

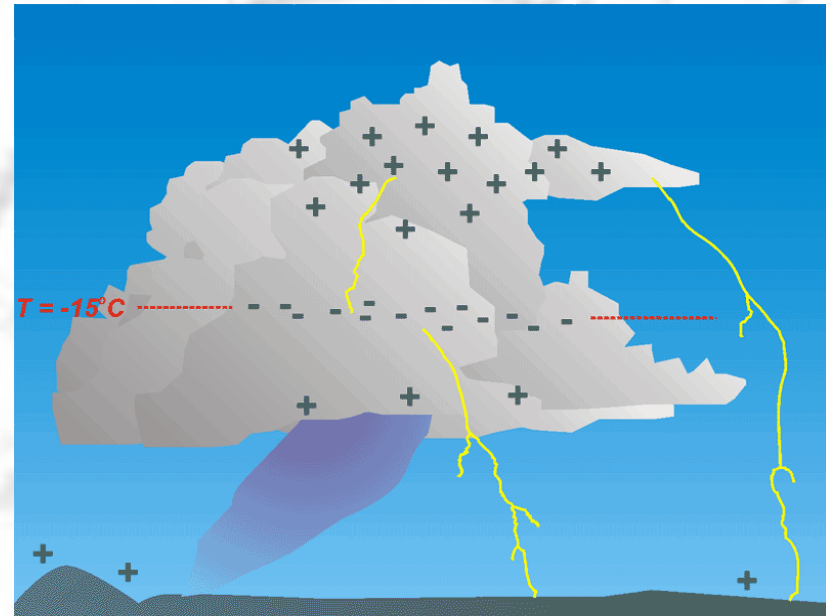


12th AGILE Science Workshop
**"ASTRO-EARTH: ASTROPHYSICS AND HIGH-ENERGY
TERRESTRIAL PHENOMENA"**
May 8-9, 2014, aula "Cassini", ASI Headquarters (Tor Vergata)

**Potential TGF impact on
on-board electronics**

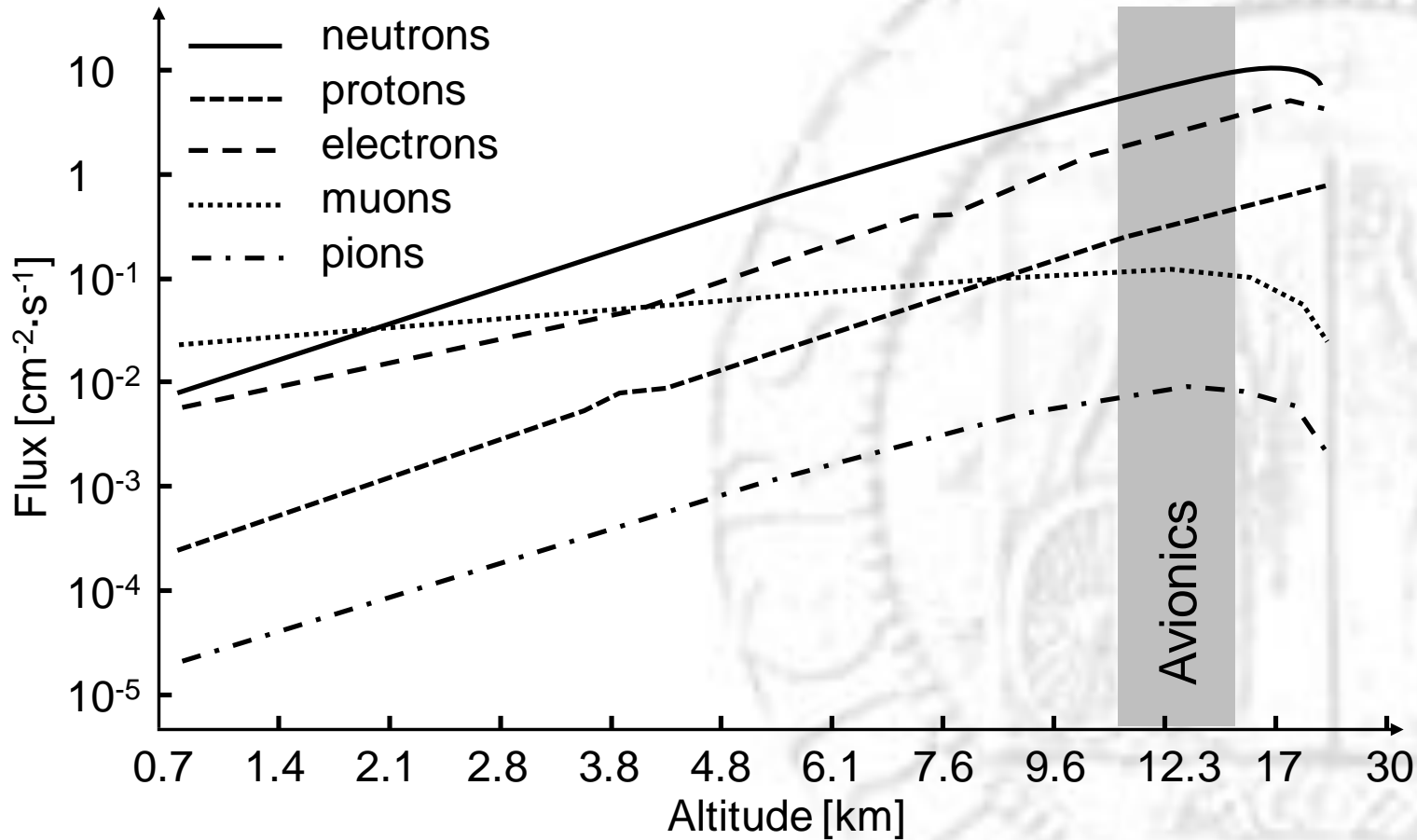
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- Thunderclouds and lightnings are powerful **particle accelerators**, generating very high-energy **electrons, positrons, X rays, and gamma rays**
- ❖ TGFs & large fluxes of high-energy radiation at about the same altitudes of commercial aircraft
(Dwyer et al., J. Geophys. Res., 2010; Tavani et al, Nat. Haz. Earth System Sci, 2013)
 - **Radiation effects on on-board electronics?**



Cartoon: Canadian Forest Service

- **Primary electrons/positrons and gamma rays** interact with the aircraft structure and are partially **attenuated and reprocessed by Al, C**, and other heavier elements contained in the aircraft
- A flux of secondary particles and gamma rays propagates inside the aircraft with two main components, whose intensities can be **much higher than the background radiation levels** naturally encountered at avionic altitudes:
 - **an electromagnetic component** (electrons/positrons and gamma rays)
 - **a neutron component** produced by photo-production processes



At avionics altitudes:

- Neutron flux is 300x compared to sea level
- **On-board electronic critical systems must not be affected!**

- **High energy neutrons** (cosmic ray byproducts, $E > 1-10$ MeV)
 - Indirect interaction through elastic or inelastic nuclear reactions, with generation of recoil nuclei (typically Si) or reaction fragments with high LET
- **Low energy neutrons** (thermal)
 - Indirect interaction via the $^{10}\text{B}(n, \alpha)^7\text{Li}$ nuclear reaction
- **Alpha particles** *from radioactive decay of contaminants (from U, Th decay chains) in the chip/package/solder*
 - *Short range in Si, small LET, direct interaction*
- **Muons**: *a possible concern for future technological generations*

➤ Total Ionizing Dose

- affects **dielectric layers** (e.g., gate, isolation, and passivation oxides)
- causes **threshold shifts** in transistors/device parameters
- **cumulative**, usually reported as a function of **ionizing dose**

➤ Dose Rate

- affects **semiconductor material** (e.g., bulk Silicon)
- causes **radiation hardening**
- **transient**

➤ Displacement Damage

Terrestrial effects

- affects **semiconductors** (e.g. crystalline Silicon)
- depends on **ionizing energy loss (NIEL)**
- **cumulative**, usually reported as a function of equivalent neutron fluence or displacement dose

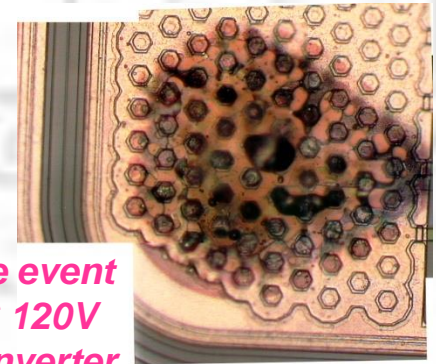
➤ Single Event Effects

- **stochastic effects**: caused by a single particle impinging randomly on a sensitive device volume
- cause a variety of different effects, **memory corruption, burn-out**, etc.



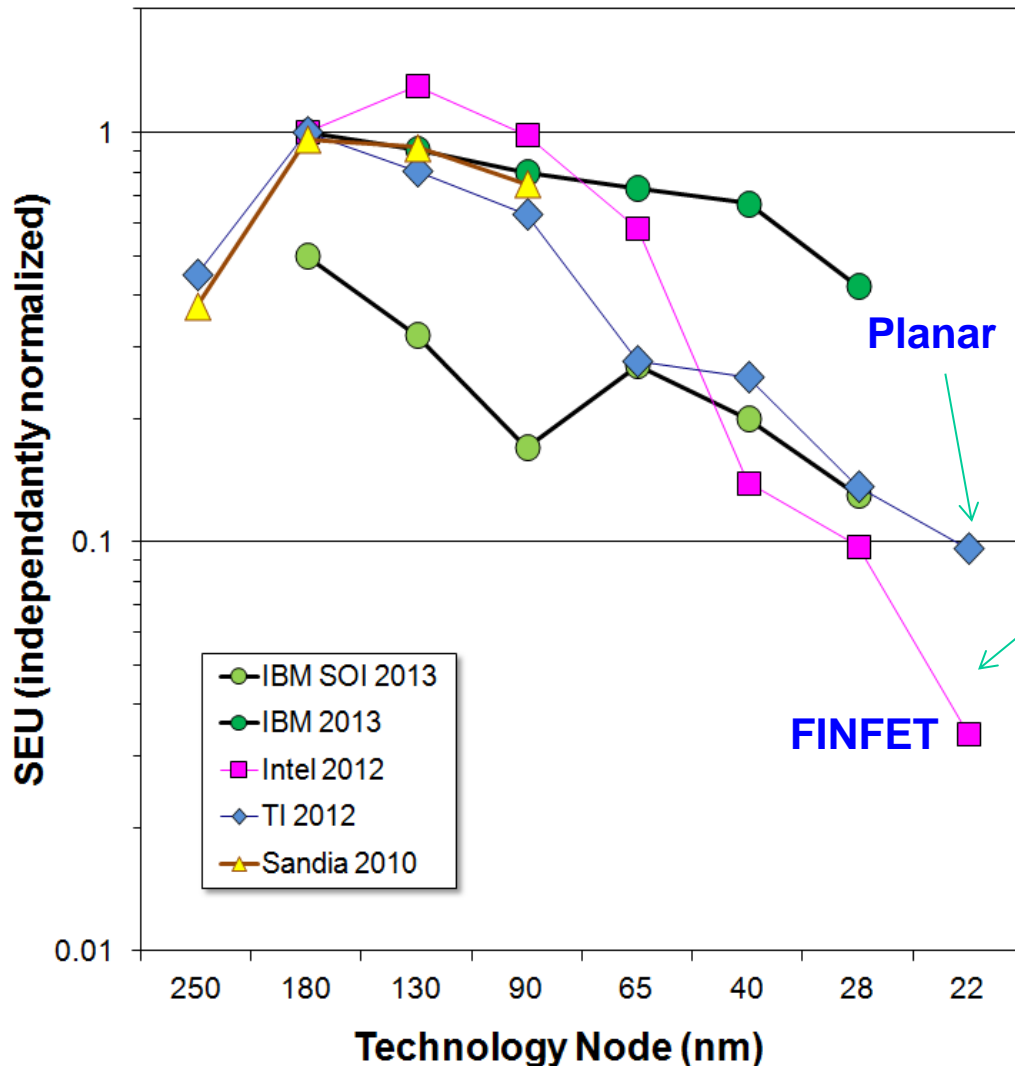
- **Non-destructive (soft errors):**
 - Single Event Transient (SET)
 - Single Event Upset (SEU)
 - Single Bit Upset (SBU)
 - Multiple Bit Upset (MBU)
 - Single Event Functional Interruption (SEFI)
 - Single Event Latchup (SEL or SELU)... *may be also destructive*
- **Destructive (hard errors):**
 - Single Event Burnout (SEB)
 - Single Event Gate Rupture (SEGR)
 - Stuck Bits

Power devices do not follow down-scaling dimensions and voltages: they exhibit larger sensitivity to neutron-induced effects, even at sea level



Destructive event in a COTS 120V DC-DC Converter

K. LaBel, EWRHE 2004

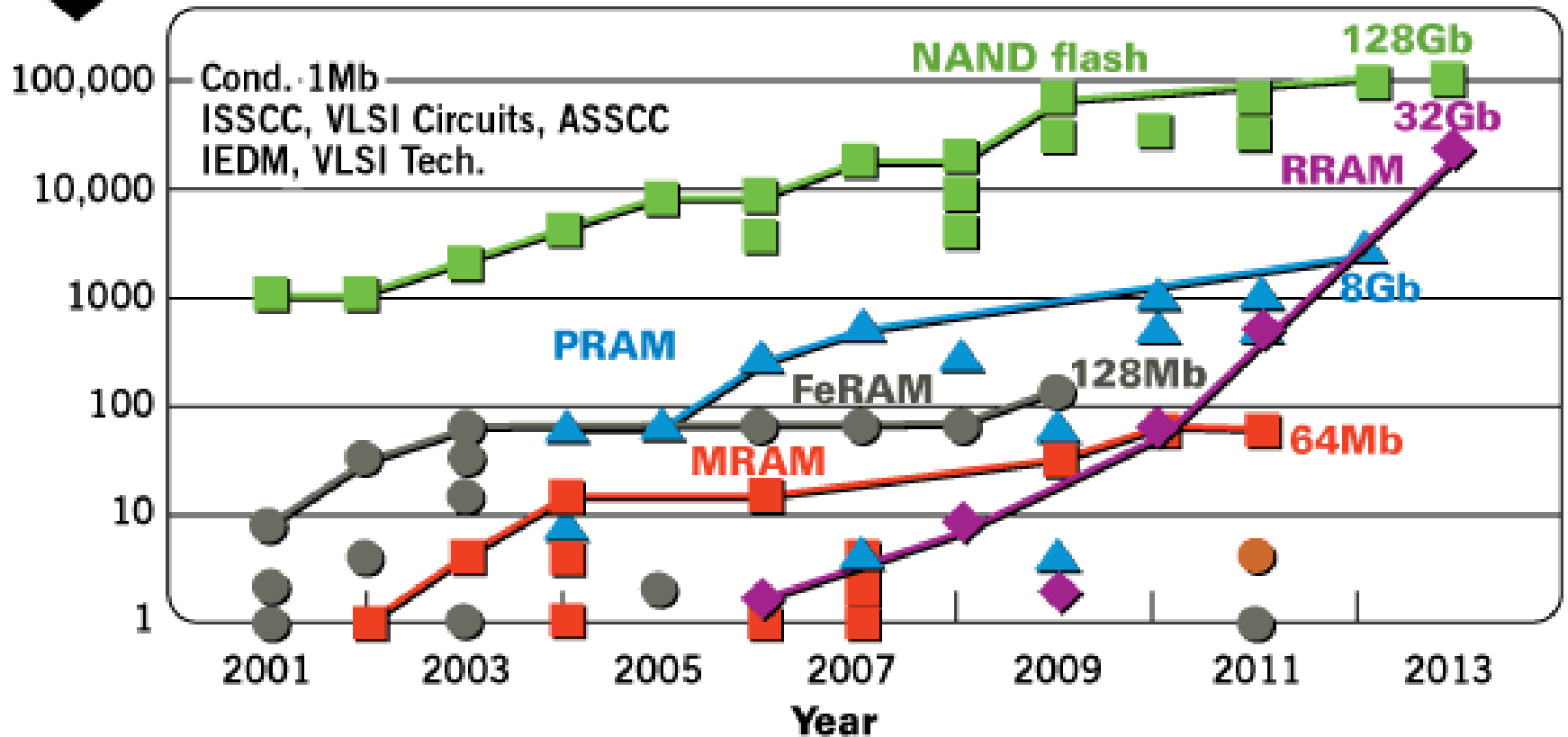


Cosmic Muon Effects may become dominant and increase bit SEU significantly once $Q_{crit} < 0.1$ fC

Per bit, SEU is going down with each generation (since 180 or 130nm)

Courtesy: Robert Baumann, Texas Instruments, 2013

Storage capacity (Mb)



Per bit, SEU is going down with each generation (since 180 or 130nm)

*“Avionics are some of the most sophisticated but safe technological systems in common use. Avionics routinely incorporate **redundant and majority voting systems to mitigate hazards** (...).*

Notwithstanding these design approaches, specific engineering steps could be required to minimise the risk from”
TGFs.

Part in italics quoted from:

Extreme space weather: impacts on engineered systems and infrastructure, Royal Academy of Engineers, 2013

Available at: www.raeng.org.uk/spaceweather

as supplied by *Dr. Clyve Dyer*

“The IEC standard on avionics atmospheric radiation (IEC 62396-1 Ed.1, 2012 section 9) provides a methodology for documenting compliance of avionics which will be operated within an atmospheric radiation environment.

This standard recommends that once the initial design is complete, all SEE sensitive electronic components should be identified and their atmospheric radiation susceptibility determined.(...)

*If the **component level SEE cannot be mitigated** within the equipment design the standard recommends that the SEE be mitigated at the equipment or systems level. If this is not feasible, the part or equipment design might need to be changed.”*

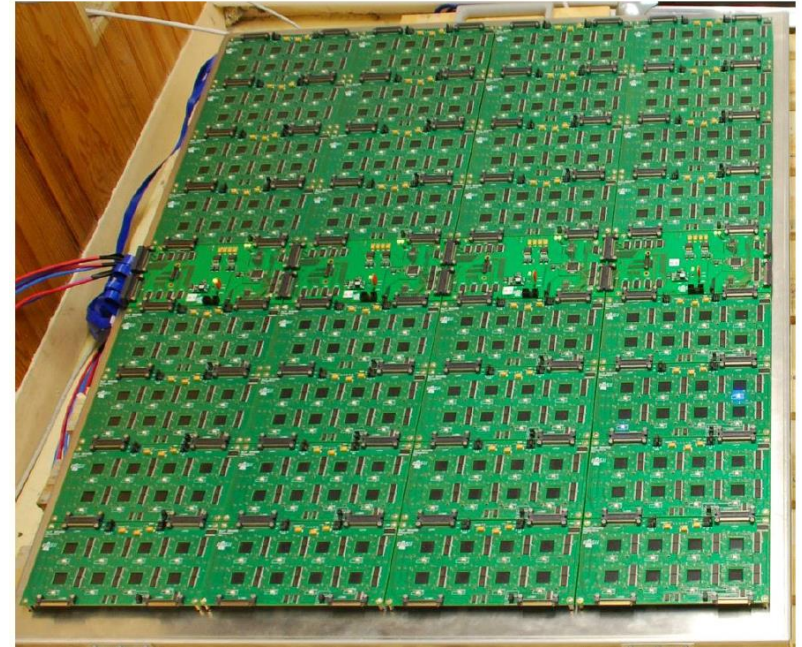
*“For aircraft systems (as opposed to components) radiation standards and industry awareness are less developed. (...) The impact on equipment and systems of extreme events might **be determined by irradiating the equipment in a wide area neutron radiation beam with the appropriate energy, spectrum and fluence, as described in technical specification IEC62396-2:2012**”*

Yet, we do not know enough about the TGF generated particles spectrum energy, to properly address the problem!

- ❖ TGF research should be pursued in its many aspects:
 - Satellite observations to improve our knowledge of the TGF physics (AGILE and new space instruments)
 - Aircraft observations and detection of TGF generated particles:
 - Commercial flights
 - Dedicated flights
 - Ground observations: meteorology and ground-based radiation/particle detection, possibly with simultaneous testing of the induced effects on electronic boards exposed to the same particle spectrum
 - Numerical modeling or radiation/particle interaction in the atmosphere, and aircraft exposure and susceptibility.

Soft Errors Life Tests @ Chilecito

- Natural neutron flux @ Chilecito is about 16x that of NYC (compare with 6x @ Plateau de Bure, France, where a similar experiment is running)
- GOAL: **real-time monitoring of neutron induced soft errors** in many electronic chips (e.g., hundreds of identical SRAMs)
- Power and network required to run this experiment
- This experiment will take advantage from the correlation with neutron and gamma detector readings, aiming to investigate the **impact of TGF generated neutrons on electronics**
- Padova-DEI group is very interested to explore the TGF effects on electronics in this way



Board containing 512 40-nm SRAMs developed in the ASTEP project, courtesy of J.L. Autran.

- TGFs produce a new radiation environment, with the simultaneous burst of electromagnetic radiation and neutrons over a short period
- Neutron energy distribution is high enough to activate SEEs in contemporary scaled electronics: the neutron flux is over the natural atmospheric one by several orders of magnitude, possibly challenging the electronic system mitigation
- Much more info are needed from basic and applied research activities to correctly evaluate the impact of the phenomena and the possible threats
- Experimental researches in the field are active in EU (F, NL) and USA, at least
- **The knowledge edge accumulated in the Italian groups should not be lost!**