COPPER: IR Imaging and Radiation Studies

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http://astrolab.slu.edu

Overview

Payloads

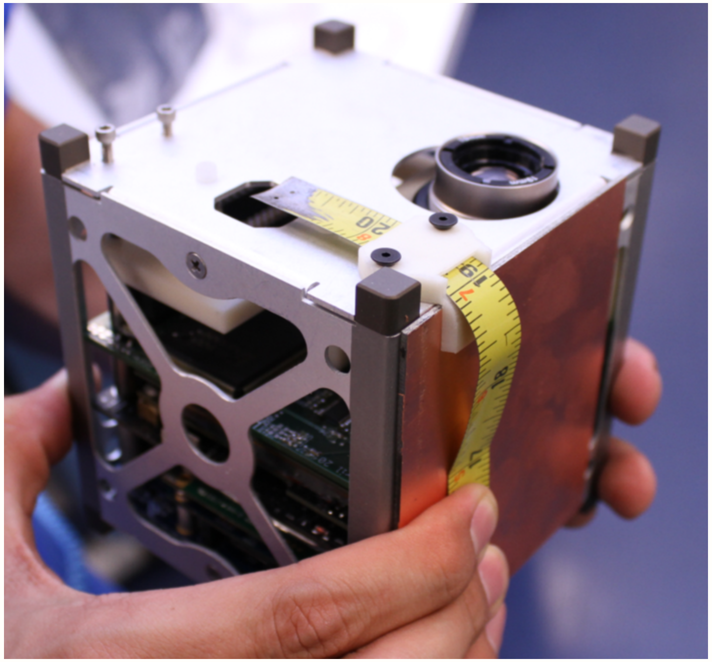
Spacecraft Bus

Conclusion

Saint Louis University
Space Systems Research Lab

- **Parks College of Engineering, Aviation and Technology**
  - 36 full-time faculty, 600 students
  - AE, ME, EE, BME, Civil, Aviation, Physics
  - SSRL organized in 2009
- **Joined AFRL's University Nanosatellite in 2009**
  - COPPER, Nanosat-6, 2009-2010
  - Argus-LO, Nanosat-7, 2011-2012
- **COPPER manifested through NASA CubeSat Launch Initiative**

The COPPER Mission



Imaging Mission:

Flight-test the abilities of a commercially available compact uncooled microbolometer array to take infrared images of Earth's oceans and atmosphere

Radiation Mission:

Improve the predictive performance modeling of radiation effects on small, modern space electronics devices by collecting radiation particle collision data from electronics monitoring experiments and relaying the data to the ground

Project Duration: 2009-2012

Initial concept: 2009-2010 Nanosat competition

Mission Modified to Fit the CubeSat Launch Initative

Manifested for Launch: NASA CRS-2 (ELaNa IV, March 2012), Falcon-9

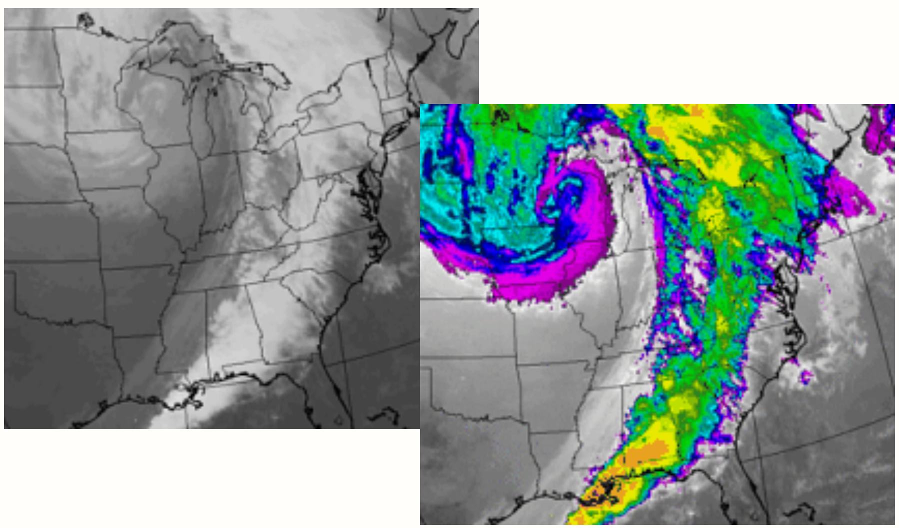
Science Basics

Imaging Payload

Long wave infrared (LWIR), 7 to 13 microns

Thermal emissions night and day

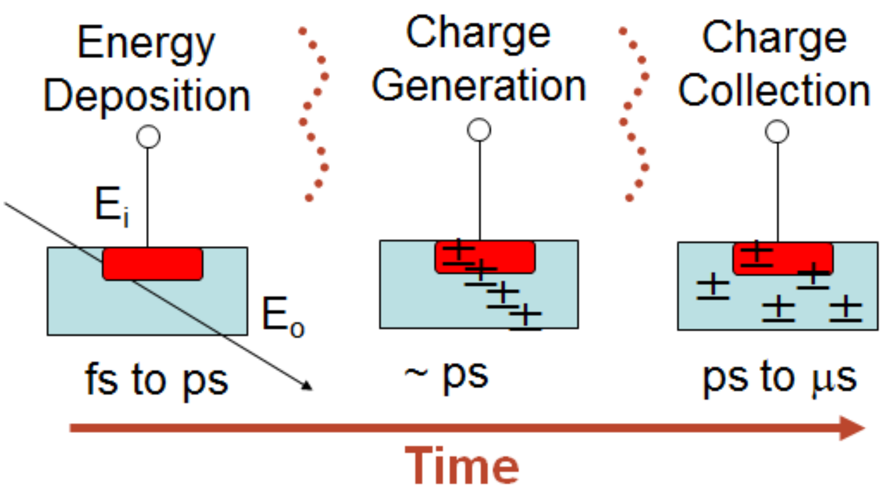
Clouds, ocean features, and urban heat islands



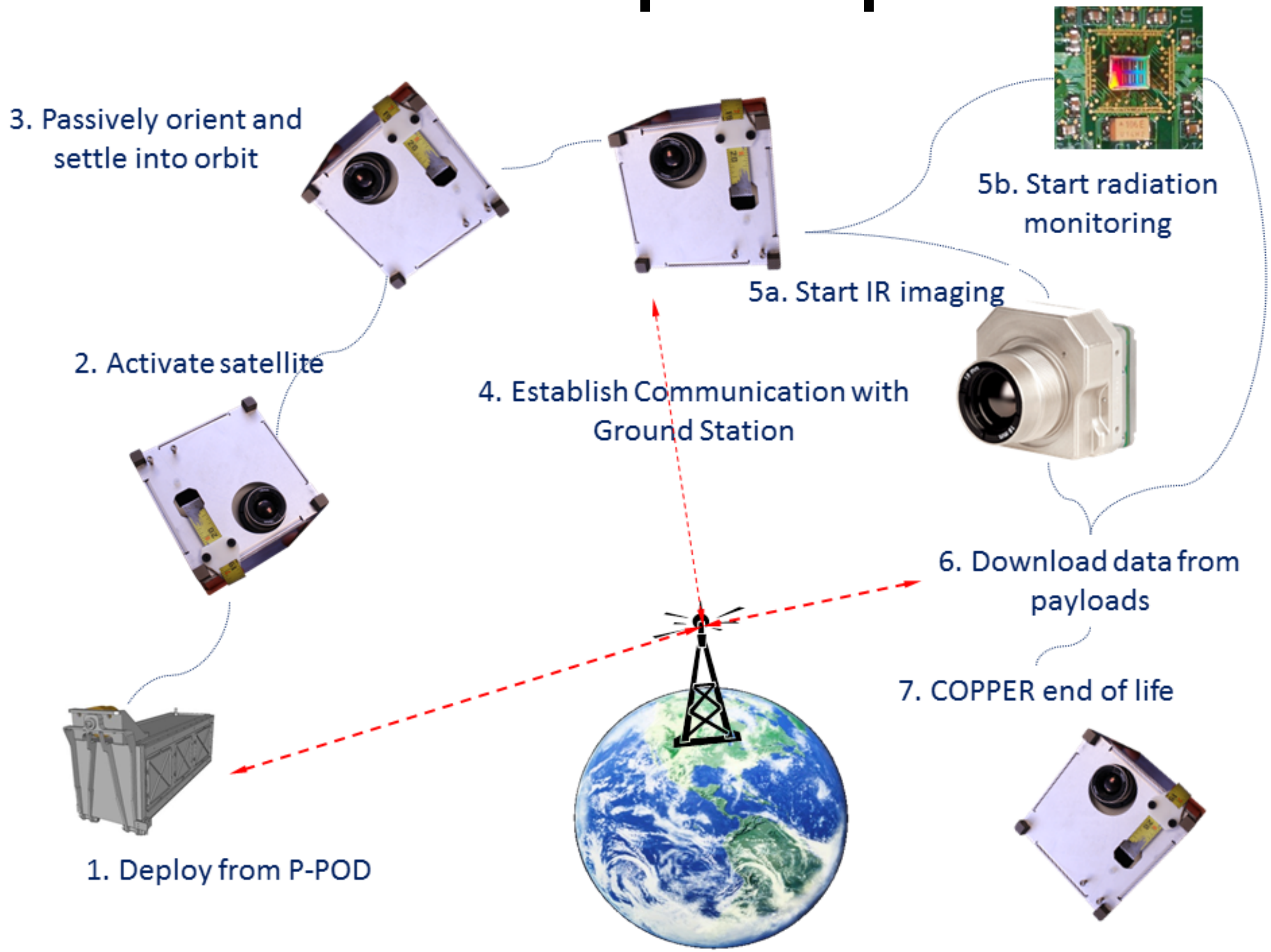
Radiation Payload

Small electronics with bit-flip monitoring system

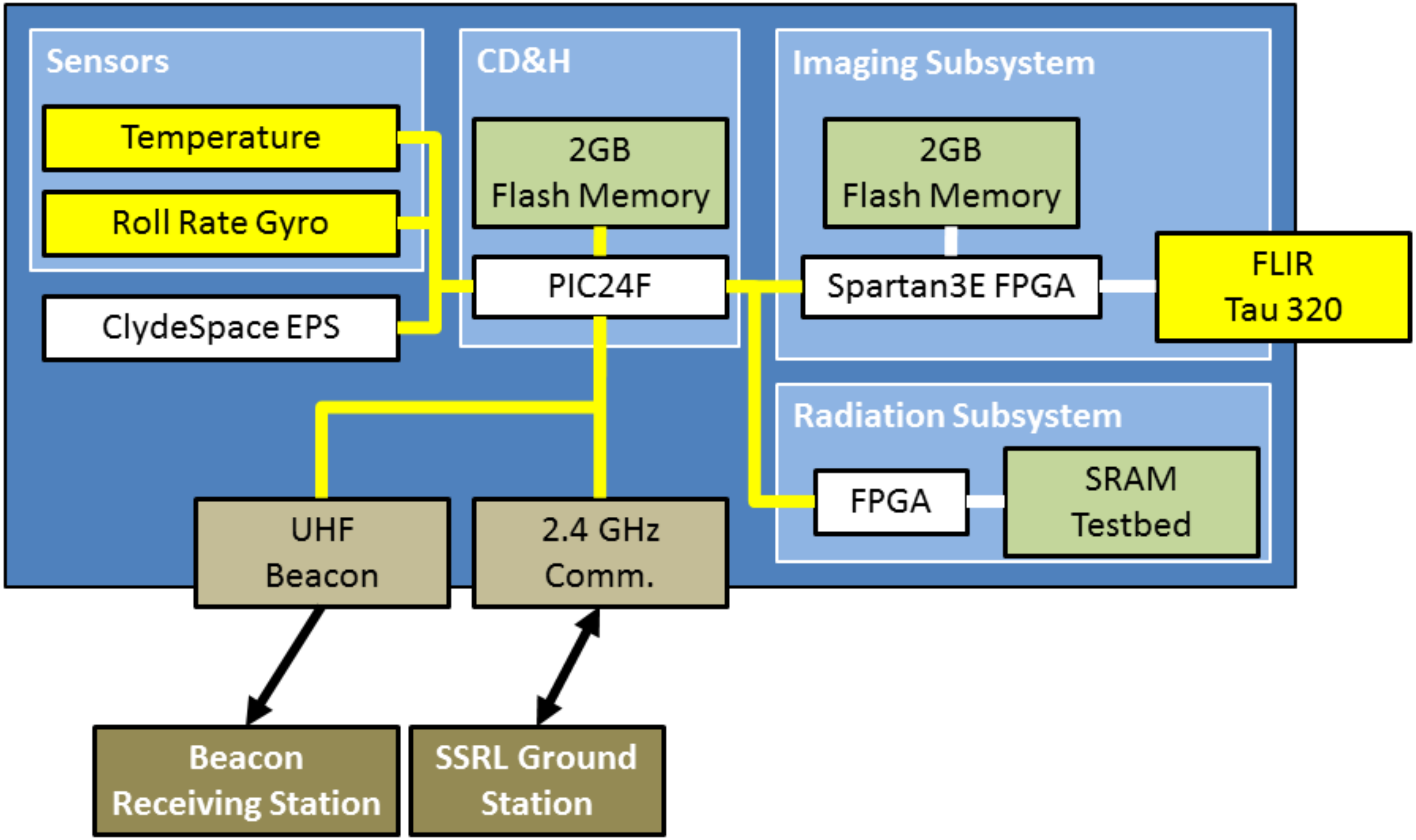
Memory elements between 20nm and 40nm



COPPER Concept of Operations



COPPER Dataflow



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Imaging Payload (Why?)

- CubeSats benefit from near-standardized components for CD&H, power, and communication subsystems.
- No imaging solution currently exists
- COPPER's imaging desires to satisfy three niches
  - Space Situational Awareness
  - On-Orbit Servicing
  - Earth Observation

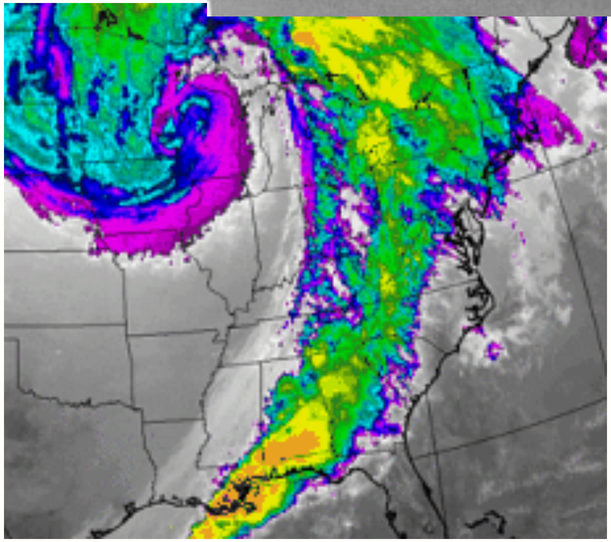
Imaging Payload Applications

Space Situational Awareness

- What objects are near a High Valued Asset?
- Active spacecraft will need to activate thrusters for orbital insertion and maintenance
- Energetic thruster plumes cannot be hidden.
- Visible-light already extensively studied; infrared camera chosen.
- COPPER will flight-qualify the imaging subsystem for future SSRL SSA missions.

Earth Observation

- Multiple useful phenomena visible in infrared
- Greenhouse gasses
  - Ozone, 9.6um, Methane, 7.6um, N2O, 7.9um
- Urban heat islands
- 103km by 138km viewing area for COPPER’s altitude and lens



On Orbit Servicing

- Inspection of other spacecraft on-orbit

Imaging Application Requirements

Earth Observation

- Seconds-per-frame imaging speeds acceptable
- Retrieval of lossless images over modest connection

On Orbit Servicing

- Live downlink over larger connection.
- Lossy imaging acceptable

Space Situational Awareness

- Multi-second storage of high-FPS video
- Video retrieval over modest connection

General

- Robust enough for space operations
- Power, mass, and bandwidth restrictions

Imaging Payload Development

COPPER Requirements

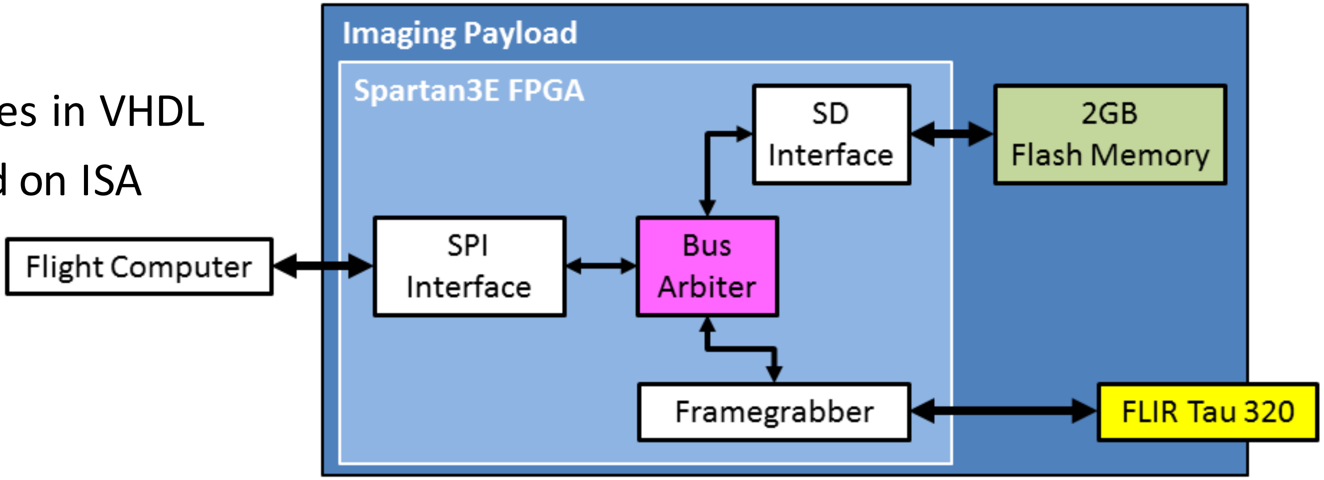
- Controllable frame rate (30FPS to 10SPF)
- Storage of images for later downlink
- Lossless image downlink (compression optional)

Hardware Chosen

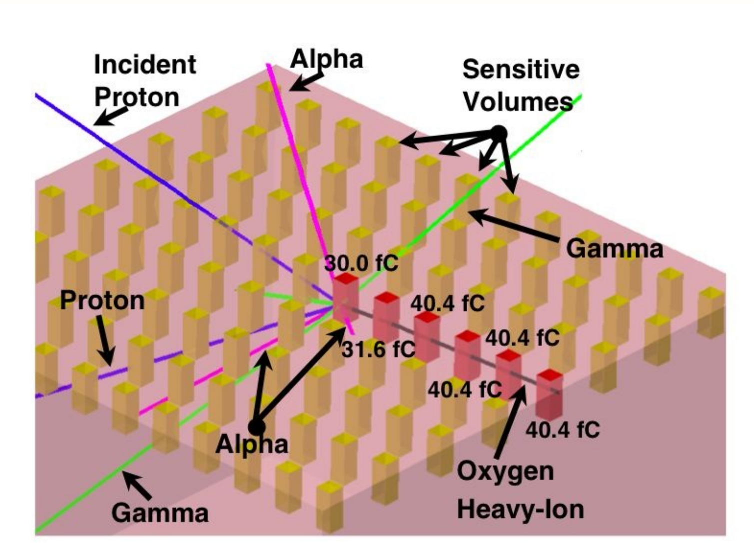
- FLIR Tau 320 Microbolomter Array
- Xilinx Spartan3E FPGA
- 2GB SD Card

Hardware Design

- SPI, SD, and Tau interfaces in VHDL
- Connected via bus based on ISA



Radiation Payload (Why?)



SCHOOL OF ENGINEERING
VANDERBILT UNIVERSITY

Vanderbilt University ISDE

Mission: To improve the predictive performance modeling of radiation effects on small, modern space electronics devices by collecting radiation particle collision data from electronics monitoring experiments and relaying the data to the ground.

Trailblazer mission for future ARGUS spacecraft in partnership with Vanderbilt University

Radiation Payload Applications

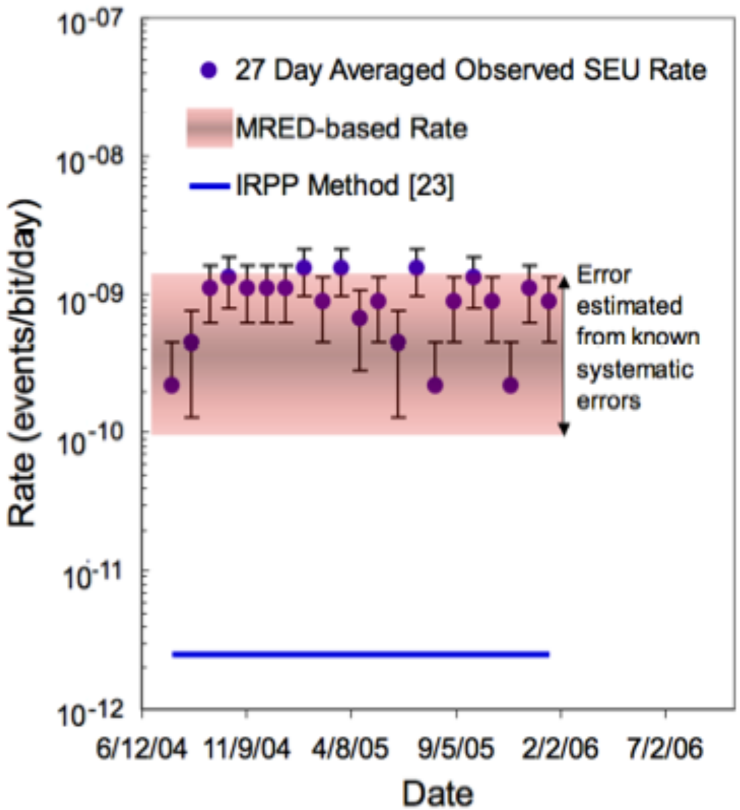
Why Test?

- Effects of space radiation on modern electronics (< 60 nm scale) are very poorly modeled (predicted rates are off by orders of magnitude)

Why Space?

- Dominant error source(s) not well-understood (low vs. high energy particles, protons vs. electrons)
- Modern electronics have many operational modes
- Ground-based testing would require years of test time and millions of dollars per memory device.

<u>Orbital testing</u> can be used to cost and time-effectively calibrate predictive models.

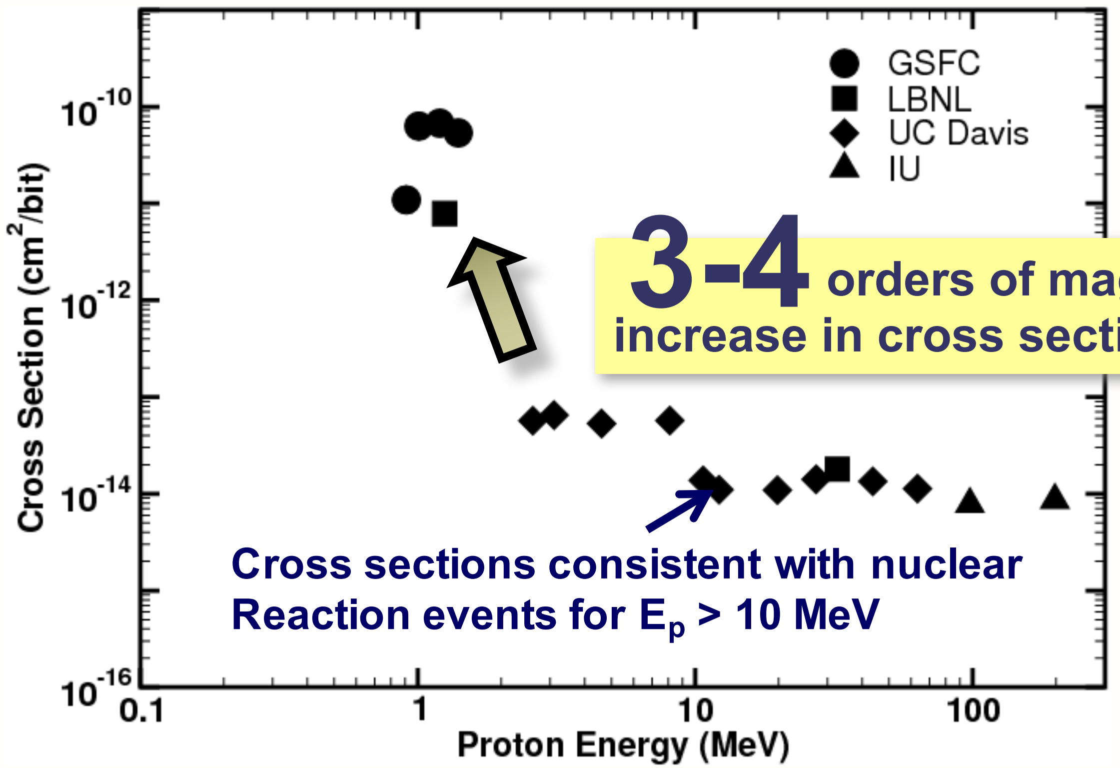


Reed, TNS, 2007

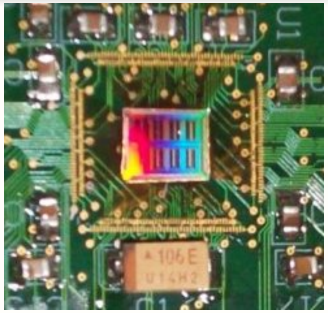
Low-Energy Proton Upsets

Previous work reported data collected by Vanderbilt and NASA Goddard on TI 65 nm bulk CMOS process [Sierawski, TNS 2009]

Consistent with evidence of proton direct ionization contributing to single event upsets (SEUs) reported for IBM 65 nm SOI process [Rodbell, TNS 2007][Heidel, TNS 2008]



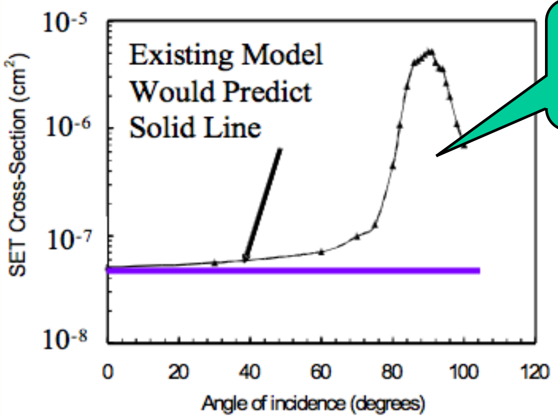
Sierawski, TNS 2009



Does this dramatic increase in cross section at low energy cause and increase in on-orbit failure rates

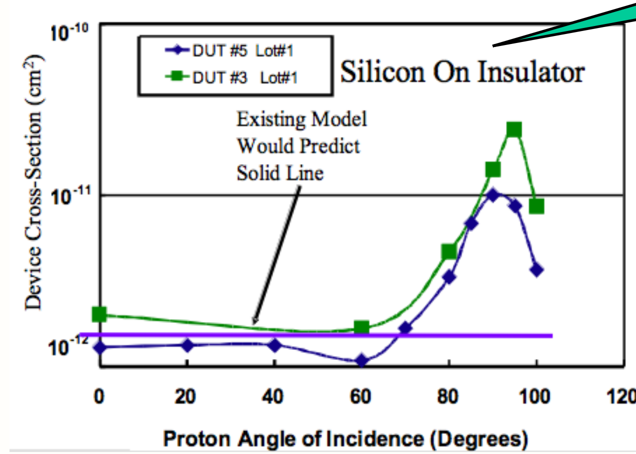
Radiation Payload

Examples of Breakdown of Older SEE Models



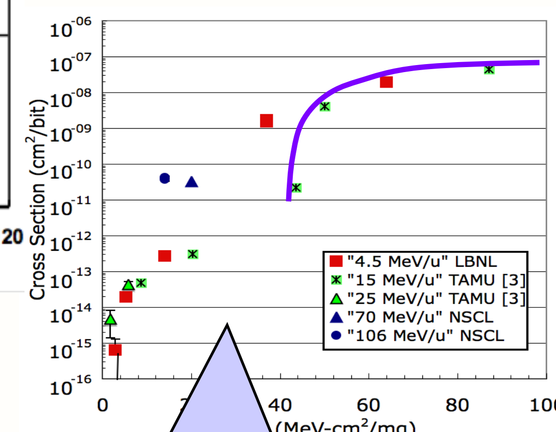
Optocouplers & Optical Links

R.A. Reed, et. al IEEE Trans. Nuc. Sci., vol. 48, no. 6, Dec. 2001, pp. 2202 – 2209.



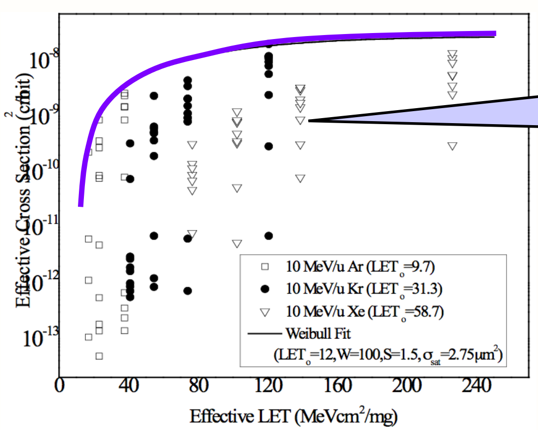
Proton effects in SOI based memories

R.A. Reed, et. al, IEEE Trans. Nuc. Sci., vol. 49, no. 6, Dec. 2002, pp. 3038 – 3044.



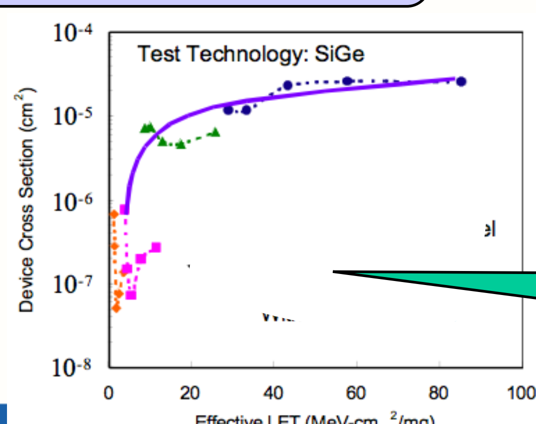
RADHARD CMOS SRAM

K.M. Warren, et. al IEEE Trans. Nuc. Sci., vol. 48, no. 6, Dec. 2005, pp. 2125 – 2131.



Heavy Ion Effects 90 nm DICE latch

K. M. Warren, et. al, IEEE Trans. Nuc. Sci., vol. 54, no. 6, pp. 2419 - 2425, 2007.



Heavy Ion Effects in SiGe HBTs

R.A. Reed, et. al IEEE Trans. Nuc. Sci., vol. 50, no. 6, Dec. 2003, pp. 2184 – 2190

Radiation Payload Development

COPPER Requirements

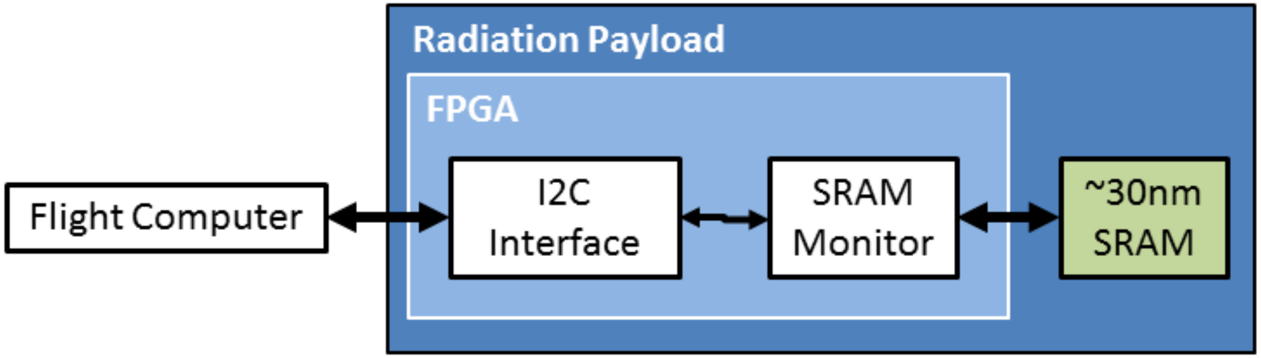
Connect to CubeSatKit bus, I2C interface

Hardware Chosen

30nm SRAM technologies

Rad-hardened FPGA TBD

Rad-hardened data storage TBD



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Power

ClydeSpace EPS
- Lithium polymer batteries

Custom solar panels
- SpectroLab TASC solar cells
- Expected 25% efficiency

2.2Wh generation per orbit

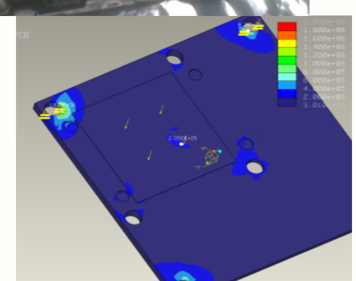
1.4Wh consumption per orbit

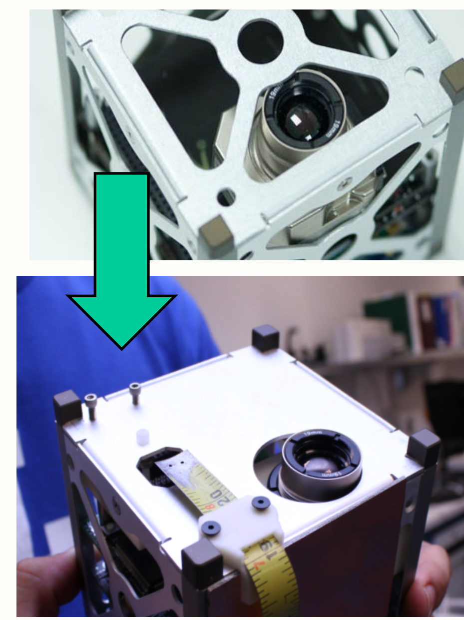
Structure

CubeSat Kit 1U Skeleton RevD

Custom top-plate
- Viewport for camera

Custom camera holder
- Reduce load of camera on PCB

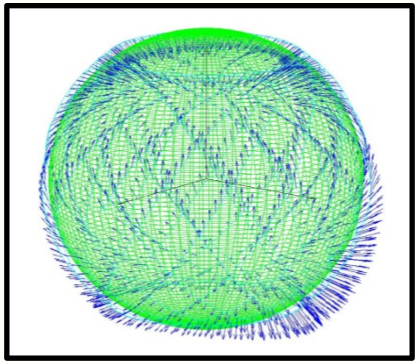


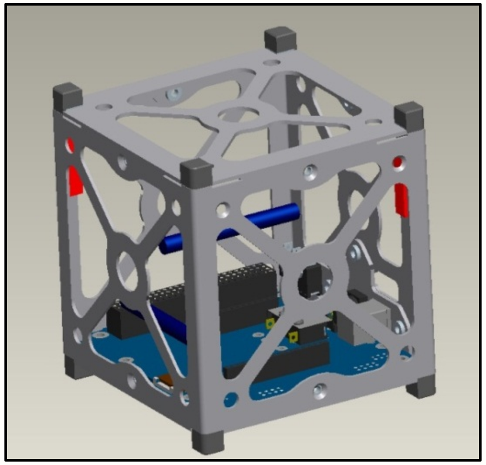


Attitude Determination and Control

Passive ADC

- Zero power consumption
- Permanent magnets
  - Aligns satellite with magnetic field lines of the earth
- Hysteresis rods
  - Dampens oscillations





Communications

Primary Communications

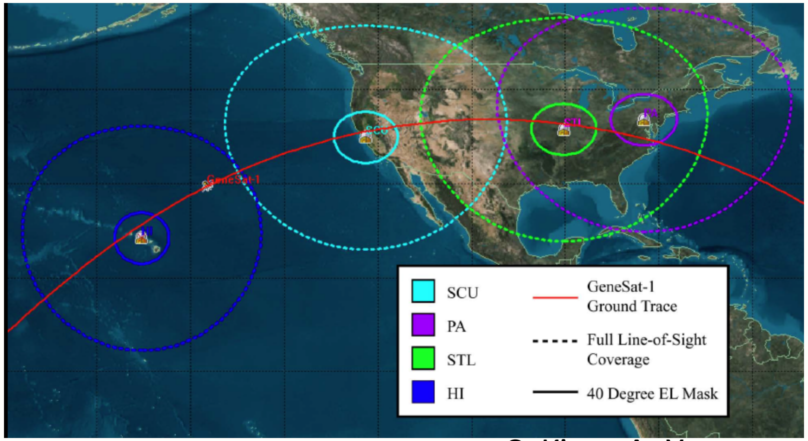
- Microhard MHX2420
- 2.4GHz spectrum, 9600bps

Secondary Communications

- StenSat Radio Beacon
- 440MHz spectrum, 1200bps

Ground Stations

- S-Band stations at SSRL, Santa Clara
- Member of Santa Clara Beacon Health Monitoring Network for 400MHz communications
- SCU licensing



C. Kitts, A. Young, et.al

C&DH

CubeSatKit Motherboard

Flight proven COTS ecosystem

CubeSatKit PIC24F PPM

Sufficient peripheral connections

32MHz operation

Image courtesy Pumpkin, Inc.

Device	Serial Communication Used
Microhard MHX2400 Radio	USART + handshaking
SD card (C&DH)	SPI (not dedicated)
Beacon Radio	USART, no handshaking
Video Payload	SPI (not dedicated)
Radiation Payload	I2C (not dedicated)
ClydeSpace EPS	I2C (not dedicated)
Debug port	USART, no handshaking
Roll Rate Gyro	I2C (not dedicated)

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Future Milestones

Date	Milestone
August 2011	P-POD integration fit check
Summer 2011	**Complete engineering unit integration and SSRL testing**
October 2011	**Complete flight unit integration and SSRL testing**
November 2011	Mission Readiness Review (Launch-120 days)
December 2011	Delivery to Cal Poly for testing (Launch-90 days)
February 2011	Cal Poly delivers COPPER to NASA facilities for integration onto Falcon-9 (Launch-30 days)
March 2012	**Launch from Cape Canaveral on Falcon-9 CRS-2**
May 2012	COPPER deorbit and End-Of-Life

COPPER Team

COPPER is a team of undergraduate students working since 2009

ADC	CDH	Communication	Ground Operations	Payload	Power	Structure	Testing	Thermal
Gerrit Smith	Maria Barna	Rubianne Garcia	Wesley Gardner	Steve Massey	Richard Henry	Rikin Parikh	Tom Moline	Mentos Olson
Phillip Reyes	Steve Massey		Joe Kirwen	Maria Barna	Gerrit Smith	Mentos Olson	Alli Cook	Rikin Parikh
Jim Dreas	Evan Cobb	Wesley Gardner	Nate Richard	Kerim Strikovic	Patrick Sullivan	Justin Krofta	Nate Richard	Aaron Rowe
Justin Krofta	Andrew Herbig	Joe Kirwen	Rubianne Garcia	Nick Elmer	Mike Ostrander	Phillip Reyes	Justin Krofta	
	Joe Kirwen	Evan Cobb	Andrew Herbig	Jessica Hill		Nate Richard	Jessica Hill	
	Wesley Gardner	Andrew Herbig	Evan Cobb			Peter Hasser	Nick Elmer	
	Jordan Wisch	Peter Hasser						

Acknowledgments

This work was supported in part by the following agencies

- NASA (CubeSat Launch Initiative)
- AFOSR & AFRL/RV (University Nanosat-6)
- NASA Missouri Space Grant Consortium
- Saint Louis University President's Research Initiative

The team would like to thank

- **Dr. Robert Reed, Andrew Sternberg** and the ISDE team
- **Dr. Michael Swartwout**, **Dr. Kyle Mitchell** and **Dr. Sanjay Jayaram** to their close assistance and mentorship.
- **Frank Coffey** and **Darren Green** for their guidance and help.
- A special thank you to **Kay Bopp** for her endless patience and perpetual assistance.

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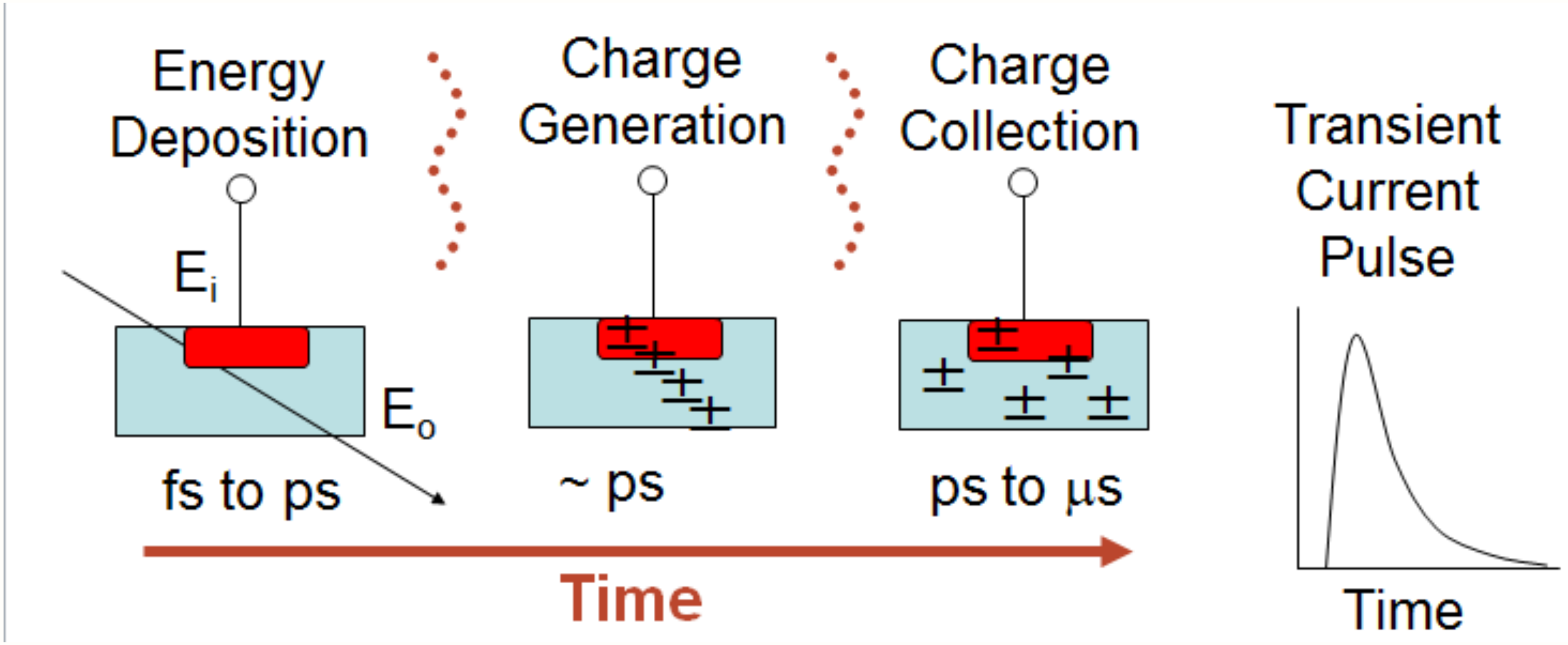
SAINT LOUIS UNIVERSITY

Backup Slides

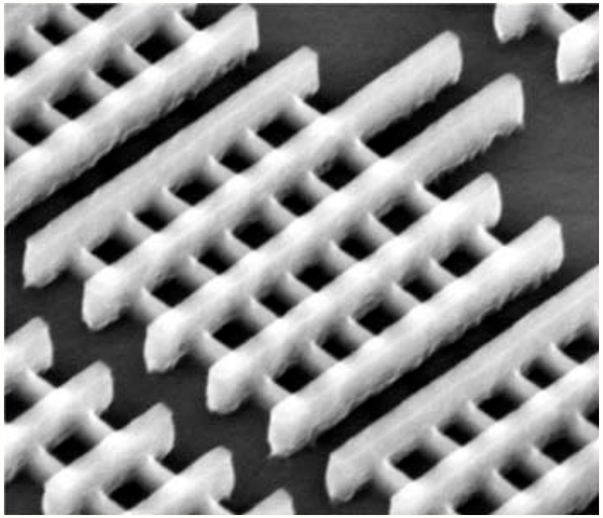
Transients from Single Particle Event



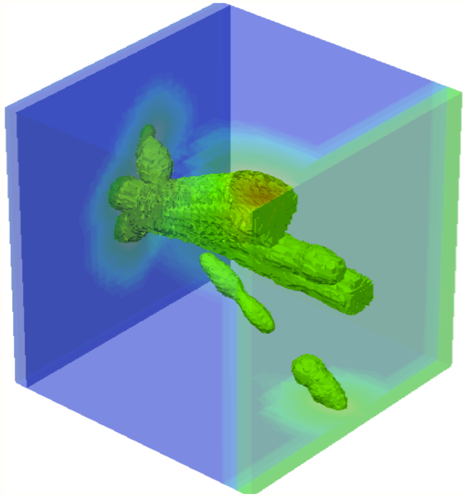
Soft Error Examples:

- Single Event Transient: A current pulse occurring at a circuit node due to single energetic particle event
- Single Event Upset: A change in a circuit's logic state induced by a single energetic particle event

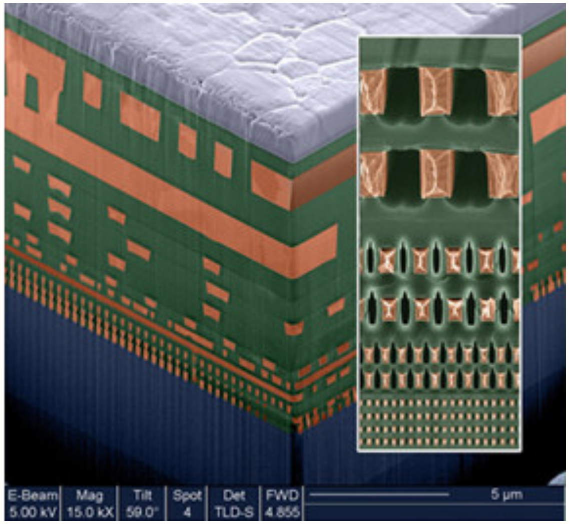
New SEE Challenges



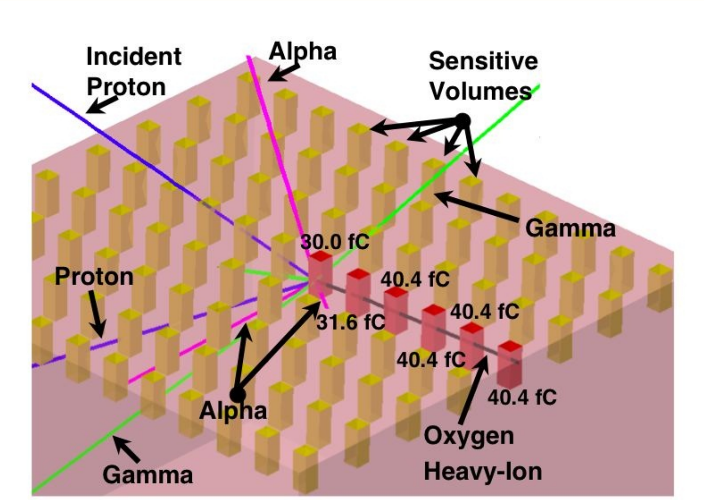
Complicated charge-collection volumes



Ion tracks larger than device sizes

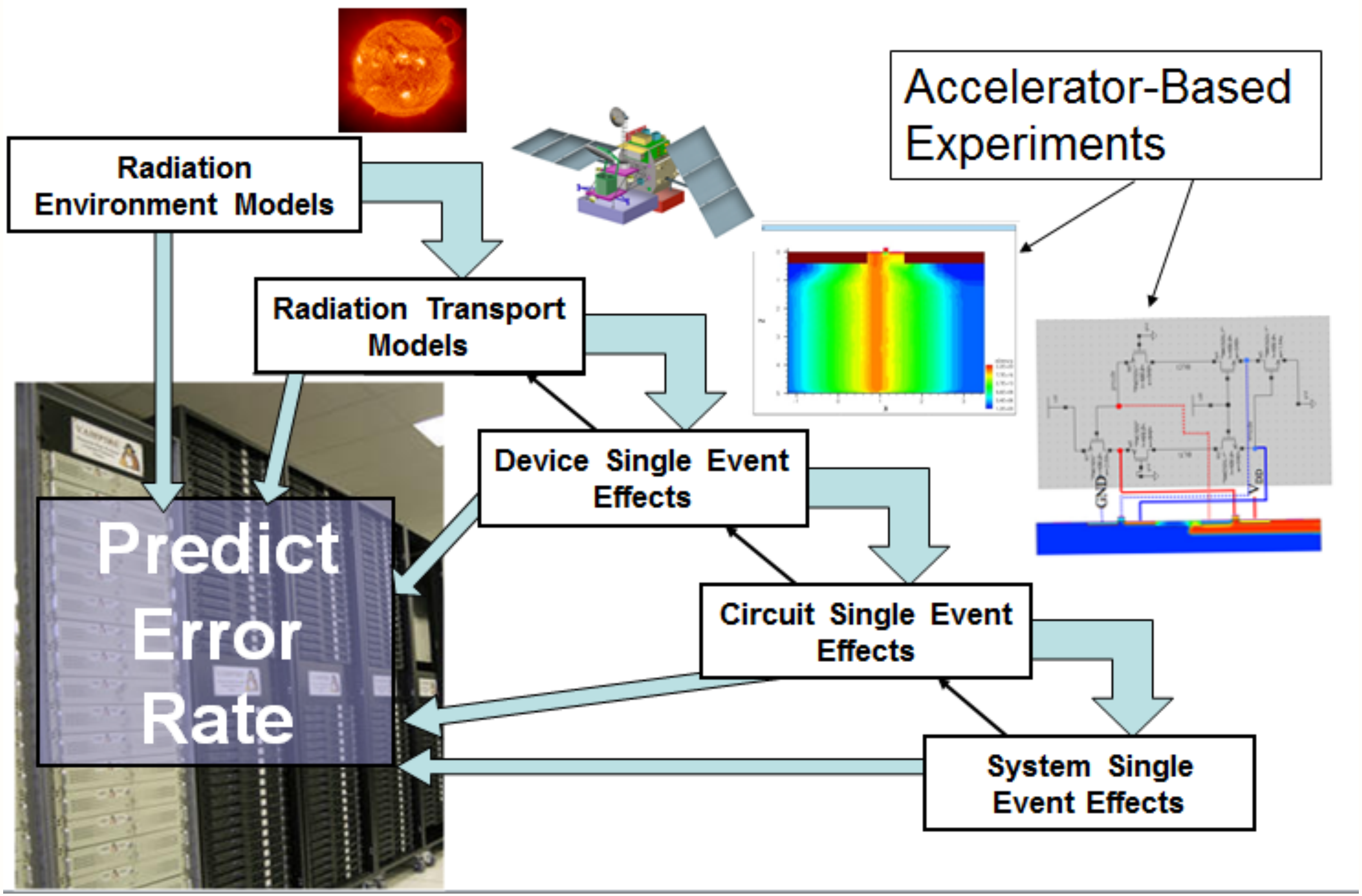


Complex Overlayers



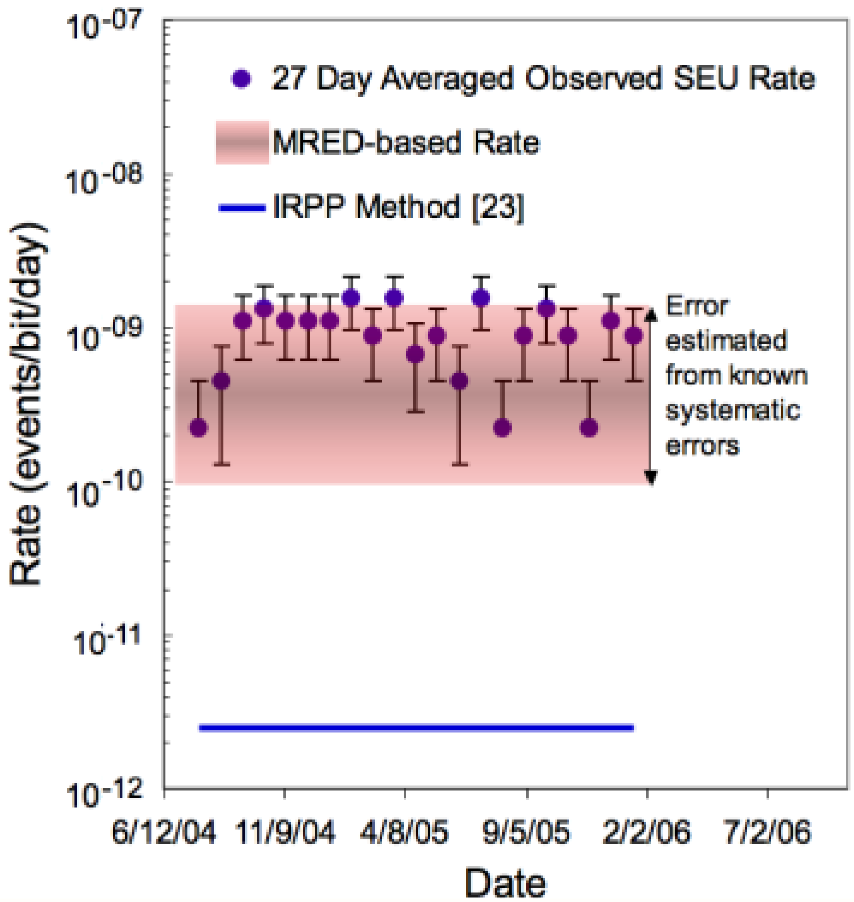
One event may affect multiple nodes

Vanderbilt's Advanced Radiation Effects Analysis



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

- SRAM used on NASA MESSENGER spacecraft
- Observed Average SEU Rate:
  - 1×10^{-9} Events/Bit/Day
- Vendor predicted rate using CREME96:
  - 2×10^{-12} Events/Bit/Day
  - Classical Method nearly a factor 500 lower than observed rate
- **MRED rate agrees with on-orbit oberservation**
  - **Believed to be due to tungsten overlayers**
  - **Need a well defined space experiment to provide proof**



Reed, TNS, 2007