On the utilization of in-flight radiation-induced performance data and anomaly resolution of Commercial Off the Shelf (COTS) electronics

Kenneth A. LaBel
NASA/GSFC Code 561
kenneth.a.label@nasa.gov
301-286-9936

Christian Poivey, SGT Inc
Janet L. Barth, NASA/GSFC

Acknowledgements

- This work is sponsored by
  - NASA Electronic Parts and Packaging (NEPP) Program
    - Deliverables based on this overview will be briefly discussed
  - NASA's Living With a Star Space Environment Testbed (LWS SET) Program
  - Defense Threat Reduction Agency

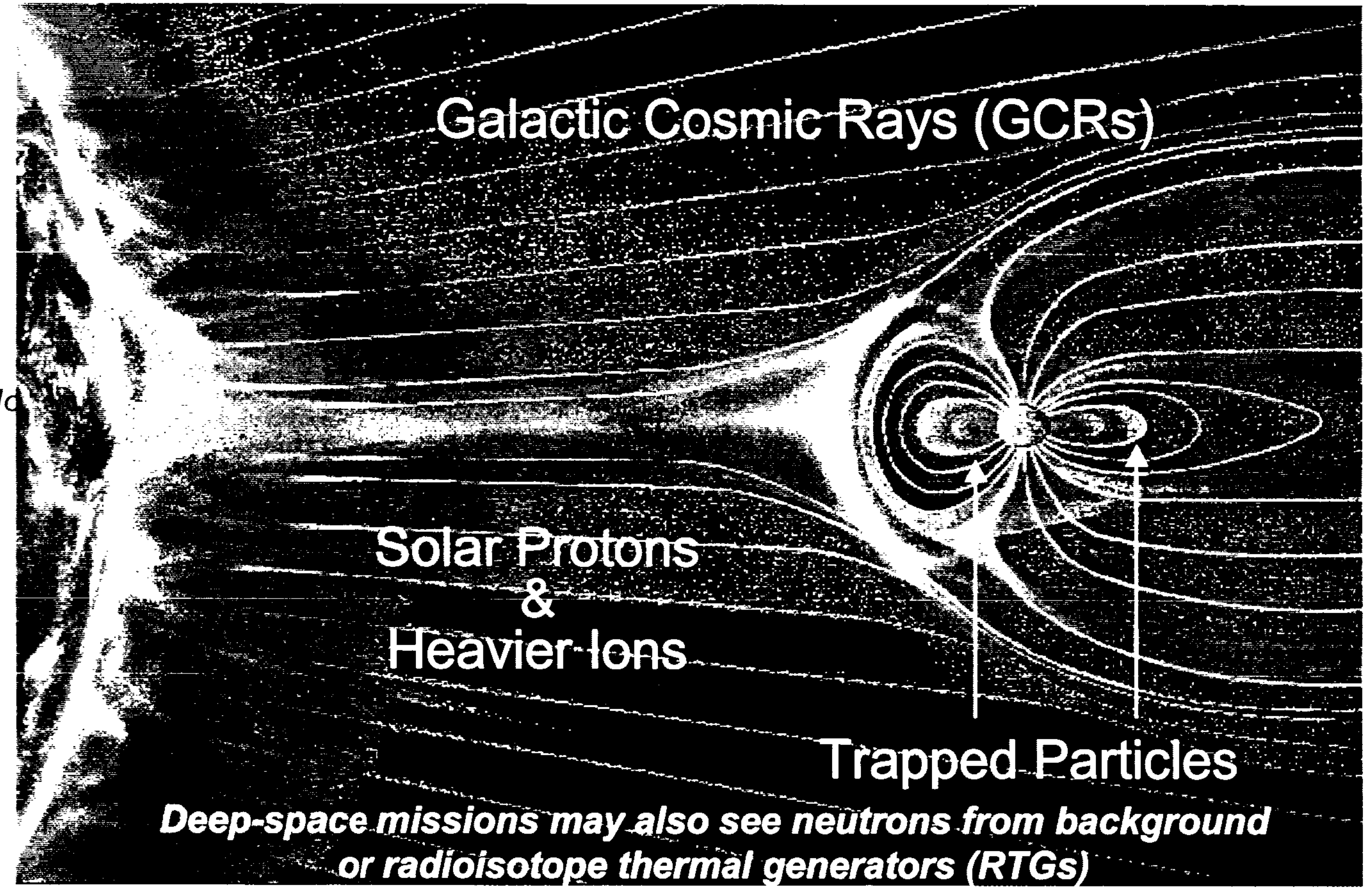
Outline

- Introduction and overview
- Rationale for tracking COTS performance in-flight
- Examples of real-life COTS performance
  - Lessons learned
- Future considerations

Introduction:
The Space Radiation Environment and COTS Electronics

HST has utilized a robust system design to conquer radiation challenges

Space Radiation Environment: Hazard for Electronics

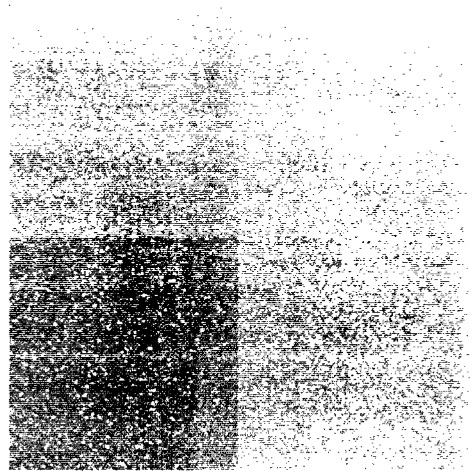


Nikkei Science, Inc. of Japan, by K. Endo

Electronics are typically most affected by the higher energy particles

Radiation Effects and Spacecraft

- **Two 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**



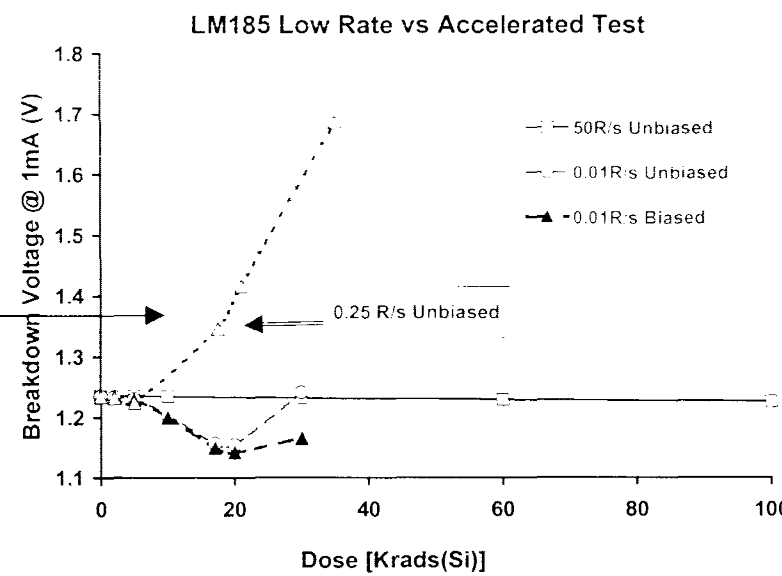
- **Four quadrants, each representing a different design**
- **Particle hits spread among multiple pixels**
- Ion strikes are minimized by utilization of a non N-well, n+ recessed implant photodetector design

Active Pixel Sensor courtesy of
Photobit Technologies via NASA SBIR and DTRA Sensors Hardening Program

Total Ionizing Dose (TID) and Displacement Damage

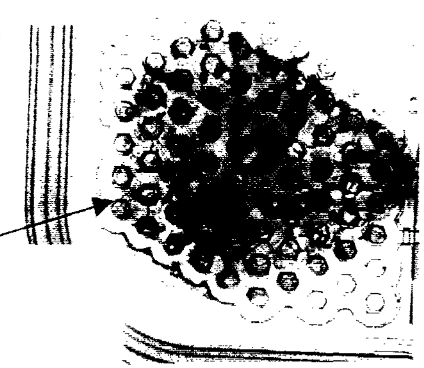
- Cumulative long term *ionizing* and *non-ionizing* damage due mostly to protons & electrons
  - Electronics can either
    - Gradually degrade over mission lifetime, or
    - Have sudden failures
- Can *partially* mitigate with shielding
  - Low energy protons
  - Lower energy electrons

Experiment to determine qualification methods



Single Event Effects (SEEs)

- An SEE is caused by a *single charged particle* as it passes through a semiconductor material
  - Heavy ions
    - Direct ionization (i.e., impact from the energy deposited in the material)
  - Protons for sensitive devices
    - Nuclear reactions for standard devices
- Effects on electronics
  - If the LET of the particle 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 errors such as latchup (SEL), burnout (SEB), ((SEGR)
- Severity of effect is dependent on
  - type of effect
  - system criticality

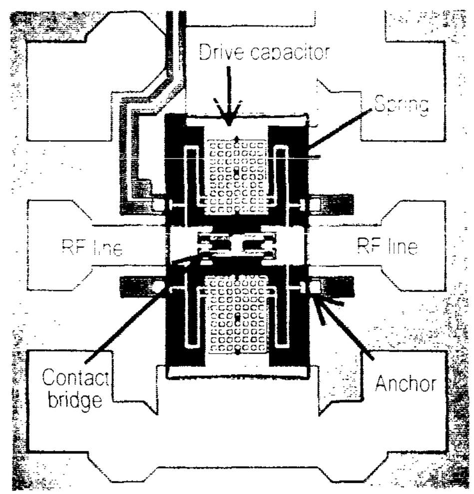


Destructive event in a COTS 120V DC-DC Converter

Why COTS?

- COTS are devices that are not designed for the space radiation environment. So why do we use them?
  - Decrease in availability of radiation hardened (RH) devices
  - Poor speed/power/density of RH devices
  - Comparable function not available in RH devices
  - Short procurement lead times
  - Perceived reduced cost (at the expense of increased reliability risks)

Rationale:
If we ground test, why do we need to track performance in flight?



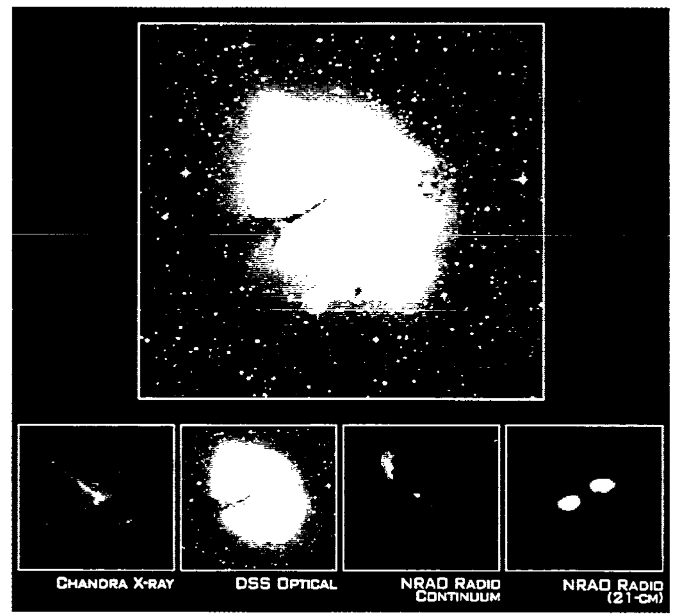
Topography of GaAs RF MEMS switch – New test techniques are required for new technologies (and new failure modes)

Three reasons to track COTS performance in-flight

- Anomaly resolution
  - Understanding what mechanisms caused an unexpected event or failure in-flight
  - Determining probability of reoccurrence or increase in degradation
  - Aiding the development of operational strategies to mitigate
- Validate ground test methods and environment predictions
  - Ground test issues include energy, direction, particle rates, etc.
  - Environment predictions have known 2-10x variances
- Provide lessons for future designers to avoid pitfalls
  - James Webb Space Telescope (formerly, the Next Generation Space Telescope) has learned valuable lessons from Chandra and ISO on infrared (IR) array degradation

COTS Performance on Science Spacecraft

Europa offers unique radiation environment challenges



Chandra has gathered aggressive science despite radiation anomalies on detectors

Sample radiation impacts on science data

Goal of these efforts:

Minimize the impact of radiation on space systems with knowledge of the effects on electronics

- Direct science impacts
  - Detector noise
    - Detector and electronics
  - Detector degradation
    - Primary and secondary radiation issues
  - Anomalies requiring spacecraft safing and recovery
    - Solar events
    - Random single event
  - Reduced mission lifetime
  - Inability to operate-through solar events or planetary belts
  - Anomaly-inducing failure

- Indirect science impacts
  - Degraded spacecraft power output
    - Increased electronics power consumption
  - Decreased speed or data retention capabilities
  - Increased design needs for shielding or redundant electronics
    - Decreases available resources for science instrument

Post-irradiation latent damage

SOHO/LASCO C3 Coronograph

July 14, 2000

Space Weather induces transients in a Charge-Coupled Device (CCD)

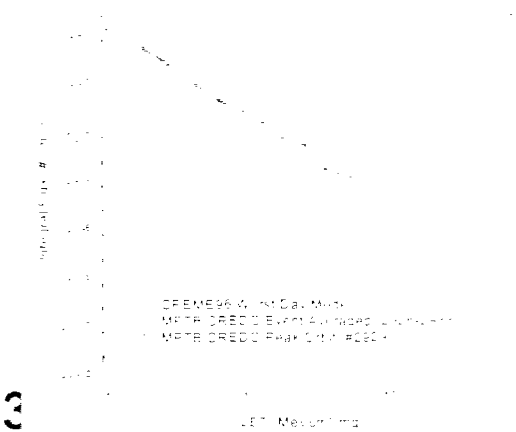
Safehold due to particle overload. NEPP is developing a lessons-learned on test and flight experience with visible sensors in FY03

Microwave Anisotropy Probe (MAP):

Single particle-induced transient in a analog device

- MAP was launched in June 2001 to a L2 orbit
  - Anomaly occurred in Nov 2001 causing the command and data handling processor to reset
    - System worked as designed for recovery of anomalies
- Event occurred during a solar particle event
  - Heavy ion contribution was likely the cause
- Sensitive design issue: linear comparator used with a small differential input
  - Much more sensitive than with larger differential input
  - Potential for further processor resets from both solar events and GCR
- NEPP is developing guidelines for test and application of these types of devices in FY03

MAP Spacecraft

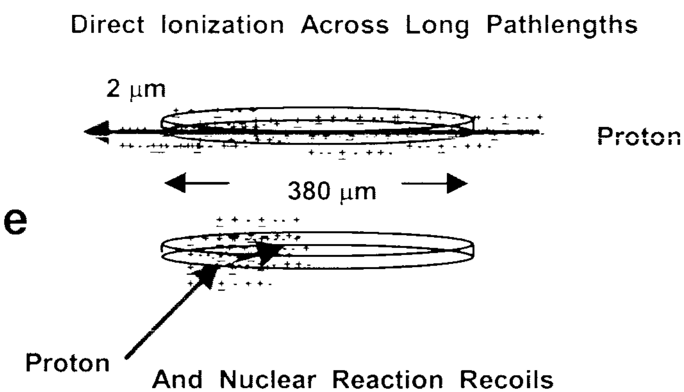


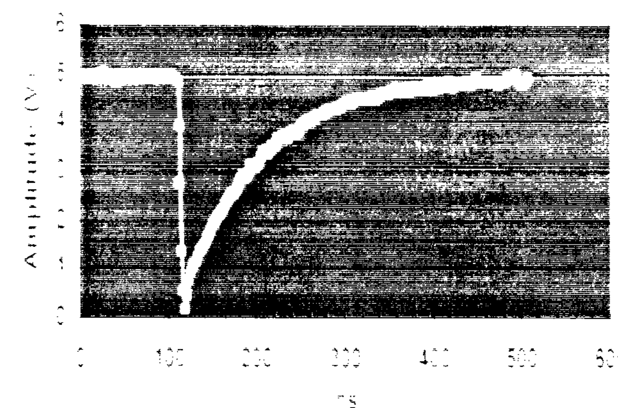
Heavy ion spectra from solar particle event

Hubble Space Telescope (HST) Optocouplers

Changes in technology make old devices, new issues

- In February of 1997, several anomalies occurred in a HST instrument while transiting through the SAA
  - High-speed optocoupler identified as the potential source
    - This was verified by ground testing in March 1997
  - Device was not reviewed for radiation issues other than total dose
    - Common philosophy prior to this timeframe on slower optocouplers
- Science instrument operations modified such that no operations were active during SAA transits
- NEPP is releasing a final guideline for test and application of optocouplers in FY03



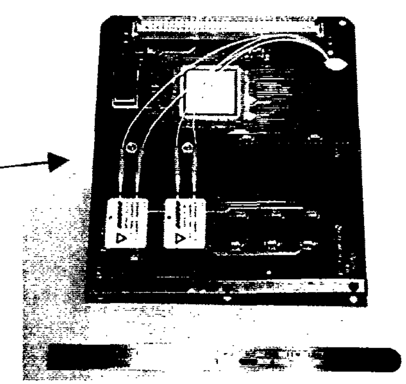


Microelectronics and Photonics Testbed (MPTB) Dual-Rate Fiber Optic Data Bus (FODB)

Reliability of optical interconnects should be considered

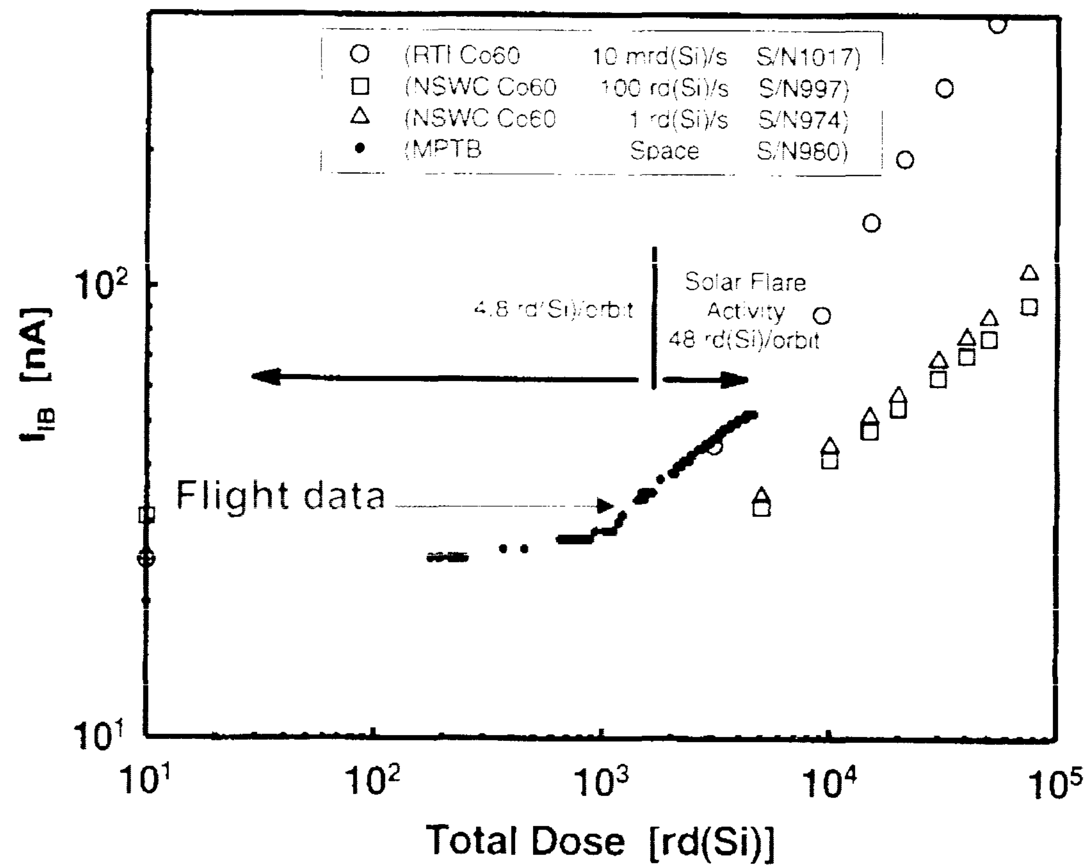
- **MPTB spacecraft was launched in Nov of 1997 into a highly elliptical orbit (HEO) that is "ideal" for space radiation exposure**
- **NASA flew an experiment for the AS-1773 1/20 Mbps FODB (transmitter, receiver, optical fiber, coupler)**
  - Two links with two differing physical interconnection methods
    - Air gap and no air gap
  - Bit error rates (BERs) observed
    - <<1E-9 errors/bit
      - No air gap ~ 2 orders more robust that air gap
- **NEPP report due in FY03**

MPTB AS-1773 Flight Experiment



MPTB Enhanced Low Dose Rate (ELDRs) Effects

Some technologies degrade more rapidly at LOWER dose rates



This is flight data from the Microelectronics and Photonics TestBed (MPTB) for a linear device. This data illustrates the effect of true space dose rates have when compared with traditional ground test data. The filled in circles represent the actual flight data for a device parameter (I_{IB}) versus cumulative dose received. These data points overlay fairly nicely on the open circles which are a very lose dose rate ground test performed on this device type. The traditional higher dose rate ground tests (the open triangle and the square) show less damage at a given TID than the flight or low dose rate data. Thus, the traditional ground test methods would provide misleading results potentially leading to premature mission failure.

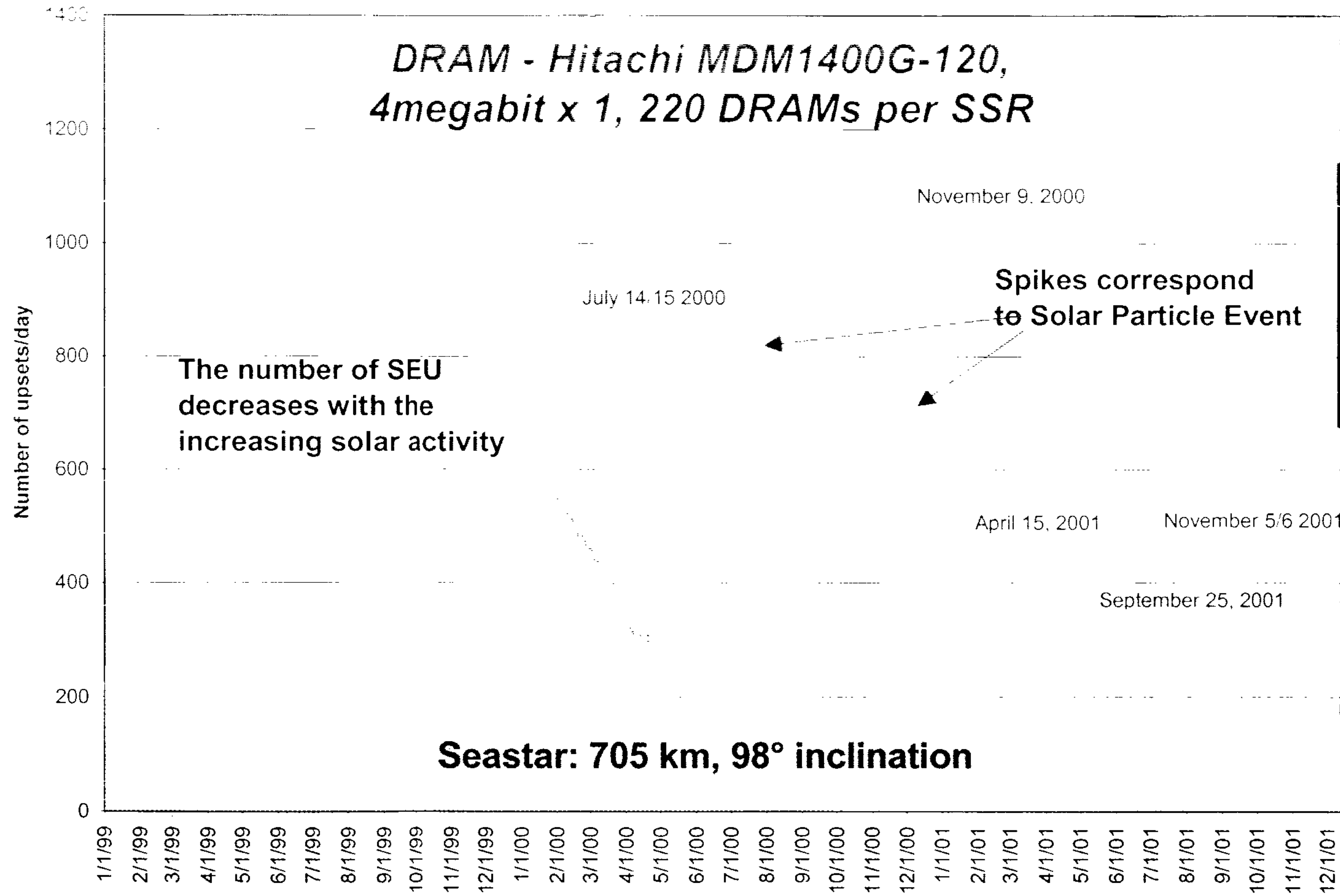
Chandra X-Ray Observatory

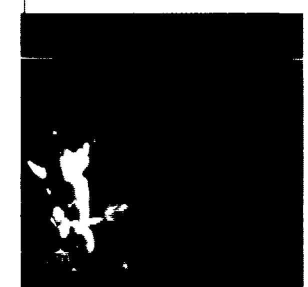
Items that may not be an issue to shielded electronics, may be an issue for detectors

- **In Sep 1999, unexpectedly high levels of degradation were noted in-flight on a X-ray telescope that had a CCD detector**
  - CCD was known to be sensitive to radiation-induced degradation and higher energy particles were well-shielded and modeled (10's of MeV)
- **However, low energy particles (100's of keV) were able to scatter down the mirror structure and cause increased damage in the form of reduced charge transfer efficiency (CTE)**
  - Impacts:
    - Operational: close the telescope during portions of the orbit when viewing was desired
    - Loss of image resolution (non-recoverable)

ORBVIEW-2 Solid State Recorder (SSR):

NEPP delivers a lessons-learned for SSRs in FY03





Single bit EDAC can be used effectively with x1 devices in most system implementations

Caveat: beware of more modern devices that have other failure modes!

HST Co-Processor:
Acceptable Mission Risk

- HST wanted to increase in-flight processing capabilities
  - GSFC Radiation Group was hired to evaluate the Intel 80486DX33 (CHMOS III) processors radiation characteristics
    - A sample of a Intel 80486DX2-66 (CHMOS IV) was also available for tests
  - High currents noted on DX33 device, but not on DX2-66
- **Decision made to go forward with design using DX2-66**
  - 3 additional lots tested (first 2 had procurement issues)
  - 3rd lot ("same process") showed high current events NOT observed in previous lots
    - This is the lot that was procured for flight
- **Despite high current events, probability of occurrence in-flight for HST orbit was low**
  - < 1 per 100,000 years
- **Deemed acceptable risk**
  - No incidents noted in over 6 years in flight

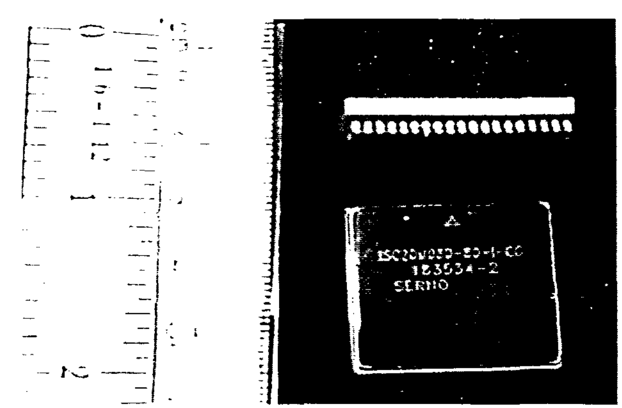
INTEL 80486DX

Hubble Space Telescope (HST) SSR:

Use of a robust Error Detection and Correction (EDAC) scheme and testing significant sample size

- Feb 1996 Hubble Space Telescope
  - Upgraded SSR installed on HST with 1440 16Mbit IBM Luna ES Rev C DRAMs (12 Gbits)
- Ground testing performed on small sample sizes
  - Row and column errors observed with heavy ions, but not protons: concept of limiting cross-section
- HST is a low-inclination, low altitude mission
  - Very few heavy ions expected
- However
  - Row and column errors observed in flight!
  - Larger sample size proton tested
    - Events similar to flight anomalies noted at a rate consistent with flight observations
- Reed-Solomon Encoding scrubbed all errors = no data lost

Stacked IBM DRAMs



Future considerations

How accurate are we at predicting and determining performance?

- Pre-flight predictions of technology performance often over-predict or under-predict the issue
  - High design margins are often required to be conservative (reduce risk)
  - New technologies sometimes see unexpected performance issues in-flight or are MORE robust than expected
  - Sources of the variance are from the environment and from the technology itself
- Even though we can learn many valuable lessons from observing in-flight performance, it is difficult to truly determine prediction and performance without in-situ environment measurements
  - Ex., dose rate issue such as Enhanced Low Dose Rate (ELDRs)
    - LWS SET is funding current data analysis on one such flight experiment (MPTB)
- Adding simple environment monitors to every mission would go far in determining "the source of error" and allow for more realistic design margins

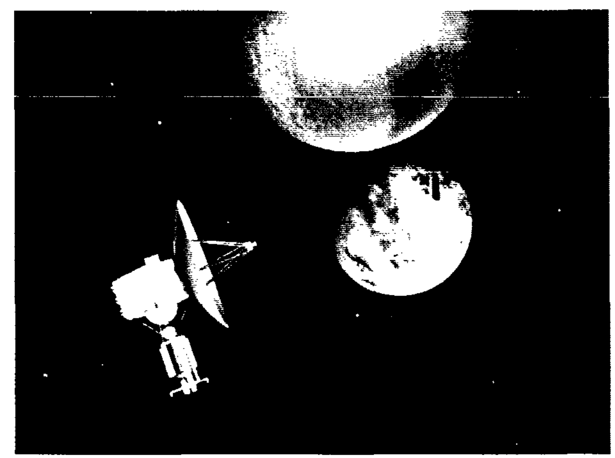
Living With a Star Space Environment Testbed (LWS SET) provides the opportunity for in-flight investigations

- SET provides opportunities for flight validation experiments on technologies
  - Microelectronics
  - Photonics
  - Materials
  - Sensors
- These investigations focus on
  - Demonstration of environment tolerance
    - Radiation hardening approaches
  - Validation of technology ground test methods and performance prediction techniques
    - Ex., correlate space dose rates to ELDRS sensitive device performance

Space Technology Research Vehicle 1-d with NASA experiments

Summary

- The radiation environment is a major difficulty in the use of COTS electronics in space
- NASA is working towards understanding these issues using both ground data (NEPP) and flight (LWS SET, for example)
- In-flight data can show both success (no loss of science data) or failure (anomaly) with the same device depending on its application
- Increased knowledge is the key
  - Environment interaction with the spacecraft
- Contact for more info
  - kenneth.a.label@nasa.gov
  - http://nepp.nasa.gov
  - http://lws-set.gsfc.nasa.gov



Pluto: challenges for radiation, temperature, and lifetime