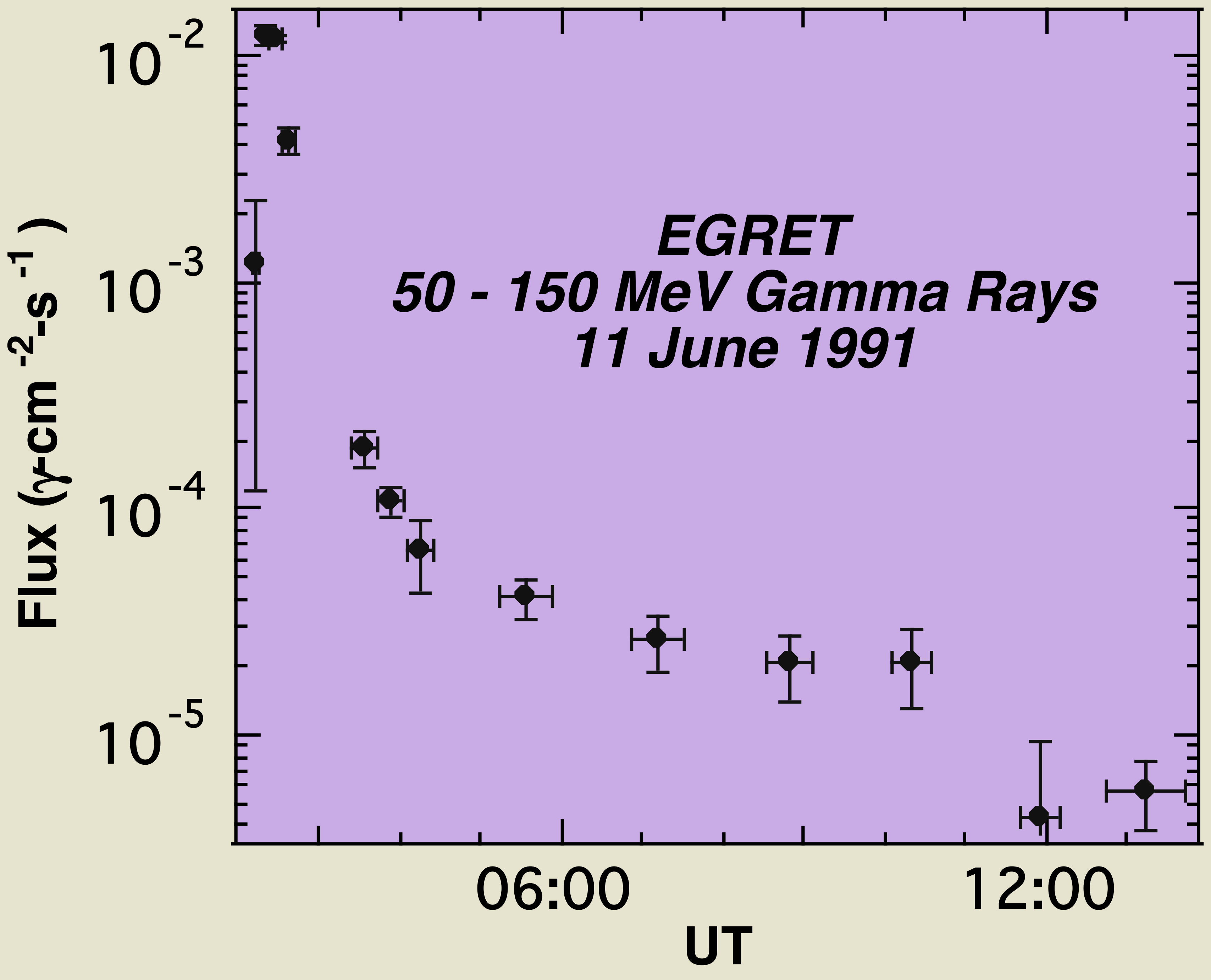
What Do the SEP events and the Associated High- Energy Flares of 2012 March 7 Tell Us About Long Duration Gamma-Ray Flares?

James M. Ryan (UNH), Georgia de Nolfo (GSFC)

Long Duration Gamma-Ray Flares (LDGRF)

- *Extremely* long duration (hours), smooth exponential decay, often with minute(s) delay after impulsive phase.
- *High* energy π-decay produced (>1 GeV) photons.
- No primary electron component detected.



1991 June 11 LDGRF as measured with EGRET. Others detected before *Fermi* (Chupp and Ryan 2009)

Where do they originate and how?

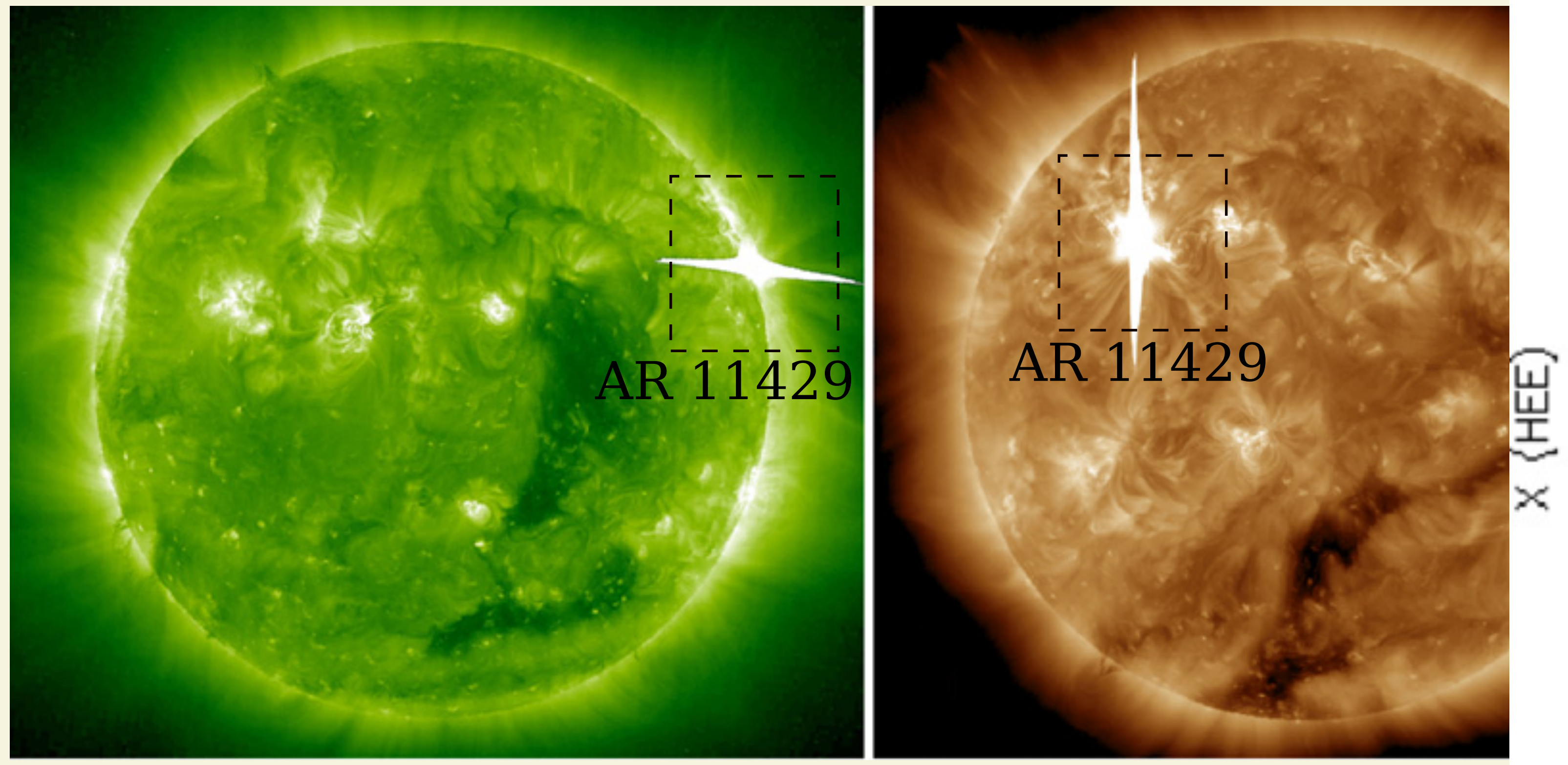
- Delayed onset, relativistic ion energies, long duration—similar to GLEs. Maybe the coronal shock that produces a GLE can feed particles back to the Sun to radiate. If not shocks, then where?
- Let’s examine this? Are there counterexamples?

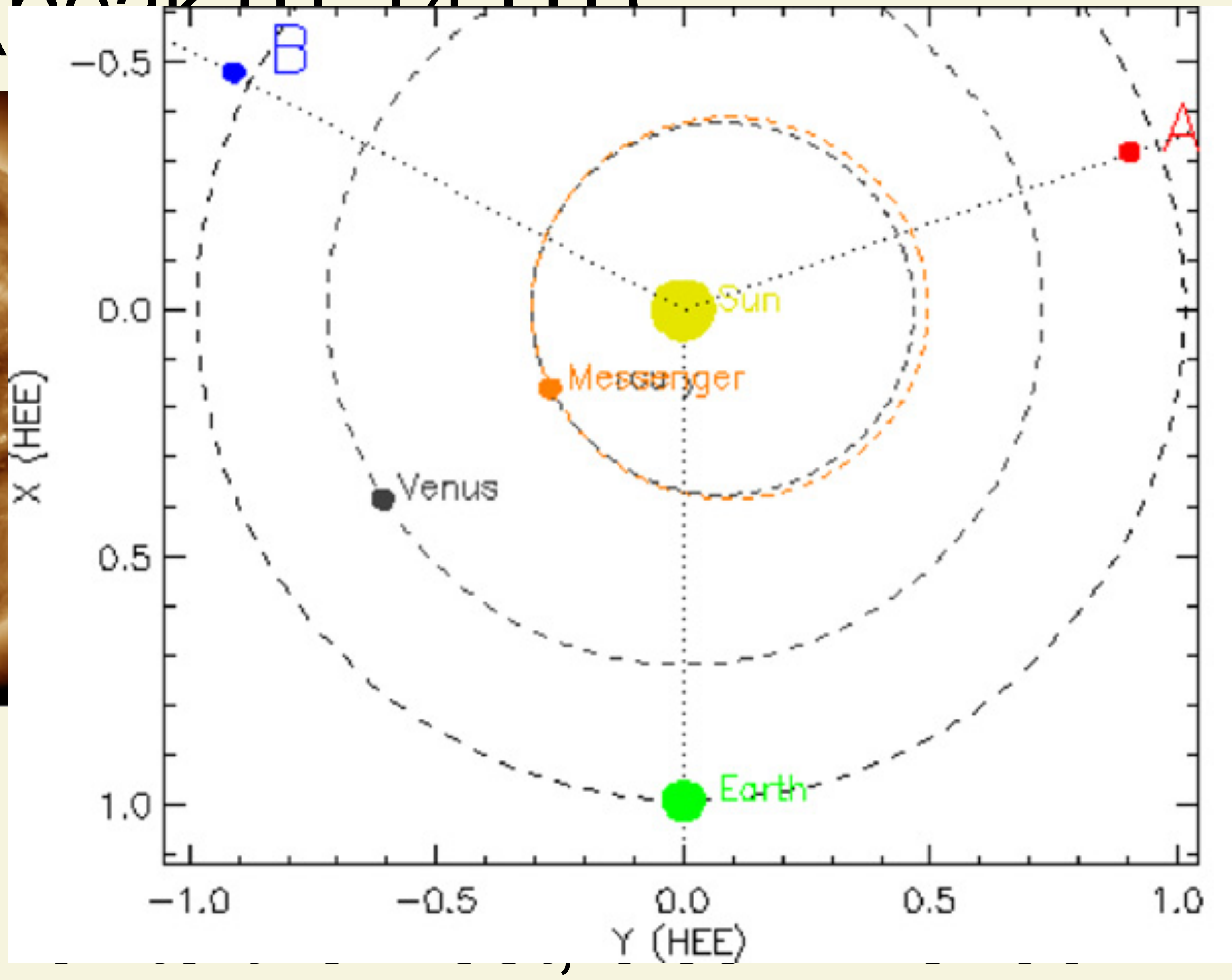
1. Find a shock/SEP event with no LDGRF—but maybe poor connection back to Sun, or
2. find a LDGRF with no corresponding shock/SEP event to provide particles.

2012 March 7 may be such an event

- Two X-class flares one hour apart from AR 11429 N16°E29°, X 5.4, 00:02 UT (peak 00:24 UT) and X1.4, 01:05 UT (peak 01:14 UT).

STEREO B

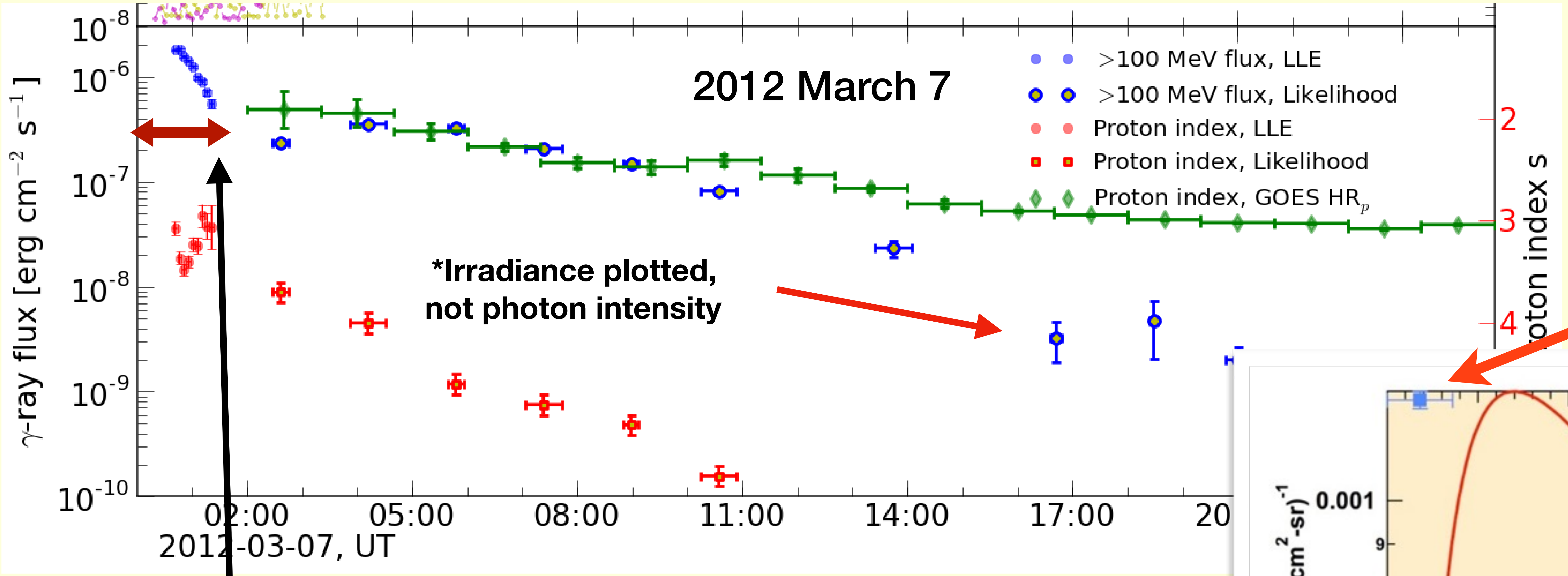


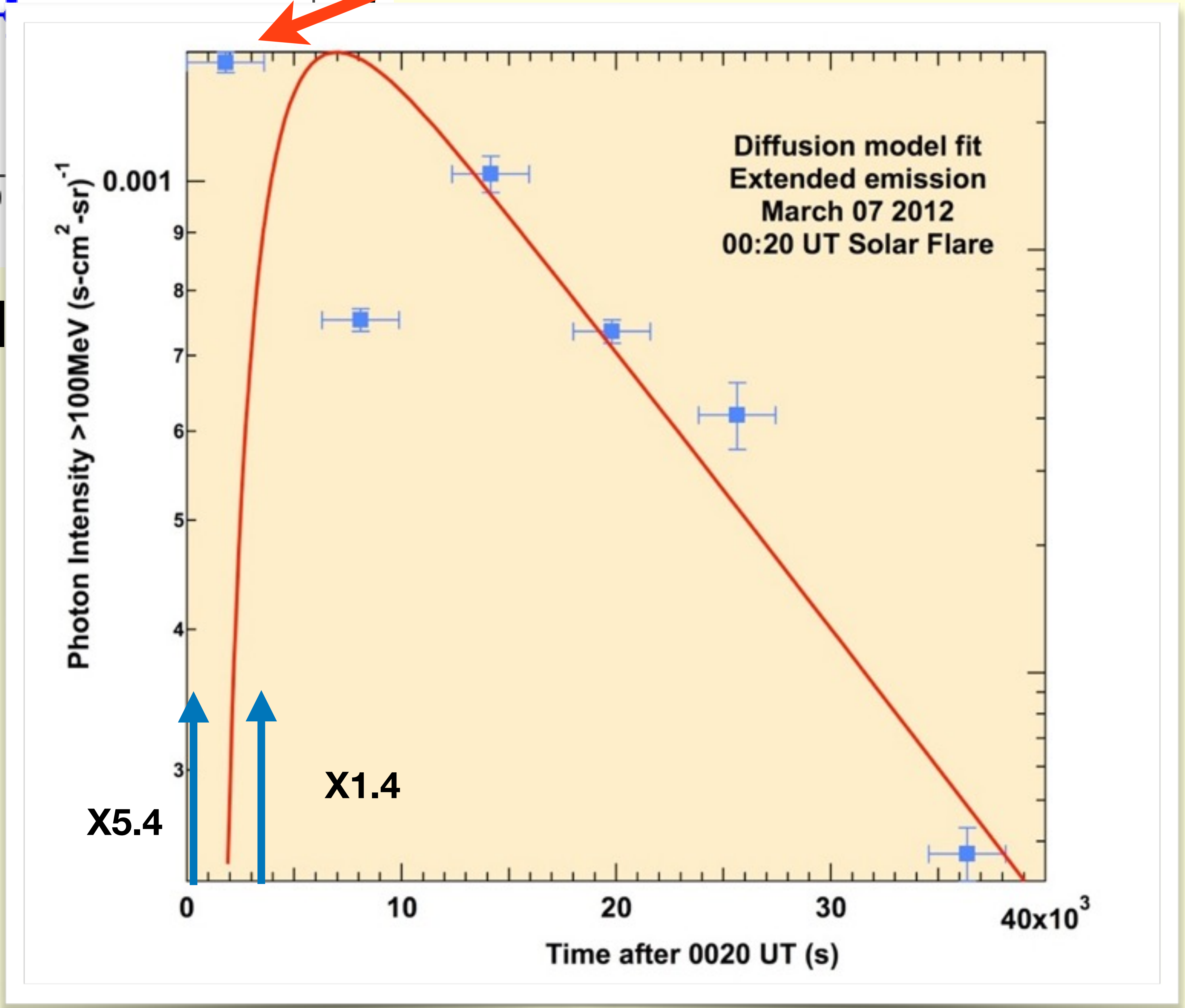


Summarizing results of Kouloumvakos et al. (2016)

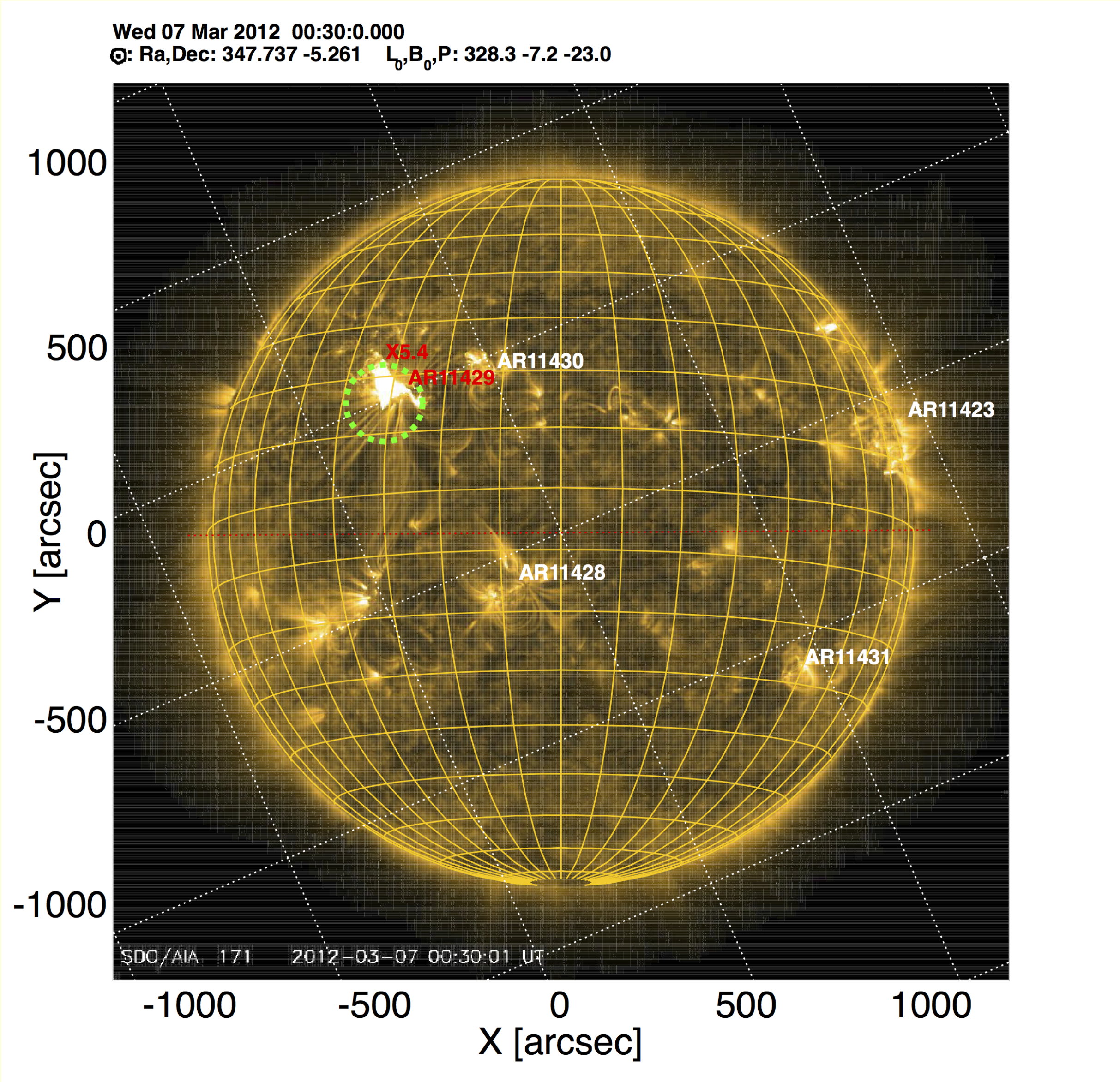
- First X5 flare/CME responsible for SEP event at Earth and STA 2800 km-s^{-1}. Supported by Ding et al. (2016) and Richardson et al. (2014).
- Inferred shock (slower) from second X1 flare, just low corona phenomenon, but **no IP particle production**. Supported by above researchers.
- X5 active region had oor connection to Earth, producing diffusive-like SEP event. Only STB has good connection to WL or EUV signatures.
- Clear low-corona particle activity from both events (X/γ and μ waves)

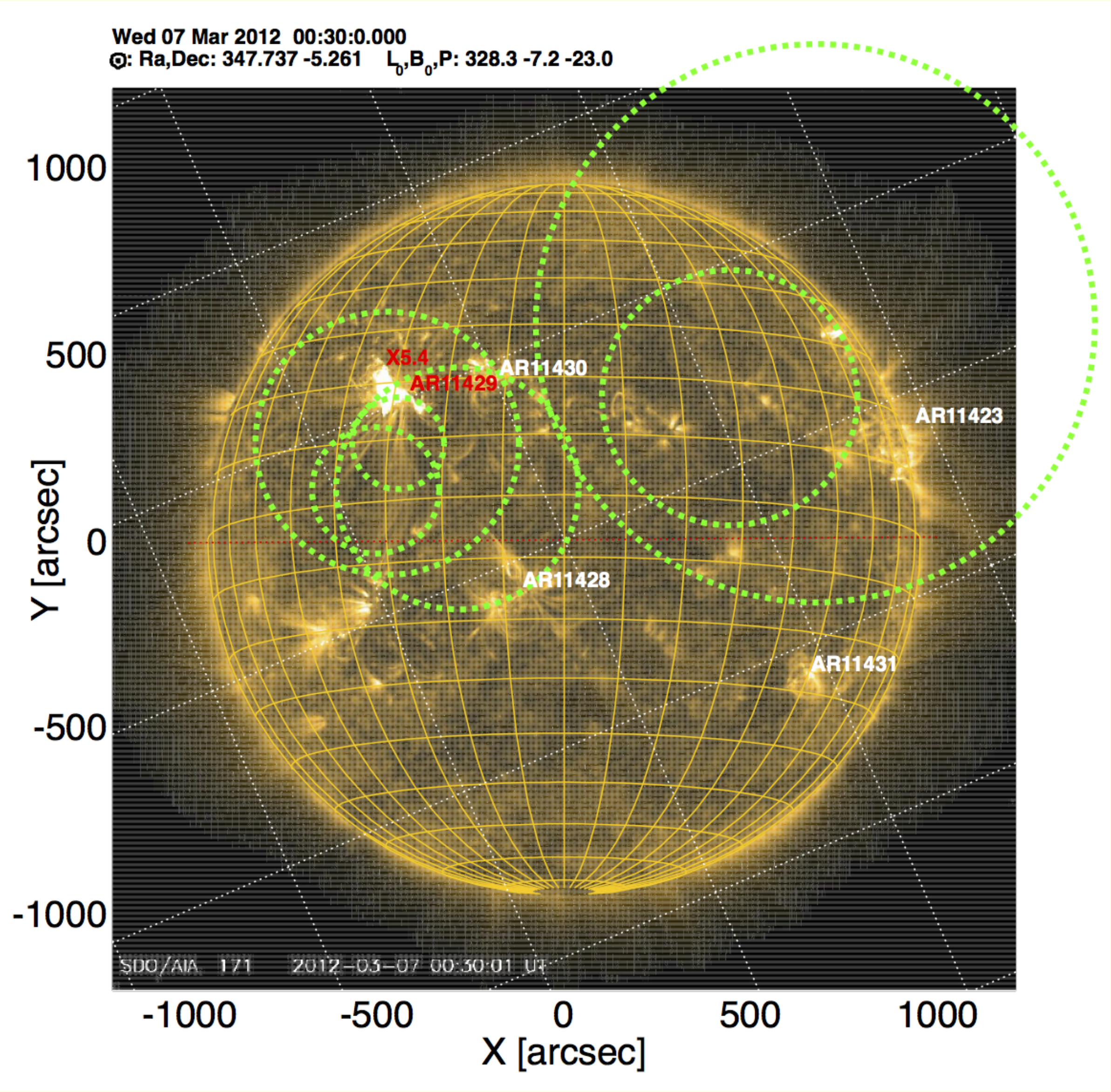
"Impulsive Phase"



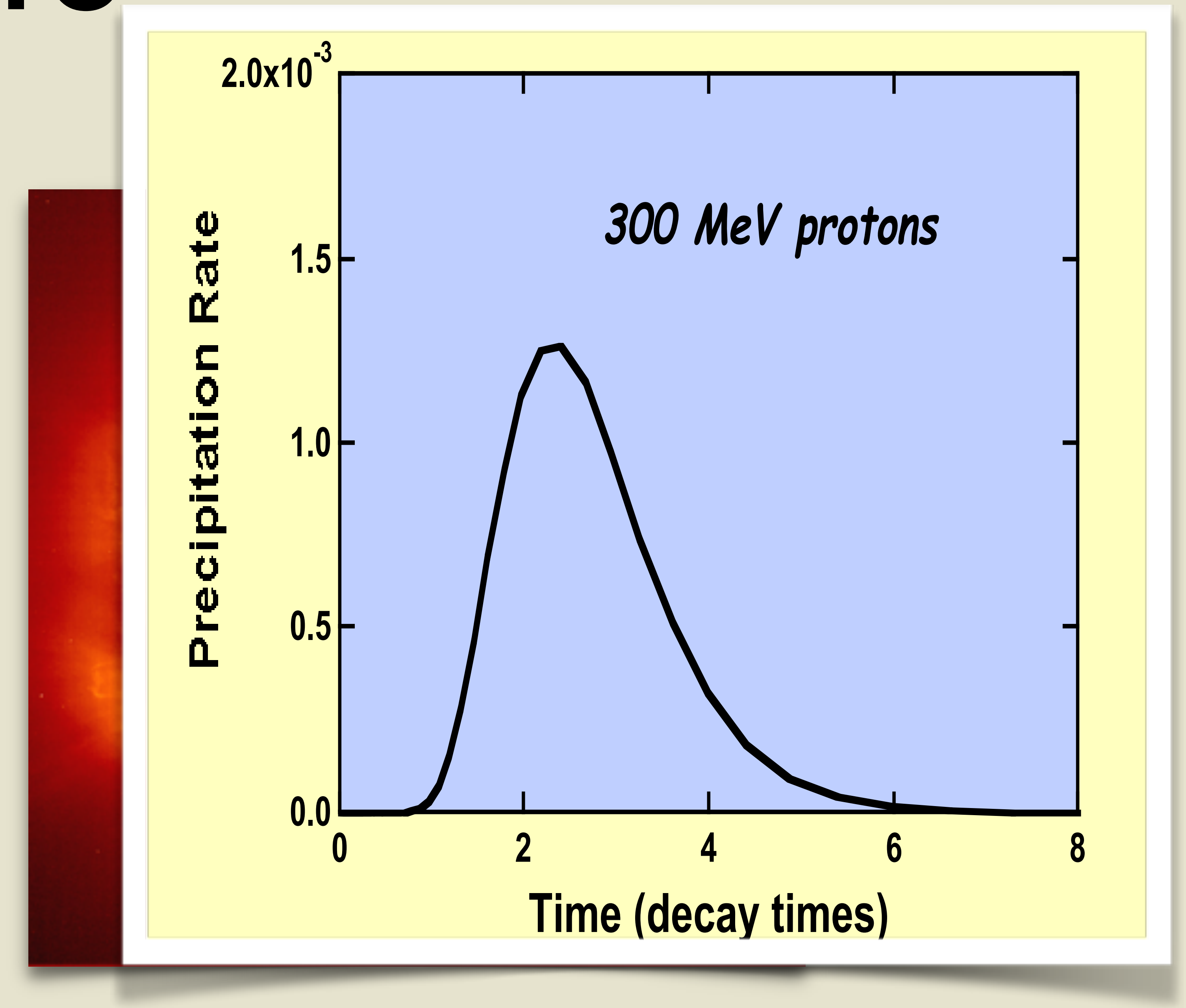


Dubbed "impulsive phase" by Ajello et al



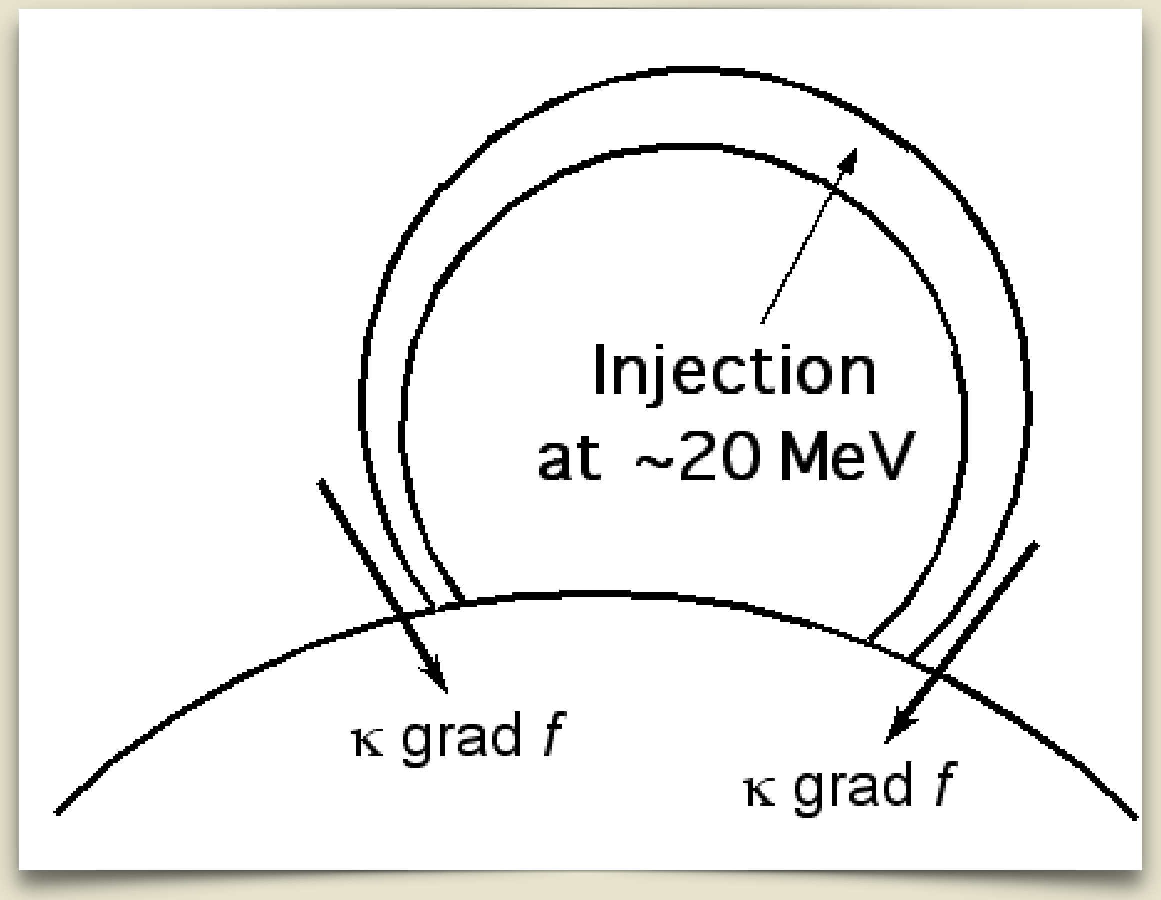


Alternative Continuous Acceleration Process in Static Structure



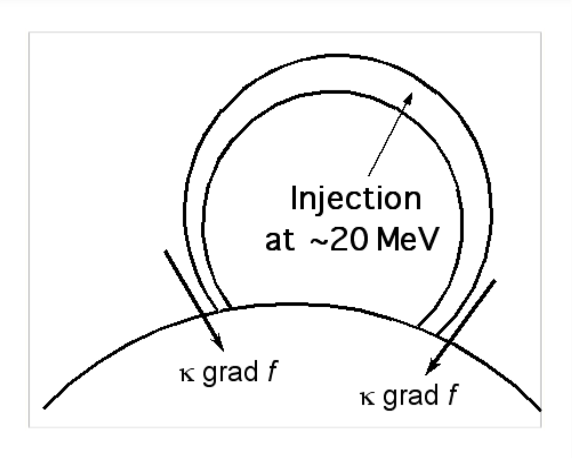
- Leakage from ends of rarified large loop (10^9 cm^{-3}, $>10^5$ km)
- Long lasting MHD turbulence resonant with ~100 MeV protons.
- Inject monoenergetic protons (20 MeV)
  - Diffusion in *x* and *p*. $\tau = L^2/\pi^2\kappa$
- Delay comes from transport and pion threshold.

$$\frac{\partial f}{\partial t} = p^{-2}\frac{\partial}{\partial p}\left\{p^2\left[D(p)\frac{\partial f}{\partial p} - f\dot{p}(p)\right]\right\} + \frac{\partial}{\partial x}\left(\kappa\frac{\partial f}{\partial x}\right) - \frac{f}{T} + Q(x,p,t)$$



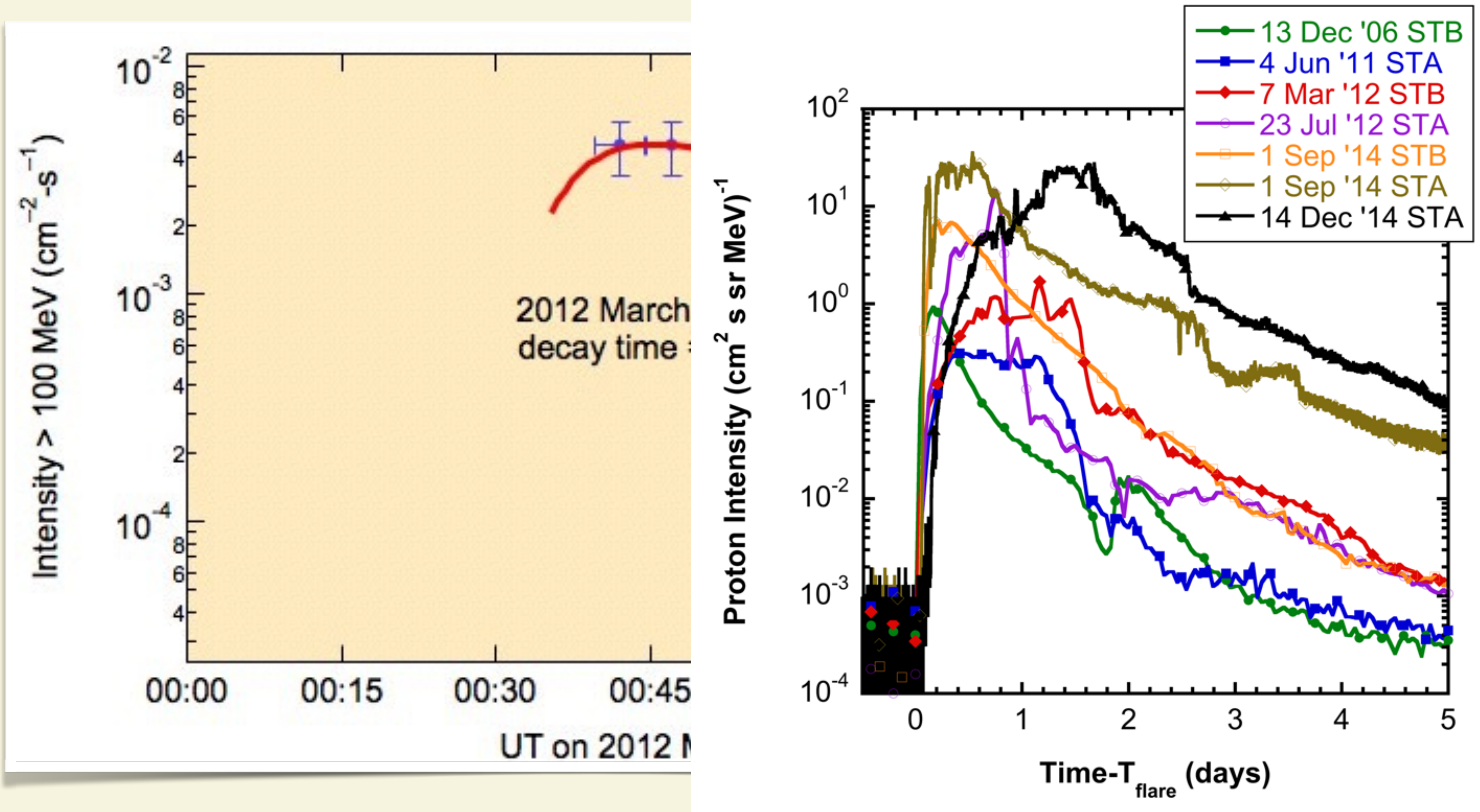
☞ ***Long duration Hi-E emission***

Possible Complications



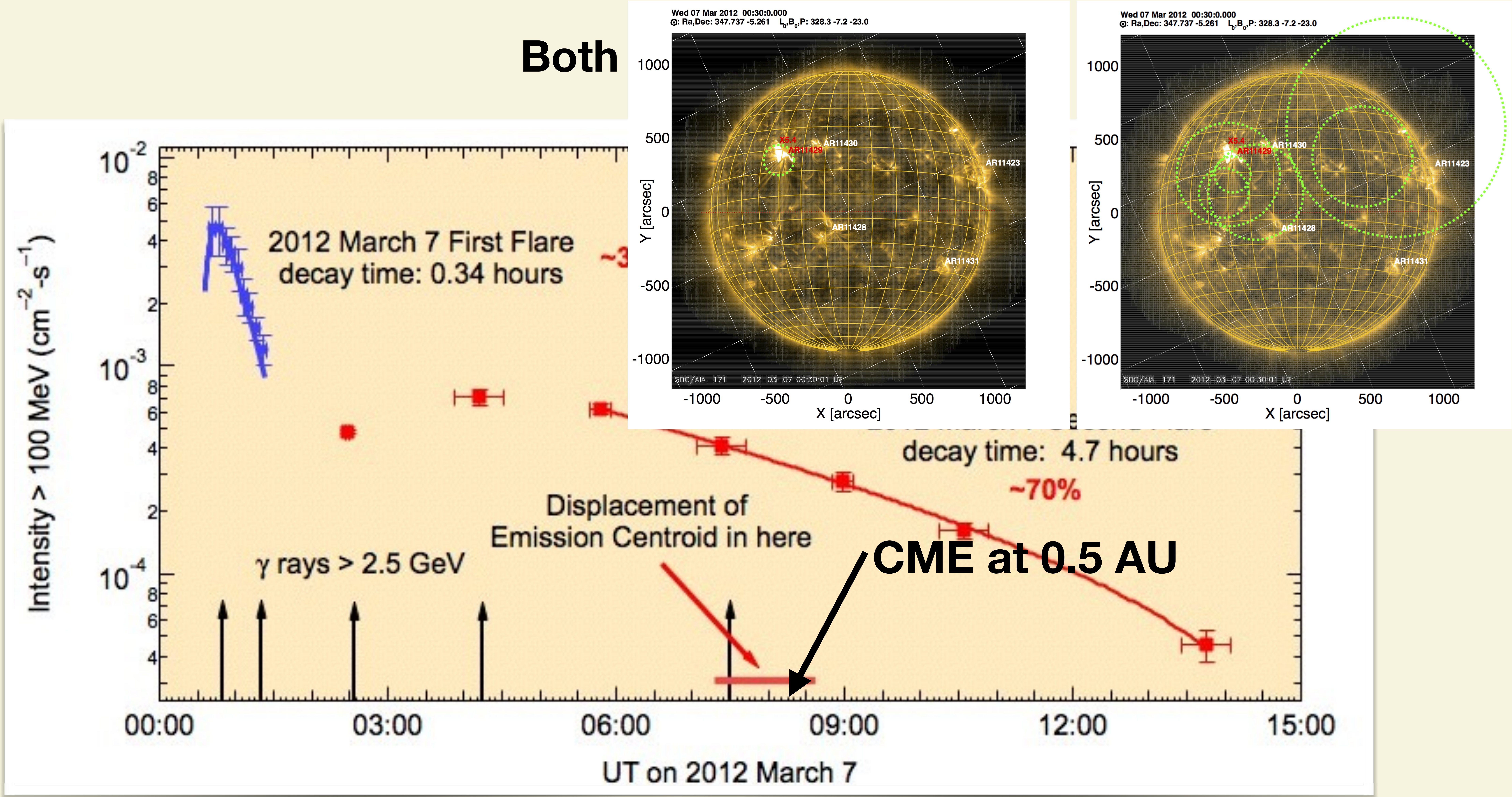
- Energy loss from collisions with electrons. OK if density is low—large loop.
- Curvature and gradient drifts. Could be an issue for the 20-h 2012 March 7 event. *Could be path for getting particles into IP space.*
- Maintenance of turbulence to both trap and accelerate the ions. *Easy to initiate, and may have been detected (De Moortel et al., 2014).* Turbulence itself could be trapped.
- We also take the spatial diffusion coefficient κ to be independent of energy and position, making the momentum diffusion $\propto p^2$.

Continuous Acceleration model for 1st Flare (X5)



Requires loop length > 1 R$_\odot$

Both



CME at 0.5 AU at time of centroid displacement

Summary

- Two LDGRFs occurred on 2012 March 7, **separated by about one hour**.
- Both produced **similar HXR/γ and μ wave intensities** but differing by 5× in SXR.
- Earlier flare produced LDGRF with a ~1 $R_\odot$ loop.
- Having the second IP shock produce 20-h emission at the Sun is unattractive from other observations.
- Second flare produced the 20-h LDGRF with no contribution from IP space.
- Compatible with trapping and acceleration in a magnetic structure between AR11429 and AR11423, but needs further study.
- No particle in space registered > 1 GeV (PAMELA collab., priv. comm.)
- Particles in space >500 MeV roughly comparable to or less than those deduced from γ data (de Nolfo et al., 20 minutes ago)

Future Work for Loop

- Investiga particles into space, e d how that affects fits.
- Must inv ace, e.g., length scales, a good fits.
- Interpret fit parameters in the context of other data.
- Study other LDGRFs to search for patterns and similarities.

ARGOMoon
Italy’s Eye on the Moon

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiPpeHE8tHaAhXCMd8KHZTtBJYQ3ywlKTAA&url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DJsfHuSqLIEw&usg=AOvVaw1cPRNsqAfWty5Po2uNhKlO