# Accurate Environment Simulation

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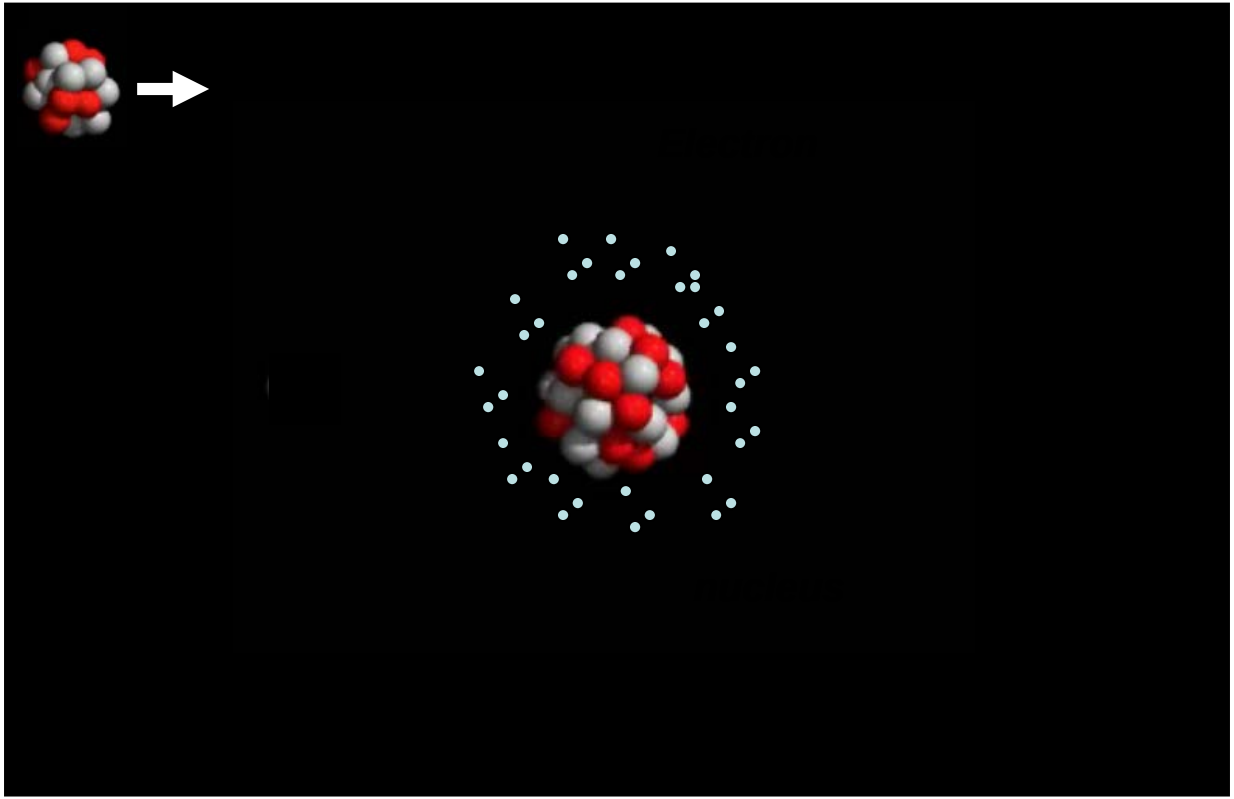
# Outline

- Radiation Transport
- Heavy Ion Radiation Environments
- Track Structure and Charge Motion (focus on >100 MeV/u)
  - Commercial devices
  - Rad-hard devices

# Electronic Stopping – Linear Energy Transfer (LET)



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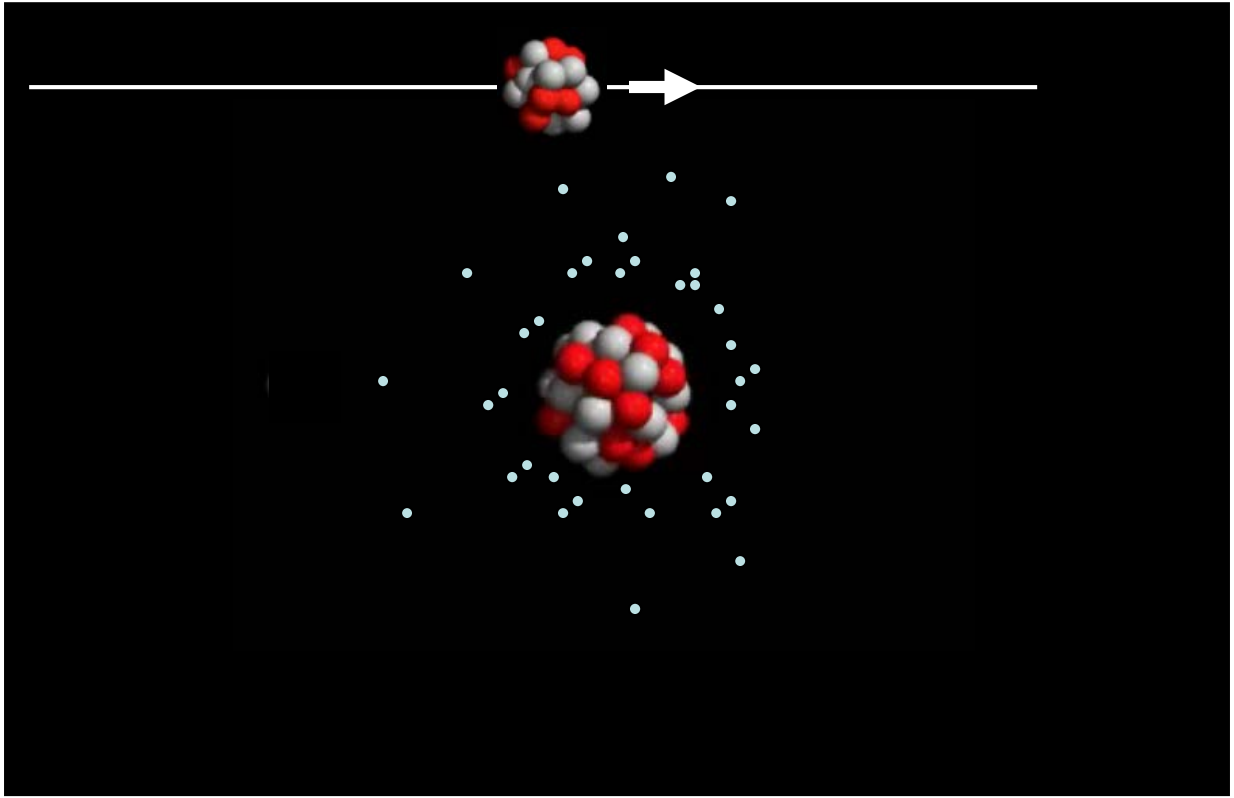
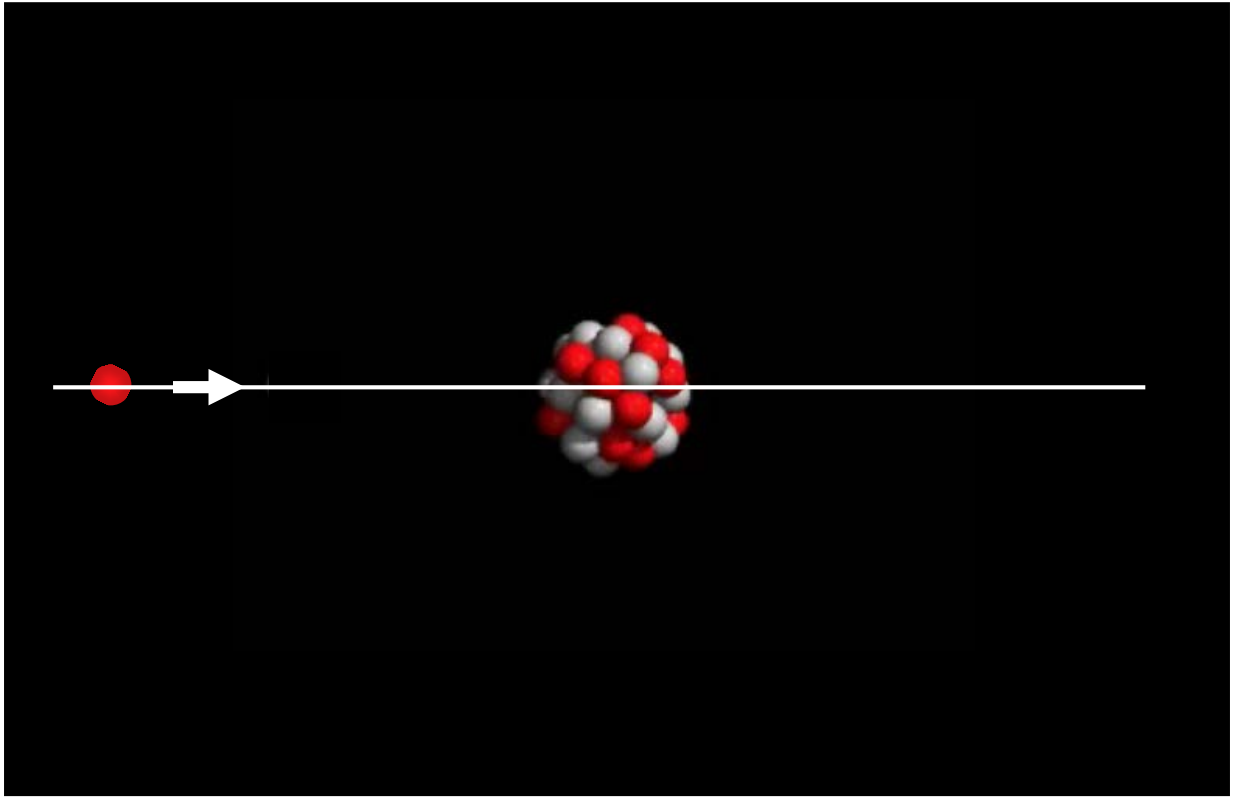


# Nuclear Reactions (Inelastic)



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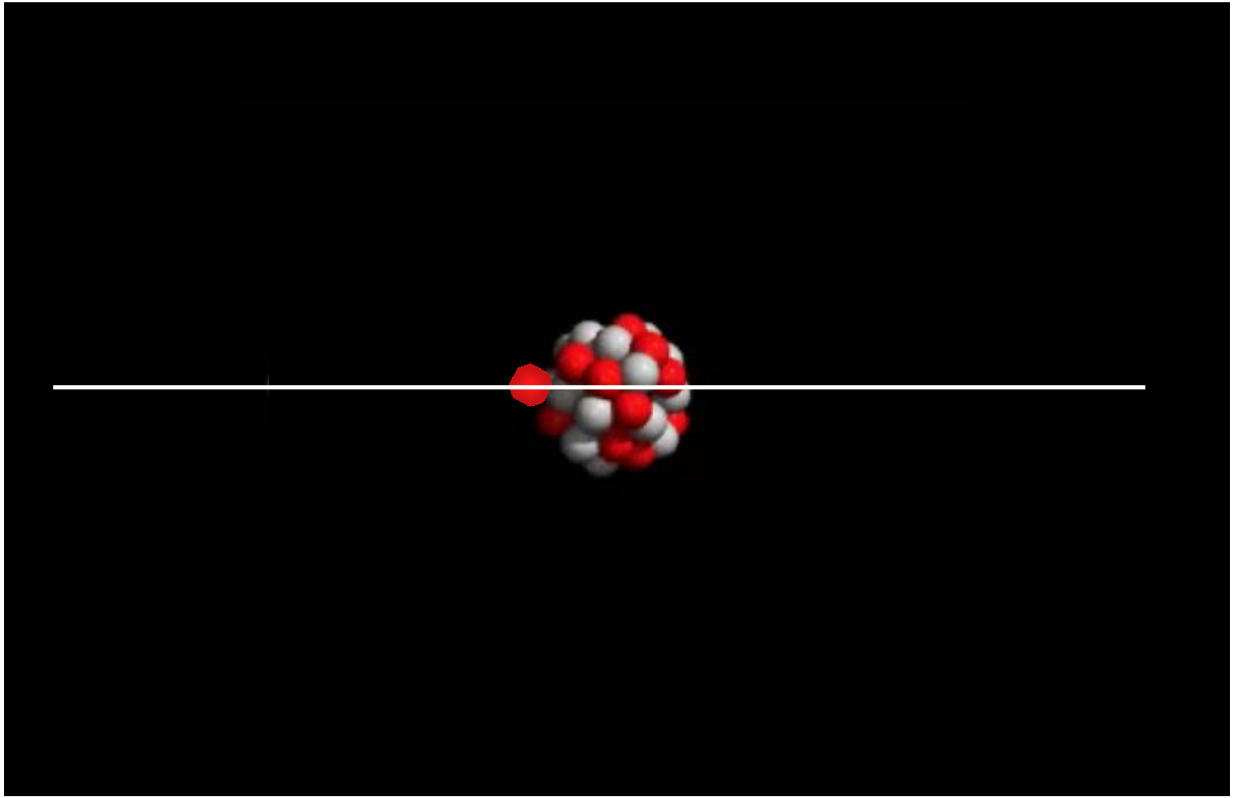

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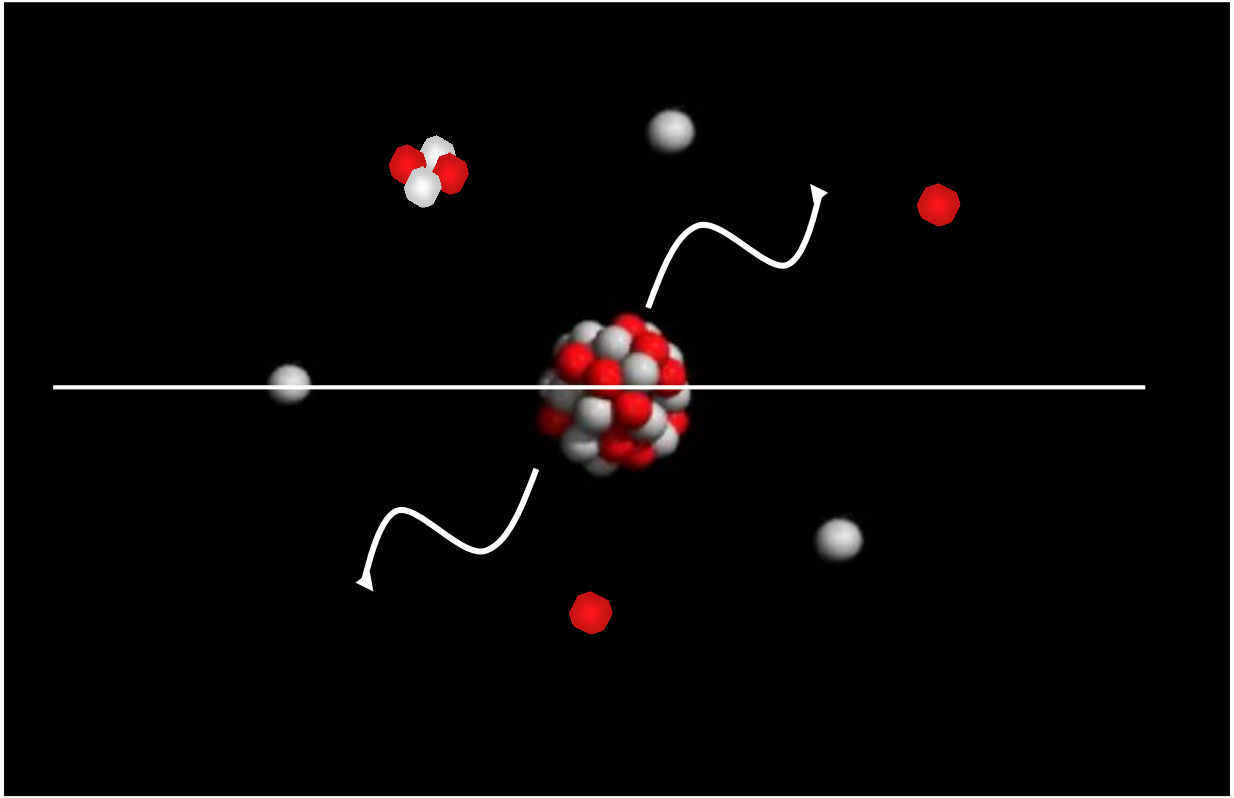

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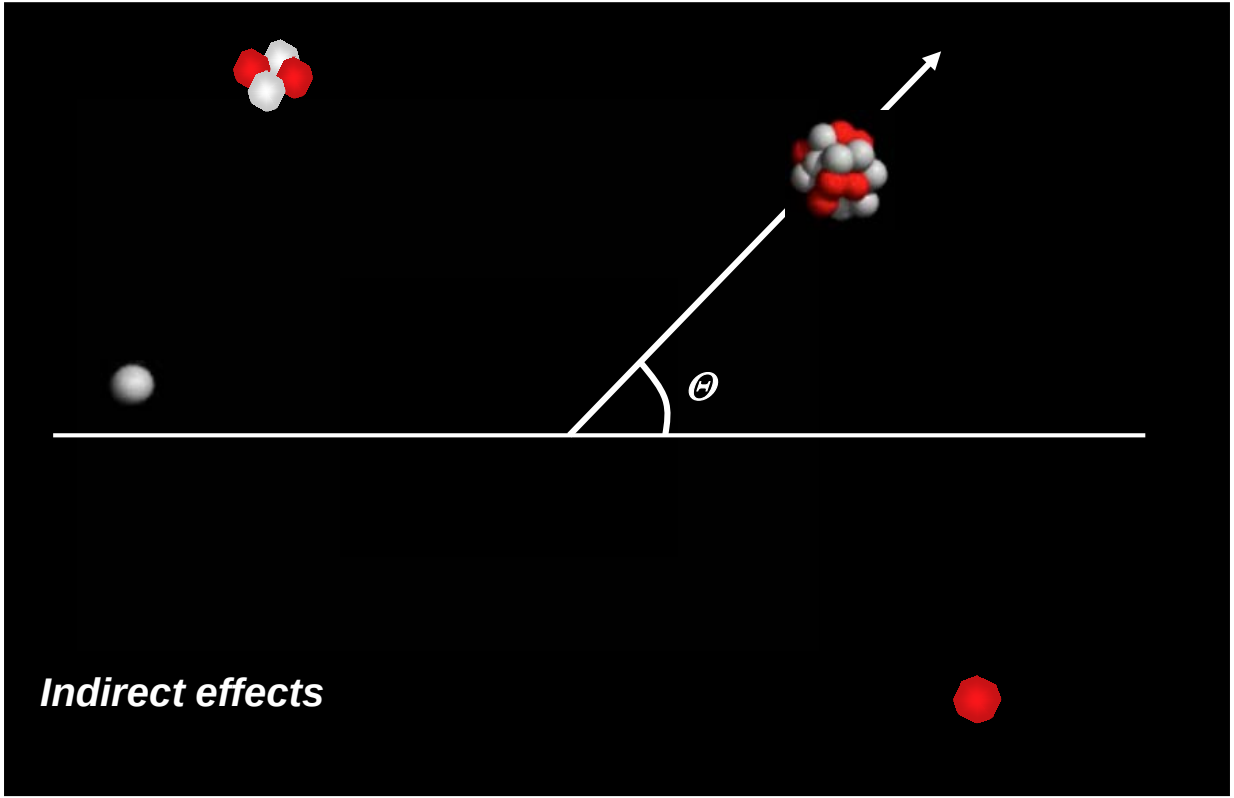
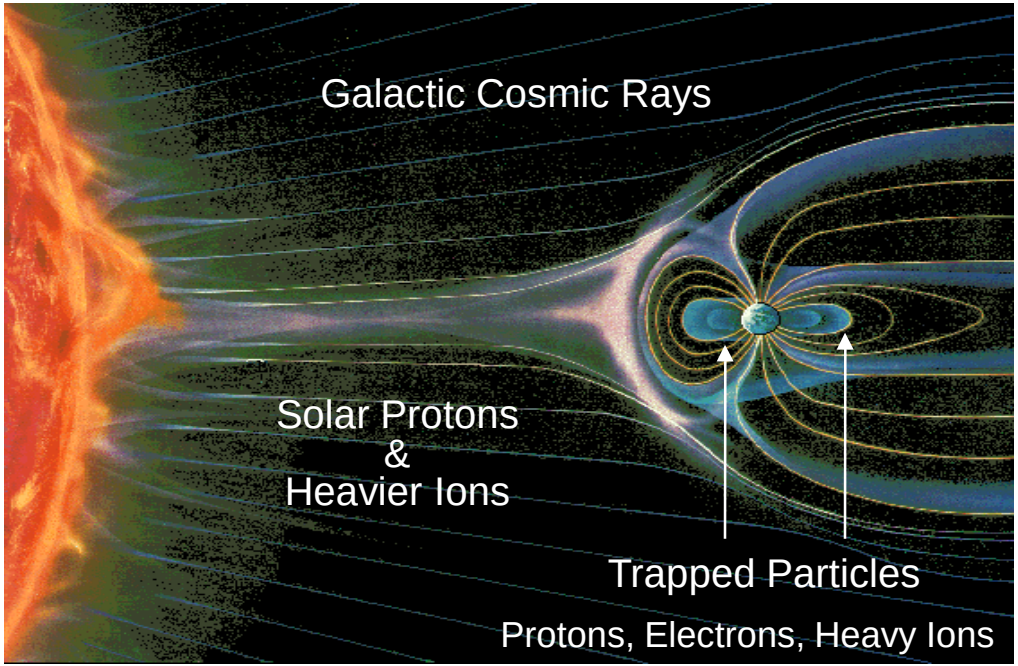
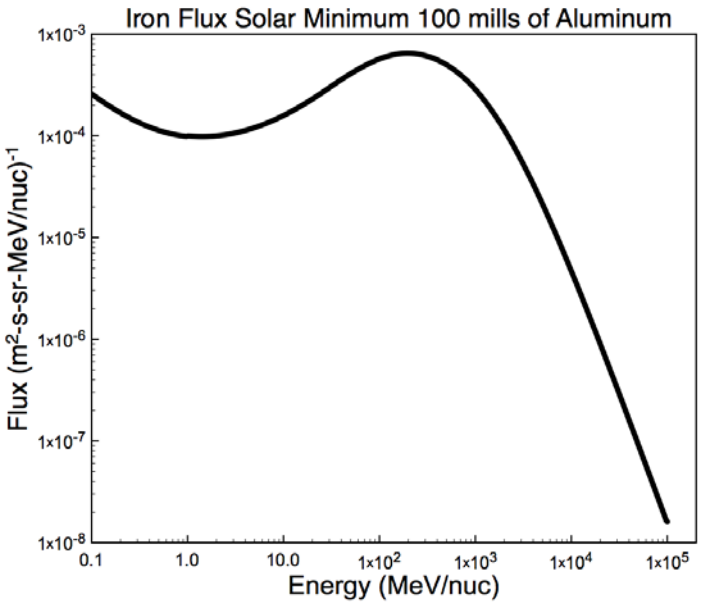


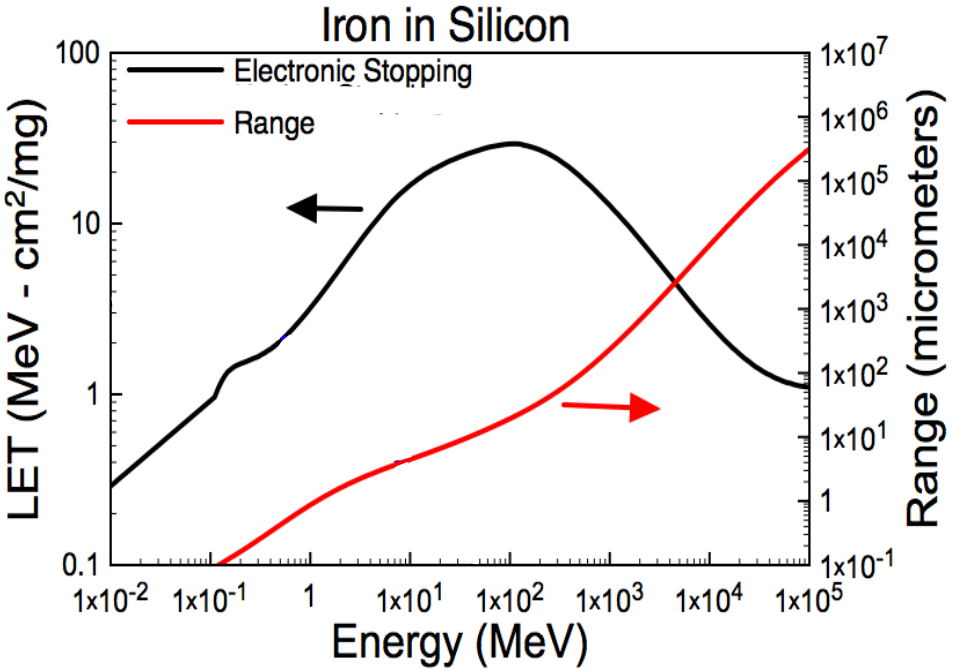
# Space Radiation Environment




Nikkei Science, Inc. of Japan, image by K. Endo

# Galactic Cosmic Rays – Iron only




https://creme.isde.vanderbilt.edu/

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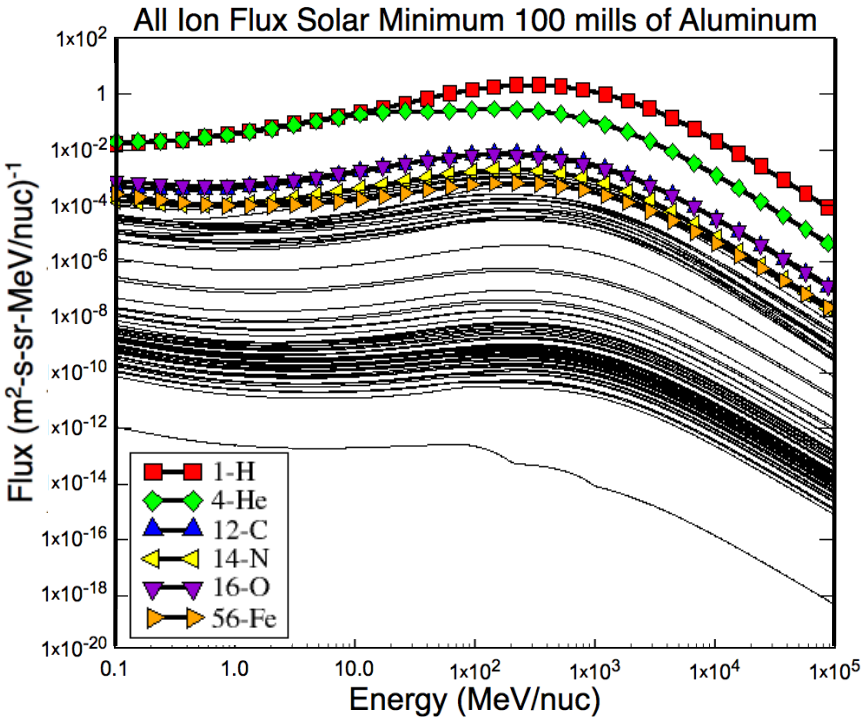


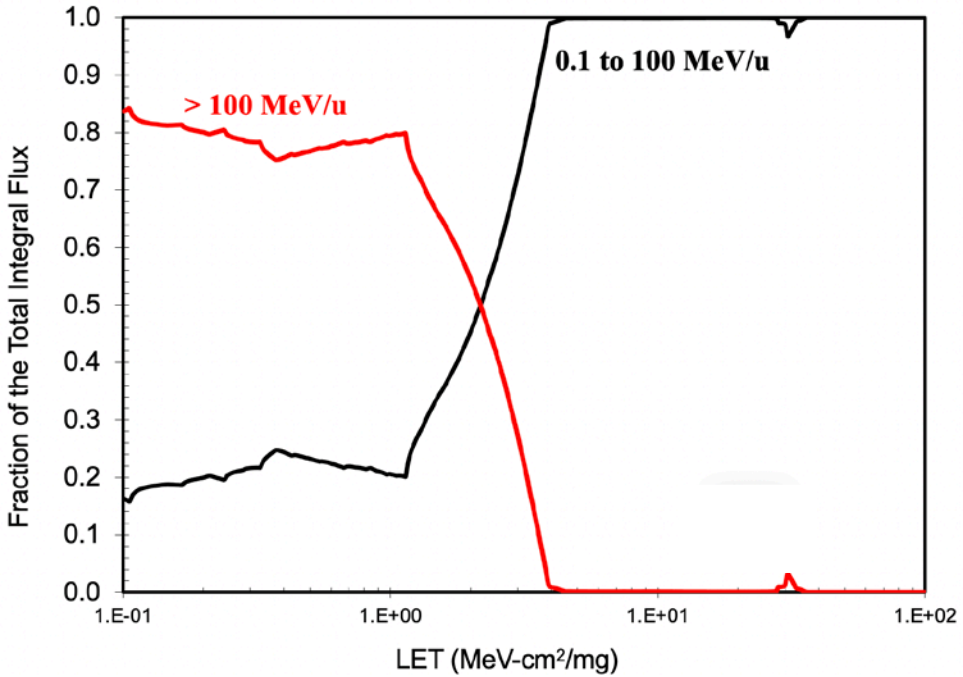


Typically :

- higher LETs - destructive events
- lower LETs - soft commercial devices Z

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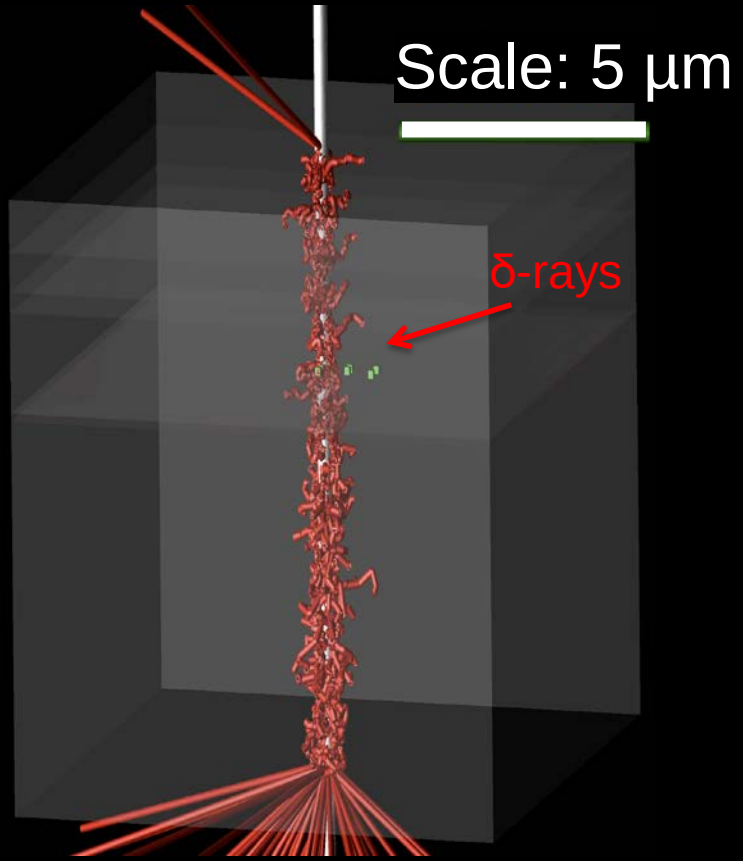
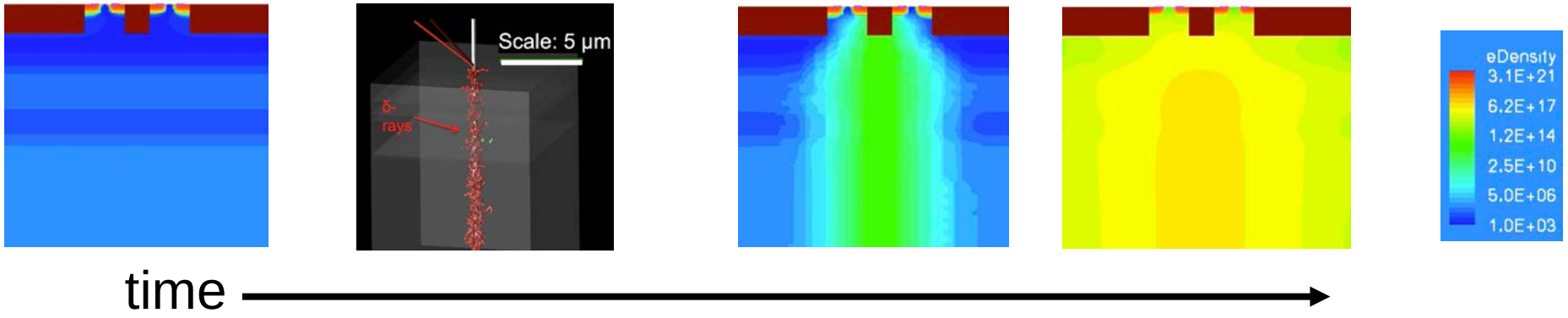
# Monte Carlo Simulation of Radiation Transport

- Monte Carlo tools contain comprehensive set of physical models for radiation transport
  - Geant4, MCNPX, Fluka, PHITS, JQMD, PENELOPE etc..
- Vanderbilt tool: MRED
  - Unique combination of models developed by the physics community



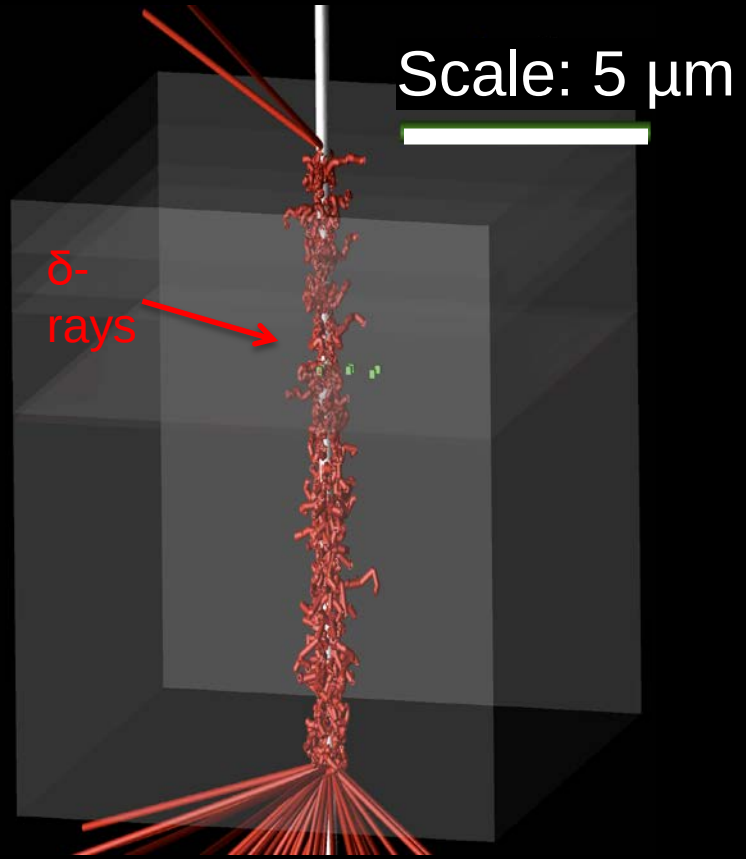
# Charge Sharing




- Time steps of charge motion
- Initial charge distribution spreads rapidly, faster than circuit response time
- A single ion event can induce current on more than one transistor
- Implications for different track structure for low and high energy ions with same LET

O. A. Amusan, TNS 2006 &2007 - TCAD Simulation Courtesy John Hutston

## 5 MeV/u Fe Strike

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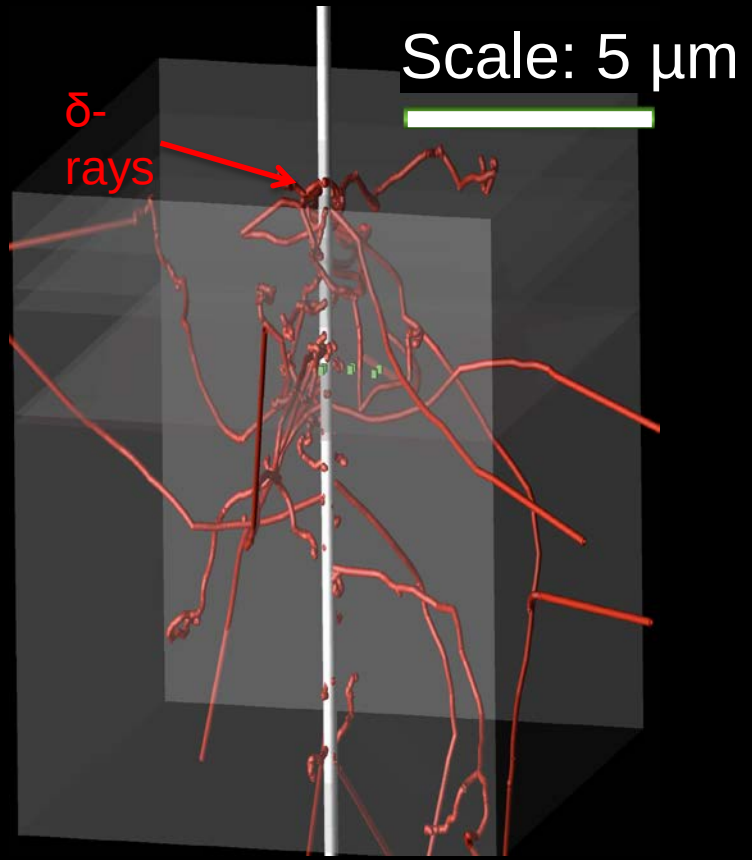
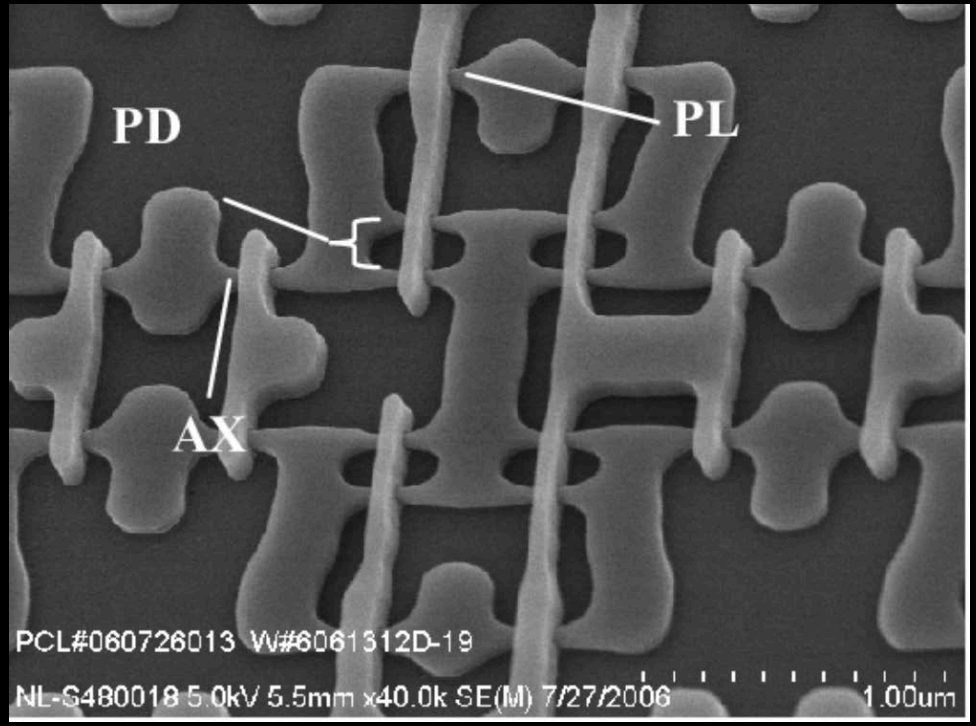


# Advanced Devices and Ion Tracks

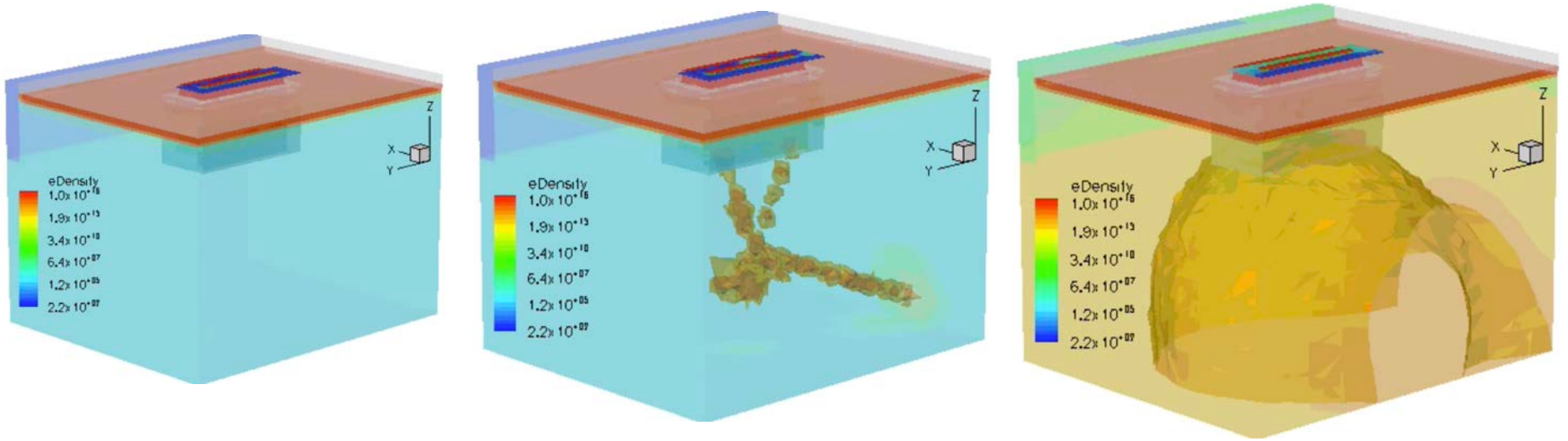
D. Lu, et. al., “Compact modeling of variation in FinFET SRAM cells,” IEEE Design and Test of Computers 27(2):44-50, March 2010





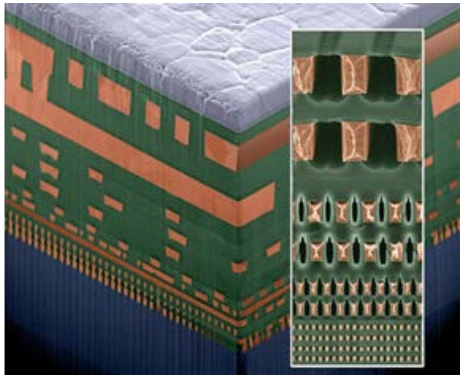
Scale: 5 µm

# Nuclear Reactions




time

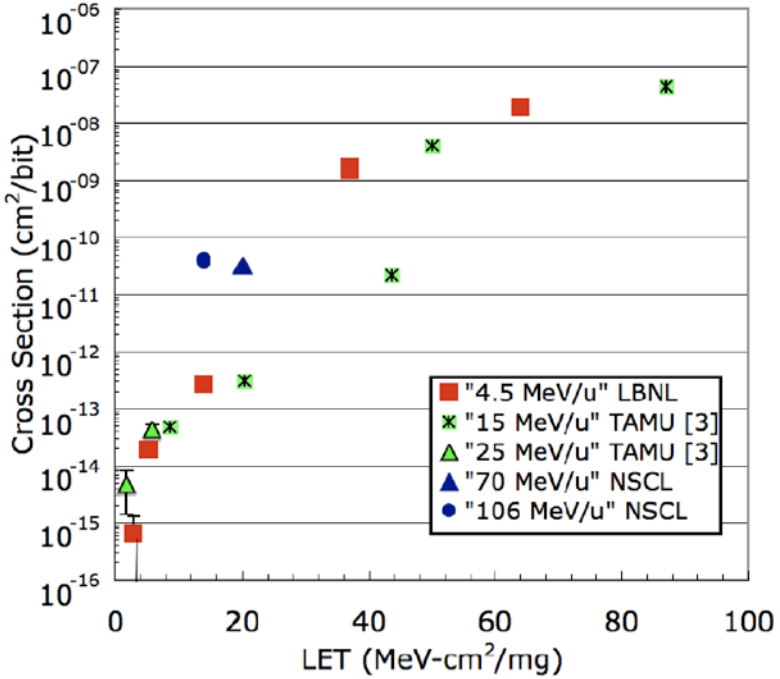
# Complex Material Systems – Nuclear Reactions



http://images.dailytech.com/nimage/4621_21476.jpg

- Ion-Ion nuclear reactions in non-silicon material near the sensitive volume contribute to the soft error response
- To date, this is only important for radiation harden circuits

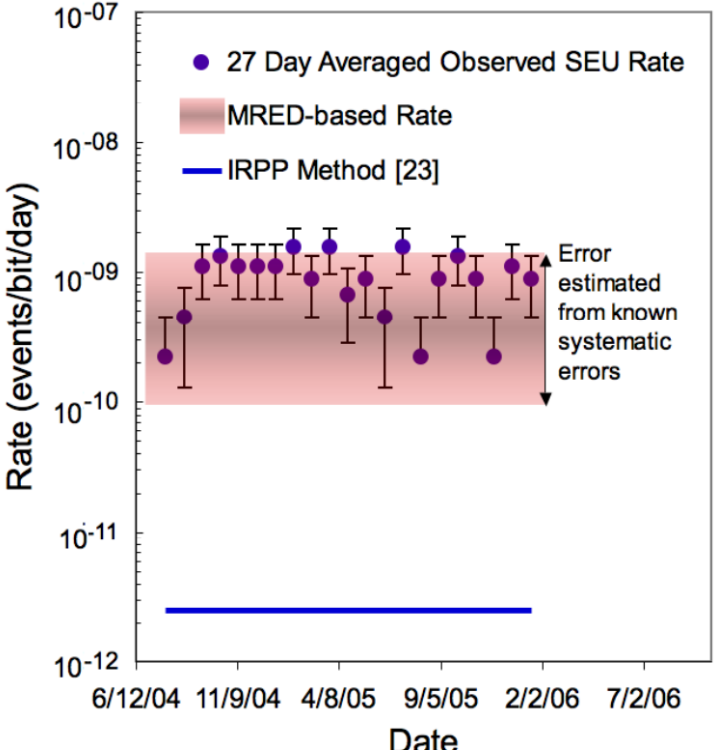
Experimental evidence for this effect on a CMOS SRAM




Warren et al. TNS 2005, Dodd et al., TNS 2007, Reed et al. TNS 2007

# Observed and Predicted SEU Rate for a RAD-HARD SRAM

- SRAM used on NASA MESSENGER spacecraft
- Observed Average SEU Rate:
  - **$1x10^{-9}$ Events/Bit/Day**
- Vendor predicted rate using CREME96:
  - $2x10^{-12}$ Events/Bit/Day
  - Classical Method nearly a factor 500 lower than observed rate




Reed, TNS, 2007

# Summary

- Radiation environment covers a wide range of ion energies
  - Energy >100 MeV/u dominate for LETs < 3 MeV-cm$^2$/mg
- Ion track effects (two regimes)
  - Long range delta rays (commercial)
  - Nuclear reactions (rad-hard)
- > 100 MeV/u beams needed to characterize these effects
- Other considerations, e.g., longer range of higher energy particles, will be discussed by other speakers.