# Cosmic Ray Effects on Micro-Electronics (CRÈME) Tools

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**2017 SEESAW**

# CRÈME Website

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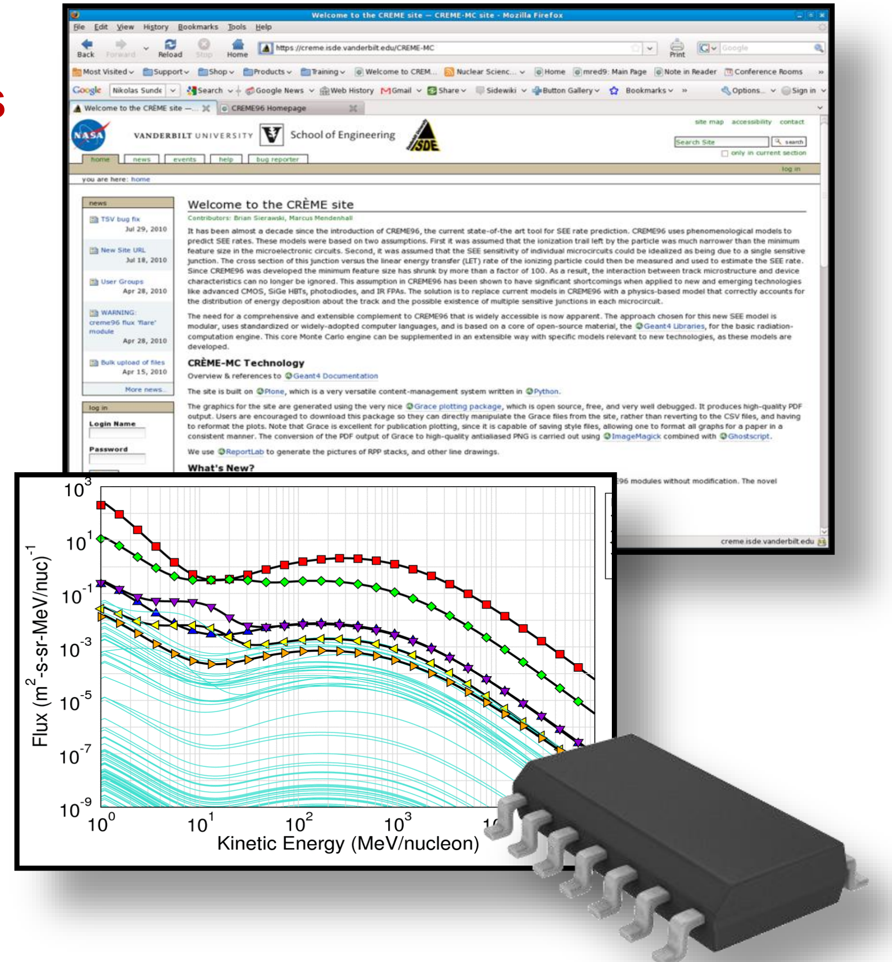
- ISDE hosts the CRÈME tool suite for predicting on-orbit error rates and proton total ionizing dose in microelectronics
- While there are multiple open-access options available, none are U.S.-based and controlled except for CRÈME
- ISDE maintains the code and operation of CRÈME, ensuring trust as well as continuing access
- Supports over 2000 users!




https://creme.isde.vanderbilt.edu

# Radiation Effects on Micro-Electronics

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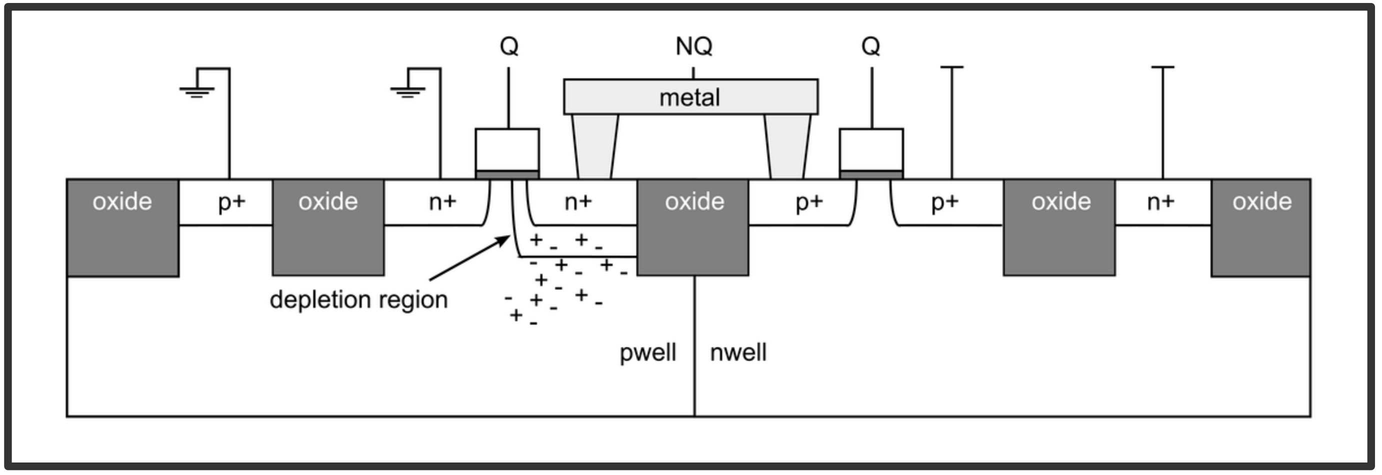
- **Single event effects are unwanted or erroneous responses triggered by the passage of a high energy particle through the active region of that device**
  - e.g. single event upset (SEU) in memory cells
- **Total ionizing dose due to protons and electrons causes devices to suffer threshold shifts, increased current leakage (and power consumption), timing changes, decreased functionality**
- **Others not addressed by CREME**

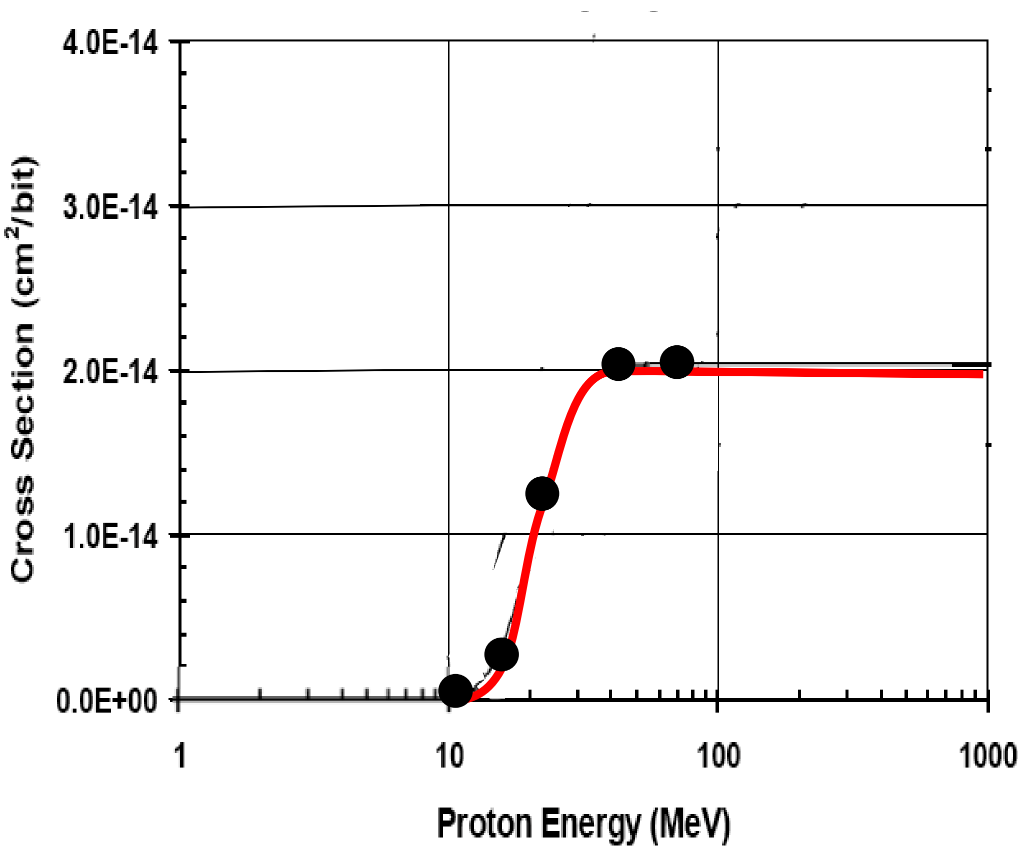


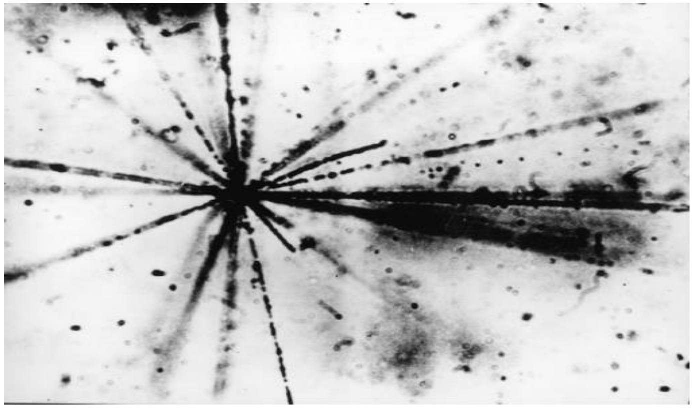
# CRÈME Environments

- **Near-Earth particle environment (Sawyer & Vette ‘76)**
  - Extracted from tables of AP8 proton fluxes
  - User selects between solar minimum and solar maximum
- **Geomagnetic shielding (Nymmik ‘91)**
  - Precomputed vertical cutoff magnetic rigidity values
  - Generates a geomagnetic transmission function (percent vs rigidity)
  - User selects between quiet and stormy conditions
- **Galactic cosmic ray environment (Nymmik ’92)**
  - Relates intensity to Wolf sunspot number
  - Typically transported through spherical shell shielding
  - Reduced to linear energy transfer spectrum
- **Solar particle events**
  - Based on the October 1989 event, provides worst-week, worst-day and peak 5 minute fluxes

# Ground Test: Proton-induced Cross Section

**Cross-section ($cm^2$/bit) = # of errors / (fluence · #bits)**



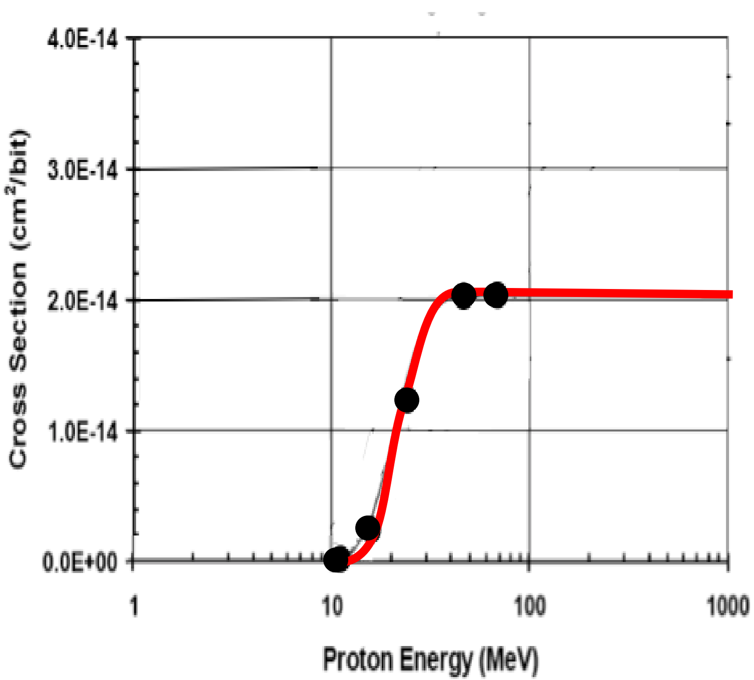
**Indirect**

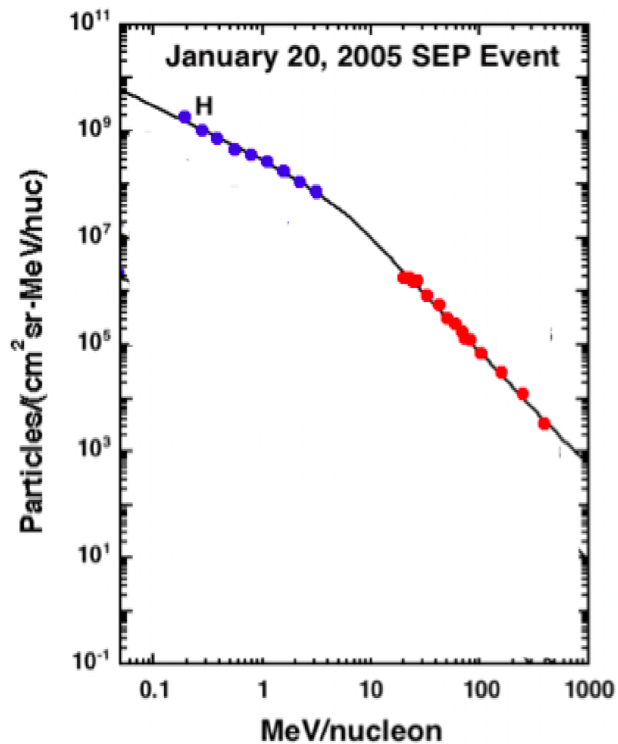
After Petersen, NSREC SC, 2008

# Proton Event Rate Predictions (Circa 1980)



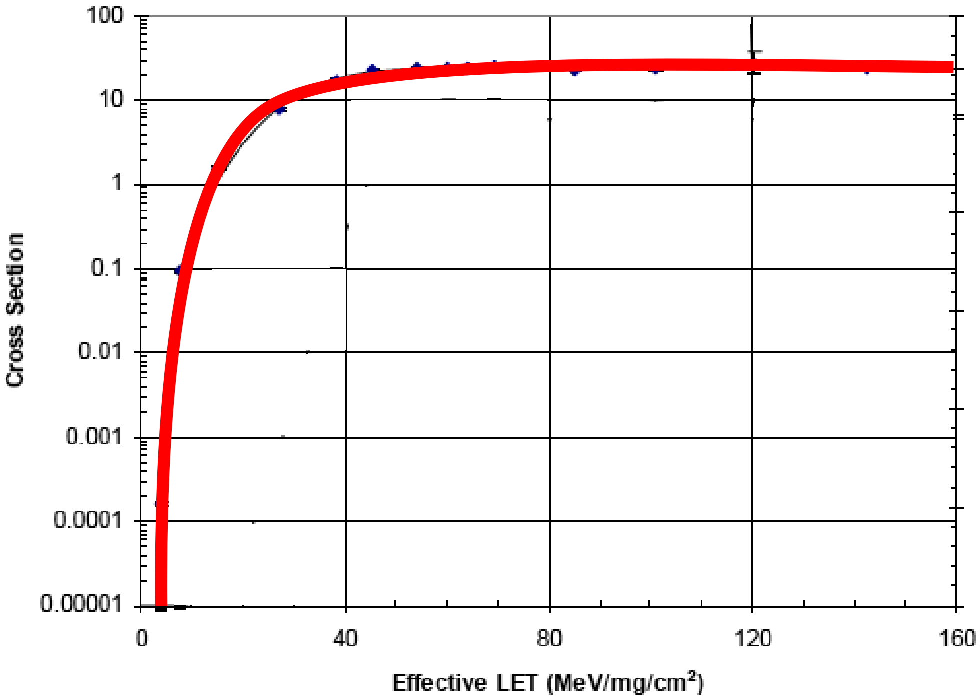
**SEE On-Orbit Rate = Ò Measured Cross Section over a certain energy * Space proton Flux at the energy dE**

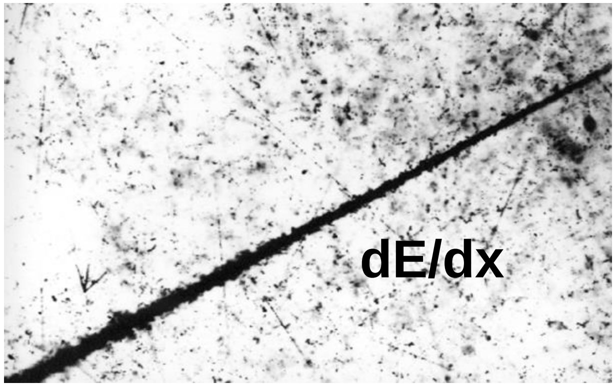


# Ground Test: Heavy Ion Cross Section

## Cross-section ($cm^2$) = # of errors / fluence



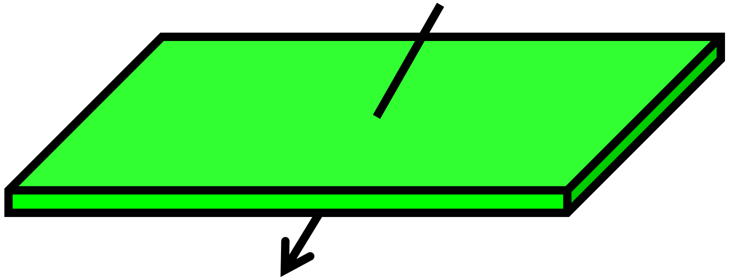




**Direct**

After Petersen, NSREC SC, 2008

# Ion Event Rate Predictions (Circa 1980)

- **Pickel and Blandford investigated upsets in silicon NMOS dynamic RAM**
- **Introduced right parallelepiped (RPP) sensitive volume**
  - Diffusion ignored
- **Sensitive region transistor diffusion, connected to storage capacitor**
- **Sensitive volume approximated as 21 μm x 3.5 μm RPP**
- **Integration over path length distribution yields rate**



**$Q_{crit}$ = 0.25 pC**

J. C. Pickel and J. T. Blandford, Jr., "Cosmic Ray Induced Errors in MOS Memory Cells," IEEE Trans. on Nucl. Sci., vol. 25, no. 6, pp. 1166-1171, 1978.

# SEUs from Lightly Ionizing Particles

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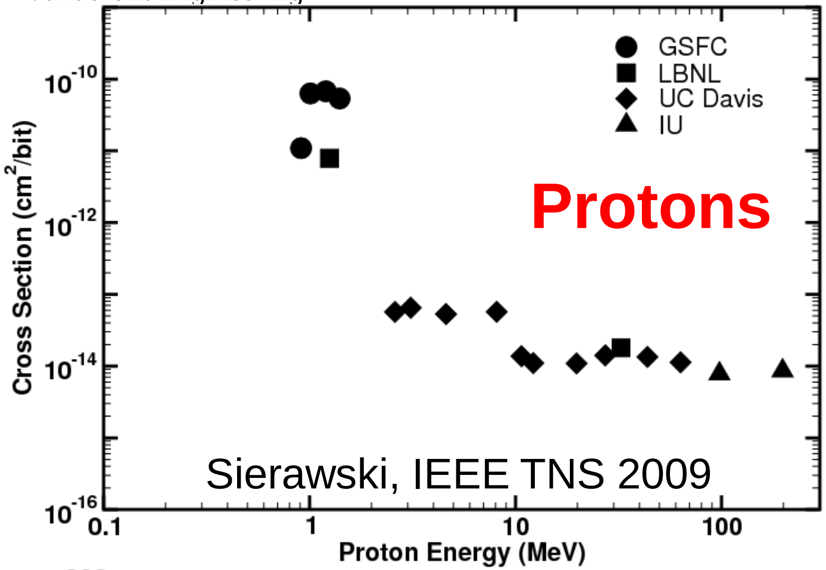
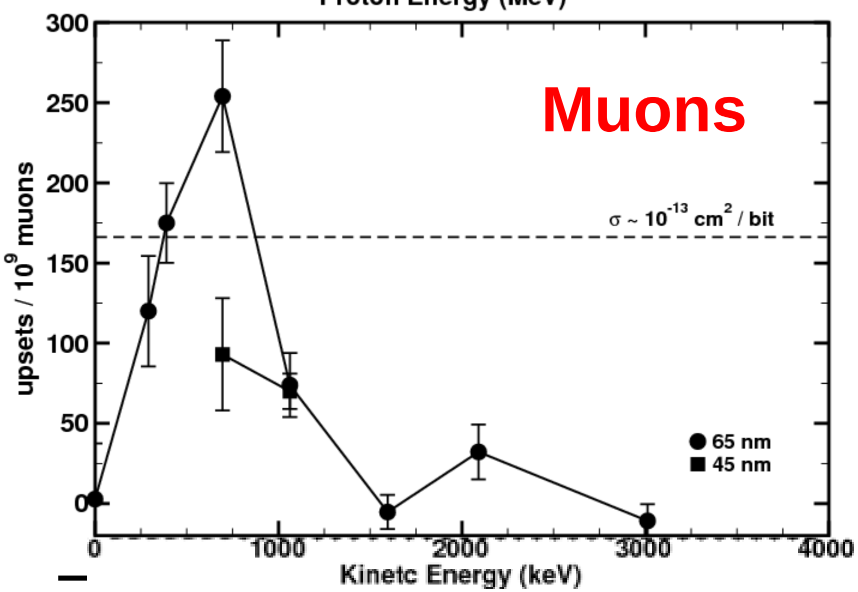
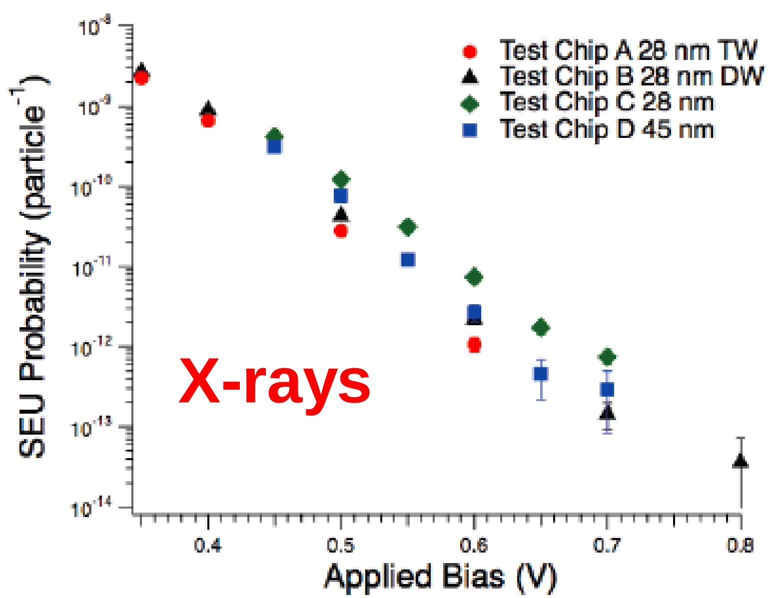
- **Decreasing features sizes have lead to a reduction in critical charge**
- **With $Q_{crit}$ < 1 fC SRAMs have become sensitive to effects from lightly ionizing particles**




Sierawski, IEEE TNS 2010




King, IEEE TNS 2013

# Estimated SEU rates: GEO

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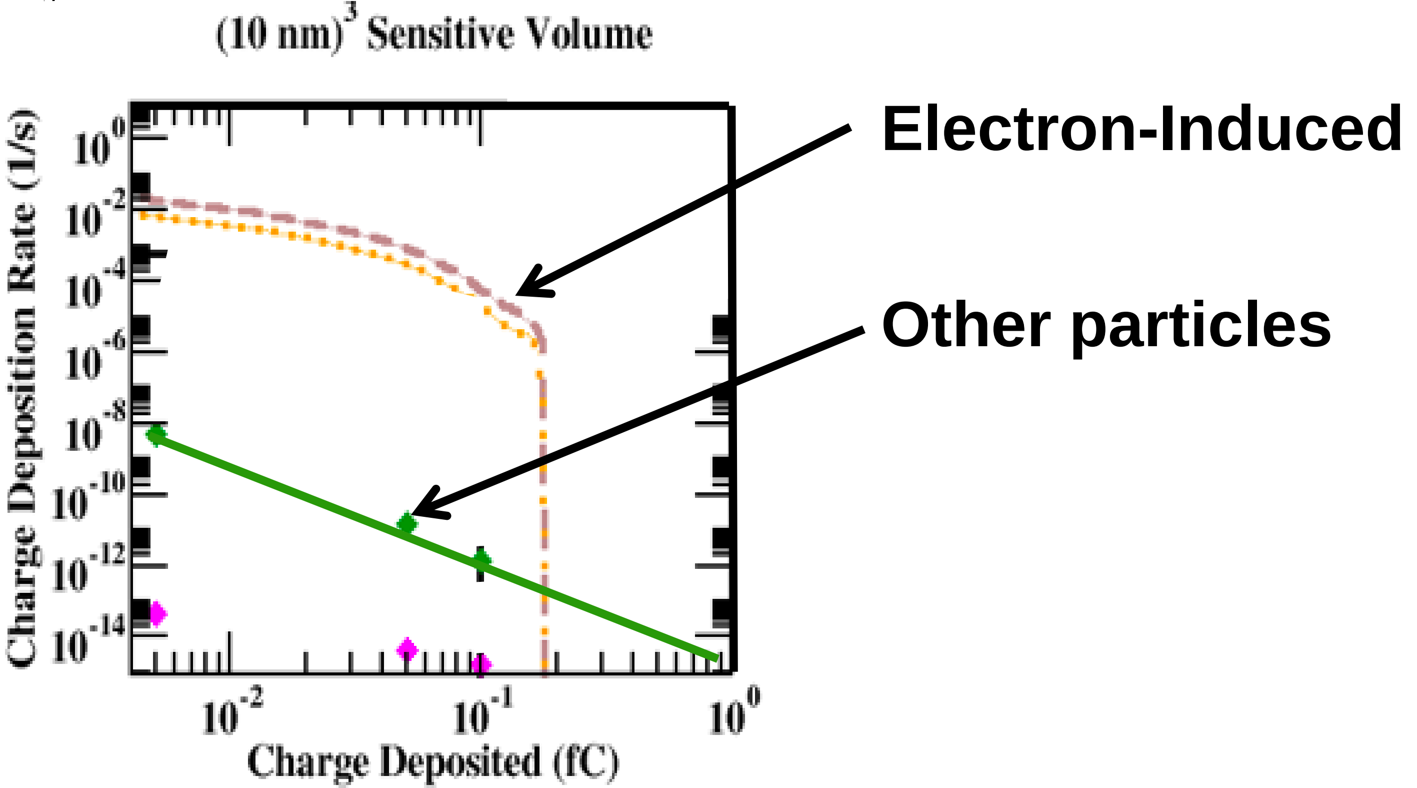


- **SEU rates are dominated by electron environment if critical charge is low enough and geometry is large enough**
- **This is true for other particles environments**

J. M. Trippe *et al*., "Electron-Induced Single Event Upsets in 28 nm and 45 nm Bulk SRAMs," in *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2709-2716, Dec. 2015.

# Monte Carlo Rate Predictions

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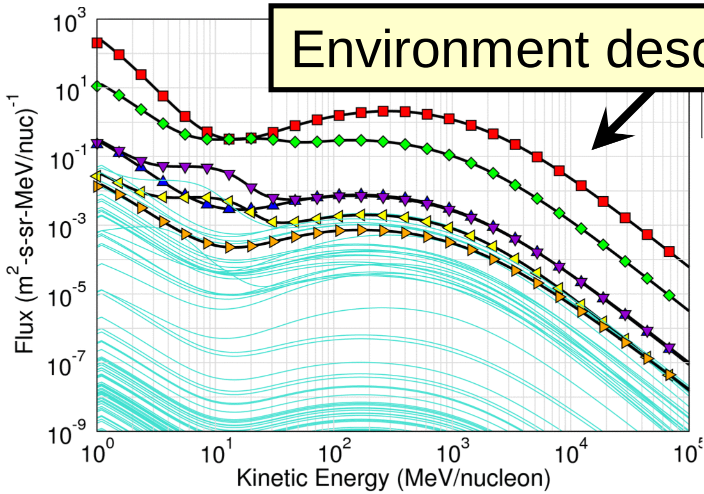


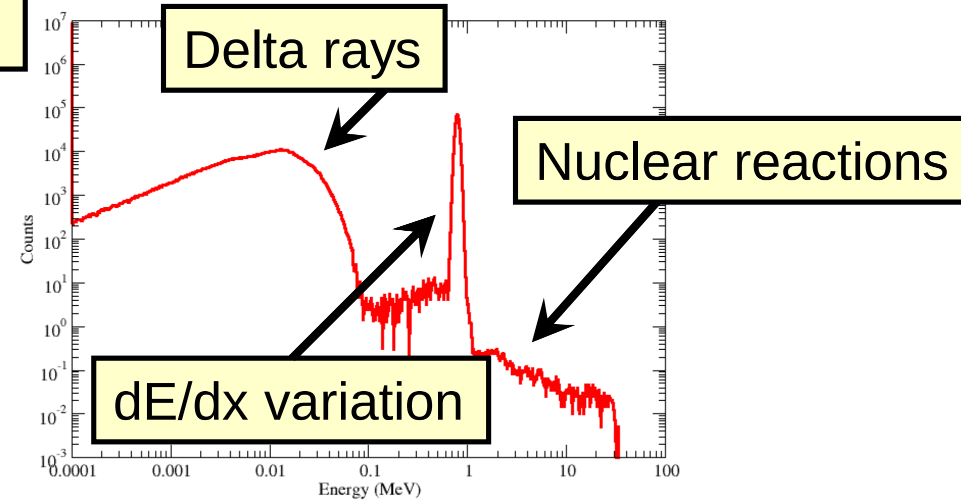


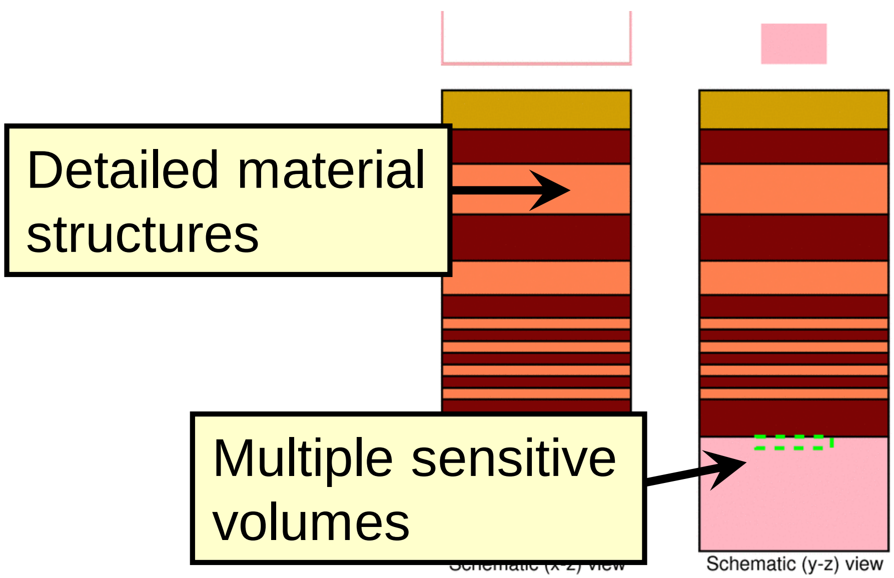


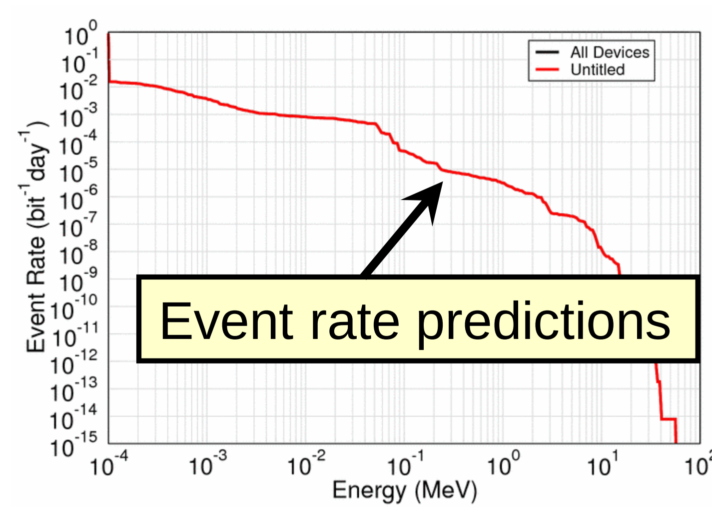

# RadFx Missions

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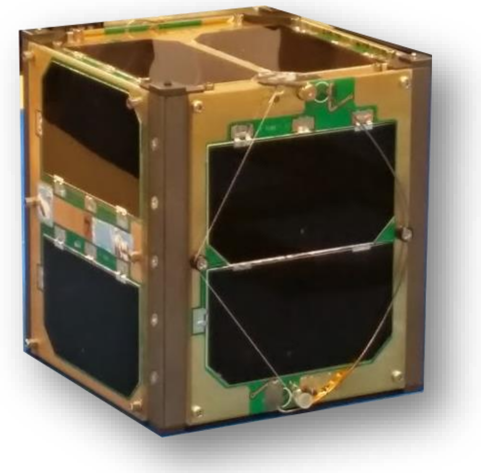
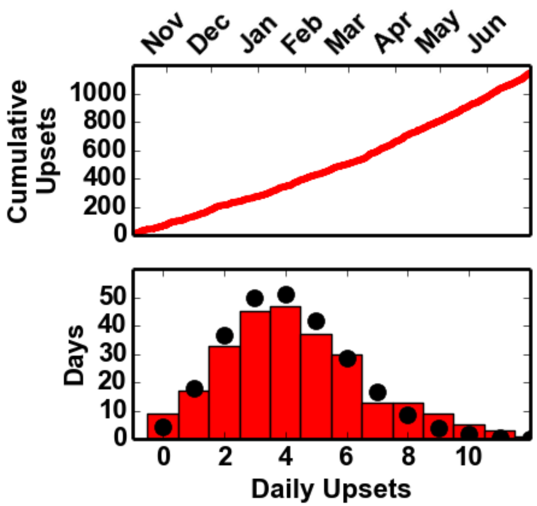
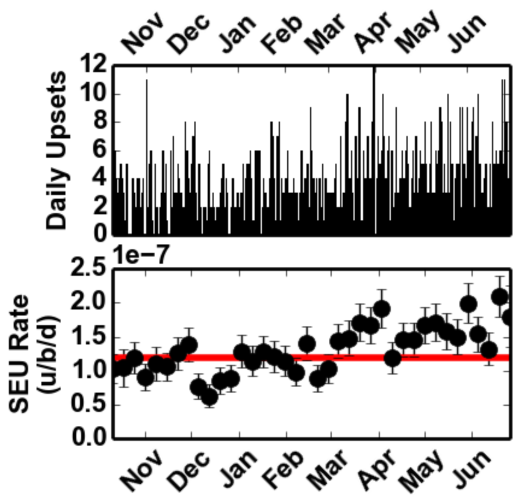
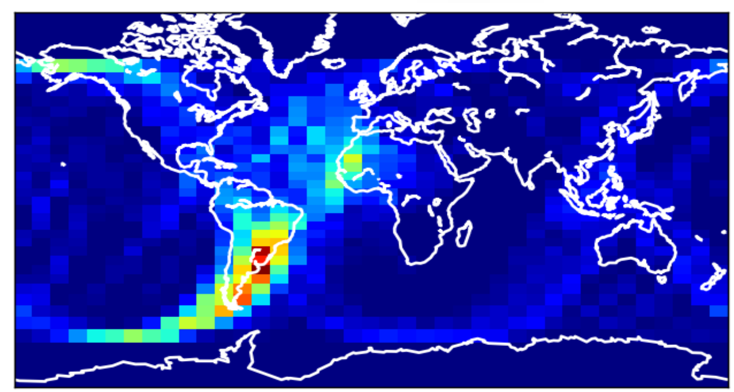
- **Launched Oct. 8, 2015 on board Atlas 5 from Vandenberg, CA**
- **Achieved 800 – 500 km, 65° inclination orbit**
- **Carries Vulcan payload (1 LEP) with 8 x 4Mb SRAM (ISSI IS64WV25616B) SEU experiment**
- **Nearly world-wide radio coverage provided by amateur radio community**
  - Reports single event upsets, resets, power





# Conclusions

- **Combating evolution of environments, devices, and tool use by**
  - Incorporating AP9, updating GCR and geomagnetic models
  - Applying Monte Carlo methods to capture device response
  - Developing an API to access CREME96 calculations
  - Operating a CubeSat program to generate on-orbit datasets for advanced memories
- **Collaboration with partners is necessary for continued improvement**

# References


- R.A. Nymmik, “An Approach to Determination of Real Cosmic Ray Rigidities", Proc. 22nd Internat. Cosmic Ray Conf. (Dublin) 3, 652 (1991).
- R.A. Nymmik, M.I. Panasyuk, T.I. Pervaja, and A.A. Suslov, “A Model of Galactic Cosmic Ray Fluxes", Nucl. Tracks Radiat. Meas. 20, 427 (1992).
- D.M. Sawyer and J.I. Vette, "Trapped Particle Environment for Solar Maximum and Solar Minimum (AP8)", NSSDC Report 76-06, (1976).