Observation and Interpretation of Energetic Neutral Hydrogen Atoms from the 5 December 2006 Solar Event

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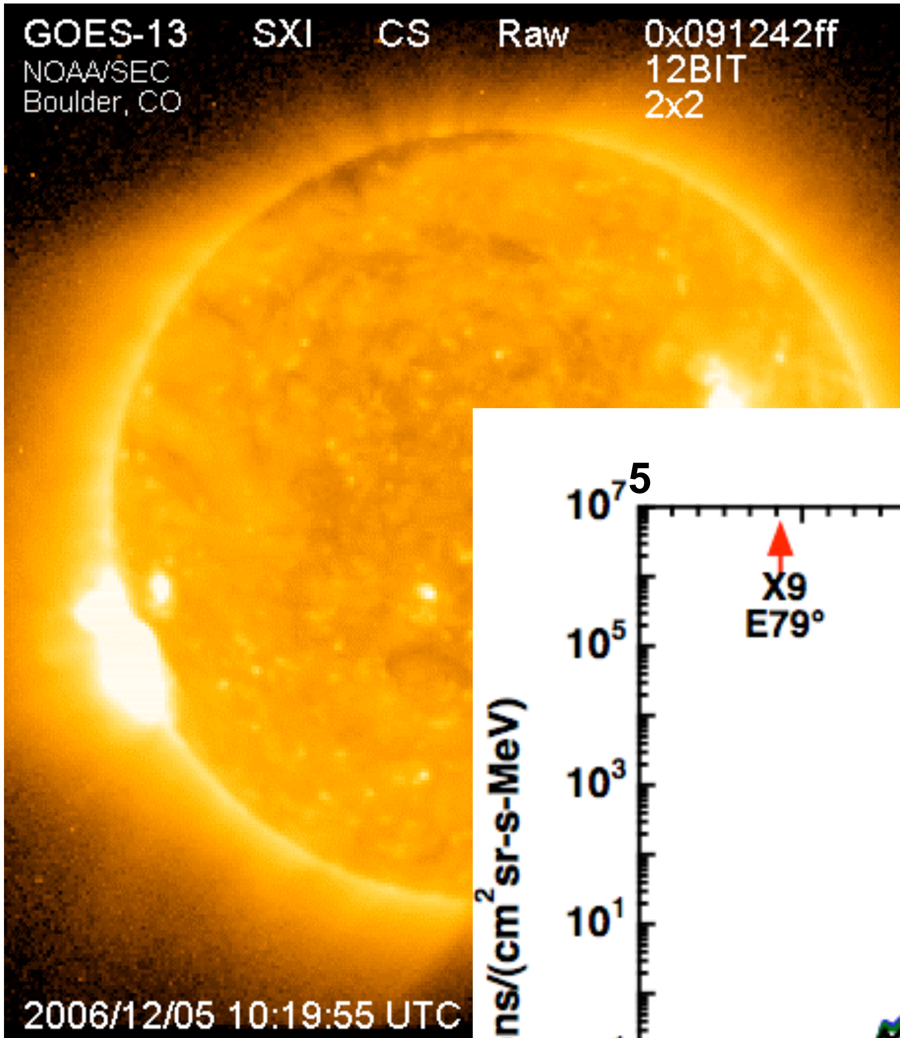
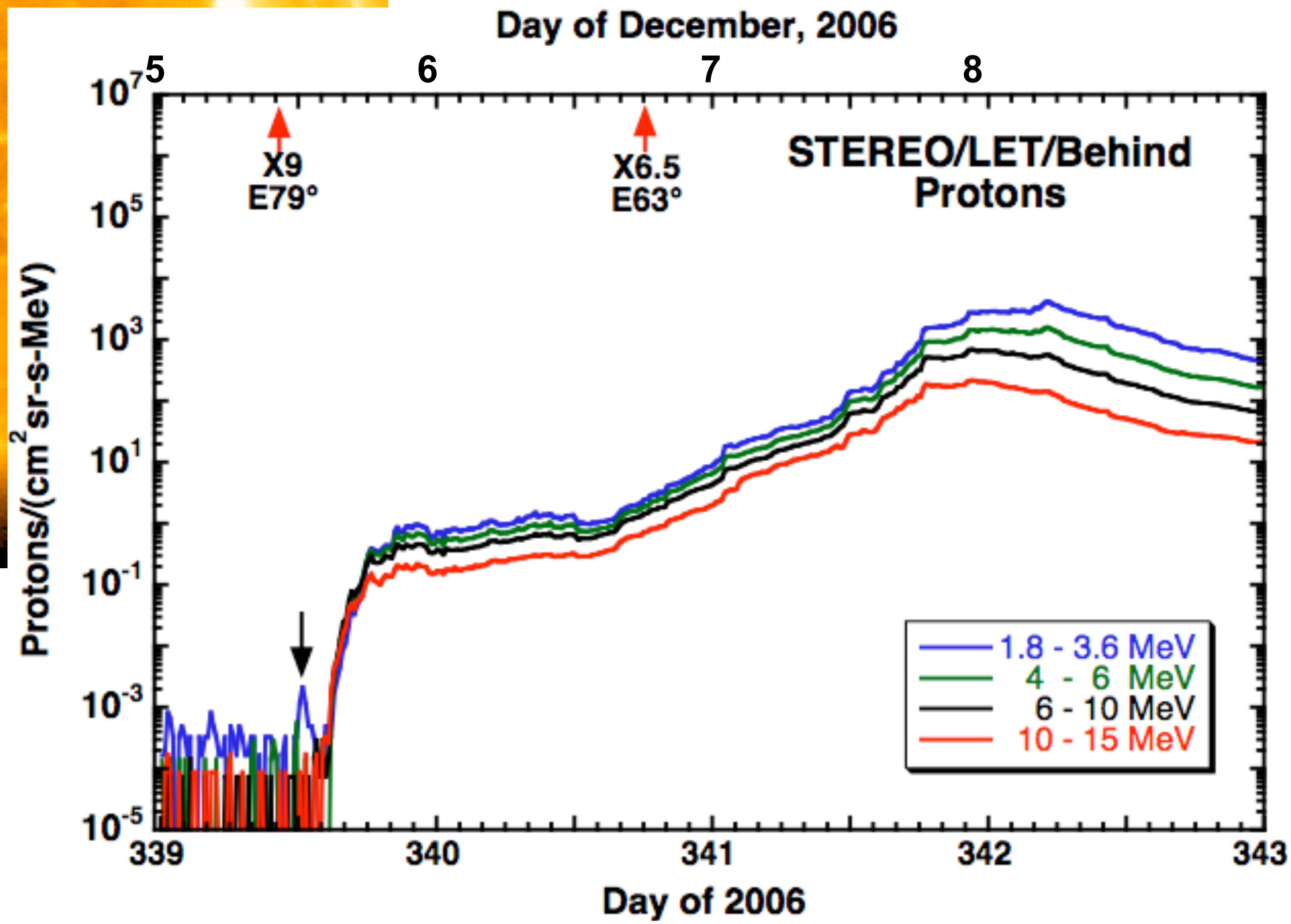
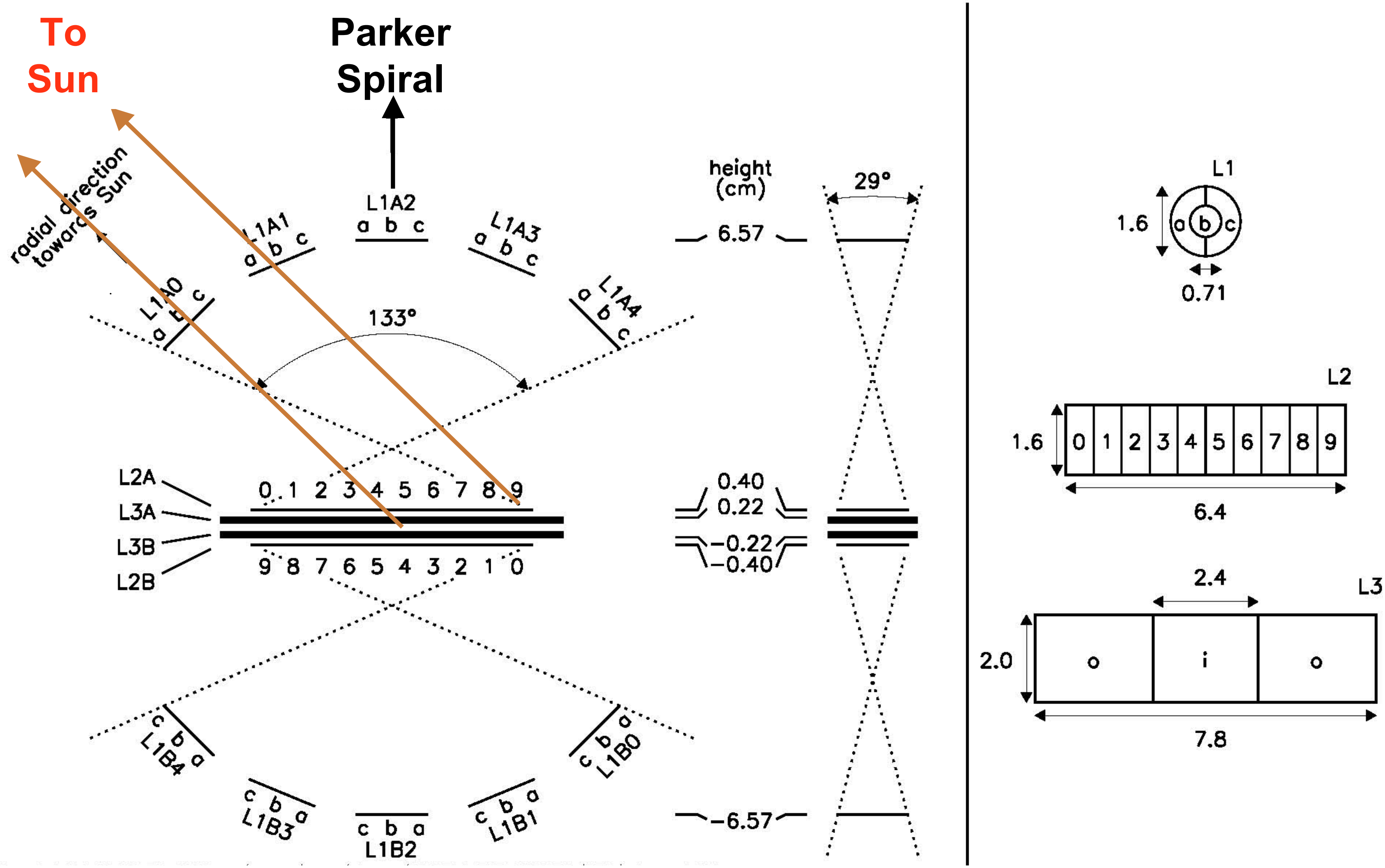
STEREO SWG#20
Meridith, NH
October 28, 2009



On December 5, 2006, the solar community was caught off guard by an X9 flare at E79. It was soon followed by 3 more X-class flares

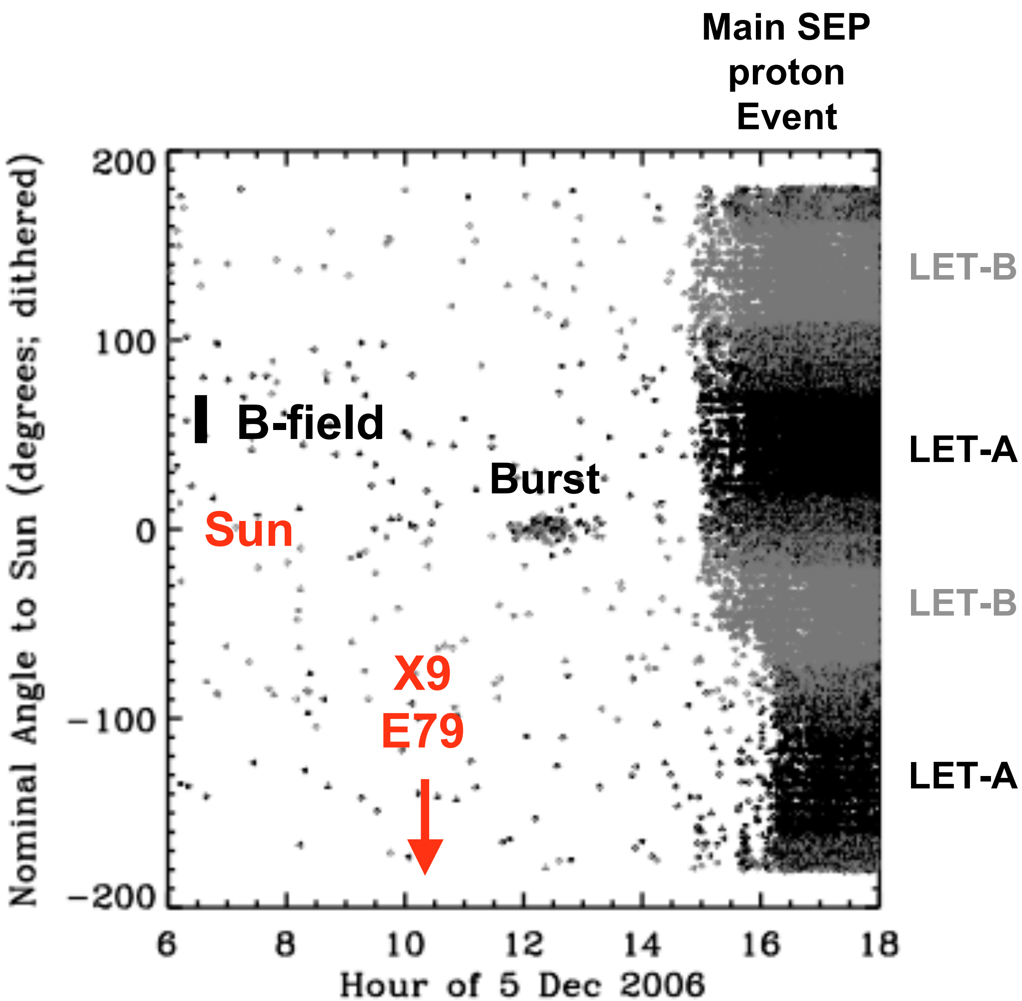


Low-Energy Telescopes on STEREO A & B

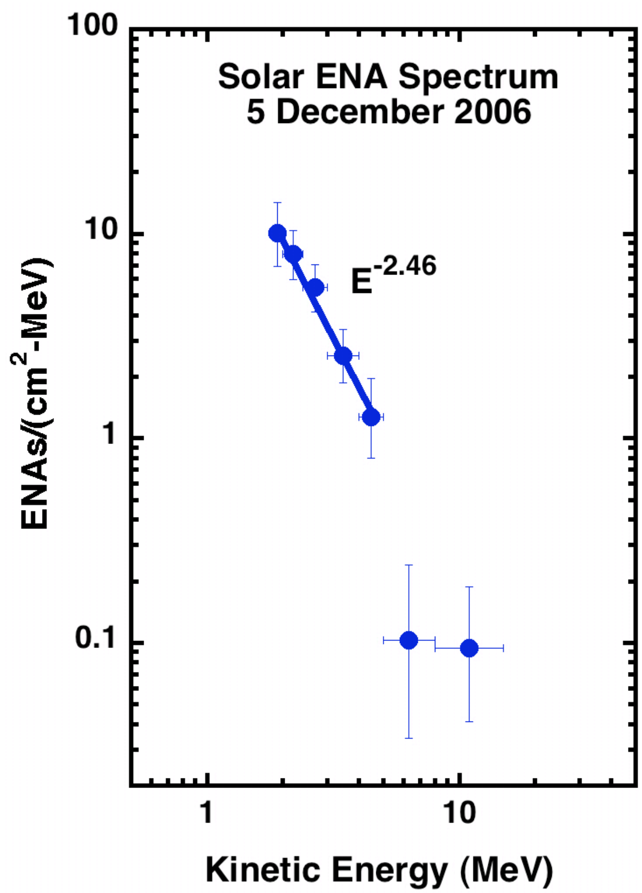


Evidence for Solar ENAs

The burst must be neutral !

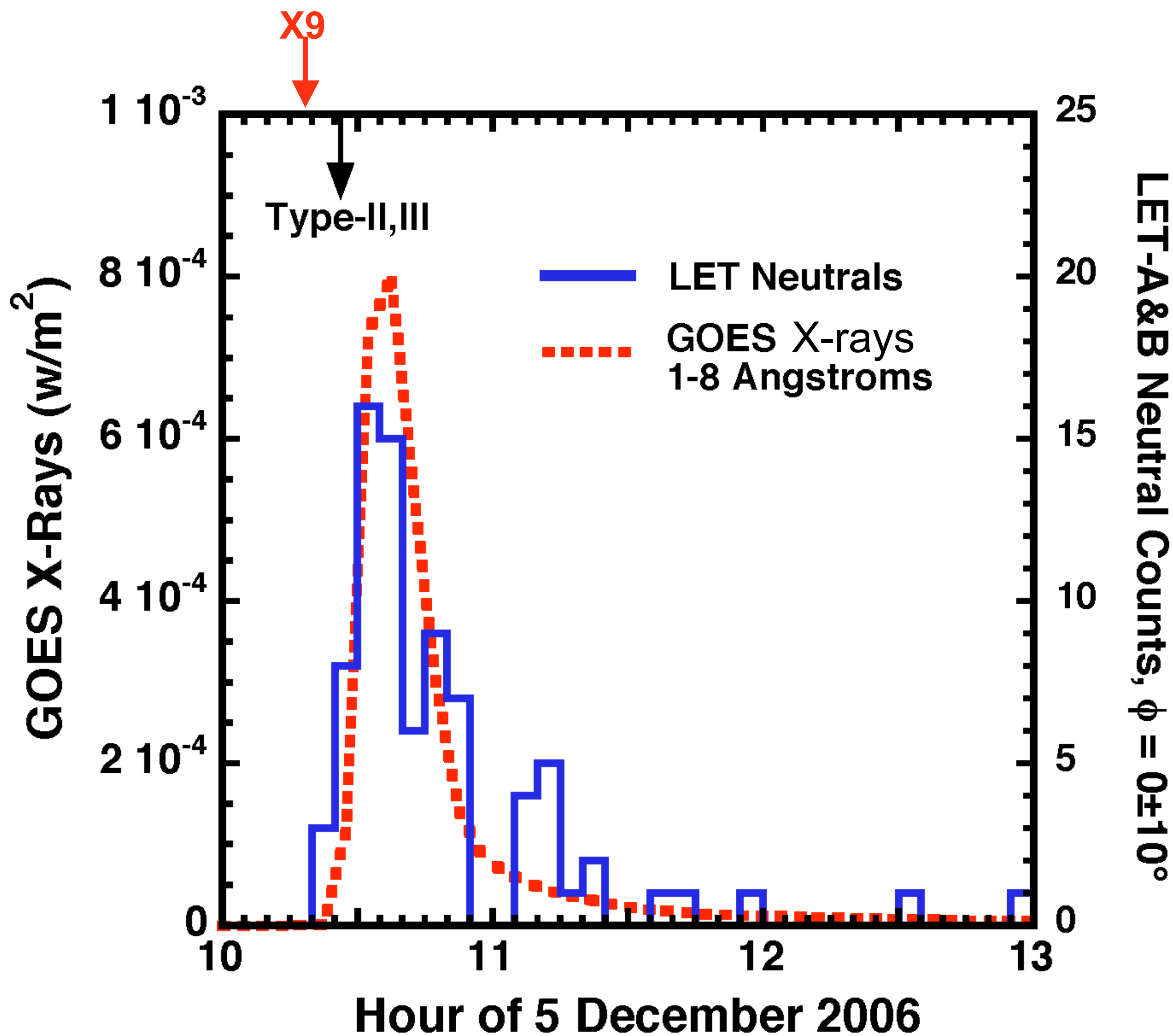


Energy spectrum of the burst



Compute the neutral emission profile by tracing particles back to the Sun using the velocity obtained from the measured energy: $v = (2E/m)^{1/2}$

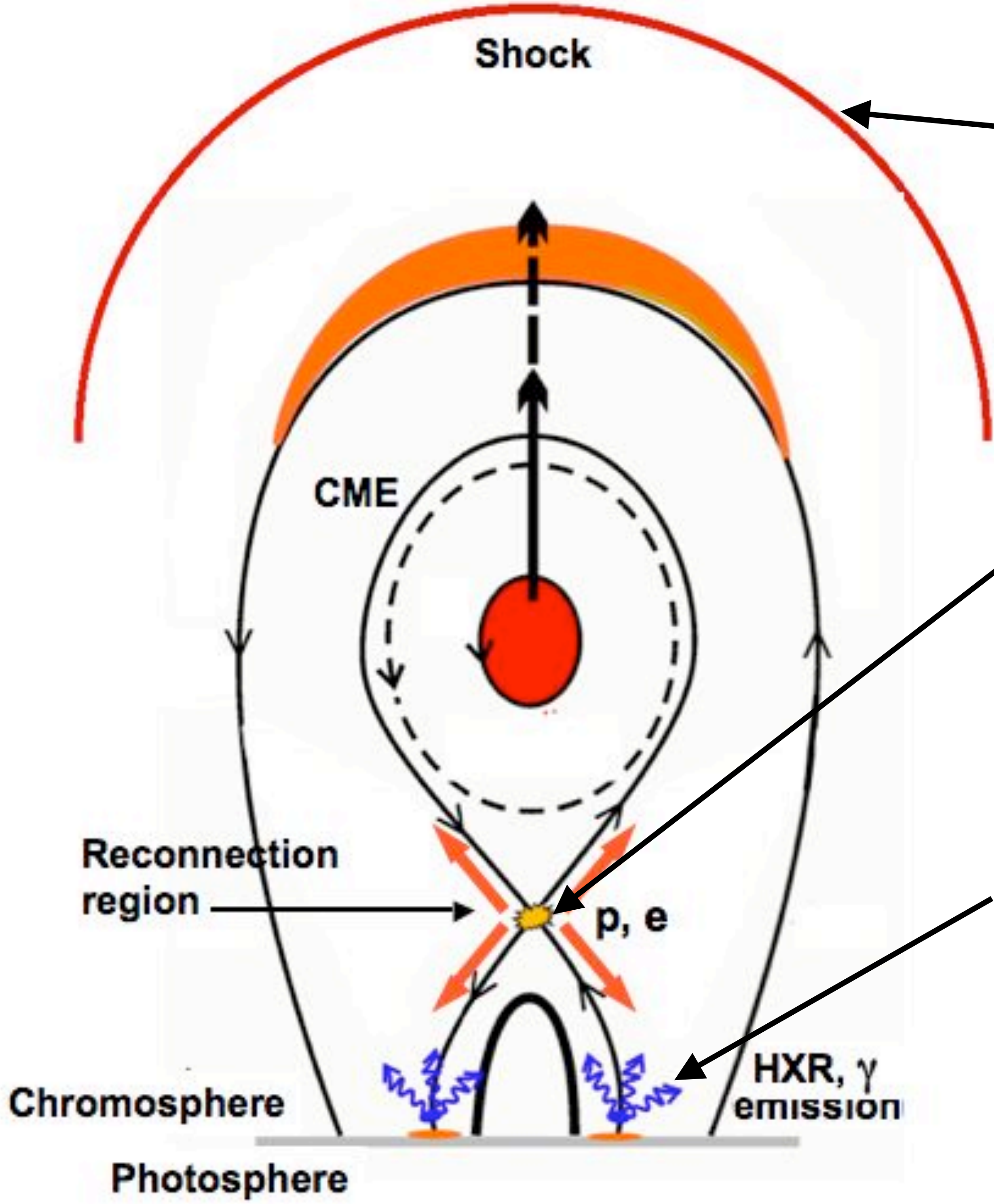
$$T_{Sun} = T_{obs} - (R_{St}/v) + 492 \text{ sec.}; \quad R_{St} = 0.983 \text{ AU}$$



Burst might be associated with either the flare or the CME !

Mewaldt et al., ApJL 693, l11 (2009)

ENA Production Sites



CME-driven shock in high corona (or escaping flare particles)
$n \sim 10^4 - 10^6$ cm^{-3}

Reconnection region: $n \sim 10^9$ cm^{-3}; but no neutral H or He for charge exchange

- $H^+ + e \rightarrow H + \gamma$ (radiative recomb.)
- $H^+ + O^{+6} \rightarrow H + O^{+7}$, also Si, Fe

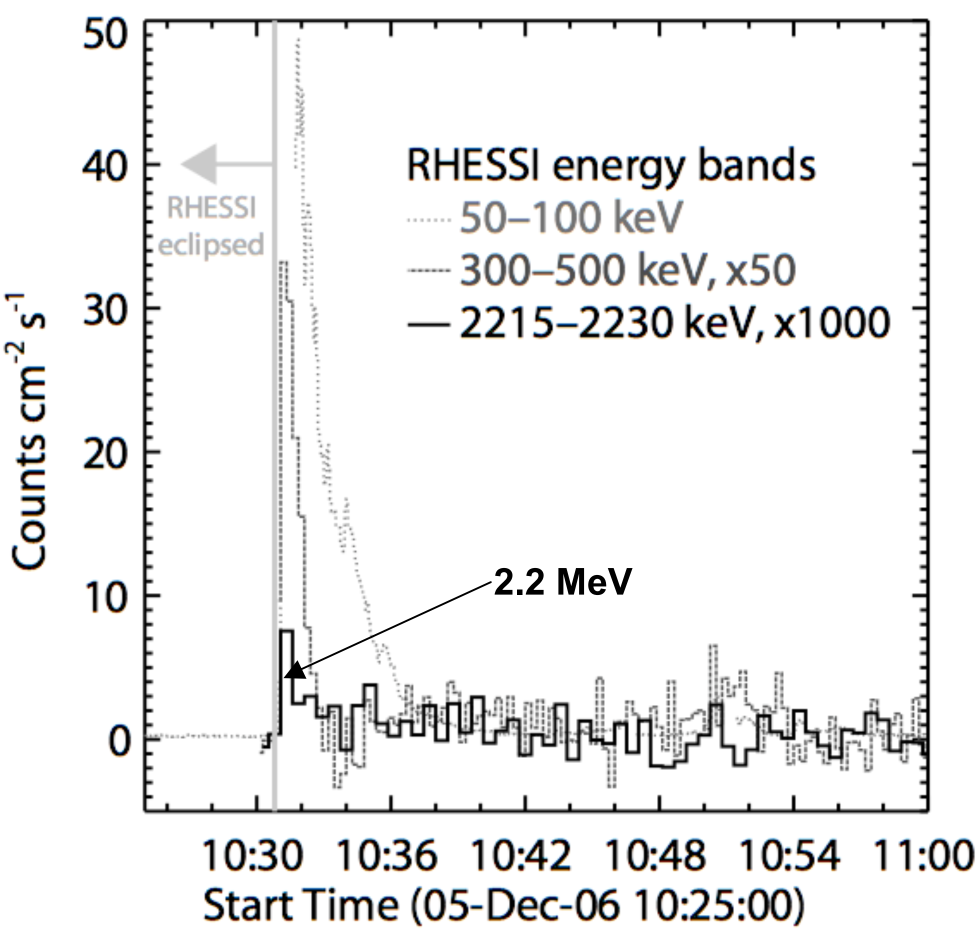
Foot-points: $n \sim 10^{10} - 10^{16}$ cm^{-3}
Have neutral H & He!

Can ENAs escape from $<1.1\ R_S$?

Cartoon based on a RHESSI science nugget

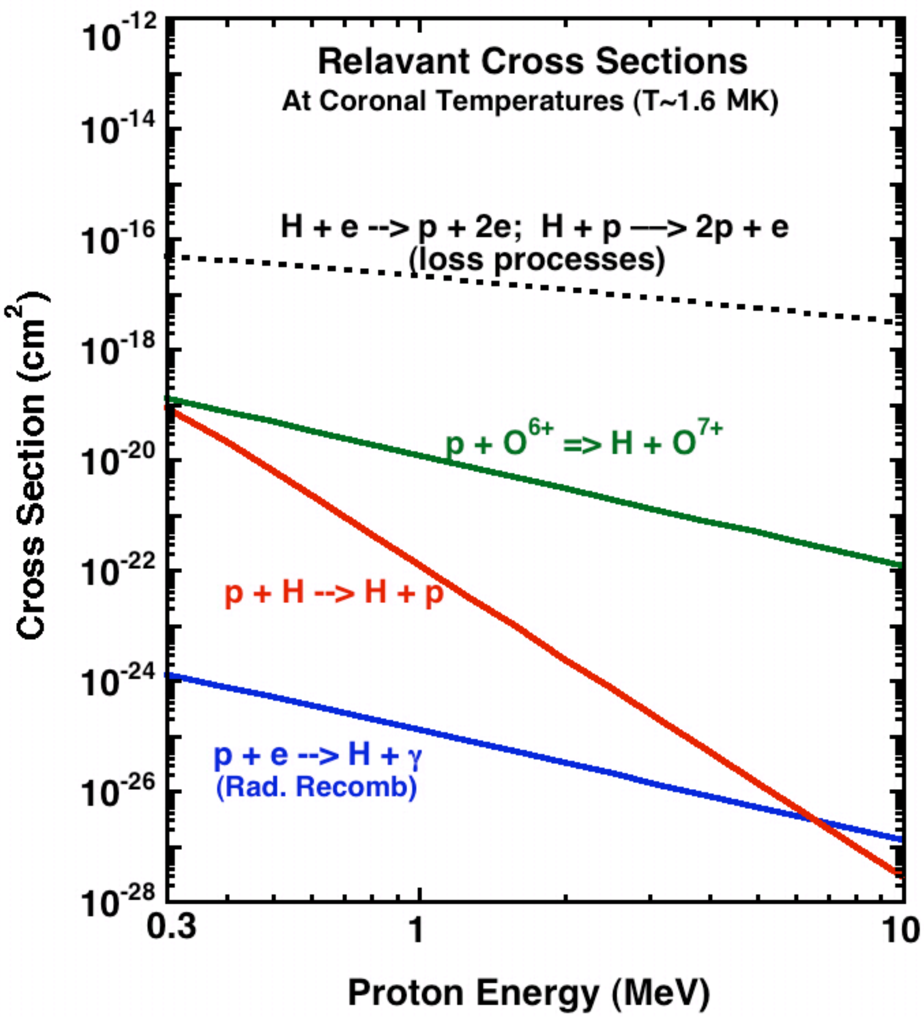
RHESSI observed neutron-capture γ-rays from the December 5, 2006 event starting at 1031 UT, after coming out of eclipse

- RHESSI 2.2 MeV γ-ray fluence => >1.3 x 10^{31} protons with ≥30 MeV interacted in the solar atmosphere
- For an $E^{-3.5}$ energy spectrum, => >1.2 x 10^{34} accelerated protons with 1.8 - 5 MeV

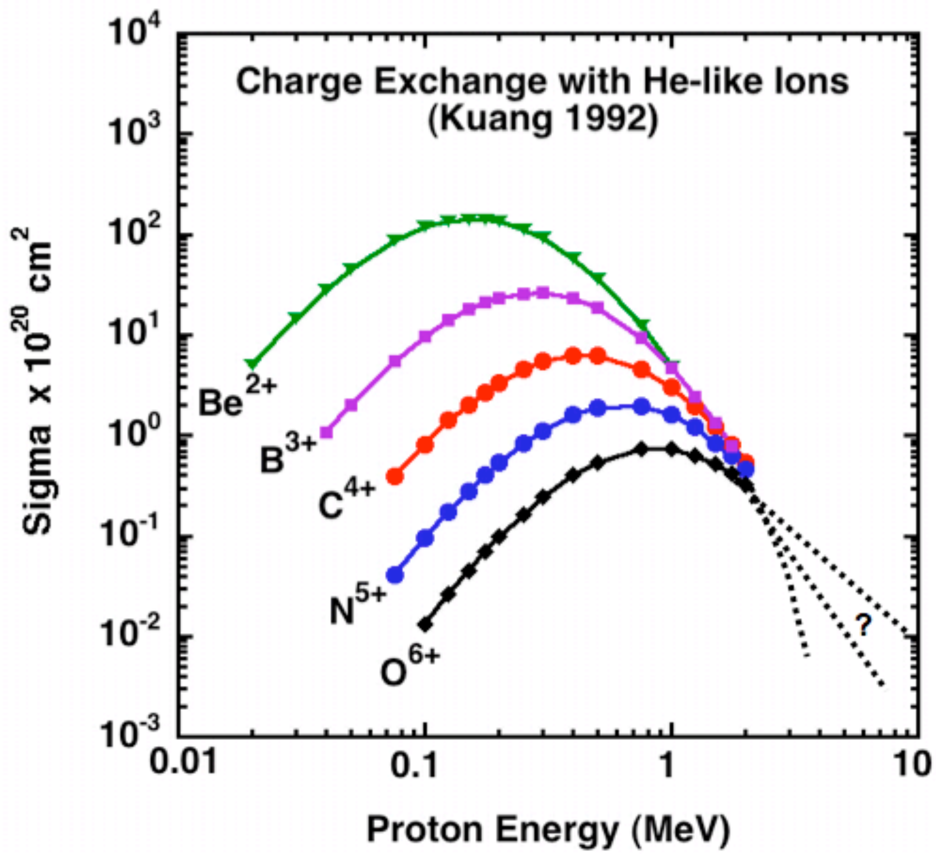


- A proton slowing from 5 MeV to 1.8 MeV produces ~0.01 ENAs
- >4 x 10^{31} ENAs produced if all 1.8 - 5 MeV protons slow and stop in the solar atmosphere
- > 1000 times more ENAs than needed

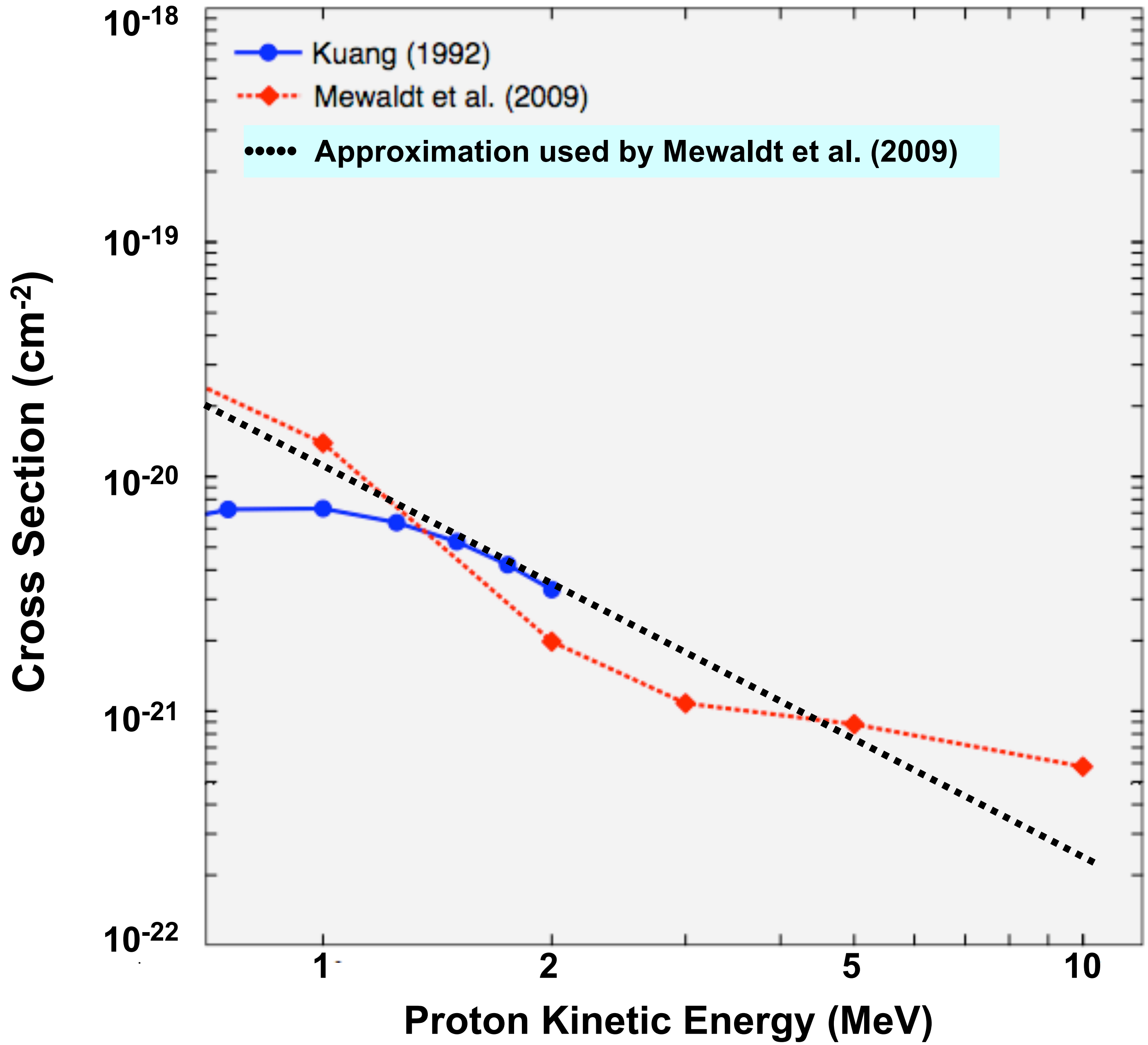
ENA Production and Loss



Kuang (1991,1992) developed theoretical cross sections for charge exchange with H-like and He-like ions (e.g., O^{+6})

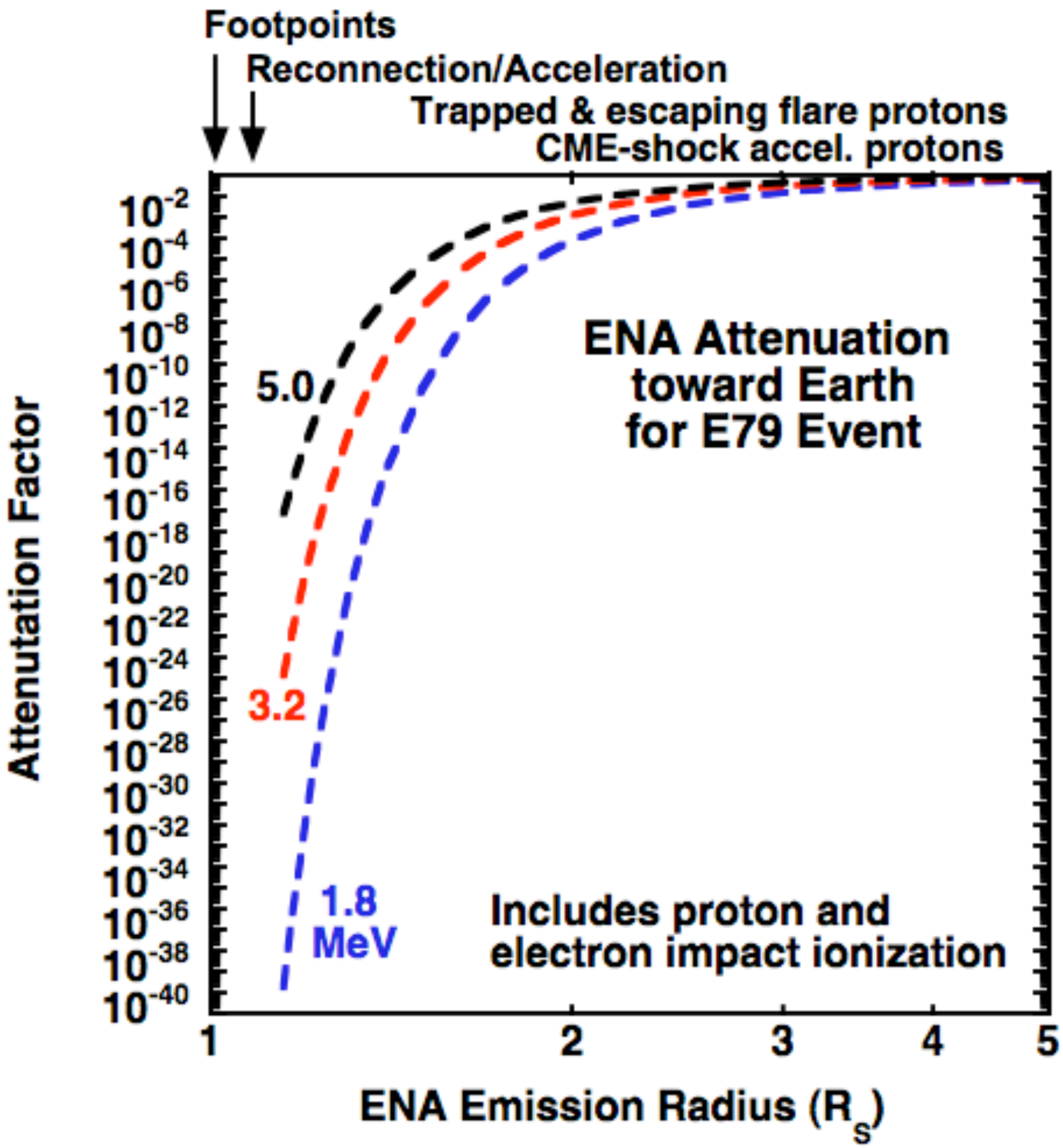


Charge-Exchange Cross-Section for $H^+ + O^{6+}$



We are pleased with the ≤ x2 agreement so far and hope to extend the Kuang formalism to higher energies.

ENA Losses



The ENAs we see must have been made in the high corona (>~2 Rs)

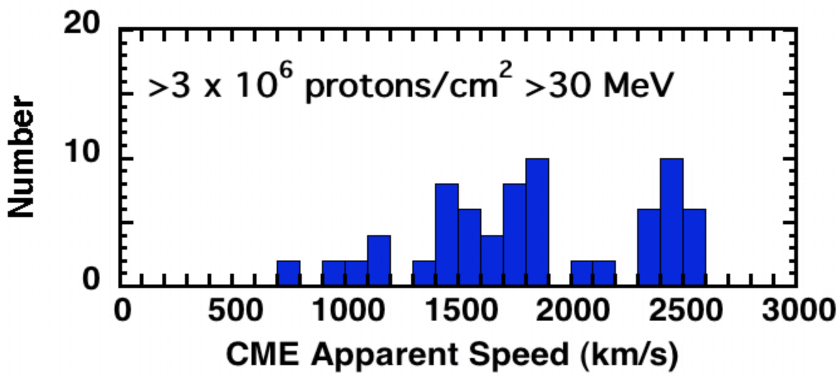
Could be either flare or CME-accelerated particles

Based on coronal densities from Sittler and Guhathakurta (1999)

Mewaldt et al. Solar Wind 12

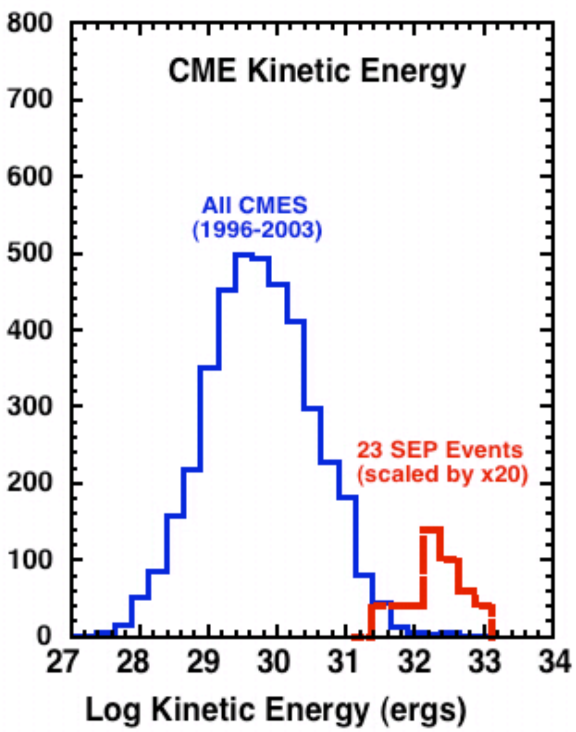
Lacking CME data, we assume average values based on large SEP events

CME apparent speeds for the top 50 SEP events of solar cycle 23



Large SEP events are due to CMEs with speeds of 1500-2500 km/s

Assume the median value of 1800 km/s

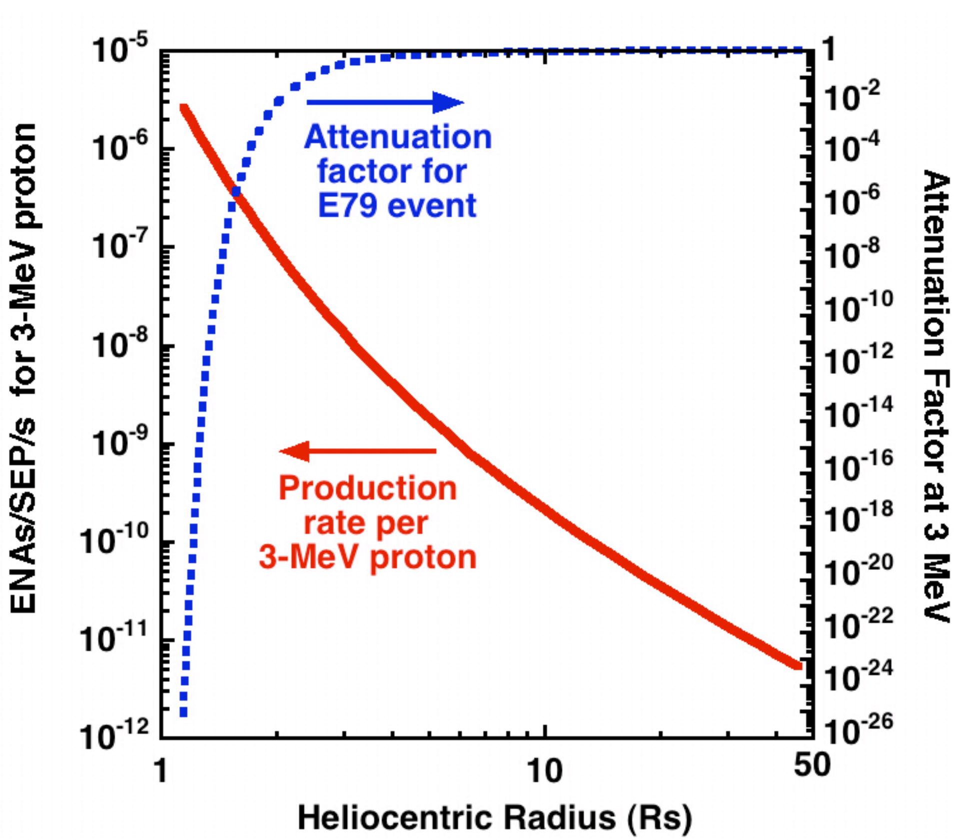


Assume the median CME kinetic energy of 2×10^{32} ergs

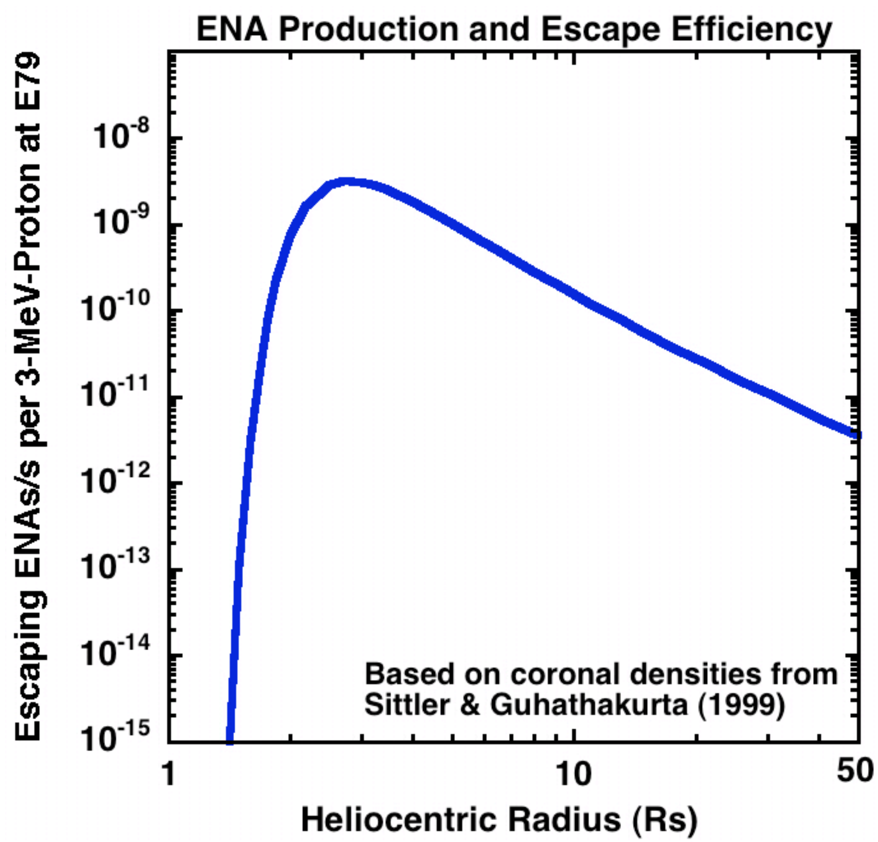
Based on Mewaldt et al. (2008) and Gopalswamy (2006)

ENA production and Loss

- ENAs produced mainly by charge exchange with heavy ions
- ENAs lost by electron & proton impact ionization
- Assume nominal coronal density and composition



- ENA production-escape peaks between ~2 and ~7 Rs
(assumes planar shock and neglects 2nd generation ENAs)

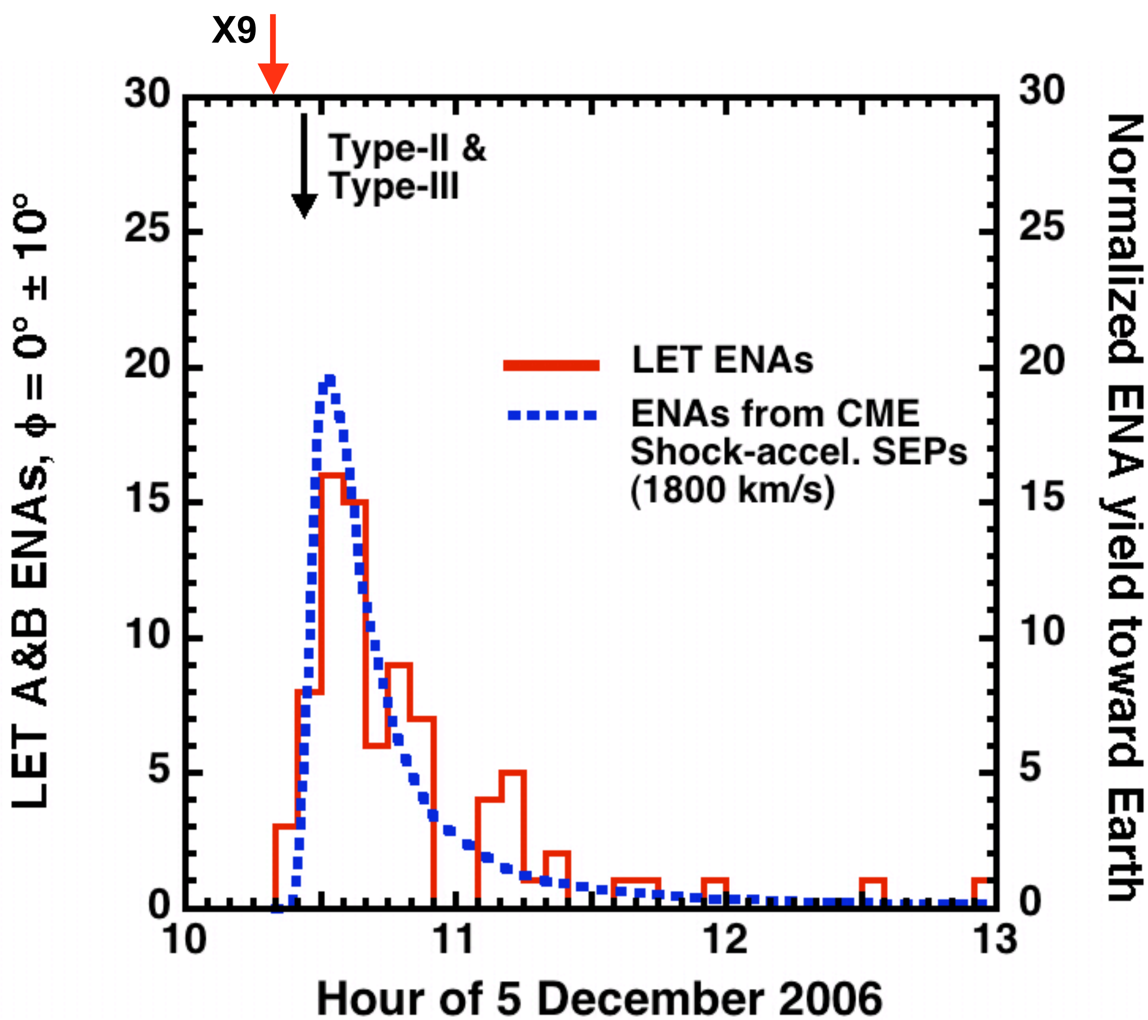


Simple estimate of ENAs from CME-driven shock acceleration

Assume 1800 km/s CME forms a planar shock at 2.2 Rs with compression ratio r = 4; => $dJ/dE \approx E^{-1}$.

Assume accelerated particle intensity starts at Type-II burst, and continues independent of radius

Assume isotropic ENA emission and calculate ENA attenuation in direction of Earth



Conclude:

The observed emission profile could be caused by shock-accelerated particles

How about the energetics?

- **$KE_{SEP}/KE_{CME} \approx 2\%$**

  (includes 0.03 - 30 MeV, 2 to 15 Rs)

In Large SEP Events

$KE_{SEP}/KE_{CME} \approx 10\%$

Mewaldt et al. (2008)

Mewaldt et al. Solar Wind 12

Summary and Conclusions

- Theoretical cross section papers confirm that accelerated protons hitting partially-stripped heavy ions are an important source of ENAs in the corona and solar wind

- RHESSI γ-ray data => >1000 times more ENAs than needed were produced by flare-accelerated particles. To be observed, a sufficient number much reach >~2 Rs

- Emission profile consistent with either flare or CME-driven shock origin if protons reach ≥2 Rs

- STEREO observations may decide between sources

- ENAs can be a new diagnostic of the acceleration and escape of low-E ions in the corona