Space Environment Testbeds (SET) Update

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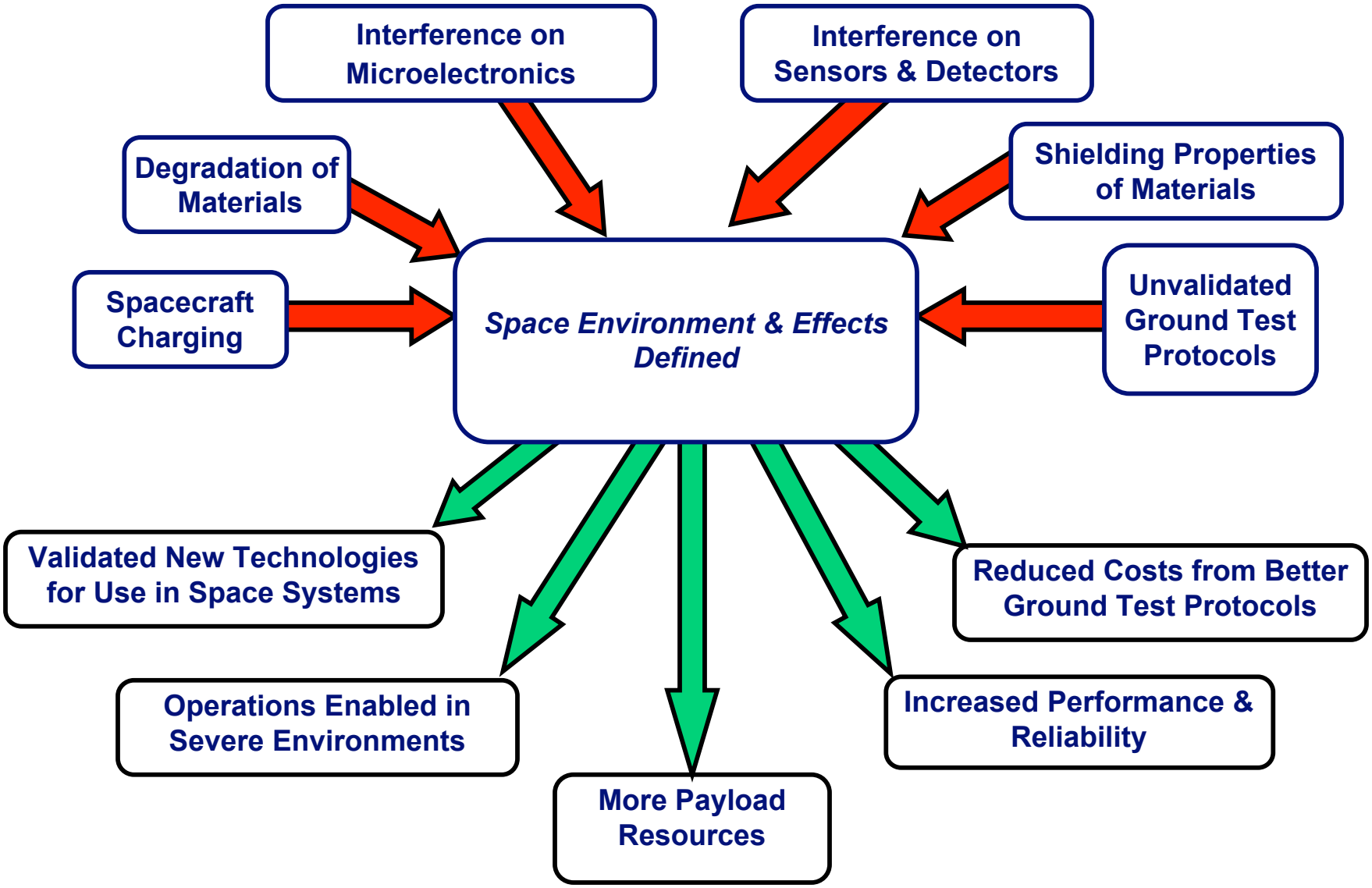
May 1, 2006

SET Background

- **Goal: Improve the engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design and operations**
- **Two parts:**
  1. Data mining investigations selected from NASA Research Announcements (NRAs)
  2. Investigations that include collecting data in space
     - **SET-1 mission – piggyback experiments and carrier**
       - GSFC in-house implementation; delivery in April 2008
       - Host: AFRL's Demonstration and Science Experiments (DSX-1) launches as a secondary payload not earlier than Oct. 2008

Large Uncertainties in Space Environment & Effects Preclude Cost Effective Use of the Space Environment

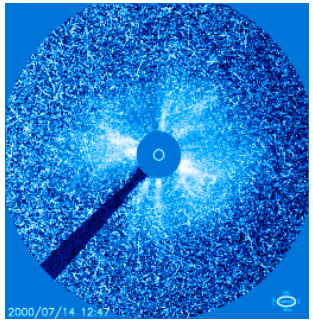


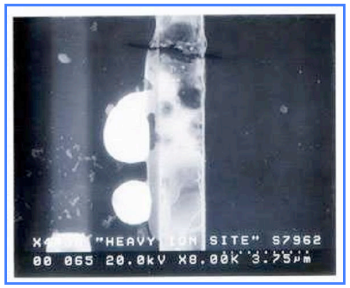
Estimates of Uncertainties

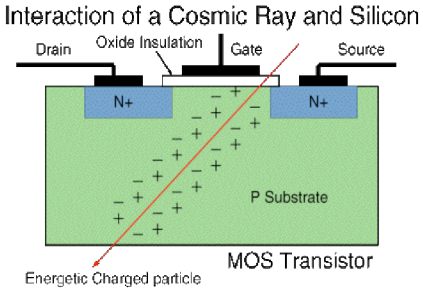
- **Well understood technologies**
  - 10-15% of technologies
  - x2 design margin applied
  - Example – CMOS, down to .25 micron
- **Poorly understood technologies**
  - 85-90% of technologies
  - Technologies currently in use
    - **x5 – x10 design margins applied**
    - **Example – linear bipolar devices**
  - Emerging technologies
    - **> x10 design margins applied**
    - **Examples - Exotic materials, SiGe**

Five Science Categories for SET

1) Characterize the space environment in the presence of a spacecraft;
2) Define the mechanisms for materials' degradation and characterize the performance of materials designed for shielding from ionizing radiation;
3) Accommodate and/or mitigate space environment effects for detectors and sensors;
4) Performance improvement methodology for microelectronics used in space; and,
5) Accommodate and/or mitigate charging/discharging effects on spacecraft and spacecraft components.







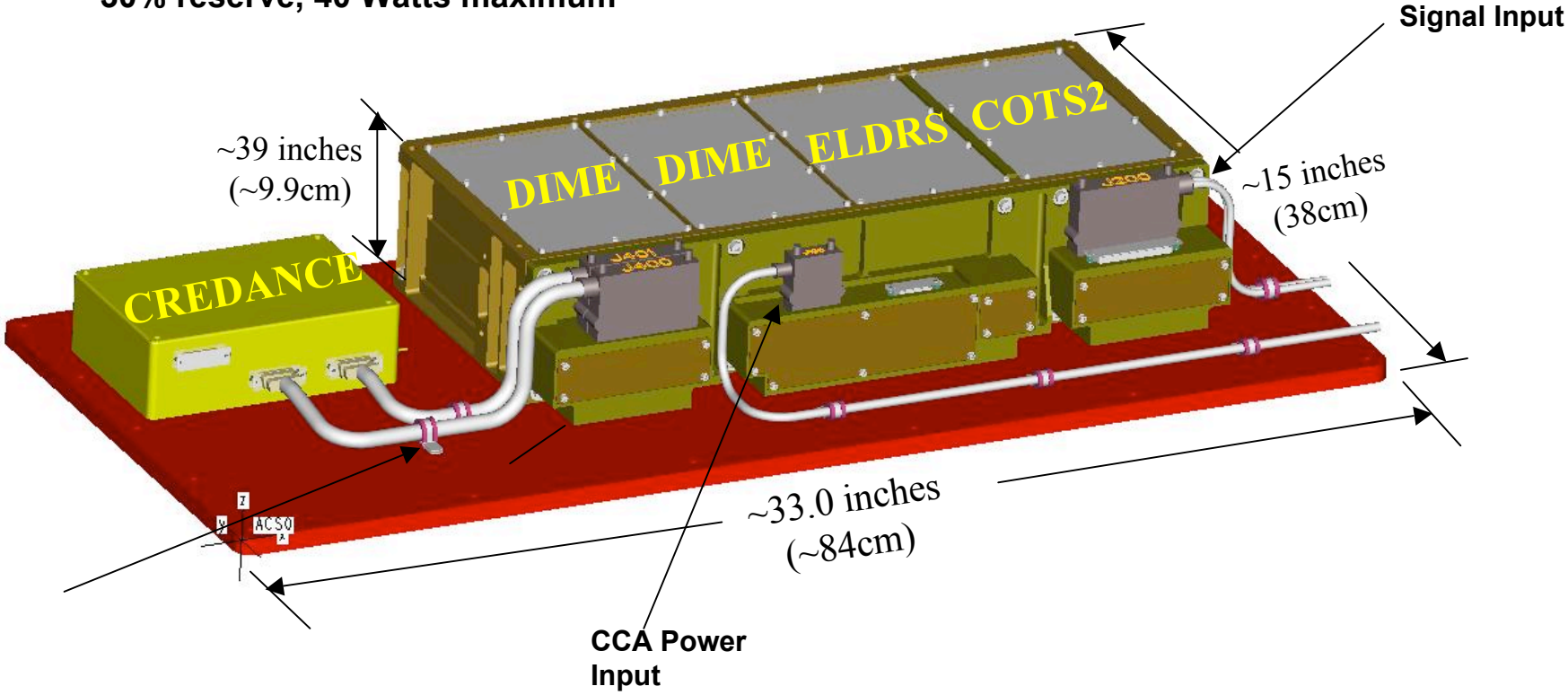
SET Approach to Science & Product Development

- **Define investigation topics through community workshops**
  - NASA, industry, universities, other government agencies
  - Technology users and technology providers
- **Acquire investigations through NASA Research Announcements (NRAs) via standard HQ peer review process and partnerships**
  - Space investigations
    - **Collect data in space to validate the performance of new technology vulnerable to the effects of the solar varying environments and instruments for LWS science missions**
    - **Collect data in space to validate new and existing ground test protocols or mechanism models for the effects of solar variability on emerging technologies and components**
  - Data investigations
    - **Improve, develop, and validate engineering environment models, tools, and databases for reliable spacecraft design and operation**
- **Transition results of investigations (products) to user community**
  - Community workshops for investigators and users
  - Presentations at conferences
  - Data and product distribution and archive

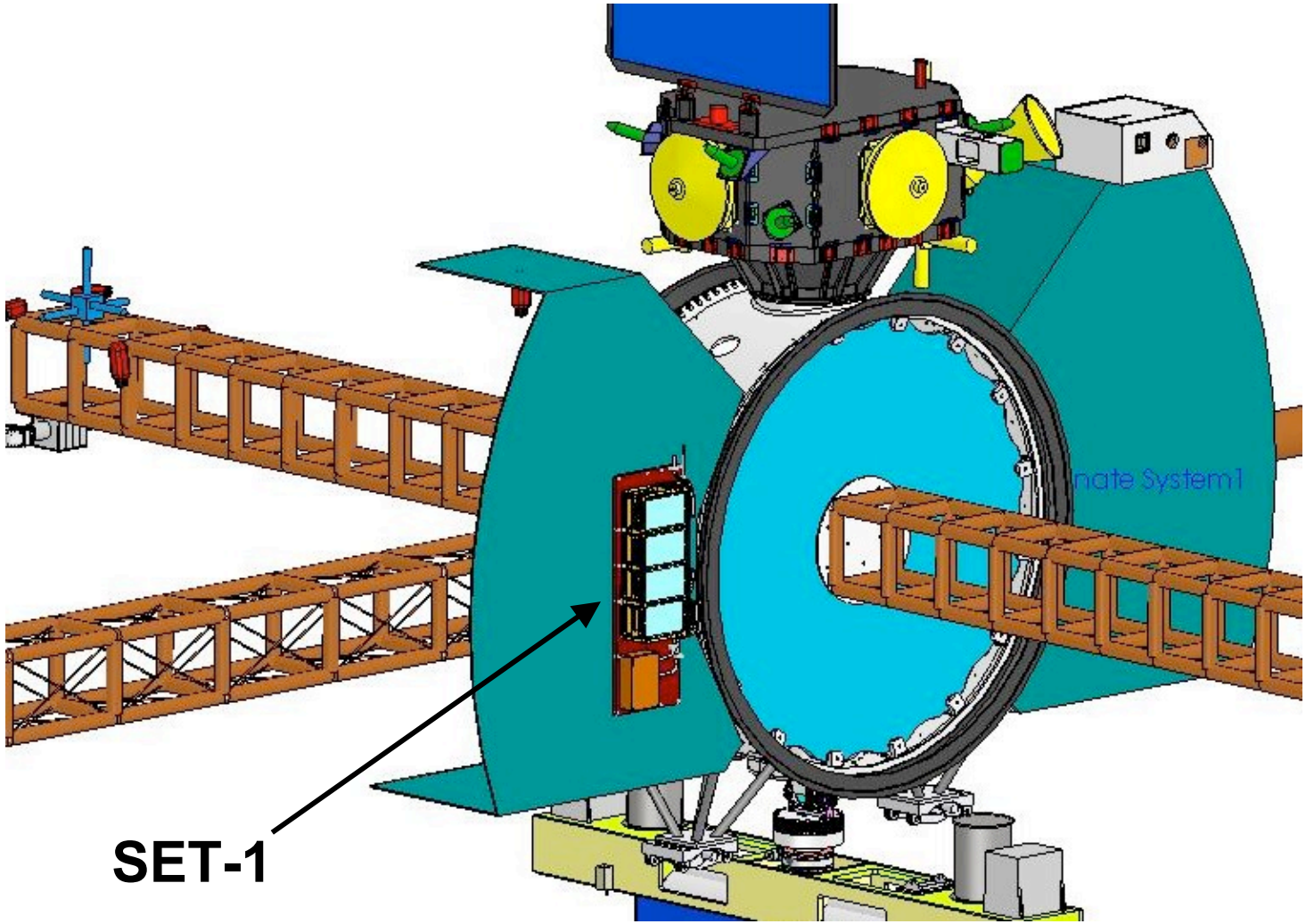
SET-1 Mission Configuration

Approximate characteristics:

- **Payload Mass: 21.5 Kg with 30% reserve**
- **Length: 84 Centimeters**
- **Width: 38 Centimeters**
- **Height: 9.9 Centimeters**
- **Power: 34.7 Watts Orbit Average including 30% reserve, 40 Watts maximum**



SET-1 on DSX Spacecraft



Payload for SET-1 Mission: CREDANCE

Cosmic Radiation Environment Dosimetry and Charging Experiment (CREDANCE)

- **PI: Clive Dyer, QinetiQ/UK**
- **Objectives**
  - Characterize the energetic space radiation environment and its interactions with spacecraft
  - Provide correlative environment data to other SET-1 experiments
- **Goals**
  - Provide data to improve radiation environment models and design tools
- **Measurements**
  - Proton flux > 40 MeV per unit solid angle
  - Charge deposition in large silicon diodes arranged in telescopes. Pulse height analysis is used to obtain ion linear energy transfer (LET) spectra of heavy ions in the 100 MeV cm2/g to 25000 MeV cm2/g range
  - Threshold voltage shift as a function of time to measure total ionizing dose in silicon at 2 different shielding depths
  - Charging current at 3 different shielding depths which provides energetic electron flux measurements at 3 energies

Payload for SET-1 Mission: DIME

Dosimetry Intercomparison and Miniaturization (DIME)

- **PI: Peter McNulty, Clemson University**
- **Objectives**
  - Use six different COTS microdosimeters to characterize the radiation induced total ionizing dose, displacement damage, and single event effects
- **Goal**
  - Provide data to permit appropriate dosimetry selection in future missions to characterize/resolve operational anomalies
  - Validate particle transport codes by varying shielding thicknesses on RADFETs
- **DIME Measurements**
  - RADFET – Radiation-Sensing Field-Effect Transistor
    - **Threshold voltage shift as a function of time and is converted to total ionizing dose**
  - EPROM - Erasable Programmable Read-only Memory
    - **Threshold voltage shift as a function of time and is converted to total ionizing dose**
    - **Number of single event upsets as a function of time to measure rates as a function of radiation level**
  - SRAM - Static Random Access Memory
    - **Hold devices at different voltages and measure single event upsets, change in voltage at which an error occurs is converted to dose**
    - **Number of single event upsets as a function of time to measure rates as a function of radiation level**
  - LET Spectrometer – Linear Energy Transfer Spectrometer
    - **Pulse height spectra as function of time is converted to LET to measure ions including protons**
  - OSL Films- Optically Stimulated Luminescent Films
    - **Visible emission spectrum as a function of time to measure micro-dose**

Payload for SET-1 Mission: ELDRS

<u>Development of Space-Based Test Platform for the Characterization of Proton Effects and Enhanced Low Dose Rate Sensitivity (ELDRS) in Bipolar Junction Transistors (ELDRS)</u>

- **PI: Hugh Barnaby, Arizona State**
- **Objective**
  - Measure ELDRS (primary) and proton effects (secondary) in positive-negative-positive (PNP) bipolar junction transistors (BJTs)
- **Goal**
  - Improve understanding of the physics of ELDRS and thereby improve/validate ground testing protocol for linear bipolar technologies and reduce design margins
- **Measurement**
  - Base and collector currents for 24 COTS BJTs as functions of the emitter and gate voltages and time

Payload for SET-1 Mission: COTS-2

Commercial Off-the-Shelf Digital Technologies (COTS-2)

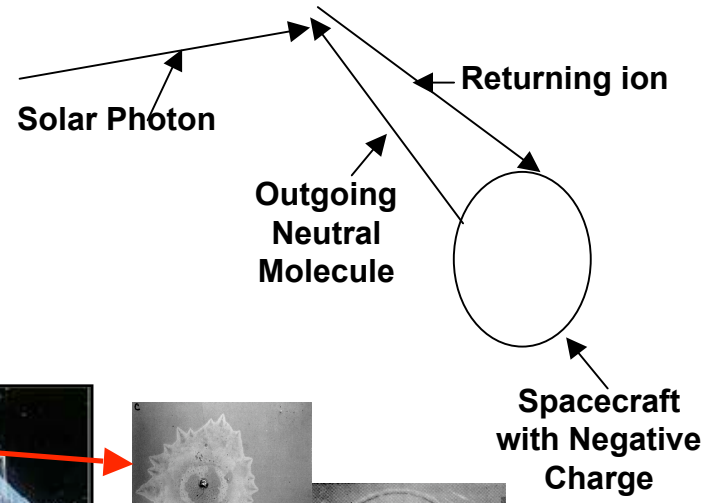
- **PI: Raoul Velazco, TIMA/FR**
- **Science Category: Performance improvement methodology for microelectronics used in space**
- **Objective**
  - Validate approaches to mitigate single event effects by comparing simulation techniques, performance models, and on-orbit data
  - Validate mitigation of single event effects during space weather events
- **Goal**
  - Increase reliability of COTS technologies for space applications and reduce design margins
- **Measurement**
  - Measure a single event effect (SEE) on COTS FPGAs, classify the event by event type, and determine if mitigation of the effect occurred without watchdog intervention

Going Forward

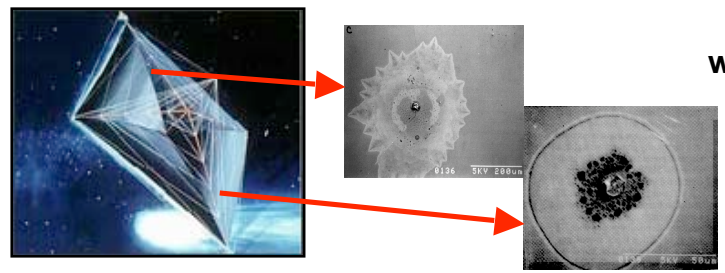
- SET-1 mission will be the only mission where NASA provides the carrier
- Beginning in 2008, SET is planning yearly data mining research opportunities

Backup Charts:
Details for SET Data Products

Electrostatic Return of Contaminants (ESR)



- **Model that predicts the level of spacecraft surface degradation from ESR**
- **Solar photons**

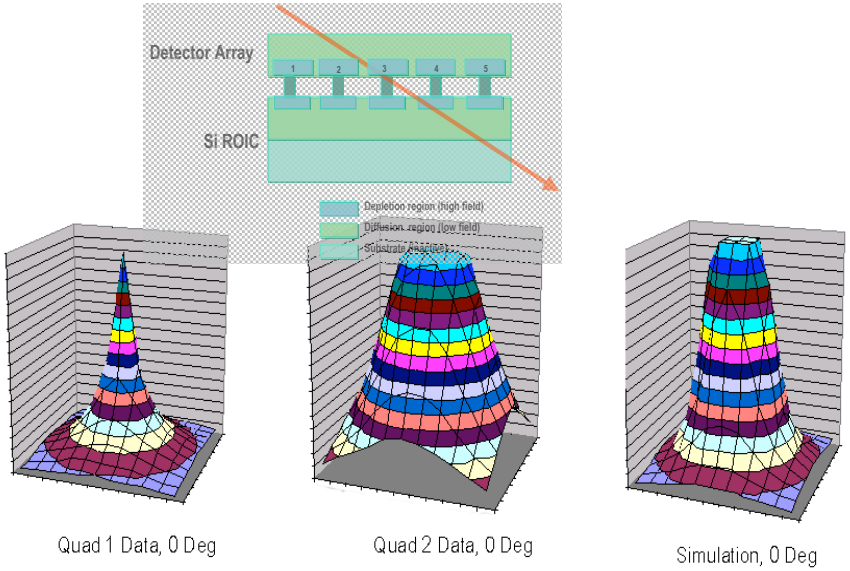


PI: R. Rantanen

- **Predicts the electrostatic return of spacecraft emitted molecules that are ionized and attracted back to the spacecraft by the spacecraft electric potential on its surfaces**
- **Provides levels of surface deposits and surface sputtering caused by the returning ions**
- **Accounts for different emitted molecular species and energy for a range of spacecraft environments (LEO, GEO, interplanetary)**

Modeling Charge Collection in Detector Arrays

- **A Monte Carlo/analytical model for focal plane array (FPA) applications**
- **High energy charged particles**



PI: J. Pickel

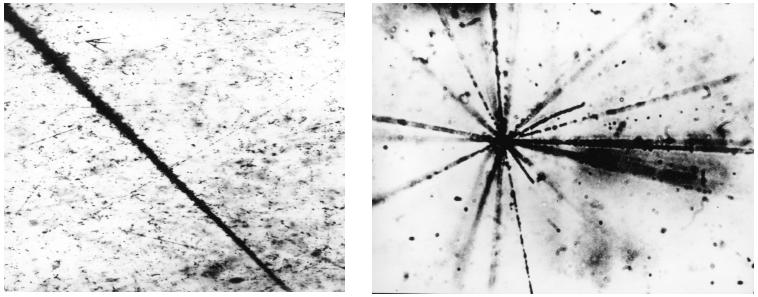
- **Addresses need for high fidelity simulation of particles interactions in complex FPA structures, including multiple layers, sub-regions with layers, variation of linear energy transfer (LET) with range, electron scattering, free-field diffusion, and field-assisted diffusion**
- **Can be applied to any semiconductor detector array**
- **Possible application to SOI and SiGe technologies**
- **Computer code, REACT, to predict charge collection in an array of elements**

Analysis of CRRES PHA Data for Low-LET Events

- **Charge collection models (COSMIC/CUPID) updated to include elastic interactions for application to modern devices where these interactions have been shown to dominate**
- **Protons and heavy ions**

PI: P. McNulty

IMPORTANT SOURCES OF SPACE RADIATION EFFECTS

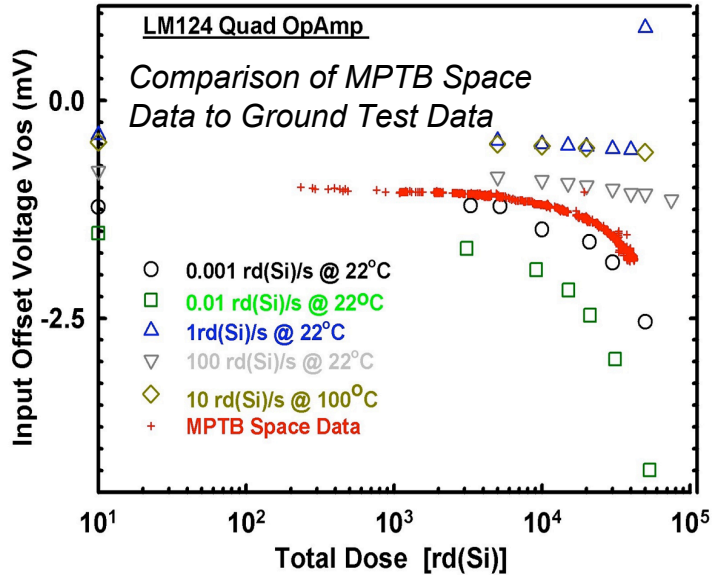


Track of an iron nucleus that stops in lower right corner A spallation reaction

- **Simulations from updated code agree well with the CRRES data**
- **Evidence for significant contributions to the spectrum from both elastic scattering at low energy depositions and pion production at high energy depositions**
- **Small number of large pulses in the data from direct traversals of the detector by heavy cosmic-ray ions**

Mining Enhanced Low-Dose Rate Sensitivity (ELDRS) Data from MPTB

- **Guidelines for accommodating the ELDRS effect on linear bipolar devices**
- **Charged particles**

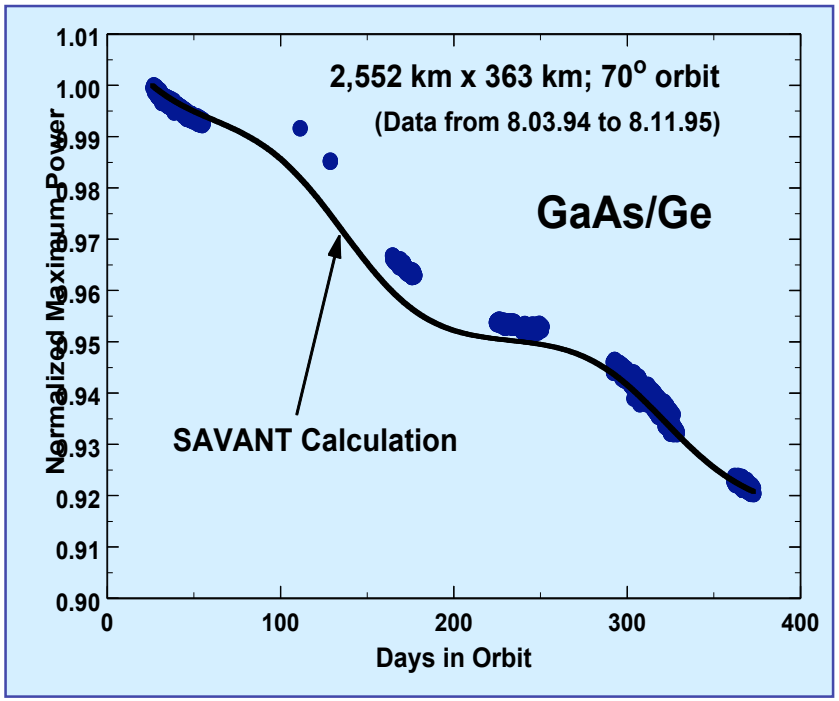


PI: T. Turflinger

- **Implications for ground testing**
  - **Microelectronics and Photonics Testbed (MPTB) observations agree well with ground test results, increasing confidence in the use of ground testing to predict ELDRS.**
  - **Relatively constant rate of degradation was demonstrated over dose rate of 0.5 mrad(Si)/s to 8 mrad(Si)/s, increasing confidence that 10 mrad(Si)/s ground data are a good predictor of space degradation.**
- **Implications for flight investigations**
  - **GTO is not the ideal platform for studying the ELDRS effect**

Solar Array Analysis and Verification Tool (SAVANT)

- A tool to predict on-orbit solar array output as a function of time
- Charged particles



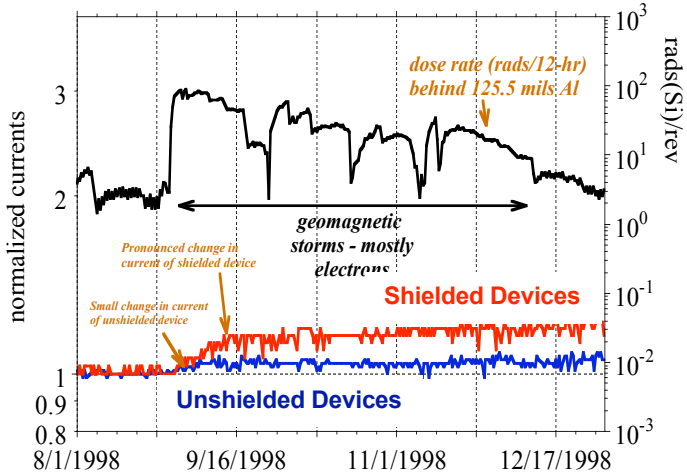
PI: R. Walters

- Windows™ based, user-friendly implementation of displacement damage (Dd) degradation method for solar arrays
  - Allows for predictions based on minimal amount of ground testing
  - Validated with Microelectronics and Photonics Testbed (MPTB) space flight data
  - Model can be extended to multijunction and thin film solar cells

TID Effects of High-Z Material Spot Shields on FPGA using MPTB Data

- **Guidelines for using spot shielding (CuW) for reduction of dose in electron dominated environments**
- **Electrons**

PI: S.Crain

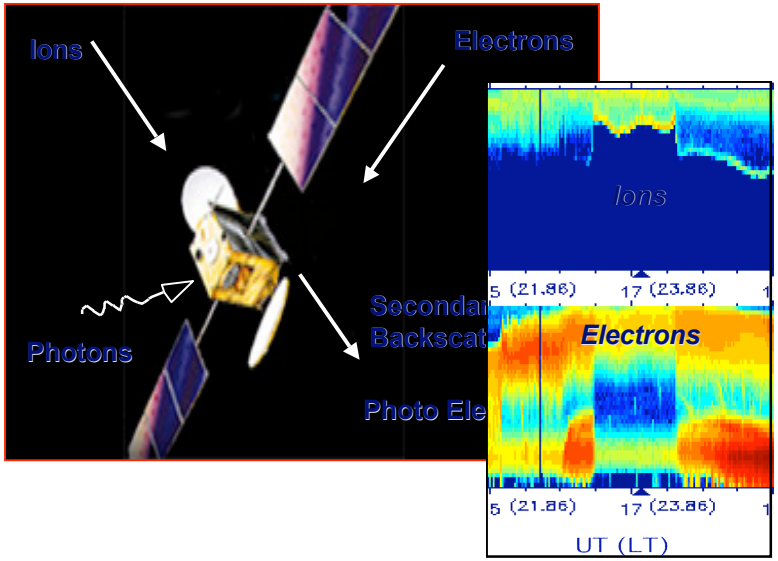


Example of anomalous response to electron storms of a shielded FPGA on MPTB

- **Could not explain the unexpected behavior of the devices that were not shielded**
  - **Models may not be accurately predicting particle interactions in devices**
    - **Particle transport codes used are limited in how they handle photons with E < 1 keV**
    - **Particle transport codes used are limited in how they handle the physics of dose enhancement at the die level**
  - **Measured energy spectra of electrons was much harder during the geomagnetic storms of 1998 than those predicted by the models that average over several solar cycles.**

Characterization of Magnetospheric Spacecraft Charging Environments using LANL Data

- **Guidelines for charging environments fitting functions for NASCAP2**
- **Low energy electrons**

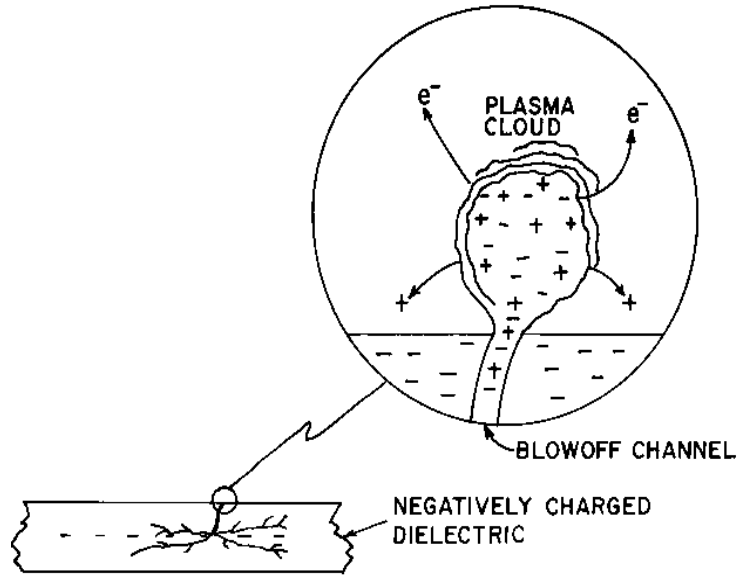


PI: V. Davis

- **Solar Minimum vs. Solar Maximum charging environments**
  - **Fluxes and resulting charging during charging periods are the same at solar minimum as at solar maximum. HOWEVER, during solar maximum, the frequency of high charging environments increases.**
- **Recommendations for environment fitting functions for NASCAP2K**
  - **Kappa fit for electrons and Maxwellian fit for ions give "post-dictions" with accuracy similar to those using the LANL measured spectra**

Mining CRRES IDM Pulse and Environment Data

- Improvements in ground test fidelity to minimize internal electrostatic discharge
- Mid-energy electrons



Charged electrical insulators break down producing large electric pulses

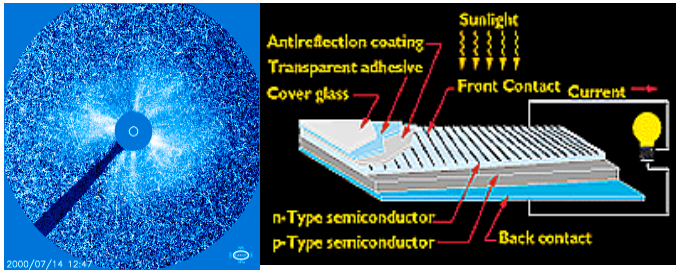
PI: R. Frederickson

- Investigate IESD pulsing by insulators flown on the CRRES spacecraft in relation to radiation-belt particle spectra
- Ground tests indicate that IESD pulse rate and pulse amplitude are proportional to electric field in the insulator. Estimate the electric fields that occurred in the insulators on CRRES as the particle spectra varied, and correlate this to measured pulse rates and amplitudes.

*Non-Ionizing Energy Loss (NIEL) Tool for Space Applications**

- A tool to calculate non-ionizing energy (NIEL) loss is the dominating damage mechanism in some optical technologies, e.g CCDs, optocouplers, solar cells
- Charged particles

Non-ionizing energy loss is the dominating damage mechanism in some optical technologies, e.g CCDs, optocouplers, solar cells.



*Co-funded with Code R, Space Environments & Effects Program

PI: M. Xapsos

- **Computer program for calculating**
  - NIEL in elemental compounds and semiconductors for electrons, protons, and heavy ions
  - NIEL spectra equivalent to linear energy transfer spectra for space environment