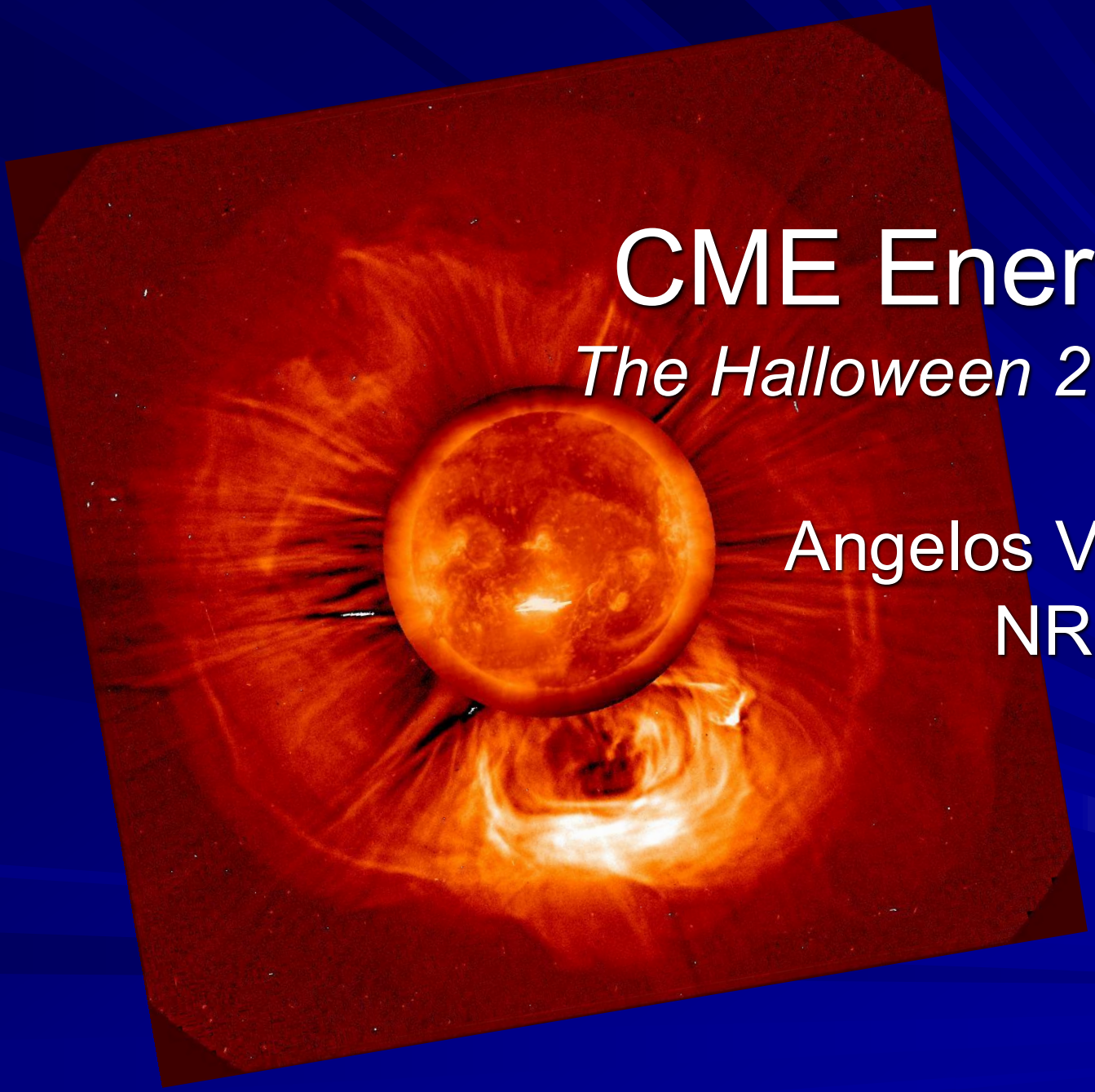


CME Energetics:
The Halloween 2003 Events

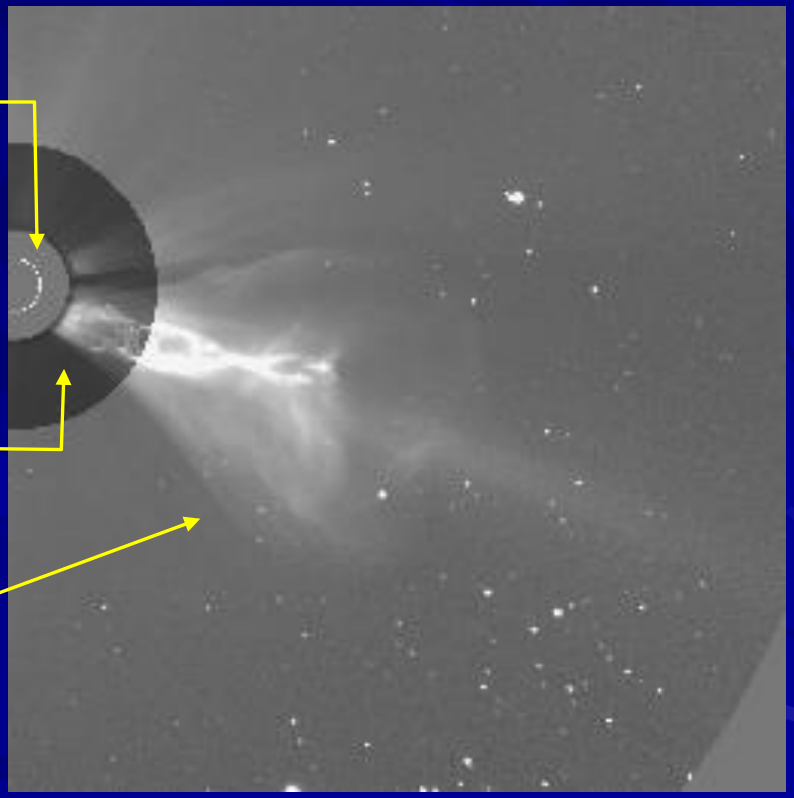
Angelos Vourlidas
NRL

CME Energetics – At what phase?

Initiation Phase
- Insufficient Observations
- Extent of event is unclear
- CME definition is ill-defined

Acceleration Phase
- Sparse temporal/spatial coverage
- Event is still evolving.
- CME-related flows unclear.

"Mature" Phase
- Good observations
- CME is well-defined
- Most mass flow visible
- Stable evolution



Mass Calculations

Assumptions:

- Emission is due to Thomson scattering of photospheric light from coronal electrons.
- All mass is on the sky plane.
- Plasma composition is 10% He, 90% H.

Limitations:

- Emission is optically thin.
- The 3D distribution of the background/ CME electrons is unknown.
- The temperature of the ejected material is unknown (coronal).

Mass Calculations

Method:

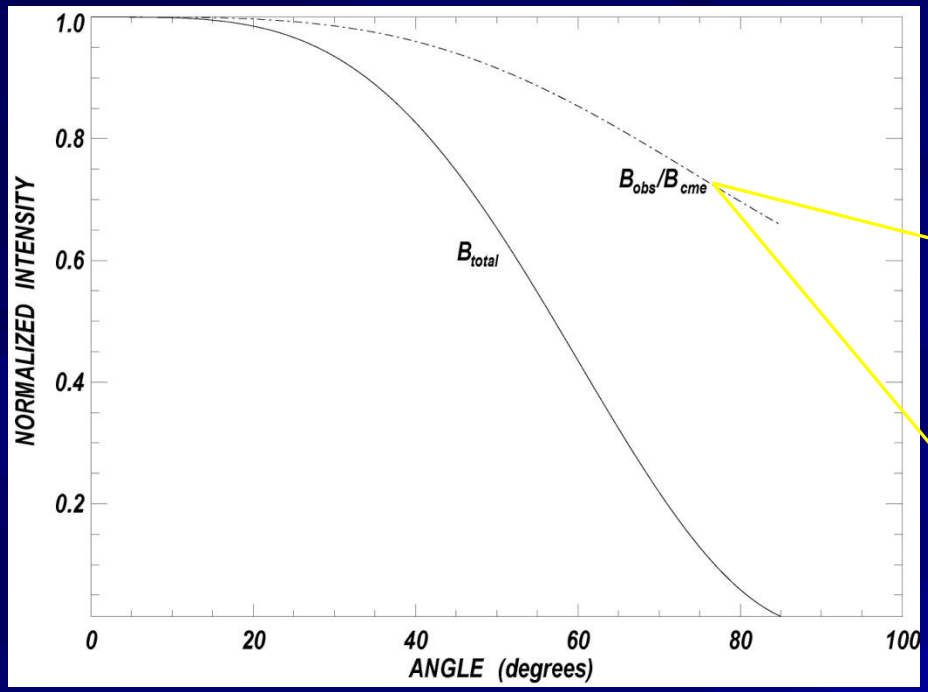
A coronagraph records the total brightness along the line of sight. We can only measure excess brightness ($I_{CME} - I_{PREEVENT}$).

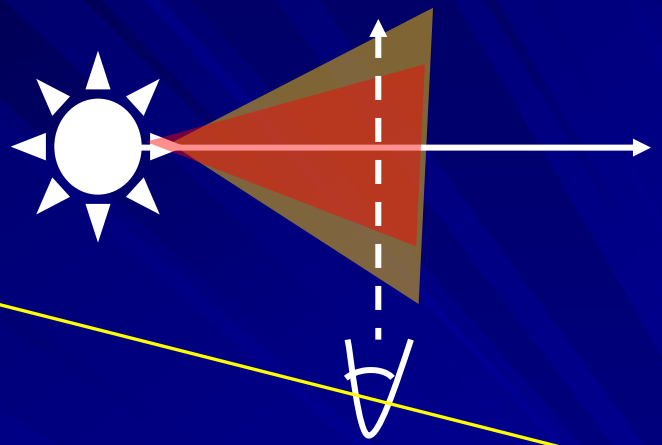
$$\text{Excess DN} \xrightarrow{\text{calibration}} B_{total} \xrightarrow{B_e} \text{No. of } e^- \xrightarrow{\text{composition}} \text{Mass}$$

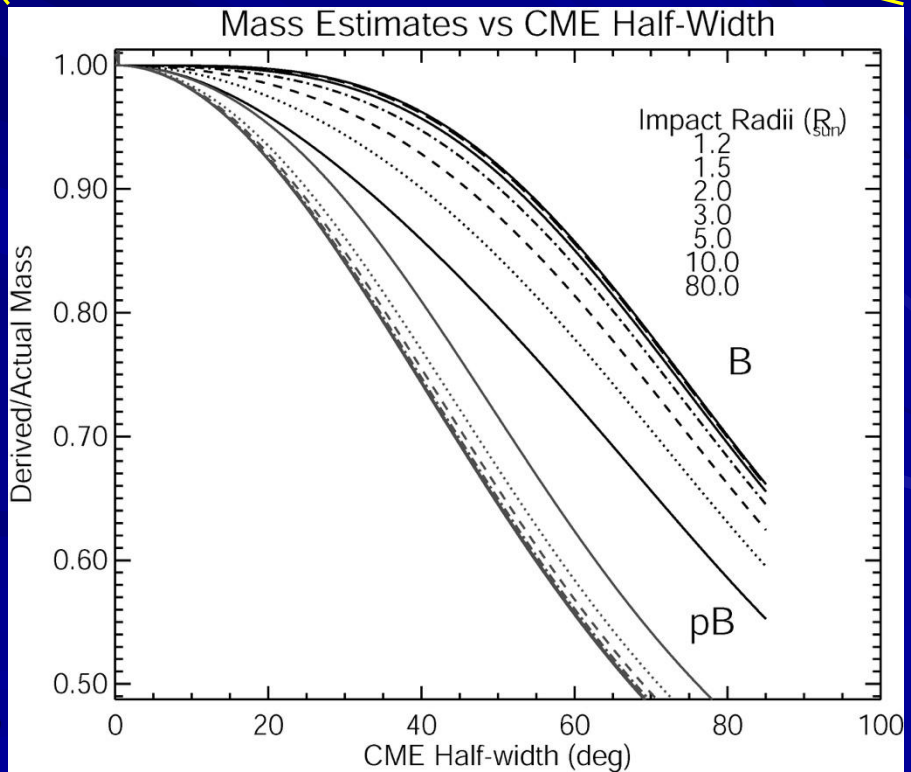
Error Sources:

exposure time	(at 10^{-4} level)
solar rotation	(not important for fast events)
cosmic rays	(a few pixels usually, should cancel out)
stars	(cancel out)
3D structure	(more on that later)
photometry	(rel ~0.1%, abs 2-3%)
composition	(~15%)

How Good Are CME Mass Estimates?







- **Mass could be ~2 times larger.**
- **Mass much larger if**
  CME is wide and
  central angle deviates from sky-plane
  → No Halos

Mass → Energy Calculations

- After measuring the CME mass, M, we can calculate the following types of energy:
  - **KINETIC**

    $E_k = \frac{1}{2} MV^2$, where V is the front speed (upper limit)
    or V is the center-of-mass speed.
  - **POTENTIAL**

$$E_P = \sum_{\text{fluxrope}} \int_{R_\odot}^{R} \frac{GM_\odot m_i}{r_i^2} \, dr_i \, ,$$

Oct-Nov 2003 Events

- **65 events were analyzed (*based on Yashiro's list*)**
- **Many particle events**
  - "Corrupted" Time Intervals (for C3)
    10/26 18:18 – 10/27 09:18 (15 hrs)
    10/28 12:18 – 10/31 07:12 (67 hrs)
    11/02 18:18 – 11/03 23:18 (29 hrs)
- **Many Wide CMEs**
  - Events > 150º not reliable
- **Focus on CMEs with X-class flares**
  - < 150 º , close to sky-plane, no/few cosmic rays
- **Found 6 Good Events**
  - 4 assoc. w/ AR 486
  - 2 assoc. w/ AR 488

Selected Events

<1> Event Number	<2> Date StartTime	<3> GOES-10 Flux	<4> NOAA Region	<5> Event Position	<6> EIT Flare Morphology	<7> EIT Coronal Waves/Dimmings	<8> RHESSI Gamma-rays (2.223 MeV)	<9> GOES-11 Protons >100MeV (protons/cm2/s/sr)	<10> LASCO CME Width (degrees)	<11> CME Velocity (km/sec)	Kinetic Energy (x10e31 ergs)
1	20031104 19:29 UT	X28	0486	S19W83	eruptive	global	none	>1	Halo C2, C3	2657	54
2	20031103 09:43 UT	X3.9	0488	N08W77	compact	local	none	none	Narrow C2, C3	1420	7
3	20031103 01:09 UT	X2.7	0488	N10W83	eruptive	local	none	none	Narrow C2, C3	827	1.3
4	20031102 17:30 UT	X8.3	0486	S14W56	eruptive	global	2.223	>10	Halo C2, C3	1826	
5	20031029 20:37 UT	X10.0	0486	S15W02	compact	global	2.223	>100	Halo C2, C3	1948	
6	20031028 09:51 UT	X17.2	0486	S16E08	eruptive	global	2.223	>100	Halo C2, C3	1785	
7	20031026 17:21 UT	X1.2	0484	N02W38	compact	global	none	<1	Halo C2, C3	1432	
8	20031026 05:57 UT	X1.2	0486	S15E44	compact	global	none	none	Halo C2, C3	1197	
9	20031023 19:50 UT	X1.1	0486	S17E84	compact	global	none	none	Partial Halo C2, C3	1136	5.2
10	20031023 08:19 UT	X5.4	0486	S21E88	eruptive	global	no data	none	Halo C2, C3	1406	10
11	20031022 19:50 UT	X1.0	0486	S22E90	eruptive	global	none	none	Partial Halo C2, C3	1085	3.7
12	20031019 16:29 UT	X1.1	0484	N08E58	eruptive	local	none	none	Halo C2, C3	458	

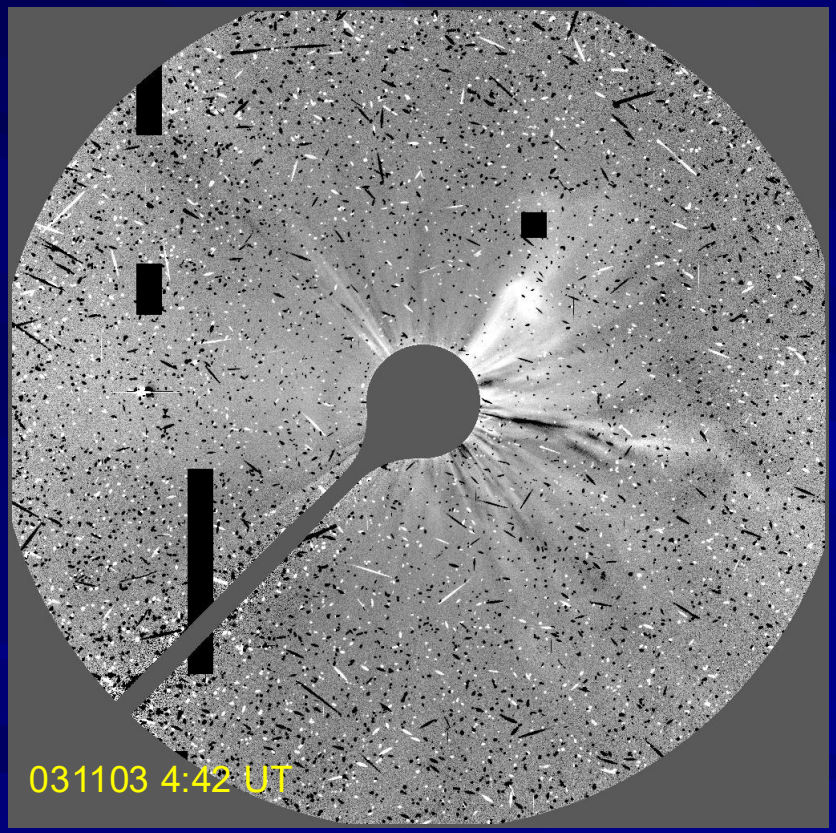
W70 < Lon < W90

E08 < Lon < W70

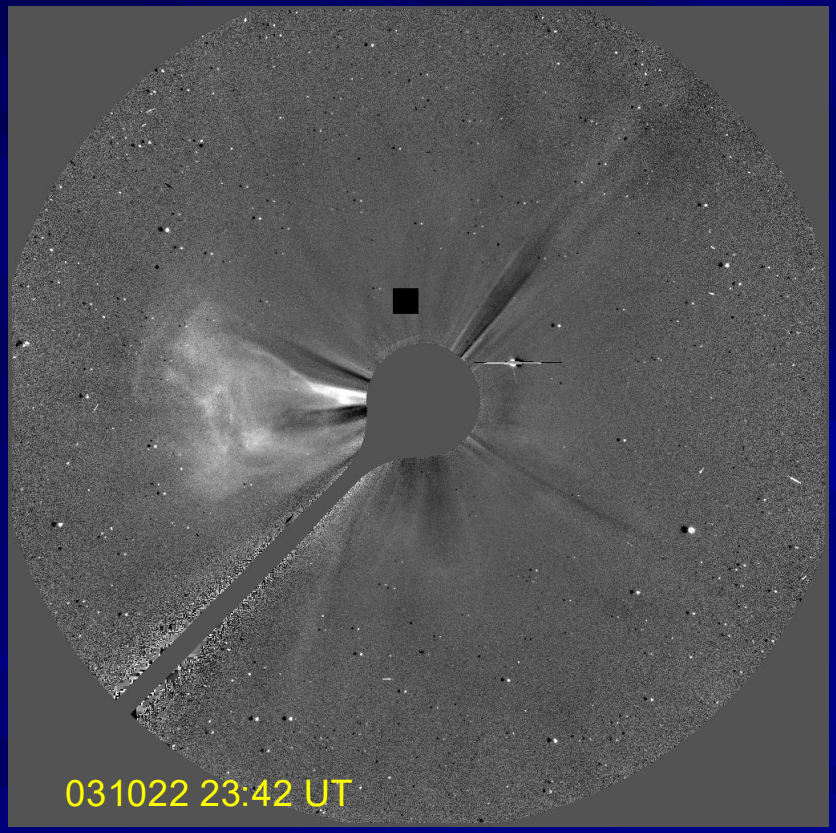
E90 < Lon < E08

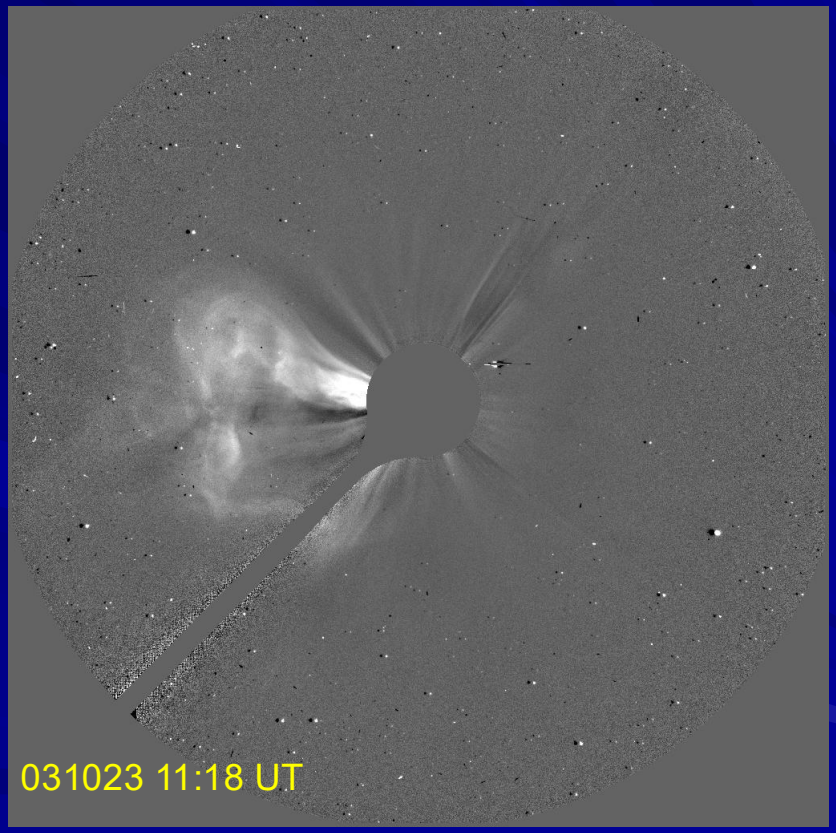
- Courtesy of P. Gallagher (http://beauty.nascom.nasa.gov/~ptg/oct-nov-2003-xflares.html)

CME Images (1)

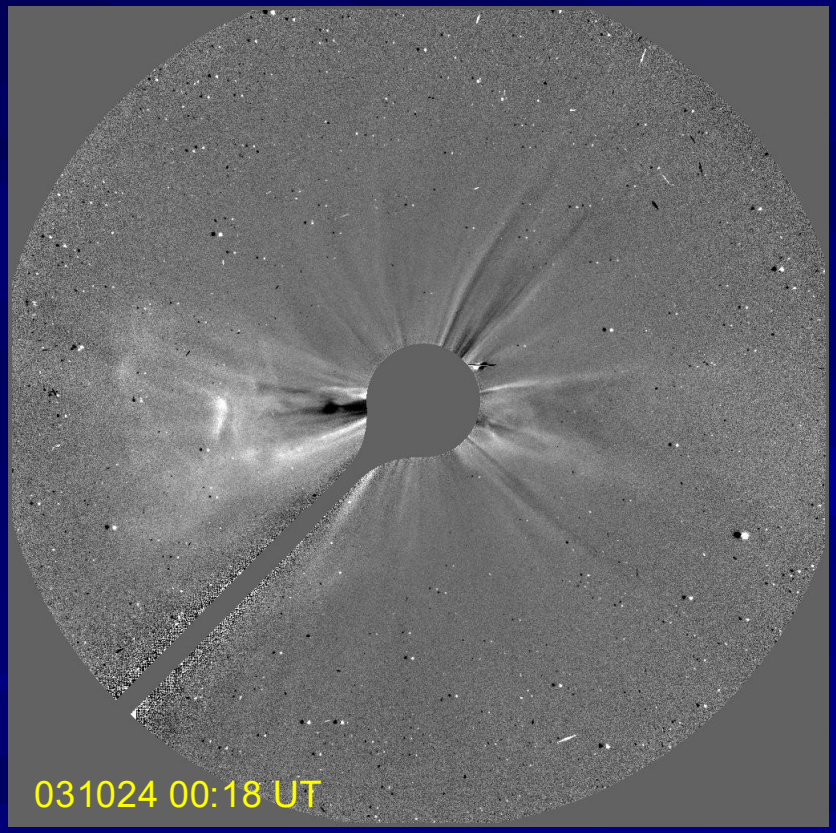


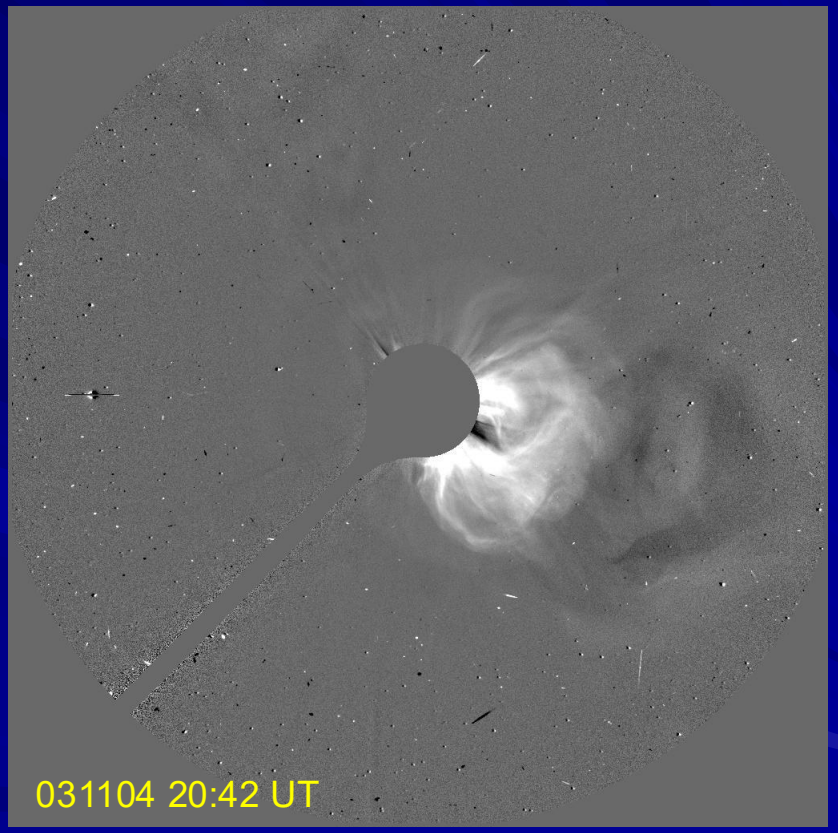
CME Images (2)



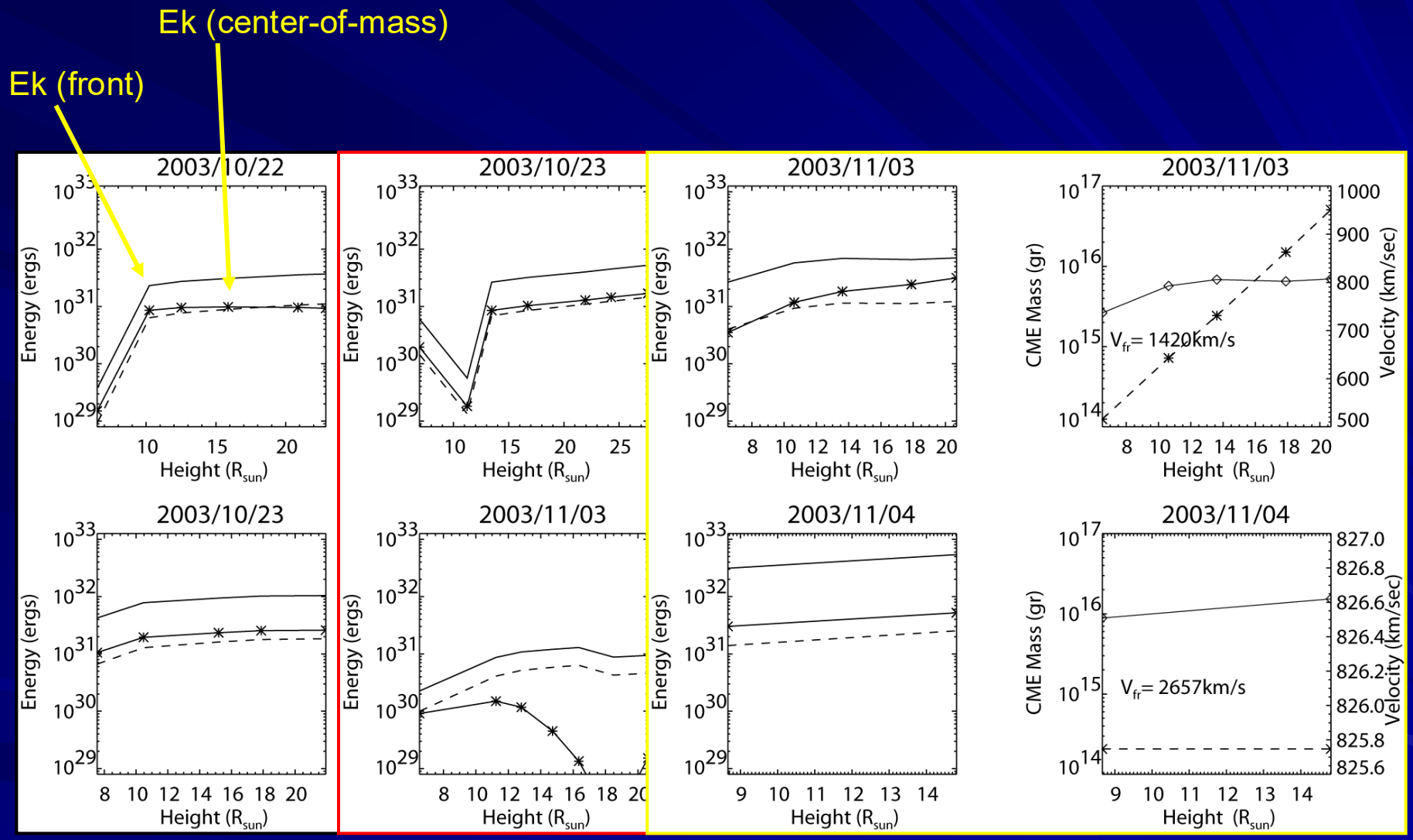


CME Images (3)



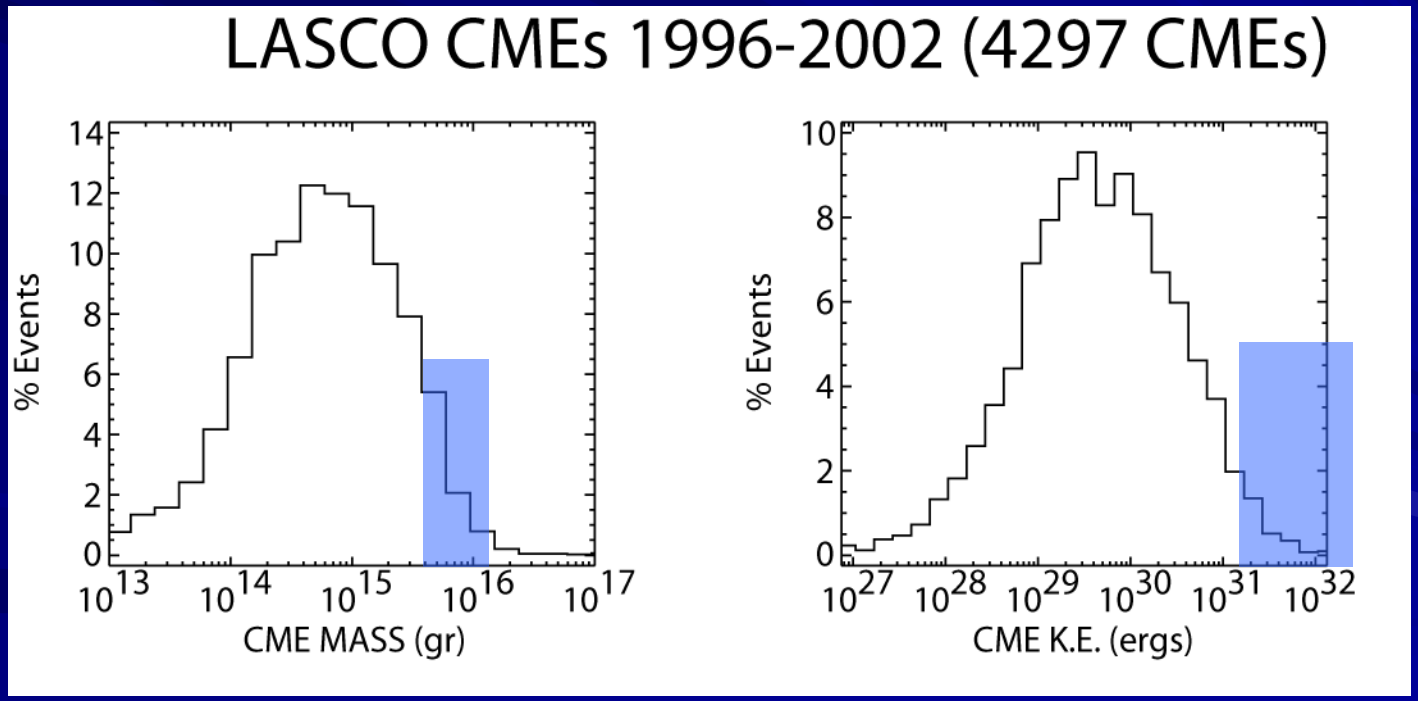


Energy Evolution



How Unusual Are These Events?

- **Comparison to full CME Sample**
  - Masses at the 1-5 % of all events
  - Kinetic Energy at < 1% of all events



Suggestions for Further Studies

- All 6 events are suitable from the LASCO viewpoint
- My own suggestion would be:
  - Nov, 4 (X28 flare): Very large (the largest?) and fast.
  - The 2 narrow CMEs on Nov, 3 (AR488): Different morphology, same region.
- Some energetics work could be possible for some of the other halo CMEs.

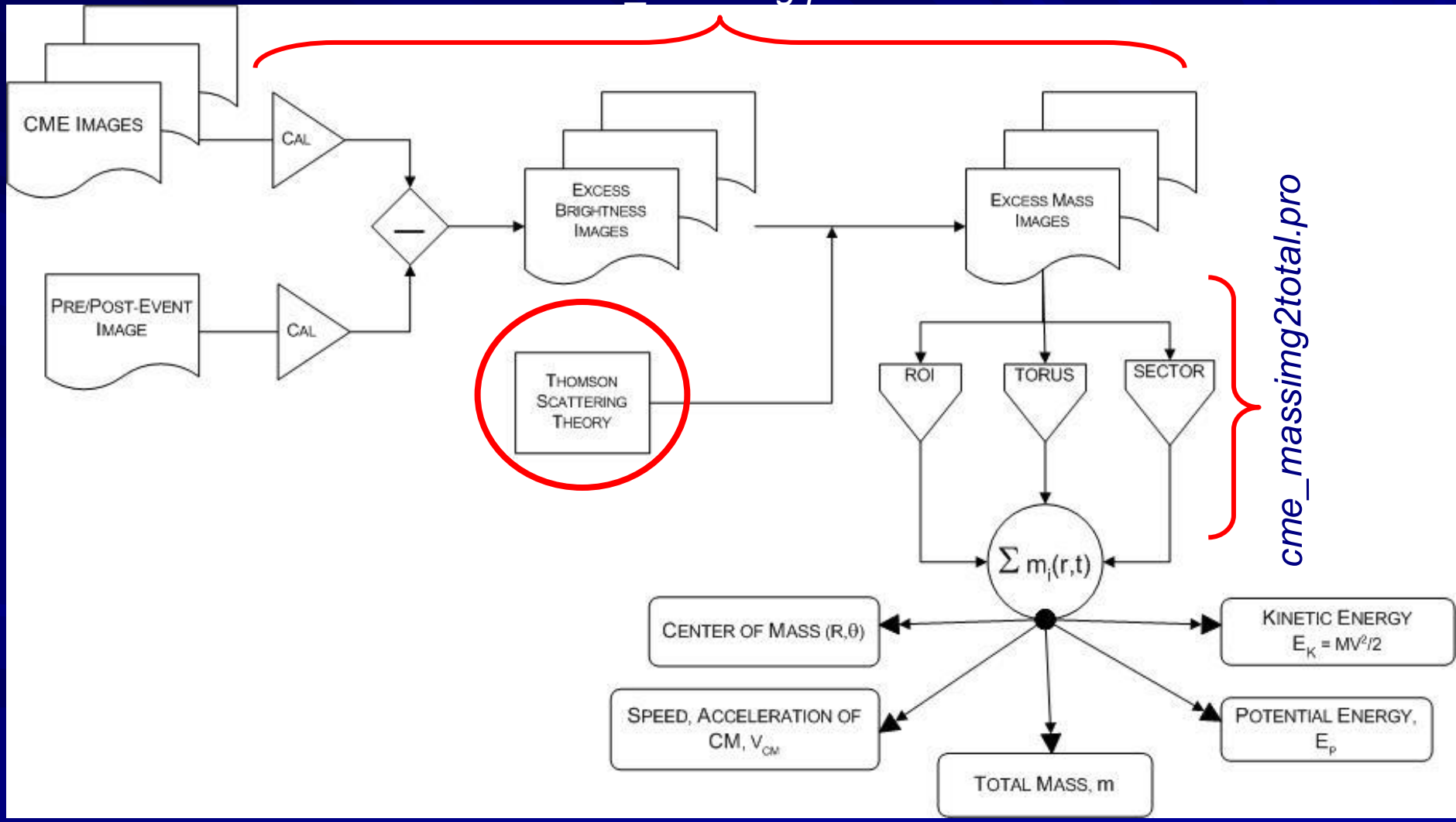
Backups

Overview

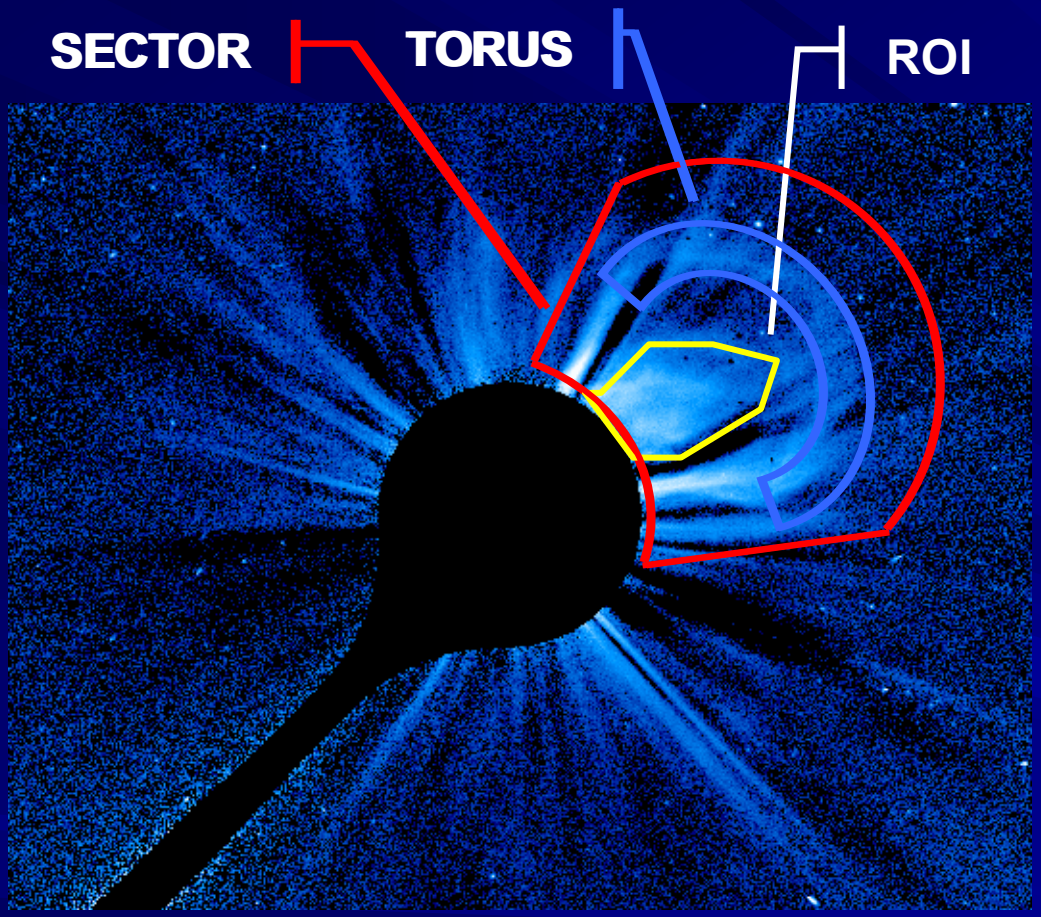
- The following questions will be addressed:
  - How can we **derive** information about CME mass/energetics?
    - What **assumption**s enter in the calculations?
    - Which are the **data analysis steps** to extract quantitative CME information from white light images?
  - How good are the numbers?
    - Can we **estimate** the errors? How?
  - What can we do with this information?
    - What **statistics** tell us?
    - What **correlations** can we find?

Mass/Energy Derivation Flow

C3_massimg.pro



Mass Calculation Methods



"Typical" C3 Mass Image

- Several ways to obtain a "mass" for an event.
- The choice depends on the desired measurement:
  - Full event
  - Specific features (i.e., core)
  - Flow measurements