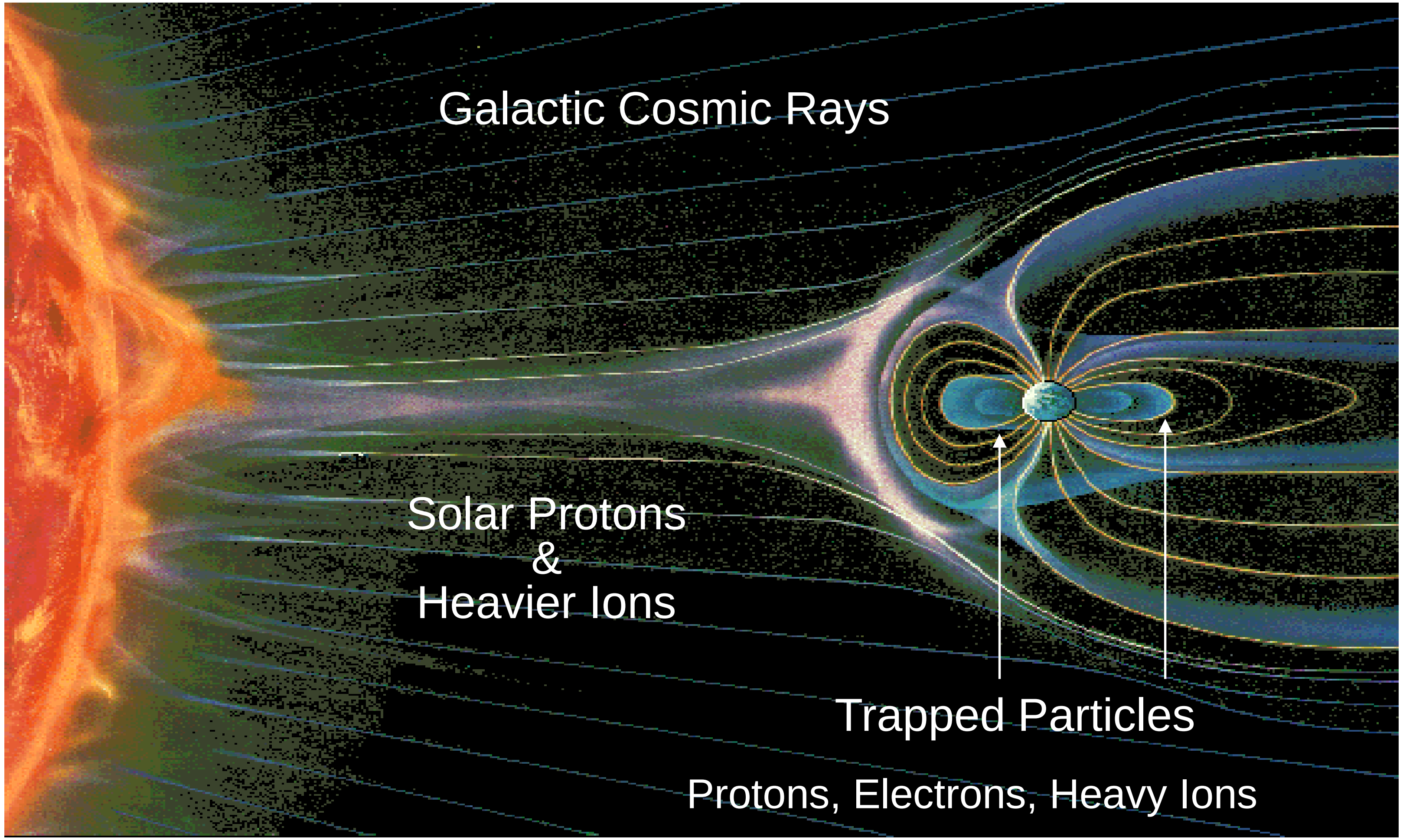
Emerging Storage Requirements For Deep Space Missions

Presenter: Raphael (Rafi) Some
RSCK Consulting LLC
rsome@twc.com

Radiation Environments

Most spacecraft environments are relatively benign, *except for radiation*
Low Earth Obit radiation is relatively benign, *deep space is challenging*
Other environmental factors include shock and vibe, thermal, power rail voltage
Lifetime for deep space missions – 20 years desired, but we try to keep temp and other stresses down

- Van Allen Belts trap electrically charged particles and shield LEO from GCRs and worst of Solar Wind.
- Atmosphere shields terrestrial environment from most of the rest
- Solar Cycles have some but relatively minimal impact on the GCR environment
- Solar CMEs have major effect on instantaneous and accumulated TID



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

Integral Cosmic Ray Spectra in Deep Space

Linear Energy Transfer for Heavy Ions

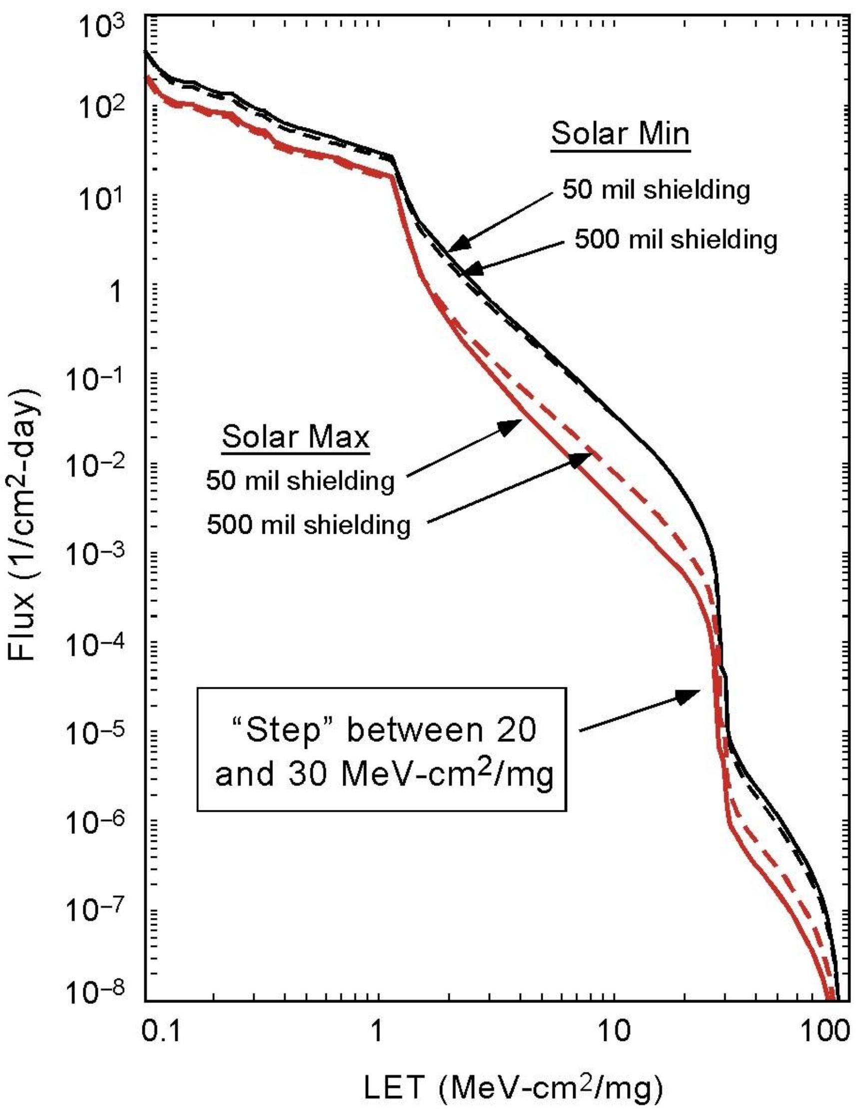
Shielding has little effect

Relatively fewer ions are present with LET values > 30 MeV-cm^2/mg

Let = 37 (Iron) is the inflection point

GCR particles are completely ionized

Abundance similar to that of elements on the Earth



Mission Environments

- Types of Missions & Environments
  - Low Earth Orbit (LEO) (< 1.2 k miles)
    - Most of the current space market
    - Easiest to meet requirements
  - MEO/Van Allen Belts (620-7.5k miles)
    - Extremely difficult radiation
    - Critical for some applications, but mostly avoided due to difficulties of high TID
    - GPS
  - GEO (22k miles), Lunar and Deep Space
    - Significant market especially for communication, observation, Lunar & Cis
  - Planetary In Situ and Other Extremes
    - Mars
    - Europa
    - Io
    - Extreme Environment Probes (Venus, Jupiter)

- Environmental Effects & Other Challenges
  - Radiation
  - Temperature & Temperature Cycle
    - Power Dissipation and Thermal Mgmt
      - (no air, no fans, oh my!)
      - Vcc/Vss +/- 10%
  - SWaP-CRL
    - Size
    - Weight
    - Power,
    - Cost
    - Reliability
    - Lifetime

So, What Do We Want/Need in the Future

- Components
  - LEO Missions
    - Capacity
    - Speed/Interfaces
    - Temperature
    - Power
    - Packaging
    - Radiation
      - TID
      - SEE
  - Deep Space Missions
    - Capacity
    - Speed/Interfaces
    - Temperature
    - Power
    - Packaging
    - Lifetime
    - Radiation
      - TID
      - SEE

SWaP-CRL

C= mission cost, not component

- Modules & Subsystems
  - LEO Missions
    - Packaging and Form Factor
    - Capacity
    - Speed/Interface
    - Temperature
    - Power
    - Radiation
  - Deep Space Missions
    - Packaging and Form Factor
    - Capacity
    - Speed/Interface
    - Temperature
    - Power
    - Lifetime
    - Radiation
      - TID
      - SEE

Radiation Environment & Requirements

Flash Memory Summit

- TID – Total Ionizing Dose
  - Gamma, electrons, protons, ions
  - Susceptibility is function of process
  - Breaks chemical bonds, typically in gate oxides – thin oxides do not absorb energy, so are more robust
  - I/O drivers, charge pumps are more susceptible than core logic and memory
  - Circuit Effects:
    - Parametric Shift
    - Timing and Threshold Shift
    - Leakage Current
    - Degradation to Failure
  - Mitigations include cold spare, shielding, time/temp annealing

- TID Environment
  - ~1-2krad/year in most applications
- TID Requirements
  - Desired 100krad (300krad for Europa)
  - Acceptable for most missions 20-30krad
  - RDF (Radiation Derating Factor)
    - 2 – 3 Desired

Radiation Environment & Requirements

- Single Event Effects (SEE)
  - Solar Protons
    - Solar Wind + CME Accelerated
  - Galactic Cosmic Rays (GCR)
    - Energetic protons and heavy ions
  - Deposited energy (LET Si)
    - Mev/mg/cm**2
    - Passage of charged particle causes a pulse in a transistor
  - Susceptibility is a function of process and circuit design
  - High voltage circuits, e.g., Flash write and charge pump are more susceptible
  - Circuit Effects:
    - Transient Pulse (SET)
    - Latch Up
      - Non-destructive
      - Destructive
    - Soft Errors (SEU, SEMU)
    - Single Event Functional Interrupt (SEFI)
      - Soft error in control logic
        - Reset
        - Power Cycle
  - Mitigations include EDAC, individual reset and chip kill, cold and hot spares, external high voltage input in place of charge pump, redundancy

- SET – Single Event Transient (pulse)
  - No specific requirements
  - Can cause havoc throughout analog and digital systems
    - PLLs
    - SERDES
    - Clocks
    - Reset
    - Effects are captured in requirements below
- SEL – Singe Event Latchup
  - LET = 75 desired,
  - 37 ok for some applications
  - 10E-4/device year ok for some applications
- SEU/SEMU - Single/Multi-bit Upset
  - AKA soft error
  - LET = 75 desired
  - 10E-10/bit day
  - 10E-8/bit day ok for some applications
- SEFI – Single Event Functional Interrupt
  - Upset of control bit(s)
  - LET =75 desired
  - 37 ok for some applications
  - 10E-3/-2/-1 per device year for Class A/B/C missions

Impact of Not Meeting Requirements

Flash Memory Summit

- Missions Lost or Severely Impacted Due to Memory Failures
  - 5 between 1997 and 2015
  - In spite of mitigations!
- Impacts of Insufficient Reliability
  - Redundancy & Complexity
  - Increased SWaP-C
  - Not meeting mission goals & objectives
- Impacts of Insufficient Lifetime
  - Redundancy & Complexity
  - Increased SWaP-C
  - Reduction in Mission Life and Capabilities
- Impacts of SWaP-CRL Budget Violations
  - Impacts every other subsystem and mission as a whole

- More Subtle Impacts
  - SWaP-CRL
    - Budgets are tight – if memory budgets can't be met, something else has to go!
      - Mission goals, objectives, duration, destinations
      - Mission cancellation (this one or others)
      - Data (dropped or not collected)
        - Instrument Data
        - Comm Data
  - Real Time Requirements Not Met
  - Growth of other subsystems
    - Thermal mgmt.
    - Comm
    - Processing
    - Structure/mechanical
    - Energy and Power
    - Complexity
      - Complexity Kills Missions!

NASA-USAF Memory Study

Flash Memory Summit

- Study indicated a need for rad-hard, high performance, high-density memory to support next generation space-based systems

Time	Memory Type	Capacity (mean)	Capacity (mean + σ)	Data Rate (mean)	Data Rate (mean + σ)
5 Years	NVM	62.2 GB	202 GB	0.125 Gbps	0.125 Gbps
10 Years	NVM	1.0 TB	2.1 TB	1.1 Gbps	1.9 Gbps
15 Years	NVM	5.7 TB	13 TB	34 Gbps	56 Gbps

Time	Memory Type	Capacity (mean)	Capacity (mean + σ)	Data Rate (mean)	Data Rate (mean + σ)
5 Years	VM	0.52 GB	0.98 GB	0.1 Gbps	0.1 Gbps
10 Years	VM	1.8 GB	3.8 GB	6.8 Gbps	13 Gbps
15 Years	VM	51 GB	91 GB	24 Gbps	37 Gbps

Synergistic Markets

- Terrestrial Mil/Aero
  - DOD (Army, Air Force, Navy, Marines, Space Force)
- Other Govt Agencies
  - DOE, MDA, NRO, …
- Automotive
- Data Centers
- Civil Aviation
- Industrial Automation
- Medical
- Other high reliability and extreme environment markets

Considerations for Working With Govt and Govt Contractors

- Testing - lots and lots of testing
  - Product Qual
  - Burn In and Test
  - Lot Qual
  - Line Qual
- Documentation
  - A LOT of documentation
    - Lot and part tracking
    - Testing per above
    - Justifications for variances or discrepancies
    - Standards and Waivers
    - Customization
  - Business Development is TOUGH
    - Slower than commercial – much slower
    - Learning curve is steep
    - Govt funding cycles
    - Govt project cycles and inconsistencies
- Utilization/acquisition of experts in dealing with govt is usually a good move