Solar Coronal Tomography

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Abstract

A simple, yet powerful, algorithm for computed tomography of the solar corona is demonstrated using synthetic EUV data. A minimum of three perspectives are required. These may be obtained from STEREO/EUVI plus an instrument near Earth, e.g. TRACE or SOHO/EIT.
Coronal Tomography (EUV)

1. Why is the Solar Corona important?

2. Background—STEREO mission

3. Science Goals

4. SMART Algorithm

5. Demonstration (synthetic EUV data)

6. Summary & conclusions
Why is the Corona interesting?

Solar Physics
- Coronal heating
- Solar flares
- Coronal mass ejections

Aerospace systems
- Radiation environment
- Human safety
- Electronics
- Satellite drag

Geoeffect
- Aurorae
- Communications
- Power systems
NASA’s STEREO Mission
(SECCHI remote sensing pkg)

- Twin spacecraft in solar orbit
- A = Ahead, B = Behind
- EUVI = Extreme UV Imager (low corona)
- Coronagraphs observe outer corona
- Heliospheric Imager
- Like human stereoscopic vision (?)

STEREO Aug 27 (-32°, +37°)
Example EUVI Data (171 Å)
Science Objectives

A primary science question of STEREO/SECCHI is:

What is the 3-dimensional structure of active regions, coronal loops, helmet streamers, etc?\(^1\)

Approach:

- Adapt Smooth Multiplicative Algebraic Reconstruction Technique (SMART) algorithm developed for MOSES.
- 3 views: STEREO/EUVI + TRACE (EUV telescope in LEO, launched April 1998).

\(^1\)Howard et al. 2007, Space Science Reviews
Inspiration from MOSES

What does this sounding rocket have to do with STEREO?

- Multi-Order Solar EUV Spectrograph (MOSES)
- NASA LCAS launch, 2006 Feb 8
- Simultaneous imaging and spectroscopy
- Tomographic inversion $\rightarrow$ spectrum
- Synergy with STEREO few-angle tomography
Observe volume EM $I(x, y, z)$ at angles $\theta_i$ by projection:

$$f_i(x, z) = \int_D \mathcal{R}_z(\theta_i) I \, dy + \text{noise}$$

Given images $f_i$ and initial guess $G(x, y, z)$, iteratively modify $G$ to approximate $I$. 
SMART Algorithm

1.
SMART Algorithm

1. Smooth $G$. 
SMART Algorithm

1. Smooth $G$.

2. Project: $f'_i = \int_D R_z(\theta_i) G \, dy \quad \forall \ i$
   - Evaluate goodness of fit, $\chi^2_{R,i}$
   - Adjust $\gamma_i$ based on $\chi^2_{R,i}$ and $\Delta \chi^2_{R,i}$
SMART Algorithm

1. Smooth $G$.

2. Project: $f'_i = \int_D R_z(\theta_i) G \, dy \quad \forall i$
   - Evaluate goodness of fit, $\chi^2_{R,i}$
   - Adjust $\gamma_i$ based on $\chi^2_{R,i}$ and $\Delta\chi^2_{R,i}$

3. Correct: $G \leftarrow G \prod_i C_i^{\gamma_i}$, where

$$C_i(x, y, z) = R_z(-\theta_i) \frac{f_i(x, z)}{f'_i(x, z)}.$$
SMART Algorithm

1. Smooth $G$.

2. Project: $f_i' = \int_D \mathcal{R}_z(\theta_i) G \, dy \quad \forall i$
   - Evaluate goodness of fit, $\chi^2_{R,i}$
   - Adjust $\gamma_i$ based on $\chi^2_{R,i}$ and $\Delta \chi^2_{R,i}$

3. Correct: $G \leftarrow G \prod_i C_i^{\gamma_i}$, where

   $$C_i(x, y, z) = \mathcal{R}_z(-\theta_i) \frac{f_i(x, z)}{f_i'(x, z)}.$$

Iterate, adjusting $\gamma_i$ to drive $\chi^2_{R,i} \to 1$. 
Synthetic Data

- Quadrupole potential field
- Coronal null: interesting geometry
- EM along arbitrary field lines
- Random latitude, longitude & clocking
- 3 viewpoints: $-40^\circ$, $0^\circ$, $+40^\circ$
- Imaged with 3000 counts in the brightest pixel
- Note square root scaling
Example 1 (E-W pan)

True (left) \textit{vs.} SMART (right). Square root scaled.
Example 1 (N-S pan)

True (left) vs. SMART (right). Square root scaled.
Example 2 (E-W pan)

True (left) vs. SMART (right). Square root scaled.
Example 2 (N-S pan)

True (left) *vs.* SMART (right). Square root scaled.
Summary & Conclusions

- Full 3D reconstruction of coronal EM
- 3 viewpoints required
- No assumptions (loops, magnetic field, etc.)
- Simple and computationally efficient
  - Examples converged in 15 iterations
  - 3 minutes on my laptop ($169^3$ voxels)
- Loops parallel to ecliptic—not so good
- Apply to EUVI data hopefully this fall!

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