How massive is a CME?
The greater accuracy offered by STEREO

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Overview

- Measuring CME masses
- STEREO and reduced uncertainty
- Some preliminary results
- Conclusions
Why study mass?

- Mass is a particular property needed for the study of CME energetics and dynamics.
- The dynamics and energetics can give an understanding of the forces responsible for CME initiation and propagation.
- Also, CME models require accurate mass estimates.
Measuring CME mass

- Use Thomson scattering theory and Van de Hulst-Minnaert coefficients

⇒ Scattered brightness per electron at any point in solar atmosphere

\[
m_{\text{pixel}} = \frac{B_{\text{obs}}}{B_e(\theta)} \times 1.97 \times 10^{-24} \, \text{g}
\]  
(Vourlidas et al., 2000)

- Scattered intensity depends on propagation angle of CME from plane of sky, \( \theta \)

WL pixel brightness

Conversion factor: 0.9H and 0.1He

Single electron brightness
Measuring CME mass

- Base-difference image with pixel values of grams
- Any excess brightness is due to excess CME mass
- Simply sum over the CME or any other feature to obtain the mass
- However...
The Uncertainty

• If there is only one viewpoint, angle $\theta$ is unknown

• Assumption: CME is directed along POS

• This assumption leads to a mass underestimation of up to 50% (Vourlidas et al, 2000)

• Projection effects is one of the biggest sources of error in CME mass estimations
The Uncertainty

- Another big source of error is unknown extent of CME finite width i.e. CME is a 3-D structure
- Assumption: All of CME mass lies on 2-D plane

Solid line: angular dependence of intensity of scattered light by an electron

Dashed line: Ratio of observed mass to actual mass as a function of angular width

(Vourlidas, Subramanian, Dere, Howard; 1999)
The Uncertainty

- Broadside events have a smaller depth along line of site and hence smaller uncertainty in mass.

**Broadside**
Width along LOS $\sim 48^\circ$

**Axial**
Width along LOS $\sim 78^\circ$

(Chen et al. 2006)
12th December 2008 CME

- CME was directed on Sun-Earth line, STEREO A and B were separated by 86.6°
- Depth along line of sight is unknown
- Morphology similar to broadside fluxrope that is slightly inclined
CME Mass vs. Height for Ahead and Behind, COR1 and 2

**COR 1**

\[
m_{\text{cor1A}} = (7.9 \pm 0.2) \times 10^{14} \text{ g}
\]

\[
m_{\text{cor1B}} = (1.2 \pm 0.6) \times 10^{15} \text{ g}
\]

**COR 2**

\[
m_{\text{cor2A}} = (1.8 \pm 0.5) \times 10^{15} \text{ g}
\]

\[
m_{\text{cor2B}} = (2.4 \pm 0.7) \times 10^{15} \text{ g}
\]
CME mass vs. time

- 0 - 200 mins: Rapid growth
- 200 mins onwards: Steady growth
- Mass approaches fixed value
How is the mass distributed throughout the CME?

- Front mass initially dominates
- Core appears at ~150 mins and grows rapidly
- After 400 mins core mass and front mass are equal
How energetic is the CME?

- Potential energy dominates kinetic energy
- After 600 mins the two energies approach:

\[ E_{\text{potential}} = 4.0 \times 10^{30} \text{ ergs} \]
\[ E_{\text{kinetic}} = 6.9 \times 10^{29} \text{ ergs} \]
Conclusions

- Use of STEREO data reduces errors on mass estimates significantly
  - Plane-of-sky error removed
  - Finite width error still exists
  - CME mass tends towards \((2.1 \pm 0.5) \times 10^{15}\) g

- Mechanical energy estimates are also subject to smaller uncertainties
- Kinetic and potential energies tends towards
  - Potential energy \(4.0 \times 10^{30}\) ergs
  - Kinetic energy \(6.9 \times 10^{29}\) ergs
- Mass and energy values are more reliable when using STEREO data