# The Space Radiation Environment and Its Implication for Designing Reliable Electronic Systems:
## *A NASA Perspective*

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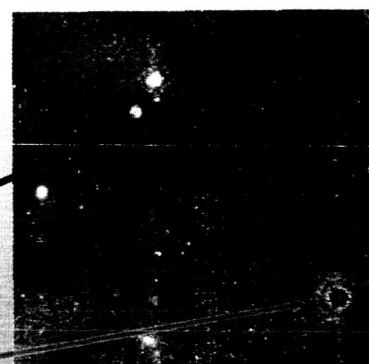
# Outline

- The Space Radiation Environment
- The Effects on Electronics
- The Environment in Action
- NASA Approaches to Commercial Electronics
  - Flight Projects
  - Proactive Research
- Living With a Star Space Environment Testbed Status
- Final Thoughts



Atomic Interactions
- Direct Ionization

Interaction with Nucleus
- Indirect Ionization
- Nucleus is Displaced

*http://www.stsci.edu/hst/nicmos/performance/anomalies/bigcr.html*

# Space Radiation Environment


*Nikkei Science, Inc. of Japan, by K. End*

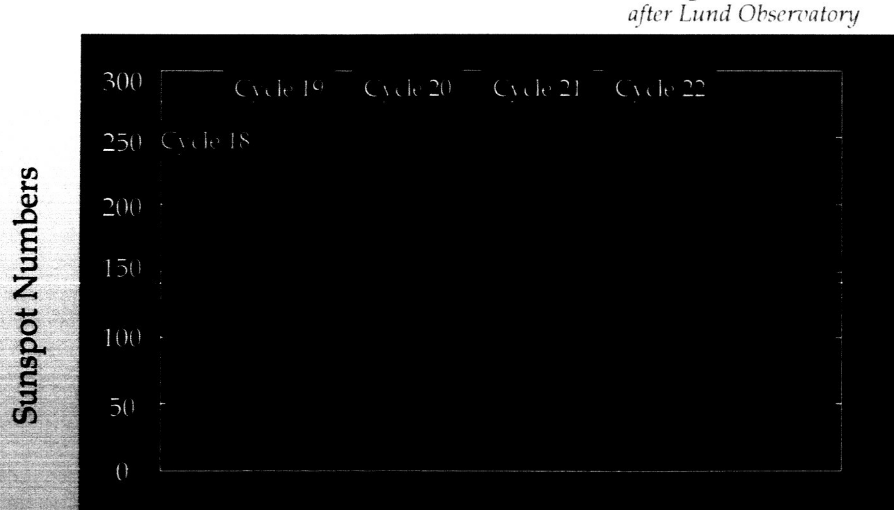
***Deep-space missions may also see: neutrons from background or radioisotope thermal generators (RTGs)***

***Atmosphere and terrestrial may see GCR and secondaries***



# Sunspot Cycle: An Indicator of the Solar Cycle

*after Lund Observatory*




**Length Varies from 9 - 13 Years**

**7 Years Solar Maximum, 4 Years Solar Minimum**

# Solar Particle Events

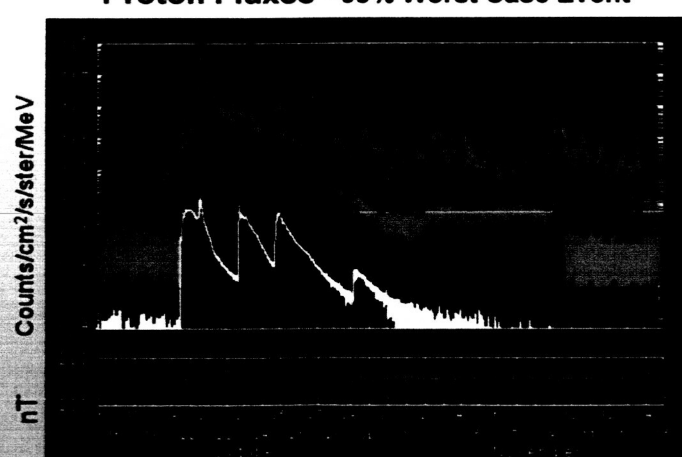
- **Cyclical (Solar Max, Solar Min)**
  - **11-year AVERAGE (9 to 13)**
  - **Solar Max is more active time period**
- **Two types of events**
  - **Gradual (Coronal Mass Ejections – CMEs)**
    - **Proton rich**
  - **Impulsive (Solar Flares)**
    - **Heavy ion rich**
- **Abundances Dependent on Radial Distance from Sun**
- **Particles are Partially Ionized**
  - **Greater Ability to Penetrate Magnetosphere than GCRs**

*Holloman AFB/SOON*



# Solar Proton Event - October 1989

**Proton Fluxes - 99% Worst Case Event**

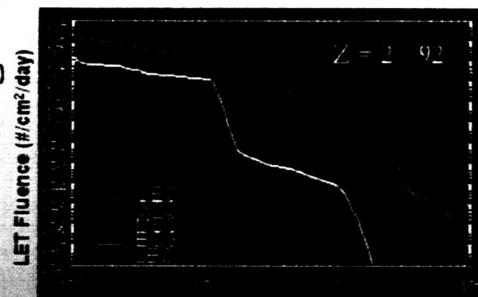



**GOES Space Environment Monitor**

# Free-Space Particles: Galactic Cosmic Rays (GCRs) or Heavy Ions

- **Definition**
  - **A GCR ion is a charged particle (H, He, Fe, etc)**
  - **Typically found in free space** (galactic cosmic rays or GCRs)
    - **Energies range from MeV to GeVs for particles of concern for SEE**
    - **Origin is unknown**
  - **Important attribute for impact on electronics is how much energy is deposited by this particle as it passes through a semiconductor material. This is known as Linear Energy Transfer or LET (dE/dX).**

CREME 96, Solar Minimum, 100 mils (2.54 mm) Al




*Time*

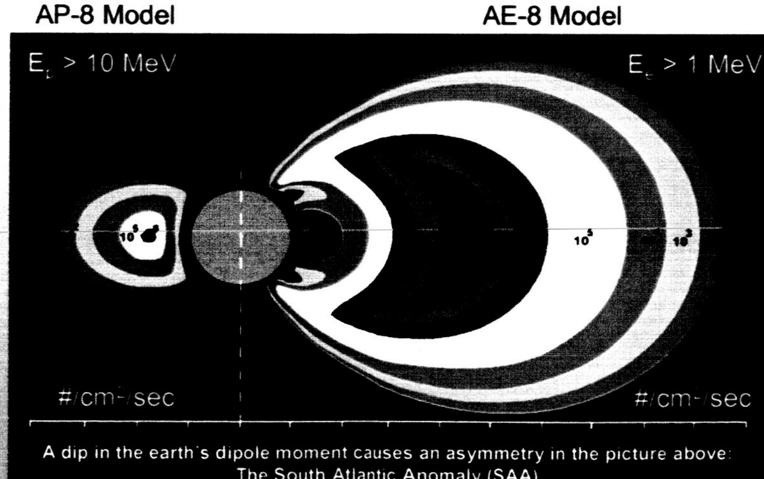
*Commercial Technology Sensitivity*



# Trapped Particles in the Earth's Magnetic Field: Proton & Electron Intensities

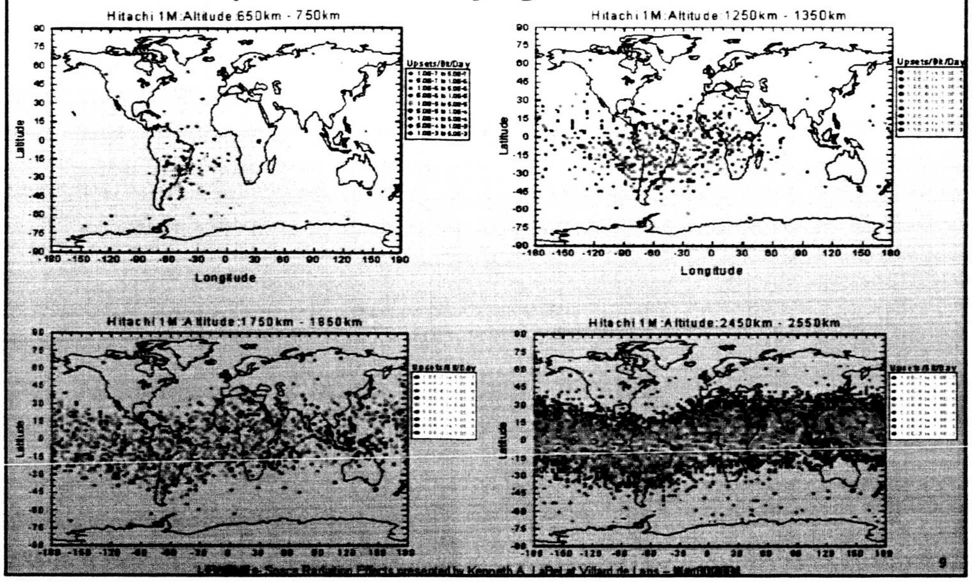
AP-8 Model

AE-8 Model




L-Shell

# SAA and Trapped Protons:
## Effects of the Asymmetry in the Proton Belts on SRAM Upset Rate at Varying Altitudes on CRUX/APEX






# Solar Cycle Effects: Modulator and Source

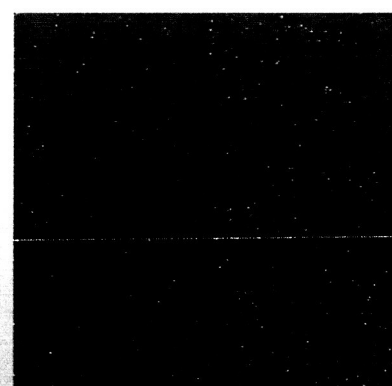
- Solar Maximum
  - Trapped Proton Levels Lower, Electrons Higher
  - GCR Levels *Lower*
  - Neutron Levels in the Atmosphere Are Lower
  - Solar Events More Frequent & Greater Intensity
  - Magnetic Storms More Frequent --> Can Increase Particle Levels in Belts
- Solar Minimum
  - Trapped Protons Higher, Electrons Lower
  - GCR Levels *Higher*
  - Neutron Levels in the Atmosphere Are Higher
  - Solar Events Are Rare

***Light bulb shaped CME courtesy of SOHO/LASCO C3 Instrument***

# The Weapons

# Radiation Effects and Spacecraft

- **Critical areas for design in the natural space radiation environment**
  - **Long-term effects**
    - **Total ionizing dose (TID)**
    - **Displacement damage**
  - **Transient or single particle effects (Single event effects or SEE)**
    - **Soft or hard errors**
- **Mission requirements and philosophies vary to ensure mission performance**
  - ***What works for a shuttle mission may not apply to a deep-space mission***



***An Active Pixel Sensor (APS) Imager under irradiation with heavy ions at Texas A&M University Cyclotron***

# Total Ionizing Dose (TID)

- **Cumulative long term *ionizing* damage due to protons & electrons**
- **Effects**
  - Threshold Shifts
  - Leakage Current
  - Timing Changes
  - Functional Failures
- **Can *partially* mitigate with shielding**
  - Low energy protons
  - Electrons



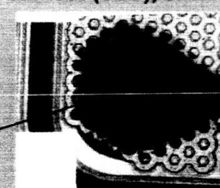
# Displacement Damage (DD)

- **Cumulative long term *non-ionizing* damage due to protons, electrons, and neutrons**
- **Effects**
  - Production of defects which results in device degradation
  - May be similar to TID effects
  - Optocouplers, solar cells, CCDs, linear bipolar devices
- **Shielding has some effect - depends on location of device**
  - Can eliminate electron damage
  - Reduce some proton damage

**Not particularly applicable to CMOS microelectronics**

# Single Event Effects (SEEs)

- An SEE is caused by a *single charged particle* as it passes through a semiconductor material
  - Heavy ions
    - Direct ionization
  - Protons for sensitive devices
    - Nuclear reactions for standard devices
- Effects on electronics
  - If the LET of the particle (or reaction) is greater than the amount of energy or critical charge required, an effect may be seen
    - Soft errors such as upsets (SEUs) or transients (SETs), or
    - Hard (destructive) errors such as latchup (SEL), burnout (SEB), or gate rupture (SEGR)
- Severity of effect is dependent on
  - type of effect
  - system criticality



*Destructive event in a COTS 120V DC-DC Converter*



# Radiation Effects on Electronics and the Space Environment

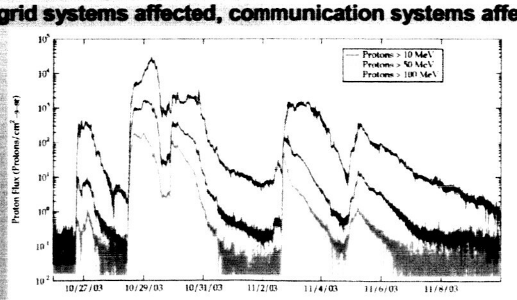
- Three portions of the natural space environment contribute to the radiation hazard
  - Solar particles
    - Protons and heavier ions
      - SEE, TID, DD
  - Free-space particles
    - GCR
      - For earth-orbiting craft, the earth's magnetic field provides some protection for GCR
      - SEE
  - Trapped particles (in the belts)
    - Protons and electrons including the South Atlantic Anomaly (SAA)
      - SEE (Protons)
      - DD, TID (Protons, Electrons)

The sun acts as a modulator and source in the space environment

# The Mass Destruction

# Recent Solar Events – A Few Notes and Implications

- In Oct-Nov of this year, a series of X-class (X-45!) solar events took place
  - High particle fluxes were noted
  - Many spacecraft performed safing maneuvers
  - Many systems experienced higher than normal (but correctable) data error rates
  - Several spacecraft had anomalies causing spacecraft safing
  - Increased noise seen in many instruments
  - Drag and heating issues noted
  - Instrument FAILURES occurred
  - Two known spacecraft FAILURES occurred
- **Power grid systems affected, communication systems affected...**

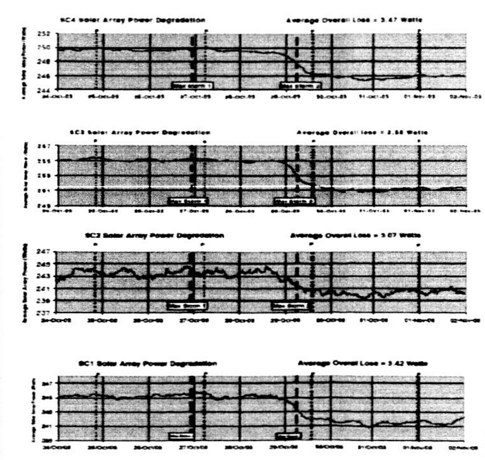


## SOHO LASCO C2 of the Solar Event



## Solar Event Effect - Solar Array Degradation on CLUSTER Spacecraft

ANNEX 1: Evolution of the Solar Array Power from 24-Oct to 02-Nov 2003 when two solar radiation storms occurred (the time of their maximum is indicated in the plot "---")
The degradation of the panels was about 1.4% and the average power loss is shown for each spacecraft.
The perigee passes are marked as "......" and labeled with "P"




**Many other spacecraft to noted degradation as well.**

## Science Spacecraft Anomalies During Recent Solar Events

| Type of Event | Spacecraft/ Instrument | Notes |
|---|---|---|
| Spontaneous Processor Resets | RHESSI | 3 events; all recoverable |
| | CLUSTER | Seen on some of 4 spacecraft; recoverable |
| | ChipSAT | S/C tumbled and required ground command to correct |
| High Bit Error Rates | GOES 9,10 | |
| Magnetic Torquers Disabled | GOES 9, 10, 12 | |
| Star Tracker Errors | MER | Excessive event counts |
| | MAP | Star Tracker Reset occurred |
| Read Errors | Stardust | Entered safe mode; recovered |
| Failure? | Midori-2 | |
| Memory Errors | GENESIS | 19 errors on 10/29 |
| | Many | Increase in correctable error rates on solid-state recorders noted in many spacecraft |



## Science Instrument Anomalies During Recent Solar Events

| Type of Event | Spacecraft/ Instrument | Notes |
|---|---|---|
| Instrument Failure | GOES-8 XRS | Under investigation as to cause |
| | Mars Odyssey/Marie | Under investigation as to cause; power consumption increase noted; S/C also had a safehold event – memory errors |
| | NOAA-17/AMSU-A1 | Lost scanner; under investigation |
| Excessive Count Rates | ACE, WIND | Plasma observations lost |
| | GALEX UV Detectors | Excess charge – turned off high voltages; Also Upset noted in instrument |
| | ACE | Solar Proton Detector saturated |
| Upset | Integral | Entered Safe mode |
| | POLAR/TIDE | Instrument reset spontaneously |
| Hot Pixels | SIRTF/IRAC | Increase in hot pixels on IR arrays; Proton heating also noted |
| Safe Mode | Many | Many instruments were placed in Safe mode prior to or during the solar events for protection |

## Selected Other Consequences

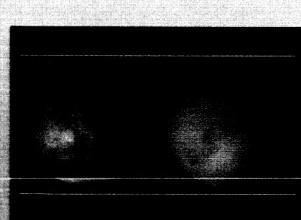
- Orbits affected on several spacecraft
- Power system failure
  - Malmo, Sweden
- High Current in power transmission lines
  - Wisconsin and New York
- Communication noise increase
- FAA issued a radiation dose alert for planes flying over 25,000 ft



## NASA Approaches to Electronics: *Projects and New Technologies*

# 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

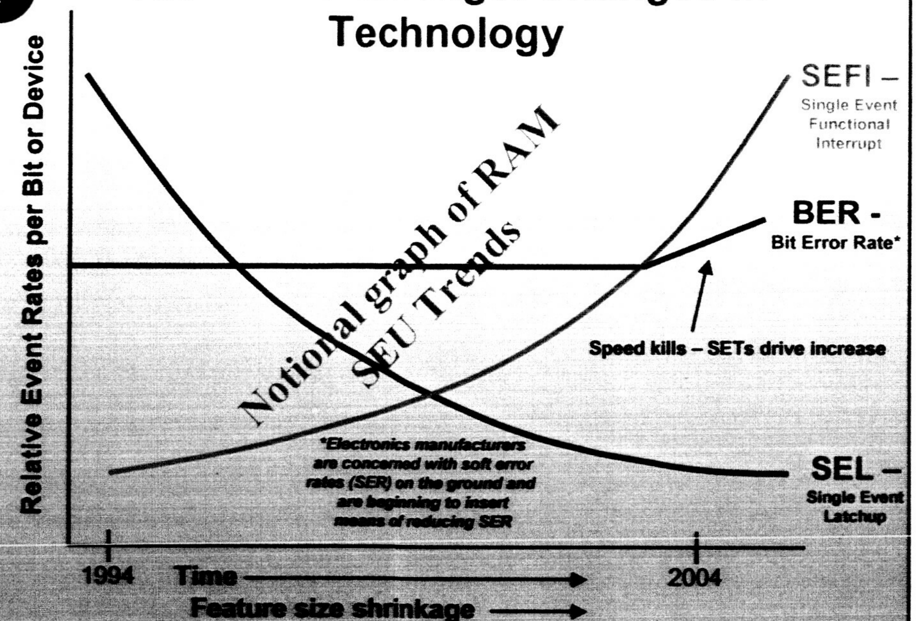


# Implications of NASA Mix

- 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*

## The New Challenge: Changes in Technology

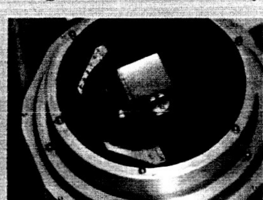





## NASA Approach to RHA

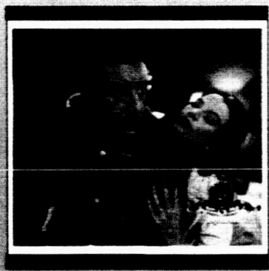
- **With commercial technology sensitivity to SEU increasing and limited radiation hardened offerings, a dual approach to RHA needs to be installed**
  - **A systems approach at the flight mission level, and**
  - **Proactive investigation into new technologies**

**Rockwell/Hawaii 2048x2048**
**5μm HgCdTe NGST FPA (ARC)**



***Candidate James Webb Space Telescope (JWST) IR array preparing for rad tests. The ultra-low noise requirement of JWST is the driver.***

## The Investigators' Process:
## *A Systematic Approach to Flight Project Radiation Hardness Assurance (RHA)*



## Sensible Programmatics for Flight RHA:
*A Two-Pronged Approach for Missions*

- **Assign a lead radiation engineer to each spaceflight project**
  - **Treat radiation like other engineering disciplines**
    - **Parts, thermal,...**
  - **Provides a single point of contact for all radiation issues**
    - **Environment, parts evaluation, testing,...**
- **Each program follows a systematic approach to RHA**
  - **RHA active early in program reduces cost in the long run**
    - **Issues discovered late in programs can be expensive and stressful**
      - **What is the cost of reworking a flight board if a device has RHA issues?**

## Radiation and Systems Engineering: A Rational Approach for Space Systems

- **Define the Environment**
  - External to the spacecraft
- **Evaluate the Environment**
  - Internal to the spacecraft
- **Define the Requirements**
  - Define criticality factors
- **Evaluate Design/Components**
  - Existing data/Testing/Performance characteristics
- **"Engineer" with Designers**
  - Parts replacement/Mitigation schemes
- **Iterate Process**
  - Review parts list based on updated knowledge



## Define the Hazard

- **The radiation environment *external* to the spacecraft**
  - Trapped particles
    - Protons
    - Electrons
  - Galactic cosmic rays (heavy ions)
  - Solar particles (protons and heavy ions)
- **Based on**
  - Time of launch and mission duration
  - Orbital parameters, …
- **Provides**
  - Nominal and worst-case trapped particle fluxes
  - Peak "operate-through" fluxes (solar or trapped)
  - Dose-depth curve of total ionizing dose (TID)

***Note: We are currently using static models for a dynamic environment***

# Evaluate the Hazard

- Utilize mission-specific geometry to determine particle fluxes and TID at locations *inside* the spacecraft
  - 3-D ray trace (geometric sectoring)
- Typically multiple steps
  - Basic geometry (empty boxes,...) or single electronics box
  - Detailed geometry
    - Include printed circuit boards (PCBs), cables, integrated circuits (ICs), thermal louvers, etc...
- Usually an iterative process
  - Initial spacecraft design
  - As spacecraft design changes
  - Mitigation by changing box location

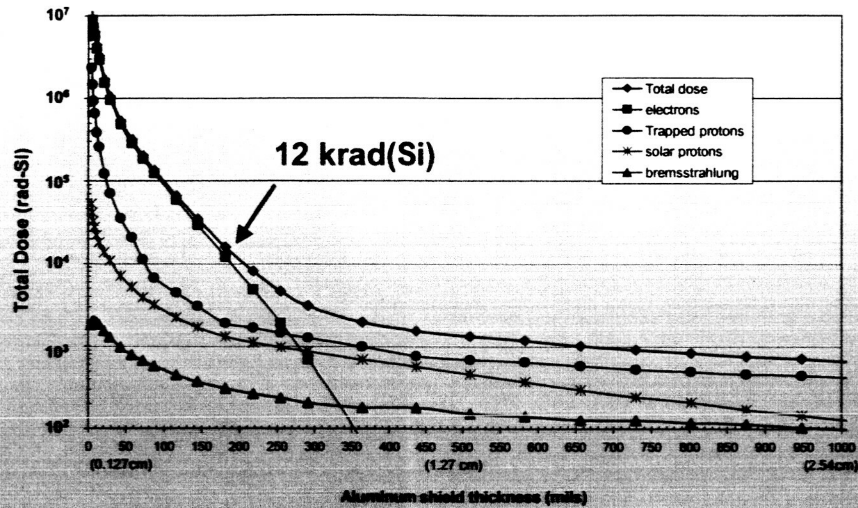


# Define Requirements

- Environment usually based on hazard definition with "nominal shielding" or basic geometry
  - Using actual spacecraft geometry sometimes provides a "less harsh" radiation requirement
- Performance requirements for "nominal shielding" such as 70 mils of Al or actual spacecraft configuration
  - TID
  - DDD (protons, neutrons)
  - SEE
    - Specification is more complex
    - Often requires SEE criticality analysis (SEECA) method be invoked
- Must include radiation design margin (RDM)
  - At least a factor of 2
  - Often required to be higher due to device issues and environment uncertainties (enhanced low dose rate issues, for example)

## Sample TID Top Level Requirement : Dose-Depth Curve

**Total dose at the center of Solid Aluminum Sphere**
**ST5: 200-35790 km, 0 degree inclination, three months**






## System Requirements - SEE Specifications

- For TID, parts can be given A number (with margin)
  - SEE is much more application specific
- SEE is unlike TID
  - Probabilistic events, not long-term
    - Equal probabilities for 1st day of mission or last day of mission
      - Maybe by definition!

## Sample Single Event Effects Specification (1 of 3)

1. Definitions and Terms

*Single Event Effect (SEE)* - any measurable effect to a circuit due to an ion strike. This includes (but is not limited to) SEUs, SHEs, SELs, SEBs, SEGRs, and Single Event Dielectric Rupture (SEDR).

*Single Event Upset (SEU)* - a change of state or transient induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components or may have effects in surrounding interface circuitry (a subset known as Single Event Transients (SETs)). These are "soft" errors in that a reset or rewriting of the device causes normal device behavior thereafter.

*Single Hard Error (SHE)* - an SEU which causes a permanent change to the operation of a device. An example is a stuck bit in a memory device.

*Single Event Latchup (SEL)* - a condition which causes loss of device functionality due to a single event induced high current state. An SEL may or may not cause permanent device damage, but requires power strobing of the device to resume normal device operations.

*Single Event Burnout (SEB)* - a condition which can cause device destruction due to a high current state in a power transistor.

*Single Event Gate Rupture (SEGR)* - a single ion induced condition in power MOSFETs which may result in the formation of a conducting path in the gate oxide.

*Multiple Bit Upset (MBU)* - an event induced by a single energetic particle such as a cosmic ray or proton that causes multiple upsets or transients during its path through a device or system.

*Linear Energy Transfer (LET)* - a measure of the energy deposited per unit length as a energetic particle travels through a material. The common LET unit is MeV*cm²/mg of material (Si for MOS devices, etc.).

*Onset Threshold LET ($LET_{th}$)* - the minimum LET to cause an effect at a particle fluence of 1E7 ions/cm² (per JEDEC). Typically, a particle fluence of 1E5 ions/cm² is used for SEB and SEGR testing.



## Single Event Effects Specification (2 of 3)

2. Component SEU Specification

2.1 No SEE may cause permanent damage to a system or subsystem.

2.2 Electronic components shall be designed to be immune to SEE induced performance anomalies, or outages which require ground intervention to correct. Electronic component reliability shall be met in the SEU environment.

2.3 If a device is not immune to SEUs, analysis for SEU rates and effects must take place based on $LET_{th}$ of the candidate devices as follows:

| Device Threshold | Environment to be Assessed |
|---|---|
| $LET_{th}$ < 15* MeV*cm²/mg | Cosmic Ray, Trapped Protons, Solar Proton Events |
| $LET_{th}$ = 15*-100 MeV*cm²/mg | Galactic Cosmic Ray Heavy Ions, Solar Heavy Ions |
| $LET_{th}$ > 100 MeV*cm²/mg | No analysis required |

2.4 The cosmic ray induced LET spectrum which shall be used for analysis is given in Figure TBD.

2.5 The trapped proton environment to be used for analysis is given in Figures TBD. Both nominal and peak particle flux rates must be analyzed.

2.6 The solar event environment to be used for analysis is given in Figure TBD.

2.7 For any device that is not immune to SEL or other potentially destructive conditions, protective circuitry must be added to eliminate the possibility of damage and verified by analysis or test.

**This number is somewhat arbitrary and is applicable to "standard" devices. Some newer devices may require this number to be higher.*

## Single Event Effects Specification (3 of 3)

2. Component SEU Specification (Cont.)

2.8 For SEU, the *criticality* of a device in it's specific application must be defined into one of three categories: error-critical, error-functional, or error-vulnerable. Please refer to the /radhome/papers/seecal.htm Single Event Effect Criticality Analysis (SEECA) document for details. A SEECA analysis should be performed at the system level.

2.9 The improper operation caused by an SEU shall be reduced to acceptable levels. Systems engineering analysis of circuit design, operating modes, duty cycle, device criticality etc. shall be used to determine acceptable levels for that device. Means of gaining acceptable levels include part selection, error detection and correction schemes, redundancy and voting methods, error tolerant coding, or acceptance of errors in non-critical areas.

2.10 A design's resistance to SEE for the specified radiation environment must be demonstrated.

3. SEU Guidelines

Wherever practical, procure SEE immune devices. SEE immune is defined as a device having an $LET_{th}$ > 100 MeV*cm²/mg.

If device test data does not exist, ground testing is required. For commercial components, testing is recommended on the flight procurement lot.



## Notes on System Requirements

- Requirements do NOT have to be for piecepart reliability
  - For example, may be viewed as a "data loss" specification
    - Acceptable bit error rates or system outage
  - Mitigation and risk are system trade parameters
  - Environment needs to be defined for *YOUR* mission (can't use prediction for different timeframe, orbit, etc...)

# Radiation Design Margins (RDMs)

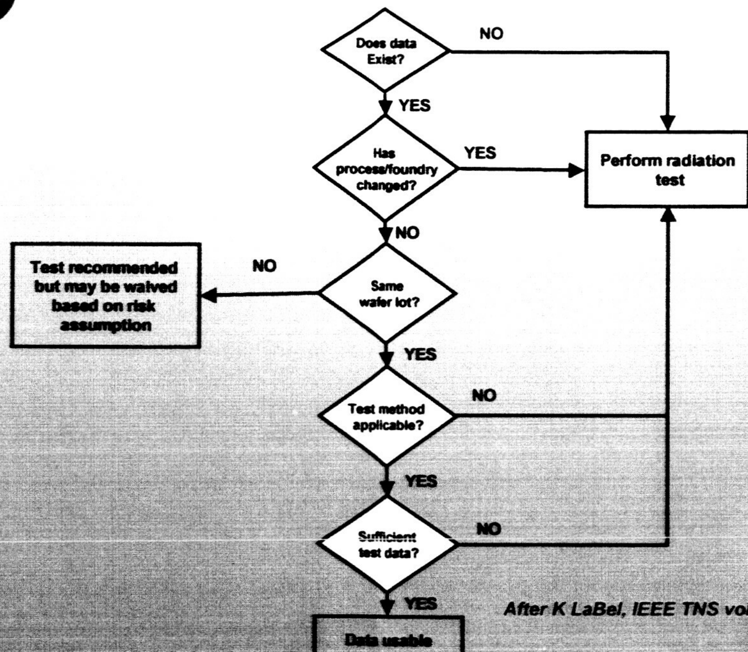
- **How much risk does the project want to take?**
- **Uncertainties that must be considered**
  - **Dynamics of the environment**
  - **Test data**
    - **Applicability of test data**
      - **Does the test data reflect how the device is used in THIS design?**
    - **Device variances**
      - **Lot-to-lot, wafer-to-wafer, device-to-device**
- **Risk trade**
  - **Weigh RDM vs. cost/performance vs. probability of issue vs. system reliability etc...**



# Evaluate Design/Component Usage

- **Screen parts list**
  - **Use existing databases**
    - **RADATA, REDEX, Radhome, IEEE TNS, IEEE Data Workshop Records, Proceedings of RADECS, etc.**
    - **Evaluate test data**
  - **Look for processes or products with known radiation tolerance (beware of SEE and displacement damage!)**
    - **BAE Systems, Honeywell Solid State Electronics, UTMC, Harris, etc.**
- **Radiation test unknowns or non-RH guaranteed devices**
- **Provide performance characteristics**
  - **Usually requires *application specific* information: understand the designer's sensitive parameters**
    - **SEE rates**
    - **TID/DDD**

## Data Search and Definition of Data Usability Flow

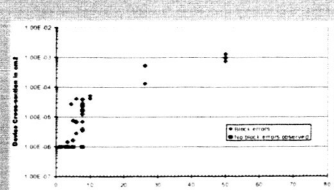



*After K LaBel, IEEE TNS vol 45-6, 1998*



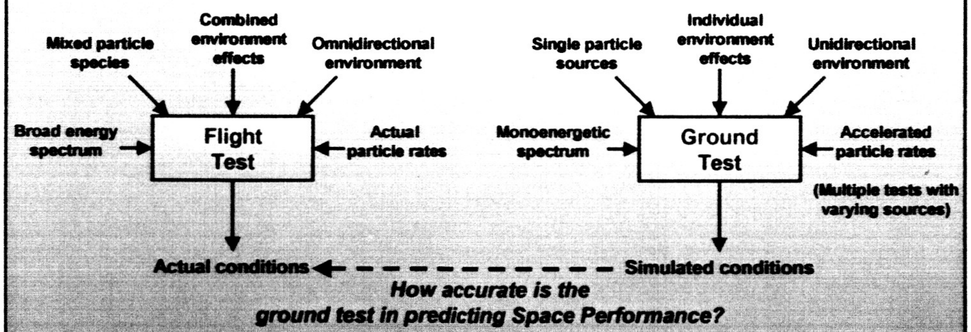
# System Radiation Test Requirements

- All **devices with unknown characteristics should be ground radiation tested (TID and SEE)**
- **All testing should be performed on flight lot, if possible**
- **Testing should mimic or bound the flight usage, if possible**
  - **Beware of new technology issues…**



**Sample Heavy Ion Test Results**

# Radiation Test Issues - Fidelity






# Engineer with the Designer

- Just because a device's radiation hardness may not meet requirements, does NOT necessarily make it unusable
  - Many concerns can be dealt with using mitigative approaches
    - Hardened by design (HBD) approaches
    - Circuit level tolerance such as error detection and correction (EDAC) on large memory arrays
    - Mechanical approaches (shielding)
    - Application-specific effects (ex., single bad telemetry point or device is only on once per day for 10 seconds or degradation of parameter is acceptable)
    - System tolerance such as 95% "up-time"
  - The key is what is the effect in THIS application
  - If mitigation is not an option, may have to replace device

***Warning: Not all effects can be mitigated safely***

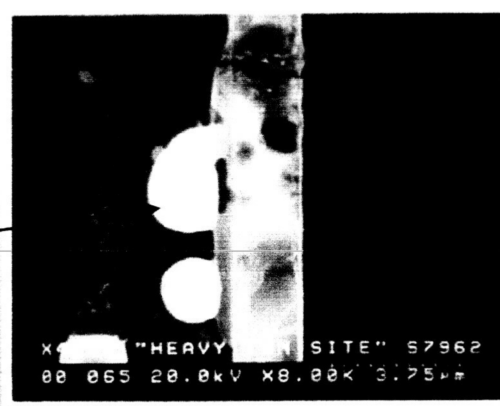
# Destructive Conditions - Mitigation

- Recommendation 1: Do not use devices that exhibit destructive conditions in your environment and application
- Difficulties:
  - May require redundant components/systems
  - Conditions such as low current SELs may be difficult to detect
- Mitigation methods
  - Current limiting
  - Current limiting w/ autonomous reset
  - Periodic power cycles
  - Device functionality check
- Latent damage is also a grave issue
  - "Non-destructive" events may be false!



# Latent Damage: Implications to SEE

- SEL events are observed in some modern CMOS devices
  - Device may not fail immediately, but recover after a power cycling
- However, in some cases
  - Metal is ejected from thin metal lines that may fail catastrophically at some time after event occurrence

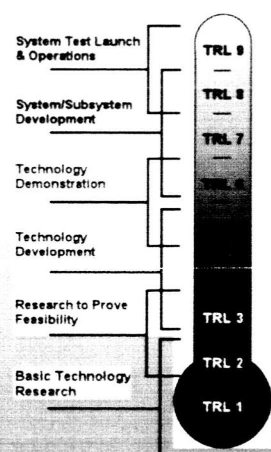



***SEL test qualification methods need to take latent damage into consideration;***
***Post-SEL screening techniques required;***
***Mitigative approaches may not be effective***

## Pre-Emptive Strikes: *Approach to Insertion of New Electronics*

## Insertion of New Technologies – A Mission Perspective

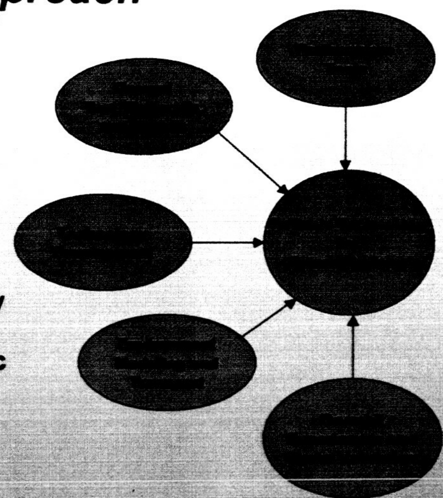
- NASA mission timeframes rarely allow for a technology development path
  - For a 2008 launch, for example, technology freeze dates are likely 2005 or earlier
    - Technology must be moderately mature when a mission is being developed
      - *There may be time to qualify a device, but there may not be time to develop/validate a new technology solution!*
    - Risk versus performance reward for using less mature or commercial off-the-shelf (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

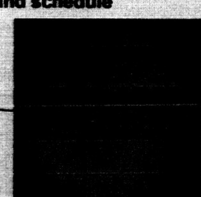




# NEPP Program - Goals and Objectives

- Main goal – *Mission reliability* and NASA science objectives
  - *Ensure reliability of 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*

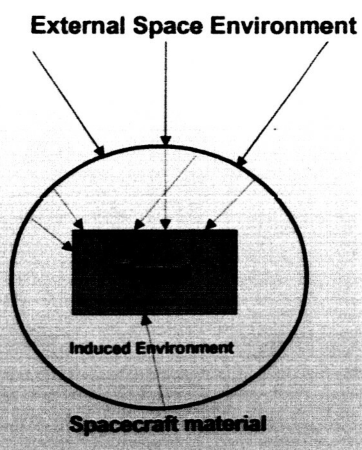
- **In FY04, the NEPP Program began a new initiative to extend the knowledge-base of new microelectronics for NASA**
  - **Develop survey products documenting the current status of technologies and identifying the gaps**
    - **Includes surveying the implications of new architectures and their implications for microelectronics needs**
- **With regards to radiation knowledge, FY04 surveys include:**
  - **Transformational Communication Architecture**
  - **Nuclear Propulsion**
  - **Widebandgap Semiconductors**
  - **Board-level Qualification Risks**
  - **COTS Field Programmable Gate Arrays (FPGAs)**
  - **COTS Foundries**
  - **Sensor Technologies**
  - **COTS Memories**
  - **Digital Single Event Transient (DSET) Risk Analysis**

***NEPP budget is too small to begin work in all but a few identified areas***

- **Focused radiation testing and modeling on SiGe, sensors, foundry assessments, and memories**
- ***Technology model assessment: Gaps widening with new technologies***



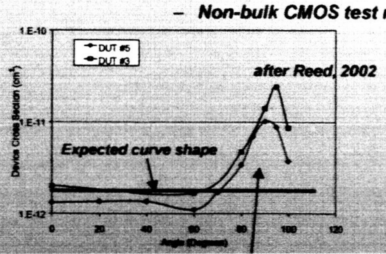
# The Physics Models of Space Radiation – Environment to Target



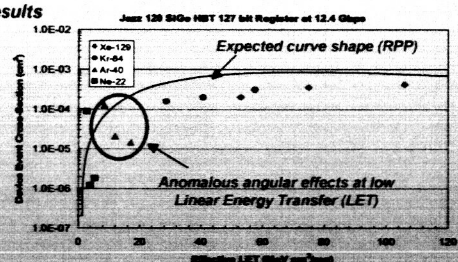

- **Predictive model of the external space radiation environment that impinges on the spacecraft**
- **Predictive model of the interaction of that environment with the spacecraft**
  - **This is the induced or internal environment that impinges on electrical, mechanical, or biological systems**
    - **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 Tool**
    - **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 (synchronous dynamic random access memories)*
      - *Non-bulk CMOS test results*




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

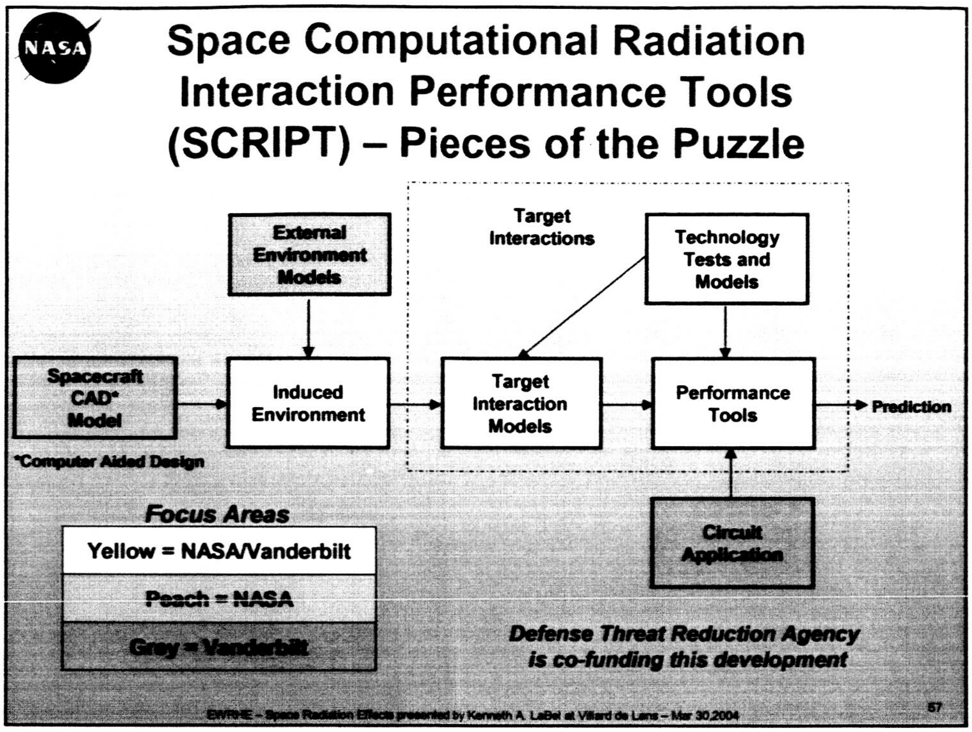



*RPP model does not fit SiGe*



# 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**
  - **Note: CNES and ESA collaboration with GEANT4 is part of the picture (Space User's Group)**


NASA
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
*Computer Aided Design
Focus Areas
Yellow = NASA/Vanderbilt
Peach = NASA
Grey = Vanderbilt
Circuit Application
Defense Threat Reduction Agency is co-funding this development
EWRHE – Space Radiation Effects presented by Kenneth A. LaBel at Villard de Lans – Mar 30,2004
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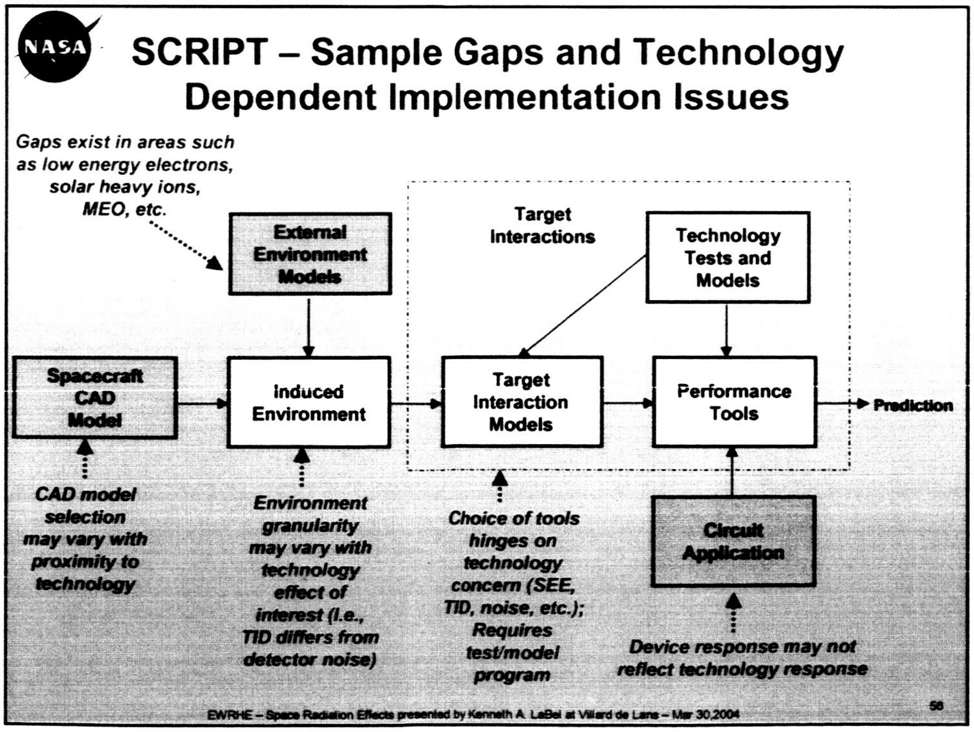
NASA
SCRIPT – Sample Gaps and Technology Dependent Implementation Issues
Gaps exist in areas such as low energy electrons, solar heavy ions, MEO, etc.
External Environment Models
Target Interactions
Technology Tests and Models
Spacecraft CAD Model
Induced Environment
Target Interaction Models
Performance Tools
Prediction
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
Circuit Application
Device response may not reflect technology response
EWRHE – Space Radiation Effects presented by Kenneth A. LaBel at Villard de Lans – Mar 30,2004
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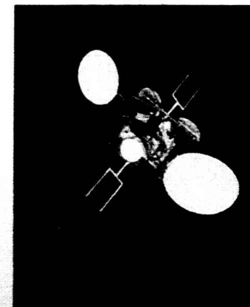
# Validation of SCRIPT – Flight Experiments and Data

- 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*



# 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
  - Carrier under development

***Investigations are selected via NASA Research Announcements (NRAs) or provided under partnering arrangements***

# LWS SET Status

- LWS program is fully funded in the President's FY05 budget request
  - No cuts due to new moon/mars initiative
- NRA-1 results are available
- Carrier design is nearing preliminary design review (PDR) level
- Flight opportunities currently being pursued with many entities
  - Planned DMSP F-18 opportunity has been dropped
    - DMSP-19 still an option
  - Negotiations with other NASA programs and Air Force and other US government agencies underway
- NRA planned for FY04 release still expected (late in FY)
  - No exchange of funds with foreign entities
- Program Manager: Neal Barthelme
- Project Scientist: Janet Barth
- Project Technologist: Ken LaBel



# Final Comments and Future Considerations

# Technology, Testing, and Flight

- Technology complicates the tests
  - Speed, Thermal, Fault Isolation, Packaging: die access!, etc
    - SETs are the "new" effect in digital devices
  - Ultra-low noise science instruments
- Future facility issues
  - Beam structure
    - Issue: At-speed testing
  - Microbeam
    - Issue: Isolation of errors / Identification of sensitive junctions
  - High energy heavy ions – Michigan State University (MSU) National Superconducting Cyclotron Labs (NSCL) now open for business
    - Issue: Increased fidelity to space environment
    - Issue: Improved ion penetration (packaging issues!)
    - Issue: Thermal (open air testing possible)
    - Issue: Speed (reduced cabling requirements)
- Nanotechnologies? MEMS?
- A proactive radiation test and modeling program is required to allow successful system RHA