Radiation-induced risks on systems

COMET Workshop, 18 May 2022, Toulouse, France

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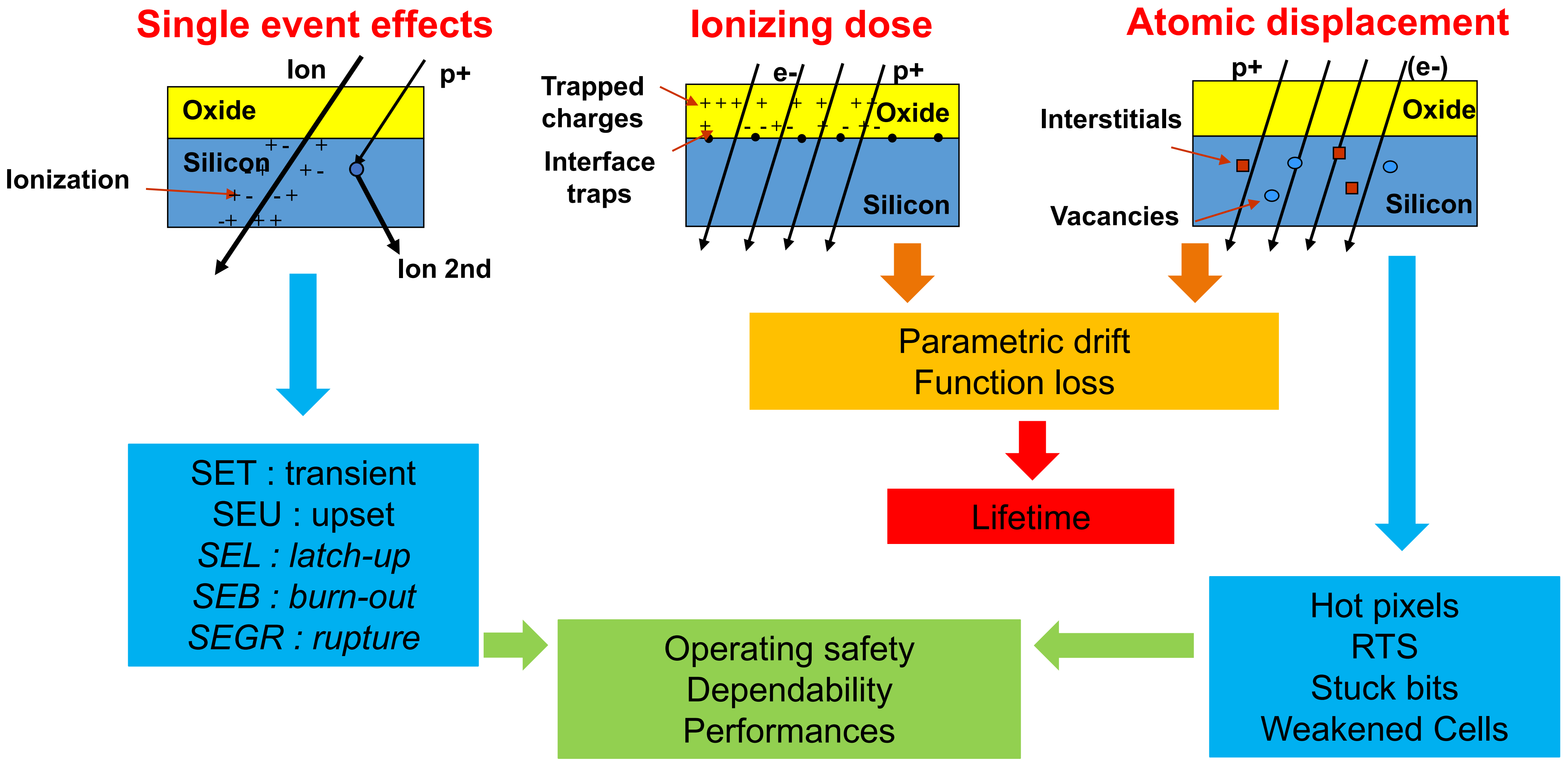
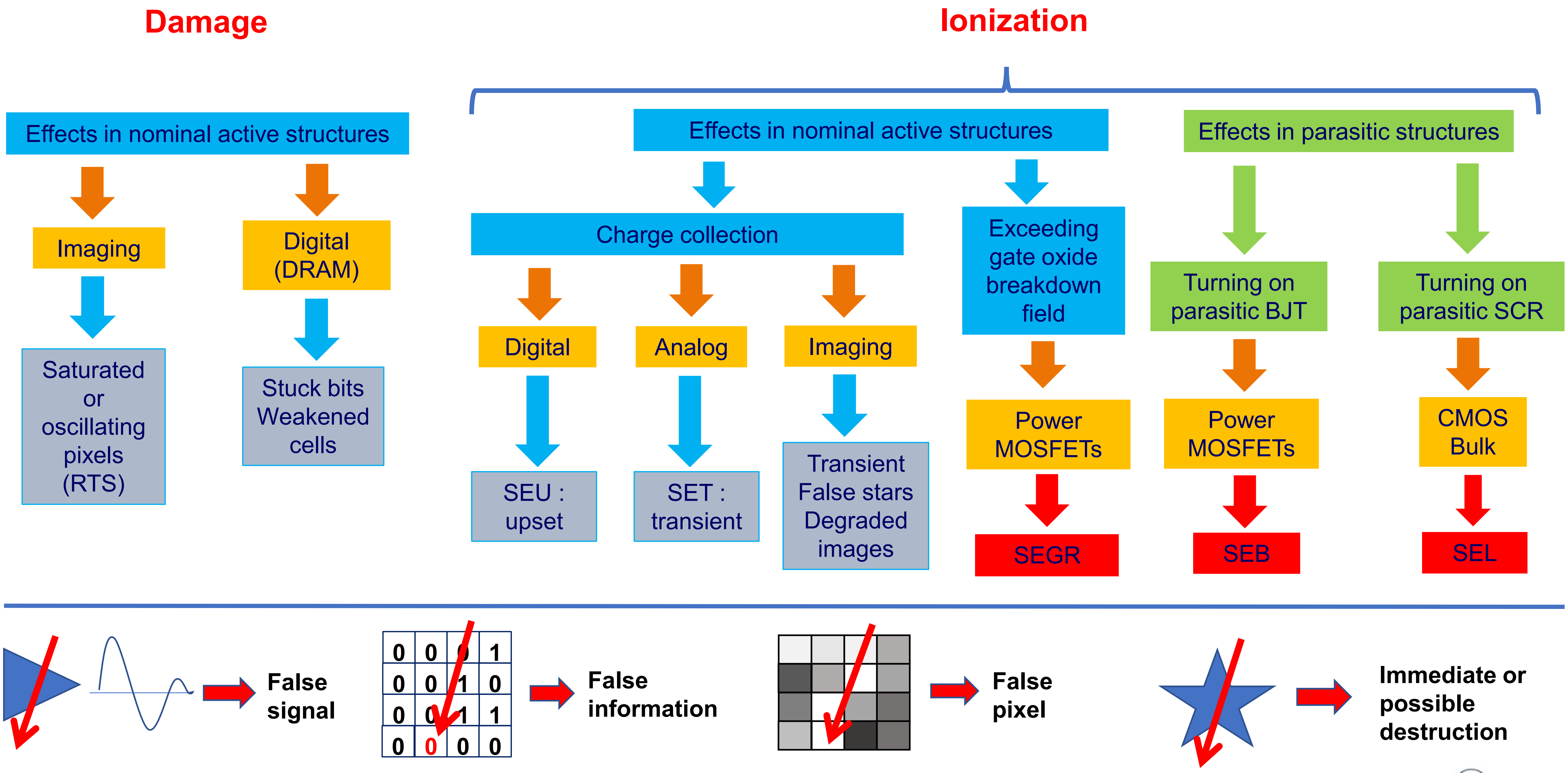
CENTRE NATIONAL D'ÉTUDES SPATIALES

Main radiation effects in electronic components

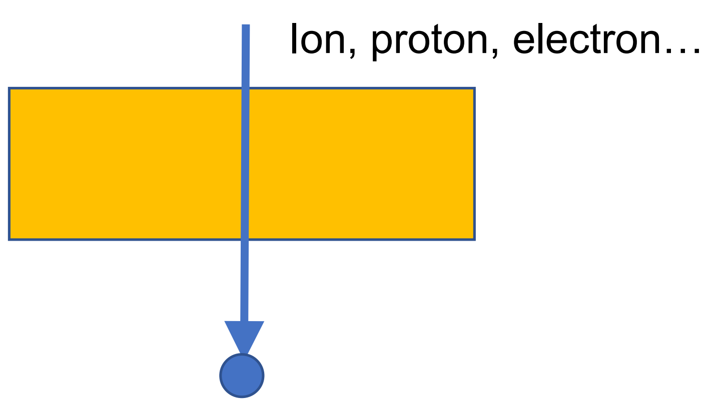


Single event effect categories



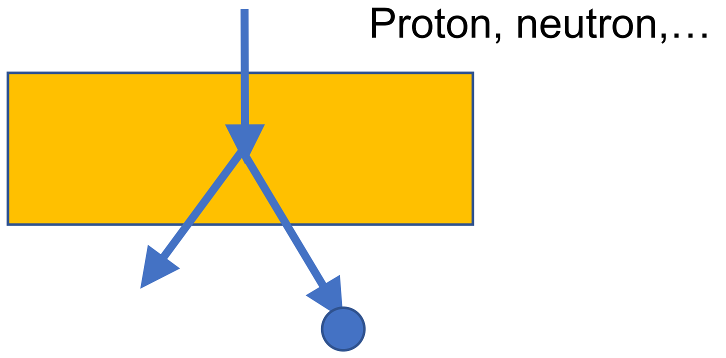
Two possible mechanisms

Direct ionization



The incident particle has enough LET to deposit a charge Q > critical charge Qc
Quantity of interest is the LET (Linear Energy Transfer, **$1/\rho$ dE/dx**) of the incident ion

Indirect ionization

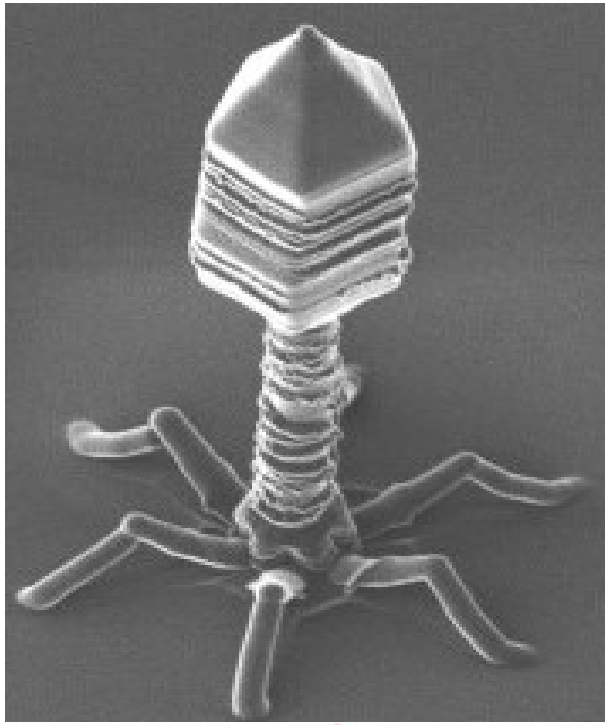


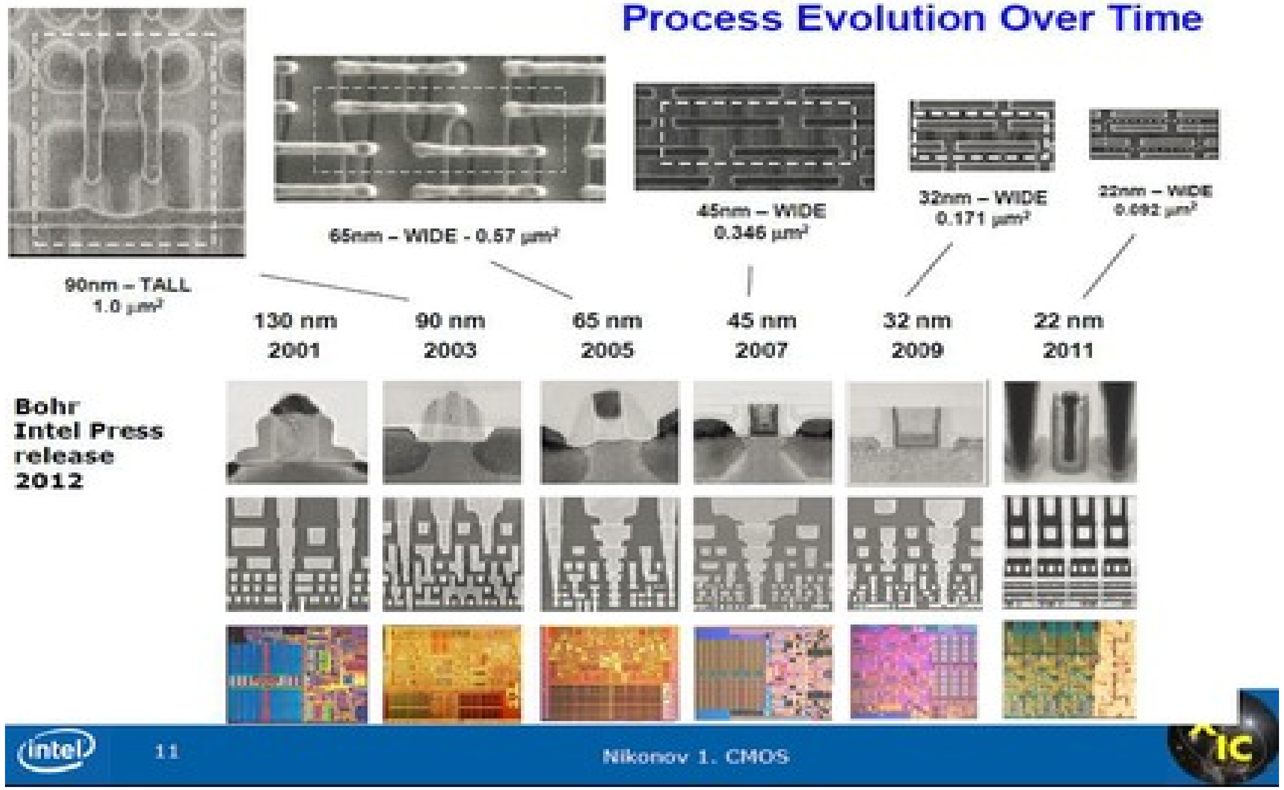
The incident particle induces a nuclear reaction. The secondary particle or particles have enough LET for Q > Qc
Can be assimilated to an ion source within the component
Quantity of interest is the **energy** of the incident proton

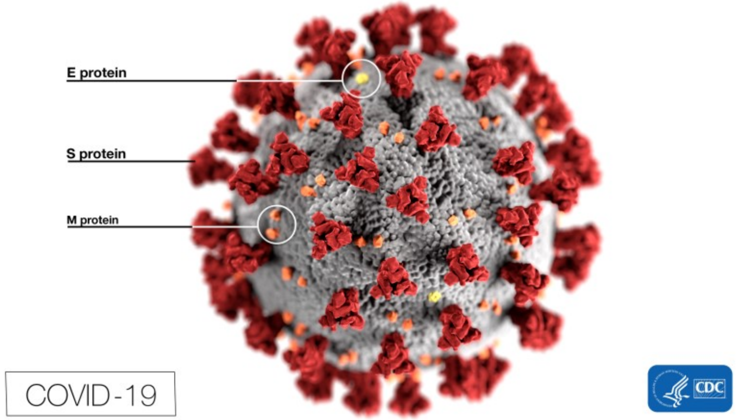
Sensitivity is defined as a cross section σ = Number of events / Particle fluence per cm²
σ is homogenous to a surface and expressed in cm²
SEE sensitivity (cross-section) is a threshold – saturation curve (less true for SETs)

Compared dimensions

About the same scale of structuration than elementary living matter

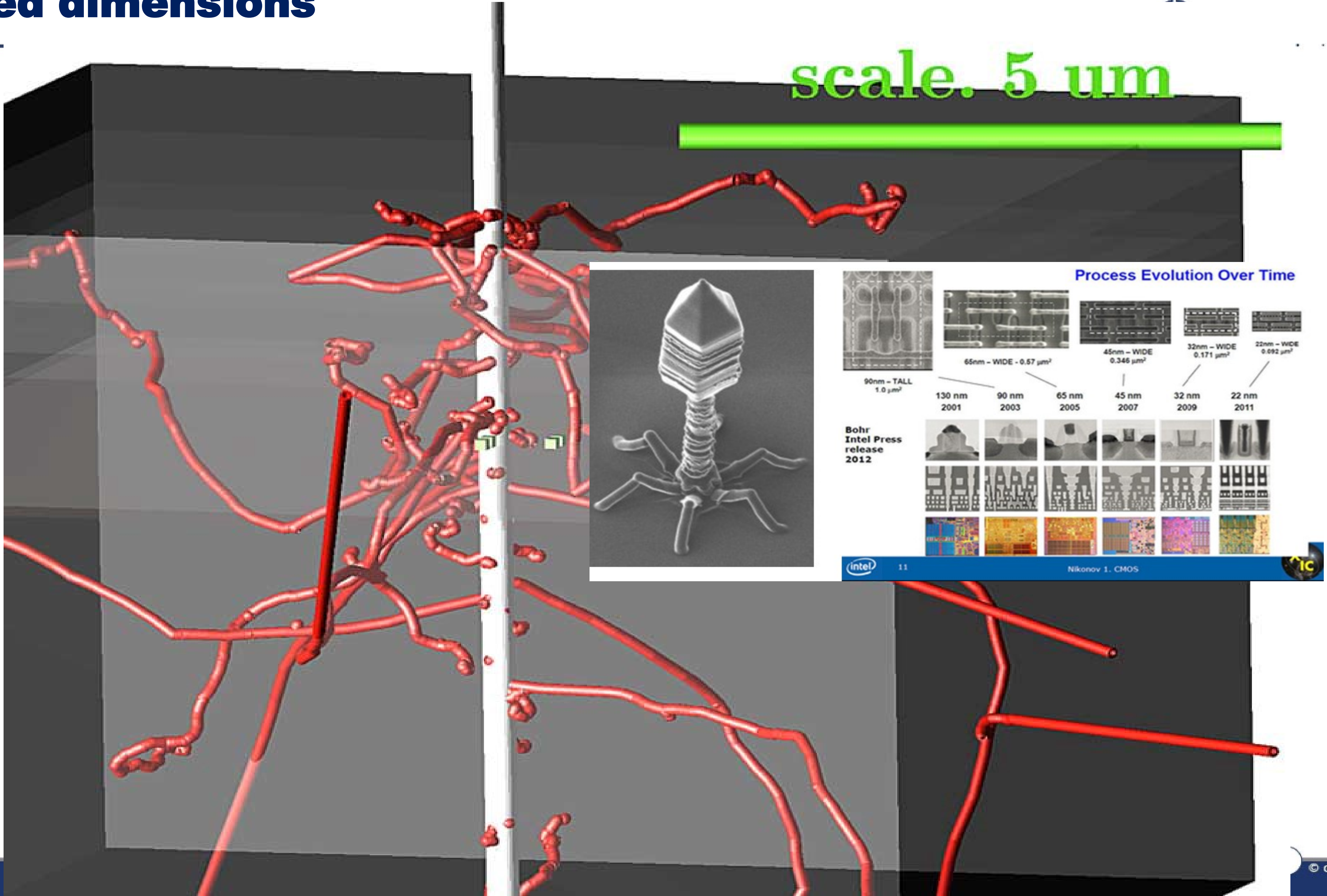






The bacteriophage virus is about 200 nm tall and 65 nm wide. CoVid-19 about 125 nm.

Compared dimensions



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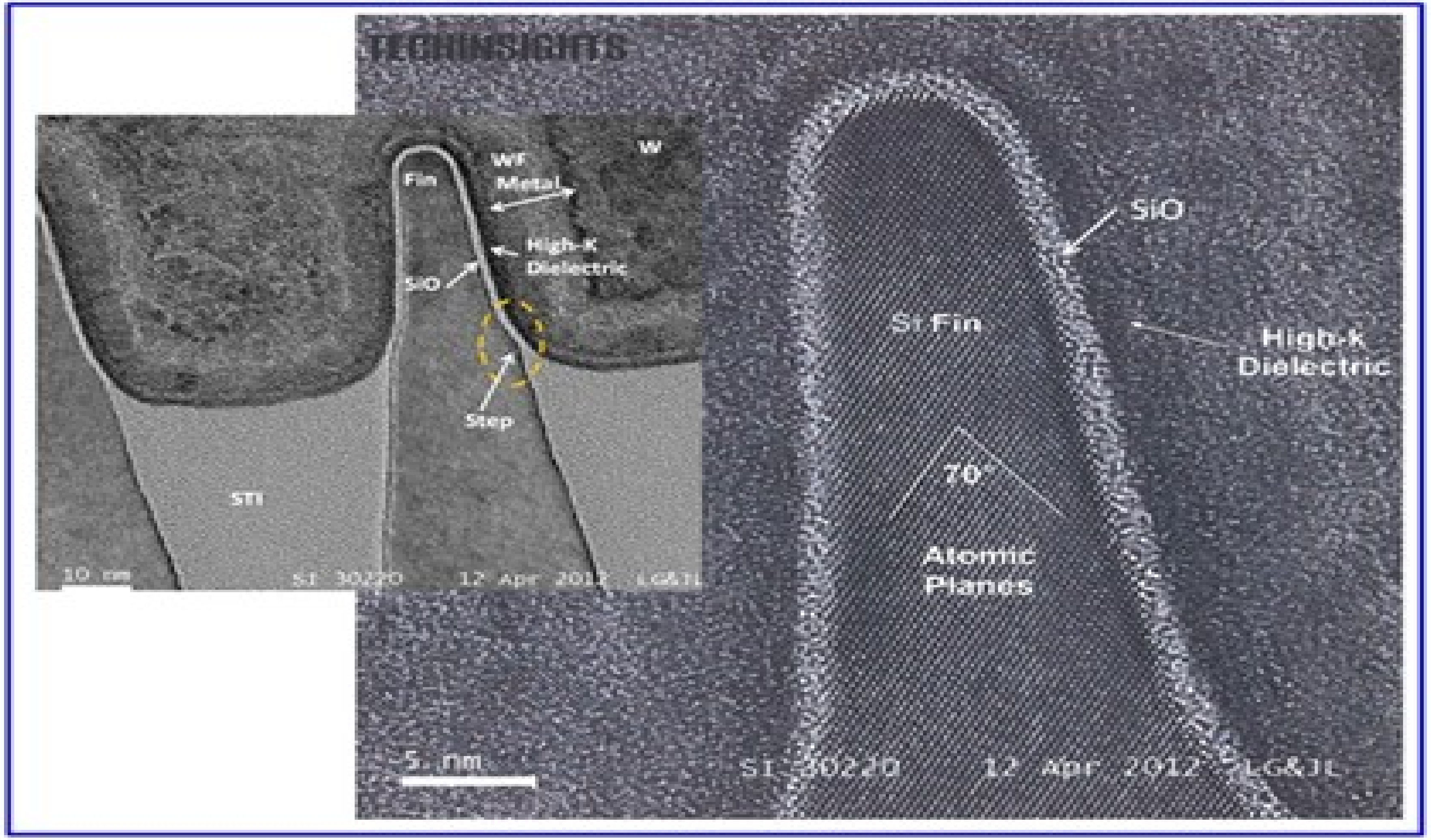
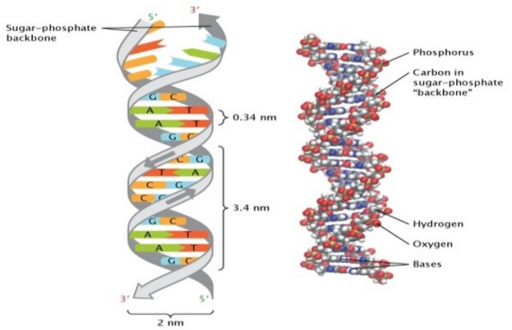
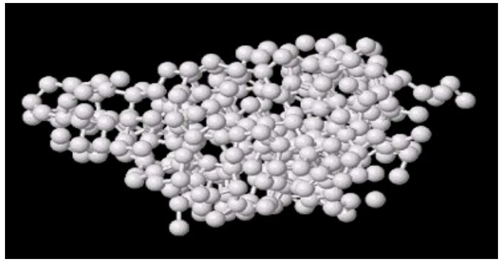


Width of DNA helix ~2 nm

www.nature.com





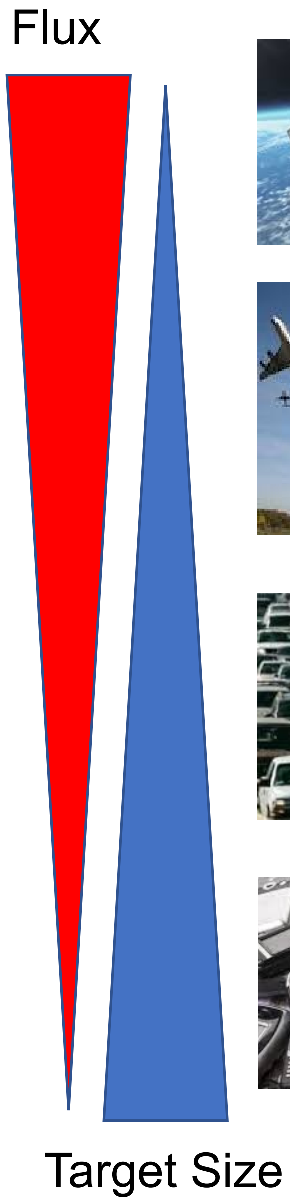
Defects cluster

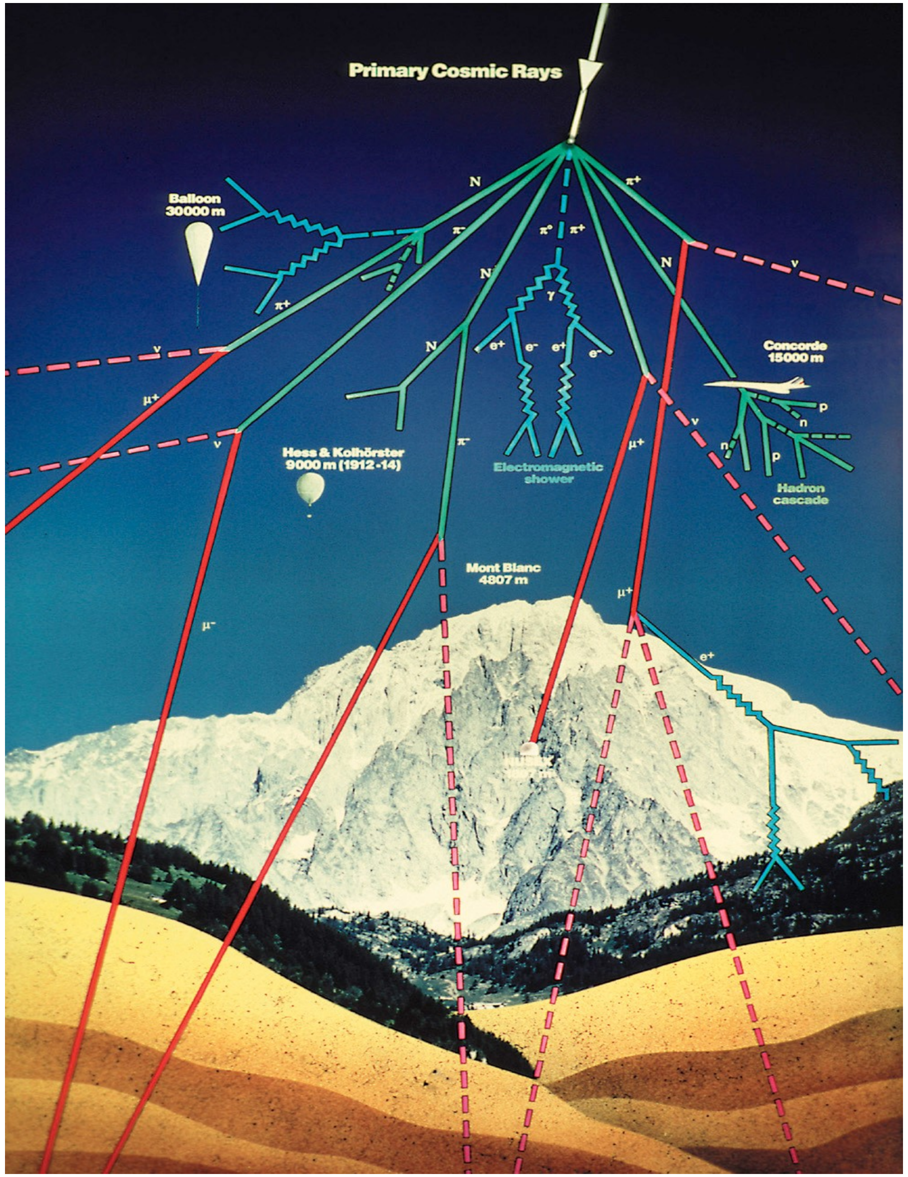
http://www.edn.com/Home/PrintView?contentItemId=4395587 Intel 22 nm node gate fin

Risks can show up from space to ground

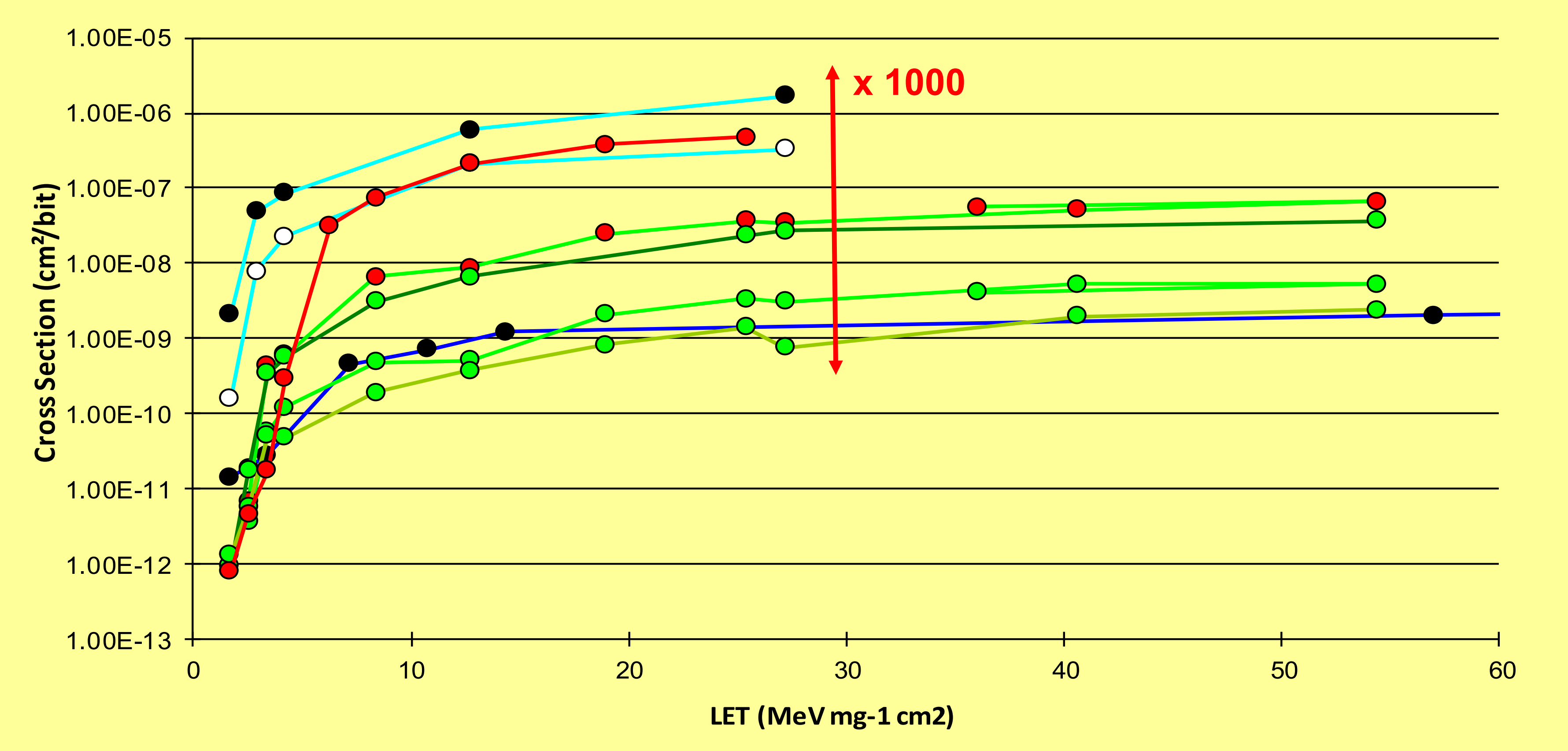
Today, **from space to ground**, almost **any particle type** (ion, proton, neutron, pion, muon, electron,…) can possibly induce single event effects and eventually local damage

Much lower fluxes
… but much larger targets
~3000 active satellites
~8000 planes in flight
~350000 trains
~3 million pacemakers
~5 million drones
~1 billion cars
~15 billion cell phones
~75 zettabytes (= 75 x 8 x 10^{21} bits)
(source : Google)





Compared SEU sensitivities

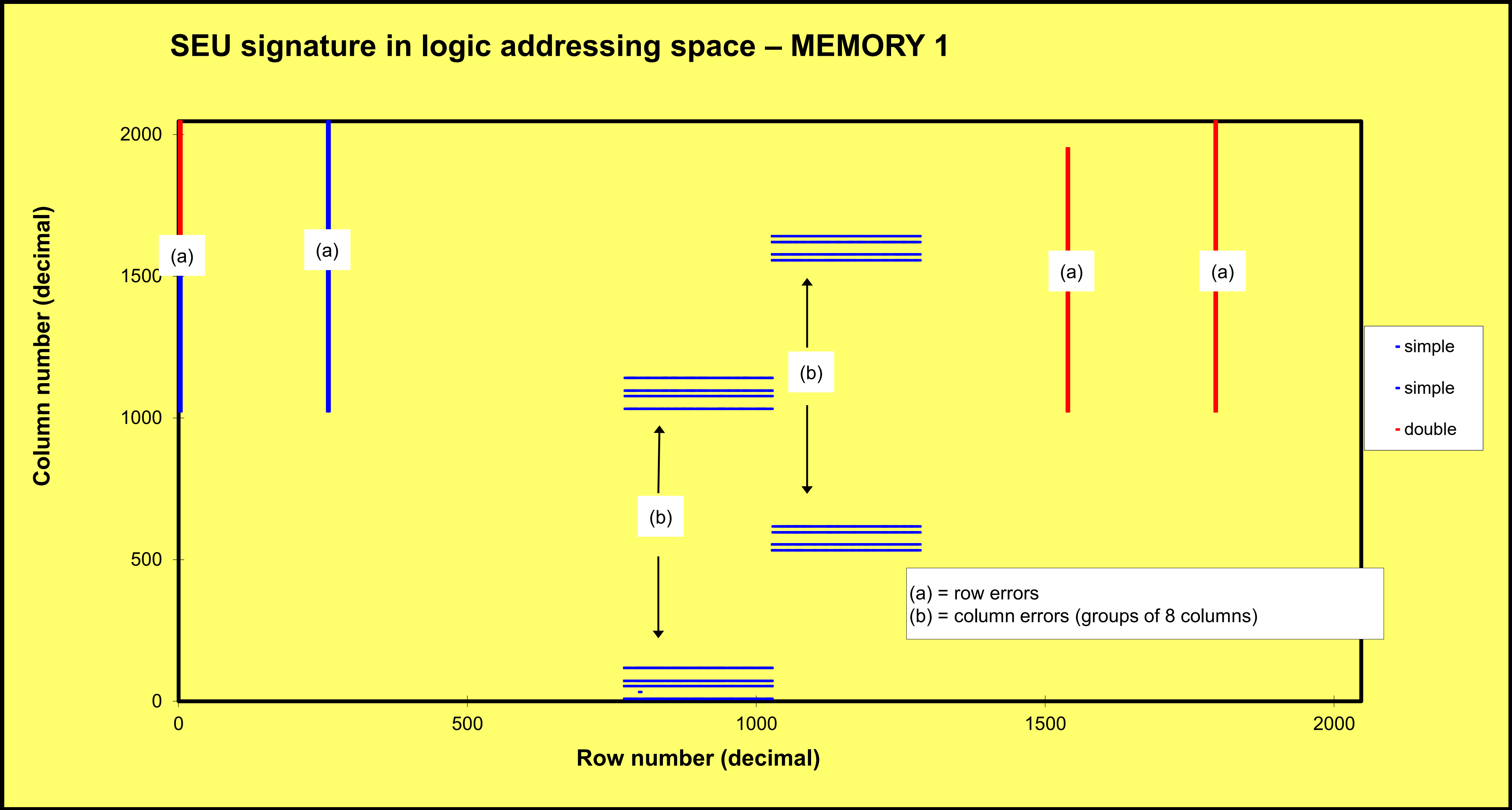


No standard behaviour within a technology “generation” or “node”

No scaling factor between generations

Complex error signatures

Compared SEU sensitivities



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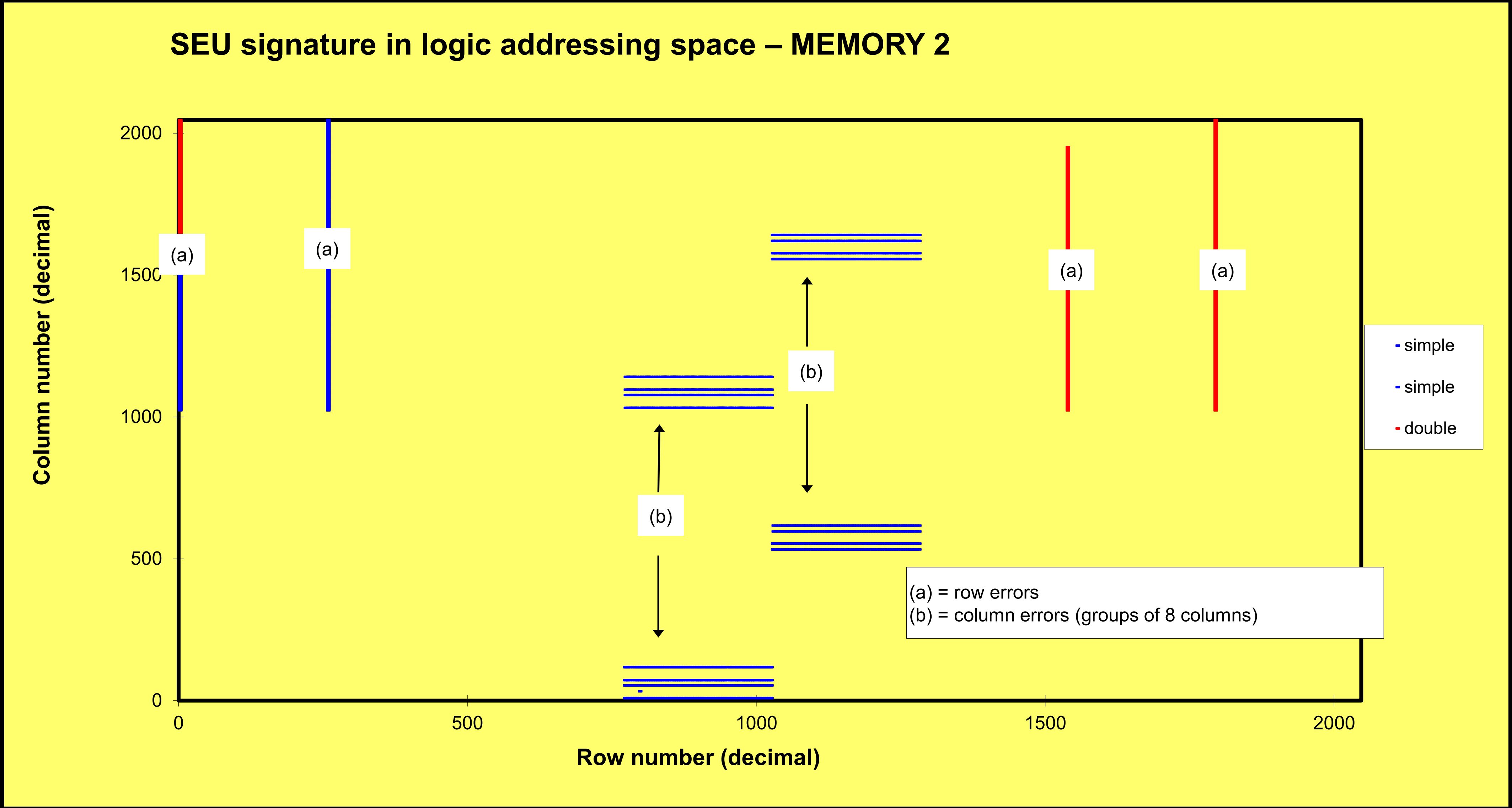
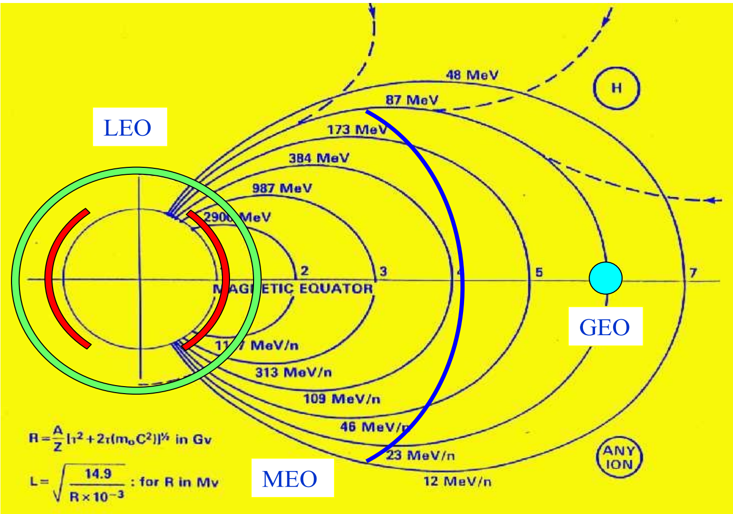
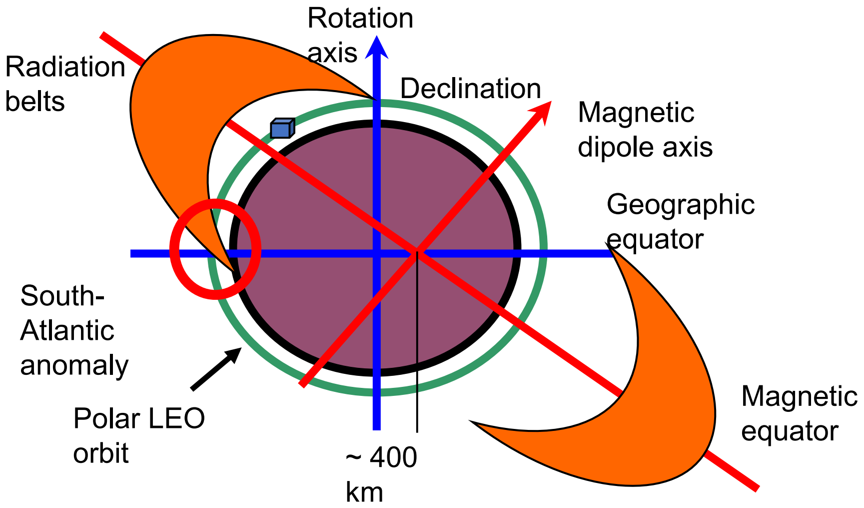
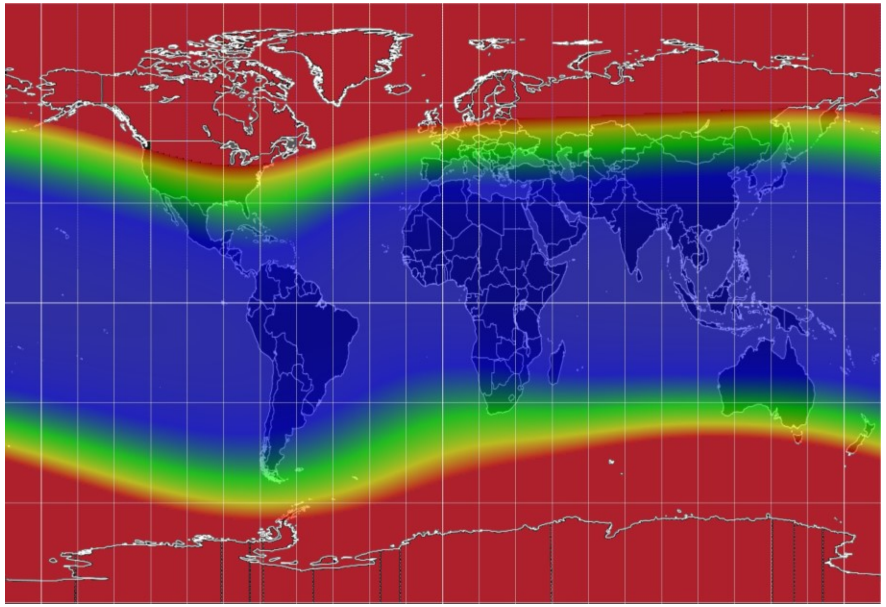
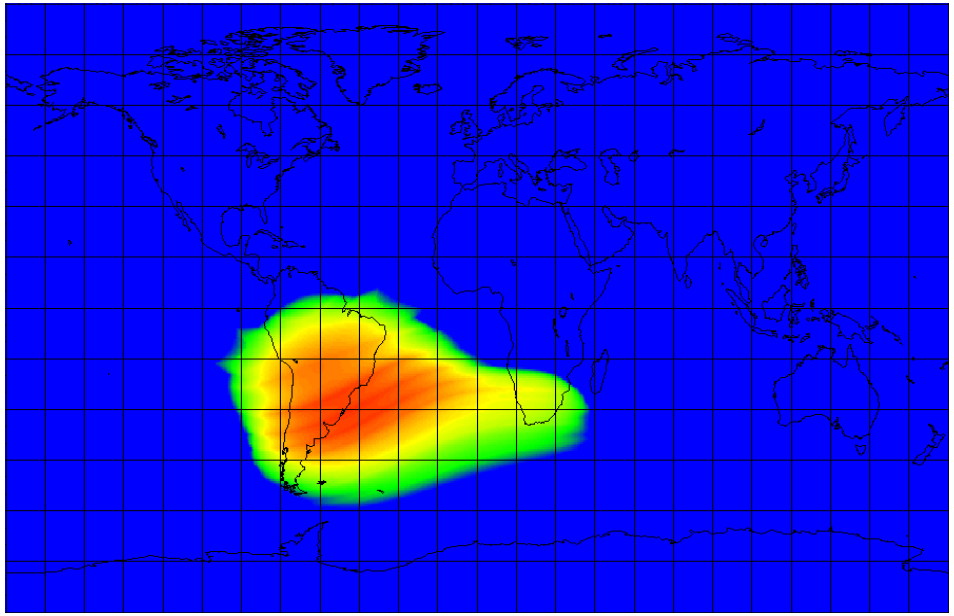


Hazard zones in low Earth orbit



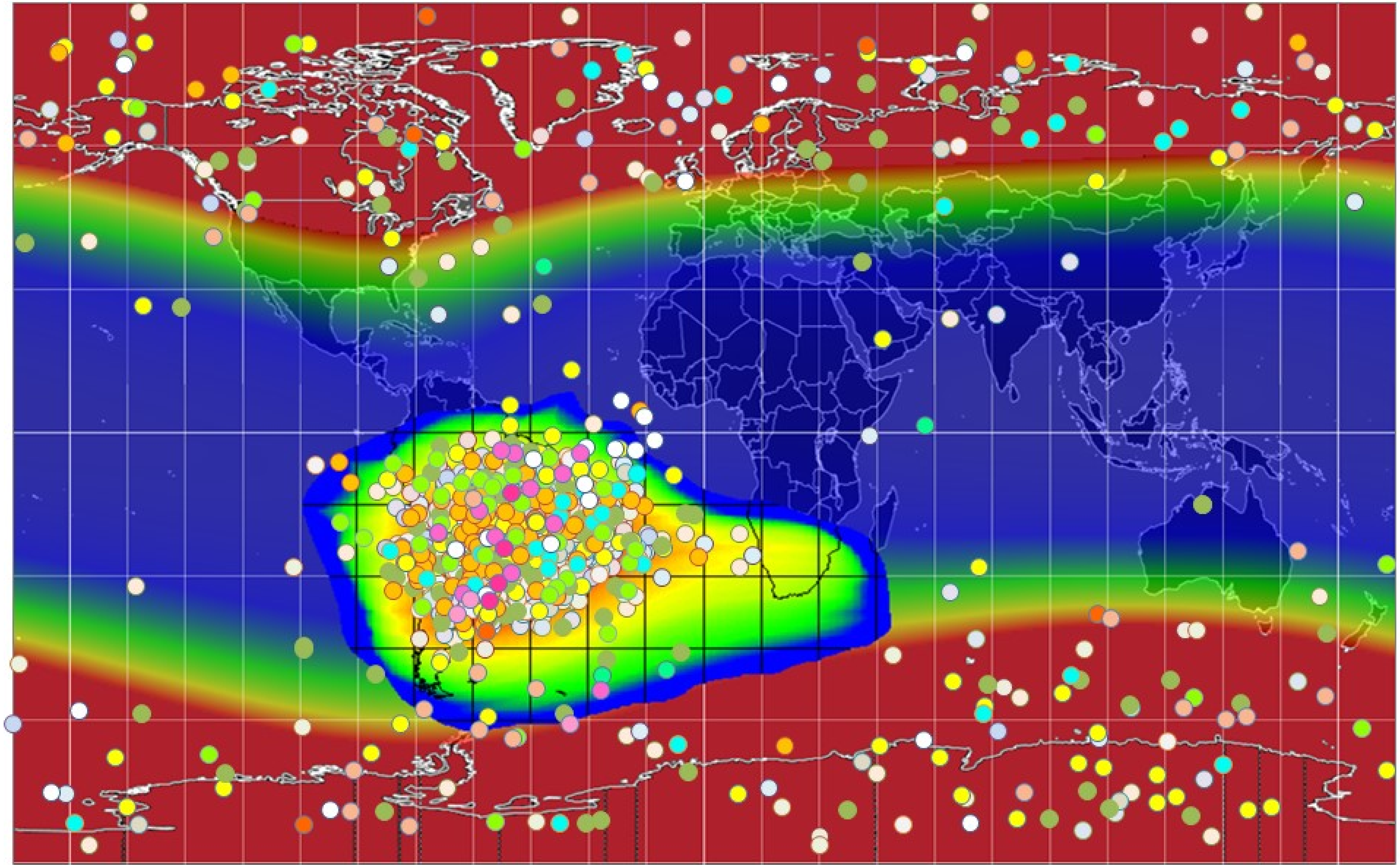






OMERE plots

Low Earth orbit in-flight feedback



System resilience

System design

Effect on individual component

X

Transfer function

Y = f (X)

Effect on system

Y

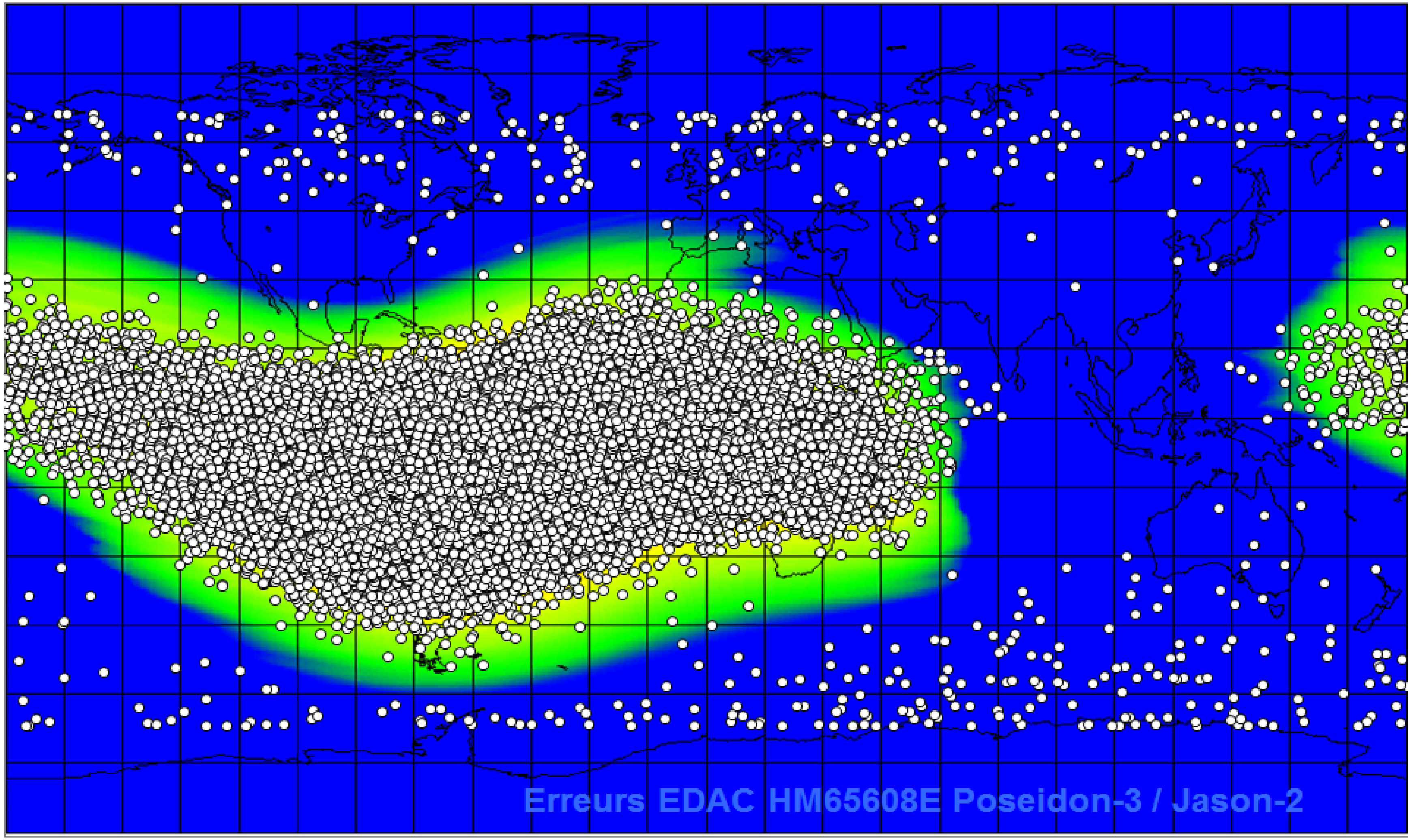
Perfect design : f = 0
Bad design : f = 1

f : availability function (performance, cost)

Expected and unexpected (true) “anomalies”

- If system availability specification is, say, 99% of the time
- System design guarantees 99,8 % → specification is made, designers did a good job
- But the 0.2% remaining is the concern for the spacecraft operator → for them, this is an “anomaly”
- “True” anomalies are surprises, they were not expected when design was made

Robust system design

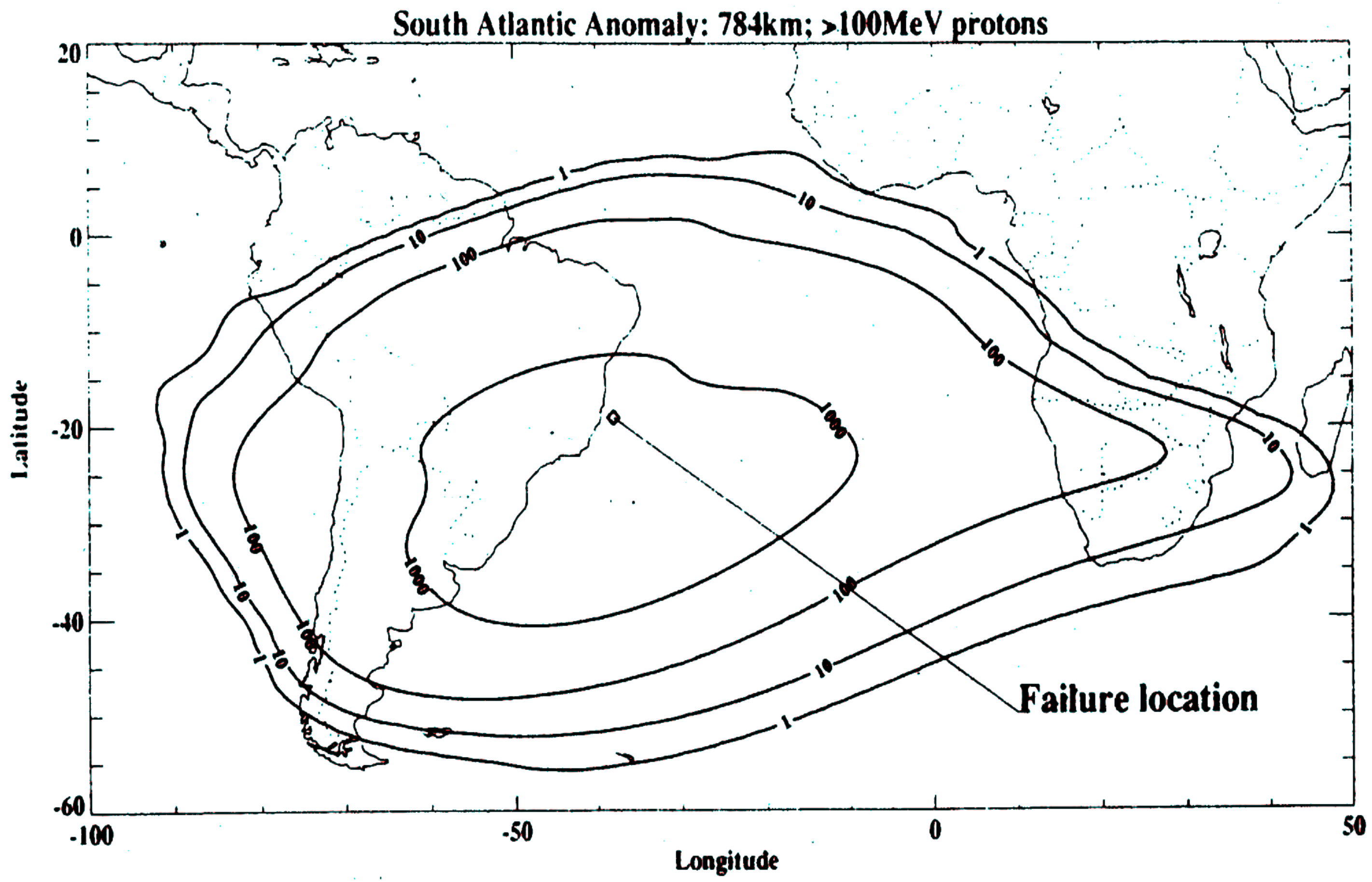


Memory errors as recorded by EDAC (error detection and correction) of the Poseidon-3 / Jason-2 Altimeter (Thales Alenia Space)

More than 100000 bit changes (upsets) !

None of these events had any impact on the altimeter's performance and availability

Poor system design



Complete loss of the PRARE altimeter on ERS-1 in 1991 after only 7 days of mission due to a destructive latch-up (short-circuit condition) on a static memory

Rate of potentially destructive events as measured in flight on commercial components chosen and operated without precautions, from CNES technological missions “CARMEN” :

Altimetry and telecom constellations (1200 – 1400 km range)
1 per day

Earth observation, telecom, science (600 - 800 km range)
1 par week

Classical SEE system effects

Memory corruption : single errors to error bursts

Functional interruption

Processor crash

Disjunction

Redundancy triggering

Mode swapping

Reset

ADC conversion errors

ADC swapping to auto-calibration mode

Gain change

Reference voltage change

Transient PLL lock loss

False signals

Star pattern loss

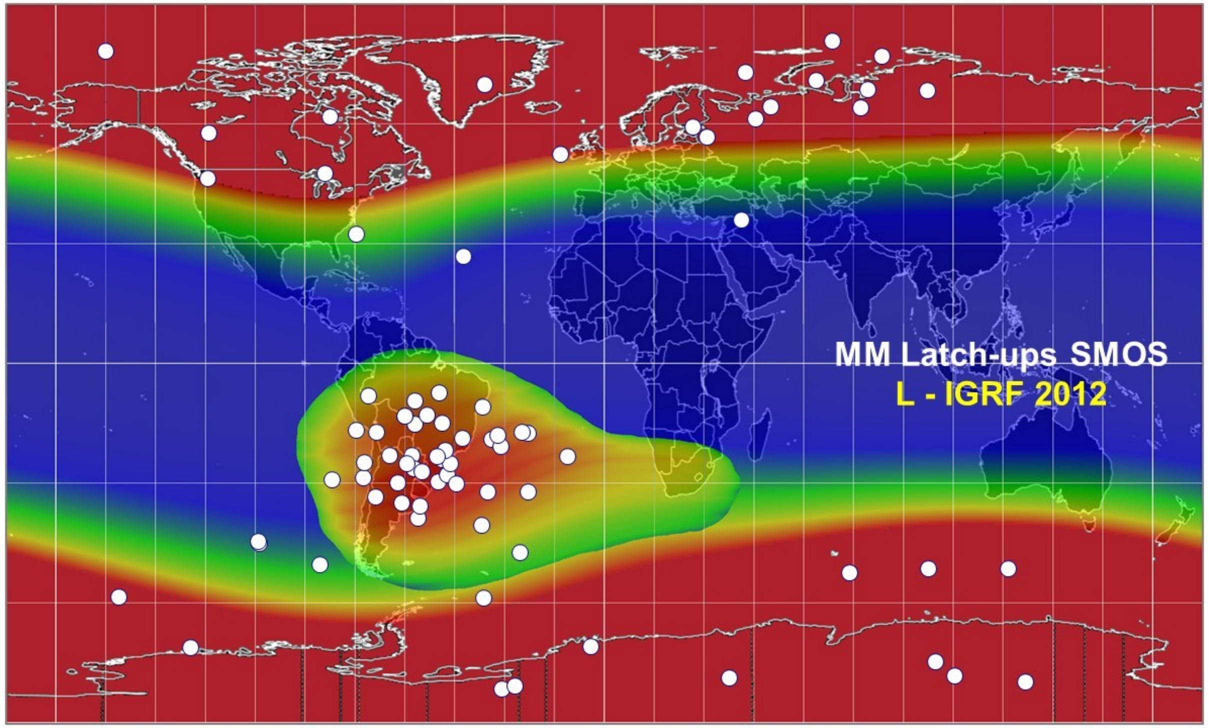
Image corruption …….

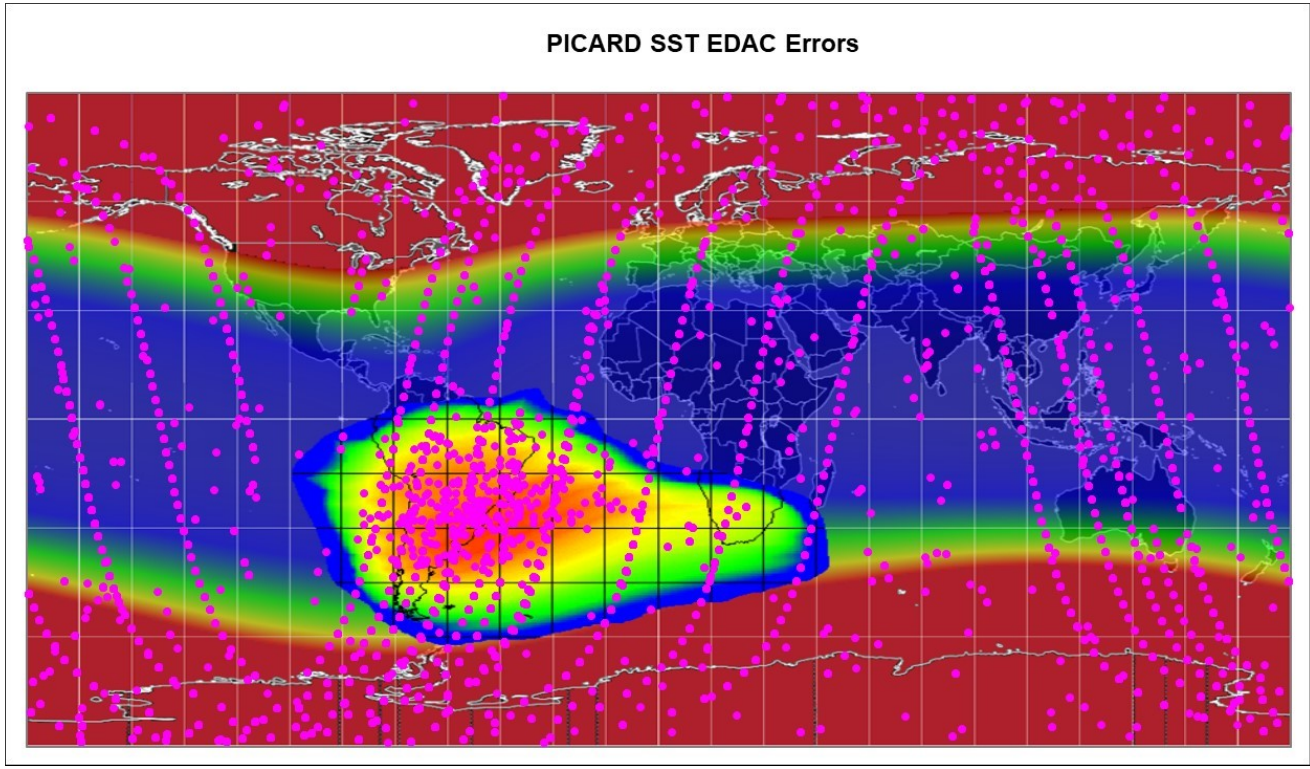
Equipment loss

Single event effects mitigation

- Transients (SET)
  - RC filters, avoid common modes, analog design
- Upsets (SEU)
  - EDAC, triplication & voting, etc….
- Latch-up (SEL)
  - De-latching : current limitation, cut power supply off (50, 100 ms)
  - Beware of validation
- FDIR (Fault Detection Isolation Reconfiguration)
  - In case of functional interrupt, always being able to reset or reboot
- Burn-out (SEB)
  - De-rating
- Gate rupture (SEGR)
  - De-rating

Beware of a priori mitigation





Conclusion : radiation hardness assurance

To guarantee the radiation survivability of on-board systems

Radiation have an effect on **components** (electronic, optoelec,…)

But the problem shows up and is solved at **system level** (performances, dependability, lifetime)

The associated tasks should accompany project design **from phase 0 to phase C/D** (radiation engineering) and even **phase E** (exploitation)

This end-to-end approach is called **radiation hardness assurance (RHA)**