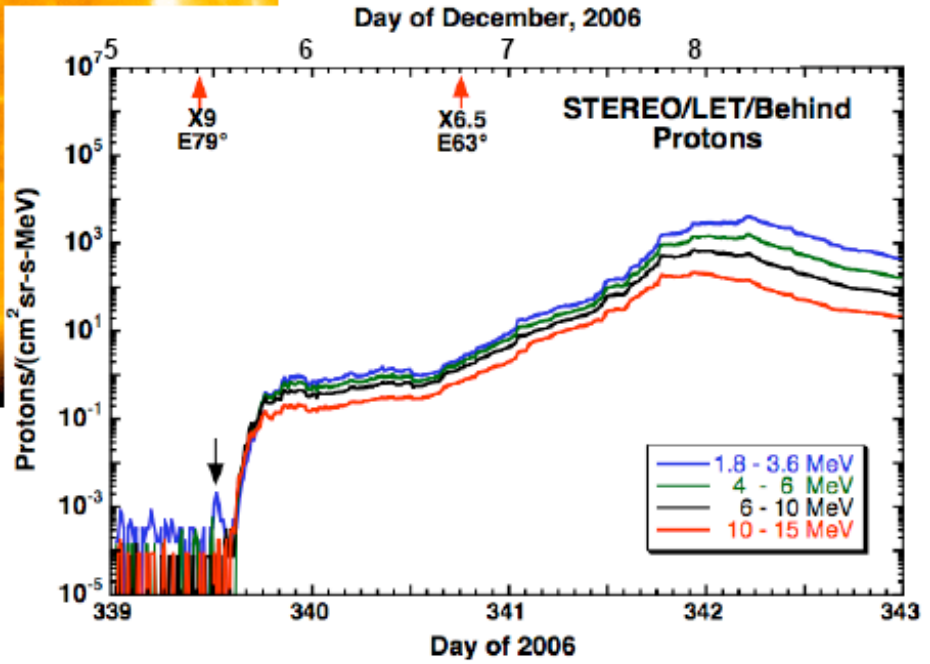
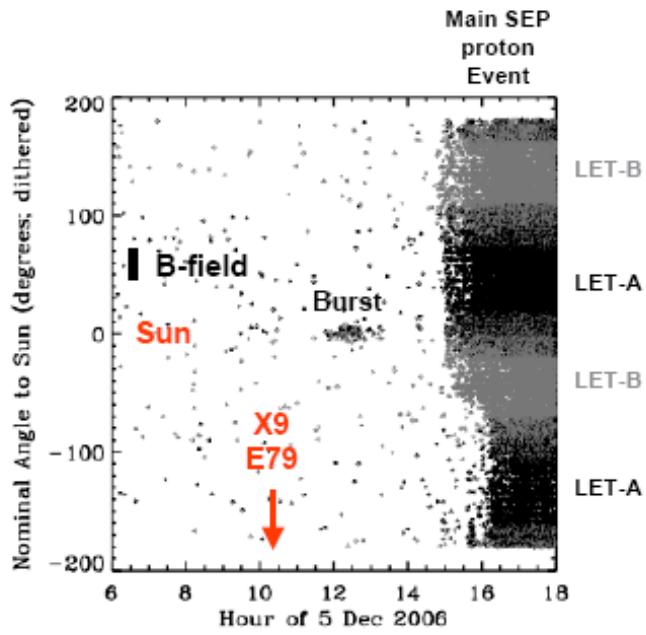


On December 5, 2006, the solar community was caught off guard by an X9 flare at E79. It was soon followed by 3 more X-class flares

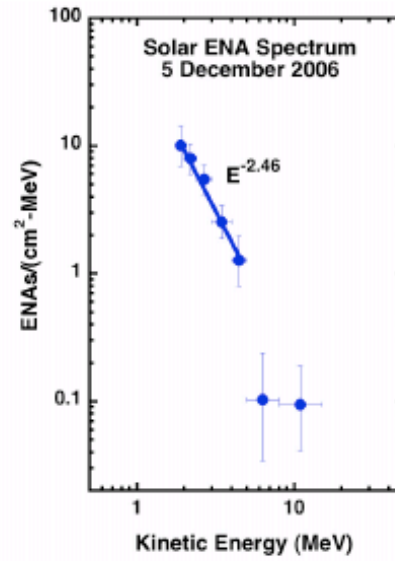


Evidence for Solar ENAs

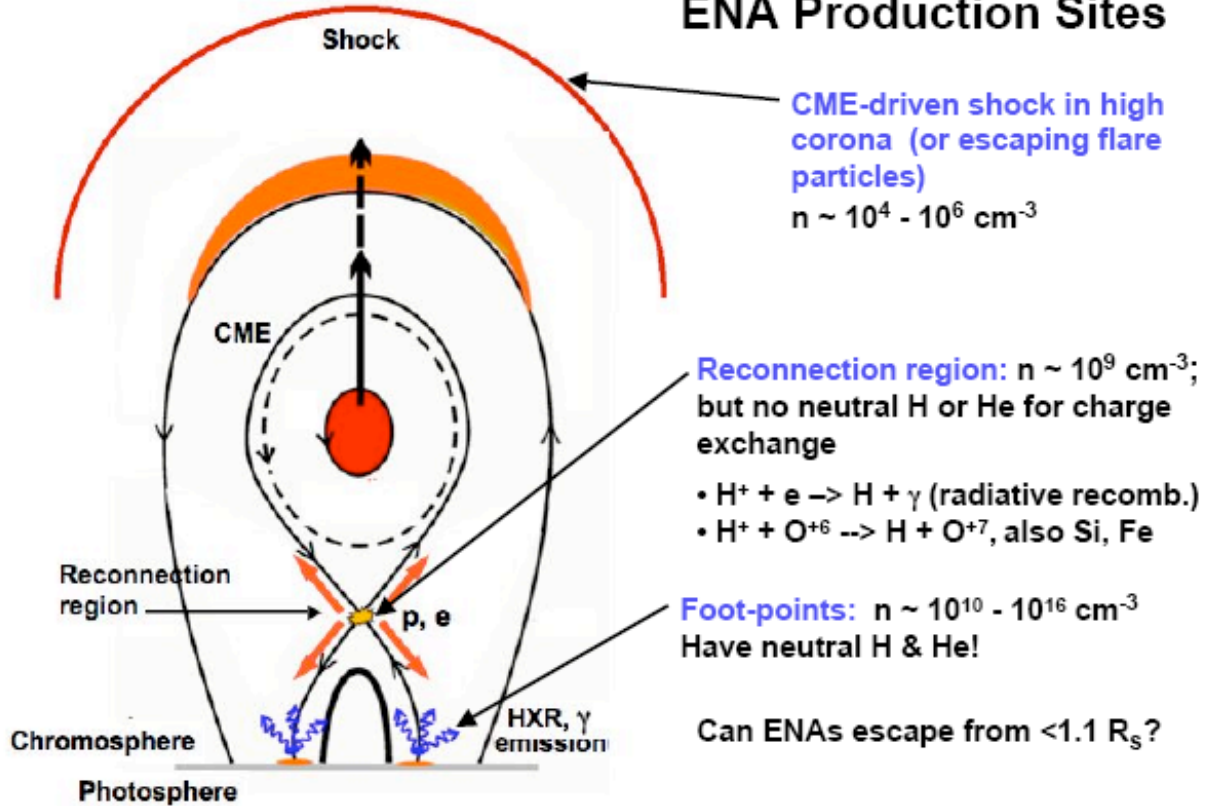
The burst must be neutral !



Energy spectrum of the burst



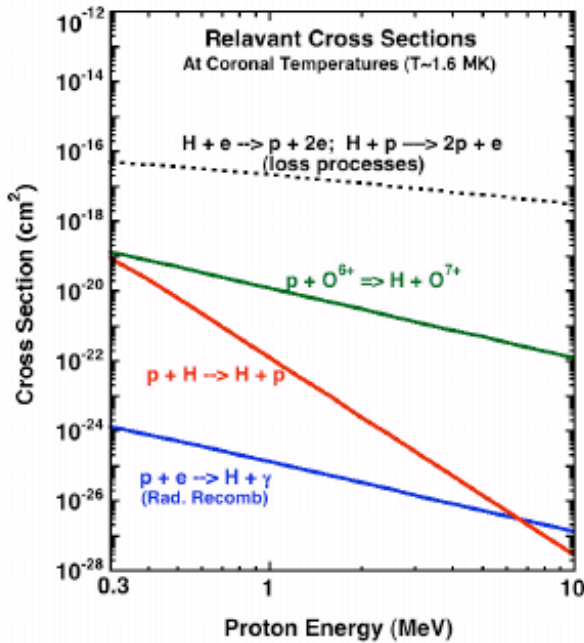
ENA Production Sites



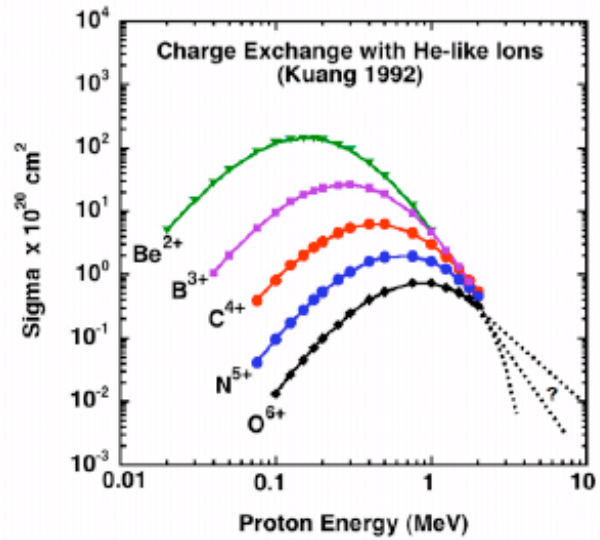
Can ENAs escape from $<1.1 R_s$?

Cartoon based on a RHESSI science nugget

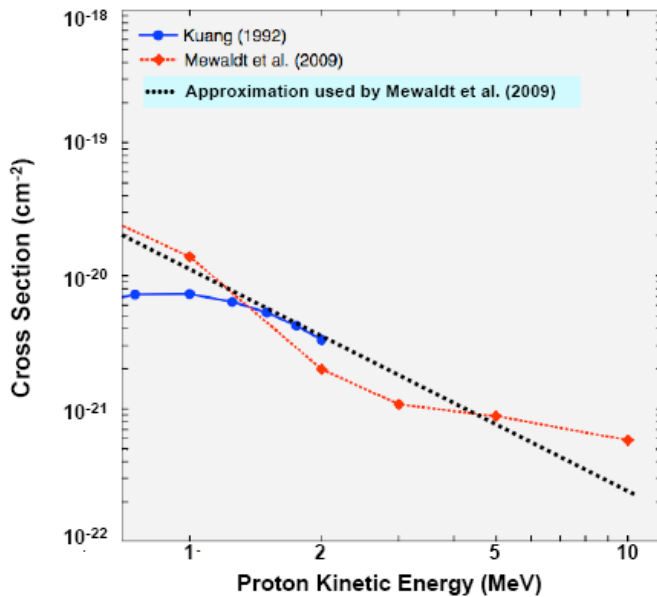
ENA Production and Loss



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

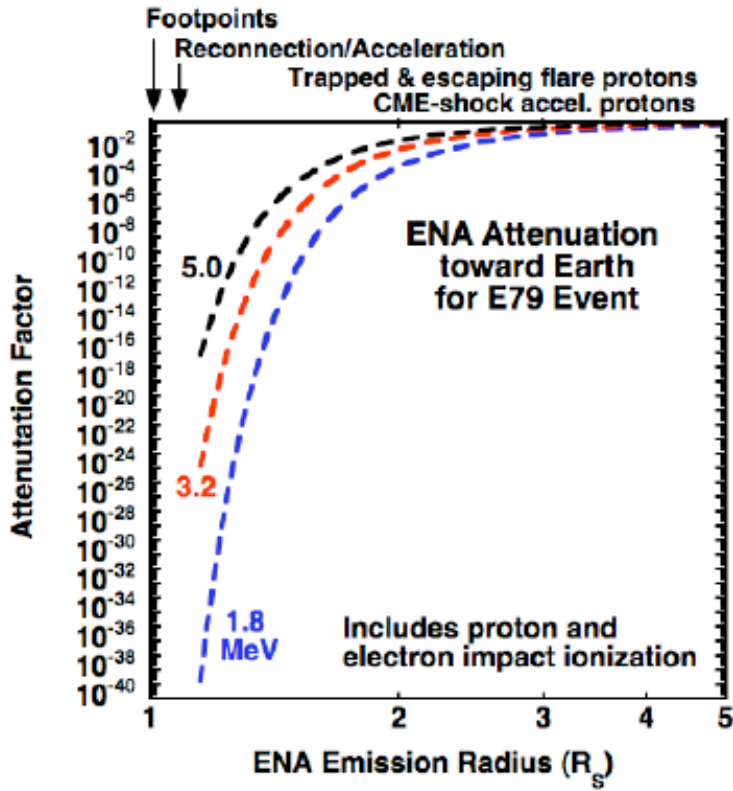


Charge-Exchange Cross-Section for $H^+ + O^{6+}$



We are pleased with the $\leq x2$ 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 ($> \sim 2 R_s$)

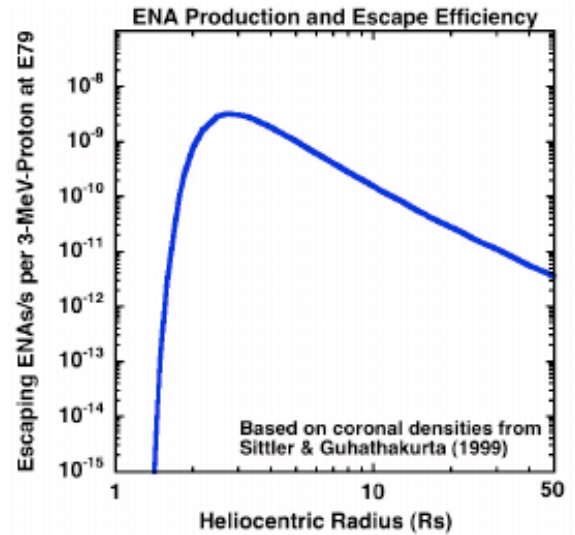
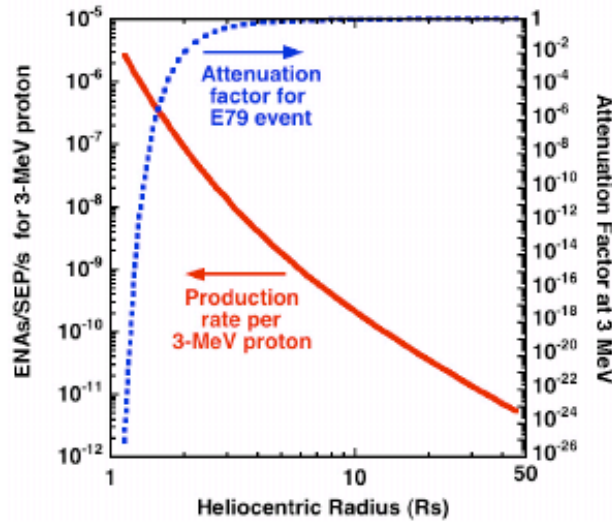
Could be either flare or CME-accelerated particles

Based on coronal densities from Sittler and Guhathakurta (1999)

ENA production and Loss

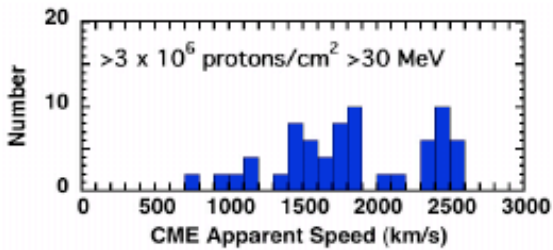
- ENAs produced mainly by charge exchange with heavy ions
- ENAs lost by electron & proton impact ionization
- Assume nominal coronal density and composition

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



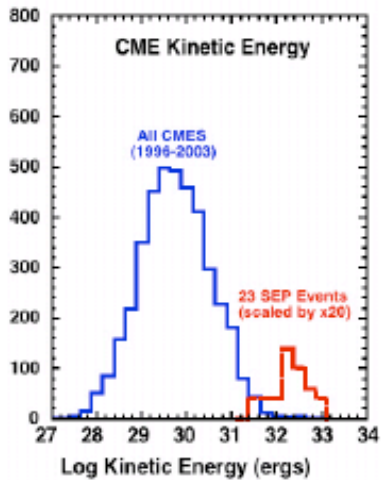
Lacking CME data, we assume average values based on large SEP events

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

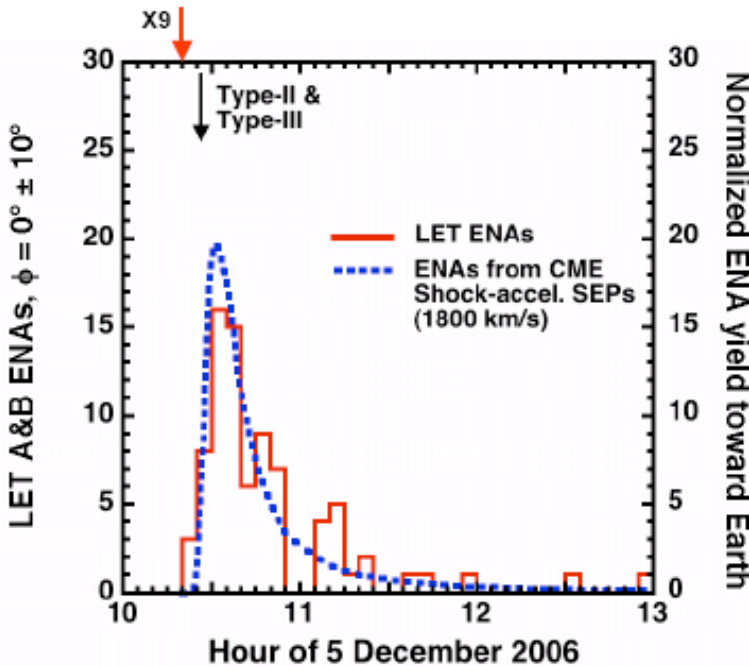
Based on Mewaldt et al. (2008) and Gopalswamy (2006)

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 $r = 4$; $\Rightarrow dJ/dE \approx E^{-1}$.

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

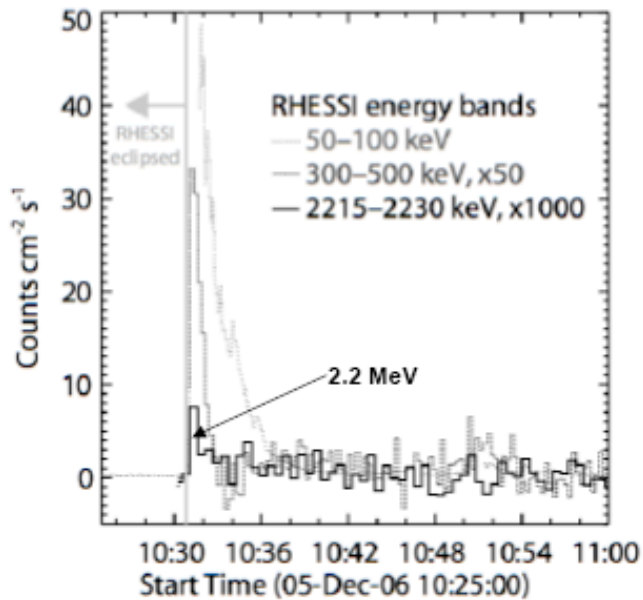
$KE_{SEP}/KE_{CME} \approx 10\%$

Mewaldt et al. (2008)

Mewaldt et al. Solar Wind 12

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



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