Reliable Aerospace Computing

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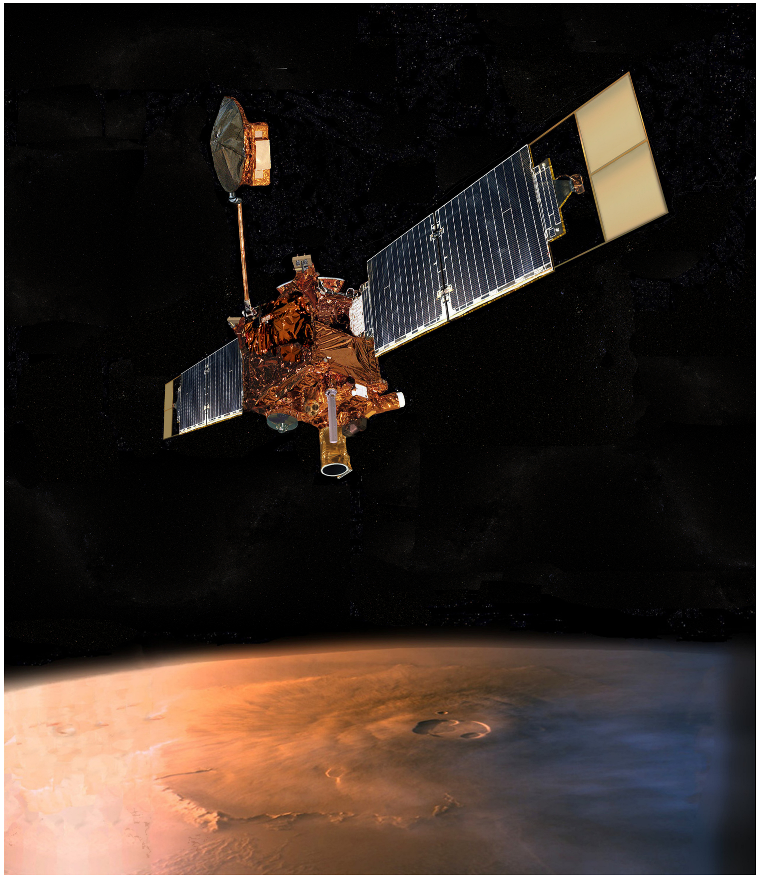
Aerospace Computing

- **Covers a wide range of missions**
  - Computer-assisted avionics
  - Deployed data processing systems
- **Increasing need for autonomous computing, especially in the national security sector**
  - Battery-powered
  - Harsh environments: radiation, temperature, weather
  - Little to no operator interaction

Satellite Deployed Data Processing

- **In recent years, the US's national security mission has focused on ubiquitous surveillance of targets and interests to provide an overall reduction of global threats**
  - This data plays an important role in national security and policy decisions
- **Many sensors, many platforms, a lot of data**
  - Automating data processing important
- **Satellite mission requirements can vary:**
  - Experiments with flexible availability
  - Operational systems with five minutes of downtime and two ground interventions per year
  - Operational systems that are expected to survive nuclear events for measurement and detection purposes



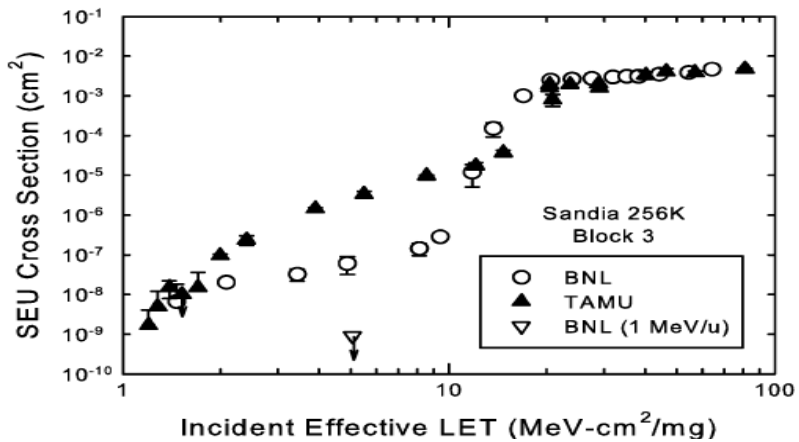
http://mars.jpl.nasa.gov/mgs/gallery/images/mgs-mons.jpg

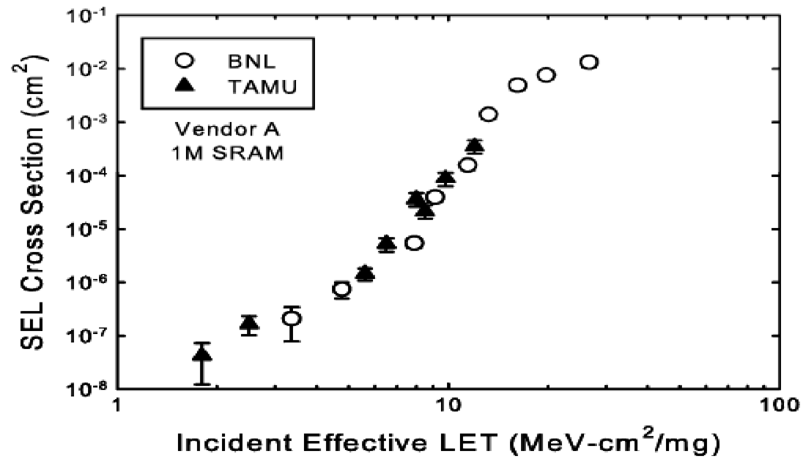
Designing Satellite Systems

- **Very harsh, dynamic radiation environment of heavy ions and protons based on orbit and solar cycle**
  - More radiation that terrestrial environment
  - Electronics affected by both the accumulation of dose (total dose) and individual ions (single event effects)
  - Heavy ion susceptibilities are 5-7 orders of magnitude worse than proton/neutron sensitivities
- **Temperature variations can be difficult**
  - Rapid temperature swings multiple times a day enhance aging effects
  - Radiation effects can be enhanced as temperature increases

The State of Space Electronics

- **Rad-hard technology tends to be older, slower, larger, more expensive**
- **"Rad-Hard" is not what it used to be:**
  - Onset thresholds for single-event upsets and single-event latchup lowering
  - Devices are increasing in size causing an increase in per-device cross-section
  - Single-event transients problems are increasing with feature shrink
- **Waiting for a better memory solution**:
  - RHBP memories: old, slow, small, not completely SEU-immune
  - Flash memories: very low total dose
  - Commercial memories: single-event latchup, B10 contamination, very high MBU rate, high current contention issues in "unscrubbable" areas of the device
  - RHBD (DICE) or chalcogenide memories a possibility for the future





Dodd, et. Al., "Impact of Heavy Ion Energy and Nuclear Interactions on Single-Event Upset and Latchup in Integrated Circuits." IEEE Transactions on Nuclear Science (Dec. 2007) vol.54, no.6, p. 2303-11

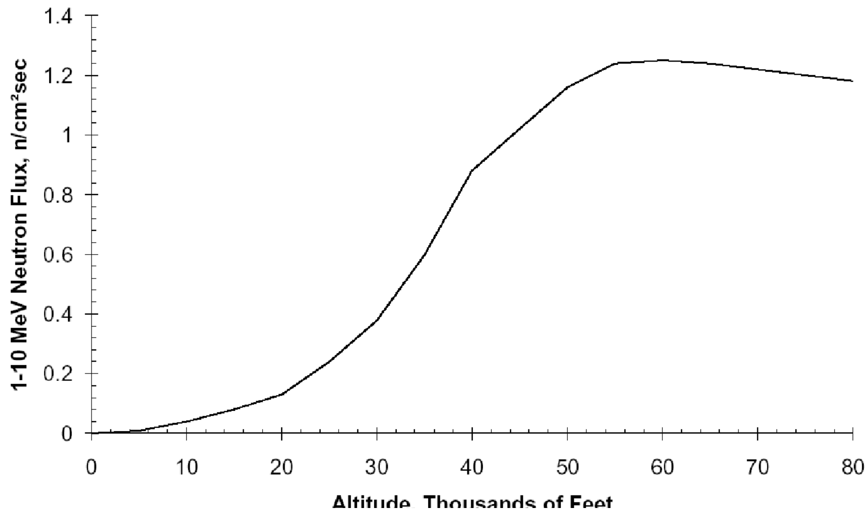
A Partial Space Solution…Fly Commercial

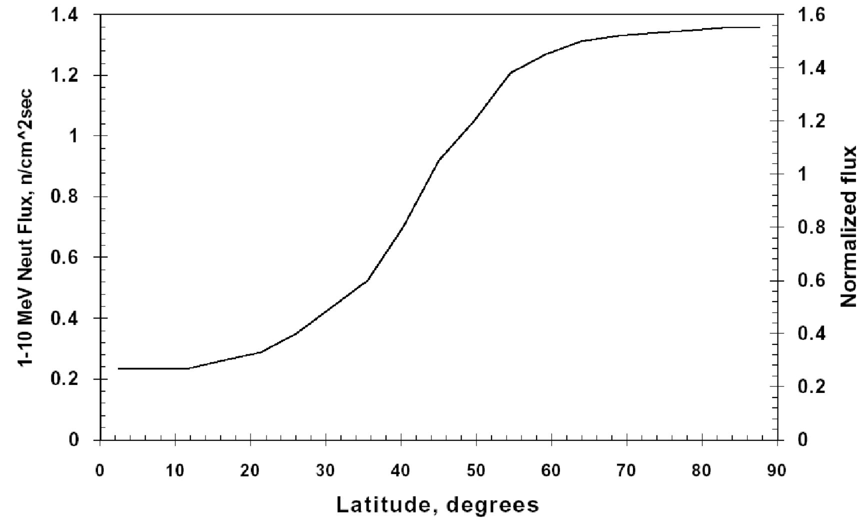
- **SRAM FPGAs from Xilinx are making inroads**
- **A number of mitigation methods were explored**
  - Spatially redundant modules: TMR, partial TMR, DWC, partial DWC
  - Quadded logic
  - State machine encoding
  - Temporal TMR
  - Everything but spatially redundant modules decreased the reliability of the circuit
- **POL, ADC, and memory devices becoming challenging**
- **Industry partnership necessary**

Cibola Flight Experiment

Airplane Systems

- **Airplane-based computational systems are increasingly important – not just for avionics but for deployed data processing also**
  - Larger cargo planes can house a small supercomputer with several sensors
  - Mission requirements not well quantified yet
- **Radiation environment is less harsh than space environment, but much harsher than sea level radiation rates**
  - Constant flux of protons and neutrons dependent on location and solar cycle
  - High altitudes and near poles can see 100-1000 times more radiation per hour than at sea level
- **Temperature variations still difficult**
- **Larger systems as vulnerable as satellites in low earth orbit**





The State of Airplane-based Systems

- **Problem is not solved:**
  - Limited test data on neutron sensitivities
  - Limited knowledge of the radiation environment both external and internal to the airplane
- **The larger system size could drive a need to mitigate radiation-induced issues**
  - Do we need to do space-level mitigation or can we scale back mitigation?
  - Current clamping for single-event latchup: no idea how quickly the system needs to be clamped, no idea on the amount of latent damage that occurs before it is clamped, no idea how that affects the mission
  - Hamming codes with data striping across memories so that entire memories can go down and be restored
  - Mitigating both FPGA circuits and software to single-event transients and single-event upsets, and deliberately sparing cores for redundancy

Things to Keep in Mind

- **Are existing problems "solved"**
  - The theory for memory correction is old, but in practice very hard to implement with current devices
  - The theory for correcting data communication errors is old, but in practice making very high speed communication reliable in a very high fault rate environments not well studied
- **Can we build systems that can seamlessly adapt to different types of environments?**
  - With different error rates?
  - With different mission requirements?
  - Without a not complete understanding of the defect/failure models?
  - Without completely redesigning the entire system?
- **What is the granularity to solve reliability problems?**
  - Can we avoid solving the component problem by addressing a system solution?
  - How do we best handle error filtering?