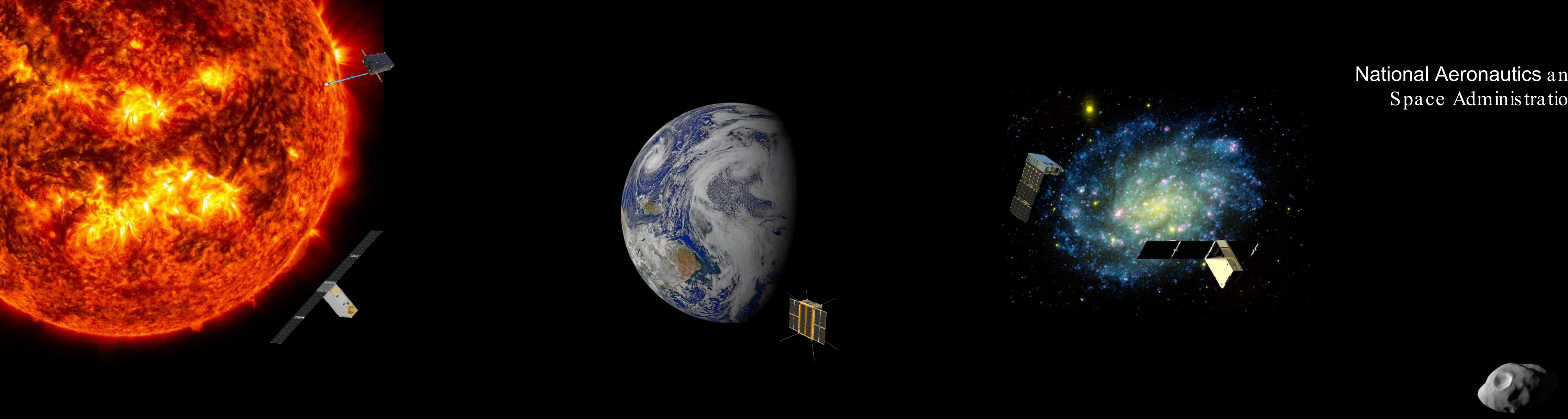
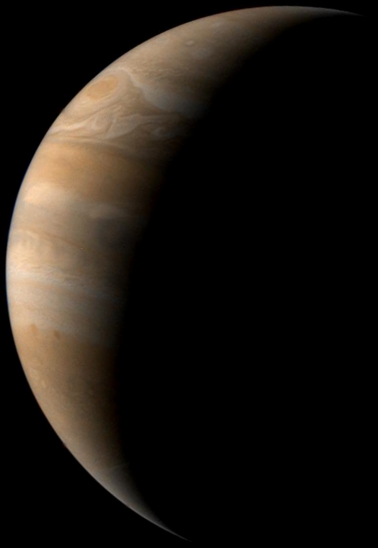
National Aeronautics and
Space Administration



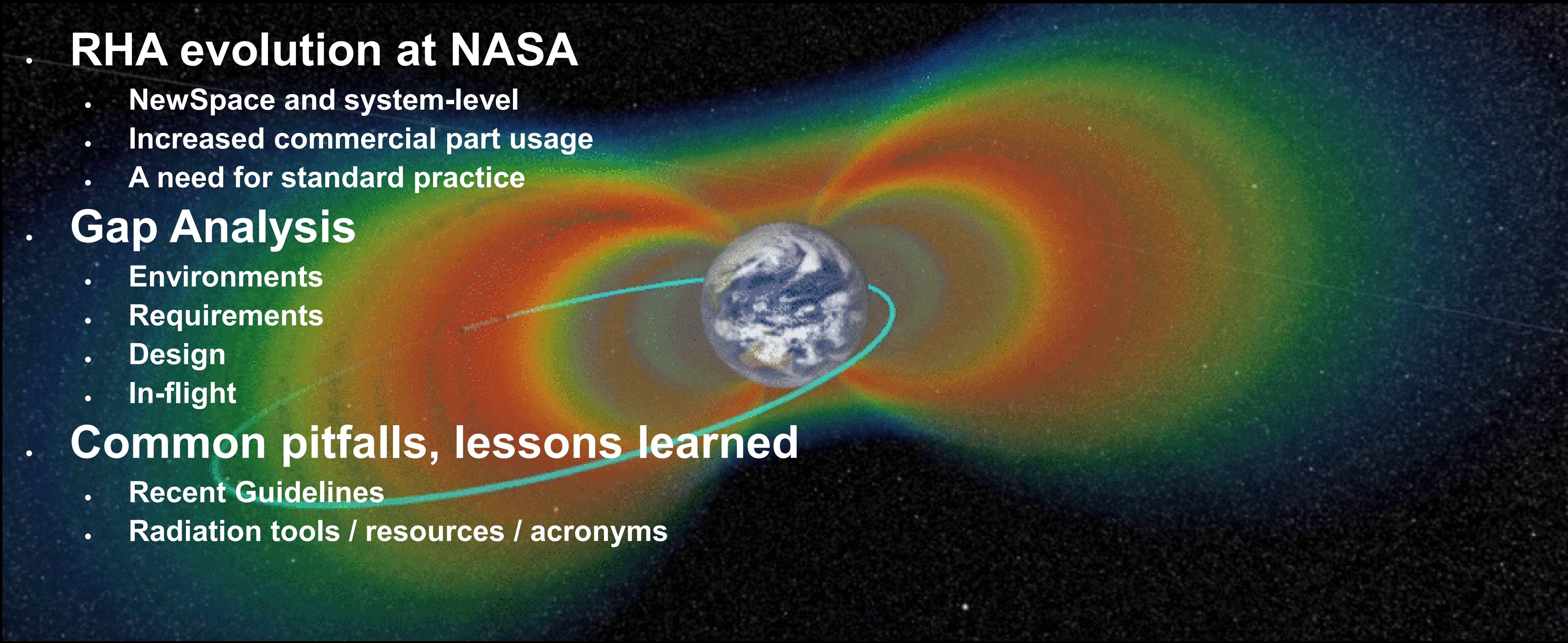
# Radiation Hardness Assurance Challenges at NASA



Michael Campola (NASA-GSFC)

NASA GODDARD SPACE FLIGHT CENTER

# Outline



- RHA evolution at NASA
    - NewSpace and system-level
    - Increased commercial part usage
    - A need for standard practice
- Gap Analysis
    - Environments
    - Requirements
    - Design
    - In-flight
- Common pitfalls, lessons learned
    - Recent Guidelines
    - Radiation tools / resources / acronyms

# RHA Evolution

## Insight

- **Starting Activities:** Early design input / controls for part applications
- **RHA Approach:** Use industry/international standards
- **Requirements fidelity:** Piece-part
- **Analyses:** Cross subsystem functional impacts and fault tracing
- **Primary Mitigation:** Circuit-level design (e.g., EDAC, filters, TMR)

## Oversight

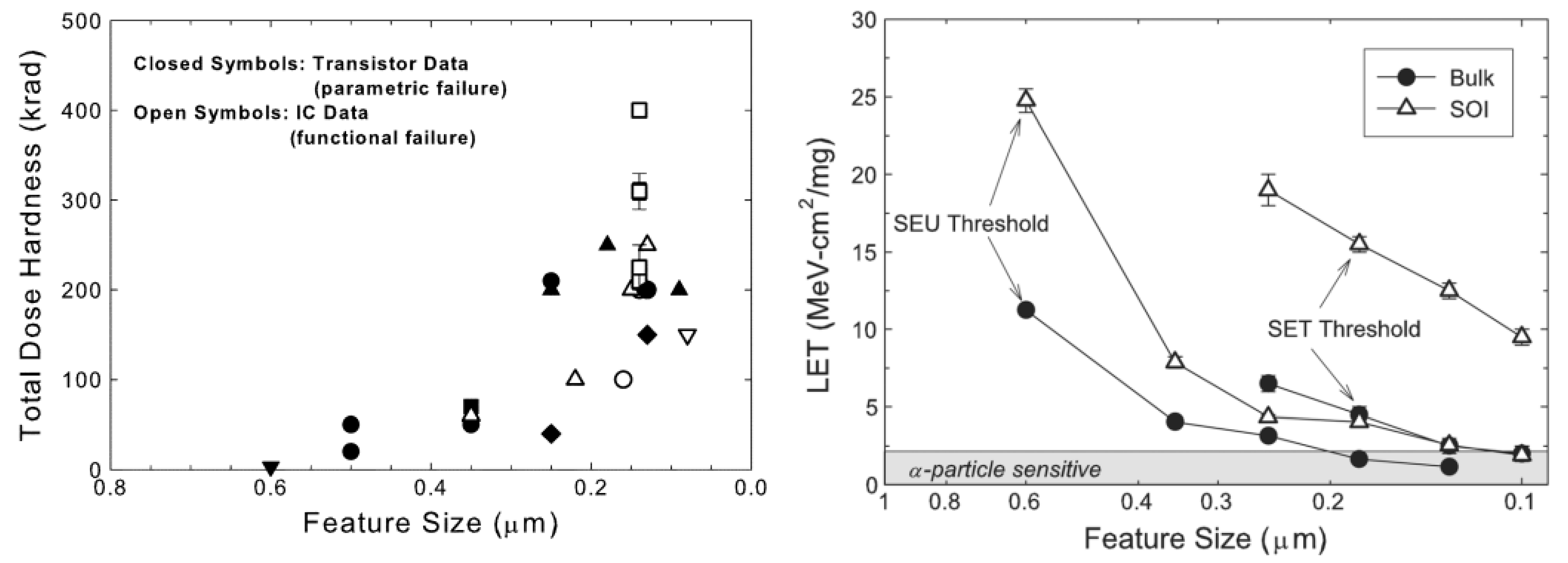
- **Starting Activities:** Performance metrics before specifications go out
- **RHA approach:** Variation on methodologies
- **Requirements fidelity:** System-level
- **Analyses:** Subsystem-level rollups, sometimes testing limited to box level
- **Primary mitigation:** Recovery and maintenance schedules after circuit-level has been implemented

Mission Class

A B C D Do no harm

# CMOS Technology Trend

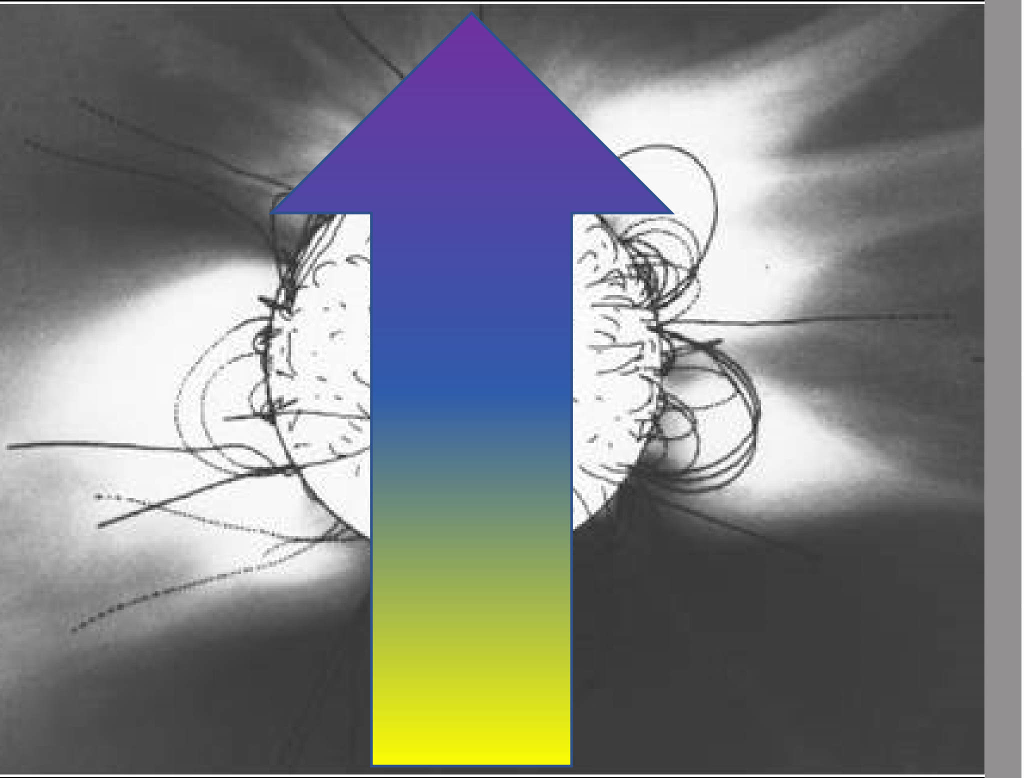
For CMOS in general, the scaling of feature size is increasing resilience with respect to dose and **increasing the susceptibility** to single event effects.



P. E. Dodd, M. R. Shaneyfelt, J. R. Schwank and J. A. Felix, "Current and Future Challenges in Radiation Effects on CMOS Electronics," in IEEE Transactions on Nuclear Science, vol. 57, no. 4, pp. 1747-1763, Aug. 2010, doi: 10.1109/TNS.2010.2042613.

# Notional TID/DDD risk factors to keep in mind

Inherently difficult to expect nominal operation in radiation environment

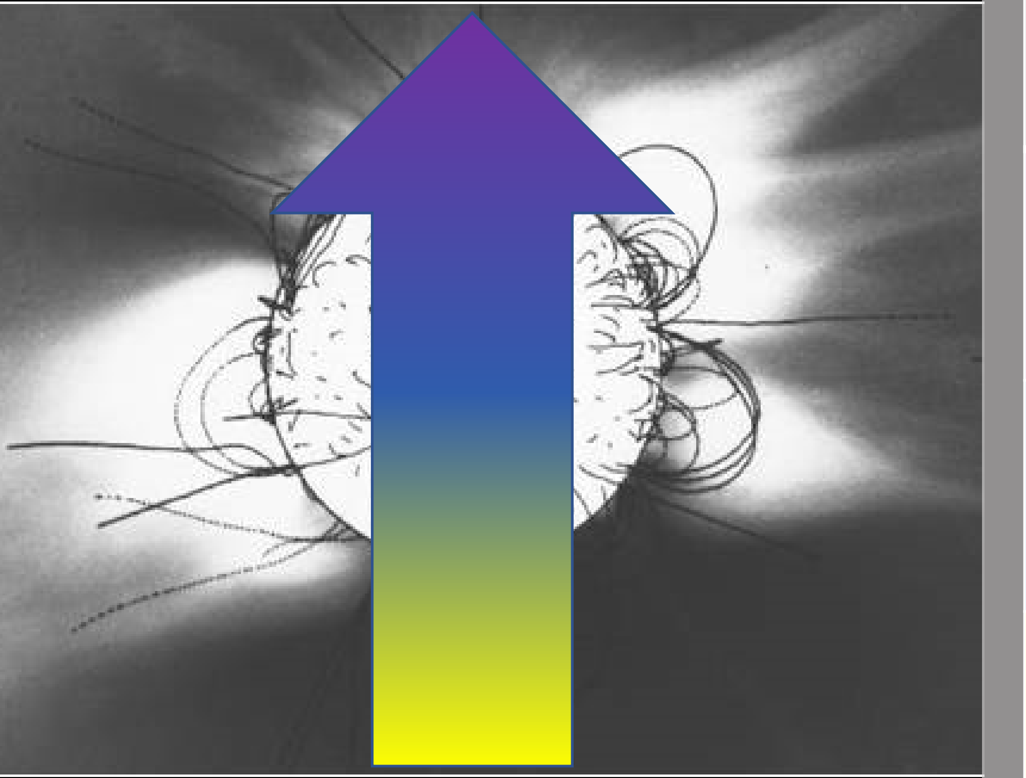


Dose signature predictable

| Environment Contributors | Technology | Device Complexity |
|---|---|---|
| Long Mission, Radiation Belts, High inclination | Bipolar, Power, Hybrid, Multi-process, opto-electronics | Memories, Processors, FPGAs |
| Solar Wind / Particle Events | CMOS (to an extent) | ICs, FETs |
| Galactic Cosmic Rays | Hardened Devices | Discrete |

# Notional SEE risk factors to keep in mind

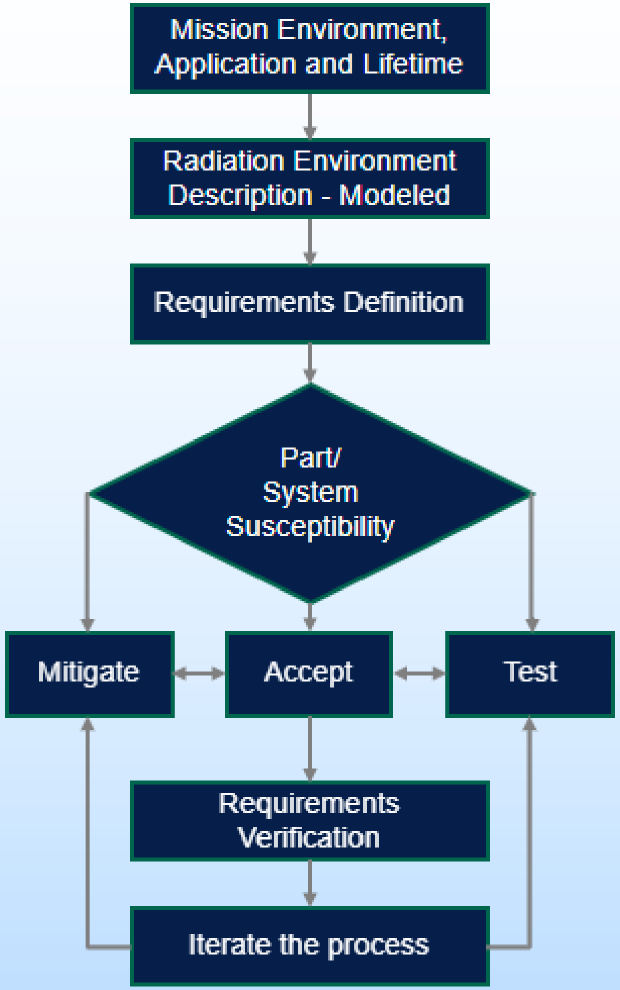
Inherently difficult to expect nominal operation in radiation environment



SEE signature less disruptive to functions

| SEE Types | SEE in Technology | Device Complexity |
|---|---|---|
| **Destructive SEE, Non-destructive SEL/SEB** | **Highly Scaled, Hybrid, Multi-process** | **Memories, Processors, FPGAs** |
| **Stuck bits, block errors, SEFI, MBU** | **Power, CMOS** | **ICs, FETs** |
| **SET, SEU** | **Bipolar, Hardened Devices** | **Discrete** |

# NewSpace system-level mitigation for radiation



- Shield for TID/TNID, tolerate parametric drift, redundancy is only relevant if parts degrade slower when off (this is not the norm)
- Avoid destructive SEE at all costs, avoid unknown untested parts, this is the parts selection concern
- Anticipate non-destructive SEE signatures for a given family of devices, this is circuit/system design concern
  - Filtered power supplies
  - Redundant computers, hardened FPGA designs
  - EDAC on memories
  - Watchdog timers and autonomous resets
  - Power limiting to susceptible devices
  - Identify the risks, explore the possible consequences
  - Be able to power-cycle part/board/box if you don’t know

# Gap Analysis

- The next few slides on “wins and gaps” were presented by Rebekah Austin for NASA-GSFC at the latest SEESAW
- COTS focused, radiation engineering perspective

# Wins and Gaps in Environment Definition

- Win: Projects moving from Radiation Design Margin (RDM) to Confidence Levels (CL) for mission dose requirements
  - As long as doses are bounding, being a little high is not usually a problem
  - M. A. Xapsos et al., "Inclusion of radiation environment variability in total dose hardness assurance methodology", *IEEE Trans. Nucl. Sci.*, vol. 64, no. 1, pp. 325-331, Jan. 2017.

- Gap: Temporal SEE rates
  - Bounding rates from tools are useful
  - Availability/Reliability requirements of missions along with increase sensitivity of parts is leading to scrutiny of nominal SEE environments
  - Example: Satellite with hundreds of FPGAs completing a critical mission step in a day. What is the SEE contribution to that failure rate?

# Wins and Gaps in Requirements Definition

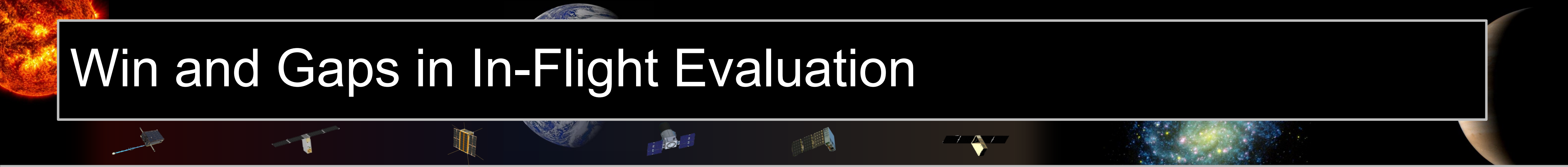
- Win: Tailoring of requirements based on Mission, Environment, Application, and Lifetime
  - Place where Digital Engineering can help capture this process
  - “Guidelines for Verification Strategies to Minimize RISK Based on Mission Environment, -Application and –Lifetime (MEAL)” NESC-RP-16-01117
  - Update to NPR-8705.4, *Risk Classification for NASA Payloads*
  - *NASA EEEE Parts Selection, Testing and Derating Standard (NASA-STD-8739.11)*

- Gap: Translating availability and reliability requirements to SEE rates
  - COTS and tech-demo missions

# Win and Gaps in Design Evaluation

- Win: Updates and creation of guidelines and standards, especially for COTS devices
- Win: Workforce training especially with respect to smart use of heavy-ion facilities (TAMU Bootcamp, NSRL Radiation Test Workshop)

- Gap: Describing part failure distributions with limited part test sample sizes and test standards
  - R. Ladbury and T. Carstens, "Development of TID Hardness Assurance Methodologies to Capitalize on Statistical Radiation Environment Models," in *IEEE Transactions on Nuclear Science*, vol. 68, no. 8, pp. 1736-1745, Aug. 2021.
- Gap: How do you evaluate a design with limited testing and visibility?



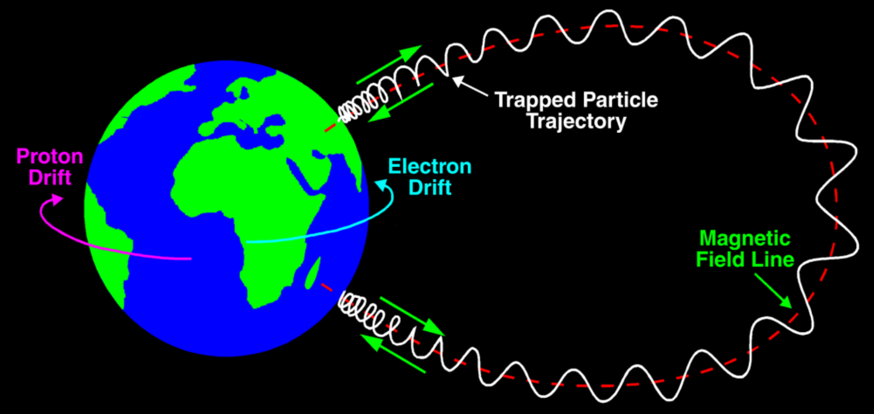
# Win and Gaps in In-Flight Evaluation

- Gap: Increase of COTS increases the need for anomaly reporting and evaluation
  - It can be difficult to determine the source of an anomaly
  - **Not** all anomalies are induced by the radiation environment
  - Device or system sensitivity (threshold LET) plays a huge role
  - Current condition of the space environment

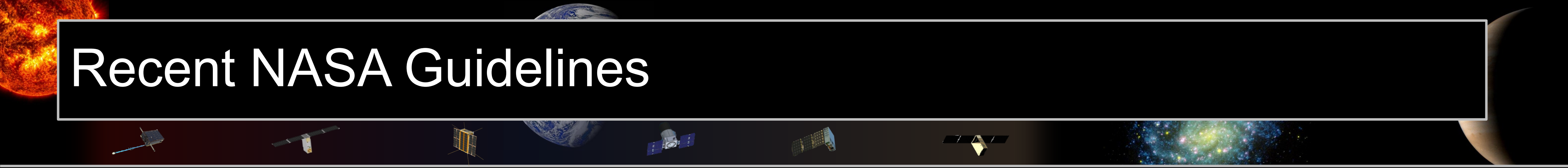
- Not all anomalies are space weather – must verify all possible sources
  - COTS devices and boxes make this more challenging

# Common pitfalls, lessons learned

- Thinking radiation is one number  to meet
    - Dose profile behind different amounts of shielding also depends on the type of incident radiation
    - SEE that have low LET susceptibilities can benefit from some shielding, higher LET will be present
    - Bringing radiation engineering in late to the design process is not a good idea
- Tight tolerance in application
    - Not considering the dynamic environmental conditions
    - Derating is your friend
- Overly complex mitigation doesn’t solve the problem
    - Verification of mitigation very well could require testing, and more money
    - Additional susceptibilities introduced into reliability overall
- Don’t forget about other environment driven failures
    - Charging / Corrosion
    - Temperature
- Heritage? What heritage?
    - Part to part variation, lot to lot variation
    - Better predictor for dose performance if you have part fidelity
    - Not very good rationale for SEE




ESA EURECA satellite solar array sustained arc damage.
*Credits: ESA*

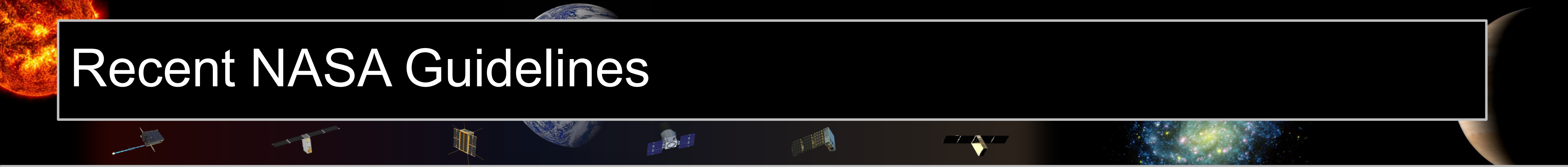


# Recent NASA Guidelines

- *Recommendation on Use of Commercial-Off-The-Shelf (COTS) Electrical, Electronic, and Electromechanical (EEE)Parts for NASA Missions (NESC-RP-19-01490)*
  - Phase I - [NESC Assessment - Recommendations on Use of Commercial-Off-The-Shelf (COTS) Parts for NASA Missions - NASA Technical Reports Server (NTRS)]
  - Phase II - [Recommendations on the Use of Commercial-Off-The-Shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) Parts for NASA Missions - Phase II - NASA Technical Reports Server (NTRS)]

- Highlighted finding:
  - F-4: There is a lack of consensus within NASA on the perception of risk using COTS parts for safety and mission critical application in spaceflight systems. It varies from feelings of “high risk” when part-level MIL-SPEC /NASA screening and space qualification are not fully performed to “no elevated risk” when sound engineering is used, and part application is understood.

# Recent NASA Guidelines



- *Avionics Radiation Hardness Assurance (RHA) Best Practices (NESC-RP-19-01489)*
  - Covers TID, TNID, and SEE - [Avionics Radiation Hardness Assurance (RHA) Guidelines - NASA Technical Reports Server (NTRS)]
  - Highlighted Finding: Need for development of new NASA technical standard for RHA

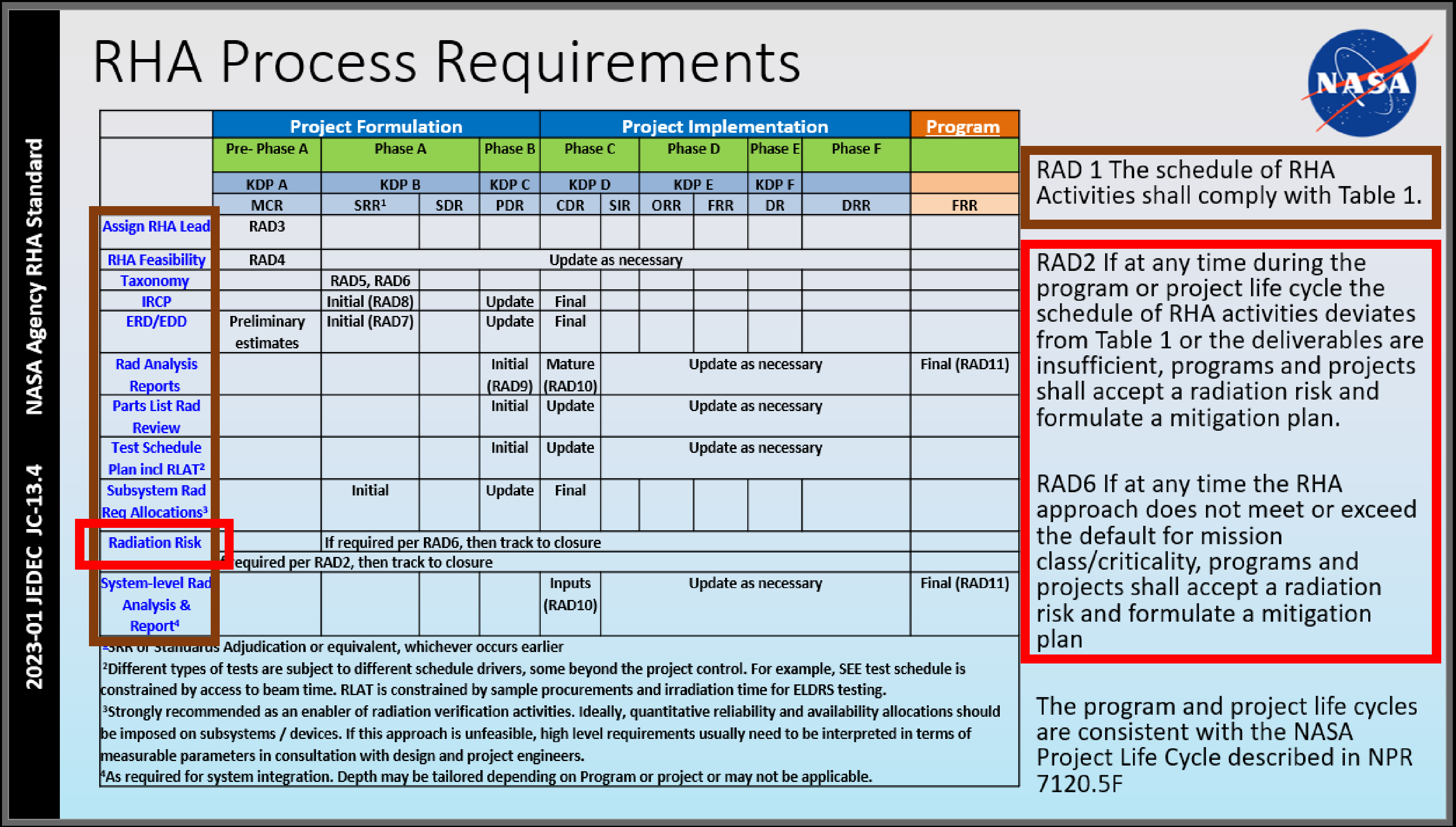
- Application to COTS Electronics
  - Radiation effects issues with COTS parts are the same as with others
  - Guidance on robust methods to handle unit-to-unit variability
  - Guidance on test and evaluation to help address COTS testing challenges
  - Single-Event Effects Criticality Analysis

# Coming Soon

A NASA RHA Standard is being developed by the NASA Electronic Parts and Packaging (NEPP) Program.

Draft to be completed this FY.

Presented at JEDEC:



2023-01 JEDEC JC-13.4 NASA Agency RHA Standard

## RHA Process Requirements

| | Project Formulation | | | | Project Implementation | | | | | | Program |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre- Phase A | Phase A | | Phase B | Phase C | | Phase D | | Phase E | Phase F | |
| | KDP A | KDP B | | KDP C | KDP D | | KDP E | | KDP F | | |
| | MCR | SRR[1] | SDR | PDR | CDR | SIR | ORR | FRR | DR | DRR | FRR |
| Assign RHA Lead | RAD3 | | | | | | | | | | |
| RHA Feasibility | RAD4 | Update as necessary | | | | | | | | | |
| Taxonomy | | RAD5, RAD6 | | | | | | | | | |
| IRCP | | Initial (RAD8) | | Update | Final | | | | | | |
| ERD/EDD | Preliminary estimates | Initial (RAD7) | | Update | Final | | | | | | |
| Rad Analysis Reports | | | | Initial (RAD9) | Mature (RAD10) | Update as necessary | | | | | Final (RAD11) |
| Parts List Rad Review | | | | Initial | Update | Update as necessary | | | | | |
| Test Schedule Plan incl RLAT[2] | | | | Initial | Update | Update as necessary | | | | | |
| Subsystem Rad Req Allocations[3] | | Initial | | Update | Final | | | | | | |
| Radiation Risk | | If required per RAD6, then track to closure | | | | | | | | | |
| | equired per RAD2, then track to closure | | | | | | | | | | |
| System-level Rad Analysis & Report[4] | | | | | Inputs (RAD10) | Update as necessary | | | | | Final (RAD11) |

[1]SRR or Standards Adjudication or equivalent, whichever occurs earlier

[2]Different types of tests are subject to different schedule drivers, some beyond the project control. For example, SEE test schedule is constrained by access to beam time. RLAT is constrained by sample procurements and irradiation time for ELDRS testing.

[3]Strongly recommended as an enabler of radiation verification activities. Ideally, quantitative reliability and availability allocations should be imposed on subsystems / devices. If this approach is unfeasible, high level requirements usually need to be interpreted in terms of measurable parameters in consultation with design and project engineers.

[4]As required for system integration. Depth may be tailored depending on Program or project or may not be applicable.

RAD 1 The schedule of RHA Activities shall comply with Table 1.

RAD2 If at any time during the program or project life cycle the schedule of RHA activities deviates from Table 1 or the deliverables are insufficient, programs and projects shall accept a radiation risk and formulate a mitigation plan.

RAD6 If at any time the RHA approach does not meet or exceed the default for mission class/criticality, programs and projects shall accept a radiation risk and formulate a mitigation plan

The program and project life cycles are consistent with the NASA Project Life Cycle described in NPR 7120.5F

# Radiation tools out there (free)

- SmallSat / System Architecture
  - R-Gentic – https://vanguard.isde.vanderbilt.edu/RGentic/
  - SEAM – https://modelbasedassurance.org/
- Rate Calculations / LET
  - CRÈME – https://creme.isde.vanderbilt.edu/
  - SRIM – http://www.srim.org/
- Environments and Transport
  - Spenvis – https://www.spenvis.oma.be/
  - OMERE – http://www.trad.fr/en/space/omere-software/
  - OLTARIS – https://oltaris.nasa.gov

# Acronyms and Abbreviations

- AWS: Amazon Web Services
- CL: Confidence Level
- CMOS: Complementary metal-oxide semiconductor
- ConOps: Concept of Operations
- COTS: Commercial Off The Shelf
- DDD: Displacement Damage Dose
- EDAC: Error Detection and Correction
- EEE: Electrical, Electronic, and Electromechanical
- EEEE: Electrical, Electronic, Electromechanical, and Electro-optical
- EMI: ElectroMagnetic Interference
- FET: Field-Effect Transistor
- FPGA: Field Programable Gate Array
- GSN: Goal Structuring Notation
- Hi-Rel: High Reliability
- IC: Integrated Circuit
- LET: Linear Energy Transfer
- MBU: Multi-Bit Upset
- MOSFET: Metal-on-Silicon Field Effect Transistor
- NESC: NASA Engineering and Safety Center
- RDM: Radiation Design Margin
- R-GENTIC: Radiation Guidelines for Notional Threat Identification and Classification
- RHA: Radiation Hardness Assurance
- SEAM: System Engineering and Assurance Modeling
- SEB: Single-Event Burnout
- SEE: Single Event Effects
- SEECA: Single Event Effects Criticality Assessment
- SEFI: Single-Event Functional Interrupt
- SEGR: Single-Event Gate Rupture
- SEL: Single-Event Latch-up
- SET: Single-Event Transient
- SEU: Single-Event Upset
- STTR: Small Business Technology Transfer
- TID: Total Ionizing Dose
- TMR: Triple Modular Redundancy
- TNID: Total Non-Ionizing Dose

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# THANK YOU