Risk Management of New Microelectronics for NASA: Radiation Knowledge-base

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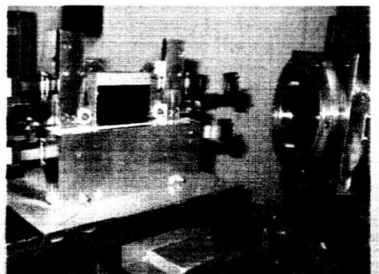
Outline

- **NASA Missions**
  - **Implications to reliability and radiation constraints**
- **Approach to Insertion of New Technologies**
- **Technology Knowledge-base Development**
- **Technology Model/Tool Development and Validation**
- **Summary Comments**



CCD ready for protons at UC Davis Crocker Nuclear Lab. Courtesy of NEPP Program and Defense Threat Reduction Agency (DTRA)

NASA Missions – *A Wide Range of Needs*

- **NASA typically has over 200 missions in some stage of development**
  - **Range from balloon and short-duration low-earth investigations to long-life deep space**
  - **Robotic to Human Presence**
- **Radiation and reliability needs vary commensurately**

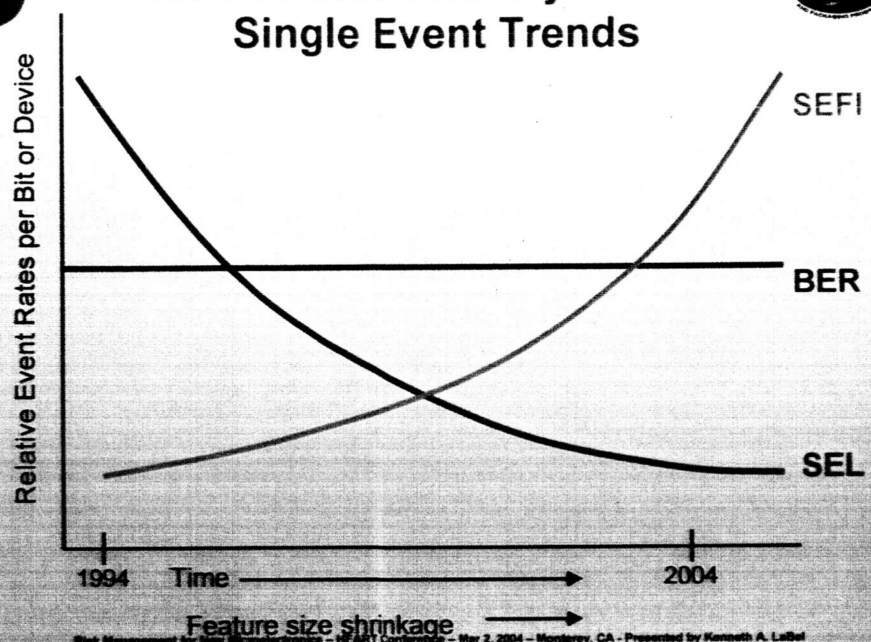
Mars Global Surveyor
Dust Storms in 2001

Implications of NASA Mix

- Prior to the new Presidential "Moon-Mars" vision
  - >90% of NASA missions required 100 krad(Si) or less for device total ionizing dose (TID) tolerance
    - **Single Event Effects (SEEs) were prime driver**
      - **Sensor hardness also a limiting factor**
    - **Many missions could accept risk of anomalies as long as recoverable over time**
- **Implications of the new vision are still TBD for radiation and reliability specifics, however,**
  - **Nuclear power/propulsion changes radiation issues (TID and displacement damage)**
  - **Long-duration missions such as permanent stations on the moon require long-life high-reliability for infrastructure**
    - **Human presence requires conservative approaches to reliability**
      - ***Drives stricter radiation tolerance requirements and fault tolerant architectures***

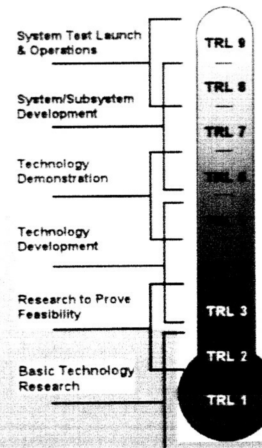
Lunar footprint
Courtesy of NASA archives

Non-volatile Memory-related Single Event Trends



Insertion of New Technologies – A Mission Perspective

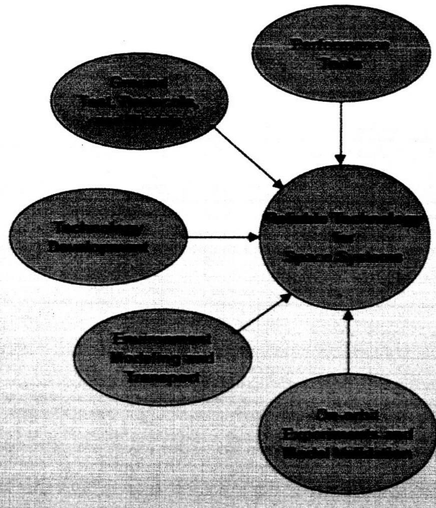
- **NASA mission timeframes rarely allow for a technology development path**
  - **For a 2008 launch, for example, technology freeze dates are likely 2005 or earlier**
    - **Technology must be moderately mature when a mission is being developed**
      - ***There may be time to qualify a device, but there may not be time to develop/validate a new technology solution!***
    - **Risk versus performance reward for using less mature or COTS technologies**
- **Technology development and evaluation programs need to be in place prior to mission design**
  - ***Strategic planning***



NASA Technology Readiness Levels (TRLs)

Insertion of New Technologies
An Approach

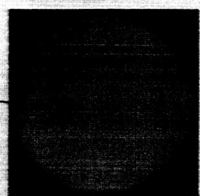
- Develop knowledge-base of existing technology information
- Determine reliability/radiation gaps
- Performance ground-based tests
  - May be sufficient to "qualify" for a specific mission, but not generically for all
- Develop technology-specific models/test protocols
  - Performance Predictions
- Validate models with flight data
  - Requires in-situ environment monitoring



NEPP Program - Goals and Objectives

- Main goal – *Mission reliability* and NASA science objectives
  - *Ensure reliability missions by "smart" investments in technology knowledge gathering and research*
  - Minimize engineering resources required to maximize space and earth science data collection
- Radiation efforts objectives
  - Evaluate new and emerging technologies *with a focus on near to mid term needs*
    - Explore failure mechanisms and technology models
  - Develop guidelines for technology usage, selection, and qualification
  - Investigate radiation hardness assurance (RHA) issues
    - Increase system reliability and reduce cost and schedule

"There's a little black spot on the sun today"

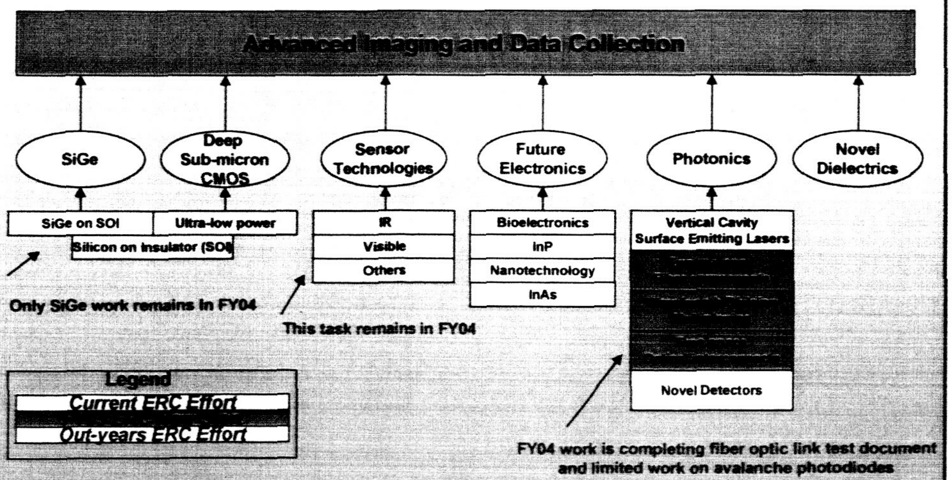


SOHO Image

NEPP Program –
Focus on Microelectronics Knowledge-base Development

- In FY04, the NEPP Program began a new initiative to extend the knowledge-base of new microelectronics for NASA
  - Develop survey products documenting the current status of technologies and identifying the gaps
    - Includes surveying the implications of new architectures and their implications for microelectronics needs
- With regards to radiation knowledge, FY04 surveys include:
  - Transformational Communication Architecture
  - Nuclear Propulsion
  - Widebandgap Semiconductors
  - Board-level Qualification Risks
  - COTS FPGAs
  - COTS Foundries
  - Sensor Technologies
  - COTS Memories
  - Digital Single Event Transient (DSET) Risk Analysis
- Other tasks (non-radiation specific) are surveying MEMS, nanotechnologies, microcontrollers/microprocessors, ADCs, embedded passives/actives, COTS PEMS, laser diodes, et al

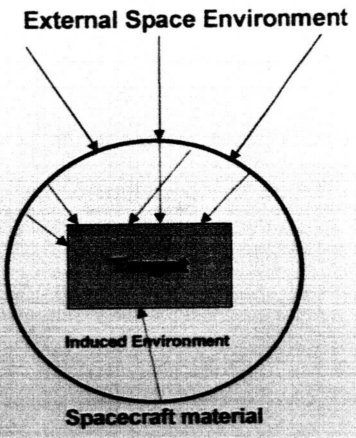
Changes in NEPP for FY03 vs. FY04:
Advanced imaging and data collection – radiation concerns



NEPP Program – *Radiation Research FY04*

- The NEPP Program, due to funding constraints, has limited work in FY04 on filling previously identified gaps in knowledge-base
- Efforts include:
  - Test Guidelines/Lessons Learned
    - Fiber Optic Link Qualification
    - ELDRS
    - FPGA (1. Test and 2. Guide for Reprogrammable)
    - Microprocessor Testing
    - Device Thinning
    - ADC Qualification
  - Focused radiation evaluations
    - SiGe Microelectronics/high-speed test techniques
    - Sensor Technologies
    - COTS Memories
    - New Non-volatile Memory Technologies
    - Foundry Assessments (limited)
  - Collaboration with Vanderbilt University/DTRA in developing improved performance prediction tools
    - Current tools are "technology deficient"

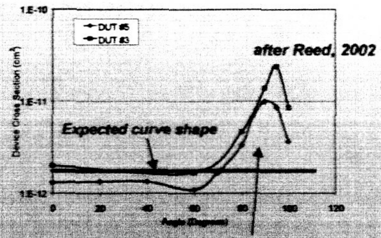
The Physics Models of Space Radiation – Environment to Target



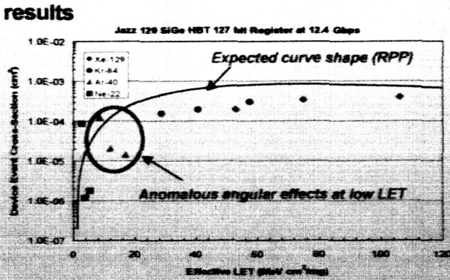
- Predictive model of the external space radiation environment that impinges on the spacecraft
- Predictive model of the interaction of that environment with the spacecraft
  - This is the induced or internal environment that impinges on electrical, mechanical, or biological systems
    - May need to consider spacecraft transport and local material transport separately
- Predictive model for the effects of the interactions of the induced environment with semiconductor, material, or biological systems (the target)

Existing Models/Tools –
Gaps for New Technologies

- **Simple example citing tool limits**
  - **CREME96**
    - **Assumption of a rectangular parallel-piped (RPP) for sensitive volume requires assessment in light of**
      - **Single event transient (SET) issues for higher speeds**
      - **Diffusion effects noted in SDRAMs**
      - **Non-bulk CMOS test results**



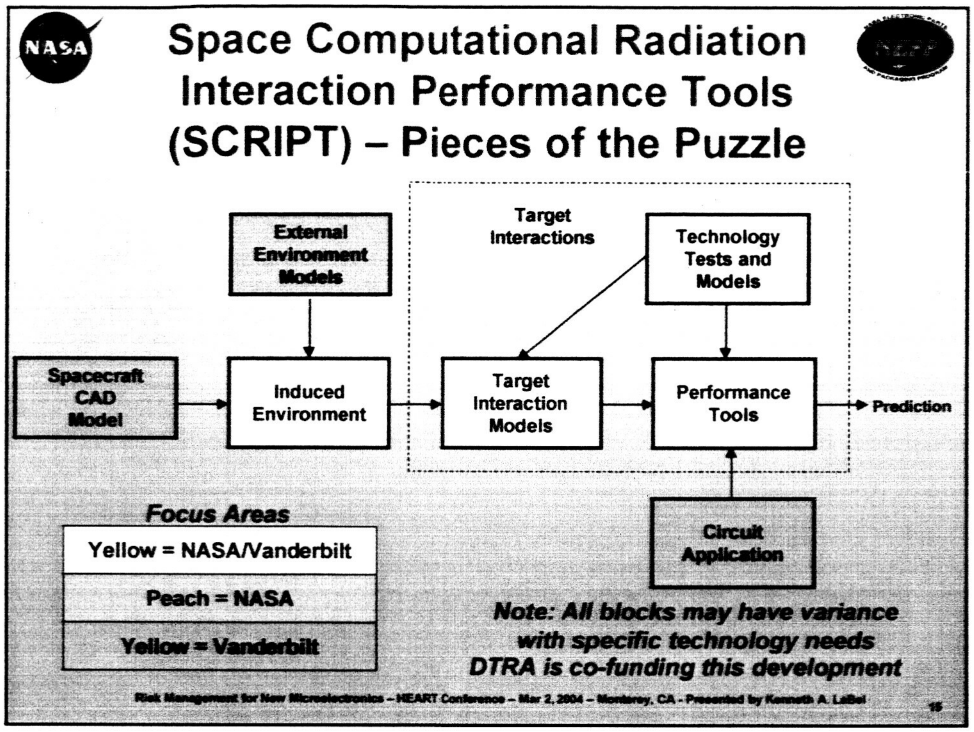
Proton-induced angular effects in SOI device with high aspect ratio



RPP model does not fit SiGe

Implications of Space Radiation Technology Tool "Gaps"

- **Simplifying assumptions (such as RPP) used in many existing tools are inadequate for new technology performance**
  - **Use of existing tools for predictive purposes may add large risk factors onto NASA missions (significant under or over prediction of performance)**
  - ***Physics-based models could provide a more accurate solution using physics-modeling codes (GEANT4, MCNPX, etc.)***
- **Comprehensive tool suite is desired using physics-based codes**
  - **Requires careful technology characterization and modeling effort**
    - **Challenge is to make the tool suite realizable (i.e., physics-based codes could take long periods of time to calculate results)**
      - **Simplifying assumptions and 1st order model development**
- **FY04 effort is to define the gaps and begin development of a Space Computational Radiation Interaction Performance Tools (SCRIPT) suite**


Space Computational Radiation Interaction Performance Tools (SCRIPT) – Pieces of the Puzzle
External Environment Models
Target Interactions
Technology Tests and Models
Spacecraft CAD Model
Induced Environment
Target Interaction Models
Performance Tools
Prediction
Circuit Application
Focus Areas
Yellow = NASA/Vanderbilt
Peach = NASA
Yellow = Vanderbilt
Note: All blocks may have variance with specific technology needs
DTRA is co-funding this development
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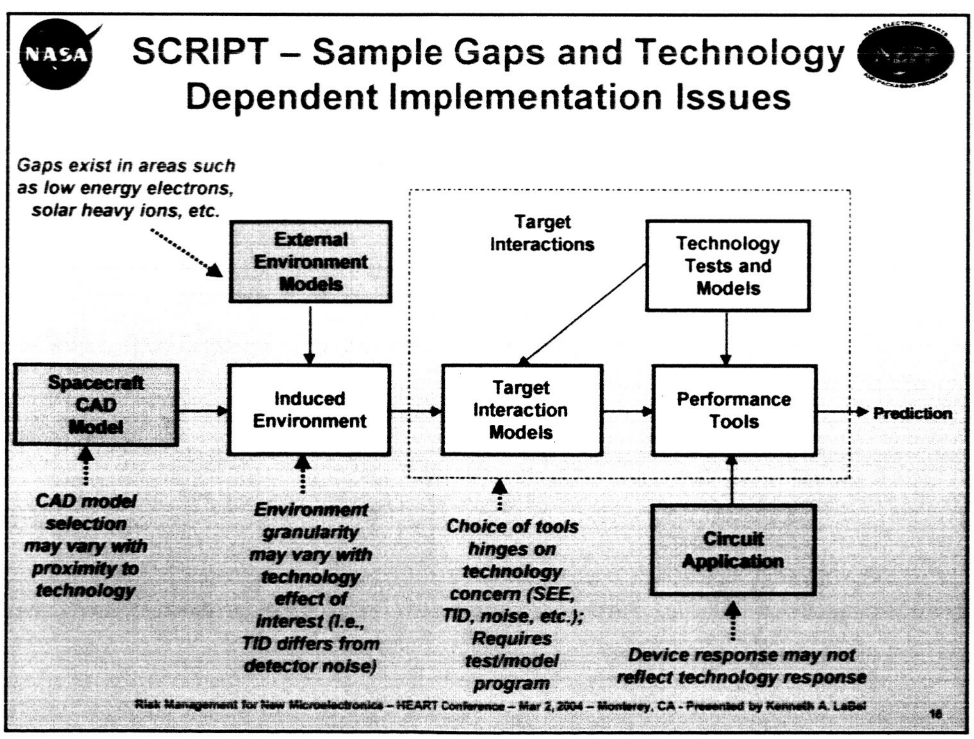
SCRIPT – Sample Gaps and Technology Dependent Implementation Issues
Gaps exist in areas such as low energy electrons, solar heavy ions, etc.
External Environment Models
Target Interactions
Technology Tests and Models
Spacecraft CAD Model
Induced Environment
Target Interaction Models
Performance Tools
Prediction
Circuit Application
CAD model selection may vary with proximity to technology
Environment granularity may vary with technology effect of interest (i.e., TID differs from detector noise)
Choice of tools hinges on technology concern (SEE, TID, noise, etc.); Requires test/model program
Device response may not reflect technology response
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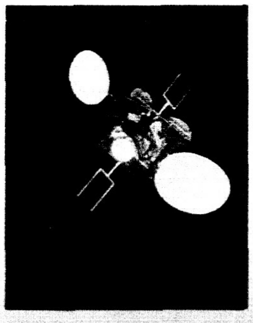
Validation of SCRIPT – Flight Experiments and Data

- Differences exist between ground-based radiation tests and the actual space environment
  - Energy spectrum
  - Directionality
  - Mixed environment
  - Particle arrival rates (flux or dose)
- Flight experiments and/or monitoring technology performance are required to validate ground-based models and tools
  - In-situ technology AND environment measurements desired



Flight technology experiments such as ACTS help provide validation for ground-based technology models and concepts

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NASA's Living With a Star (LWS) Space Environment Testbed (SET) – A Dual Approach to Flight Validation

- Data mining
  - The use of existing flight data to validate or develop improved models and tools
- Examples
  - Linear device performance on Microelectronics and Photonics TestBed (MPTB)
  - Physics-based Solar Array Degradation Tool (SAVANT)
- Flight experiments
  - Focus on correlating technology (semiconductor to material) performance with solar-variant space environment (radiation, UV, etc.)
    - Model/technology validation and not device validation are the goals
  - In-situ environment monitoring allows for ground test protocol/model correlation
  - Multiple flight opportunities

Investigations are selected via NASA Research Announcements or provided under partnering arrangements

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Summary Comments

- Technology needs to be planned for strategically
  - Long-term needs and not point solutions
- Mission risk revolves around radiation "unknowns"
  - Need a significant effort in advance of mission timelines for new technology development/testing/modeling
    - Infrastructure needs to be in place to support technologies
      - Schedules don't allow time for creating new capabilities once mission design has started
- Updated tools and models are required to reduce risk of new technology insertion
- Easy access flight technology testbeds are desired to achieve near-term technology model validation
  - Ground-testing can mitigate some risk without flight data, but new technologies may have more complex space environment issues