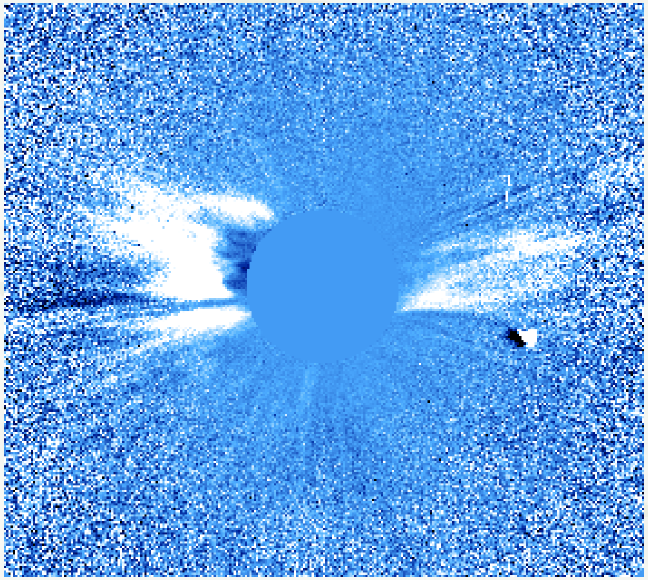
How massive is a CME?

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

Require mass

$$\rho \frac{D\vec{v}}{Dt} = \vec{j} \times \vec{B} - \nabla P - \rho \vec{g} - \frac{1}{2} \rho \vec{v}^{2}$$

$$E_{kinetic} = \frac{1}{2} \sum_{CME} m_i v_{cm}^2$$

$$E_{potential} = \sum_{CME} \int_{Rsun}^{R} \frac{G M_{sun} m_i}{r_i^2} dr_i$$

- 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

WL pixel brightness

$$m_{pixel} = \frac{B_{obs}}{B_e(\theta)} \times 1.97 \times 10^{-24} g$$

(Vourlidas et al., 2000)

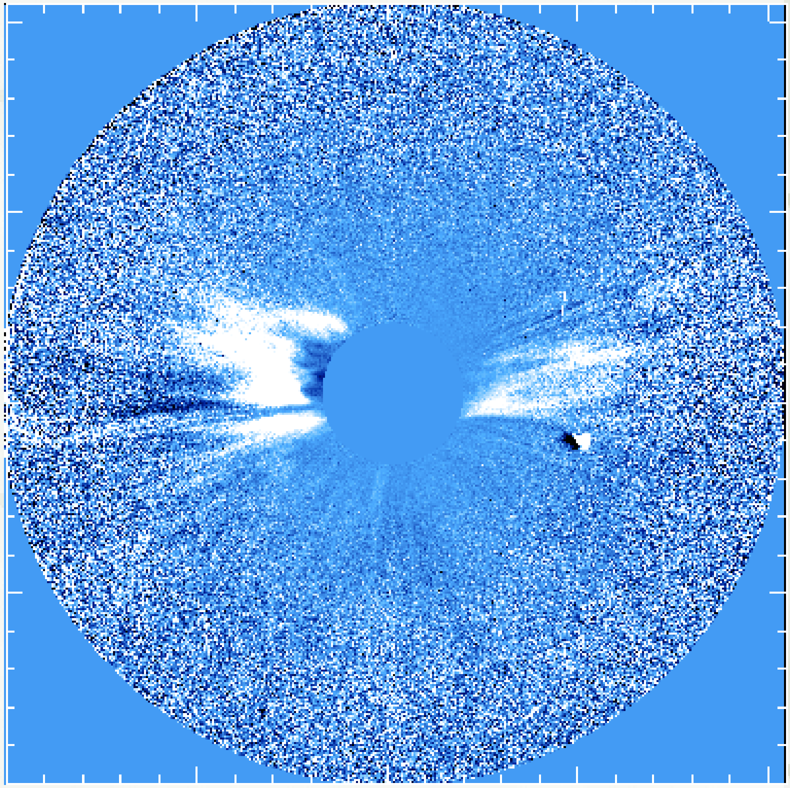
Conversion factor: 0.9H and 0.1He

Single electron brightness

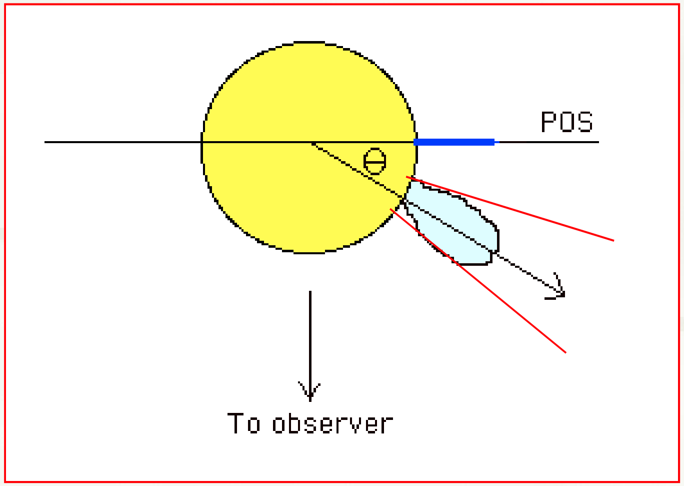
- Scattered intensity depends on propagation angle of CME from plane of sky, θ

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 θ is unknown

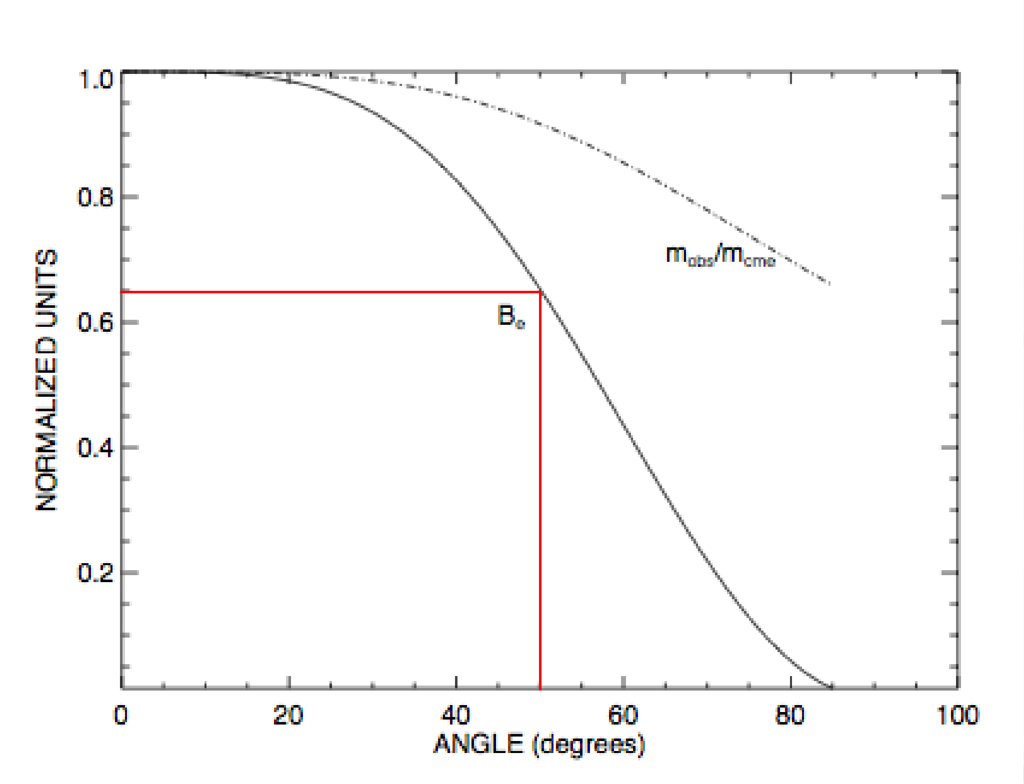
- Assumption: CME is directed along POS

- 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



(Vourlidas, Subramanian, Dere, Howard; 1999)

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

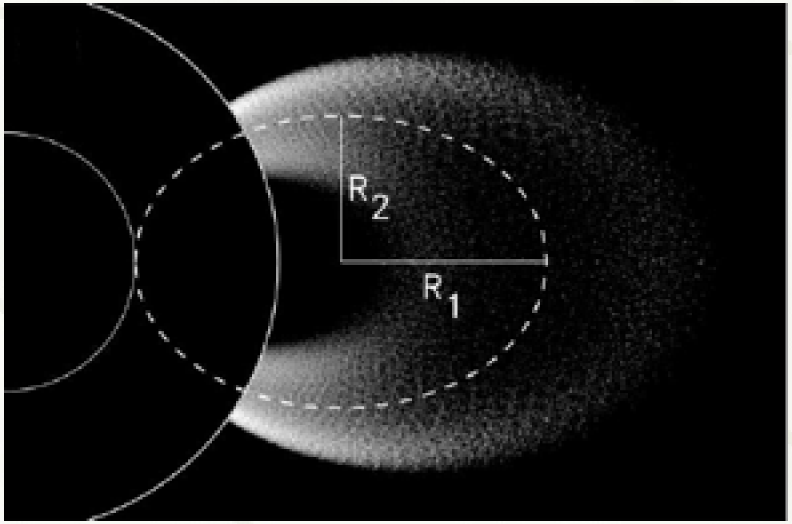
Dashed line: Ratio of observed mass to actual mass as a function of angular width

The Uncertainty

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

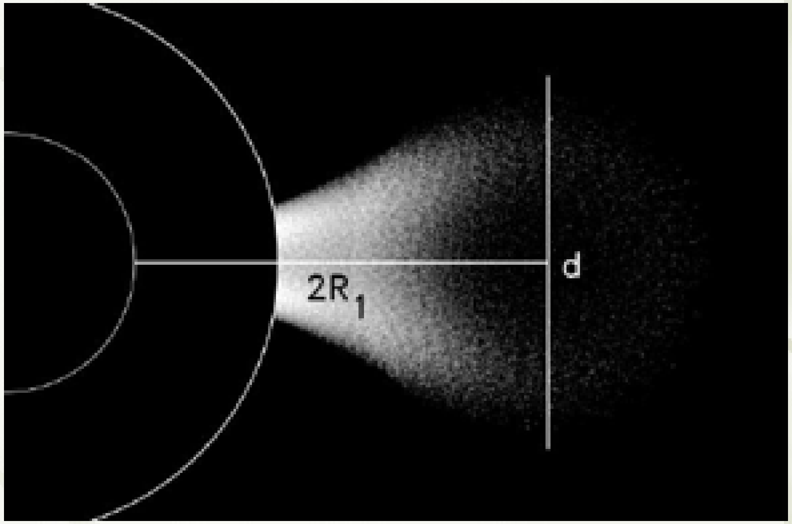
Broadside

Width along LOS ~48˚



Axial

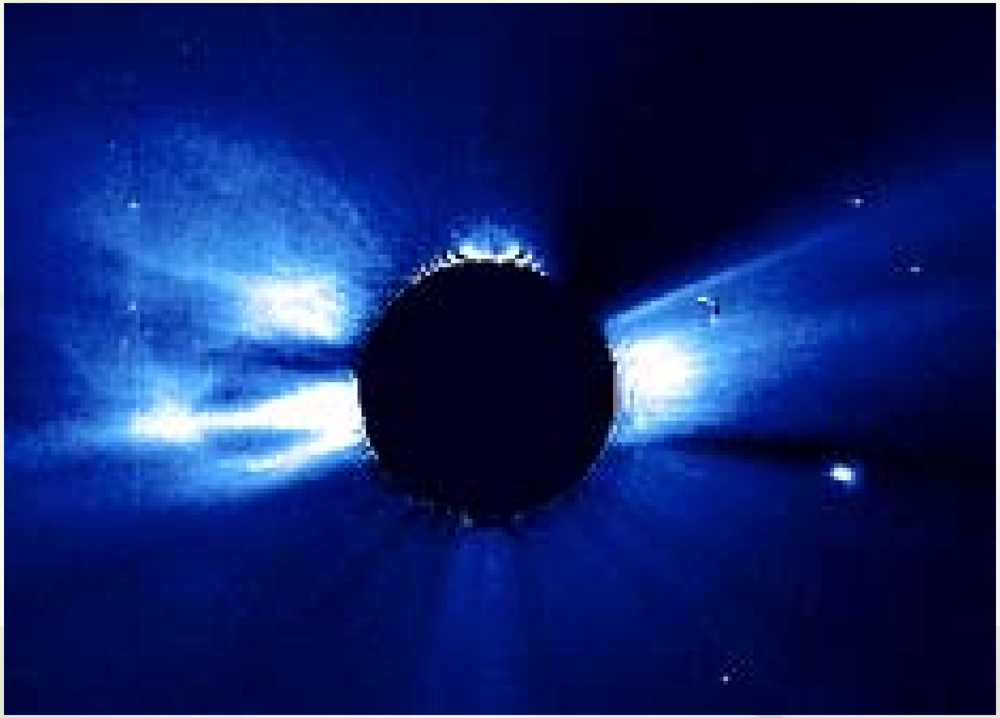
Width along LOS ~78 ˚



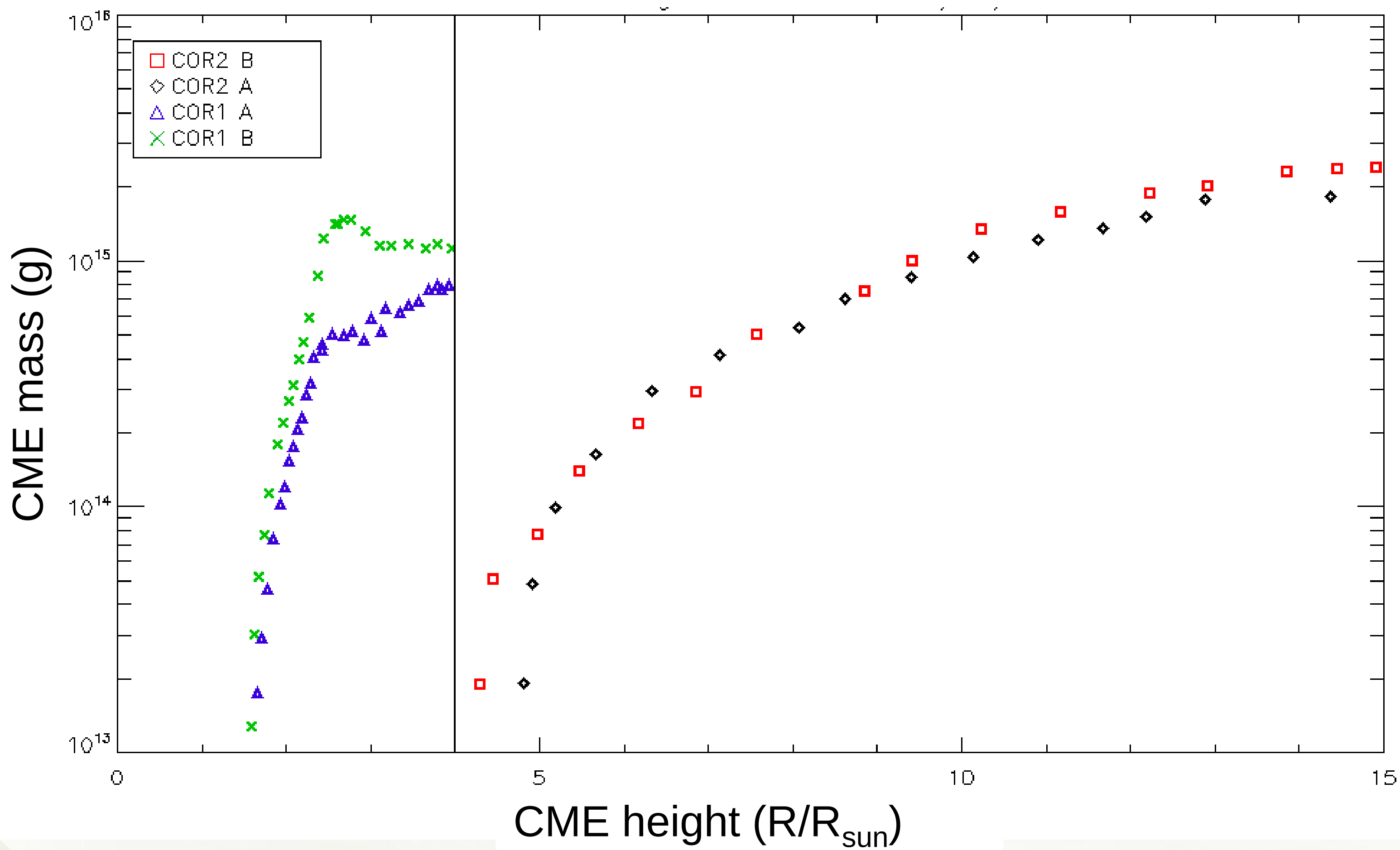
(Chen et al. 2006)

12^{th} 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

$$m_{cor1A} = (7.9 \pm 0.2) \times 10^{14}\, g$$

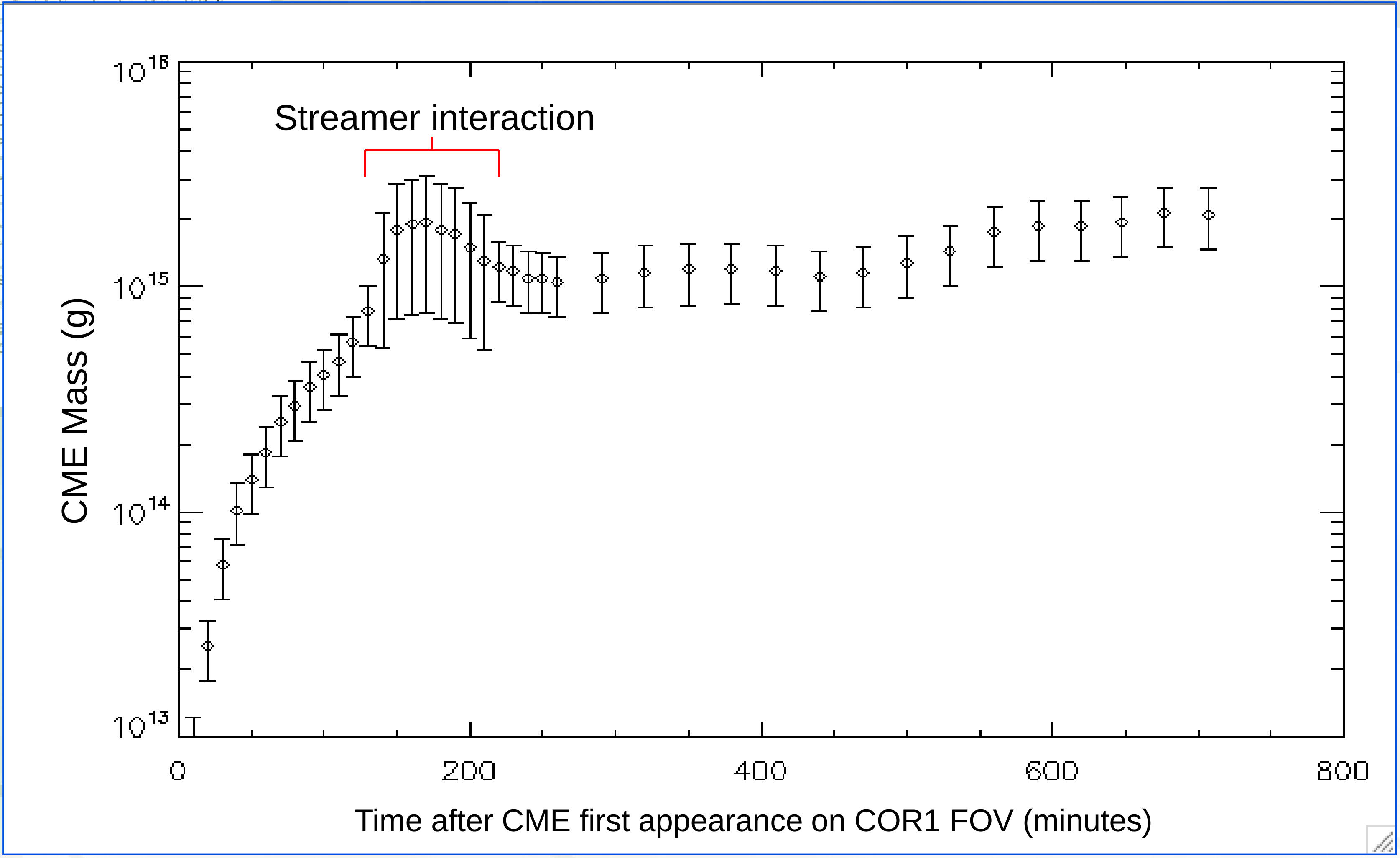
$$m_{cor1B} = (1.2 \pm 0.6) \times 10^{15}\, g$$

COR 2

$$m_{cor2A} = (1.8 \pm 0.5) \times 10^{15}\, g$$

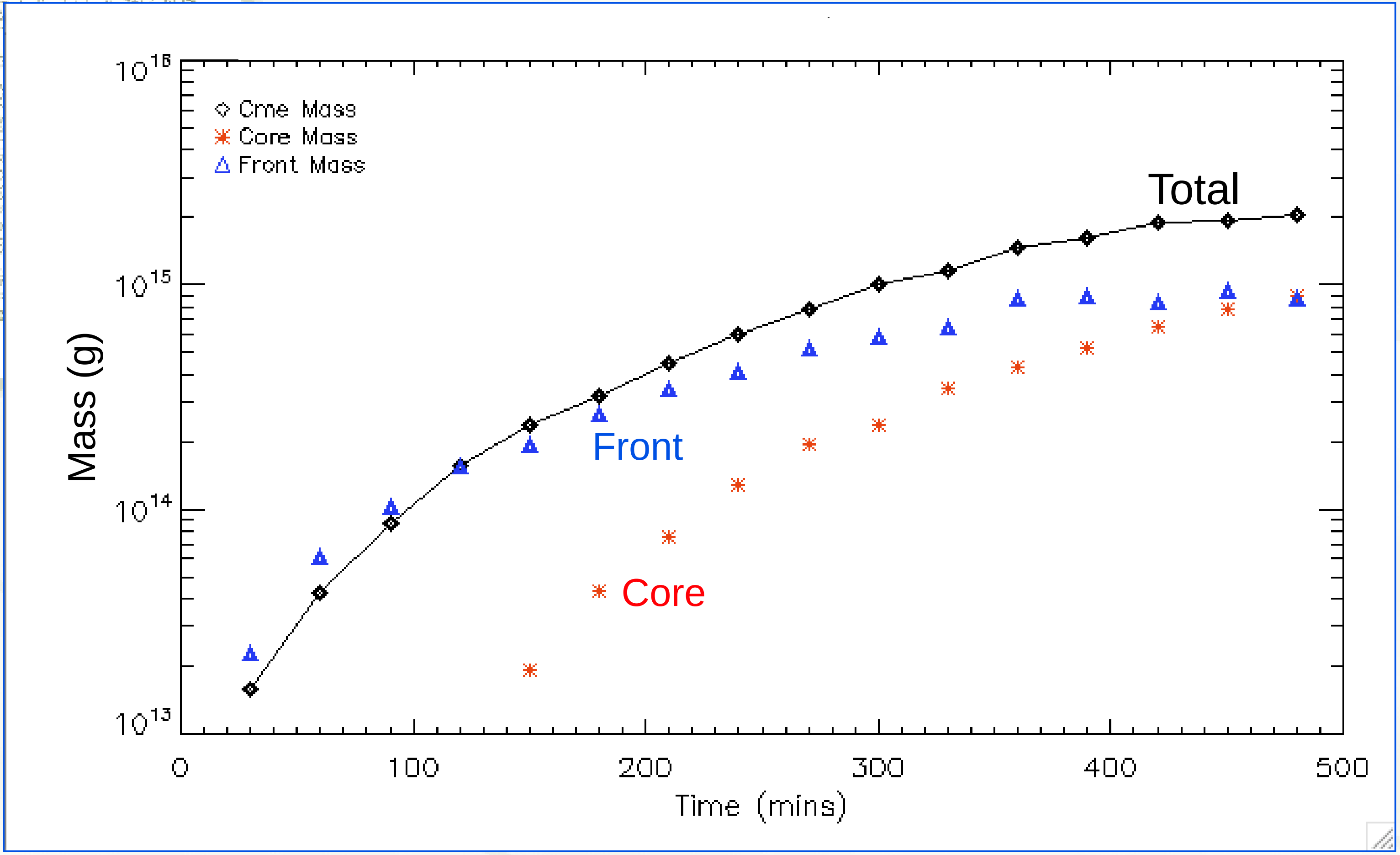
$$m_{cor2B} = (2.4 \pm 0.7) \times 10^{15}\, g$$

CME mass vs. time



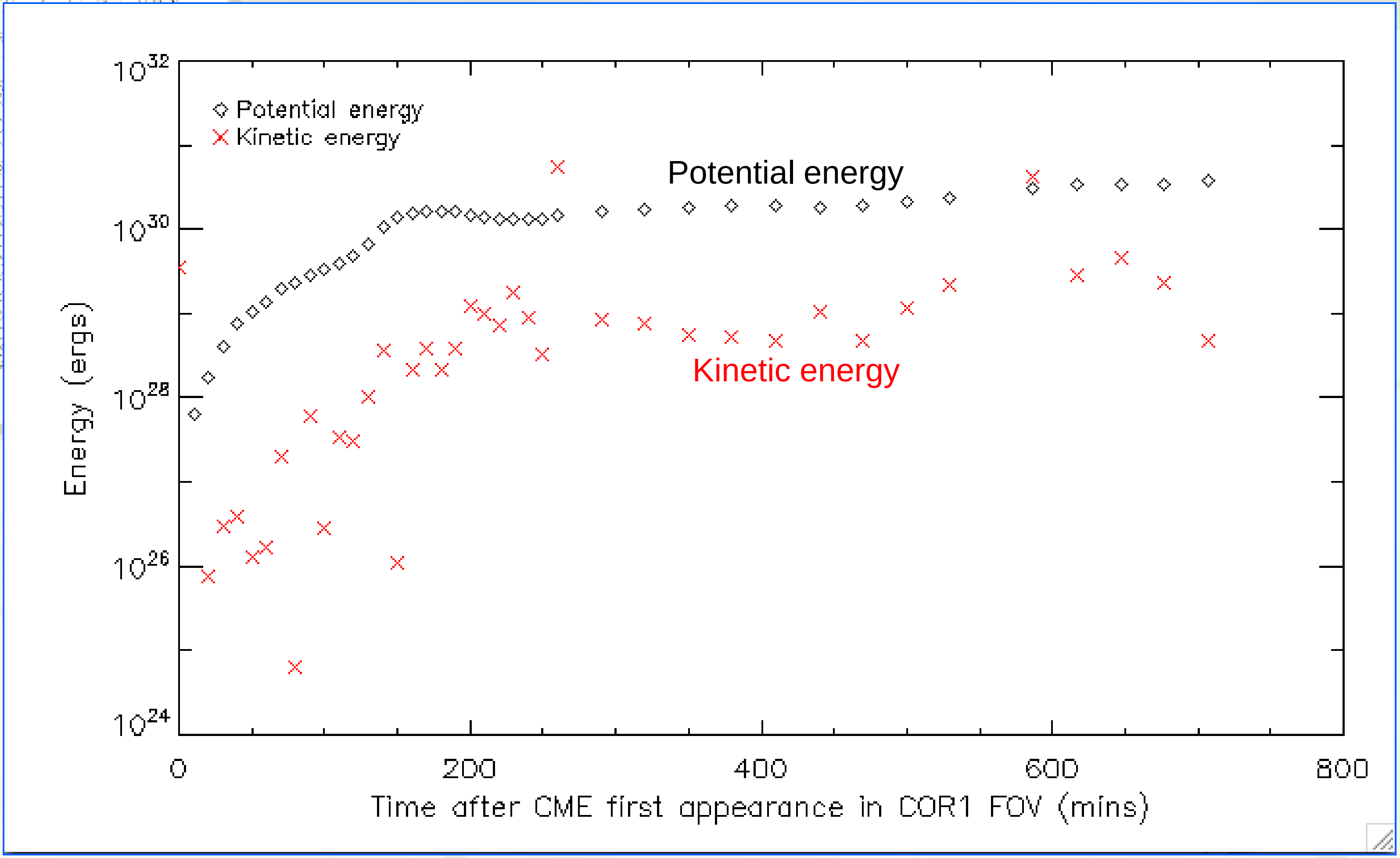
- 0 -200 mins: Rapid growth
- 200 mins onwards : Steady growth
- Mass approaches fixed value

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:

$$E_{potential} = 4.0 \times 10^{30}\ ergs$$

$$E_{kinetic} = 6.9 \times 10^{29}\ ergs$$

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 4.0×10^{30} ergs
  - Kinetic energy 6.9×10^{29} ergs
- Mass and energy values are more reliable when using STEREO data