Solar Flare Energy Partition into Energetic Particle Acceleration

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Solar Energetic Particles: An Introduction

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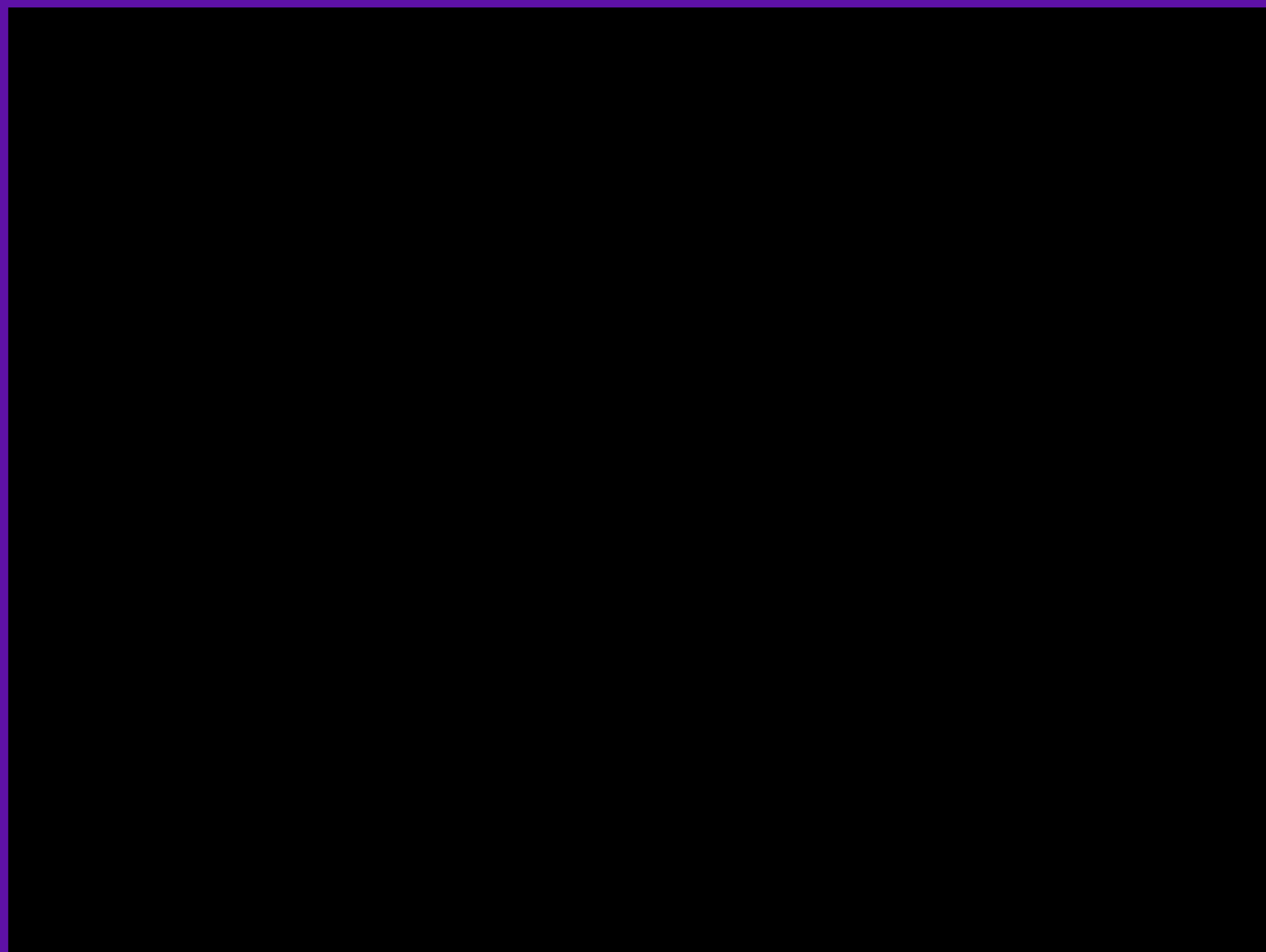
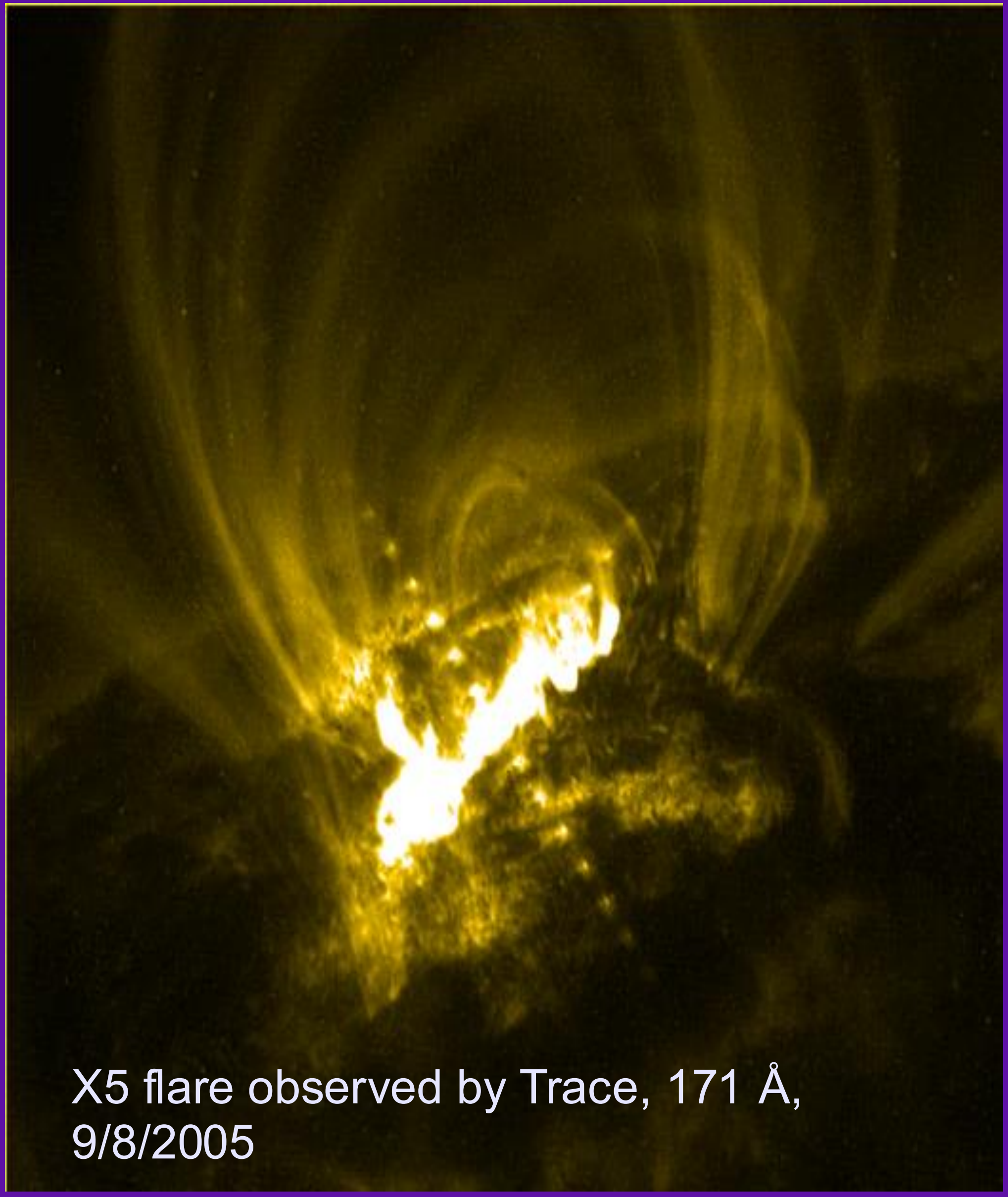


Energy Partitioning in Flares



X5 flare observed by Trace, 171 Å, 9/8/2005

A flare takes ~ 10^{32} ergs of magnetic energy and converts it into:

- X-ray producing electrons
- Gamma-ray producing ions
- Heating plasma
- Mass motion (CME)
- Interplanetary particles

Energy Partitioning in Flares

?

How much goes into each component?

Previous work: Emslie et al. 2004, two events.

Still not very well determined, more study needed.

- Goal: Estimate how much of the original flare energy goes into interplanetary particle acceleration.

- What is required to estimate this using 1 AU data?

    1) How many times does each particle cross 1 AU on average?
    2) What is the distribution function of 1 AU crossings?
    3) How much energy is lost during travel from the sun to 1 AU because of adiabatic cooling?

Energetic Particle Transport Equation

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial x_i} \quad \mathrm{K}_{ij} \frac{\partial f}{\partial x_j} \quad - v \cdot \nabla f \quad \frac{1}{3} \nabla \cdot v \frac{\partial f}{\partial v} \quad Q$$

Diffusion

Advection

Energy change

Sources and sinks

Assumes abundant scattering.

Energetic Particle Transport Effects

In the diffusive limit (abundant scattering) the particle transport equation implies:

$$\frac{E}{E_i} = \left(\frac{r}{R_i}\right)^{\frac{-4}{3}}$$

The particles lose energy as they travel outwards from the sun!

Simulation: Parameters

- Simple particle motion, assume adiabatic over short timescales
- Parker spiral magnetic field, radial solar wind
- We're not solving the transport equation!
- We are calculating the particle trajectories and comparing it with the simple analytic result shown previously.

Simulation: Parameters

- Mono-energetic, impulsive release of particles at the sun.

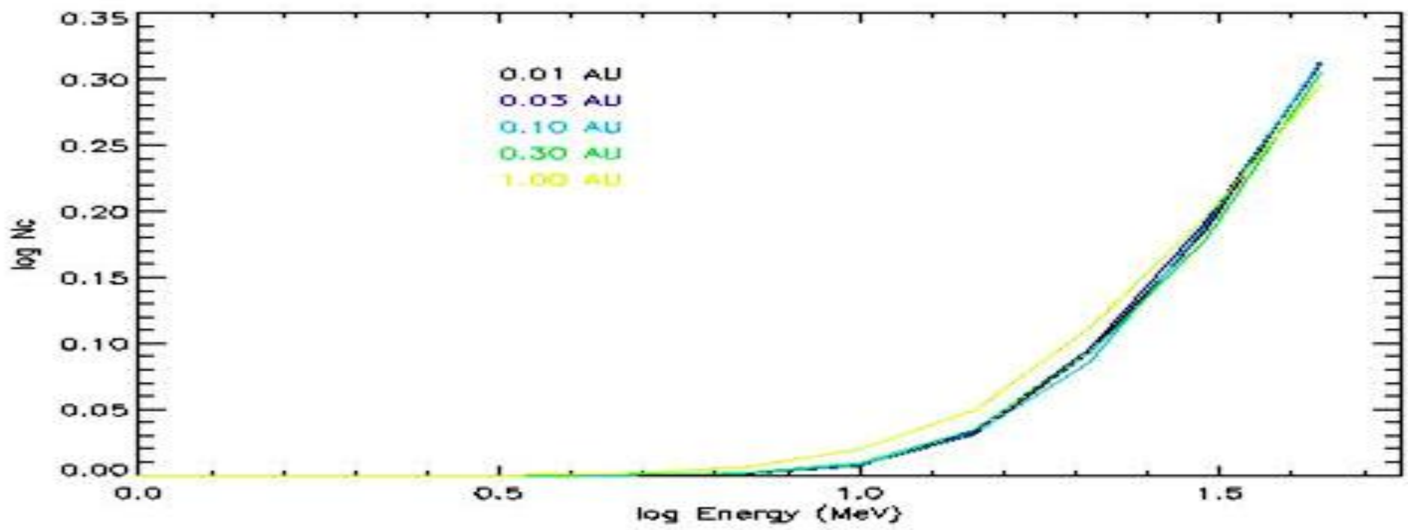
- Scattering off magnetic irregularities: accepts mean free path as input.

- Only considering iron nuclei, can compare with ACE and Wind data.

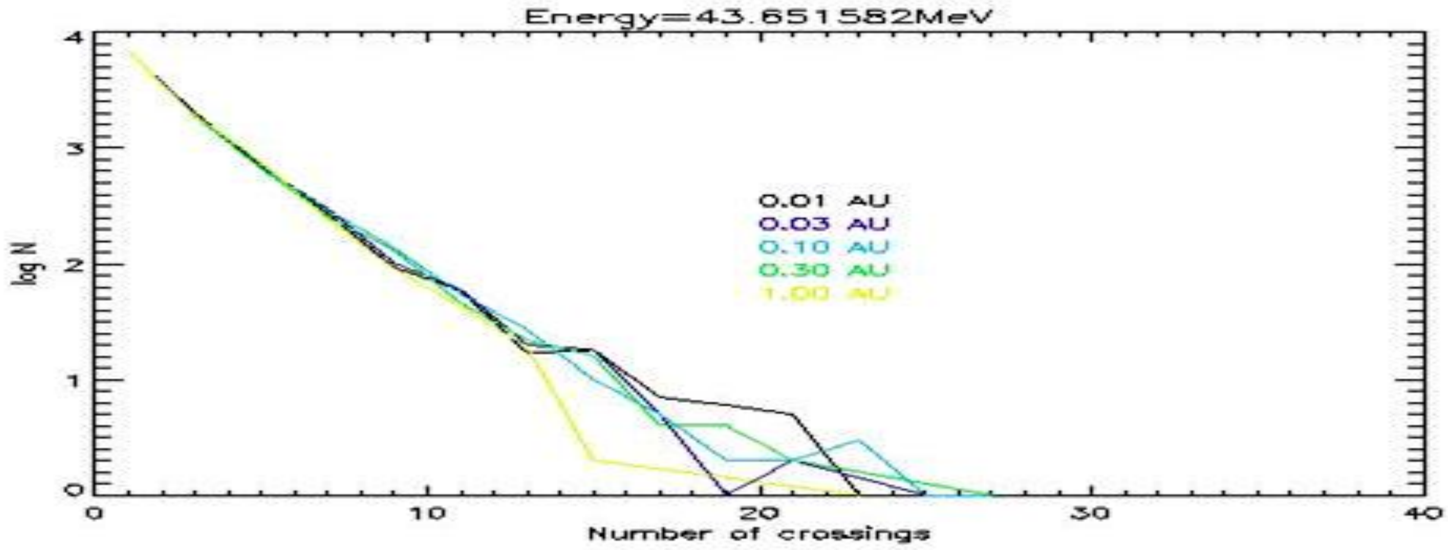
- Non-relativistic: only valid for particle energies up to ~ 50 MeV.

- 5 mean free paths, 30 energy steps (logarithmically spaced), 10,000 particles each.

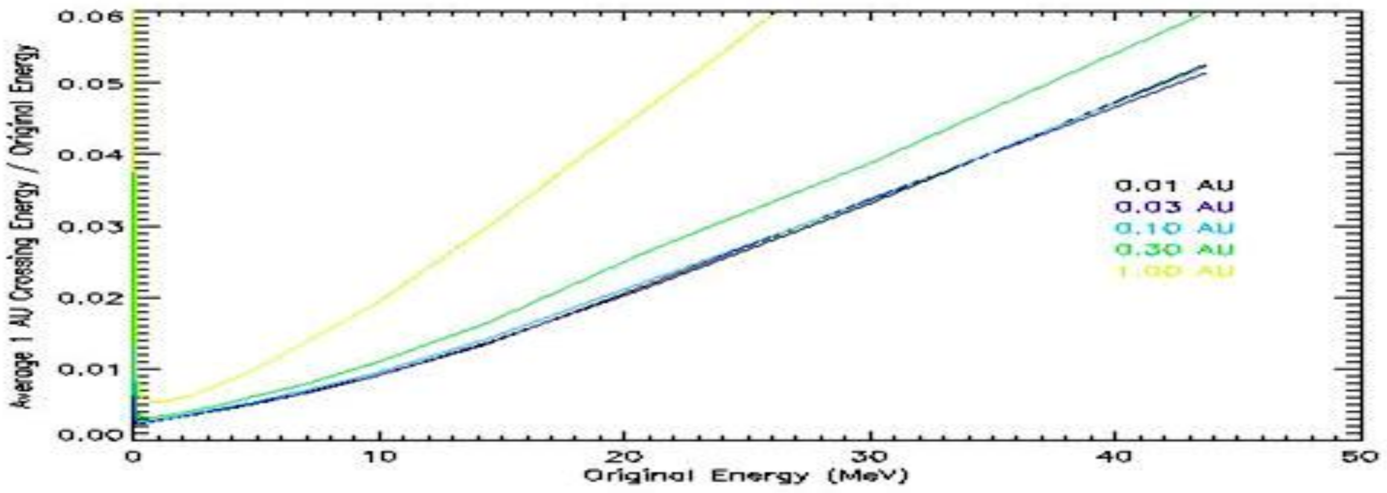
Simulation: Results I



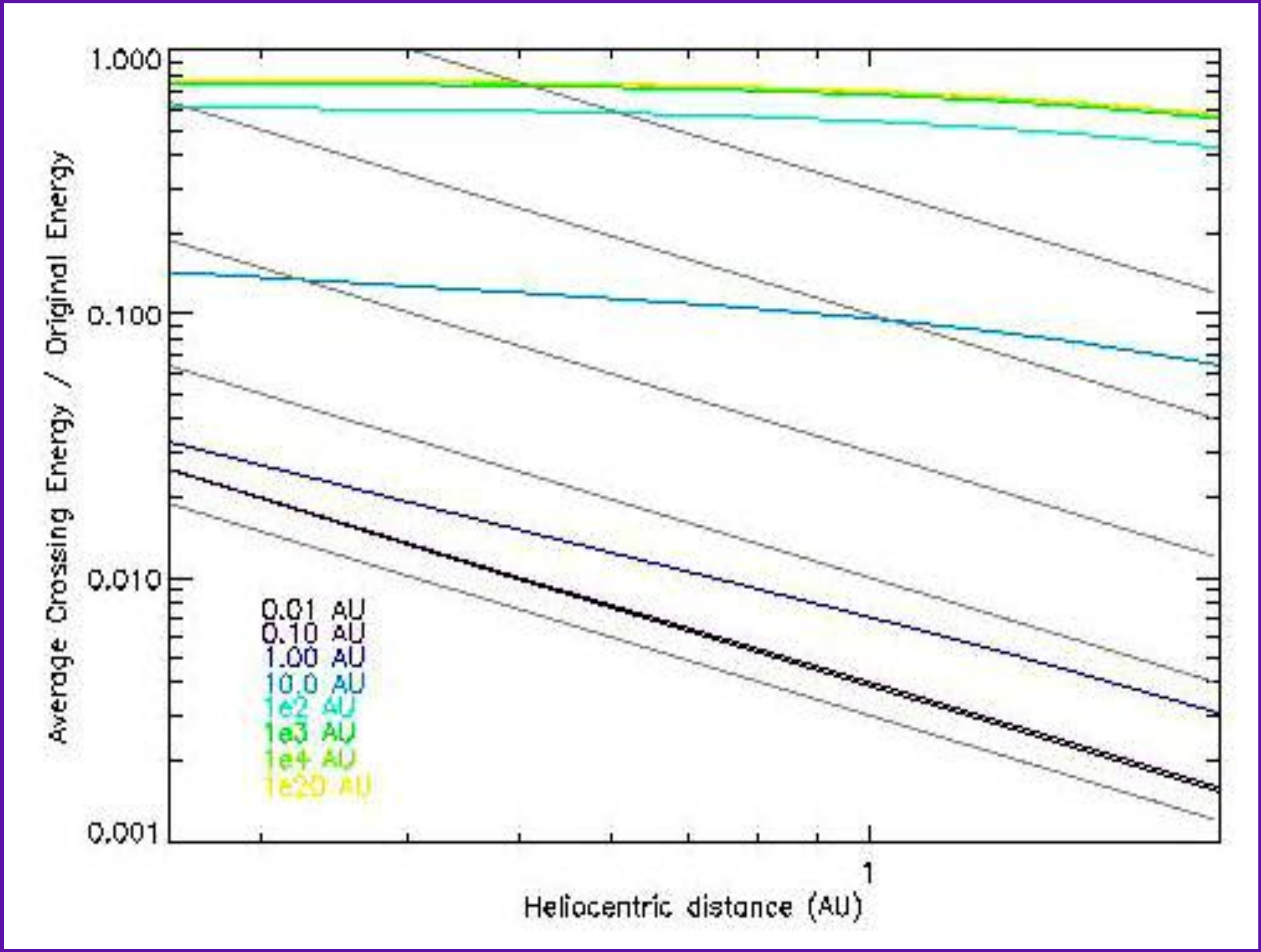
Simulation: Results II



Simulation: Results III



Simulation: Results IV



Conclusions

- 1 AU crossings increase with particle energies, weak dependence on mean free path

- At low energies, essentially all particles cross only once. As energy increases, get an approximately exponential distribution of 1 AU crossings.

- At long mean free paths and higher energies, particles retain more of their original energy.

- For typical solar system mean free paths (< 1 AU) the diffusive approximation is fairly good.

- These results can now be incorporated into a larger study considering the other parts of solar flares.