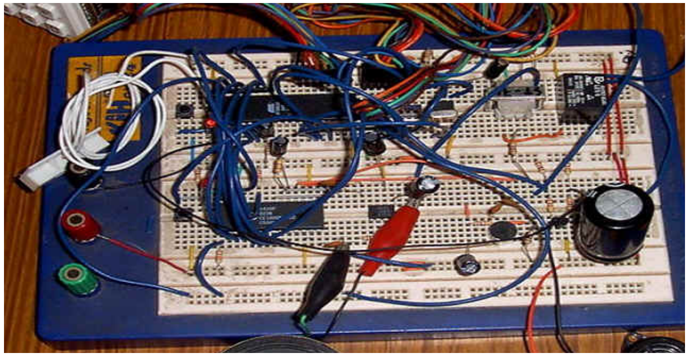
Space Electronics
Design, Production and Verification

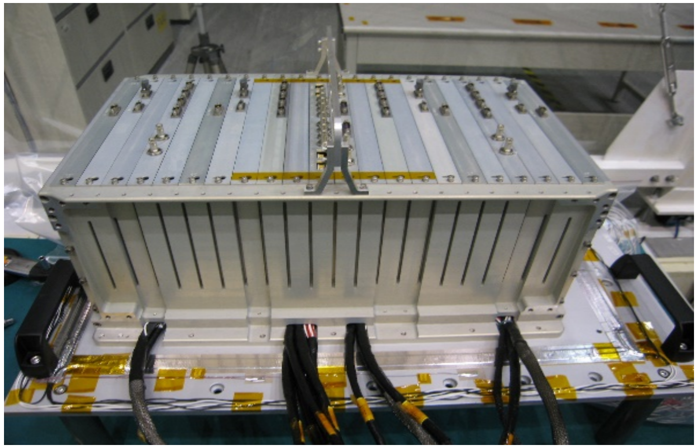
林志勳

中央研究院 物理研究所



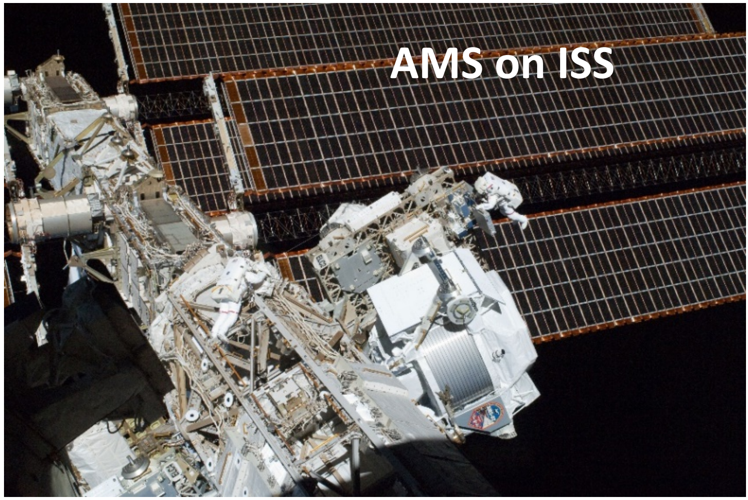
Design

AMS J-crate
PowerPC 850, 500MHz



SG100 Cloud Computer
MPC8572E, 1.5GHz, Dual Core

Verification



AMS on ISS

- Environment effects
- Design flow
- Verification tests

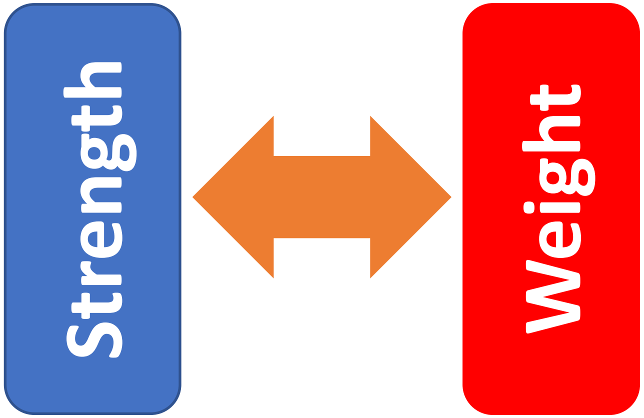
Environment Effect on Spacecraft

- Vibration, Shock and Acoustic
- Thermal environment
- Plasma and Cosmic ray radiation

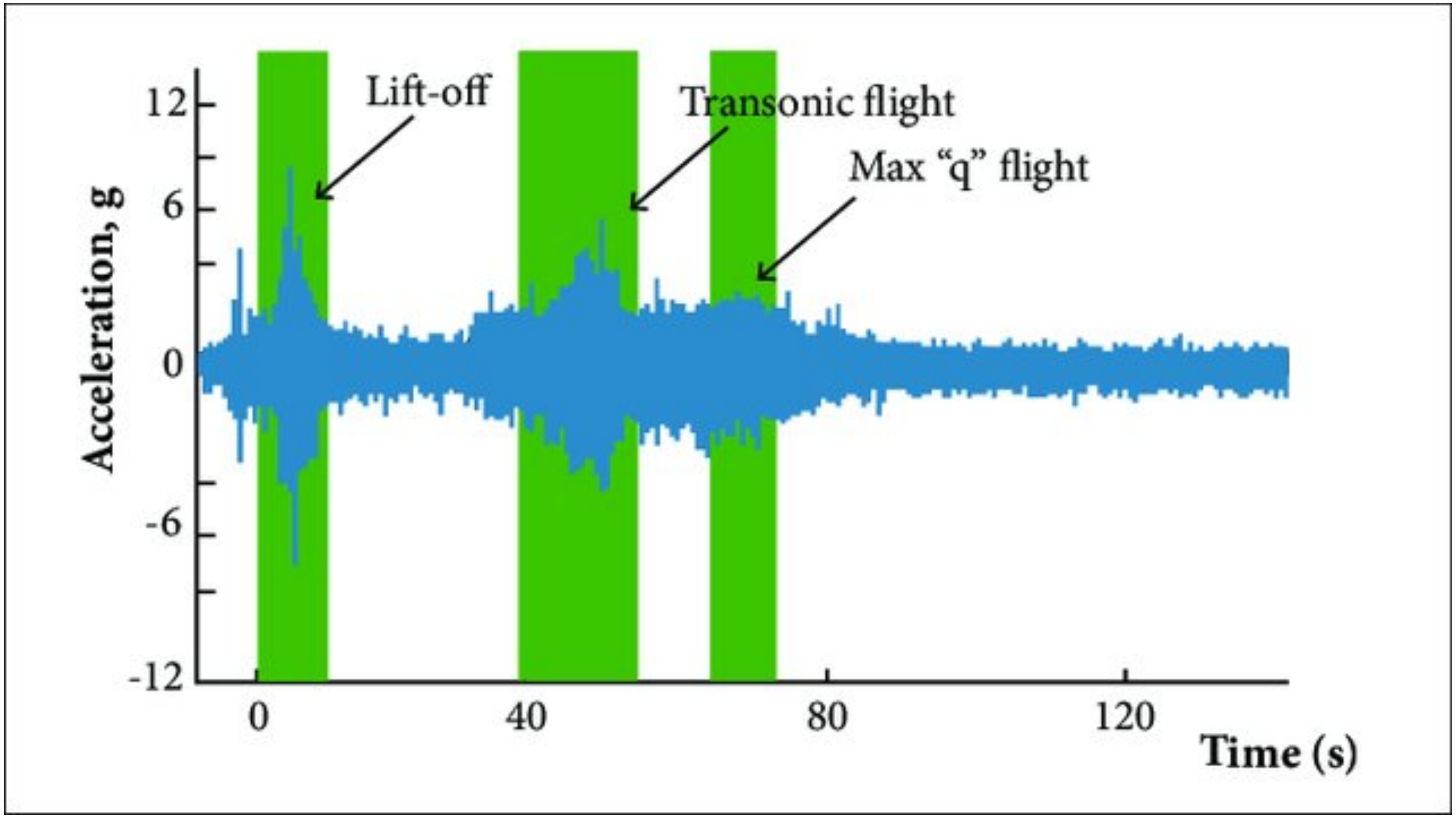
Vibration, Shock and Acoustic

- Lift off
  - Vibration
  - Acoustic
- Separation / Docking
  - Shock
- Landing
  - Vibration
  - Shock

- Specifications from launcher
  - Derive requirements for subsystems
  - Analysis and Test



Vibration time history during a Space Shuttle Launch



*J. Aerosp. Technol. Manag., São José dos Campos, Vol.X, No X, pp.1-9, XXX.-XXX., 2014

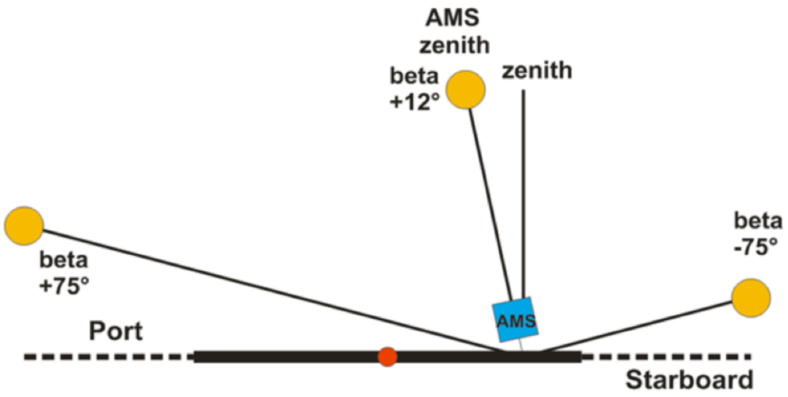
Thermal Environment

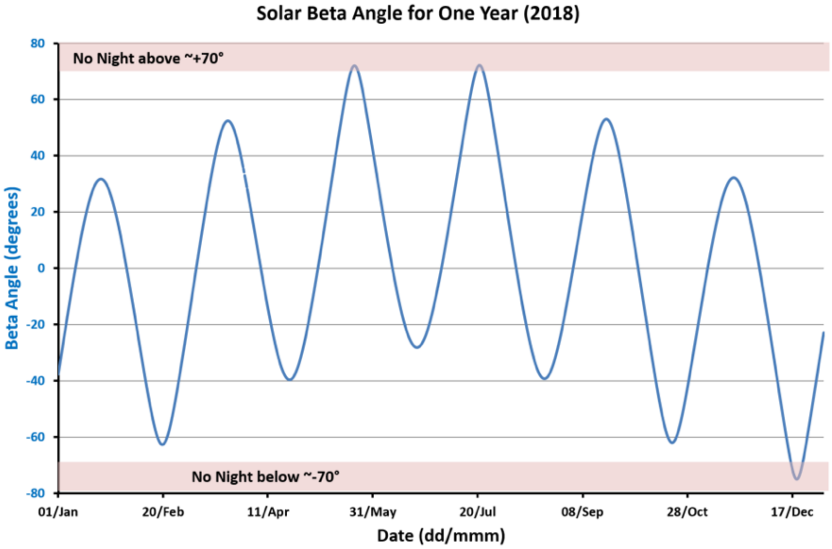
- Absorption
  - Solar radiation
    - Solar beta angle
    - Solar constant
  - Radiation from Earth

- Emission
  - Radiation to deep space

- Internal power dissipation and Attitude

AMS Beta Angle





Heat Exchange

- ~~Convection~~
- Conduction – Payloads/Subsystem
- Radiation – Satellite/Spacecraft

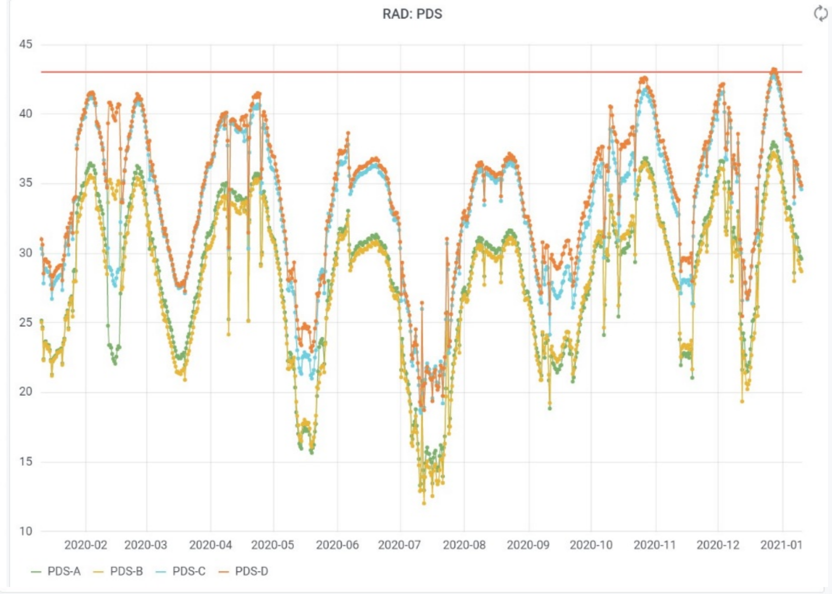
Thermal Control

- **Passive (weight)**
  - **Metal (Al/Cu Alloy):** Move internal dissipation to radiator.
  - **MLI (Multi-layer insulator):** Block radiation from Sun.
  - **Radiator:** Radiate the heat to space

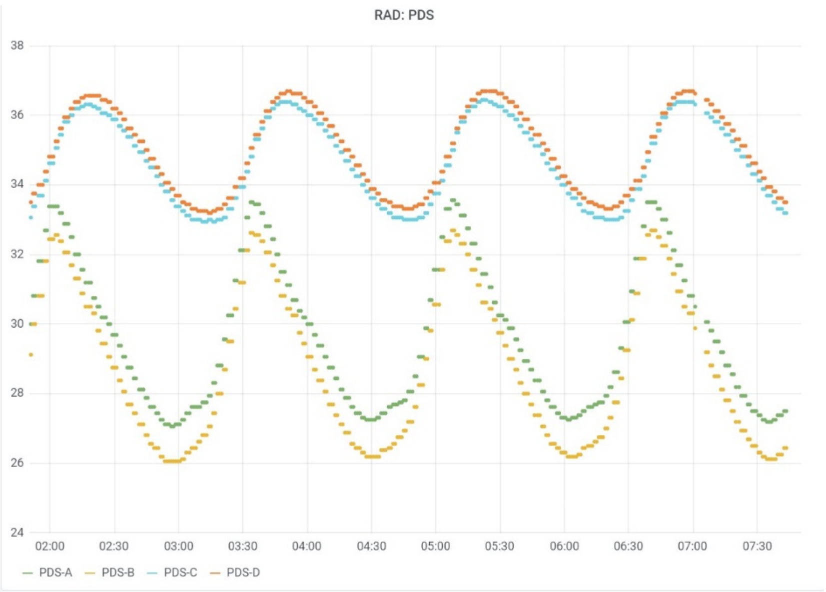
- **Active (Thermal stability) (weight and power)**
  - **Heater**
  - **Heat pipe**
  - **Two-phase cooling loop (CO_2, Ammonia)**

AMS Temperature

One Year

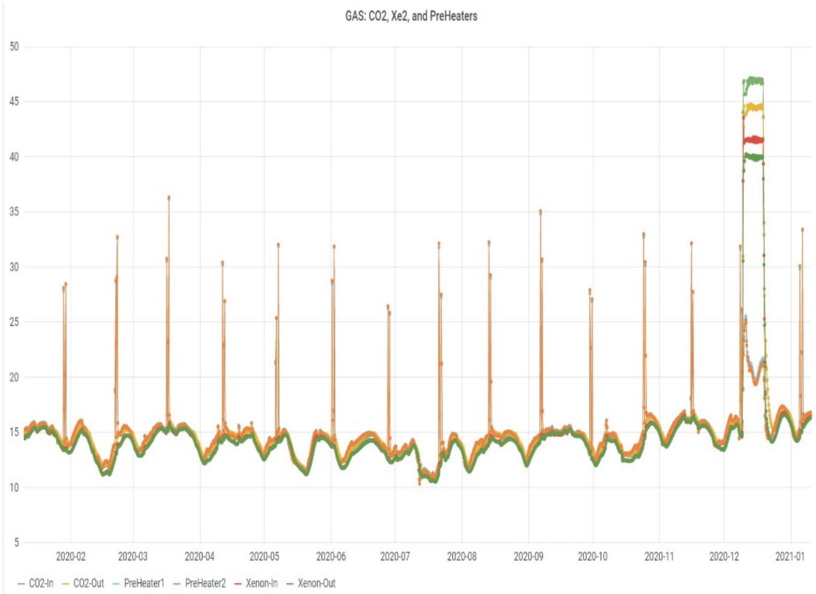


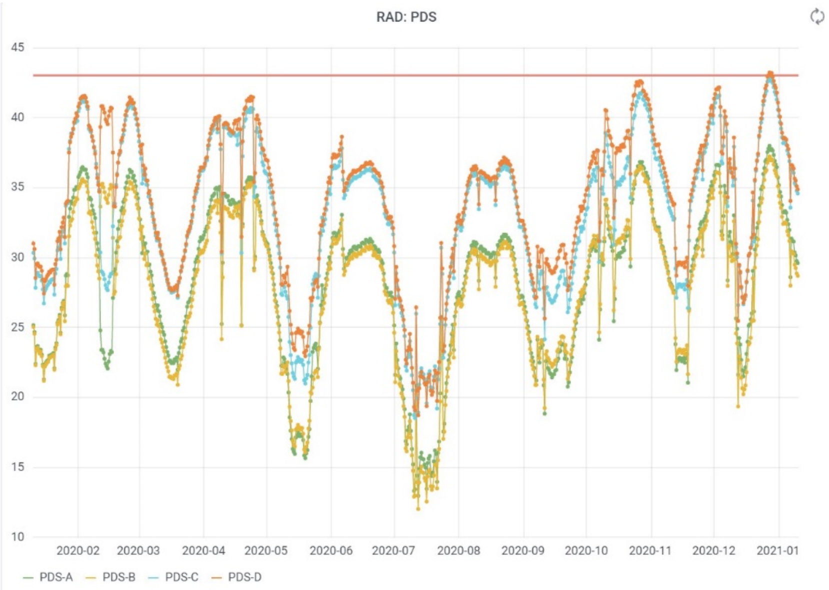
6 hours



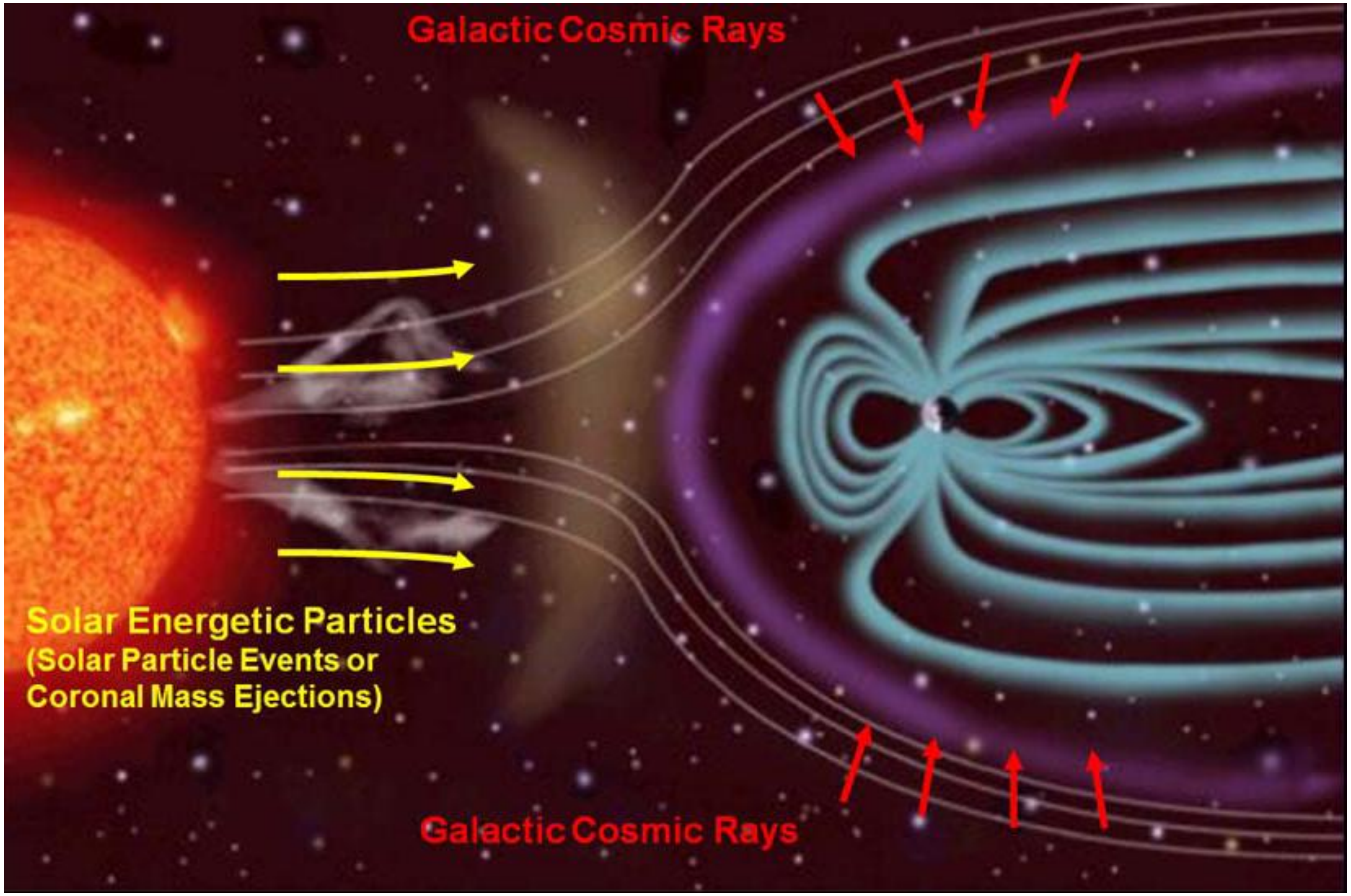
Orbit time ~ 90 minutes

AMS Temperature





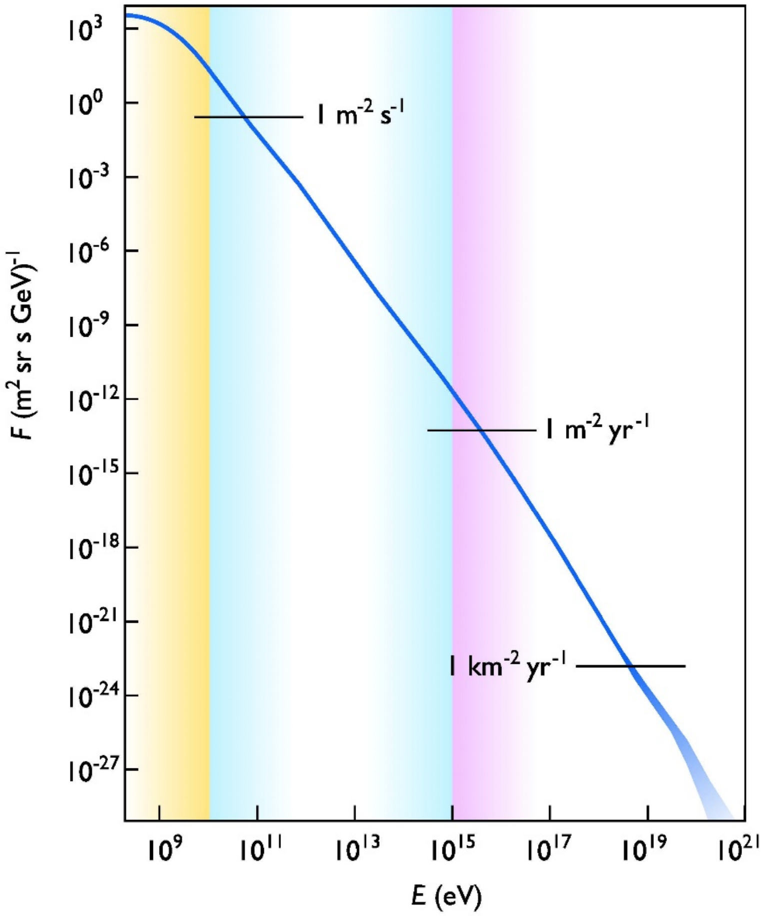
Radiation in Space



Radiation effect from charged particle/ions

Charged Particles in Space

- **GCR**
  - 87% proton, 12% alphas, 1% ions
  - Up to Fe
  - Up to 10^{20} eV
- **Solar particle**
  - 96% proton, 3.5% alphas, 0.1% ions
- **Tripped particle**
  - Proton and Electrons



Space Radiation Effect - Charging

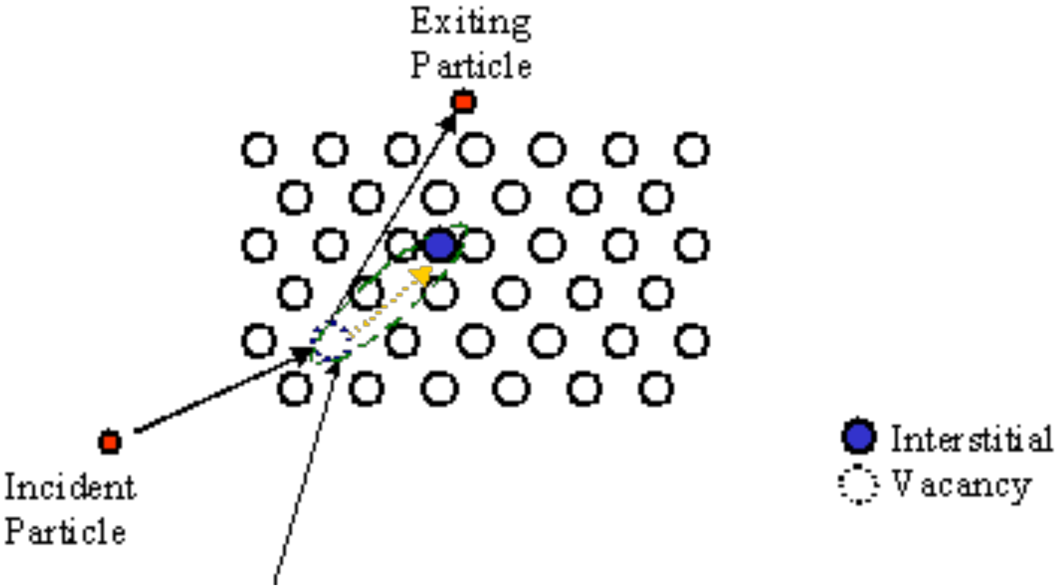
- Upper atmosphere consists of positive charged ions and free electrons.
- May develop an induced charge on spacecraft

- Large potential difference
  - Discharge may damage electronics.
  - Interference with scientific measurements.
  - Grounding is an very important issue for spacecraft.

Space Radiation Effect - Particles

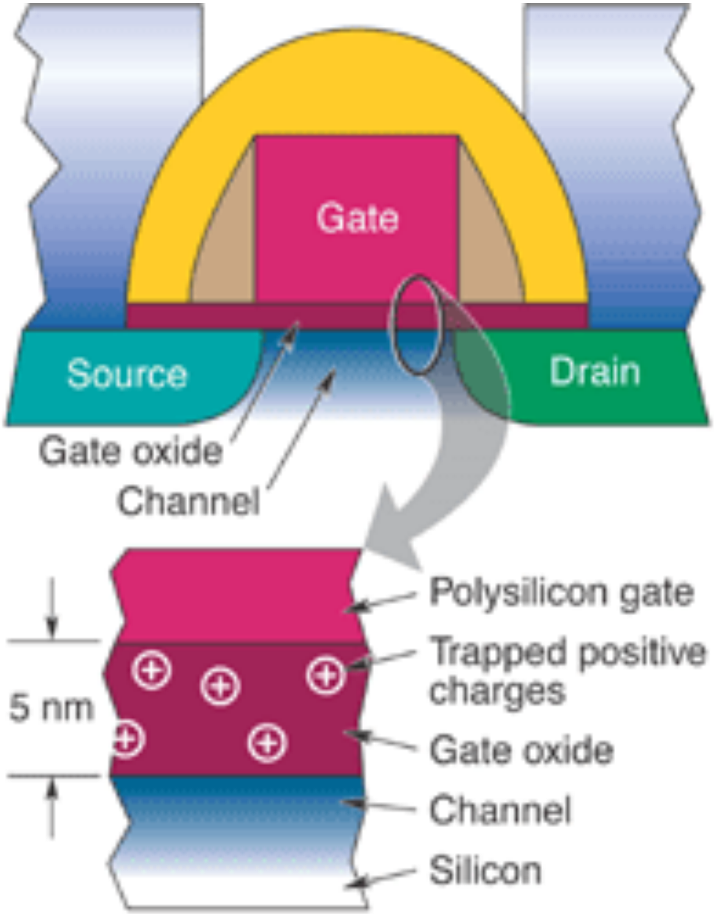
- Displacement damage effects (p & e)
- Total ionizing dose effects (p & e)
- Single event effects (p & ions)

Displacement effect



- Non-ionizing energy loss (NIEL)
- Device effects depends on doping
  - Carrier lifetime damage and Carrier Removal
  - Reduce device performance.
    (Solar Cell, LED, laser diode … etc)

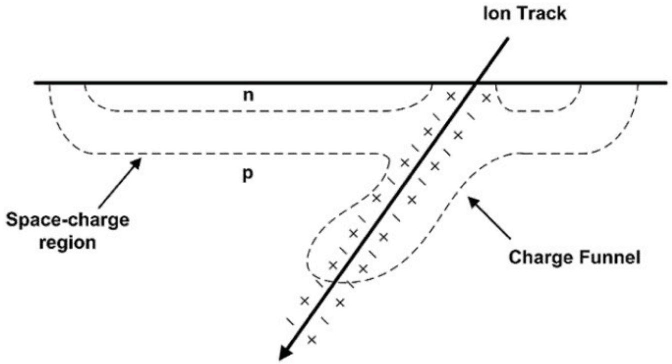
Total ionizing dose (TID)



- 17 eV to crate a e-hole pair in SiO_2.
- Oxide charge trapping
  - Induce changes in Vth and leakage.
  - Electrical performance is degraded
- Improved in submicron process technology.

Single event effect (Heavy ion)

- Single event upset (SEU)
  - Non-destructive
  - Memory
  - Register
- Single event latchup (SEL)
  - May be destructive
  - Only recovered by power cycling.



System Reliability (可靠度)

- **The failure rate can not be ZERO.**
- **High reliability also means high cost.**
- **May prevent the usage of new technologies. (lower performance)**
- **The launch cost is going down and more launch opportunities are available, which makes things different now.**

System Reliability (可靠度)

- Use new technologies
    - Low cost、high performance、low power
    - less weight and small size
    - **Higher Risk**

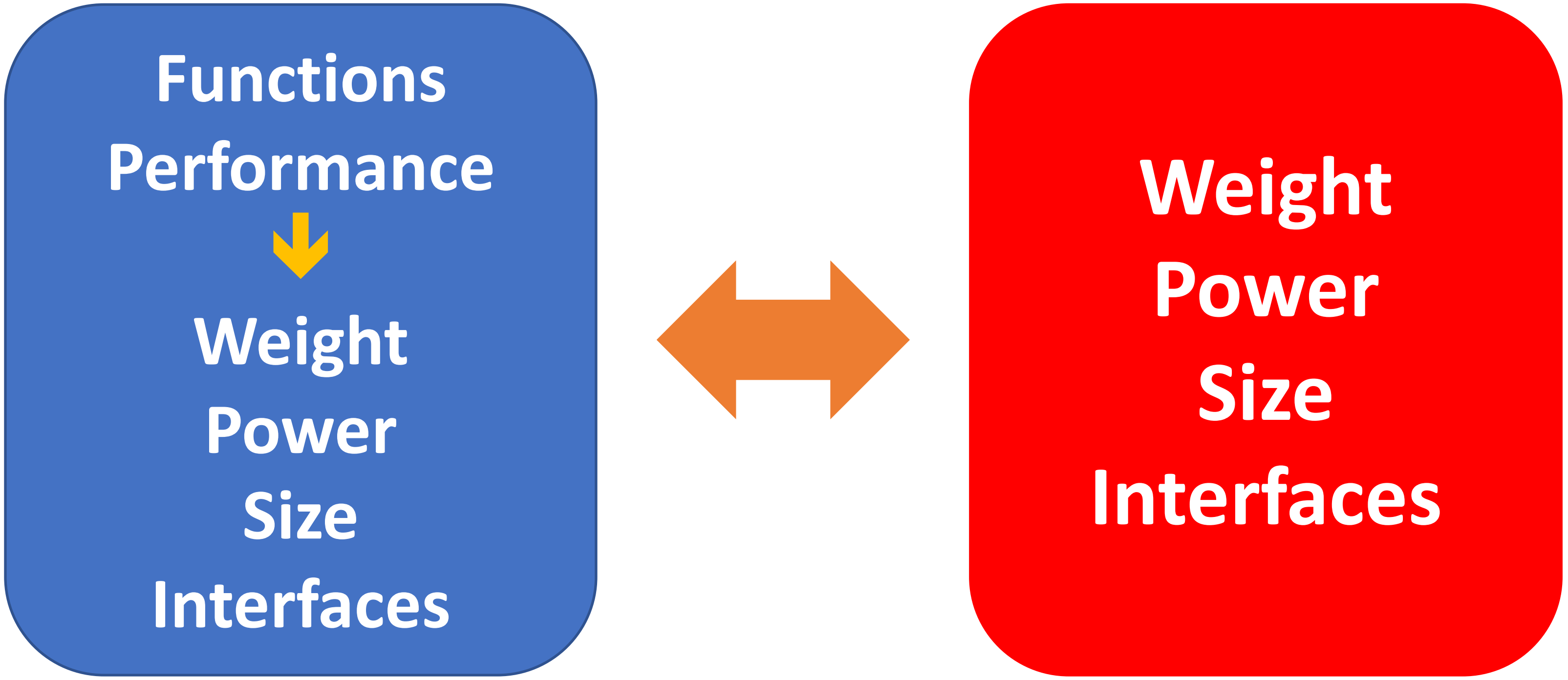
Tests

Redundancy in component and system

Short mission life

- **Environment effects**
- **Design flow**
- **Verification tests**

Define requirements and constraints



Payloads
(requirements)

Functions
Performance
↓
Weight
Power
Size
Interfaces

Bus
(constraints)

Weight
Power
Size
Interfaces

Design Flow of Space System

- Draw system requirements, derived from mission requirements
  - Functional requirements
  - Environmental specification
    - Mission life
    - Vibration level specification
    - Thermal interface specification
    - Radiation level requirement
  - Weight and power budget

- System level design

- Part selection and circuit design

Existing space qualified EEE parts

Too slow, too big

take too much power,

long lead time and export control.

Qualify commercial EEE (COTS) parts to meet our needs

SEL and SEU effects

Radiation Test

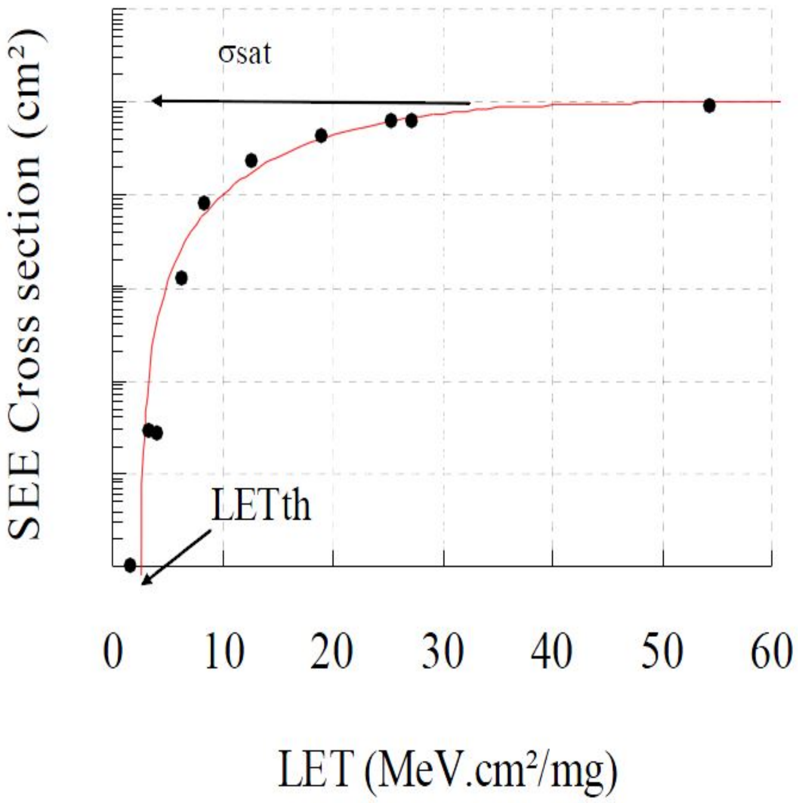
- **TID**
  - **Co^{60} ➔ γ ray (1173 keV & 1332 keV)**
  - **Proton Test**

- **SEE**
  - **Heavy ion beam (Xe^{54}, Au^{79}, U^{92} … etc)**
  - **Proton Test**

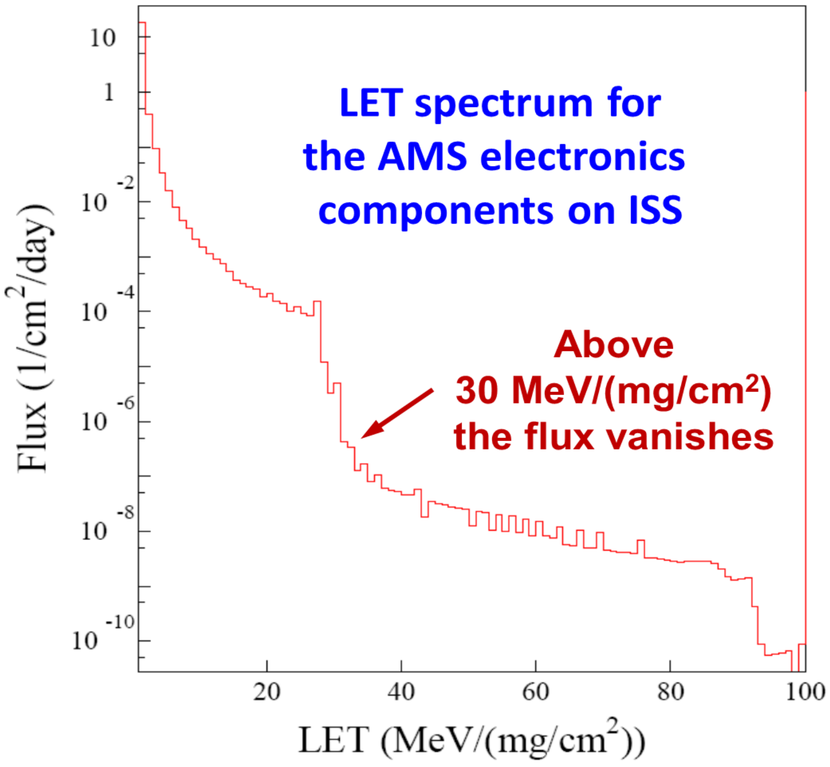
Linear Energy Transfer (dE/dx)

- Energy transfer of an ionizing particle to the matter
  - LET $\neq$ Particle Energy
  - Unit : MeV/mm or MeV/(mg/cm^2)
  - LET is a function of particle velocity.
  - LET $\propto$ Z^2 (at the same velocity)

Heavy Ion Radiation Tests



×

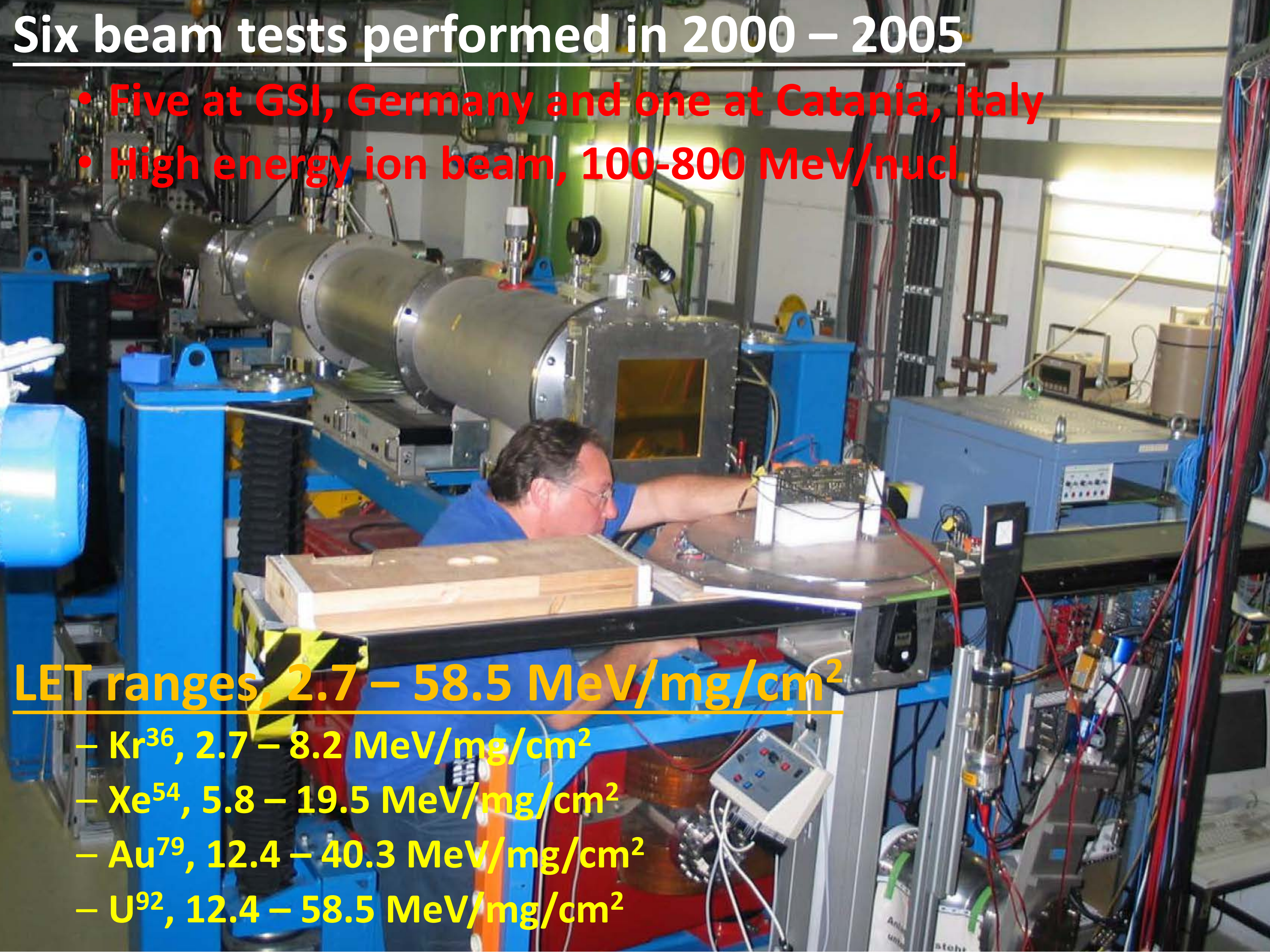


LET spectrum for the AMS electronics components on ISS

Above 30 MeV/(mg/cm²) the flux vanishes

Number of SEEs per day on orbit

Six beam tests performed in 2000 – 2005



- Five at GSI, Germany and one at Catania, Italy
- High energy ion beam, 100-800 MeV/nucl

LET ranges, 2.7 – 58.5 MeV/mg/cm^2

- Kr^{36}, 2.7 – 8.2 MeV/mg/cm^2
- Xe^{54}, 5.8 – 19.5 MeV/mg/cm^2
- Au^{79}, 12.4 – 40.3 MeV/mg/cm^2
- U^{92}, 12.4 – 58.5 MeV/mg/cm^2

77 parts were tested in AMS:

- ✓ 69 parts are accepted.
- ✓ One part is accepted with current protection.

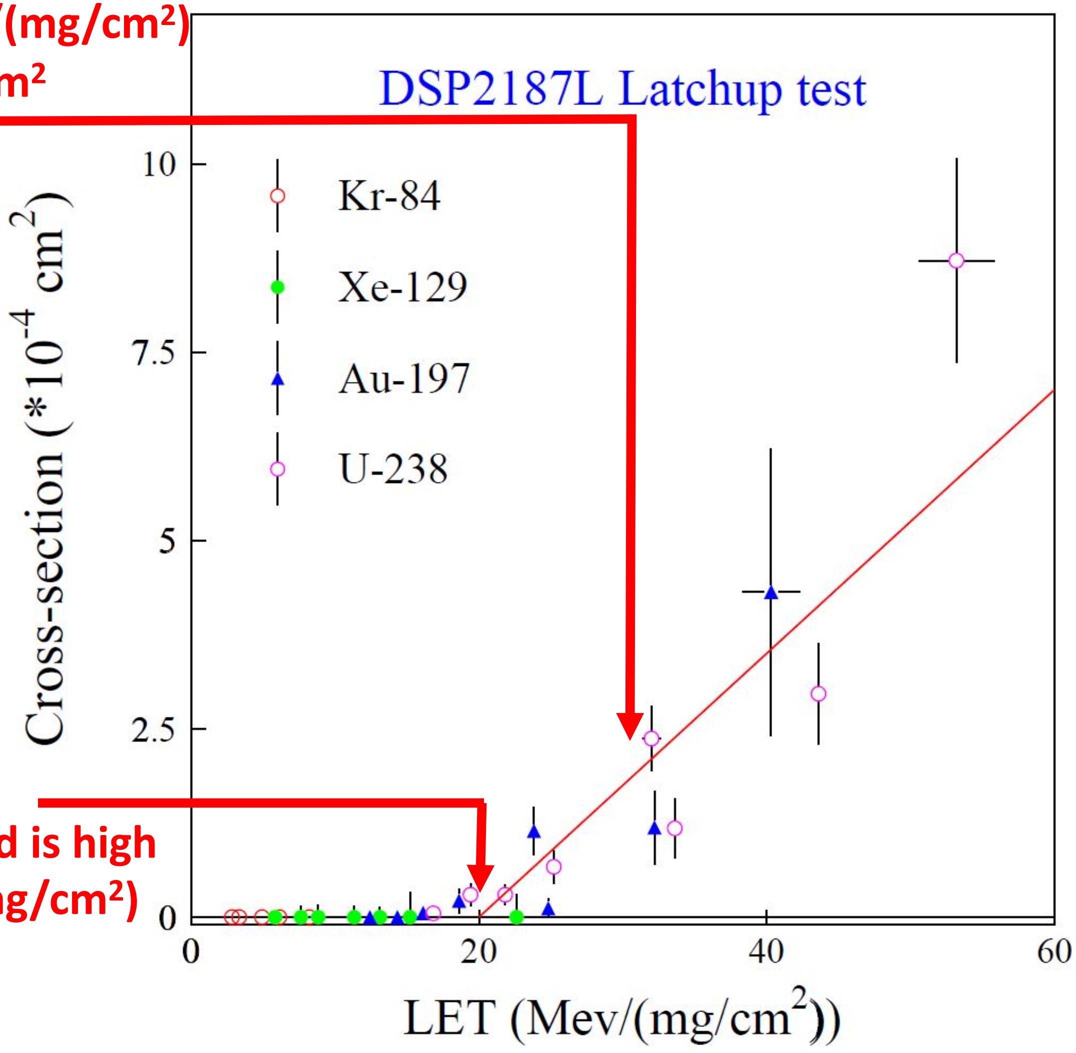
Component	Part	Results	Use in AMS
DSP	**ADSP-2187L**	**Accepted**	**DAQ**
FPGA	A54SX32A	Accepted	JMDC,DAQ
FPGA	A54SX72A	Accepted	DAQ
SP-SRAM	K6R1016V1	Accepted	DAQ
SP-SRAM	K6R4016V1C	Accepted	DAQ
DP-SRAM	CY7C028V	Accepted	JMDC
CPU	**PPC750**	**Accepted**	**JMDC**
Bridge	CPC700	Accepted	JMDC
Clock Driver	MPC972FA	Accepted	JMDC
PCI Adaptor	PCI9080	Rejected	-
WDT	MAX706ESA	Accepted	JMDC
SDRAM	V54C3256403VAT7	Rejected	-
SDRAM	NT5SV32M8AT-7K	Rejected	-
SDRAM	K4S561632C-TL75	Accepted	JMDC

Component	Part	Results	Use in AMS
MOSFET	FDD2570	Accepted	DC-DC
MOSFET	IRFR5305	Accepted	DC-DC
MOSFET Driver	TPS2814	Accepted	HV
FE ASICs	Custom ASIC	Accepted	Sub-detectors
HV CTRL	MHV100	Accepted	TRD
OPA	AD8052	Accepted	DAQ
OPA	LM258	Accepted	DAQ
V reference	LM4040	Accepted	DAQ
Comparator	LM239AD	Accepted	DAQ
LV regulator	LM2989A	Accepted	JMDC,DAQ
Transceiver	SN54LVTH16245A	Accepted	JMDC,DAQ
LVDS RX	SN65LVDS390	Accepted	JMDC,DAQ
LVDS TX	SN65LVDS391	Accepted	JMDC,DAQ
Level Shifter	SN74LVCC3245	Accepted	DAQ

ADSP2187L SEL Test

Low SEL cross-section
at 30 MeV/(mg/cm²)
< 0.0002 cm²

Estimated SEL rate
< 1 x 10^{-7} / day



SEL Threshold is high
~ 20 MeV/(mg/cm²)

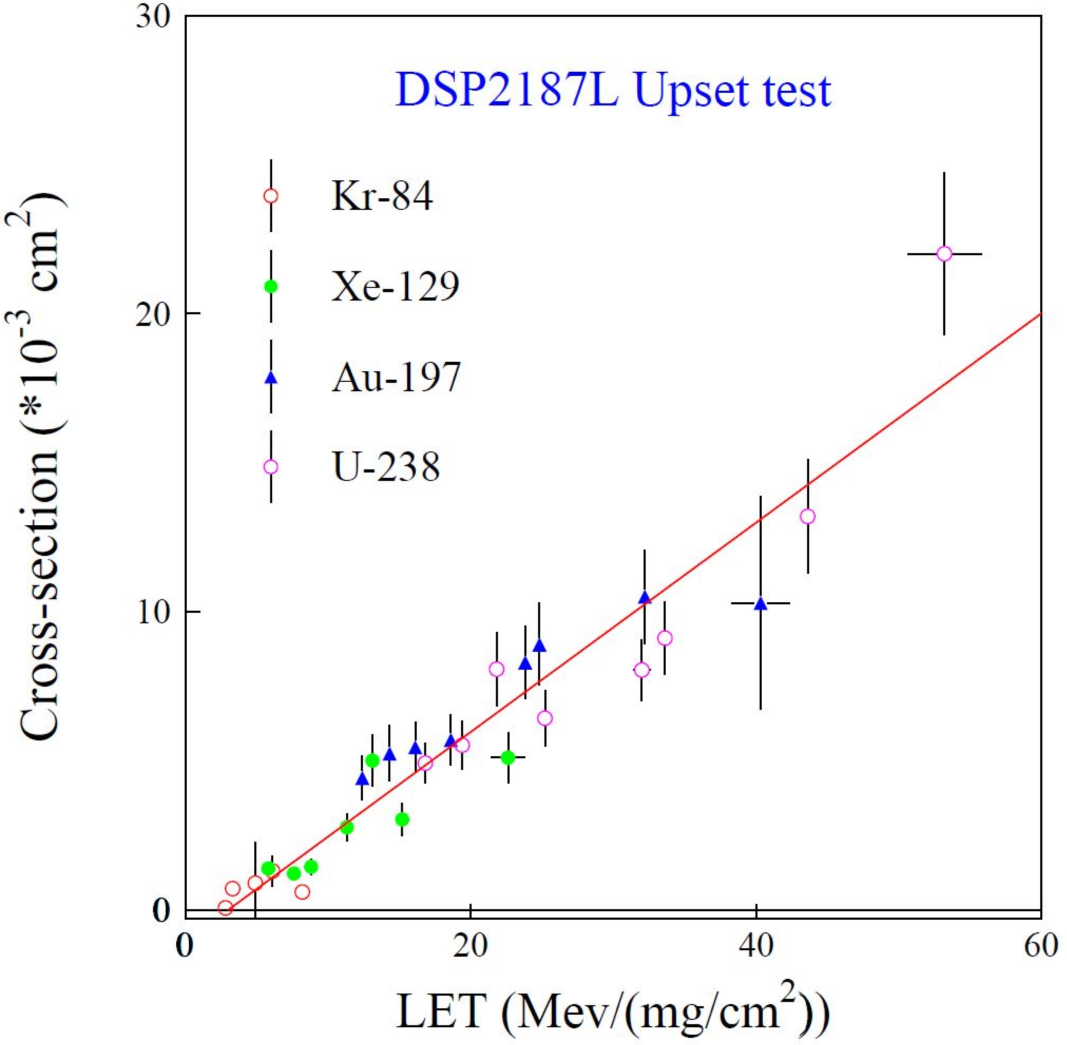
ADSP2187L SEU Test

- **Including memory errors and program hang**
- **Estimated SEU rate**

  < 2 x 10^{-4} / per day

  (1σ)
- **~ 252 active DSPs**

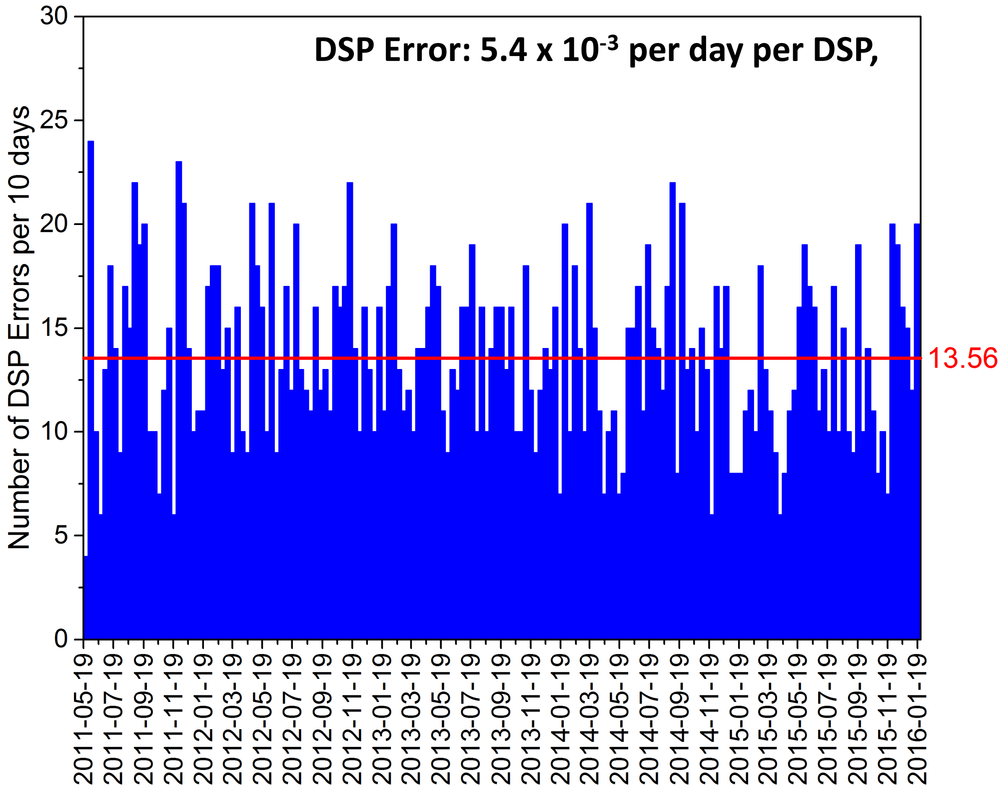
  < 0.05 DSP error per day



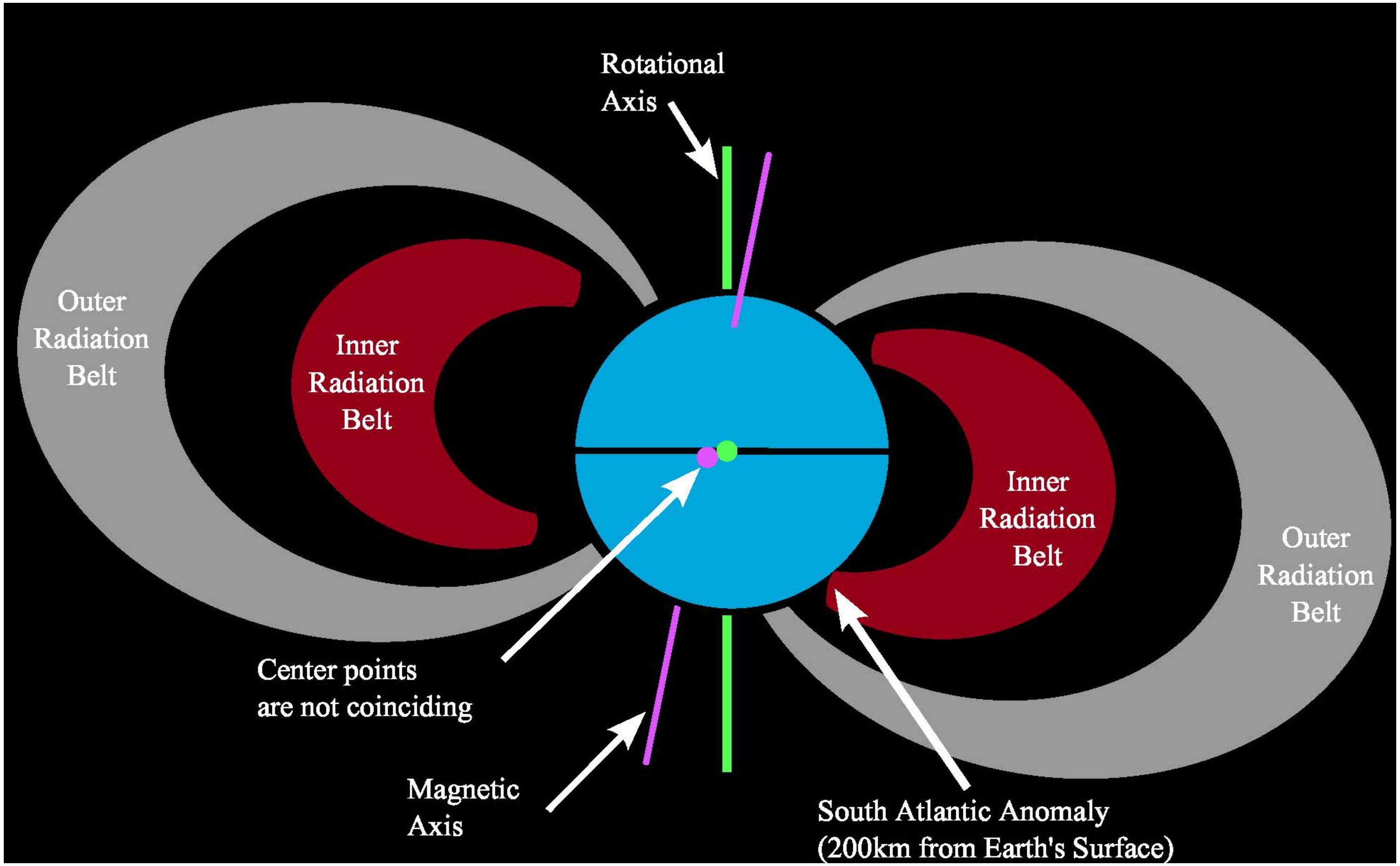
ADSP2187L Error in Flight

- **No permanent damage in ADSP2187L is observed.**
- **Variation of radiation environment in space**
  - **Solar activity and Solar cycle.**
  - **Trapped and cosmic proton flux and SAA**

51% of errors in SAA region



South Atlantic Anomaly

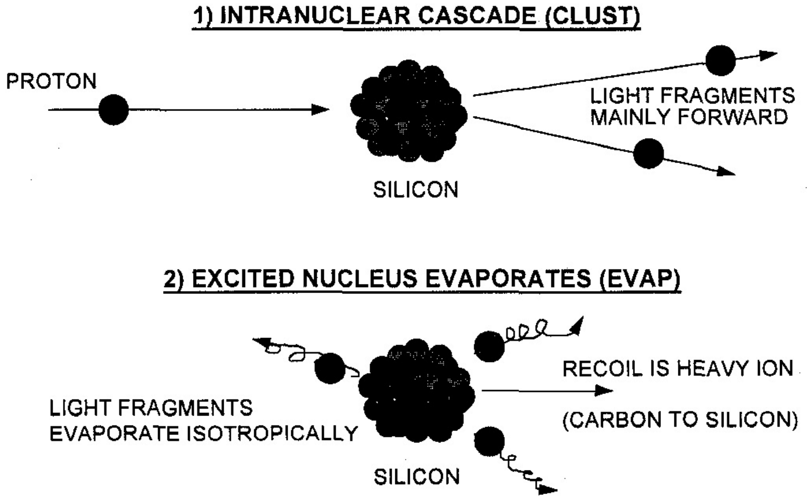


Experience from AMS

- SEU due to proton in LEO is significant.
- A COTS component can be qualified for a space application by well-prepared beam tests
  - Higher performance
  - Lower power, weight and size
  - More possibilities
- AMS experiment is a good example of it.

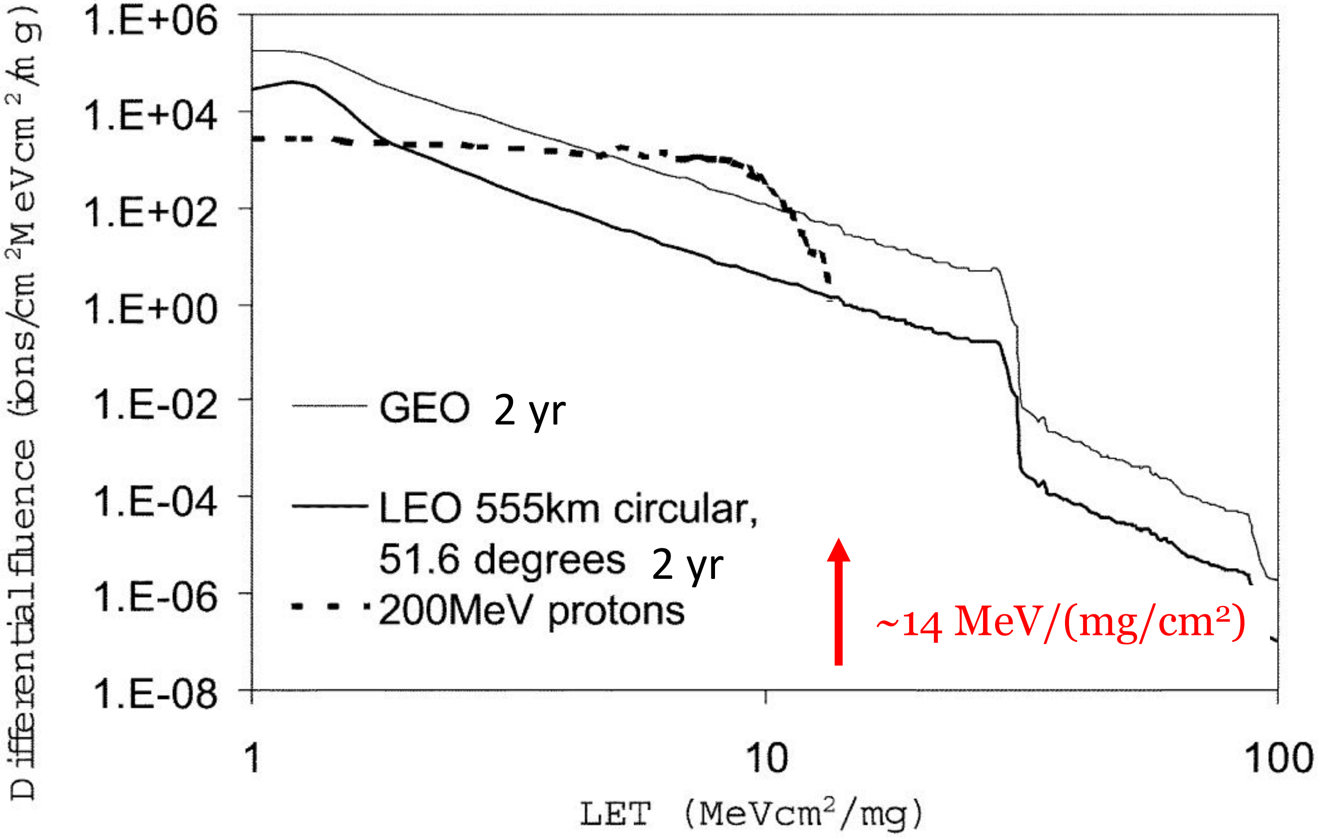
SEE due to Proton

- Very low LET from Proton itself
  - LET of 200MeV Proton ~ 3.6×10^{-3} MeV/(mg/cm^2)
- Proton – Silicon collisions produce a shower of fragments and a recoiling nucleus
  - High LET



Effective LET spectrum of 200MeV Proton

Spectrum of 10^{10} protons/cm^2



2 yr

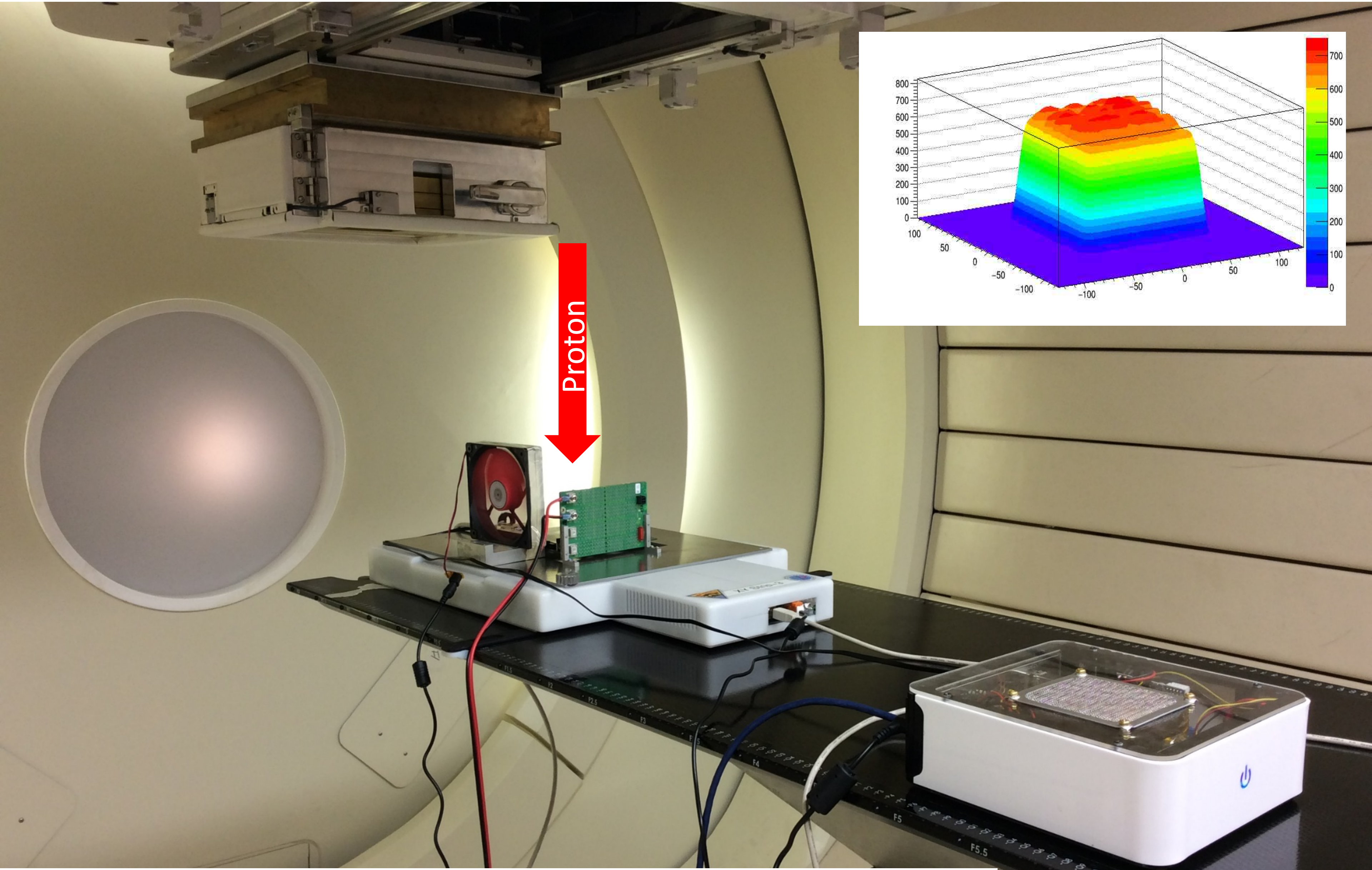
2 yr

~14 MeV/(mg/cm²)

Ref: IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 6, DECEMBER 200

Advantage of Proton Test

- High penetration
  - 120 mm Al for 200MeV proton
  - System/Component Level Test
- Easier and cheaper than heavy ion tests.
  - More test facilities available.



CGMH, 200 MeV
Scanning beam up to 20mm/msec

Disadvantage of Proton Tests

- Limited LET Range
  - No SEL info for LET > 14 $\mathrm{MeV/(mg/cm^2)}$
- No SEU cross-section curve
  - An upper bond per year can be given as:

$$\mathrm{Up} = \frac{\#\ \text{SEE for } 10^{10}\ \text{protons/cm}^2}{\#\ \text{years on-orbit}}$$

  - 10^{10} proton/cm^2= # years on-orbit × the integrals of on-orbit LET spectrum from 1MeV/(mg/cm^2)
  - 10^{10} proton/cm^2 ~ 2-6 years for LEO,

- **Environment effects**
- **Design flow**
- **Verification**

Verification Flow

- Engineer Breadboard (EBB)
  - Verify circuit design concept and its functions
- Engineer model (EM)
  - Verify circuit design and its functions
  - Verify thermal and mechanical design

EQM

- Qualification model (QM)
  - Verify functions in all environmental stress tests with high safety factor ~ 1.5.

PFM

- Flight model (FM)
  - Verify functions in all environmental stress tests with high safety factor ~ 1.1. (Acceptance test)
- Flight spare (FS)
  - Verify functions in all environmental stress tests with high safety factor ~ 1.1. (Acceptance test)

Environmental Stress Tests

- Vibration/shock tests
- Thermal cycling tests
  - Board level screening
  - System functional tests
- EMI/EMC
- Radiation Test
- Thermal Vacuum Test

Vibration Tests

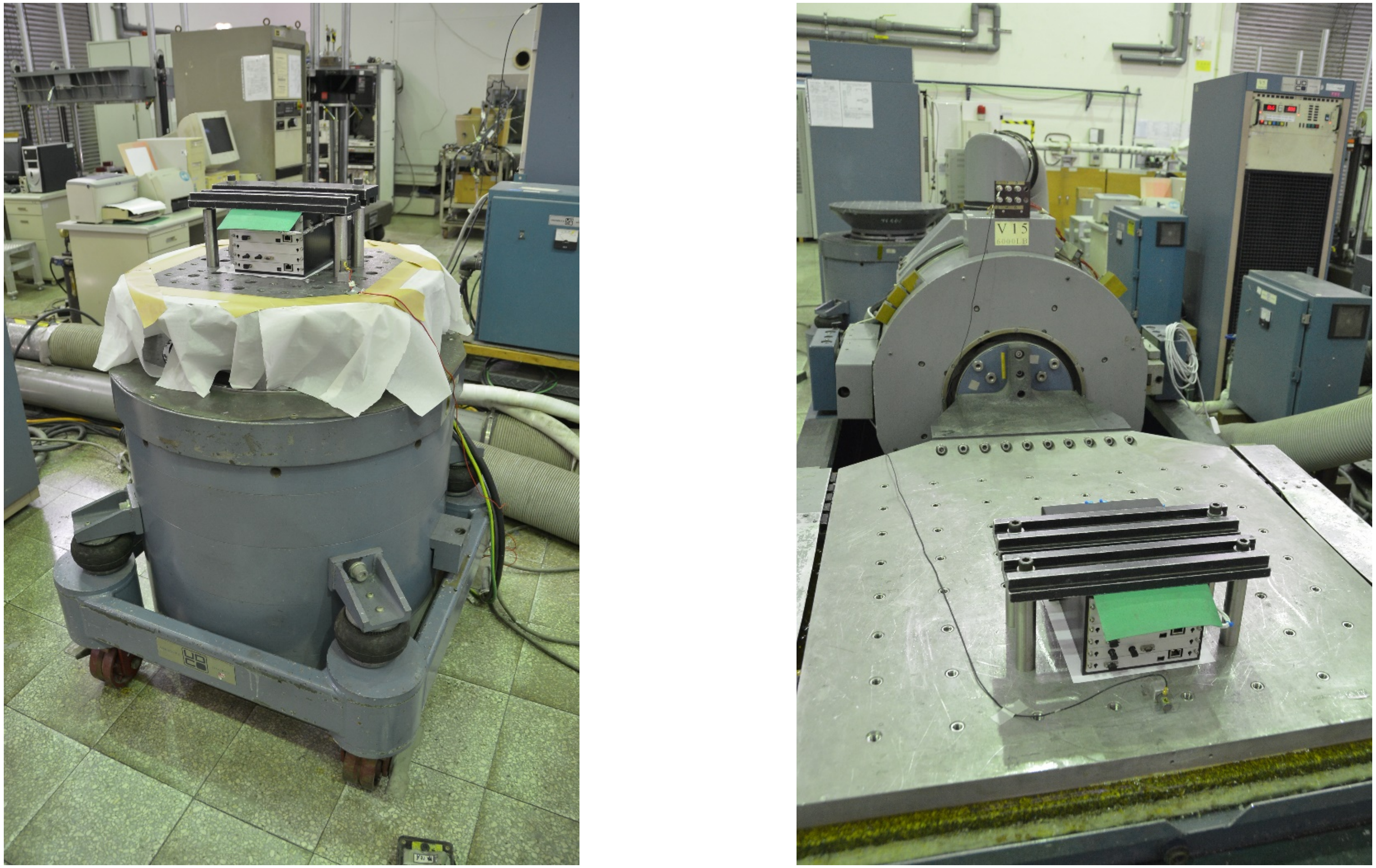
- Analysis must be performed first.

- Sine vibration test
  - Single frequency (scan a frequency range)
  - Find resonant frequency

- Radom vibration test
  - Comprise of vibration energy at all frequencies over a specified range.

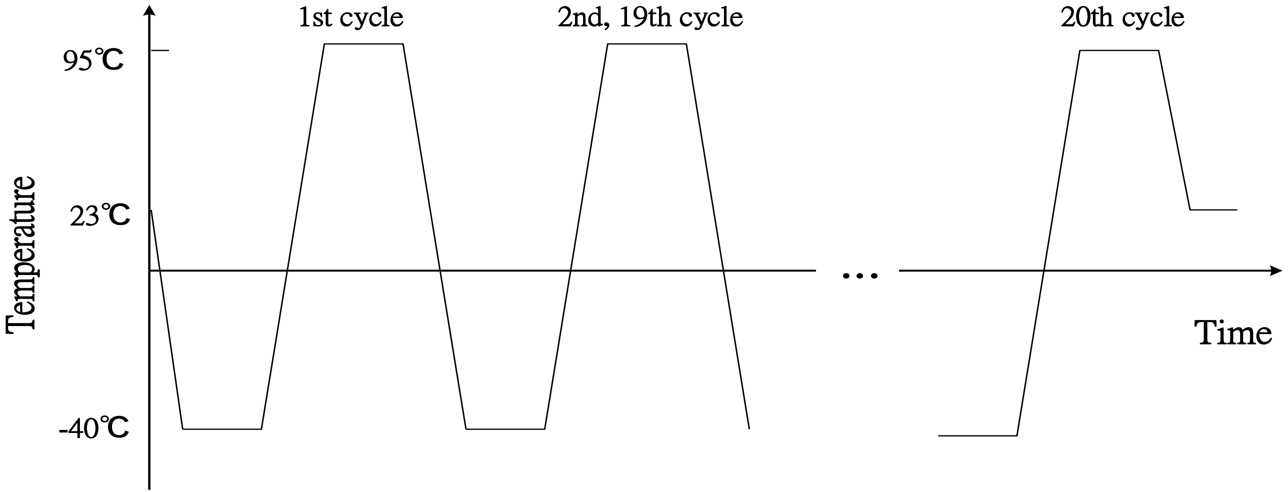
- Shock Test
  - May be replaced by analysis

Vibration Test of SG100



Thermal Cycling Test - Board level

- Verify board assembly
- 20 cycles



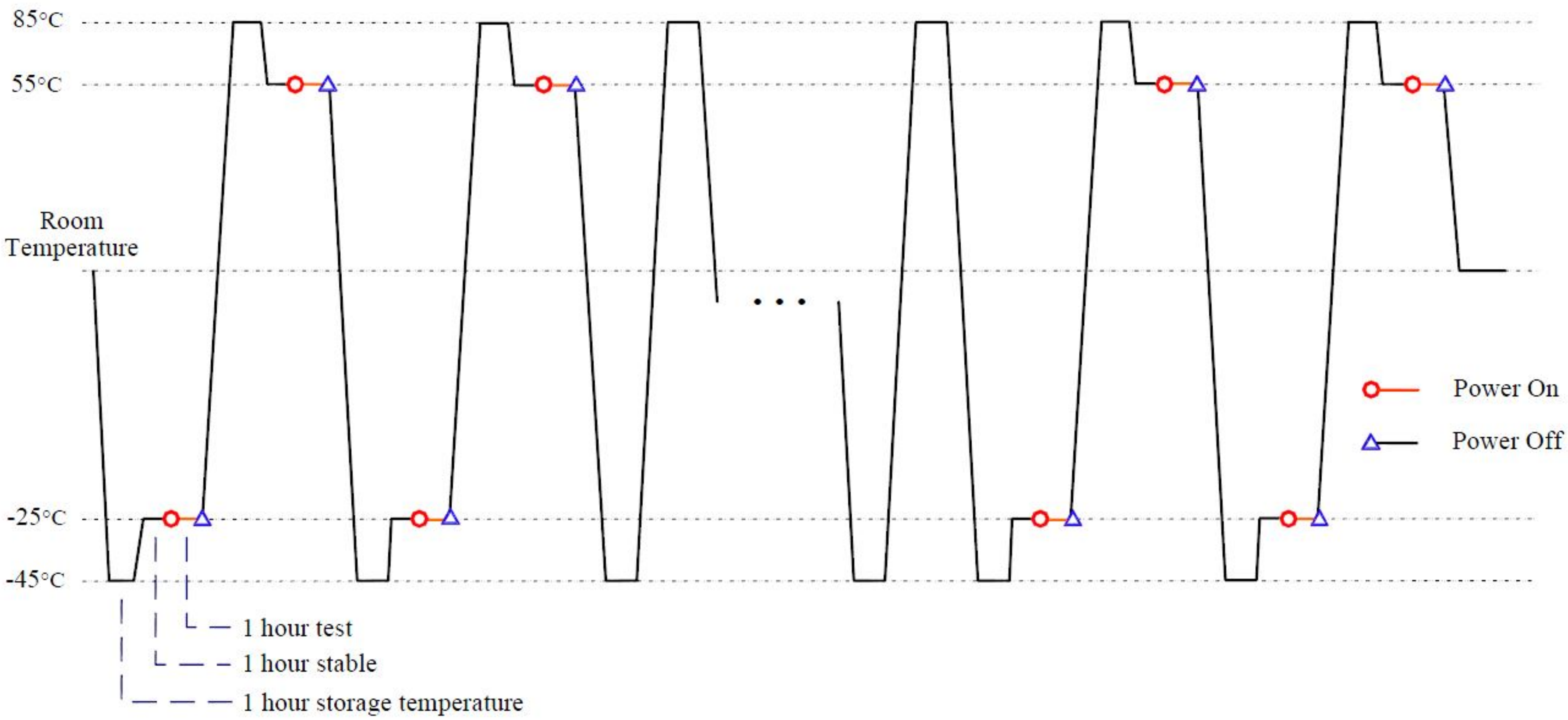
- Temperature Change Rate >= 15 ℃/min.
- One Hour Dwell Time For Each Step

Temperature Cycling Test Profile for PCB of AMS

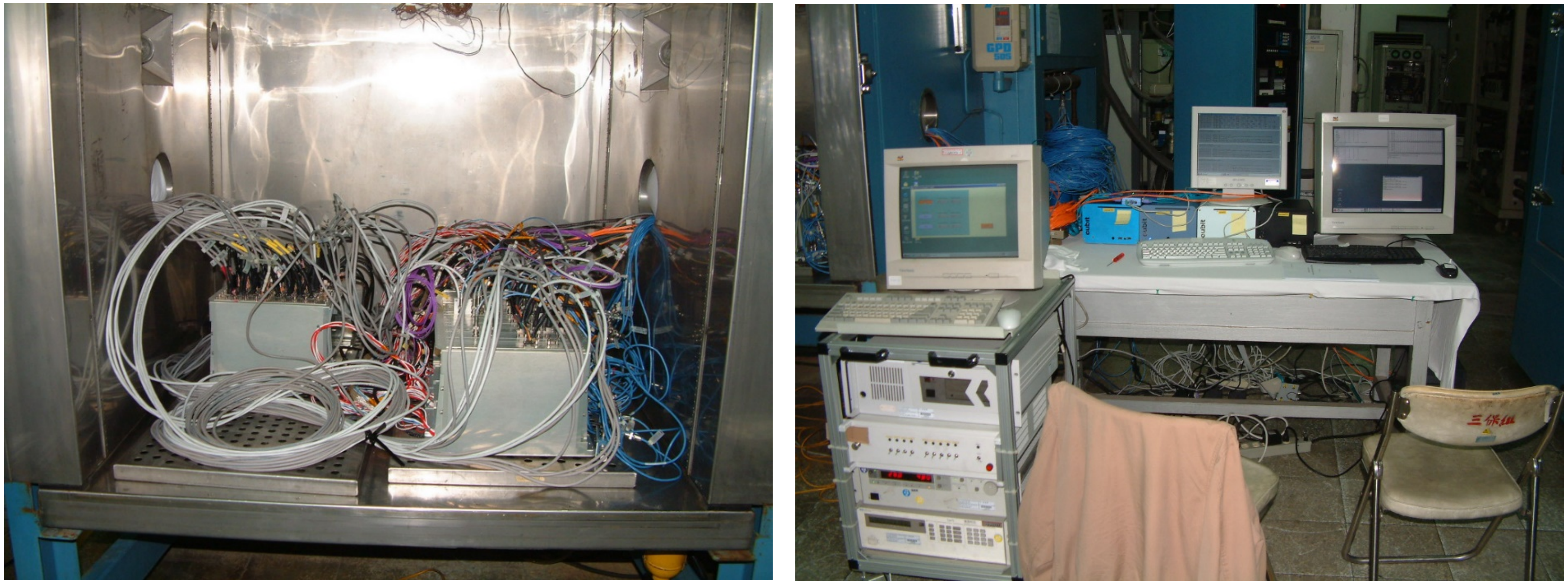
Date: July 9 1997
No: AMS-ESS-TC01

Thermal Cycling Test – System Level

- **Verify its operations under the hot and cold environments.**

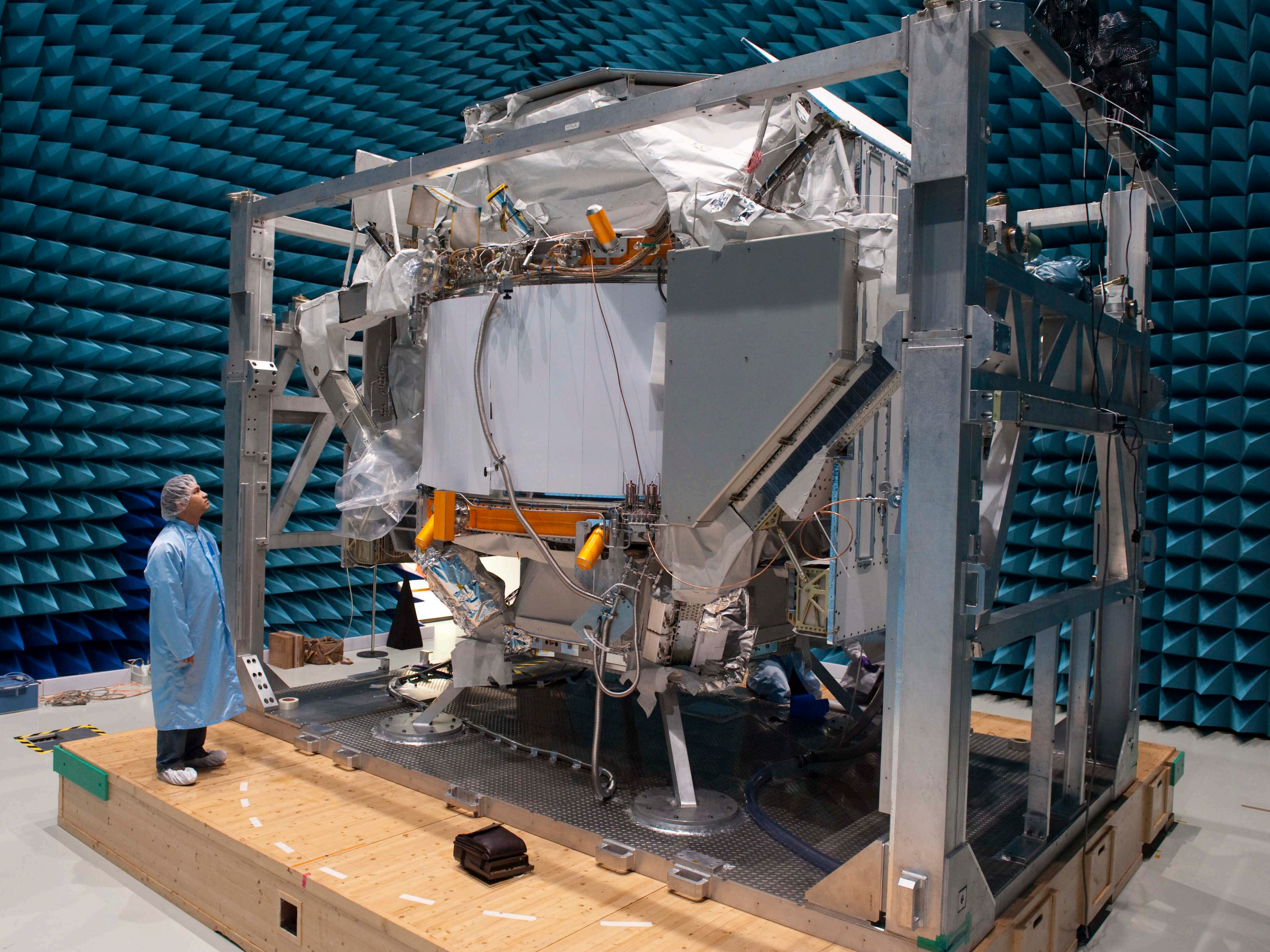


Thermal Cycling Test - AMS J/JT/JPD

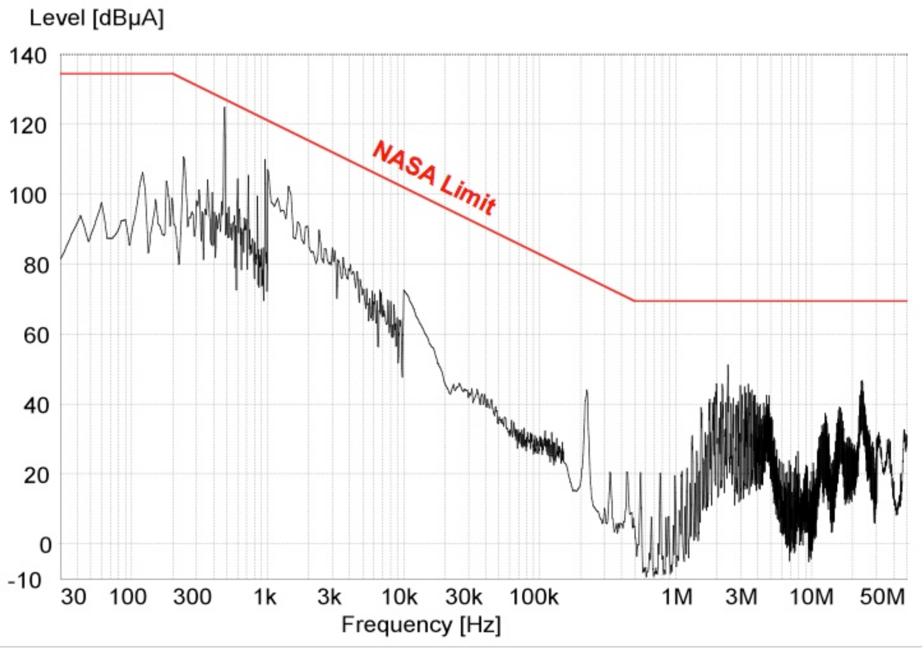


EMI and EMC Tests

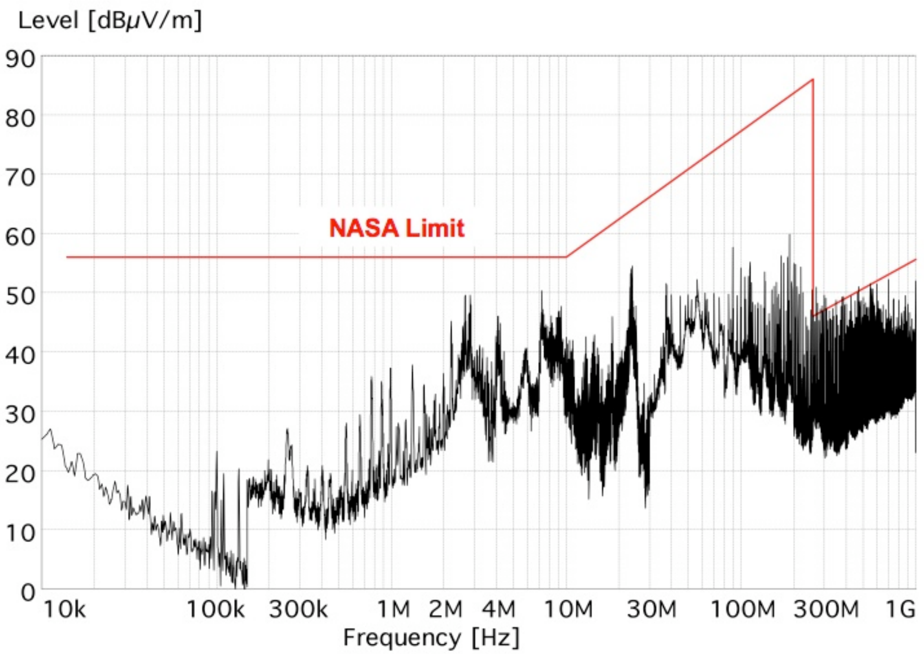
- Follow NASA/ESA/MIL standard
- Conducted emissions and susceptibility (via power line)
- Radiated emissions and susceptibility



AMS EMI/EMC Test



CONDUCTED EMISSION
Frquency domain on Power return line.
AMS in nominal configuration



RADIATED EMISSION Ams POWER On configuration Antenna position 1 Vertical Polarization

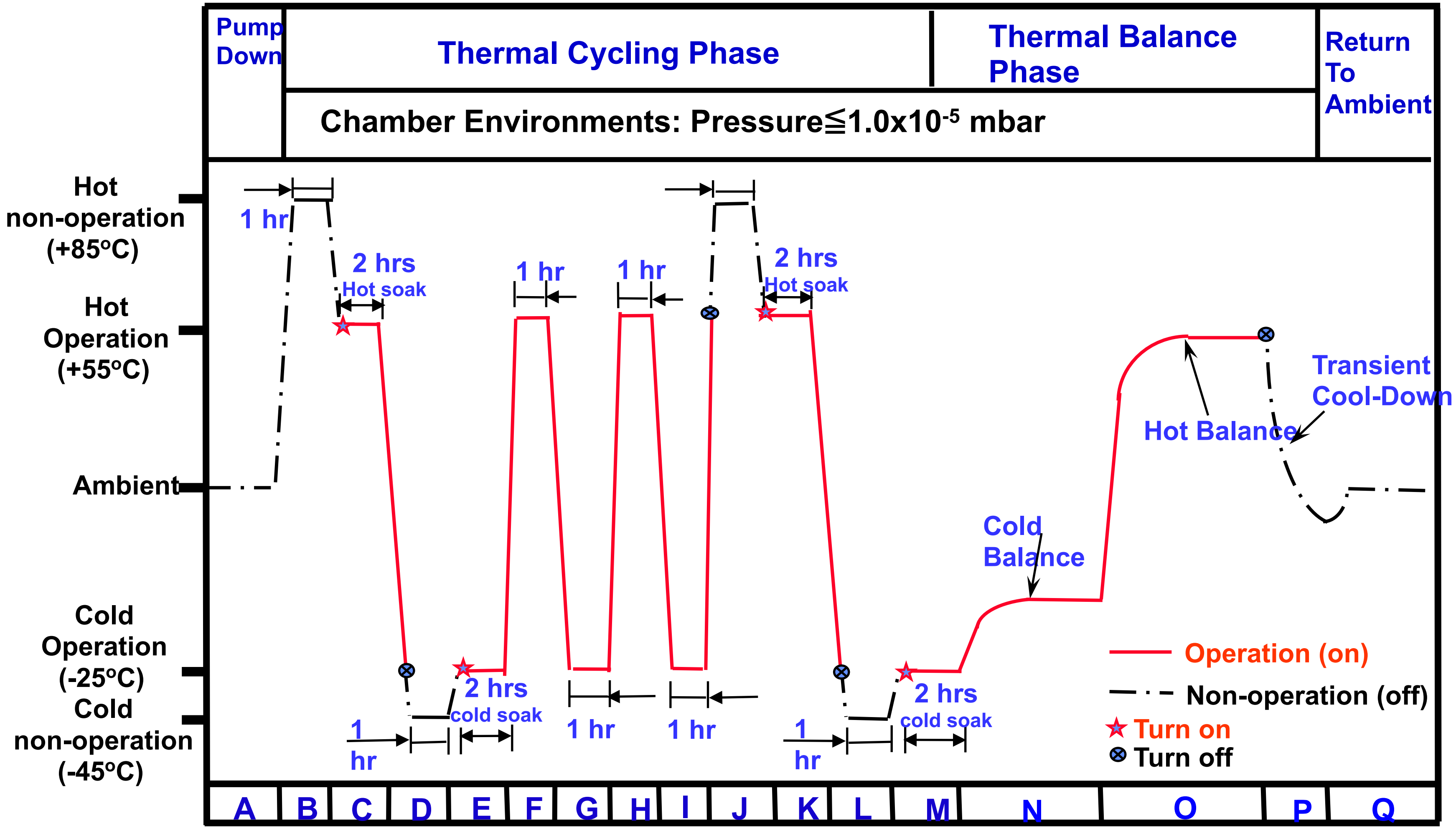
The EMC tests were passed successfully

Thermal Vacuum Test

- **Verify the operation of system under the space environment.**

- **Verify and obtain parameters of thermal models.**

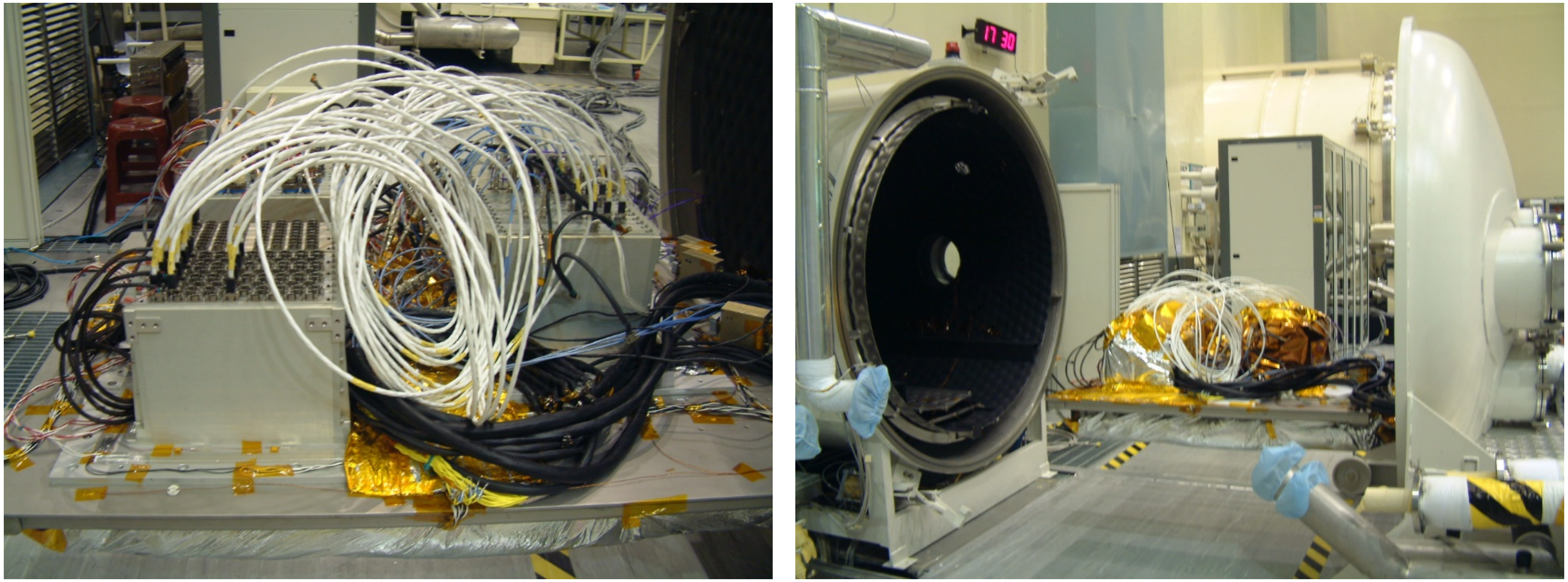
Thermal Vacuum Test - AMS J/JT/JPD

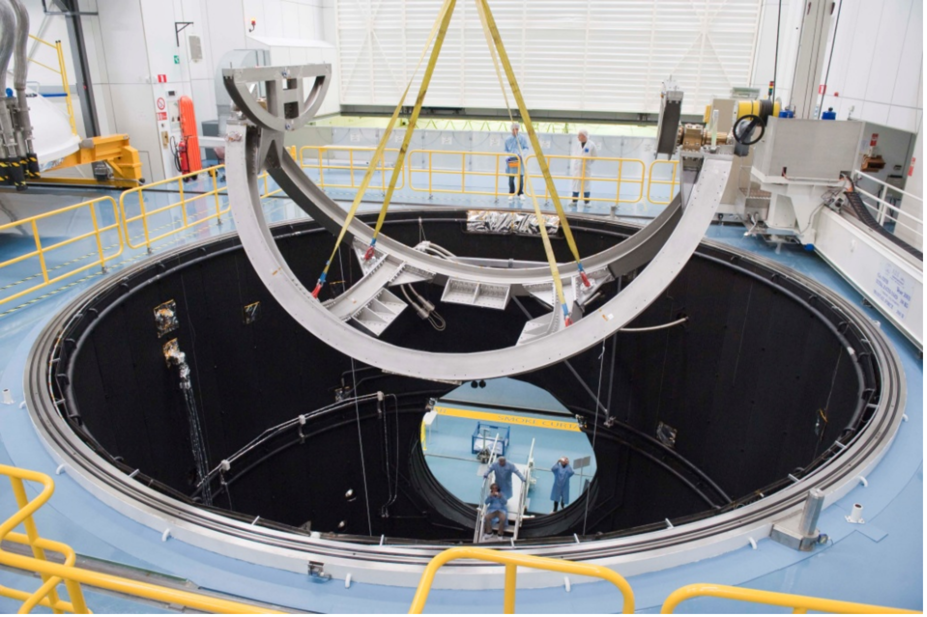


Thermal Vacuum Test – AMS J/JT/JPD

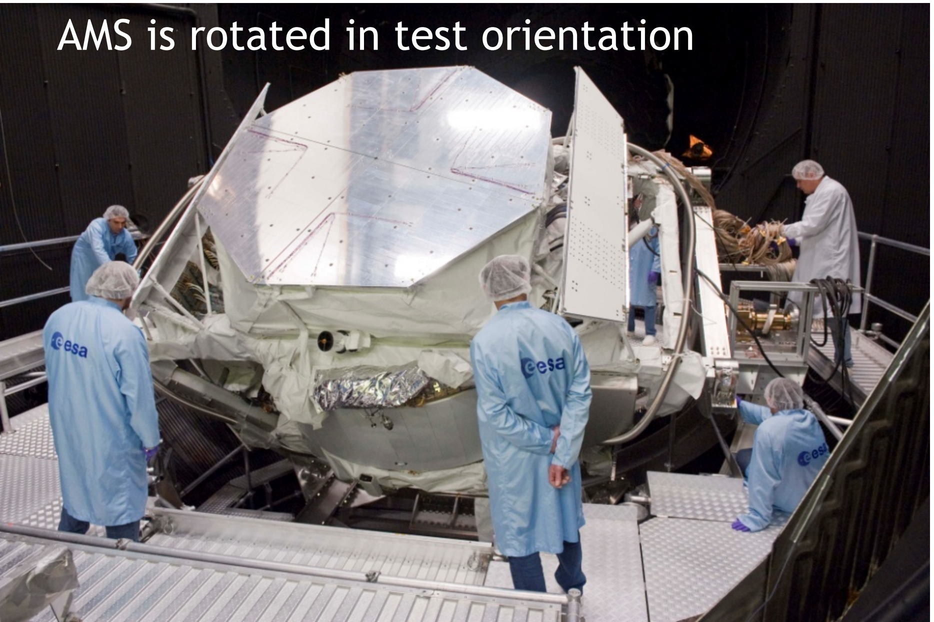

NSPO

Thermal Vacuum Test - AMS J/JT/JPD





Thermal Vacuum Test



AMS is rotated in test orientation

Documentation

- **It is painful but very important.**
- **keep records and traceability**

  ➔ **Key for solutions of issues in flight.**

- **Documents**
  - **Requirements**
  - **Design reports**
  - **Interface control documents**
  - **Mechanical/Thermal analysis reports**
  - **Test plan / procedure / report.**
  - **Assembly plan / procedure / record**