SI-2024: Introduction to CubeSat and Satellite Communication

Raspberry Pi for Space

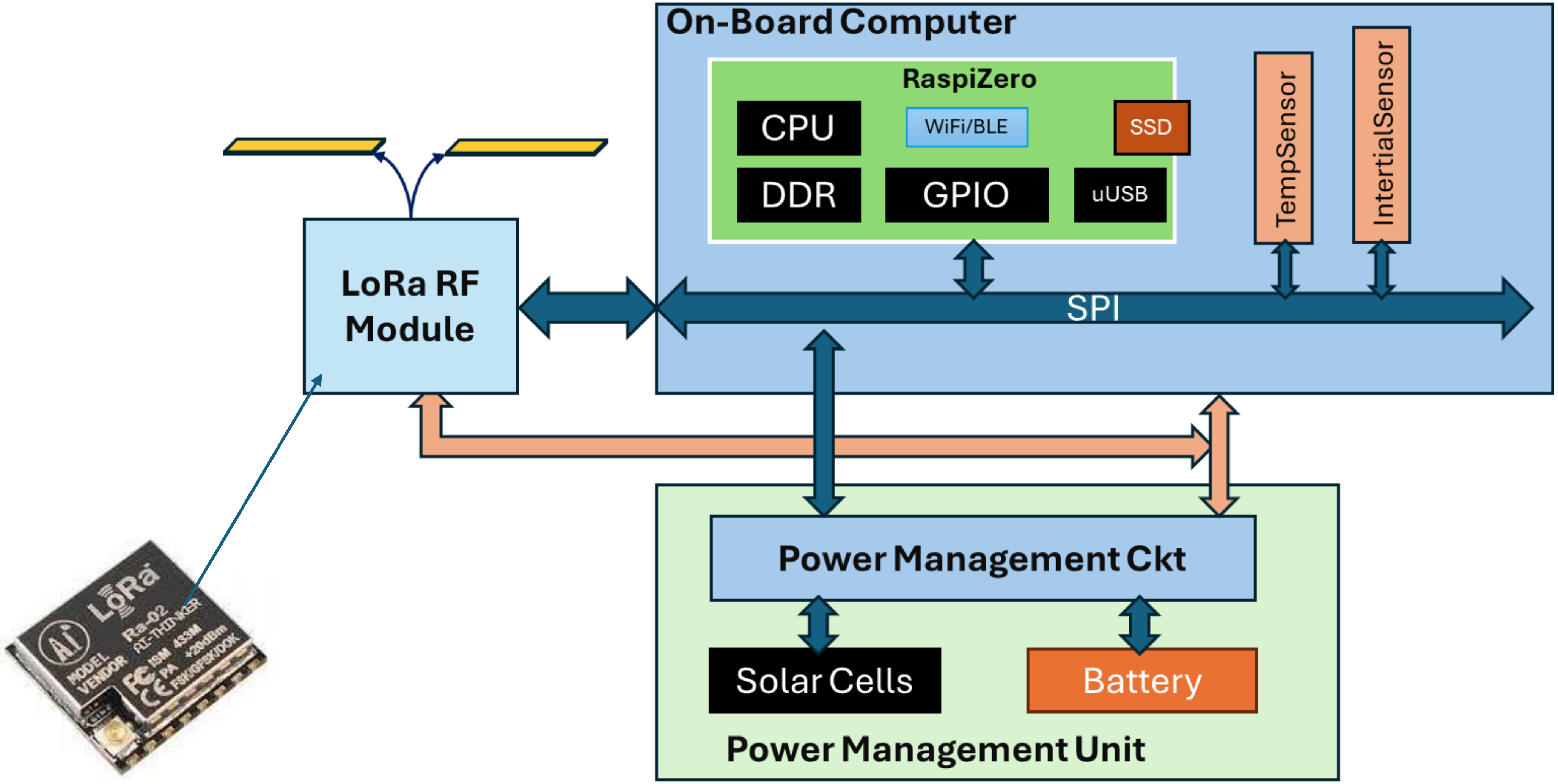
10th July 2024

SiliconTech

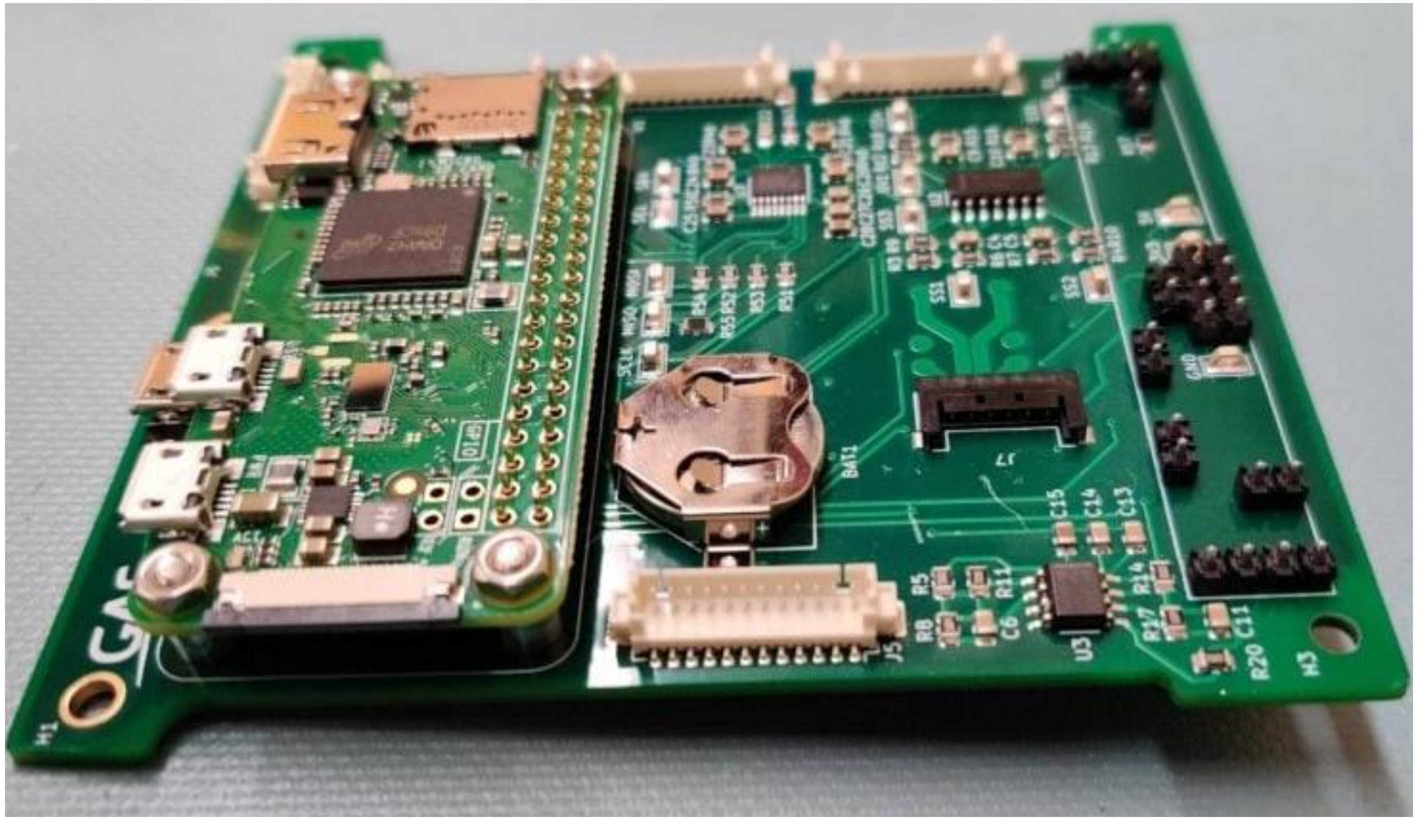
Goals and Scope of Space Guideline for RaspPi

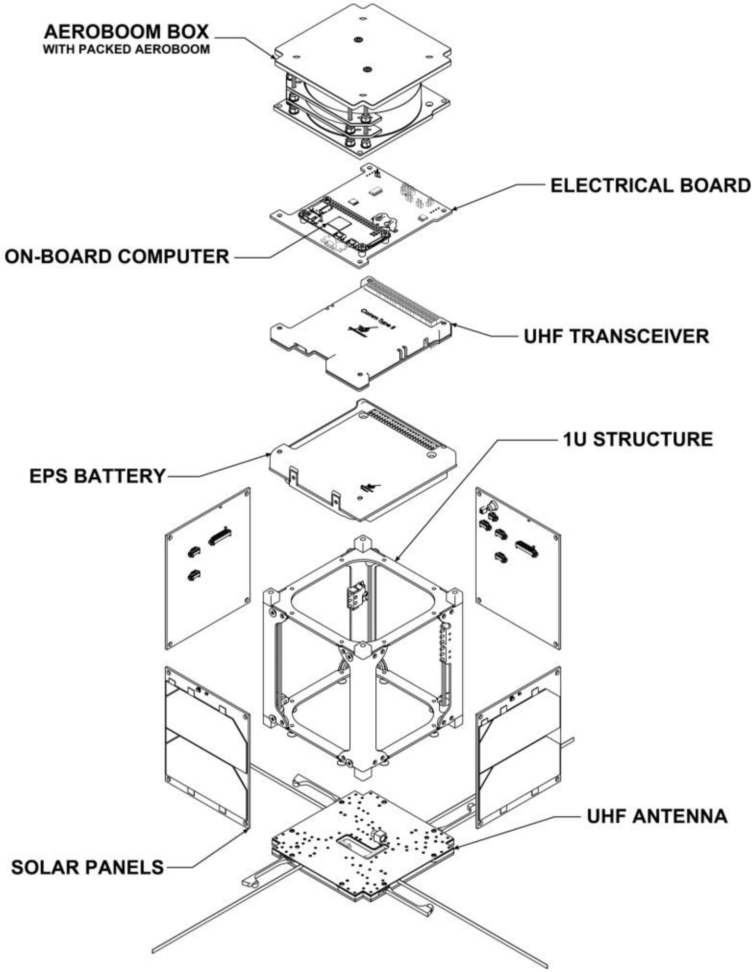
- Typical applications run on Raspberry Pis
- Types of problems likely to occur and H/W considerations.
- Error rates and failure rates due to radiation effects
- Principal sources of other failures that tend to be unique in space mission

CubeSat Minimal Architecture



First RaspPi on a CubeSat





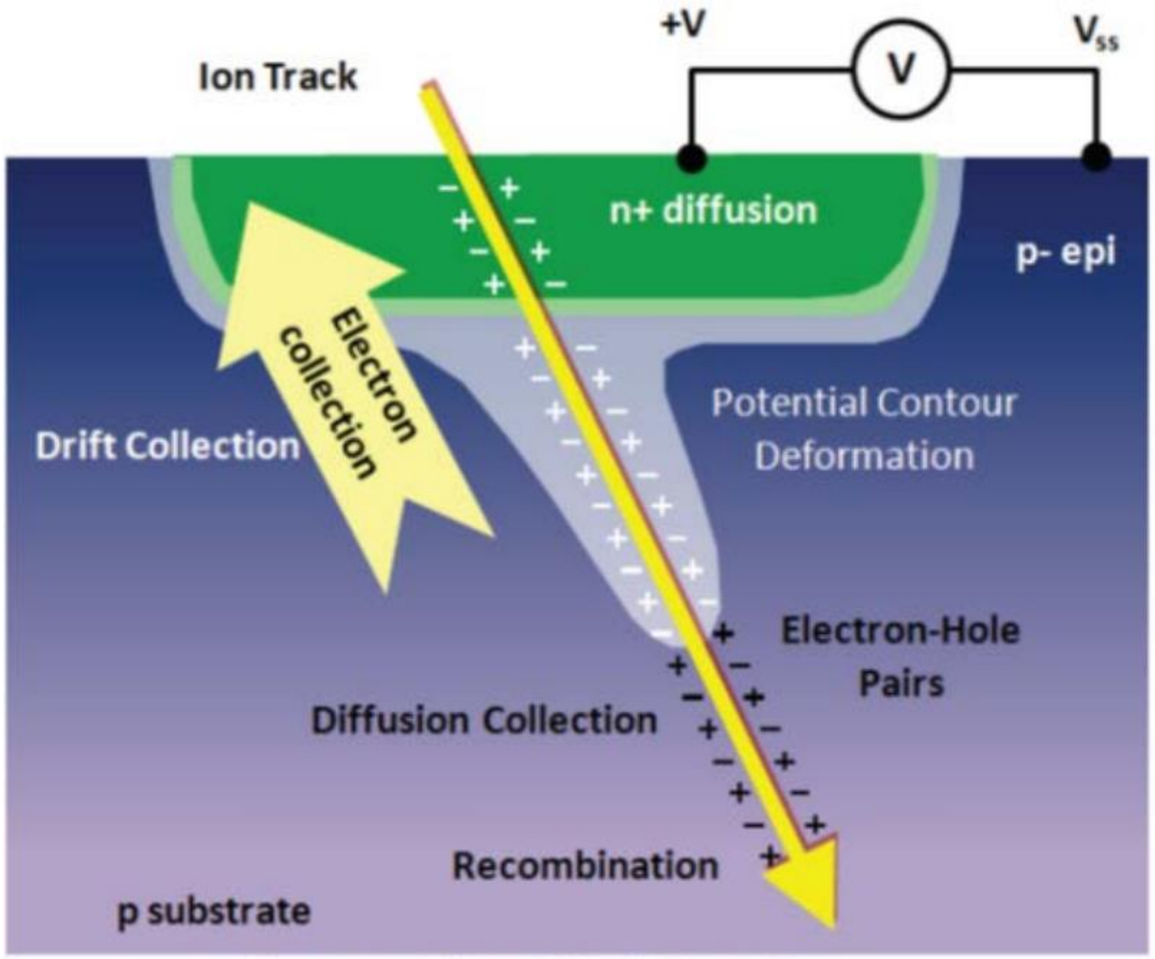
GASPACS features a custom 3-layer PCB based around Raspberry Pi Zero W

The NASA-sponsored GASPACS (Get Away Special Passive Attitude Control Satellite)

Key Radiation Effects

- **Single-event effects (SEE)** is the error or failure caused by single ionizing particle.
- **Total ionizing dose (TID)** is the summation of the overall accumulated dose from various sources such as electrons, protons, heavy ions, x-rays, g rays, et
- **Single-event functionality interrupt (SEFI)** is a type of soft error in ICs caused by an SEE causing reset or hang that may or may not require power cycling.
- **Single-event latchup (SEL)** is a potentially destructive hard error due to SEE
- **Single-event upset (SEU)** is a change of state caused by an SEE event.

Single Event Effect (SEE) in a Semiconductor Device



Reverse-biased N+/P junction

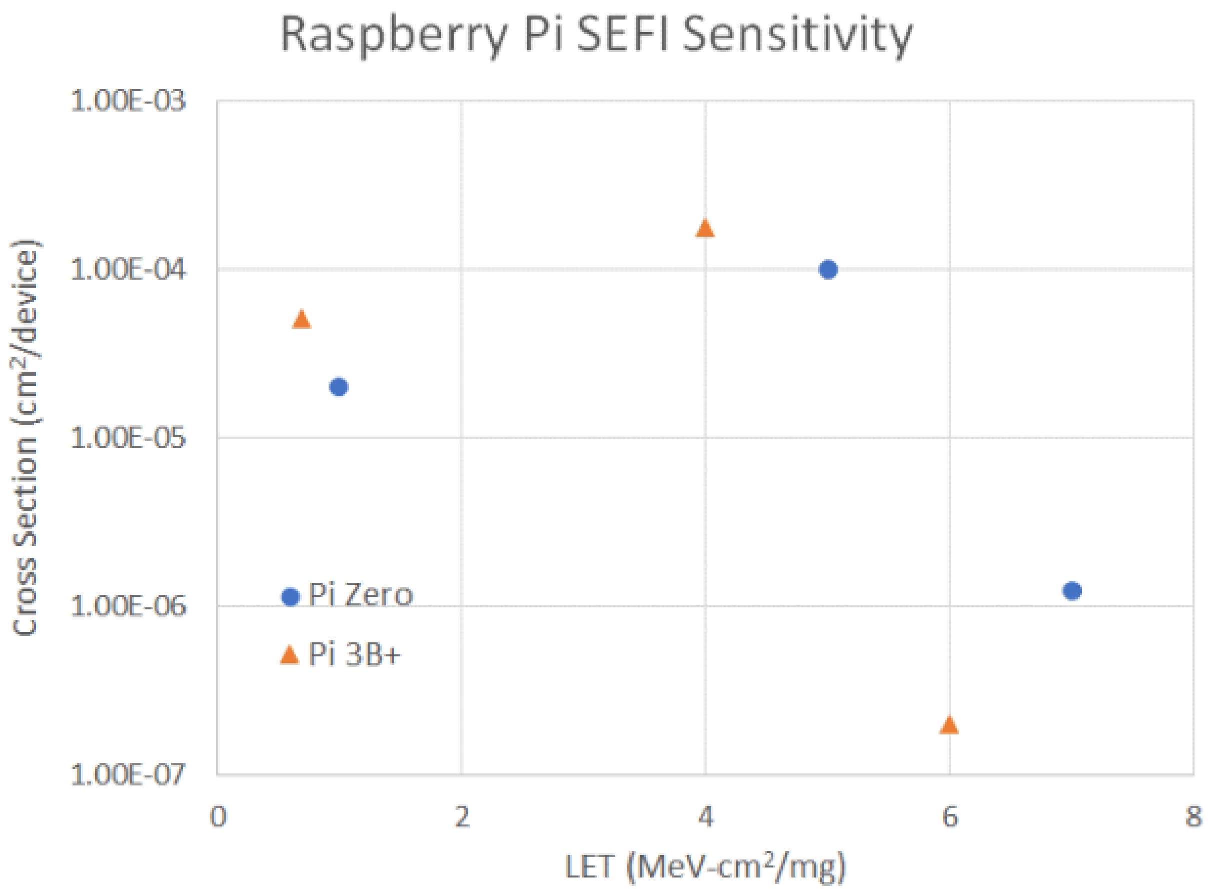
Hardware Consideration for Space Electronics

- **Thermal** cooling in terrestrial device is by convection but in space its conduction.
- **Power** must be *fused* to avoid burn down by high current event such as SEFI
- **Communication** should be galvanically isolated to avoid breakdown by system noise
- **Vibration** immunity to shock and g-loading during launch.
- **Charge accumulation** needs to avoided by using metal and ESD-aware material.
- **Failure analysis** needs to be done for SEE and long-term TID
- **Permanent failure** handling plan needs to be devised unless it’s the main computer.
- **SEFIs** are most likely events for a onboard computer like Raspberry Pi. Plan to detect it so it can be power cycled.

Raspberry Pi Radiation Effects: TID performance

- Several groups have characterized TID performance for Raspberry Pis
- 30-100 krad[Si] TID tolerance has been reported.
- NOTE: This is generally difficult to benchmark

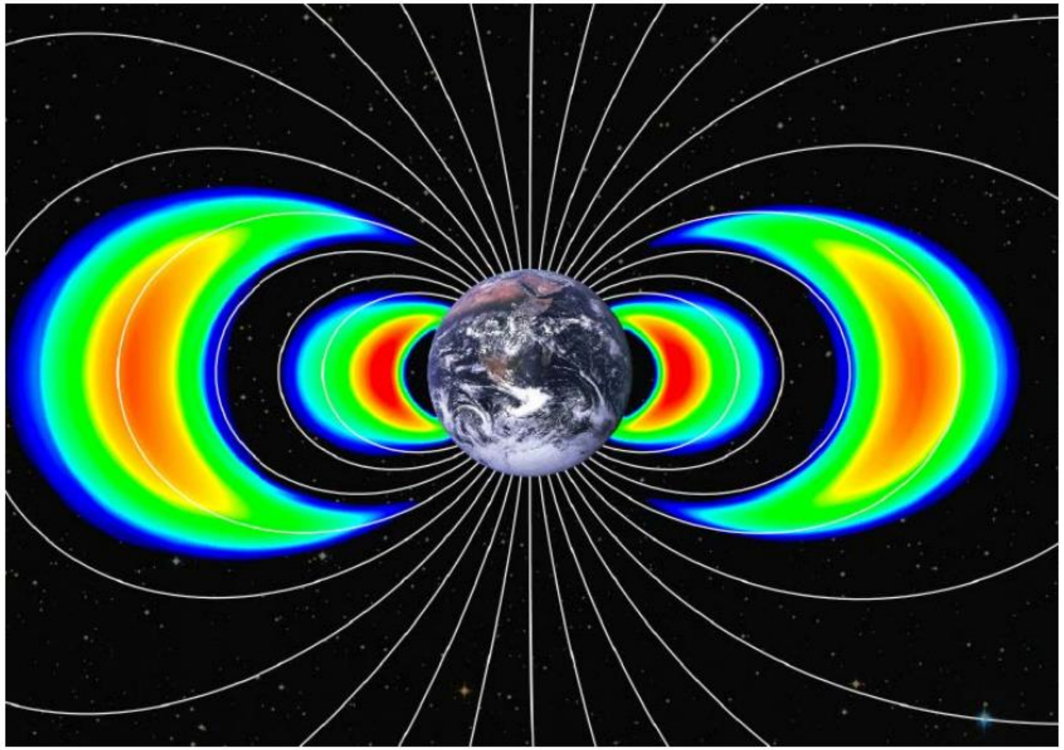
Raspberry Pi SEFI Sensitivity



- RaspPis appear to saturate at cross section of about 3e-4
- Linear Energy Transfer (LET) is a masure of the energy transferred by ionizing radiation typically expressed in units of energy per unit length.

Radiation Environment in LEO Orbits

- Low Inclination LEO Orbit: Typical TID is 1-2 krad[Si]/year. RasPi life ~ 5 years
- High inclination LEO Orbits have similar TID but are more sensitive to solar flares.



The magentic field of the Earth is not aligned with the rotational axis. This gives rise to the South Atlantic Anomaly,

where the inner proton belt drops into the LEO altitude range

- Krad[Si] stands for kilorad (silicon)

Flash Memory on Raspberry Pi

- TID is the greatest risk for NAND Flash. SLC NANDs have shown to have better radiation performance. Even a hardcoded boot ROM should be considered.
- **SD Card Failure:** This is most likely caused by charge pump failure due to TID.
- **High Current:** due to TID sensitivity
- **High Bit Error Rate** during code execution.
- **SEFIs** are the grab bags of SEEs so unexpected behaviour can be expected.