ANALYSIS AND TESTS FOR SPACE QUALIFICATIONS OF THE PAYLOADS ELECTRONICS OF THE NUSES MISSION.

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Activities taken during the first year

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- Seven courses taken and exams successfully completed.
- Taking regular individual classes on electronics and DAQ for radiation detection.
- Attended Summer School on Particle Physics, Astrophysics and Cosmology in Palermo from the 17^{th} to the 27^{th} of September 2024.
- Attended the IAC congress, in Milan, from the 12^{th} to the 19^{th} of October 2024.
- Thesis title: Analysis and tests for space qualifications of the payloads electronics of the NUSES mission.

Introduction to the NUSES mission

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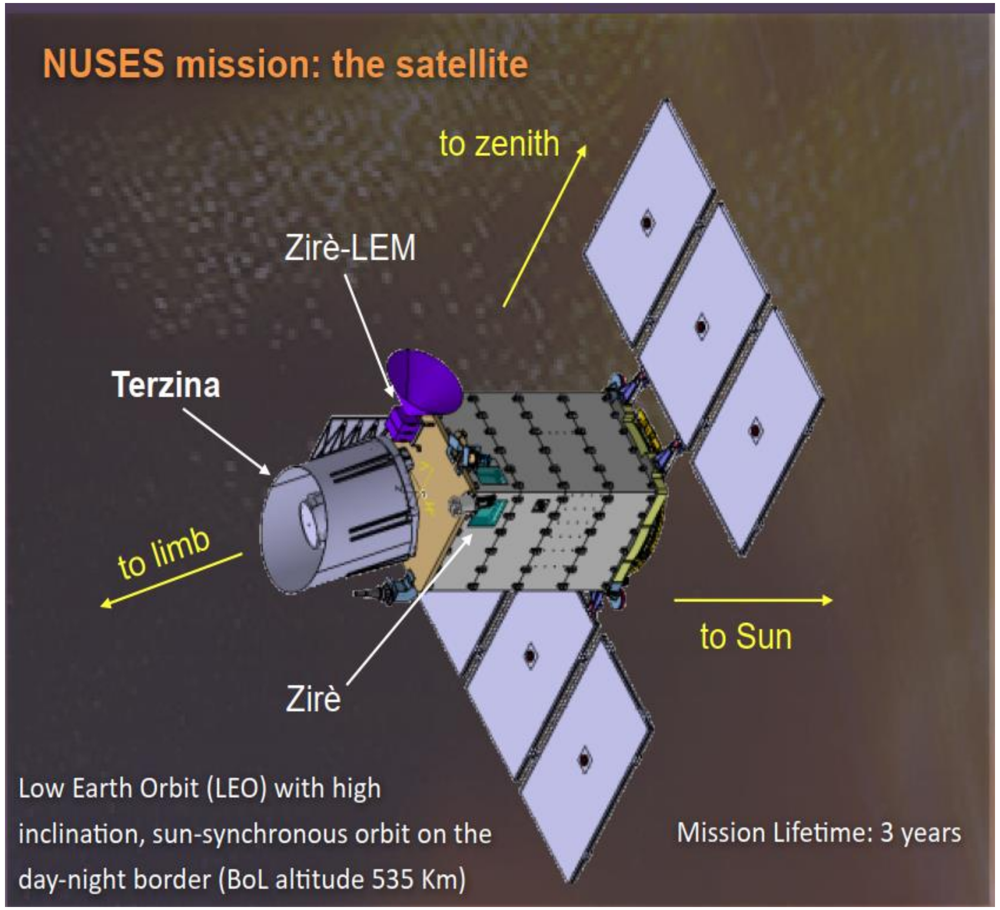
- Mission objective: designed to explore new scientific and technological opportunities for space-based detectors in the field of astroparticle physics.
- **Payload Description**:
  - Zire: Features and scientific goals
    - Focuses on studying Gamma-Ray Bursts (GRBs) and detecting cosmic rays (CRs) in a wide energy range (from a few to hundreds of MeVs).
  - Terzina: features and scientific goals
    - The Terzina detector is composed by a near UV-optical telescope, with Schmidt-Cassegrain optics, and a Focal Plane Assembly.
    - Terzina is also a pathfinder of future missions, like POEMMA (Probe of Extreme Multi Messenger Astrophysics).
    - Observation of astrophysical **neutrinos** at energies > few PeV (only possible from space).
    - Detection of high-energy **cosmic rays** (E > 1 PeV) through EAS Cherenkov emission.
    - Total weight of the Terzina payload: ~35 kg.



NUSES Electronics

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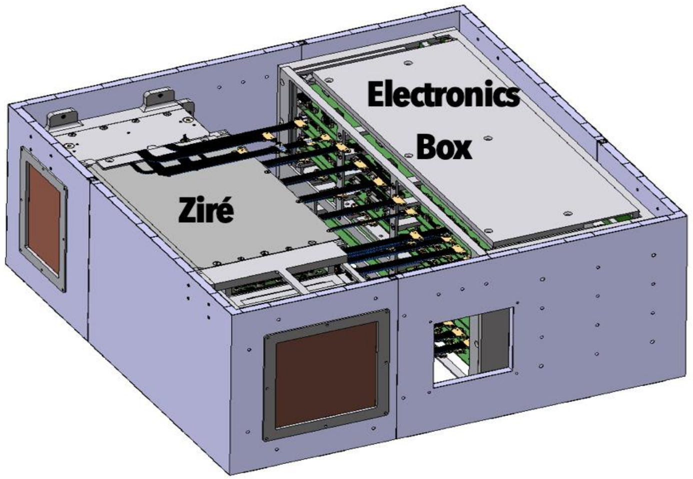
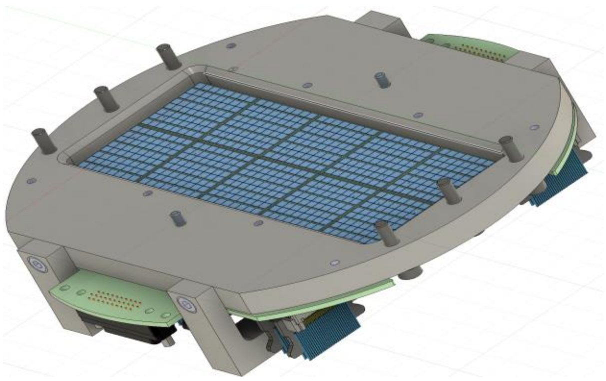
- The NUSES electronics comprises of:
  - **Electronic Box: P/L Power Supply** - Provides power distribution to the payload electronics.
  - **Electronic Box: DAQ Board and Data Concentrator** - Collects and manages data from various sensors for transmission.
  - **Zirè Instrument (Detector boards)** - Detects charged particles as part of the cosmic ray observation system.
  - **Terzina Instrument (Focal Plane Assembly Board)** - Captures and processes optical or UV photons from atmospheric events (from both below and above the limb).
  - **LEM Instrument (Low Energy Module)** - Measures lower energy particle interactions to aid in cosmic ray analysis.

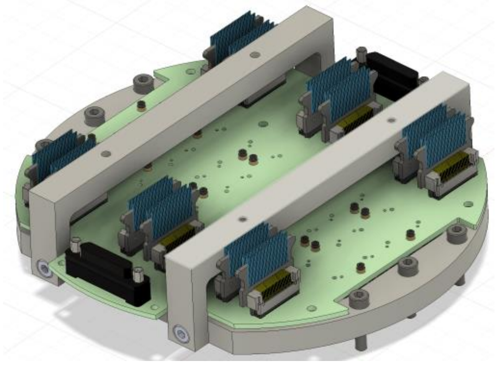


This research aims to analyze the test results of these critical electronics components under extreme space conditions, such as radiation exposure, temperature fluctuations, and mechanical vibrations, ensuring that they meet space qualification standards.

The Focal Plane Assembly (FPA)



Top view of the SiPM-based camera (10 arrays of 8 x 8 SiPMs)



Bottom view of the interface board (connection SiPMs ↔ FE electronics)

Mission Requirements for Payload Electronics

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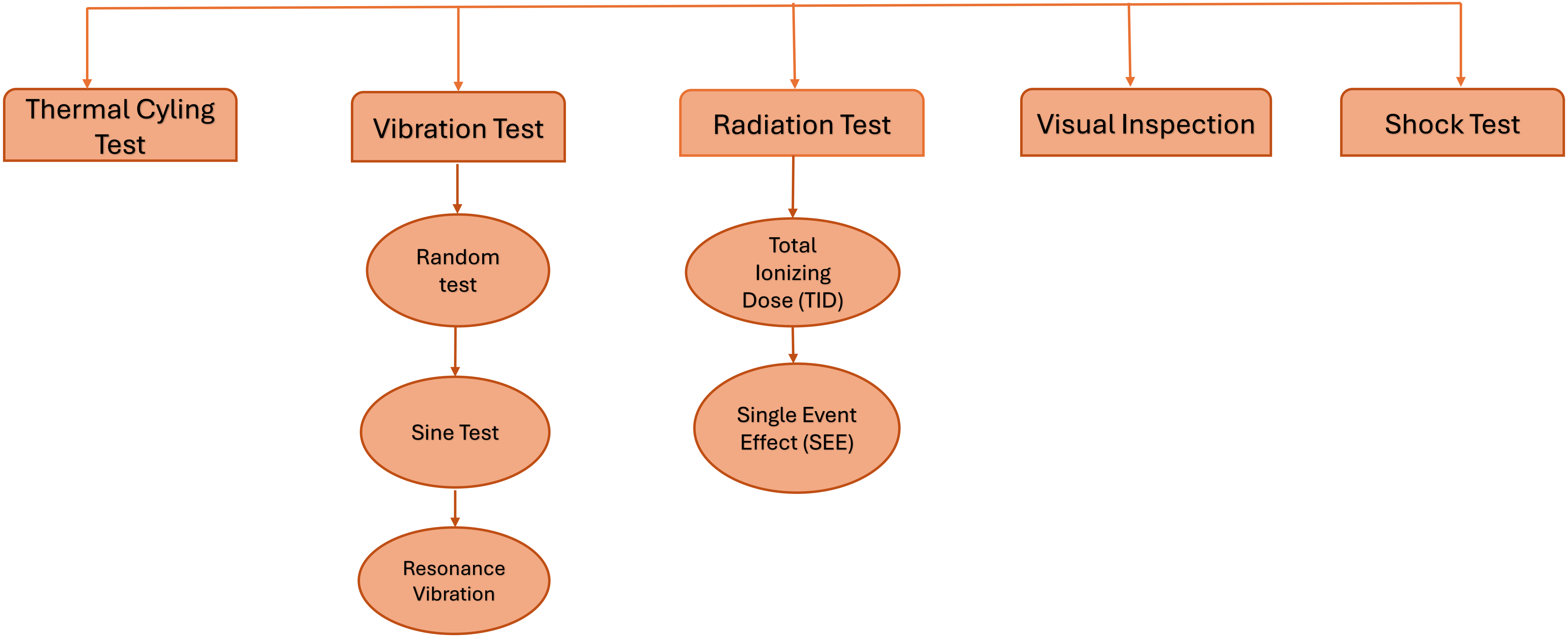
- Operational Environment in Space:
  - Temperature ranges: from -15°C to +45°C operationally and from -55°C to +100°C for qualification
- Exposure to
  - Radiation
  - Vibration
  - Thermal cycling
  - Shock

Altitude	535	km
Earth Radius	6378	km
a	6913	km
Graviational Constant	6.67E-11	$m^3/(kg\ s^2)$
Earth mass	5.97E+24	kg
μ	398199	km^3/s^2
Orbital period	5723	seconds
	95	minutes
	1.59	hours
	0.0662	Days
	0.0002	years
Life time	3.5	years
Orbit per day	15.10	
Number of orbit	19299	

Qualification Tests



Temperature Challenges for Space Electronics

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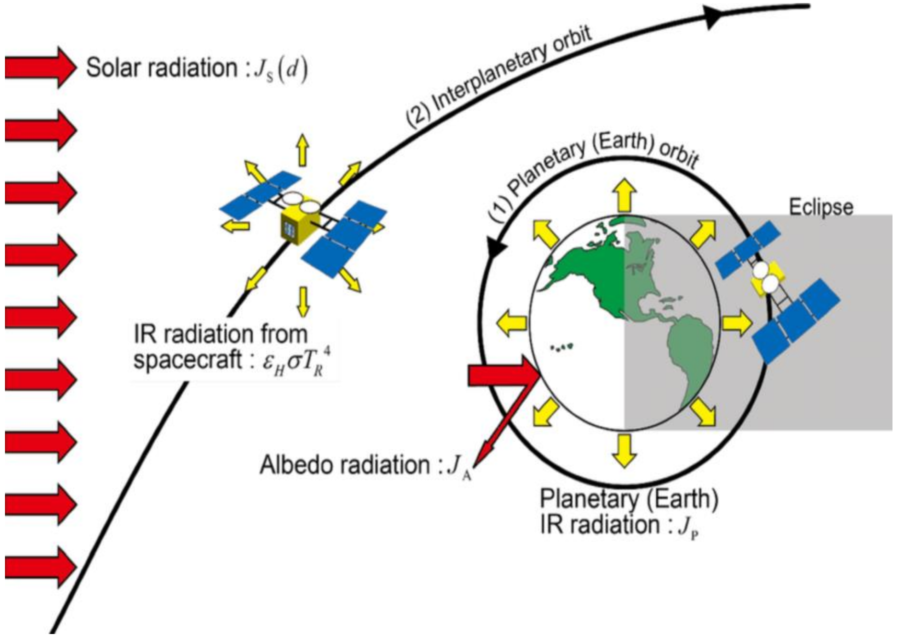
1. Temperature extremes
   - Sun-facing surfaces can reach +120°C to +150°C
   - Shadowed areas can drop to -150°C to -170°C
2. Heat Dissipation Issues:
   - No convection cooling in vacuum
   - Heat can only be removed through radiation or conduction
3. Thermal Cycling:
   - Satellites in low Earth orbit can experience these temperature swings every 90 minutes
   - The rapid cycling causes repeated expansion and contraction
   - Materials with different thermal expansion coefficients create internal stresses



Given the intense temperature fluctuations in space, thermal cycling tests are essential to simulate the rapid heating and cooling that the electronics will endure in orbit and to ensure they are up to standard.

Thermal Cycling Tests

- **Purpose:** To simulate repeated thermal stresses experienced during orbit
- **Thermal Range and Cycles:** Operating range: -15°C to +45°C
- Average temperature around 28°C with 6°C fluctuations.

QUALIFICATION TEST SUMMARY							
Input data					N Test Cycles		
Type	Tmin [°C]	Tmax [°C]	Dwell Time [min]	Ramp [°C/min]	Total without margin	Safety Factor	Total with margin
Electronic Box	- 40	90	15	5	174	1,6	**278**
LEM	- 40	90	15	5	69	1,5	**104**
Ziré	- 40	90	15	5	122	1,6	**195**

Vibration challenges for space electronics

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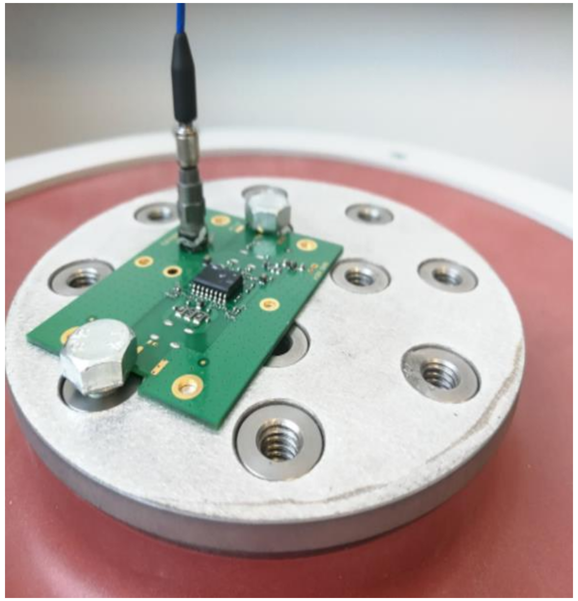
1. Launch Phase Vibrations:
   - Most severe vibration period
   - Random vibrations: 20-2000 Hz frequency range
   - Shock loads up to 100g or more
   - Risk of immediate component failure
2. On-Orbit Vibration Sources:
   - Reaction/momentum wheels for attitude control
   - Moving mechanical parts (solar arrays, antennas)
   - Micrometeoroid impacts
3. Critical Component Vulnerabilities:
   - Solder joint fatigue and cracking
   - PCB flexing and stress
   - Connector pin fretting



Vibration challenges for space electronics

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4. Common Failure Modes:
    - Component desoldering
    - Structural fatigue
    - Connection loosening
    - Mechanical resonance

To ensure that the payload electronics can withstand the extreme vibrations encountered during launch and the mechanical stresses from on-orbit operations, there is need for comprehensive vibration tests that simulate these dynamic conditions.

Vibration Testing

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- **Objective:** Evaluate mechanical integrity under dynamic conditions
- Ranges of frequency and power spectral density levels
- Importance for simulating launch and operational conditions
- **Vibration Testing Phases:**
  - Resonance research
  - Sine vibration
  - Random vibration

Sine Vibration

Range (Hz)	Power Spectral Density Level (g^2/Hz)	Sweep Rate (octaves / minute)
Spacecraft		
25 to 100	25	1
100 to 200	15	1
Duration: 1 cycle up from 25 Hz to 200 Hz		

Resonance Research (sine survey)

	LEVEL AND FREQUENCY
Amplitude	0.5 g^2/Hz (0 to peak)
Frequency Range	10 Hz to 200 Hz
Sweep Rate	2 octaves / minute
Direction	X, Y, Z axes

Random Vibration

Perpendicular to PCB		Parallel to PCB	
Range (Hz)	**PSD Level**	**Range (Hz)**	**PSD Level**
20 to 100	+ 6 dB/oct.	20 to 100	+ 6 dB/oct
100 to 500	1 g^2/Hz	100 to 800	0.5 g^2/Hz
500 to 2000	-6 dB/oct	800 to 2000	- 3 dB/oct.
Global: 28.5 g r.m.s.		Global: 27.1 g r.m.s.	

Radiation challenges for space electronics

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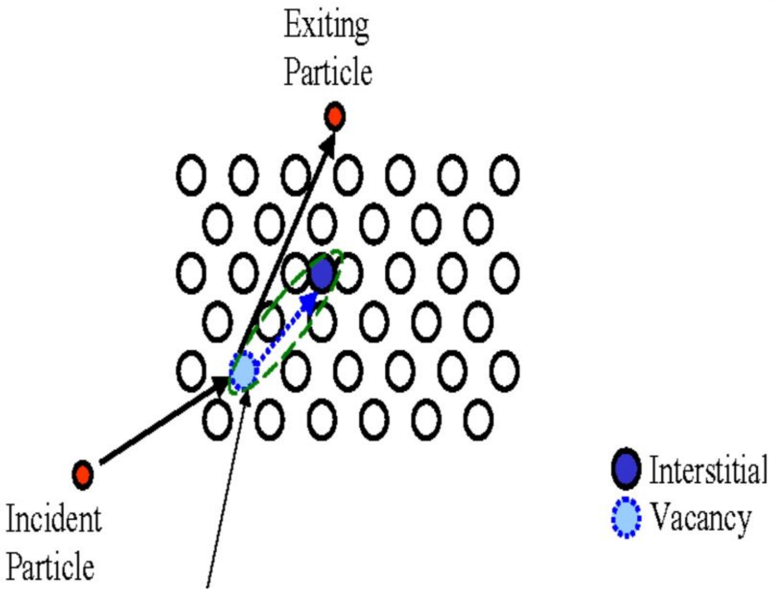
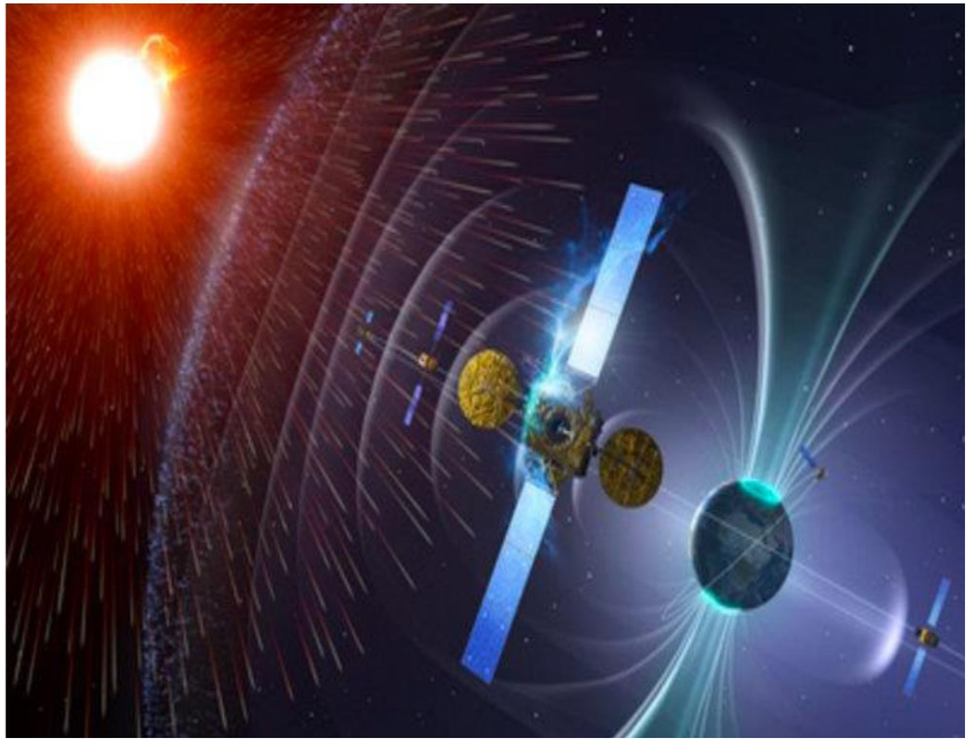
- Radiation

1. Displacement Damage:
   - Physical atomic displacement
   - Affects semiconductor properties (ex: FPGAs)
   - Impacts optoelectronic devices (ex: SiPMs)



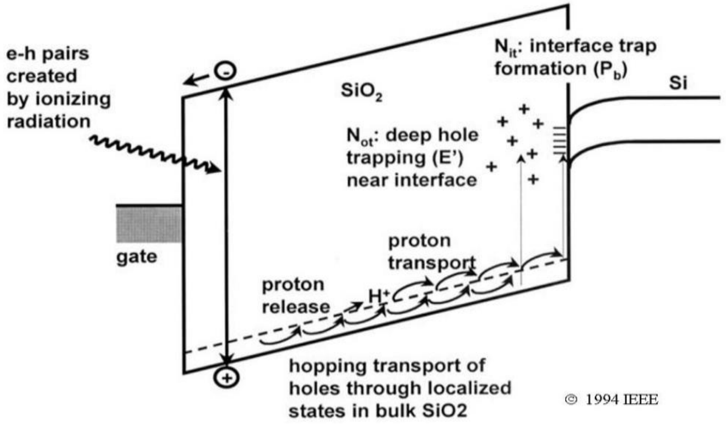


Radiation challenges for space electronics

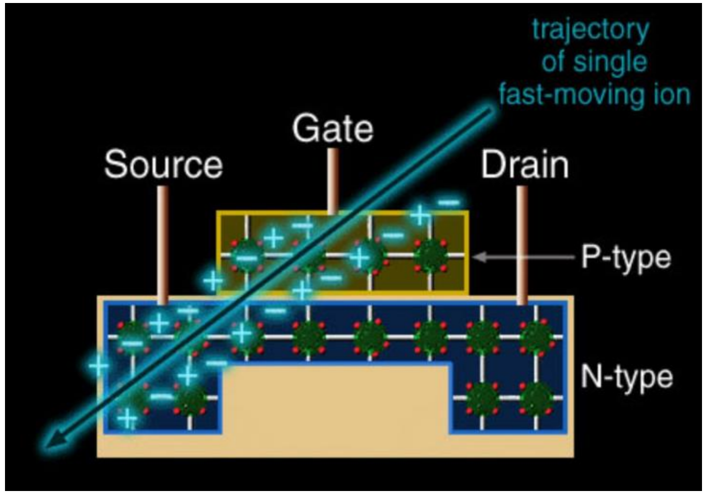
1. Single Event Effects (SEEs):
   - Single Event Upsets (SEUs): bit flips in memory
   - Single Event Latchup (SEL): Potential destructive shorts
   - Single Event Burnout (SEB): Power device failure
2. Total Ionizing Dose (TID):
   - Cumulative damage over time
   - Threshold voltage shifts
   - Increased leakage currents
   - Eventual device failure

Radiation testing, specifically Total Ionizing Dose (TID) and Single Event Effect (SEE) testing, directly addresses the high-radiation exposure risk that the electronics face in space.

Tota Ionizing Dose



Single Event Effect



Radiation Testing (TID and SEE)

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- Radiation Sensitivity Evaluation
- Selection of critical PCBs for irradiation (DAQ, data concentrator, power supply)
- **TID (Total Ionizing Dose) Testing:**
- Exposure levels (1 krad to 5 krad)
- Stepwise radiation exposure with electrical measurements
- Annealing process for recovery post-irradiation (room temp and 80°C over 168 hours)

Visual Inspection and Electrical Testing

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Visual Inspection:

- Methodology in accordance with ECSS standards
- Inspect for visible defects: soldering issues, contamination, cracks, etc.
- Critical to ensuring reliability in severe space conditions

- **Electrical Testing:**
- Conducted before and after environmental tests
- Key electrical parameters: voltage, current, signal integrity
- Ensures all functionalities work post-vibration, thermal, and radiation exposure

Shock test

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Purpose: ensure that electronic components can withstand sudden, high-magnitude shocks encountered during spacecraft launch, separation, and deployment, ensuring reliable operation in space.

1. Low Frequency Region (100 Hz, 20g):
    - Represents structural response regime
    - Primary spacecraft modal frequencies
    - Affects large components and assemblies
2. Mid Frequency Region (1500 Hz, 2200g):
    - Transition to high-energy shock response
    - Maximum acceleration level achieved
3. High Frequency Region (10000 Hz, 2200g):
    - Plateau region of shock response
    - Maintains maximum acceleration

Nominal Curve	
Frequency (Hz)	Acceleration (g)
100	20
1500	2200
10000	2200

Summary

- **Key Results from Each Test Type:**
- Vibration: Structural resilience of PCBs
- Visual/Electrical: Absence of defects, performance after stress tests
- Thermal Cycling: Durability under fluctuating temperatures
- Radiation: TID results and expected tolerance levels

Thank you for listening