SHINE June 28 – July 2, 2004 Big Sky - Montana

Properties of CME Acceleration in the Low Corona

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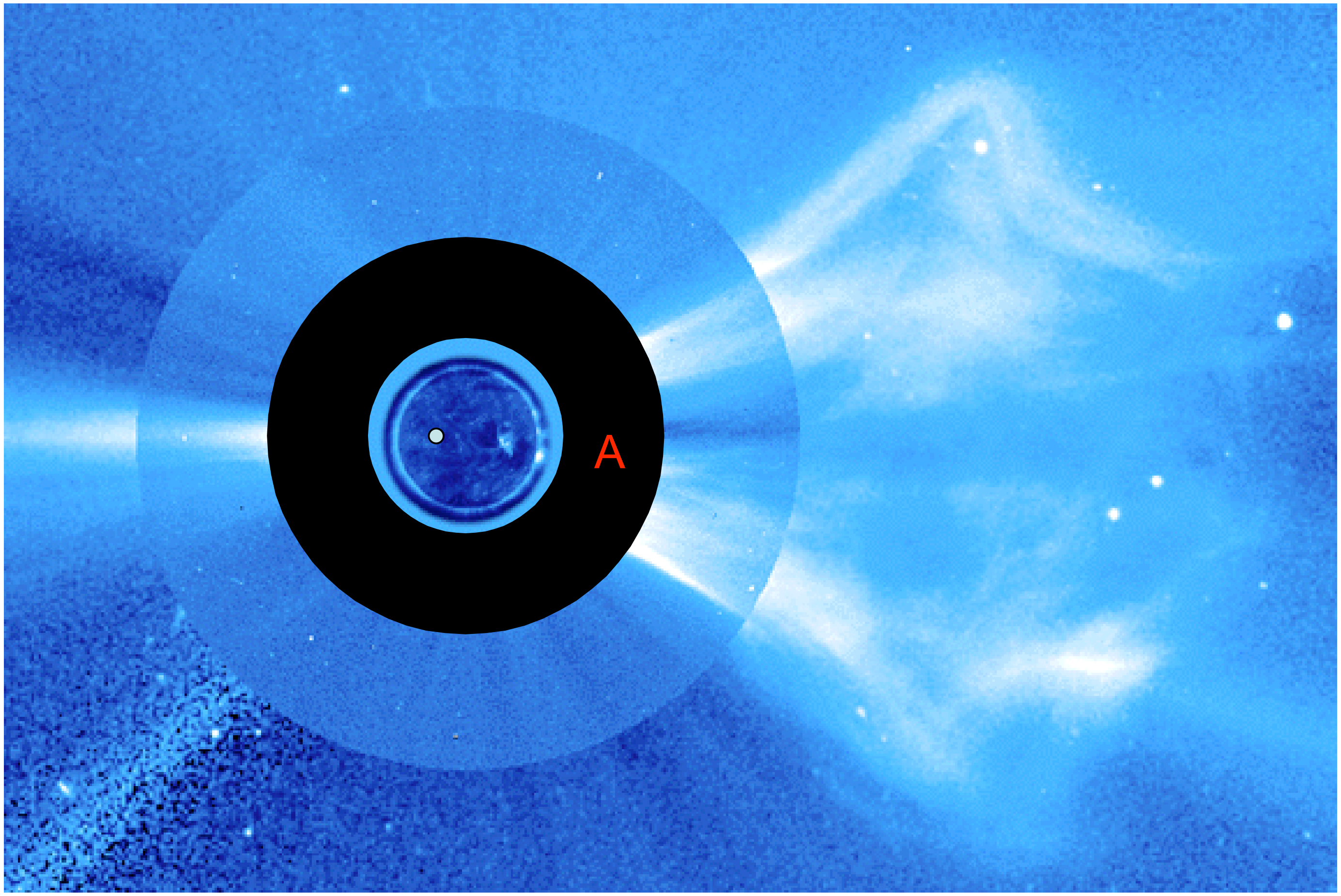
Address the CME acceleration issue from the observational point of view:

- **What?**
  - **Duration Magnitude Distance**
- **When? (Flare)**
  - **Onset Time Phases Time Coincidene**
- **Where? (Flare)**
  - **Size and Location**
- **Discussions**

Poster 39

Observations: EIT, LASCO C1/C2/C3

- **CME acceleration starts in the inner corona, and mainly occurs in the inner corona.**



Observations: C1

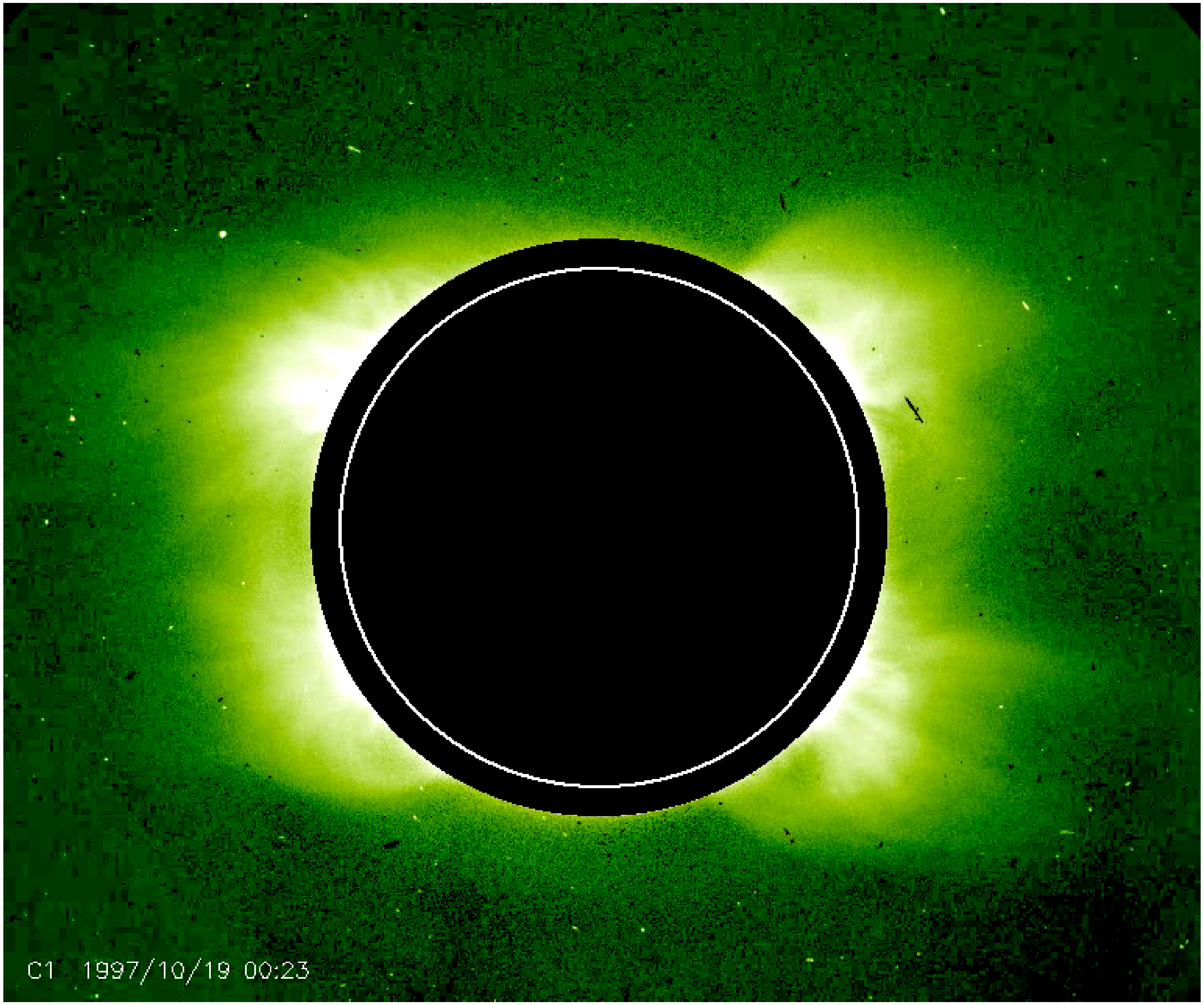
- About C1
  - Field of view: 1.1 to 3.0 Rs
  - Equipped with Fabry-Perot Interferometer
  - Coronal green line at 5302 Å, from Fe XIV
  - Coronal red line at 6376 Å, from FeX

- To study CME acceleration, we have systematically examined all LASCO C1 images, about 100,000 images in total from 1996 January to 1998 June

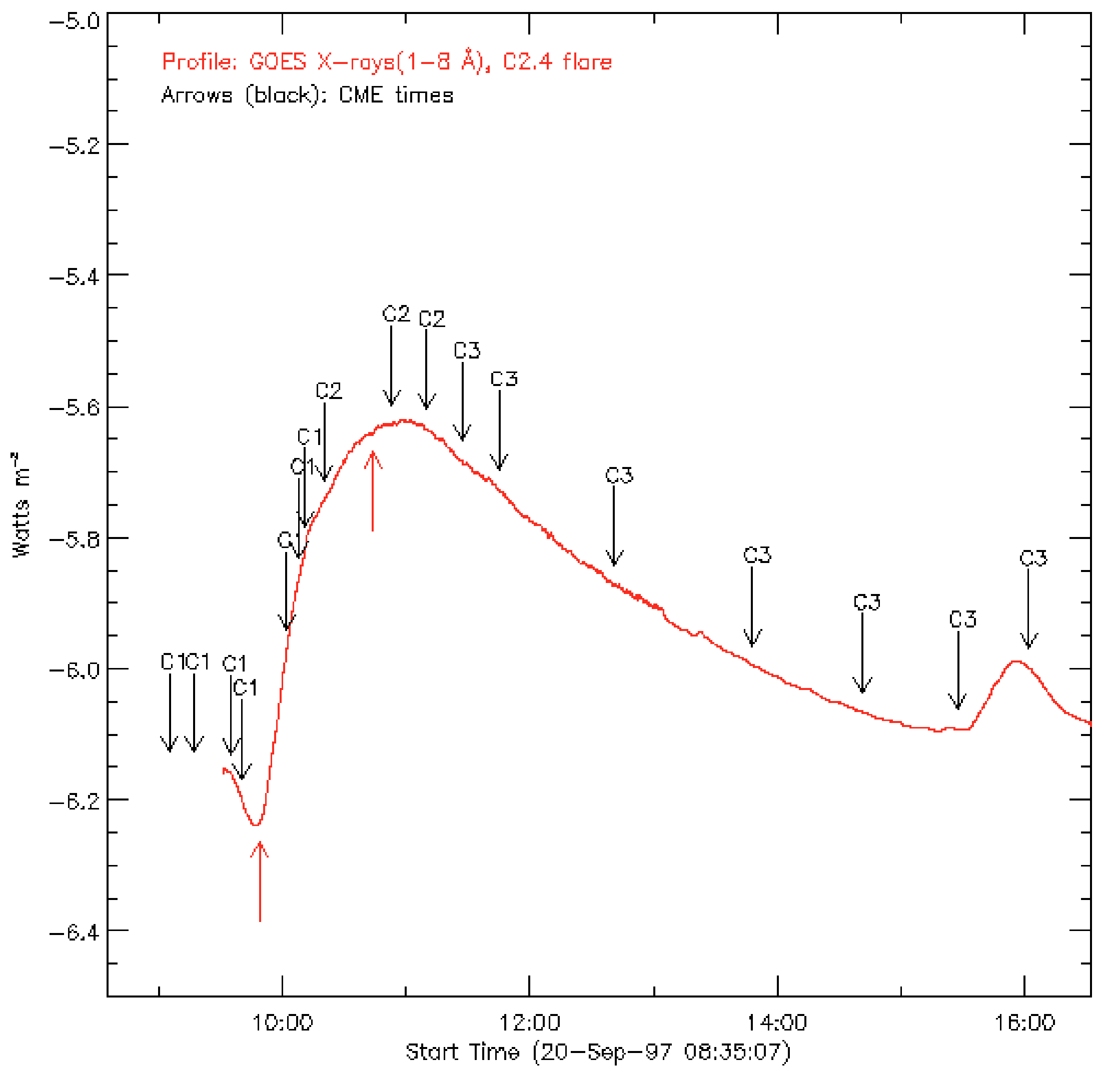
- Online at http://solar.scs.gmu.edu/research/cme_c1/index.html

  - A list of all coronal activities, including CMEs, loop arcades, transient brightenings and dimmings et al.
  - A list of 101 CMEs, each with at least 1 LE seen by C1
  - A sub-set of 27 CMEs, each with at least 3 LE seen by C1

Observations: C1 movie



Observations: Example: 1997 Sep. 20 event

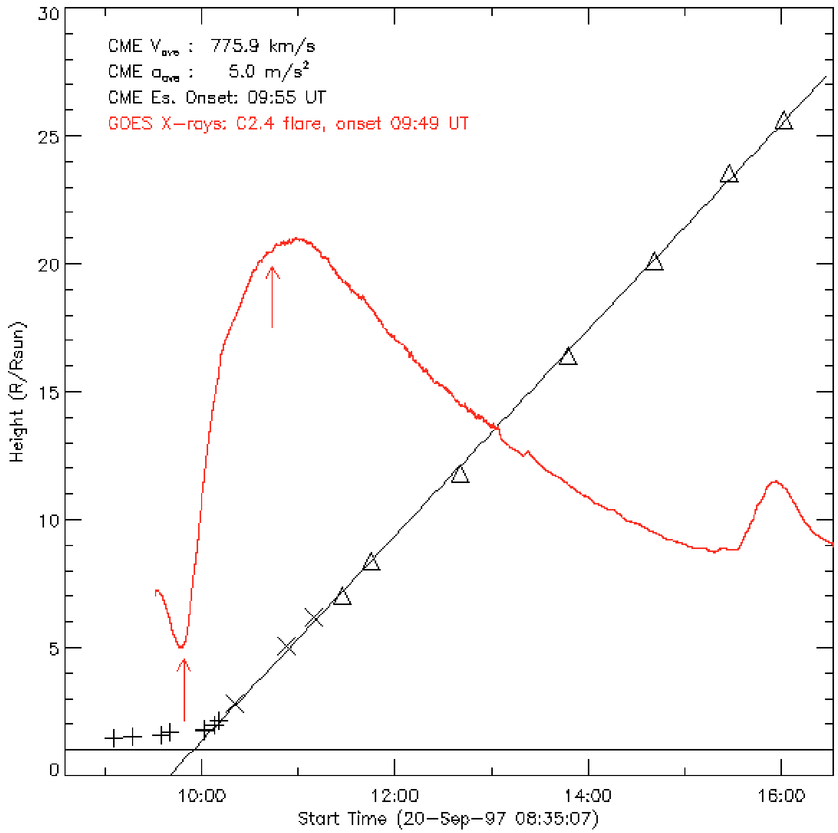


Time

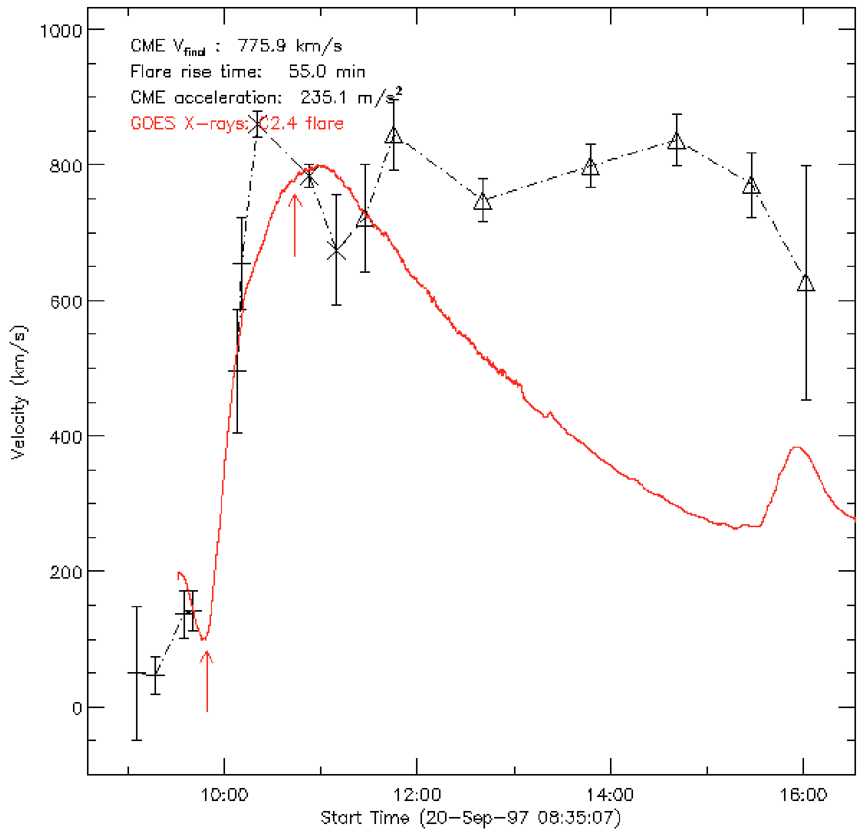
C1: 8 images
C2: 3 images
C3: 7 images

GOES X-ray Flare: C2.3

Observations: Example: 1997 Sep. 20 event (Cont.)



Height --Time Plot

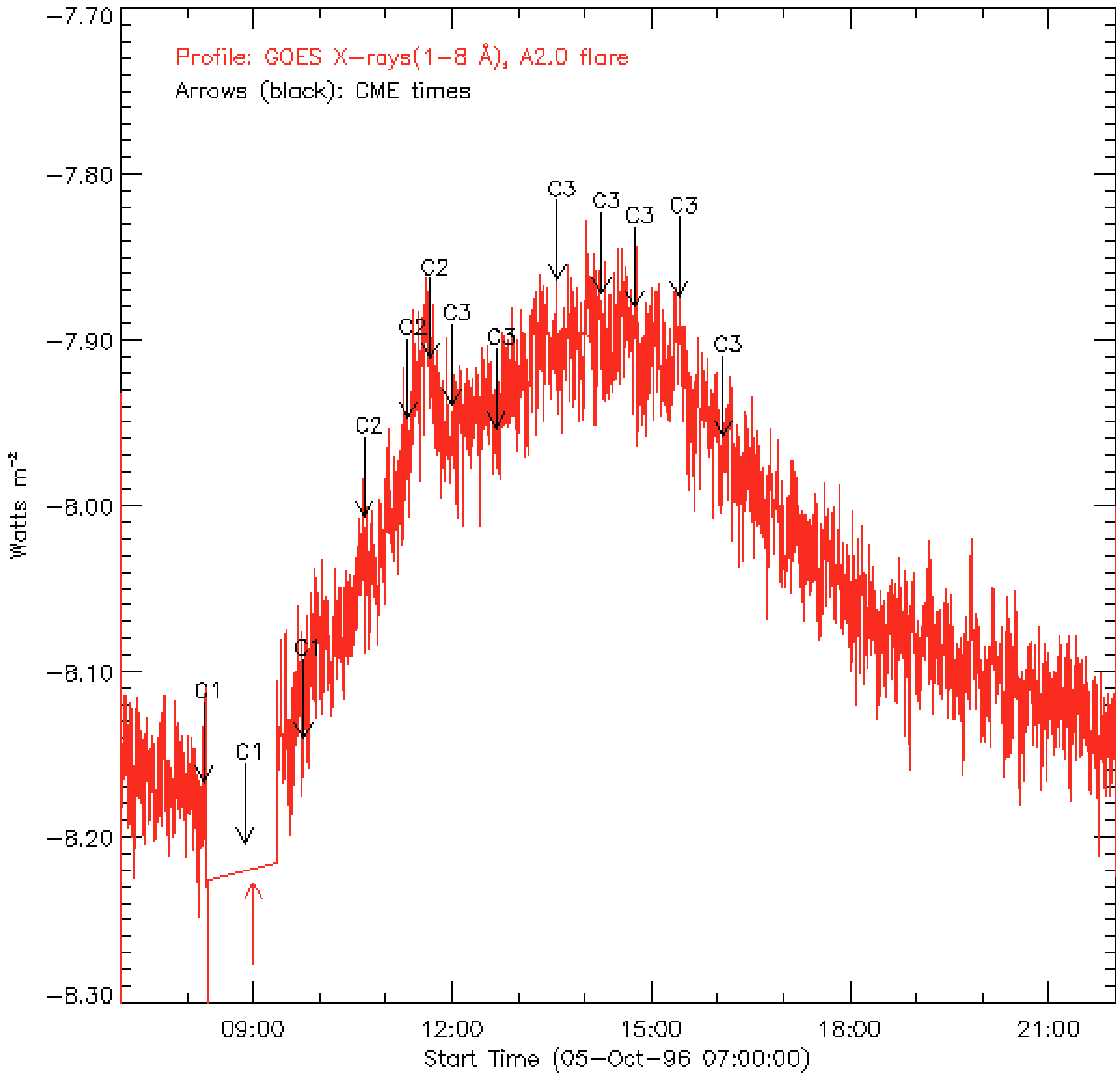


Velocity -- Time Plot

ave. velocity in C2/C3:	**775.9 km/s**
ave. acceleration in C2/C3:	**5.0 m/s^2**

acceleration time:	**55 min**
propagation velocity:	**775.9 km/s**
acceleration in acc. phase:	**235.1 m/s^2**

Observations: Example: 1996 Oct. 05 event

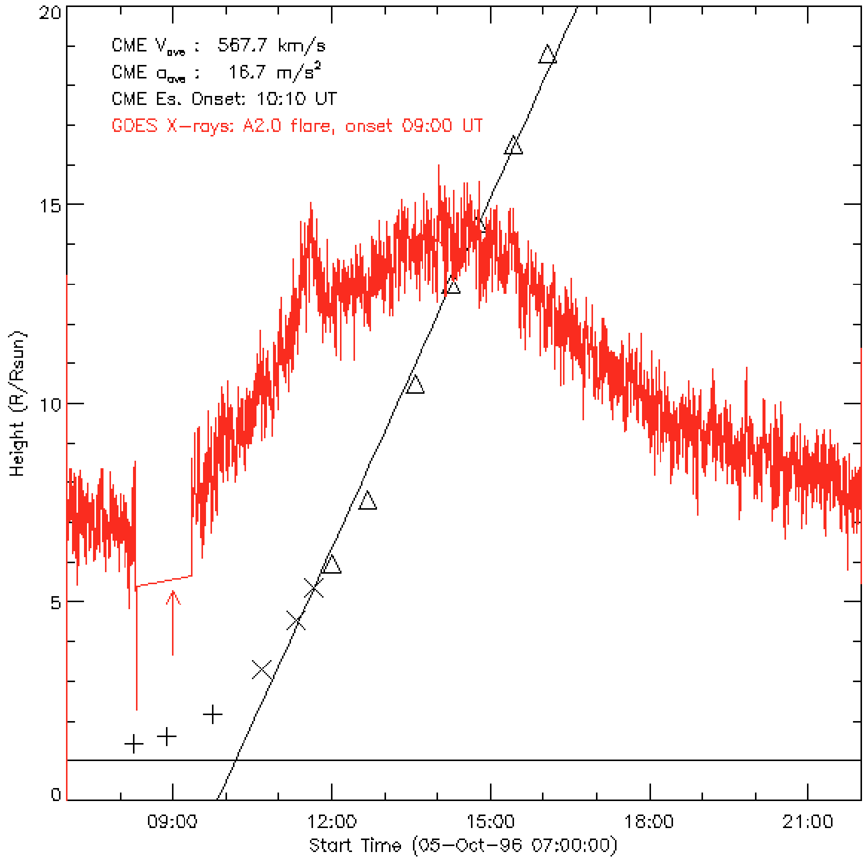


Time

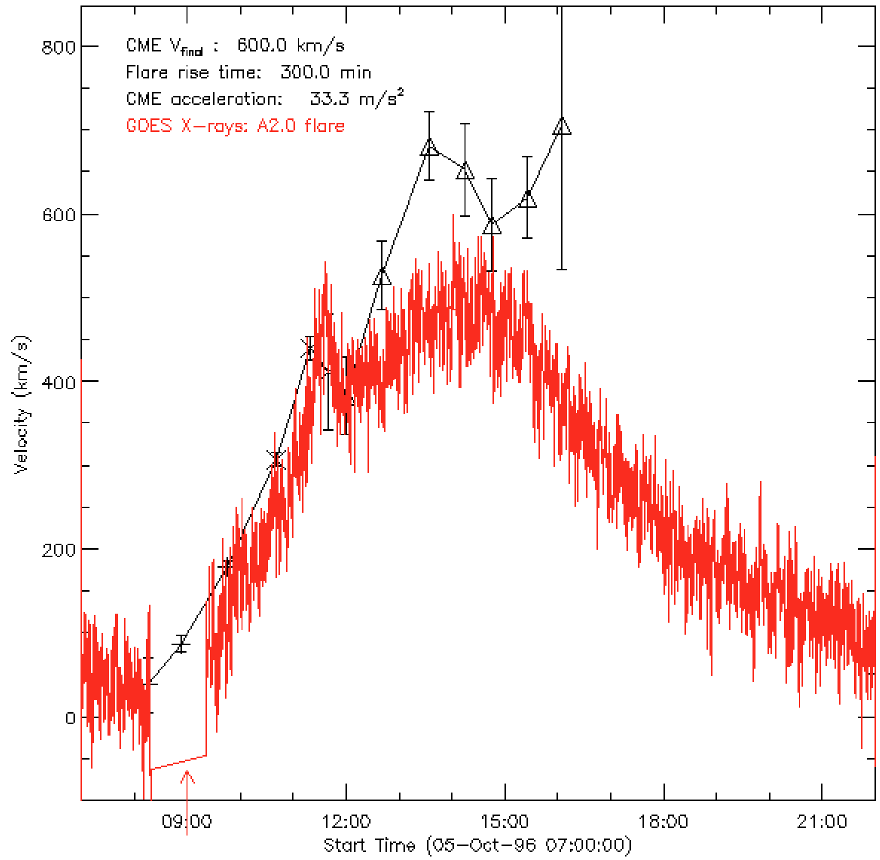
C1: 3 images
C2: 3 images
C3: 7 images

GOES X-ray Flare: A1.2
not in NOAA/SEC catalog

Observations: Example: 1996 Oct. 5 event (Cont.)



Height --Time Plot

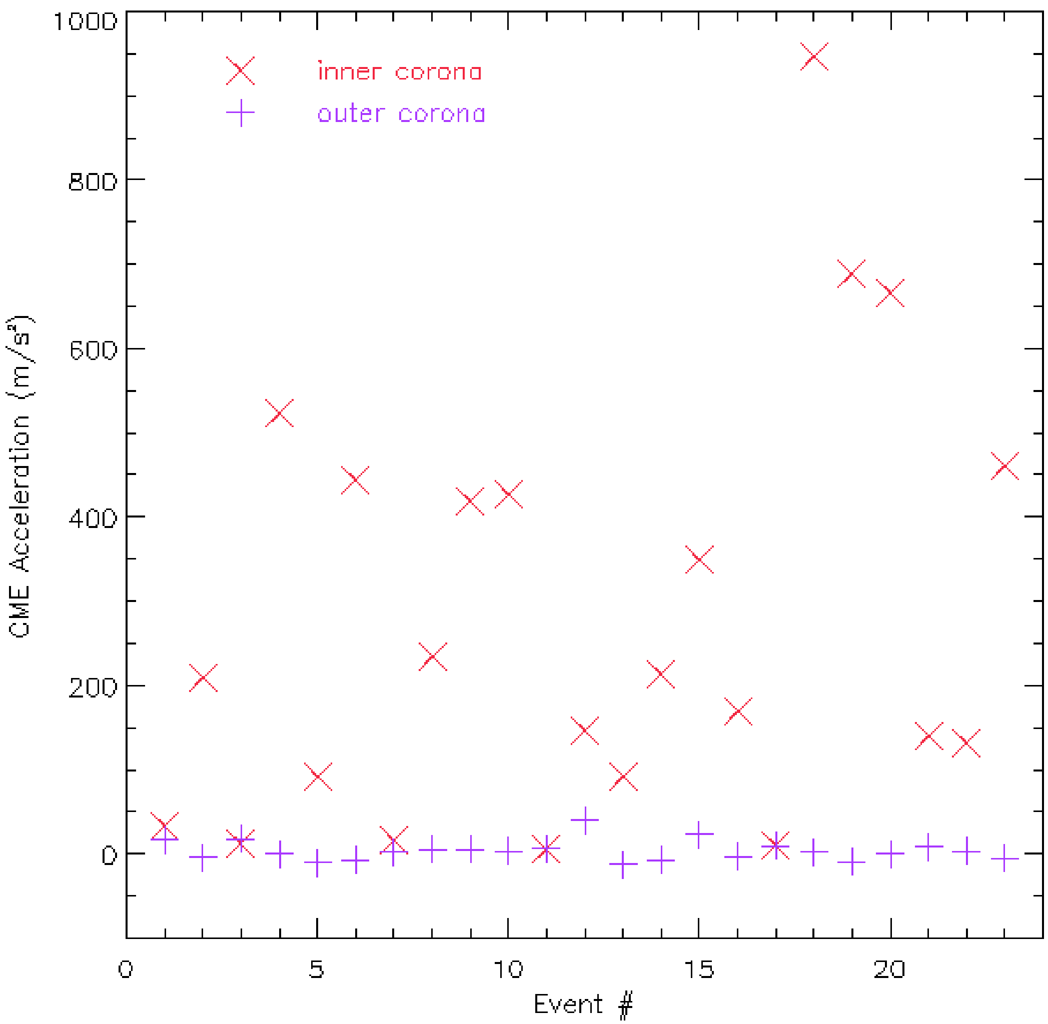


Velocity -- Time Plot

ave. velocity in C2/C3: 569.0 km/s
ave. acceleration in C2/C3: 16.8 m/s^2

acceleration time: 300 min
propagation velocity: 600.0 km/s
acceleration in acc. phase: 33.3 m/s^2

What? Magnitude



23 best observed events with at least 3 LE seen in C1

Outer Corona Acc.: averaged in C2/C3

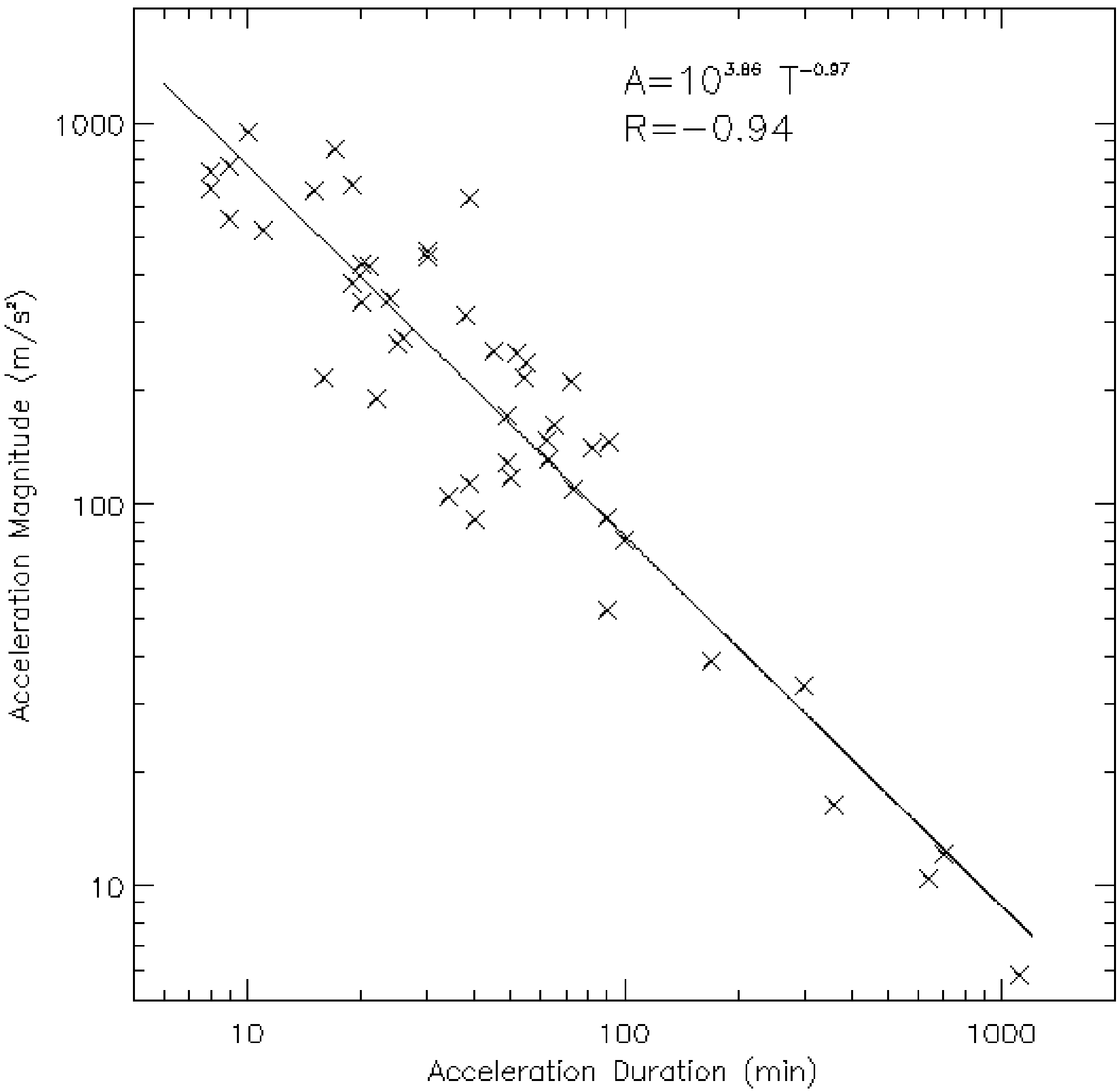
Inner Corona Acc.: measured in the acc. phase

	Inner	Outer
Lowest	+5.8	-12.8
Highest	+946.9	+39.6
Medium	+209.0	+2.6
Average	+279.0	+3.5

(m/s^2)

St.Cyr et al (1999)
Average +274
Medium: +44 (-218--+3270)

What? Duration and Magnitude



48 events

Duration of acc. phase:
- **Minimum: 6 min**
- **Maximum: 1113 min**
- **Average: 103.6 min**
- **Medium: 40 min**

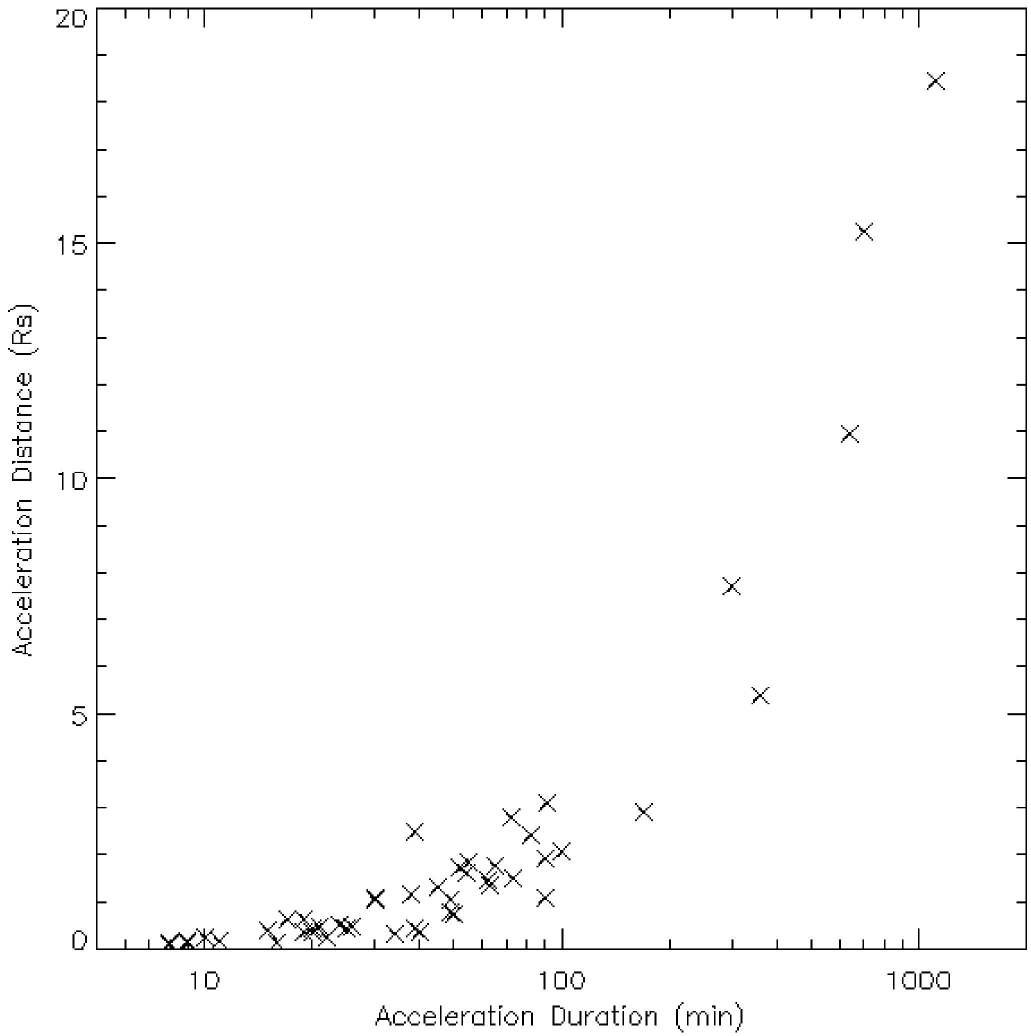
A Scaling Law:

A = $10^{3.86}$ T $^{-0.97}$

Or simply

A (m/s^2) = 7000 / T (min)

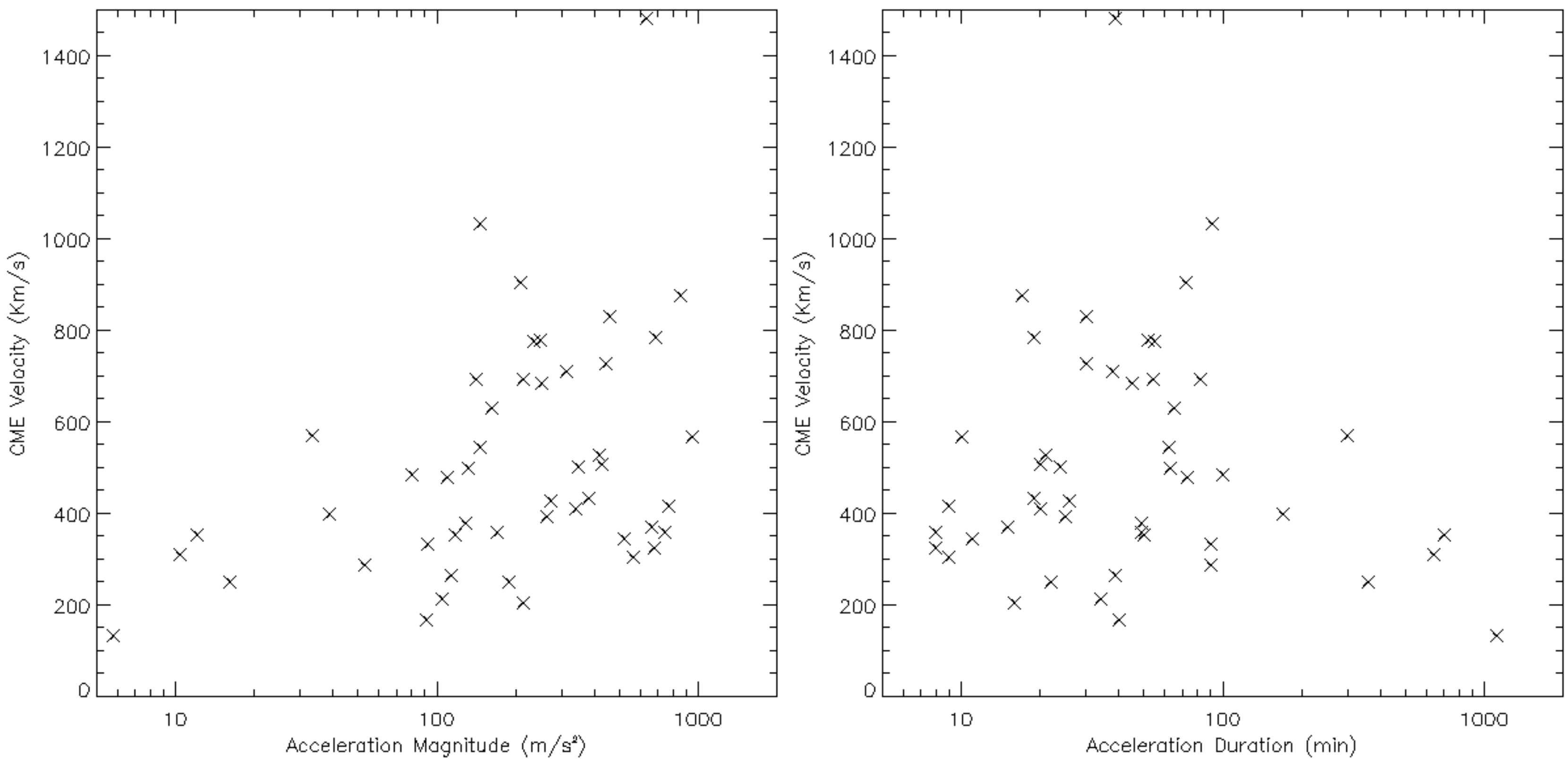
What? Distance and Duration



Distance traveled in the acc. phase:

- **Minimum: ~ 0.1 Rs**
- **Maximum: ~ 19 Rs**
- **Average: 2.12 Rs**
- **Medium: 1.05 Rs**

What? Effect on Final Propagation Speed



Magnitude

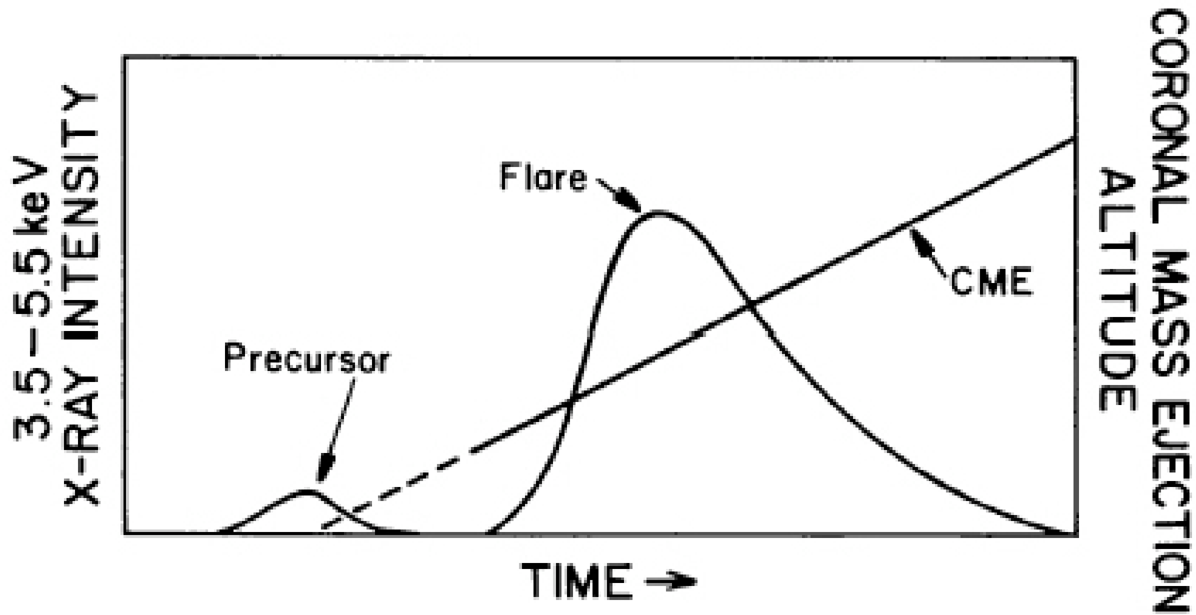
Duration

- **Not dominant by acceleration magnitude**
- **Not dominant by acceleration duration**
- **Equally determined by the two factors**

When? Onset Time

- An observational issue of what is CME onset relative to flare onset?
- How to determine CME onset time?

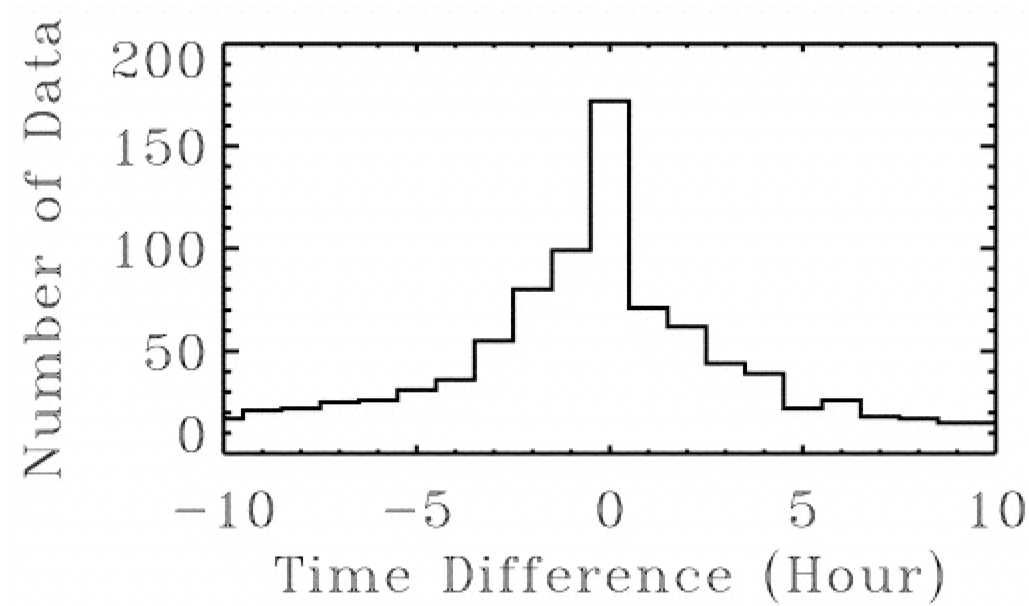
Linear Extrapolation, is it OK?



(From Harrison 1986)

When? Onset Time (Cont.)

•The extrapolation method always leads to a Gaussian-like distribution of the onset-time difference, centered at zero?



(From Moon et al. 2002, also see Harrison 1995)
(also see Yashiro's Poster 38)

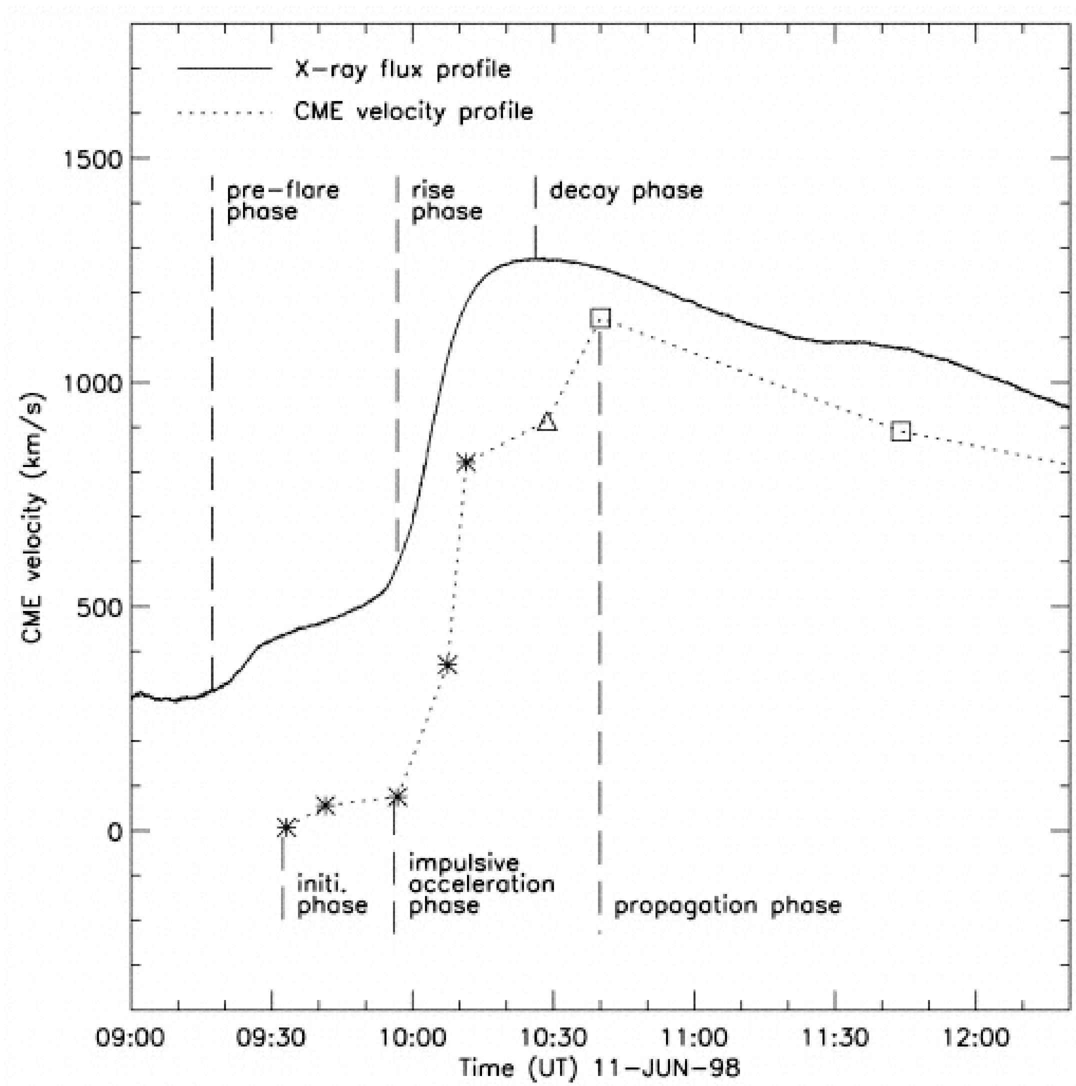
•Implication: loose association between CME and Flare (Harrison 1995)

•But errors with this method (Zhang et al., 2001, 2004)

- •CME speed is not constant in the inner corona
- •CME is not accelerated instantaneously

When? Three Phases

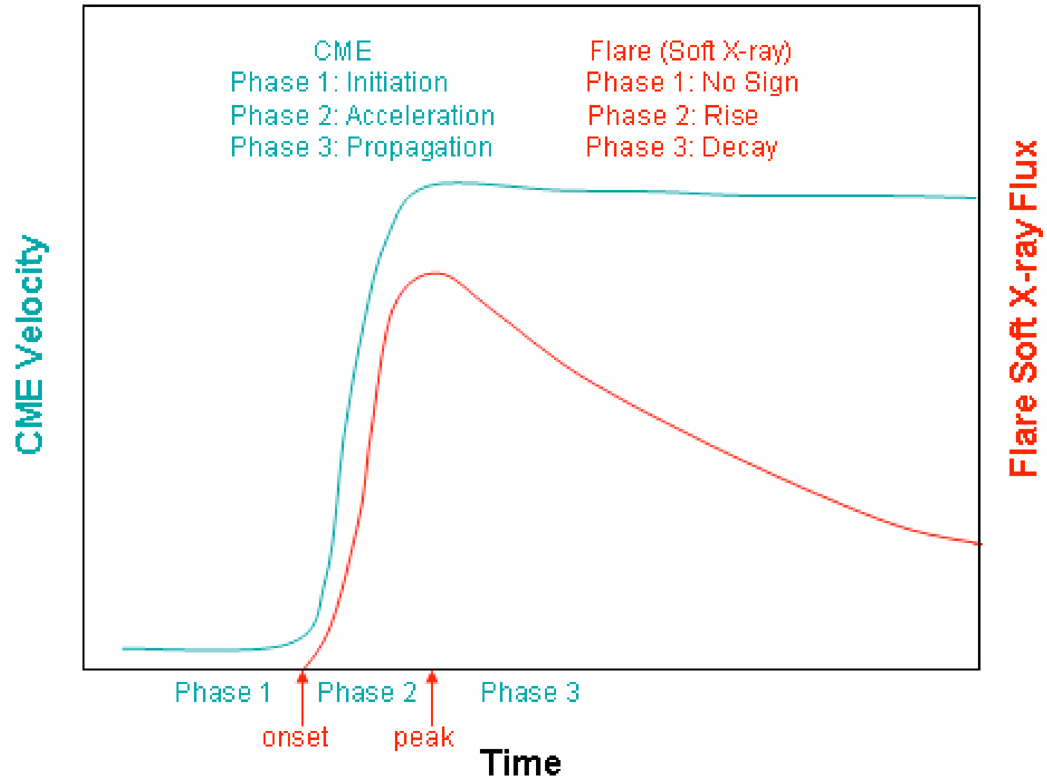
No extrapolation, and piece-wise numeric fitting to obtain velocity



(From Zhang et al. 2001)

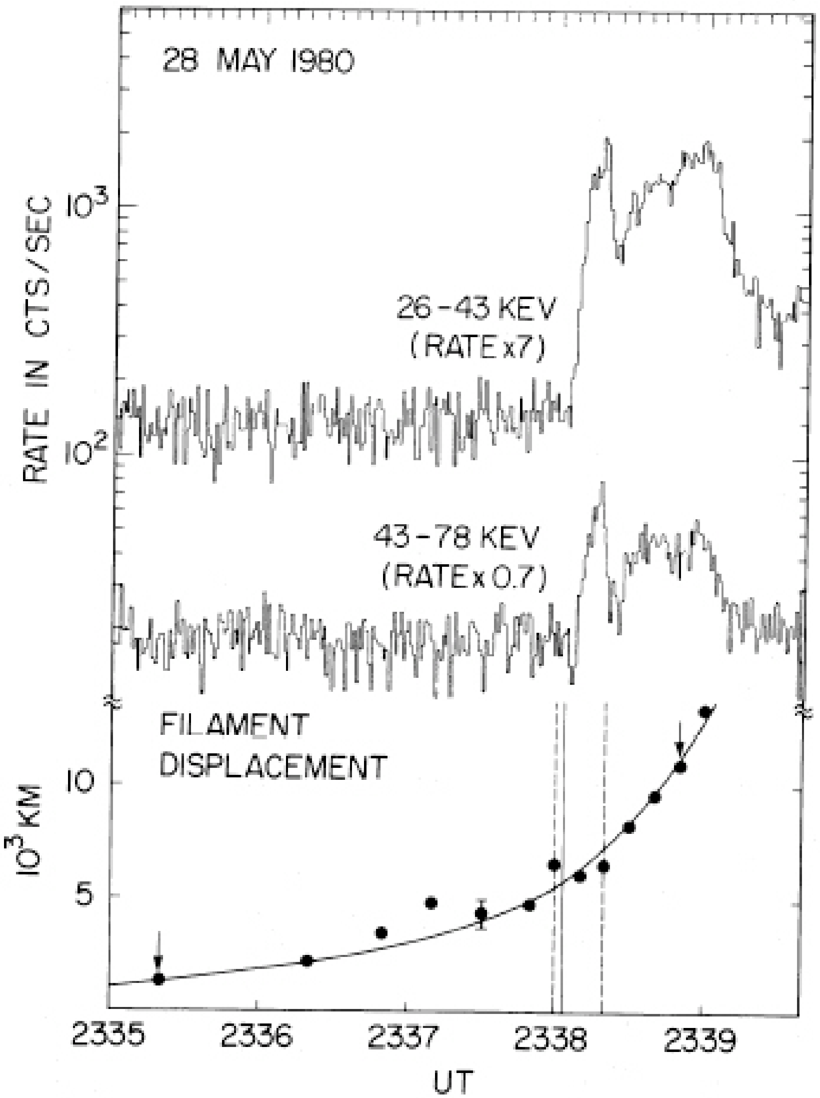
When? Time Coincidence

- **Temporal correlation between CME Kinematics and Flare Flux evolution:**
  1. (slow) initiation phase may start earlier
  2. The onset of main (often impulsive) acceleration phase coincides with the onset of the flare
  3. The peak of CME velocity coincides with the peak of the flare
- **Therefore, a strong physical relation instead of loose association**



When? Time Coincidence (Cont.)

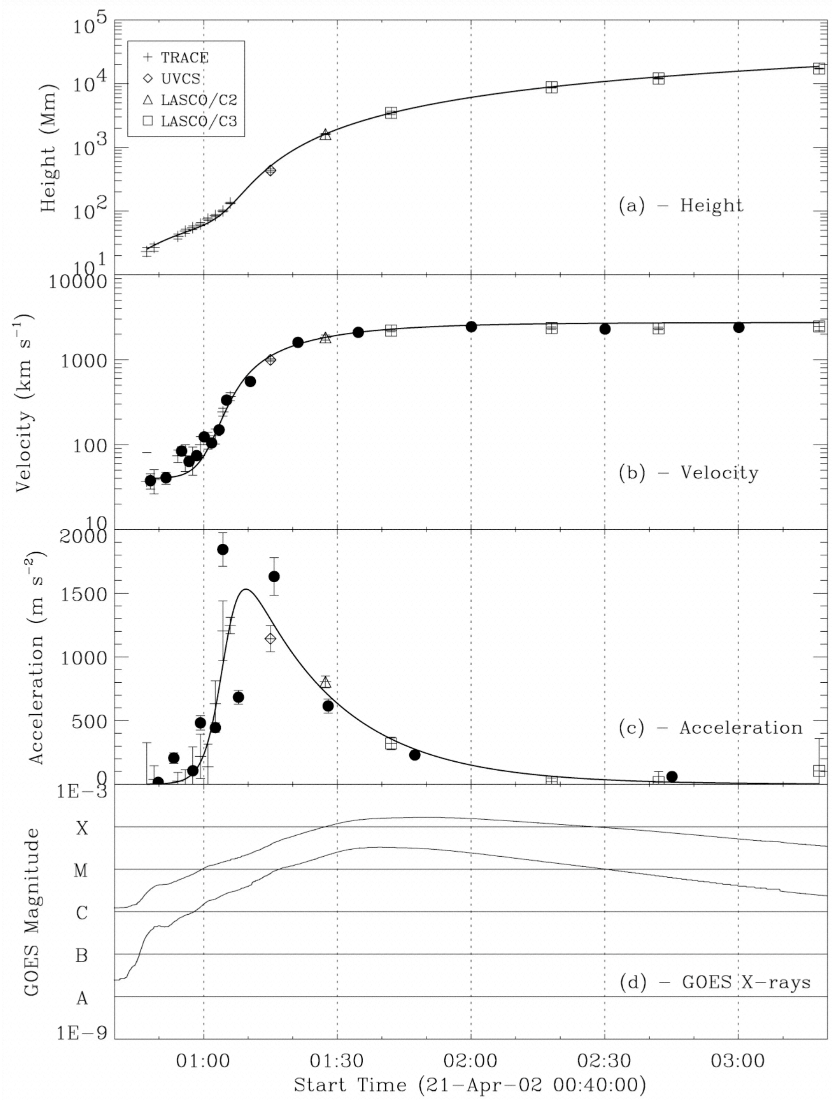
Filament -- Flare



(From Kahler et al. 1988)

When? Time Coincidence (Cont.)

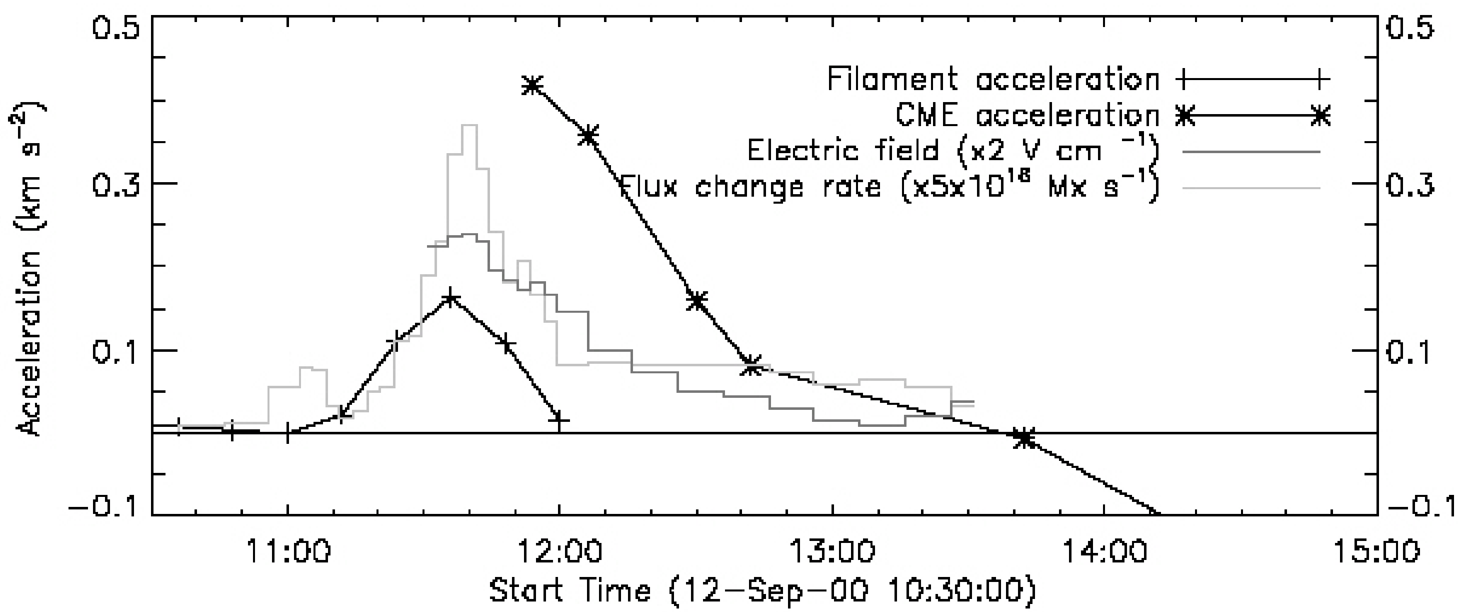
TRACE EUV ejecta/CME -- Flare



(From Gallagher et al. 2003)

When? Time Coincidence (Cont.)

H_ Ribbon/Filament/CME -- Flare

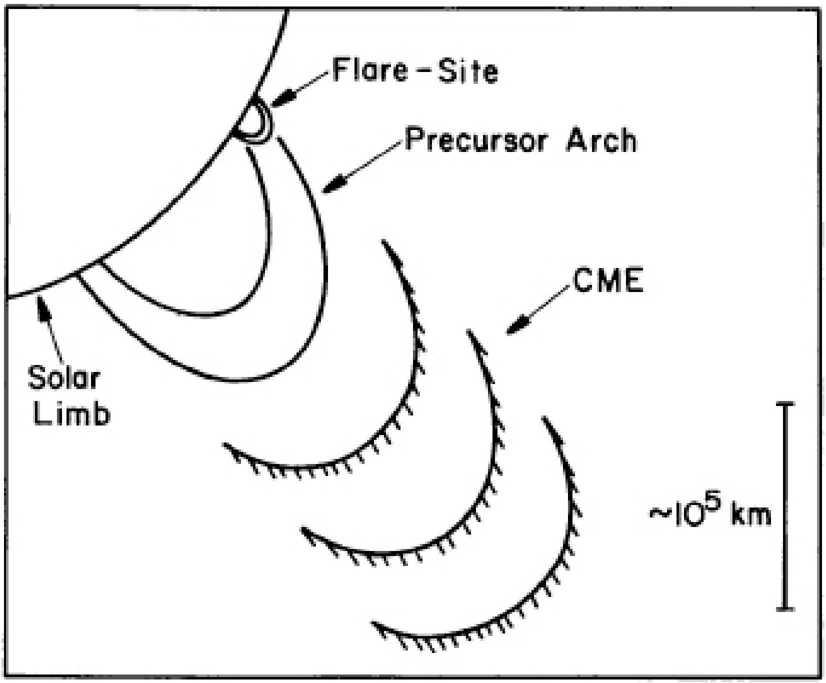


(From Qiu. 2004)

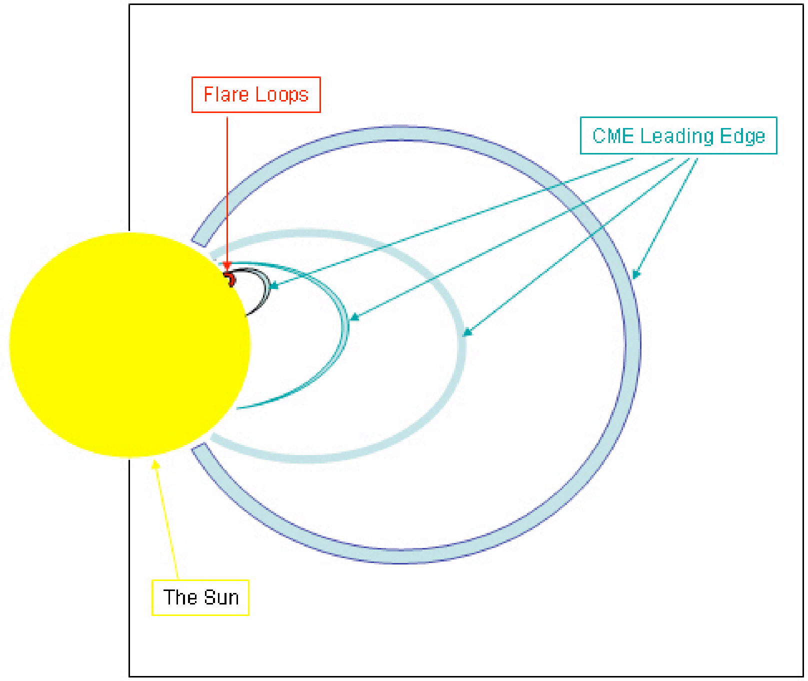
Where?

Size disparity?
Location Disparity?

Probably Not
Probably Not



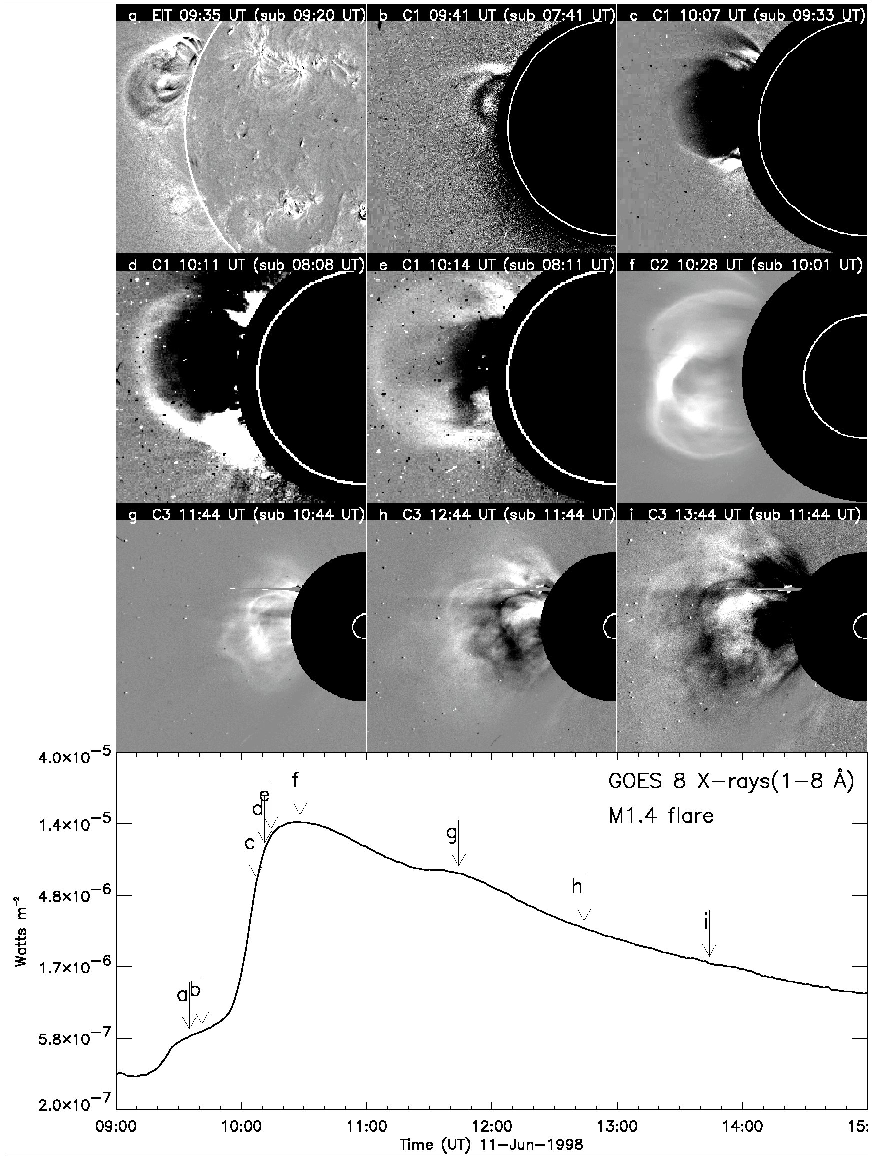
(From Harrison 1986)



(LASCO EIT/C1, present)

- (Non-radial) Super-expansion of CME in the main acceleration phase
- (Radial) Self-similar expansion of CME in the propagation phase

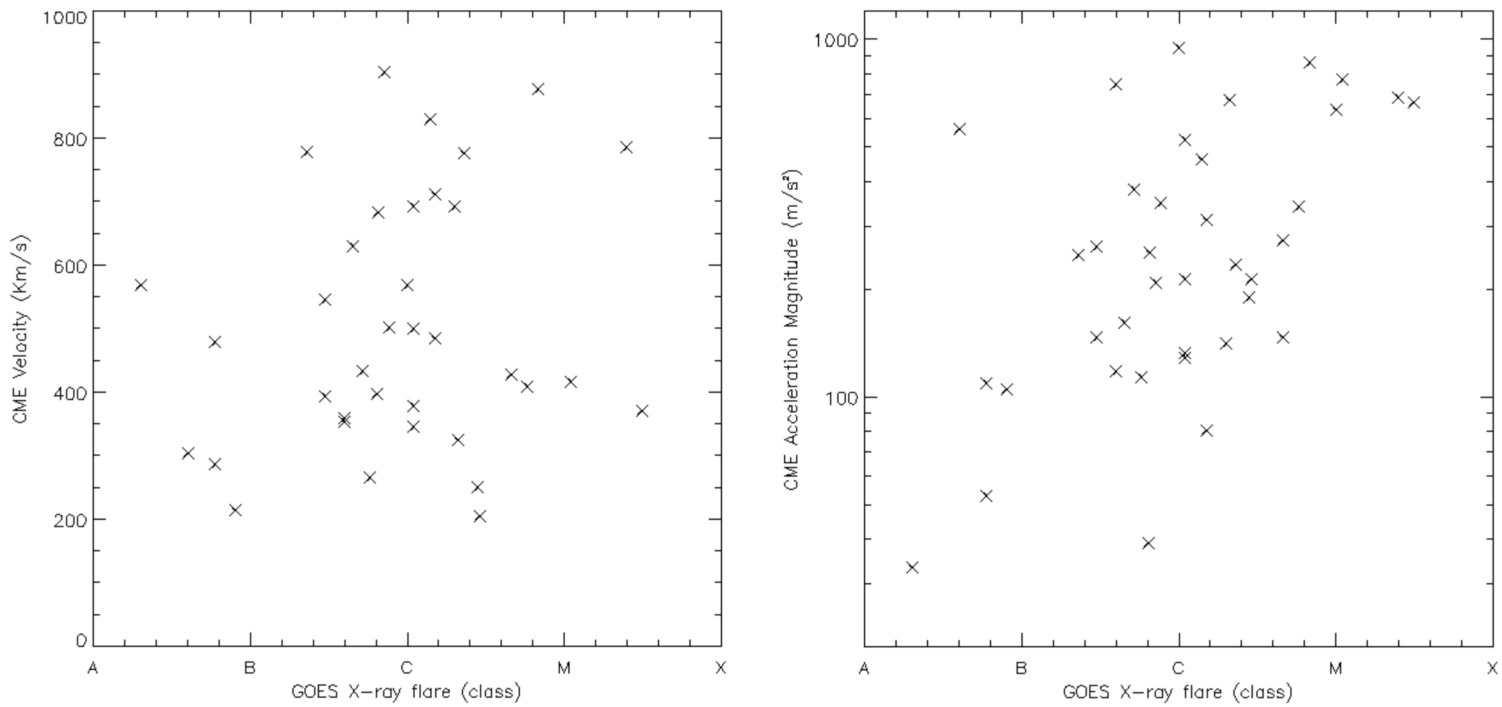
Where? (cont.)



- Super-expansion
- Self-similar expansion

CME and Fare : the Debate

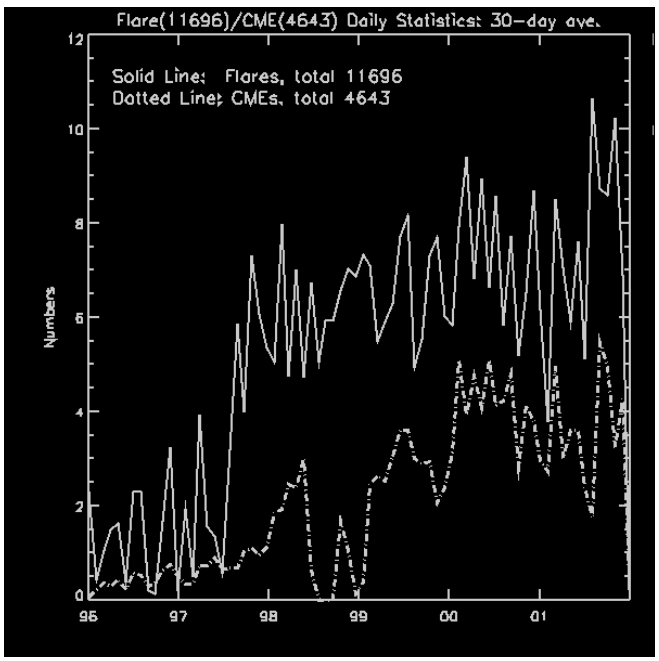
•The debate in 1990s
(e.g., Gosling 1993, Kahler 1992 versus
Svestaka 1995, Hudson et al. 1995, Dryer 1996)
•Temporal disparity? No, strong time coincidence instead
•Location/Size disparity? Probably no
•Energetic disparity? Probably yes



(also see Hundhausen 1997)

CME and Flare (Cont.): Frequency and Rate

- **Are they associated? Yes, of cause.**
  (e.g, Monro et al. 1979, Webb and Hundhausen 1987, St. Cyr and Webb 1991)
- **Are there CMEs not associated with flares? Yes (~10% to 30%)**
  (e.g., Srivastava et al. 1999, Zhang et al. 2004)
- **Are there flares not associated with CMEs?Yes (~80%, 4 out of 5)**
  (Harrison 1995, Andrews 2004)
- **But the trend is (e.g. Sheeley et al. 1975, 1983)**
  - **The stronger the flare, the higher the association rate**
  - **The longer the flare, the higher the association rate**



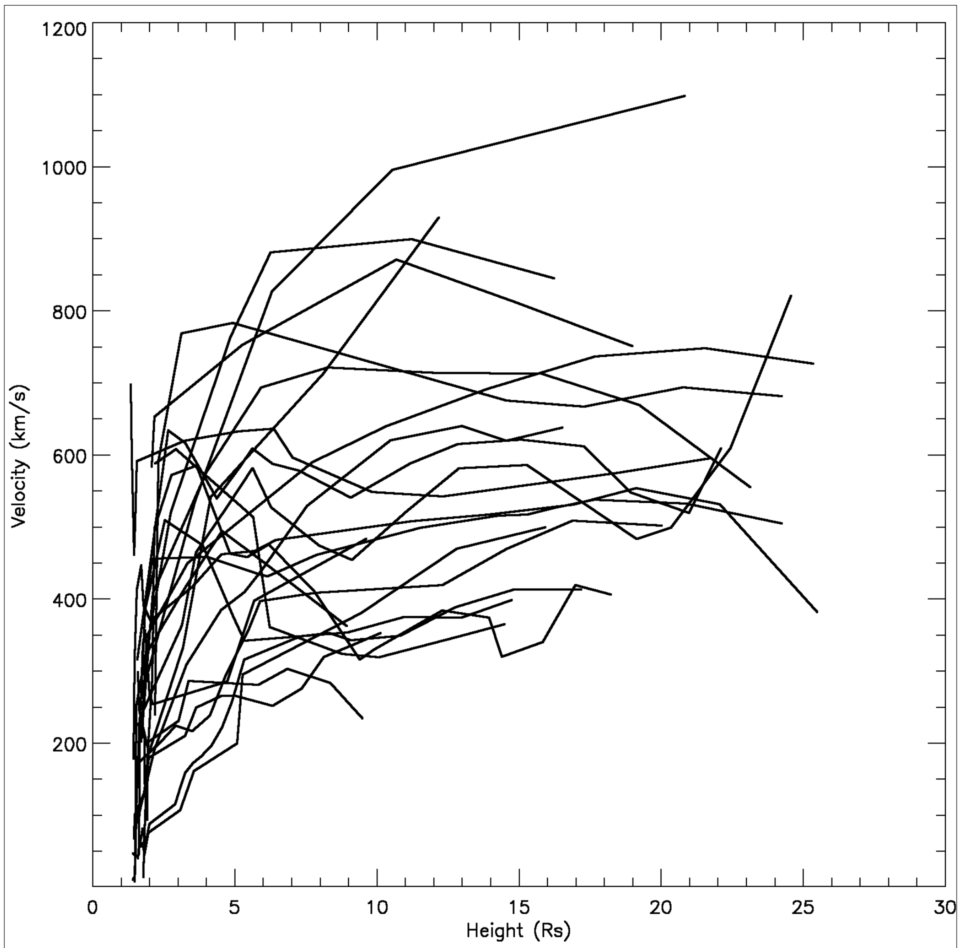
Year 1996 – 2002

Flare Number 11696
CME Number 4643

CME: Classes or diversity

- **Only two classes, impulsive and gradual?** **(e.g, MacQueen and Fisher 1994, Sheeley et al. 1999)**
- **Probably not. A possible continuous distribution in velocity and acceleration (magnitude, duration and distance)**

Velocity (km/s)



Height (Rs)

24 events

"Intermediate" CMEs:

Plunkett et al. 2000
Yurchyshyn 2002
Zhang et al. 2004

Some Final Points

1. CME, flare, (and filament), each can occur independently

2. When they occur associated (they often do), their evolution seems to show time coincidence.

3. But the energy partition is far from equal.

4. Since fast CME acceleration phase always coincides with the main flare energy release phase, (assuming due to magnetic reconnection), the reconnection may help strengthen the acceleration. It is also possible that the reconnection and the acceleration be mutually feeding each other.

Questions to modelers?

1. Can the model reproduce all kinds of CMEs with different kinematic properties, e.g., gradual CMEs, “intermediate” CMEs, and impulsive CMEs?

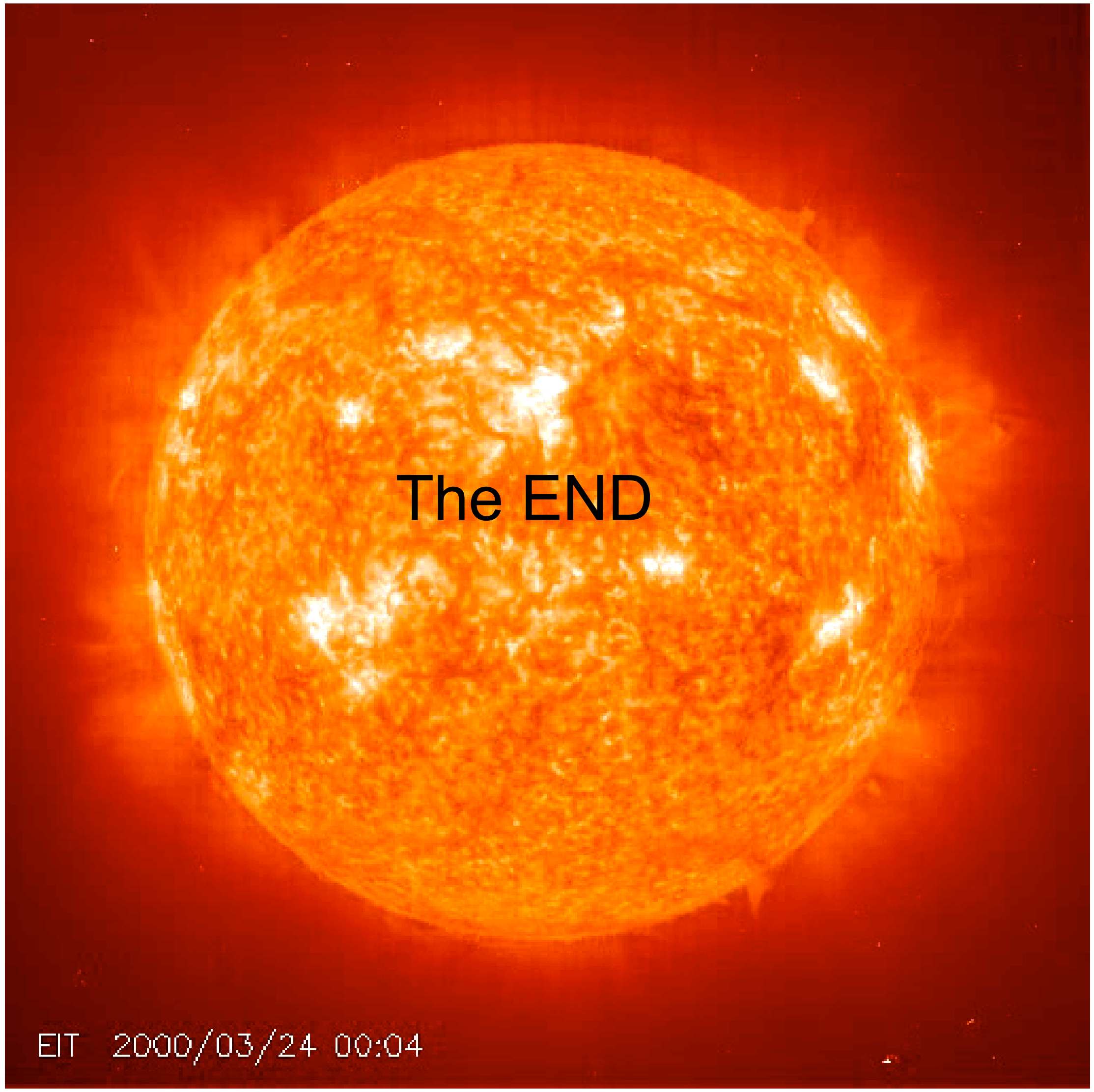
2. For gradual CMEs, flux rope shall be well formed before eruption, since there is no much reconnection (or no heating signature) to transform connected arcade to disconnected helical flux? But it may be different for impulsive CMEs?

3. Can we introduce the “flux-rope-maturity” parameter to quantify the pre-eruption magnetic configuration in the model?
   - break-out model: 0%?
   - flux cancellation model: partially 0% -- 100%?
   - flux injection model: 100%?

4. Can the model explain the time coincidence between CME and flare?

5. But in the same time, can the model explain the energy partition disparity between (CME) kinetic energy and (flare) thermal/particle energy?

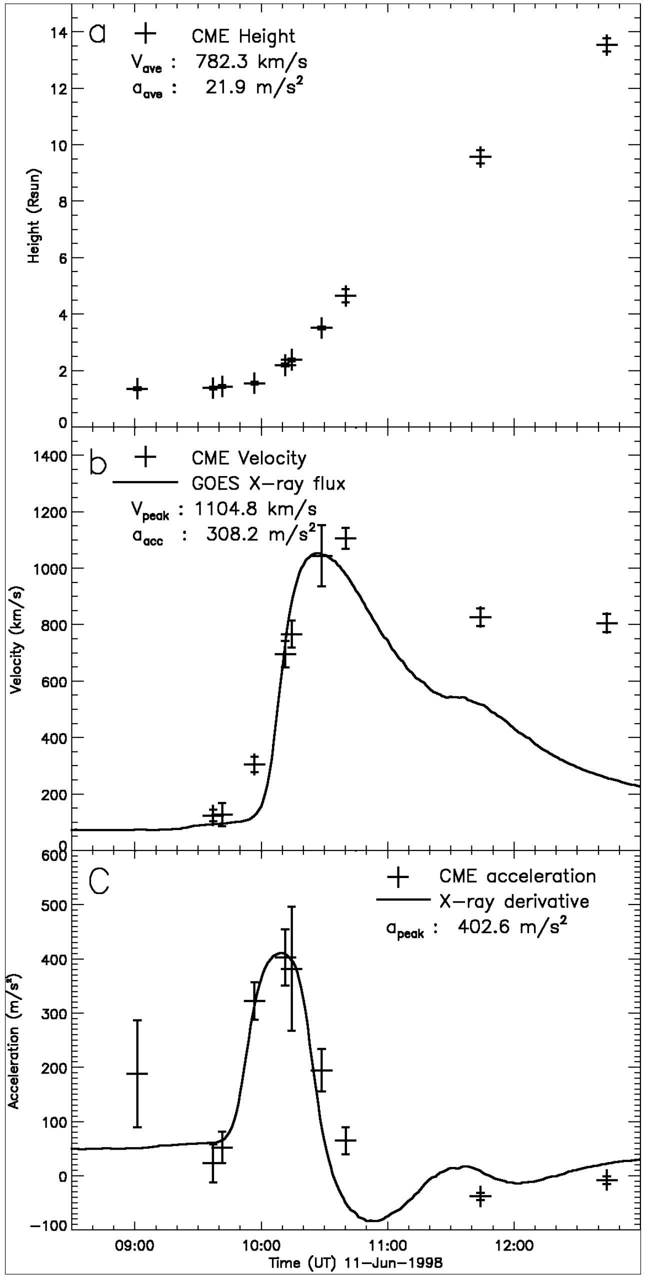
Why/how the acceleration??



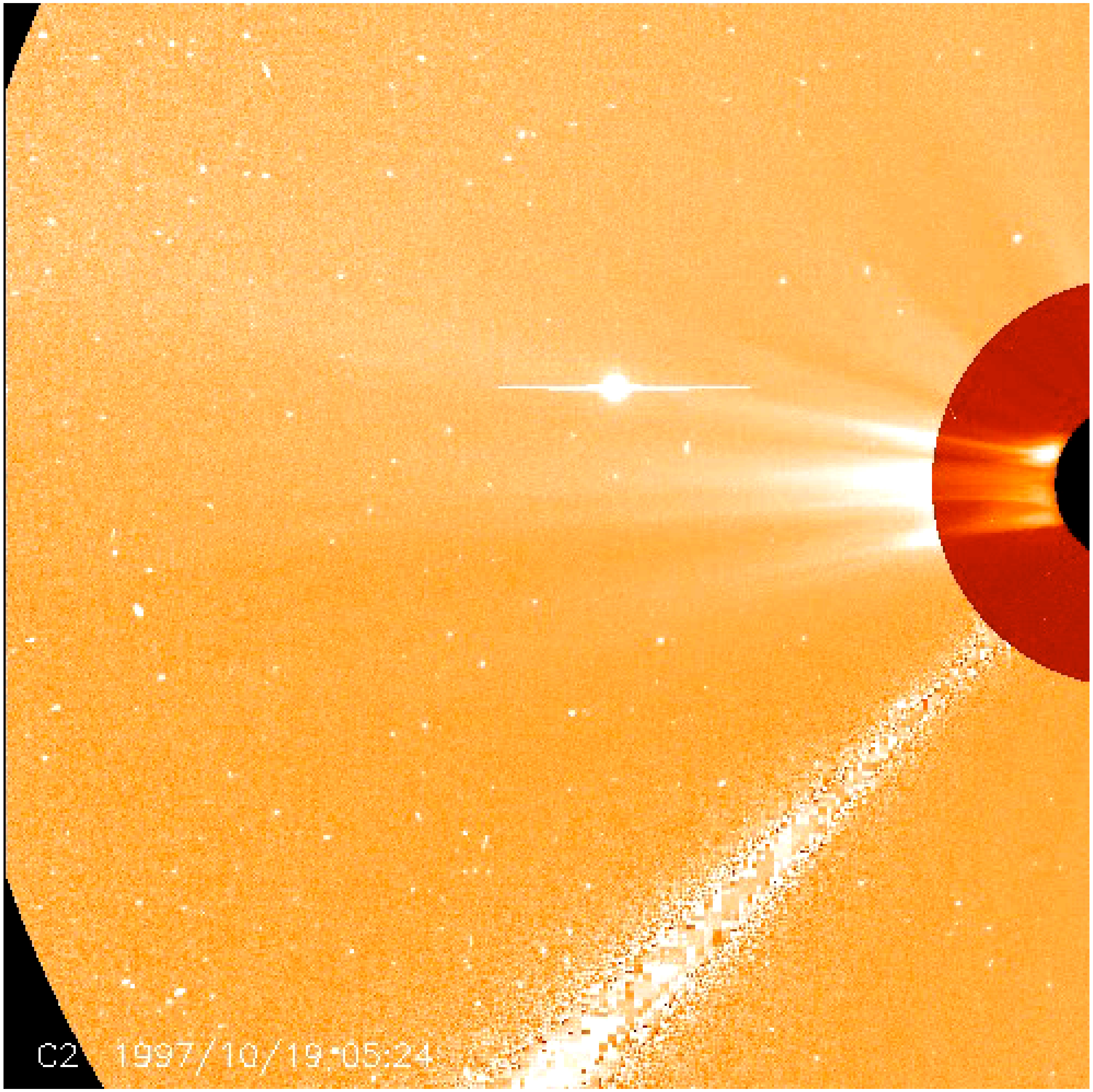
Thank you, SHINE !

Parameters for the Three CMEs (Zhang et al 2004)

Event	1998/06/11	2000/10/25	1997/10/19
Characteristics	Impulsive	Intermediary	Gradual
Average Velocity (km/s)	782	636	147
Average Acceleration (m/s^2)	21	26	4.3
Acceleration Duration (min)	30	160	1440
Acceleration Distance (Rs)	3.3	4.3	19
Acceleration in Acc. Phase (m/s^2)	308	131	4.0
Peak Velocity (km/s)	1104	954	347
Peak Acceleration (m/s^2)	402	192	12
Height at Peak Velocity (Rs)	4.6	7.0	19
Height at Peak Acceleration (Rs)	2.2	5.5	5.6
Mass (gram)	5.0e15	1.7e16	2.0e15
Net Mechanic Force (dyn)	1.5e20	2.2e20	8.0e17
Kinetic Energy (erg)	3.0e31	7.7e31	1.2e30



(Zhang et al. 2004)


C2 1997/10/19 05:24