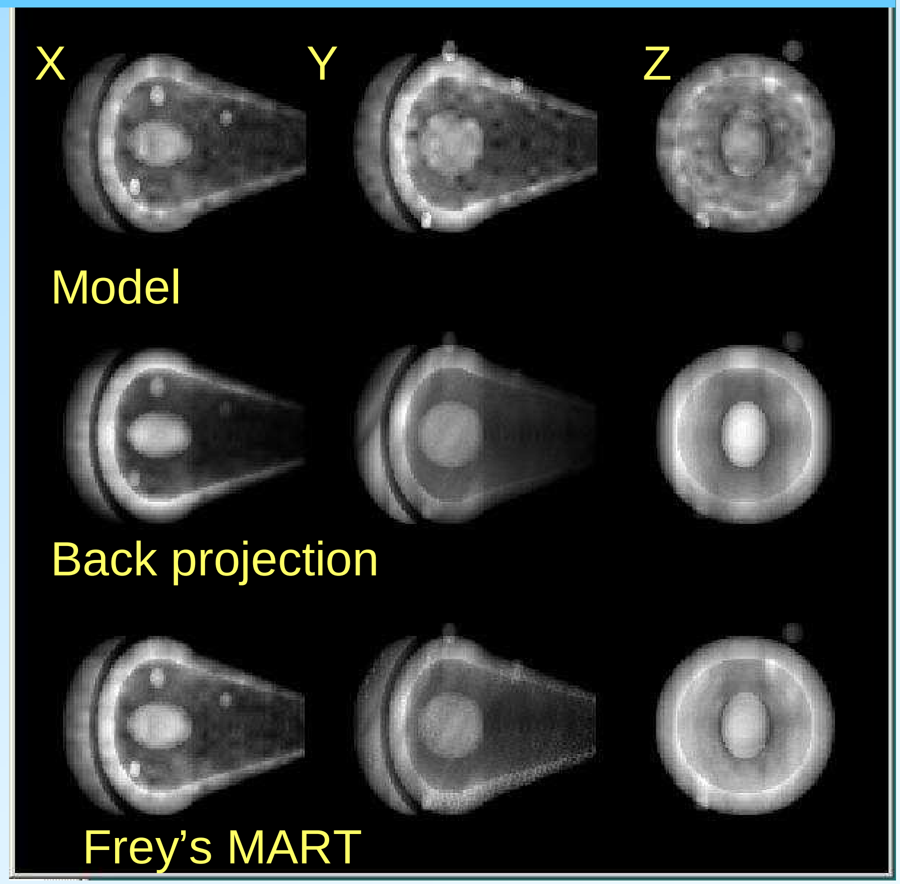
Stereographic Pairs
30^0 Separation



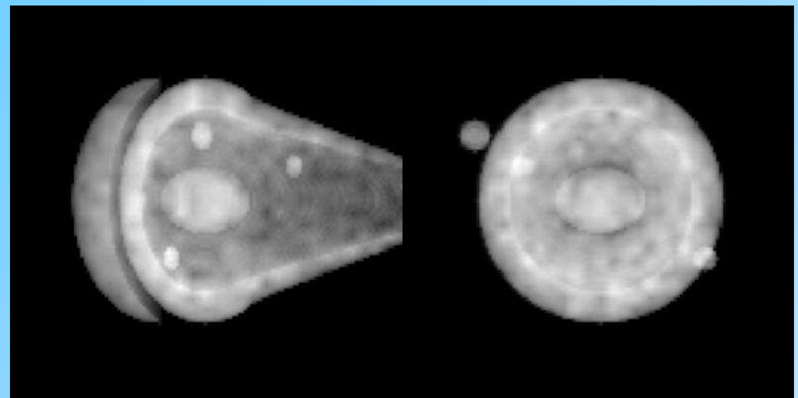
A priori information = Shape



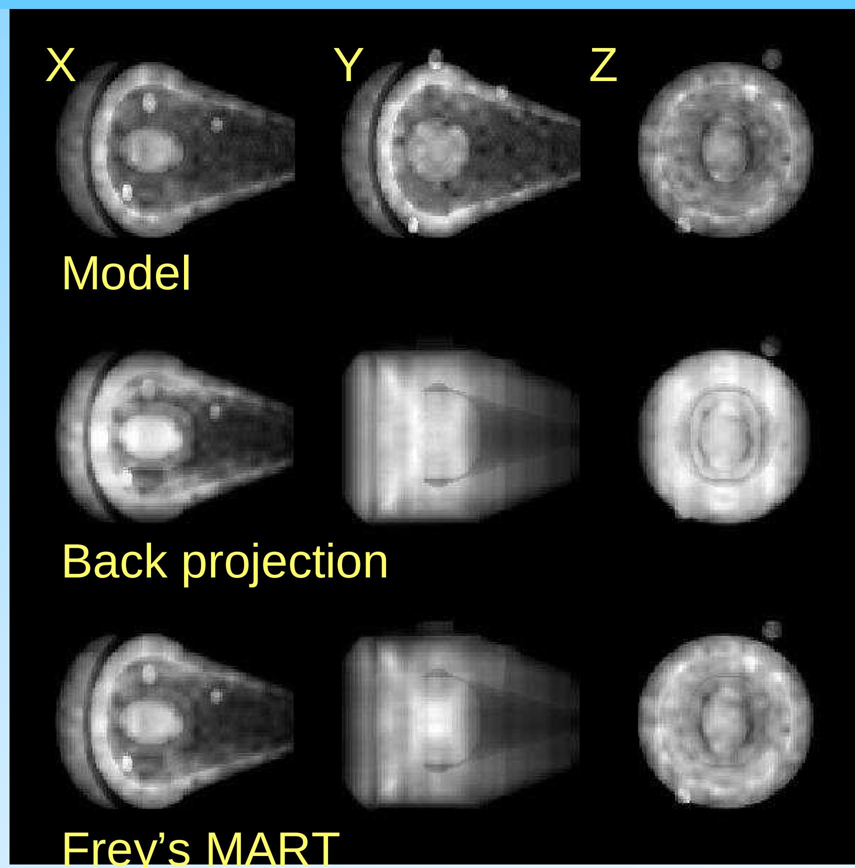
A priori information= Volume (~9%)



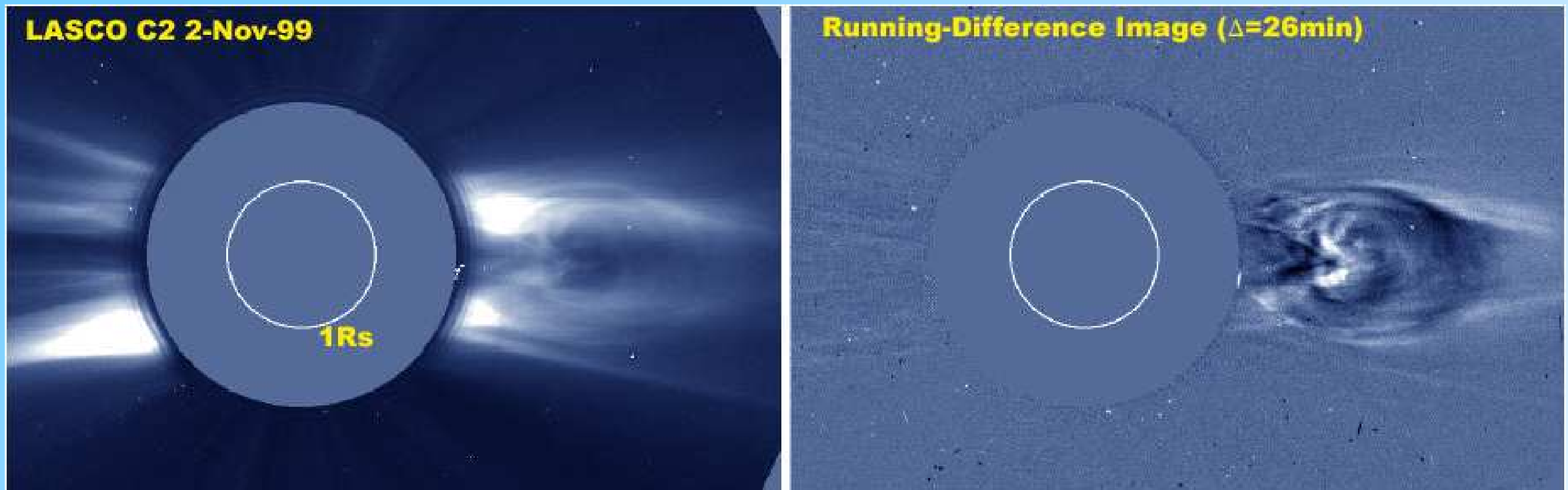
Stereographic Pairs 90⁰ Separation



A priori information = Shape



Time-differential imaging



Reference: Dere, K. P., et al. 1999, ApJ, 516,465,Fig. 5

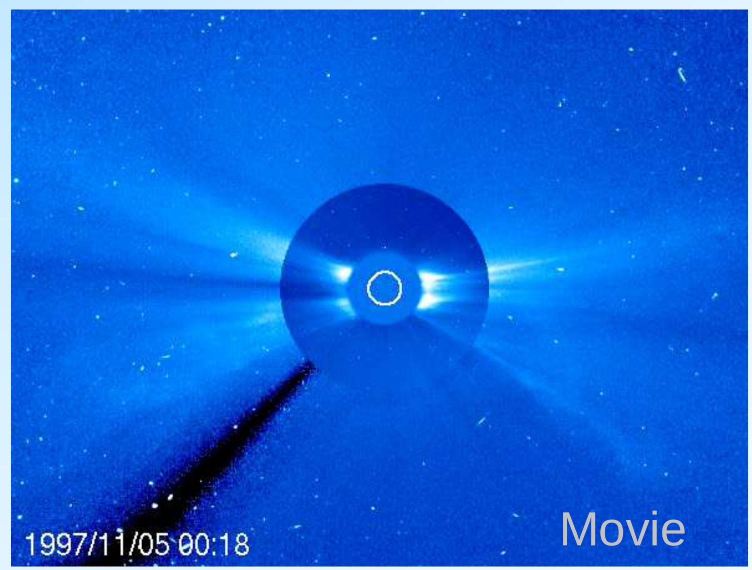
Cause of variations

Line of Sight effects

Density fluctuations

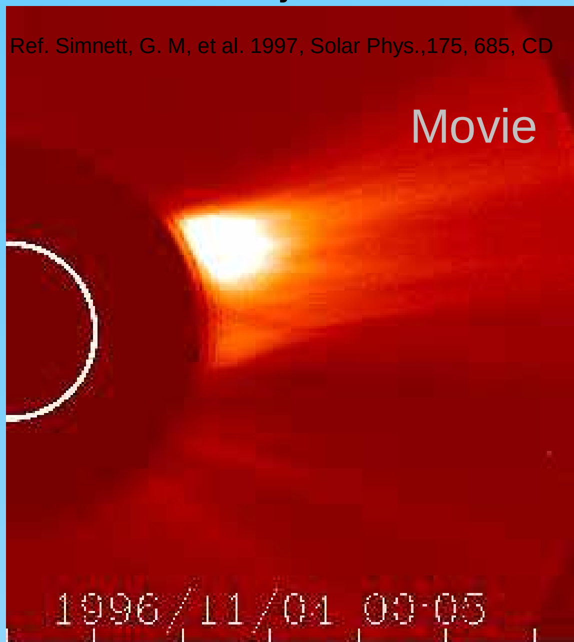
Multiple events

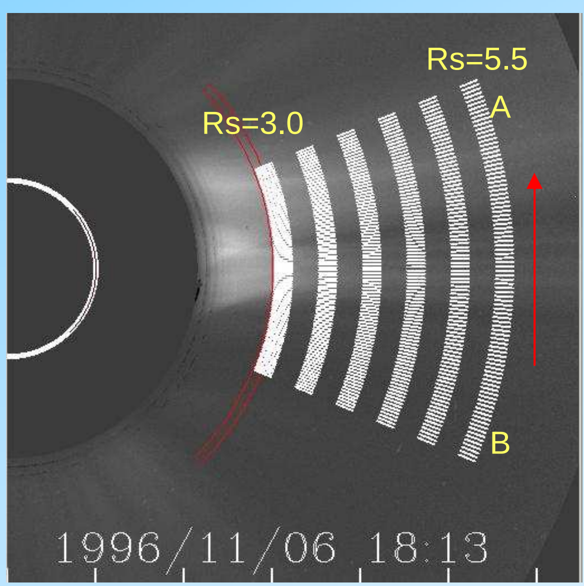
Background



“Image” of CME at Fixed Radius

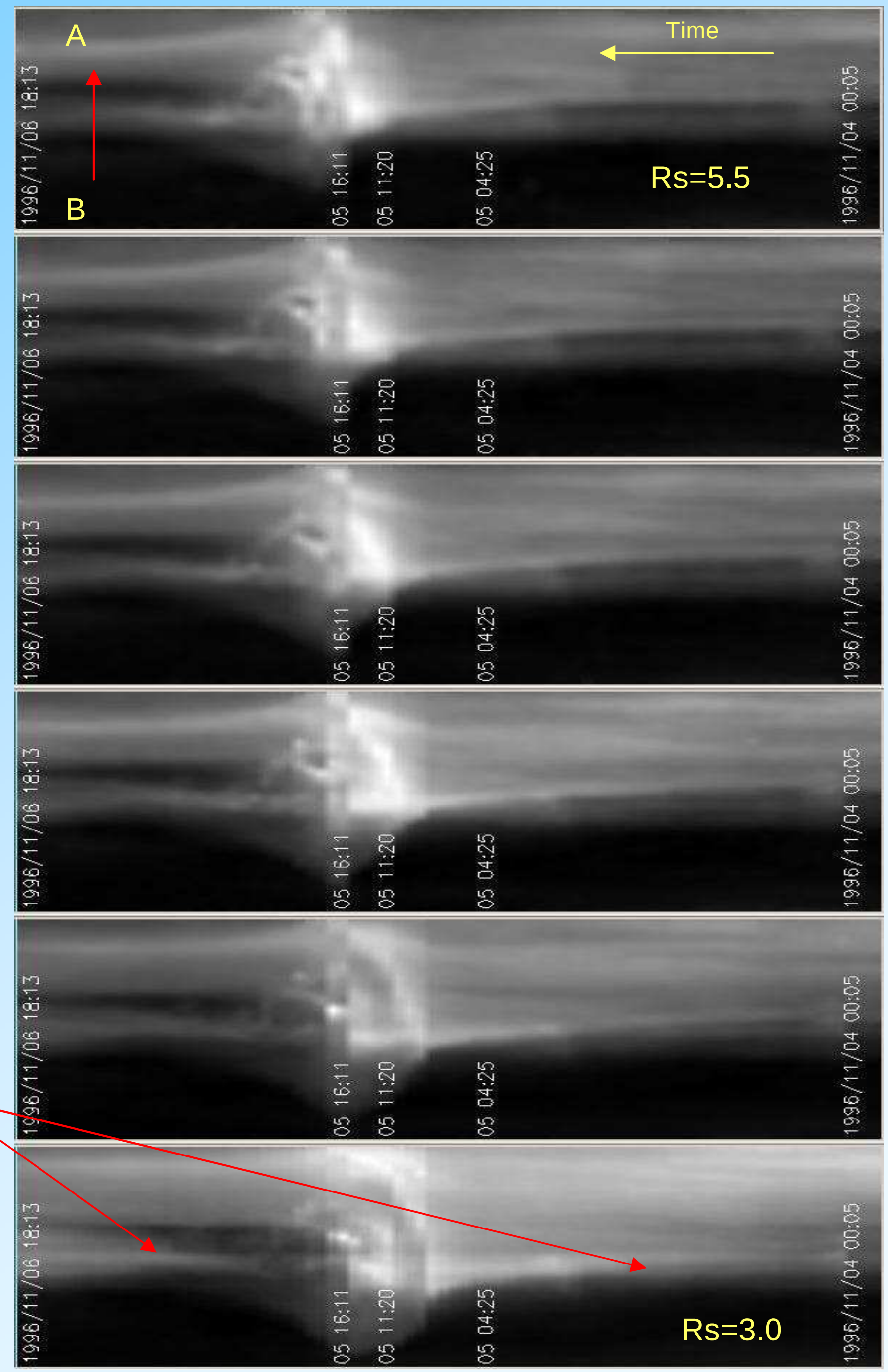
Coronal Mass Ejection 11-Nov-96



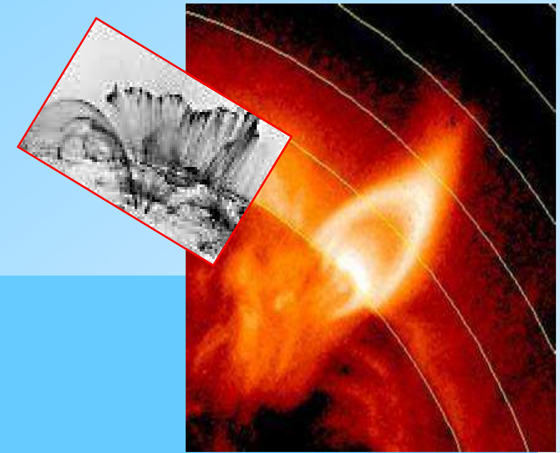


Are there similarity transformations associated with CME outflow which can defined the associated volume?

Same
Pre-Post
Streamer ?



TRACE movie of filament eruption



Plasma beta model over an active region. The plasma beta as a function of height is shown shaded for open and closed field lines originating between a sunspot of 3000 G and a plage region of 150 G.

What role does this β-transition play in the CME early evolution?

(Ref. Gary, G. A., 2002, Solar Phys., 203, 71)

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