DEEP SPACE GATEWAY CONCEPT **SCIENCE WORKSHOP**

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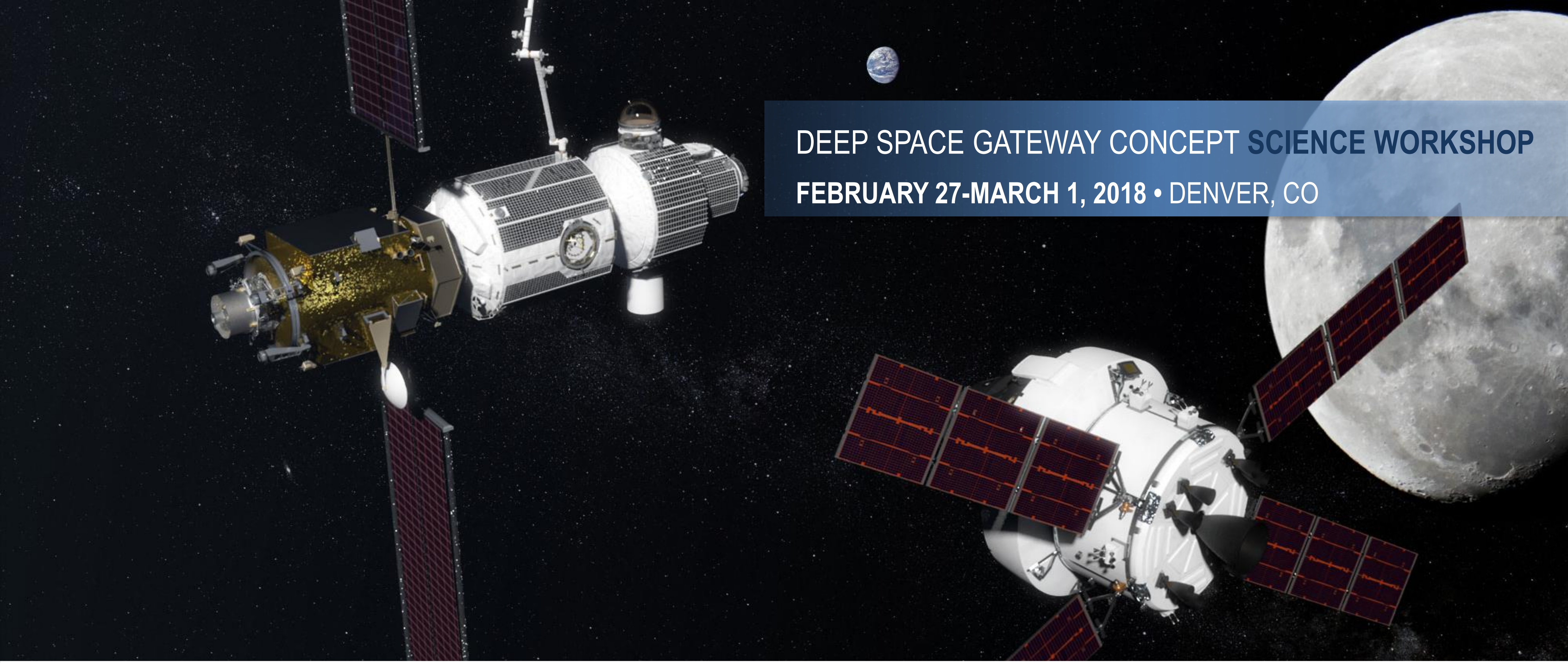

Crosscutting: Internal Payloads Panel Discussion

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Acronyms

- application-specific integrated circuits (ASICs)
- Bayesian Networks (BN)
- Complementary Metal Oxide Semiconductor (CMOS)
- Commercial Off the Shelf (COTS)
- displacement damage dose (DDD)
- NEPP Electronics Technology Workshop (ETW)
- Goal Structuring Notation (GSN)
- mission assurance (MBMA)
- model-based system engineering (MBSE)
- Multiple-Bit Upset (MBU)
- NASA Electronic Parts and Packaging (NEPP) Program
- non-ionizing energy loss (NIEL)
- Single-Event Burnout (SEB)
- Single-event effect (SEE)
- Single-Event Functional Interrupt (SEFI)
- Single-Event Gate Rupture (SEGR)
- Single-Event Latchup (SEL)
- Single-Event Transient (SET)
- Single-Event Upset (SEU)
- System Modeling Language (SysML)
- Total ionizing dose (TID)
- Total non-ionizing dose (TNID)

Weather vs. Climate

- **Space Weather**
  - *"conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."*

  [US National Space Weather Program]

- **<Space> Climate**
  - *"The historical record and description of average daily and seasonal <space> weather events that help describe a region. Statistics are usually drawn over several decades."*

  [Dave Schwartz the Weatherman – Weather.com]

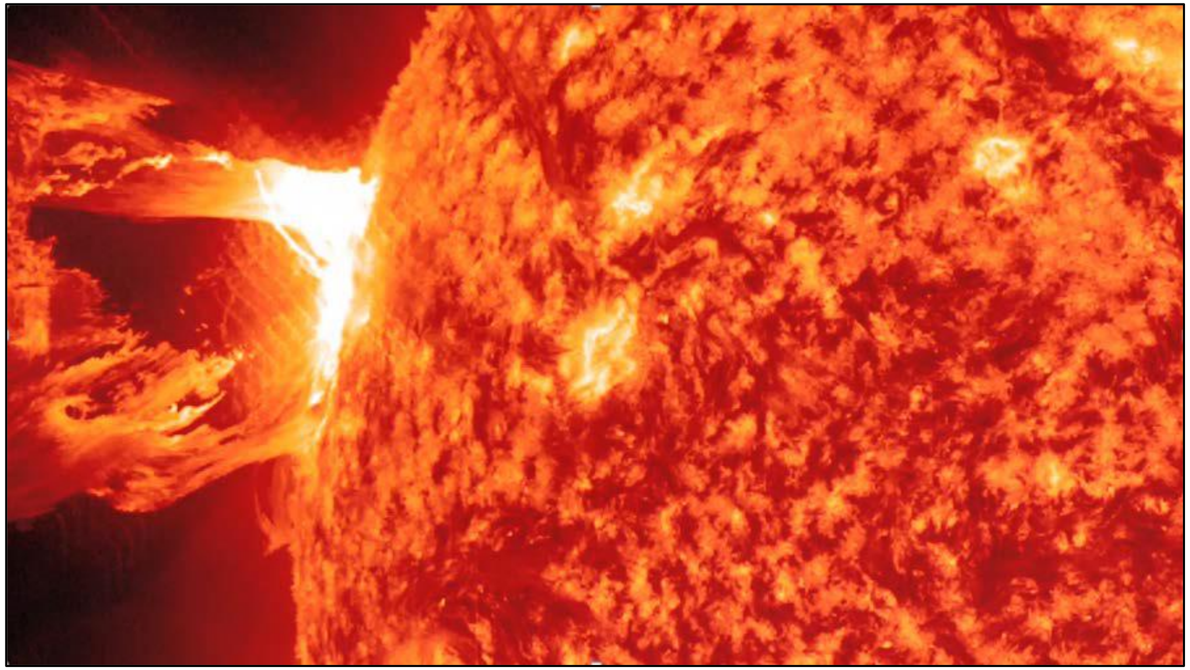
Adapted from content developed by M. Xapsos, NASA/GSFC

Image courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.

Overview

- **Basis and challenges for radiation effects in electronics / materials**
- **3 <u>main</u> types of radiation effects:**
  - Total ionizing dose (TID)
  - Total non-ionizing dose (TNID), displacement damage dose (DDD)
  - Single-event effect (SEE)
- **Examples of effects, current concerns, and possible environmental model-driven solutions**
- **Feedback required to improve**

Coronal mass ejection shot off the east limb (left side) of the Sun on April 16, 2012



NASA/Goddard Space Flight Center/SDO

What Makes Radiation Effects So Challenging?

- **Field is still evolving as are the technologies we want to use**
- **A problem of dynamic range**
  - Length: 10^{16} m → 10^{-15} m (1 light year, 1 fm)
    - 31 orders of magnitude
  - Energy: 10^{19} eV → 1 eV (extreme energy cosmic ray, silicon band gap)
    - 19 orders of magnitude
  - Those are just two dimensions; there are many others
    - Radiation sources, electronic technologies, material systems, etc.
- **Variability and knowledge of the operating environment**
- **Source of energy deposition and how it's absorbed control the observed effects**

Total Ionizing Dose (TID)

- **Total ionizing dose is the absorbed dose (e.g., Gy, rad) in a given material resulting from the energy deposition of ionizing radiation**
- **TID results in cumulative parametric degradation that can lead to functional failure**
- **In space, caused mainly by protons and electrons**

TID Effect Examples

Metal Oxide Semiconductors Devices	Bipolar Devices
Threshold voltage shifts	Excess base current
Increased off-state leakage	Changes to recombination behavior

Displacement Damage Dose (DDD)

- **Displacement damage dose is the non-ionizing energy loss (NIEL) in a given material resulting from a portion of energy deposition by impinging radiation**
- **DDD is cumulative parametric degradation that can lead to functional failure**
- **In space, caused mainly by protons and electrons**

DDD Effect Examples
Degraded minority carrier lifetime (e.g., gain reductions, effects in LEDs and optical sensors, etc.)
Changes to mobility and carrier concentrations

Single-Event Effects (SEE)

- **A single-event effect is a disturbance to the normal operation of a circuit caused by the passage of a single ion (*typically* a proton or heavy ion) through or near a sensitive node in a circuit**
- **SEEs can be either destructive or non-destructive**

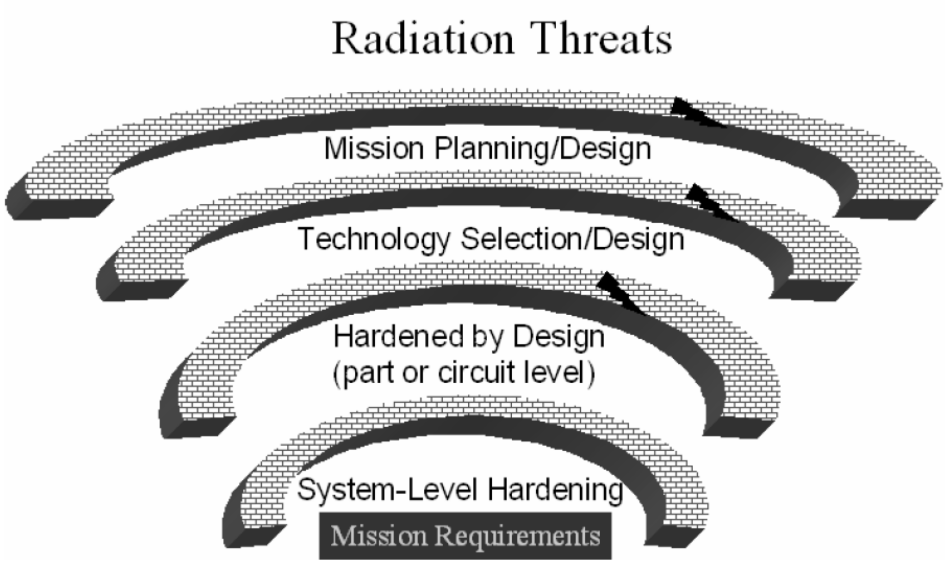
SEE Examples

Non-Destructive	Destructive
Single-Event Upset (SEU)	Single-Event Latchup (SEL)
Multiple-Bit Upset (MBU)	Single-Event Burnout (SEB)
Single-Event Transient (SET)	Single-Event Gate Rupture (SEGR)
Single-Event Functional Interrupt (SEFI)	

After S. Buchner, *SERESSA 2011 Course*, Toulouse, France.

System-Level Assurance

- **Always faced with conflicting demands between "Just Make It Work" (designer) and "Just Make It Cheap" (program)**
- **Many system-level mitigation strategies pre-date the space age (e.g., communications, fault-tolerant computing, etc.)**
- **Tiered approach to validation of mission requirements**



R. Ladbury, *IEEE NSREC Short Course*, Honolulu, July 2007.

Electronics for Space Use

- **Commercial Off the Shelf (COTS) – including automotive-grade**
    - **Designed with no attempt to mitigate radiation effects. COTS can refer to commodity devices or application-specific integrated circuits (ASICs) designed using a commercially available design system.**

- **Radiation-Tolerant**
    - **Designed explicitly to account for and mitigate radiation effects by process and/or design**

Xilinx Virtex-7 (28 nm CMOS) thinned in preparation for SEE testing

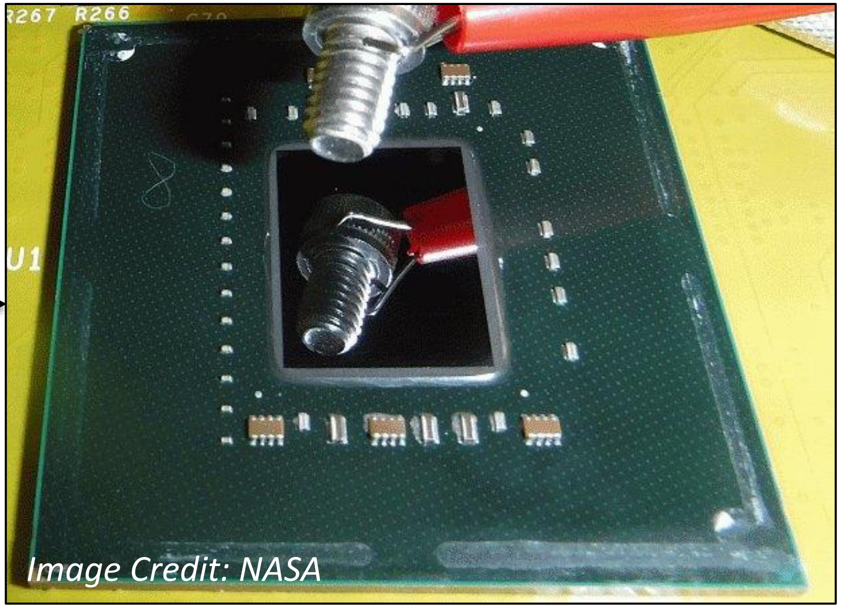


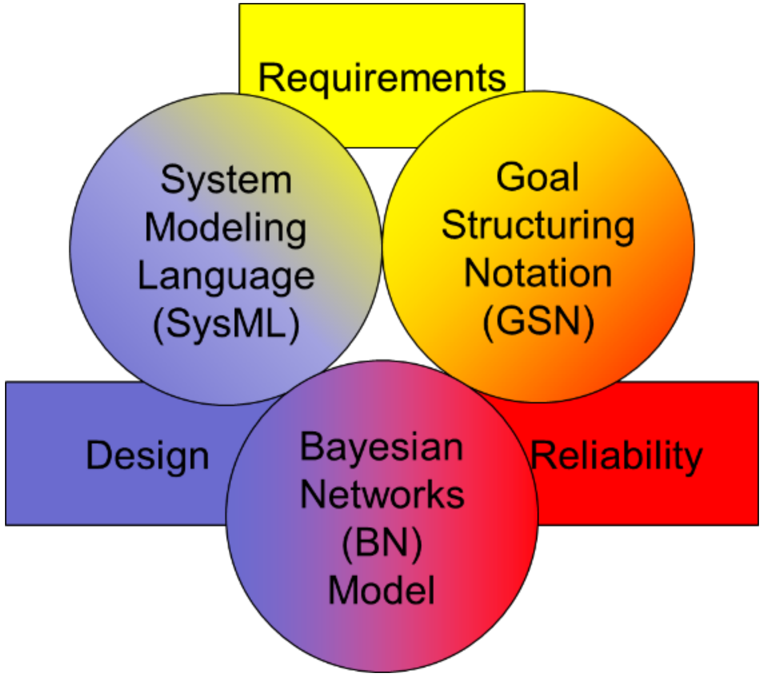
Image Credit: NASA

Technology Challenges

THEN → **NOW**

Increases in capability introduce additional evaluation challenges

- FinFETs/Tri-gate devices
- Nanowire MOSFETs
- Organic transistors
- Ultra-thin body SOI
- Ge MOSFETs
- III-V MOSFETs
- Carbon nanotube FETs
- GaN, SiC,…



Emerging Assurance Methods

(Witulski, Vanderbilt University, NEPP ETW 2017)

Need to leverage more simulation techniques, including detailed radiation transport / chemistry, coupled to model-based system engineering (MBSE) & mission assurance (MBMA) approaches

Testability, Risk Assessment & Disposition

Feedback Required

- **Need to gather performance data, both on the ground and in flight**
  - Fail smart
- **Realize that newer device, system, and packaging technologies will require more testing, not the same or less**
  - Increases importance of discipline expertise, data aggregation, and guidelines that promote sharing of consistent information
  - Use of commercial and/or automotive-grade components is not, in and of itself, a cost-saving measure --- derived benefits from their incorporation may lead to greater return on investment at system-level
- **Spend time during formulation considering the trade space between performance requirements and reliability to enable efficient system design**