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Modeling Energy Release in Solar Flares

CfA

New Mexico Tech

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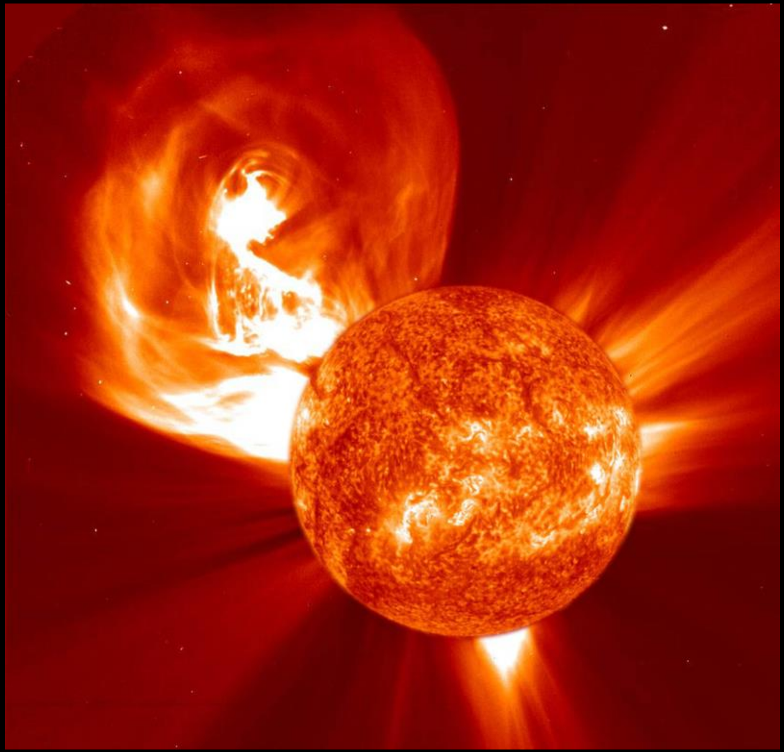
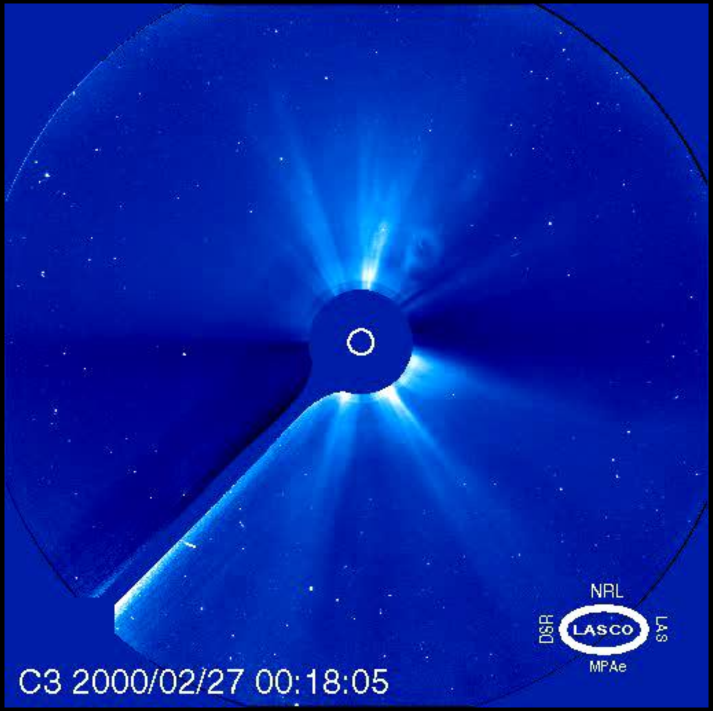


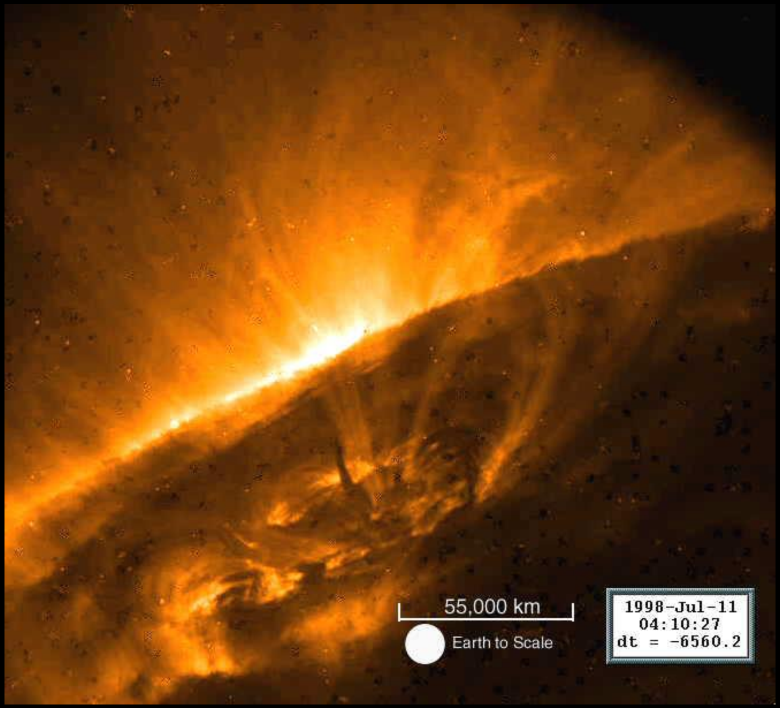
Coronal Mass Ejection. Taken from the SOHO Spacecraft January 4, 2002. Composite image of EIT (UV light) and LASCO C2 Coronograph observations. TRACE is a mission of the Stanford-Lockheed Institute for Space Research.

Coronal Mass Ejections (CMEs)

"The entire process that leads to the ejection of mass and magnetic flux into interplanetary space" (Forbes, *Journal of Geophysical Research*, 2000).



CME event of Feb 27, 2000
Courtesy of SOHO

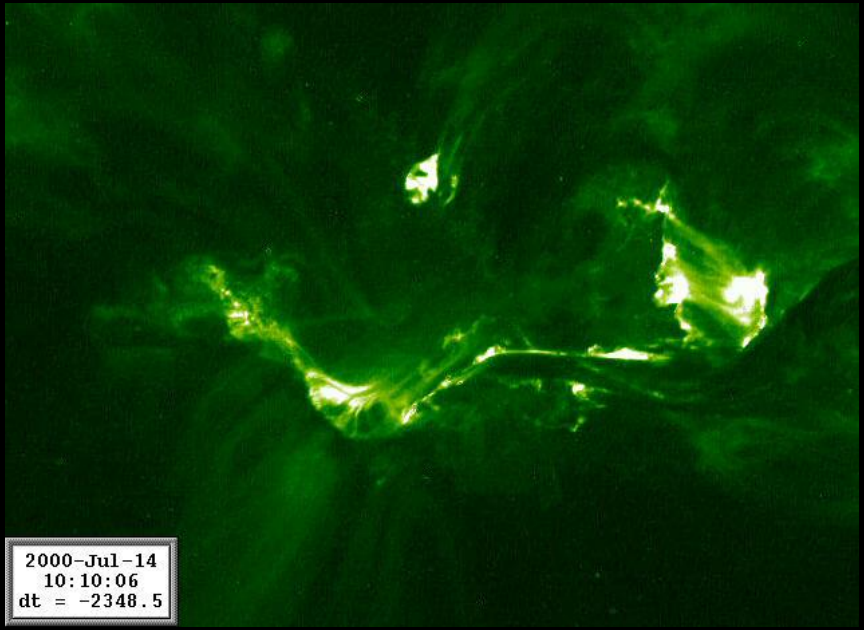


Filament eruption of July 11, 1998
Courtesy of TRACE

Flares

"The rapid onset of X-ray and UV emissions in the corona" (Forbes, *Journal of Geophysical Research*, 2000)

Flares are often seen after the take-off of a CME (Maricic, Solar Phys, 2007)



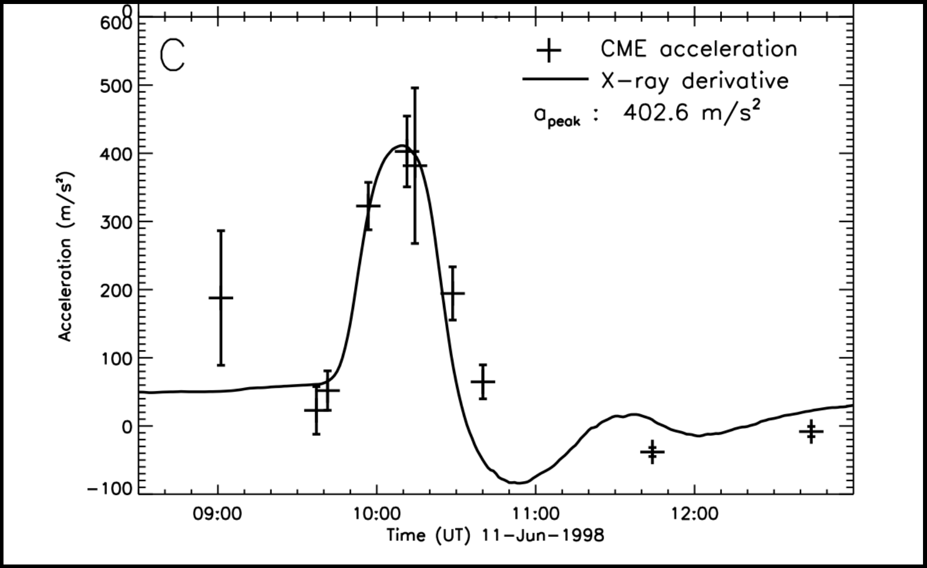
Bastille Flare, face-on, from the TRACE Spacecraft
Occurred July 14, 2000

Flare on limb of sun. Taken from the TRACE Spacecraft.
Occurred April 21, 2002

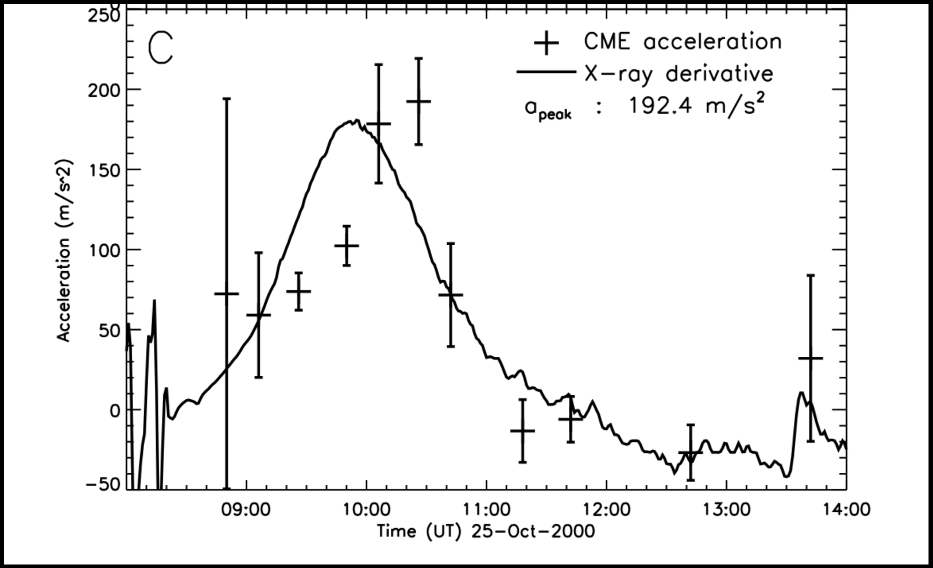
Observations

Concentrate On:
Acceleration of CME
Flux from flare

Zhang et al, *The Astrophysical Journal*, 2004



Correlated



Uncorrelated

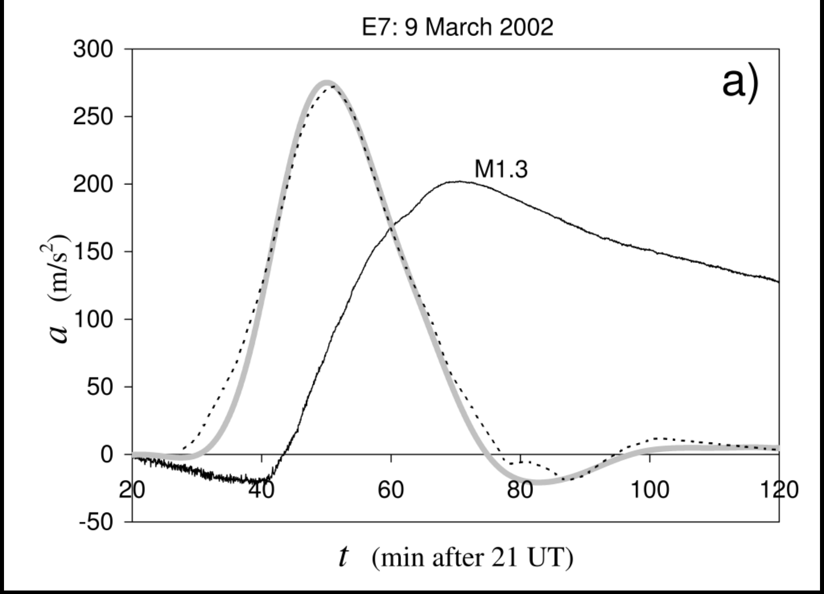
Observations Continued

Concentrate On:

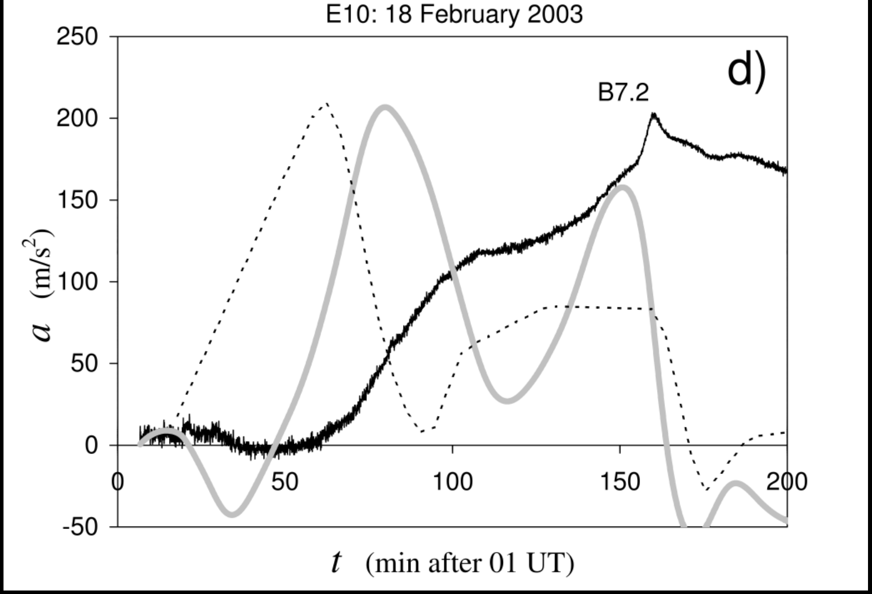
Acceleration of CME

Flux from flare

Maricic et al, *Solar Phys*, 2007

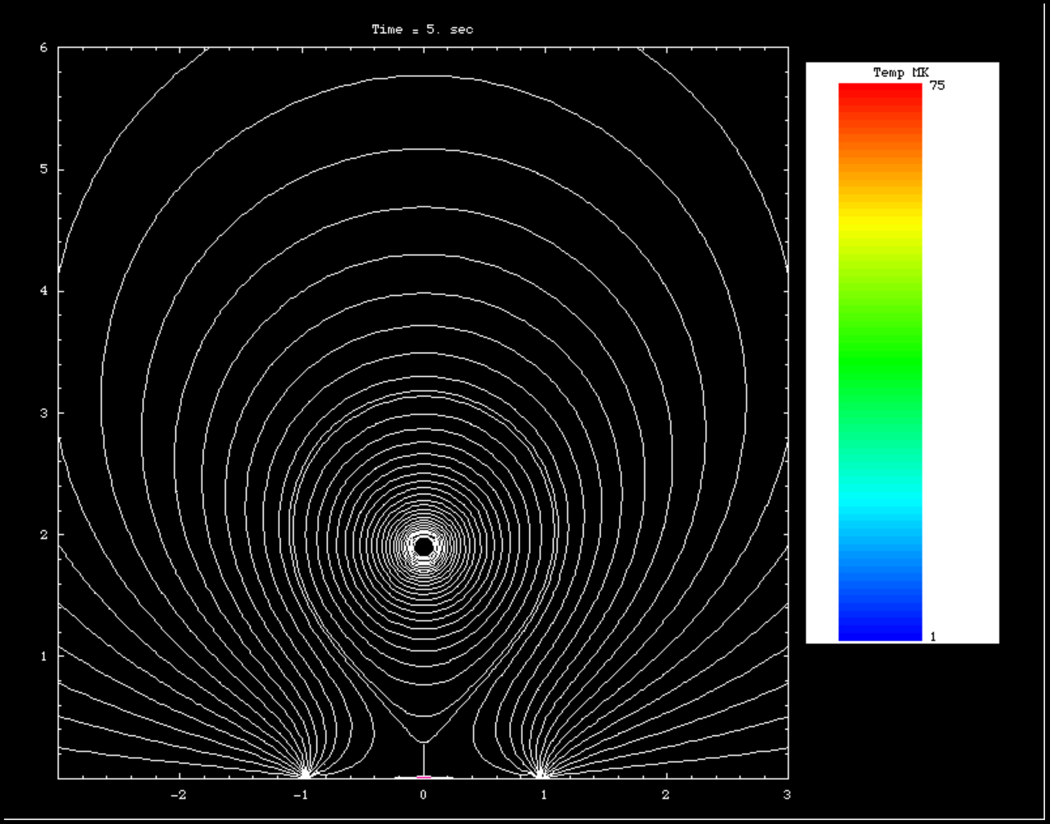


Correlated



Uncorrelated

Physical Picture

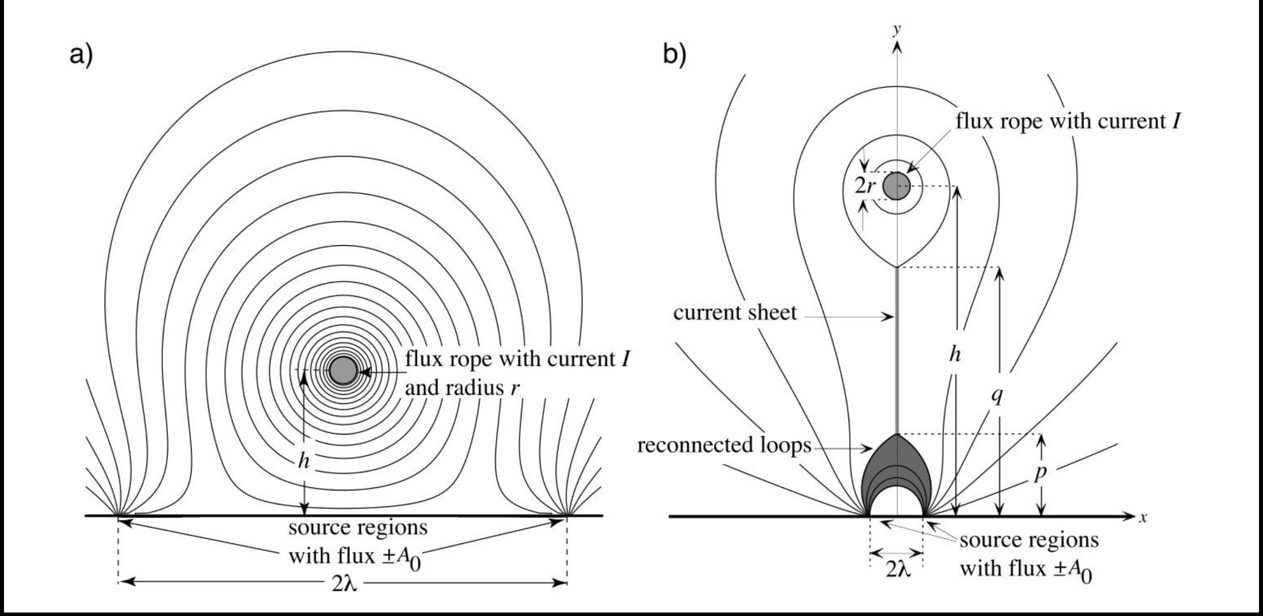


Shamelessly stolen from Reeves, K.

Model: The Magnetic Field

- Describes initiation of CME
- 2-D Model
- Mach number assumed constant, taken from the center of the current sheet
- All Poynting flux into the current sheet goes into thermal heating
- Non-thermal particles not considered in this model
- Varied 2 parameters:
  - Magnetic Field
  - Mach Number

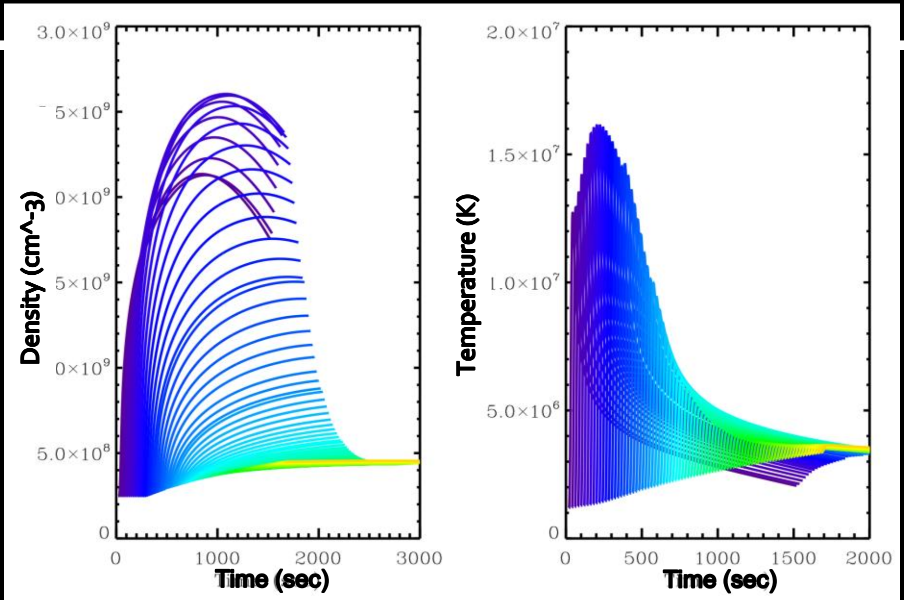
In Equilibrium | Loss of Equilibrium



Reeves, *The Astrophysical Journal*, 2006

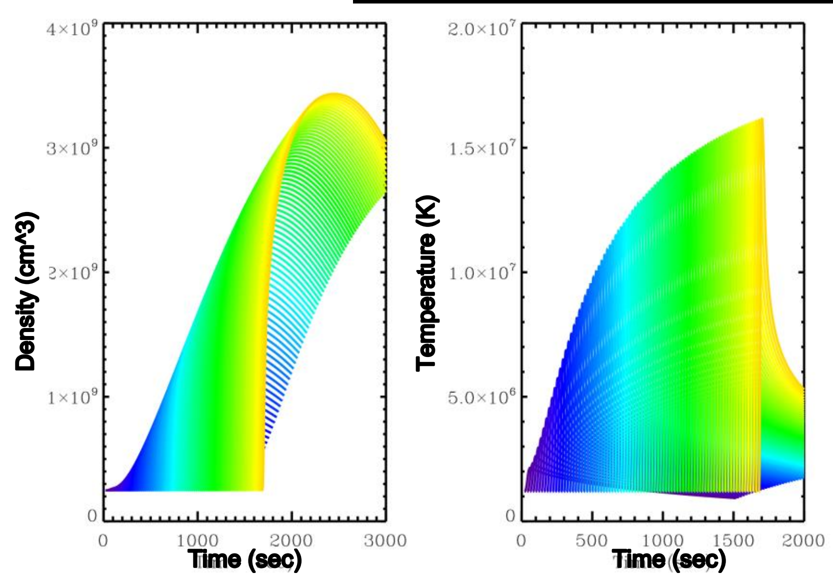
Model: EBTEL

- Energy input from Magnetic field model
- Arcade of Many Loops
- 0-D Model, Analytic Solution
- Coronal Loop Symmetry
- Gravity Negligible
- See Klimchuk and Patsourakos, *The Astrophysical Journal*, 2008



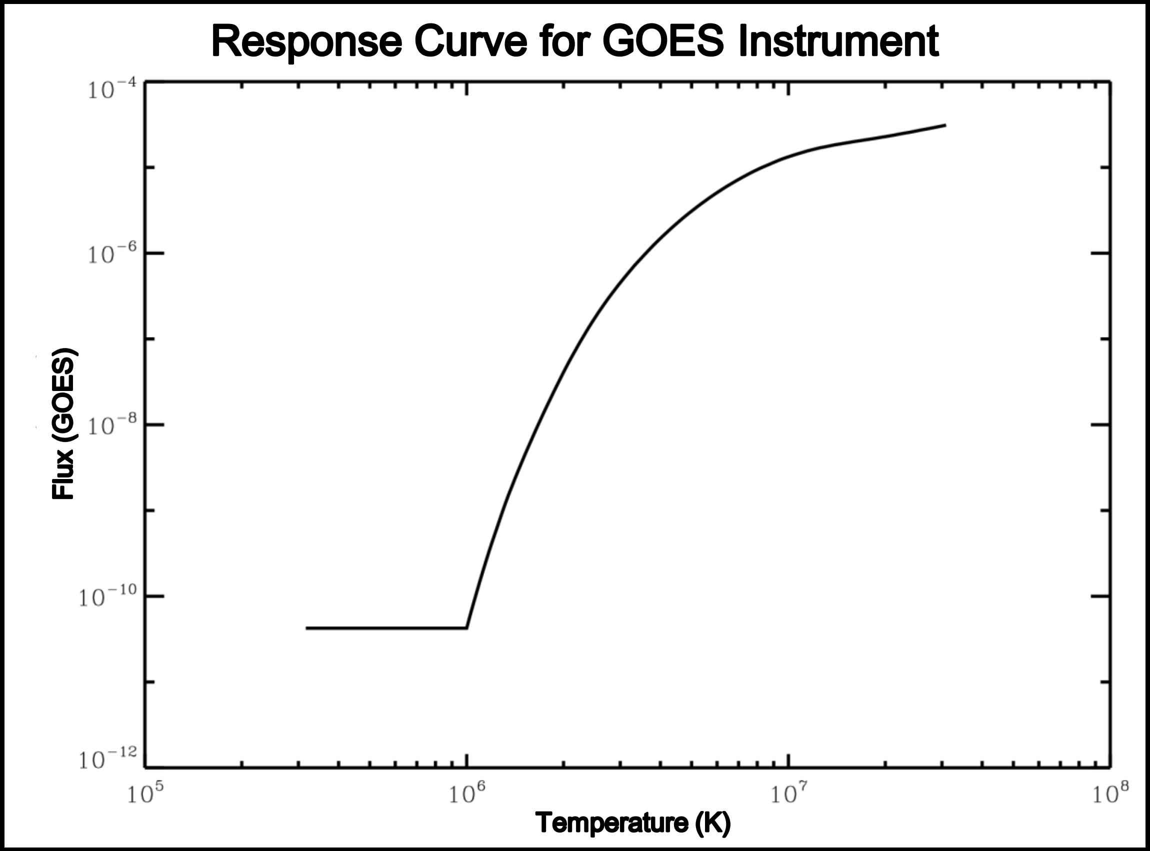
MA = 1
Mag. Field = 50 Gauss

MA = 0.001
Mag. Field = 10 Gauss



Model: GOES_FLUXES

- Instrument Response Function
- Produces Flux Curves

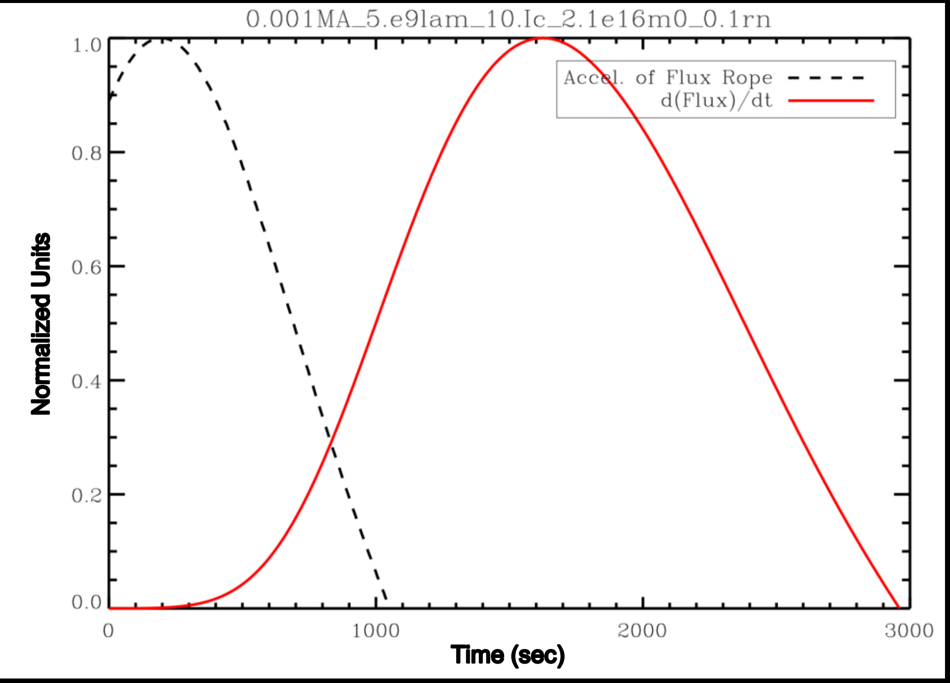


Response curve for GOES instrument, 1-8 Angstroms

Individual Cases

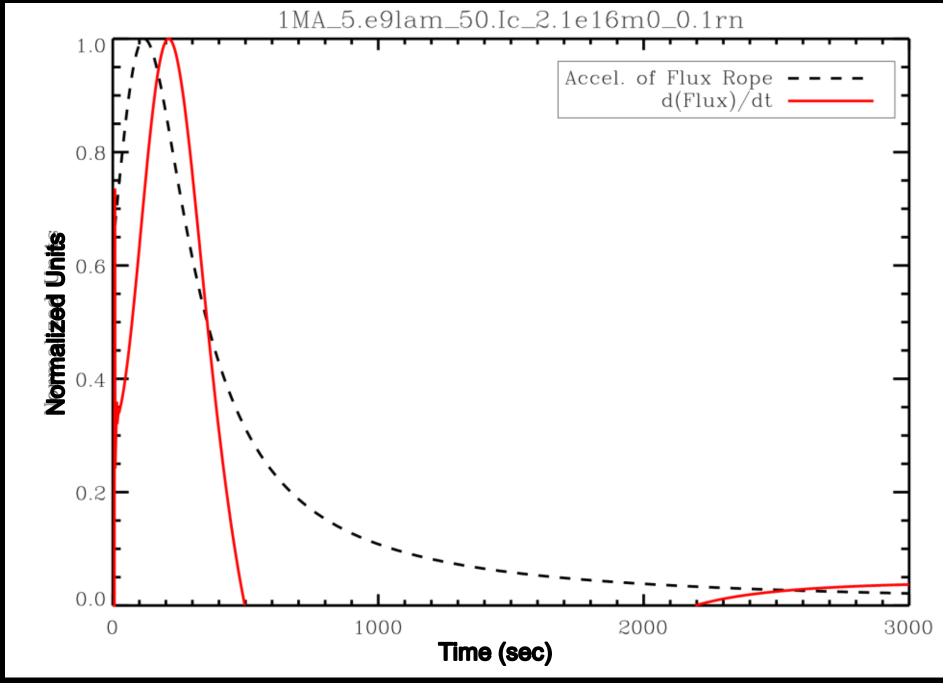
- MA = 0.001, 0.01, 0.1, 1
- Magnetic Field = 10, 12, 15, 17, 20, 25, 30, 35, 40, 45, 50 Gauss

Uncorrelated



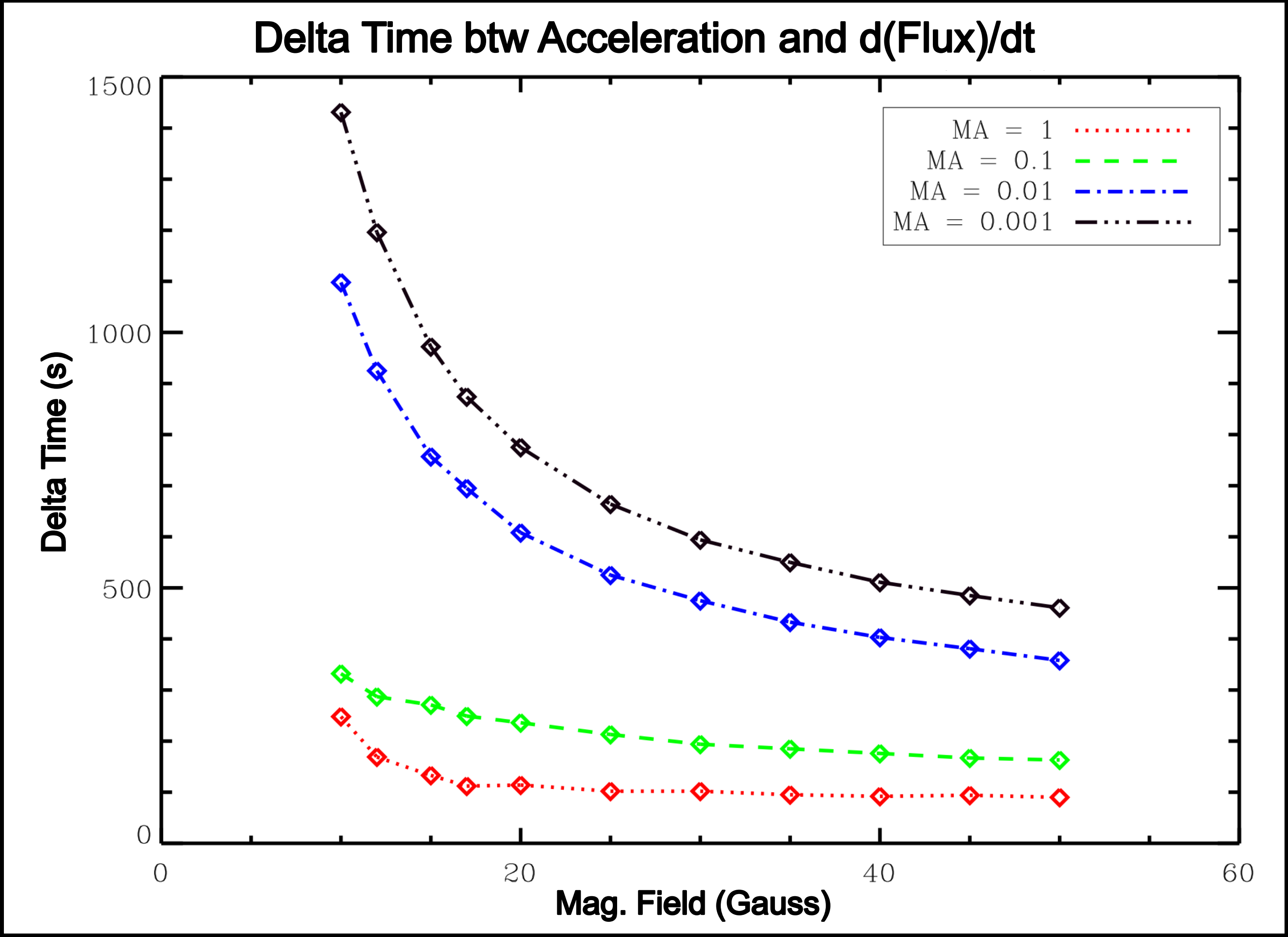
0.001MA, 10 Gauss

Correlated



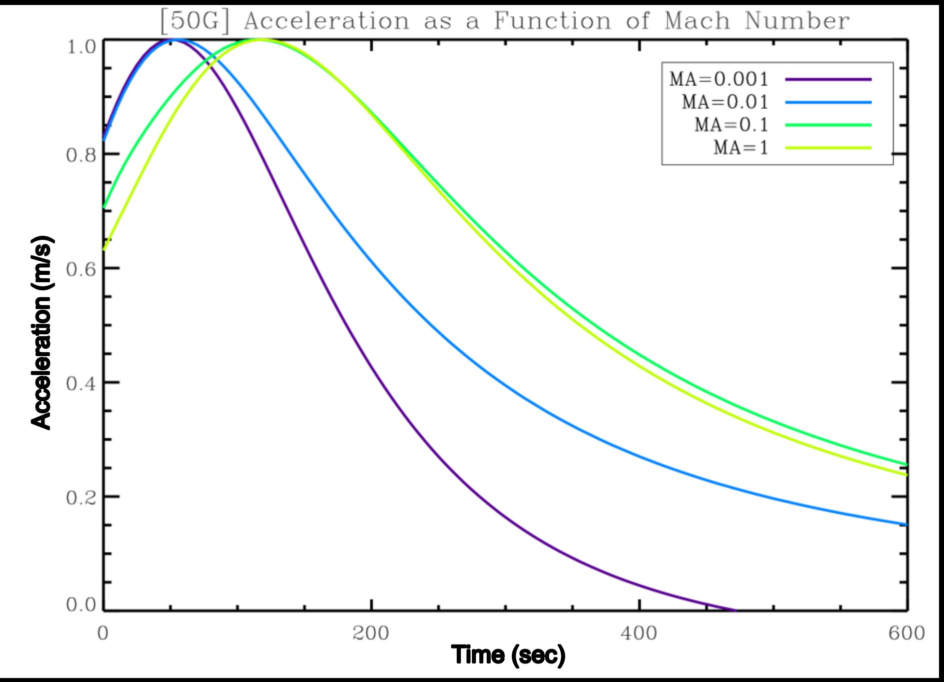
1 MA, 50 Gauss

Correlation Trends Between Acceleration and d(Flux)/dt



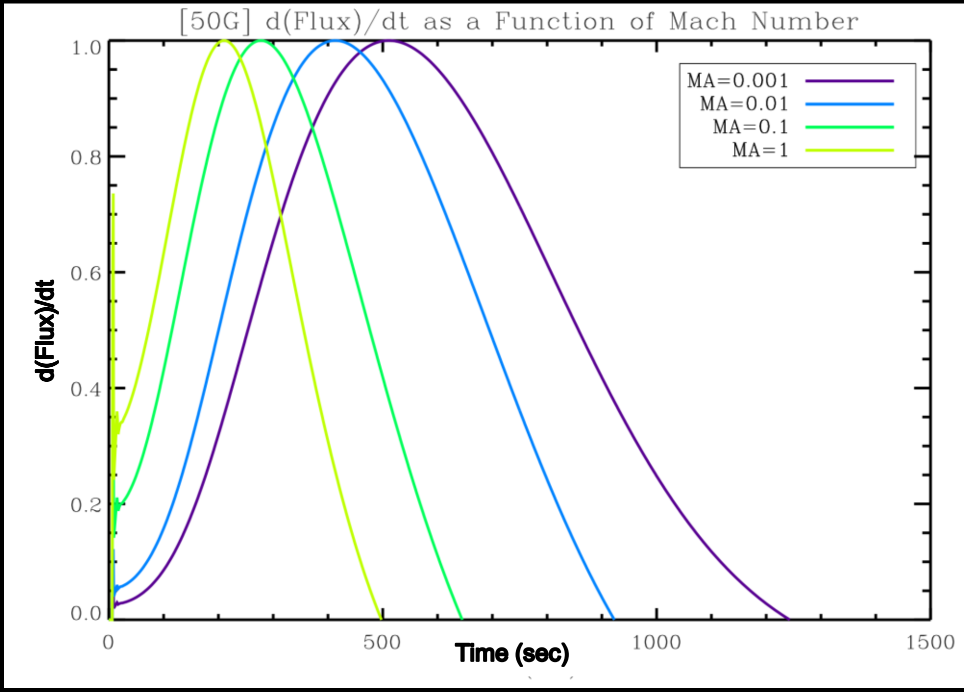
Acceleration and d(Flux)/dt vs Mach Number

- Acceleration: behavior explained by effect of current sheet (Reeves, *The Astrophysical Journal*, 2006)
- d(Flux)/dt: behavior explained by volume changes (more to come…)



Higher MA, peaks later

Higher MA, peaks earlier



The Importance of Changing Volume

- Flux relations adapted from Warren and Antiochos, *The Astrophysical Journal*, 2004, who proved that the flux derivative is NOT solely due to changes in energy.

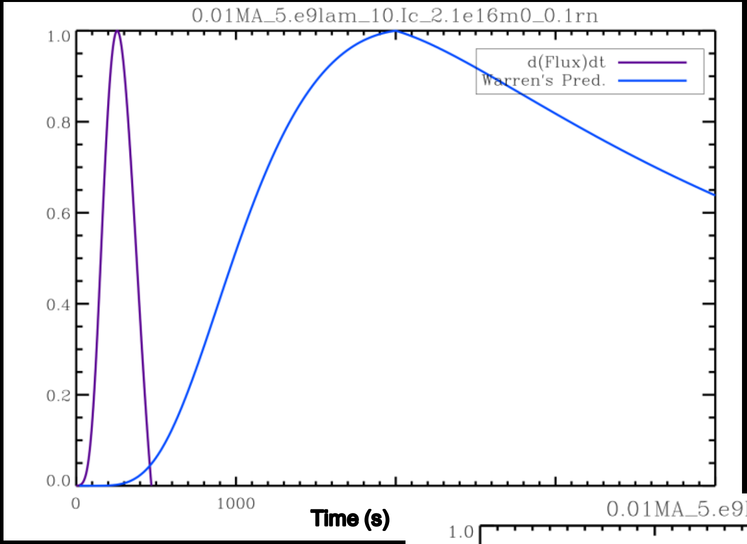
$$Flux_{1-8\mathring{A}} \cong \frac{E^{1.75}}{V^{0.75}} L^{0.25}$$

- Without Changing Volume:

$$\frac{d}{dt}\left(Flux_{1-8\mathring{A}}\right) = \frac{d}{dt}\left(E^{1.75}\right)$$

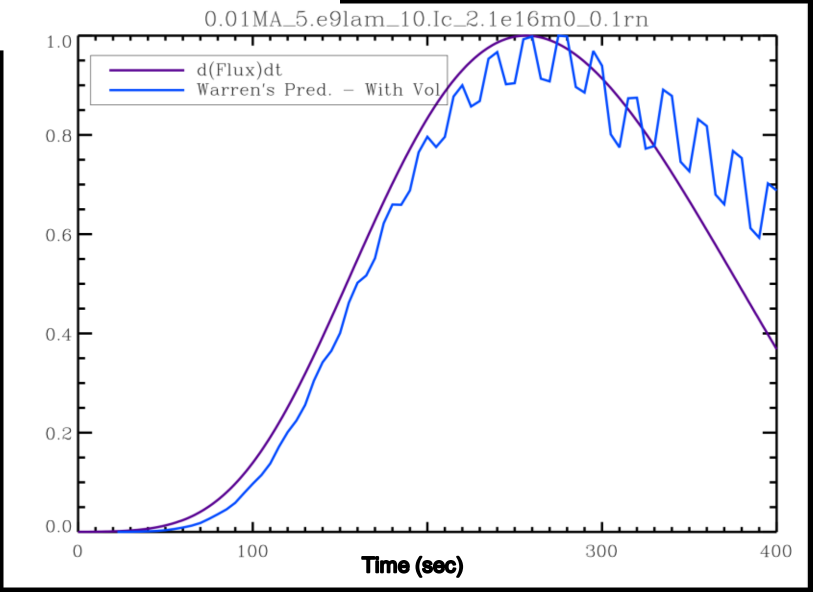
- With Changing Volume:

$$\frac{d}{dt}\left(Flux_{1-8\mathring{A}}\right) = \frac{d}{dt}\left(\frac{E^{1.75}}{V^{0.75}}\right)$$



<- No Volume Effects Included

Bad Correlation

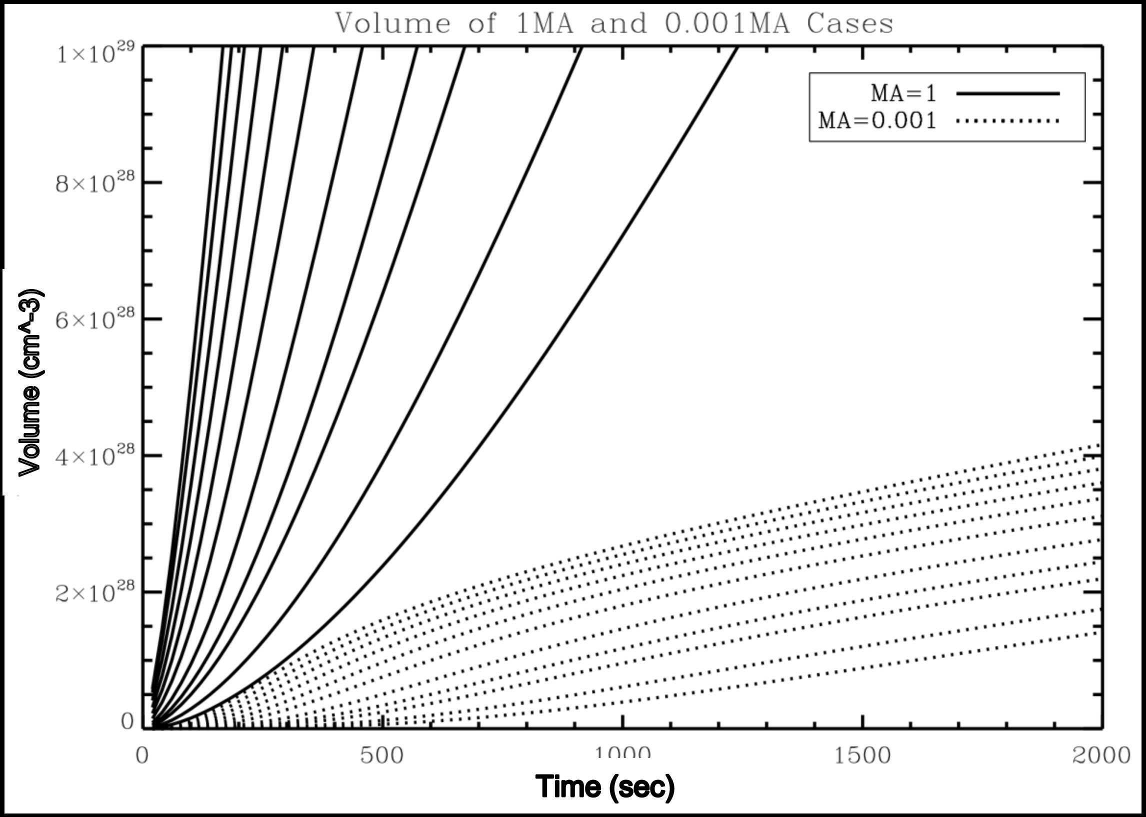


Reasonable Correlation

Volume Effects Included ->

Comparing Volume Changes

The volume increases at a much quicker rate for higher Mach numbers than lower Mach numbers. Therefore, the flux derivative peaks earlier for higher mach numbers.



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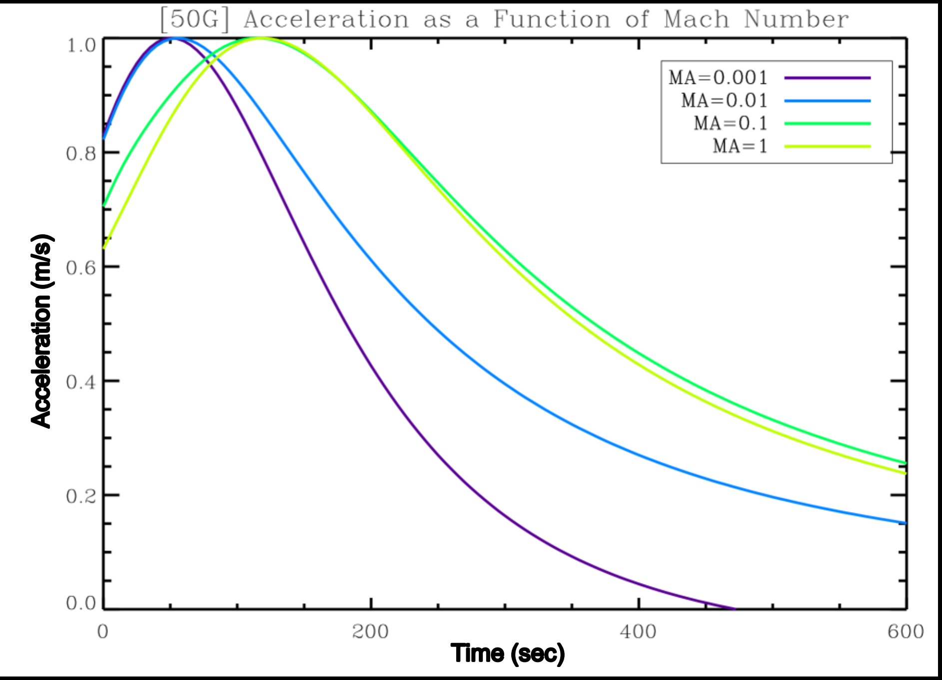

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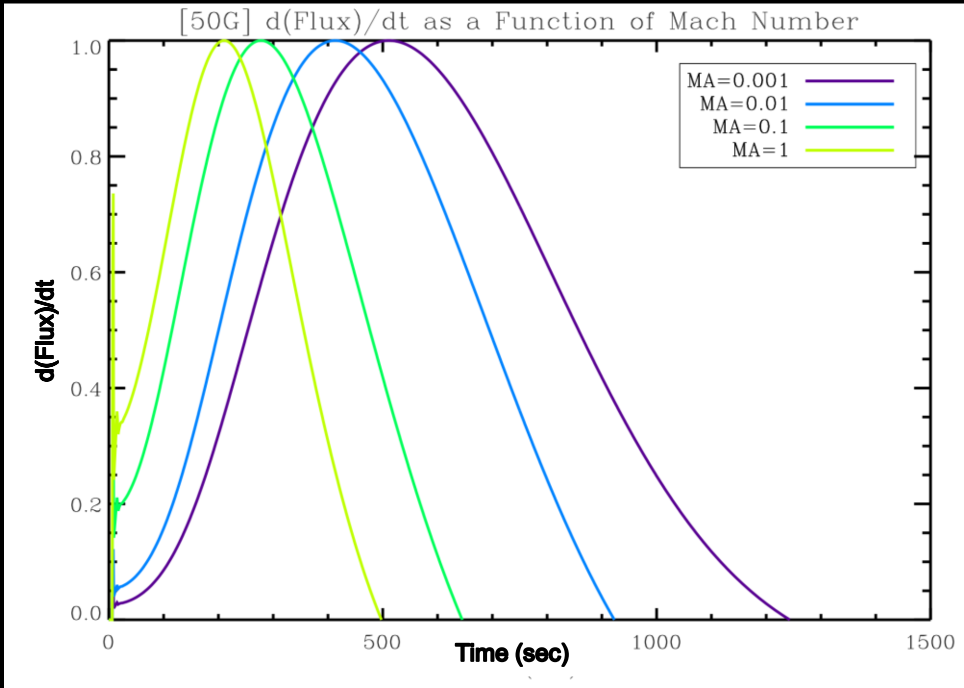

Summary of Results

- High Mach numbers and big magnetic fields lead to better correlation in the acceleration and time derivative of the flux than low Mach numbers and small magnetic fields.

- The volume and energy of a CME event determines the correlation (or lack thereof) between the energy release rate and the flux derivative.

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SOHO