Possible effects on avionics induced by Terrestrial Gamma-Ray Flashes

MARCO TAVANI

(INAF and University of Rome “Tor Vergata”)

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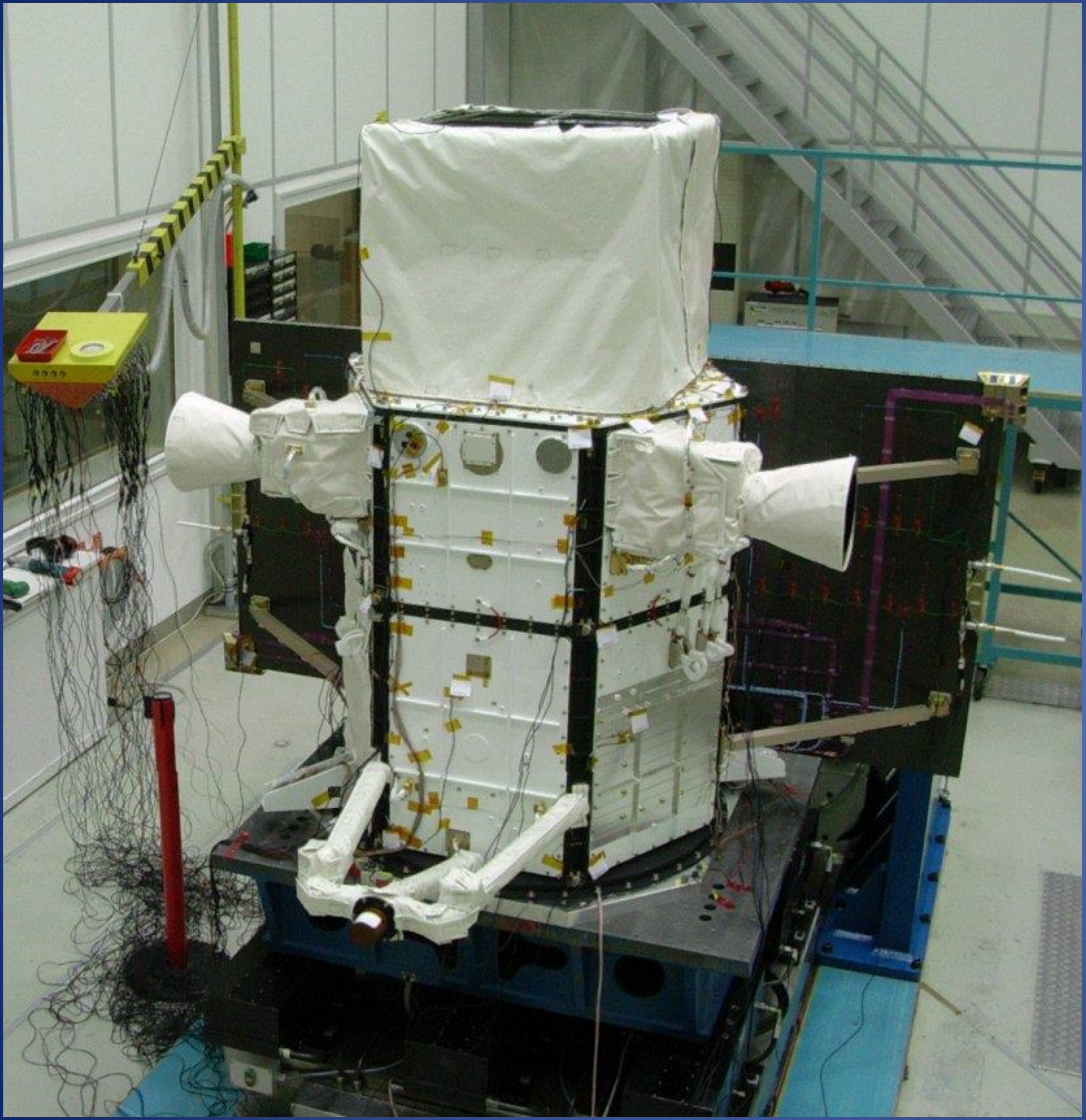


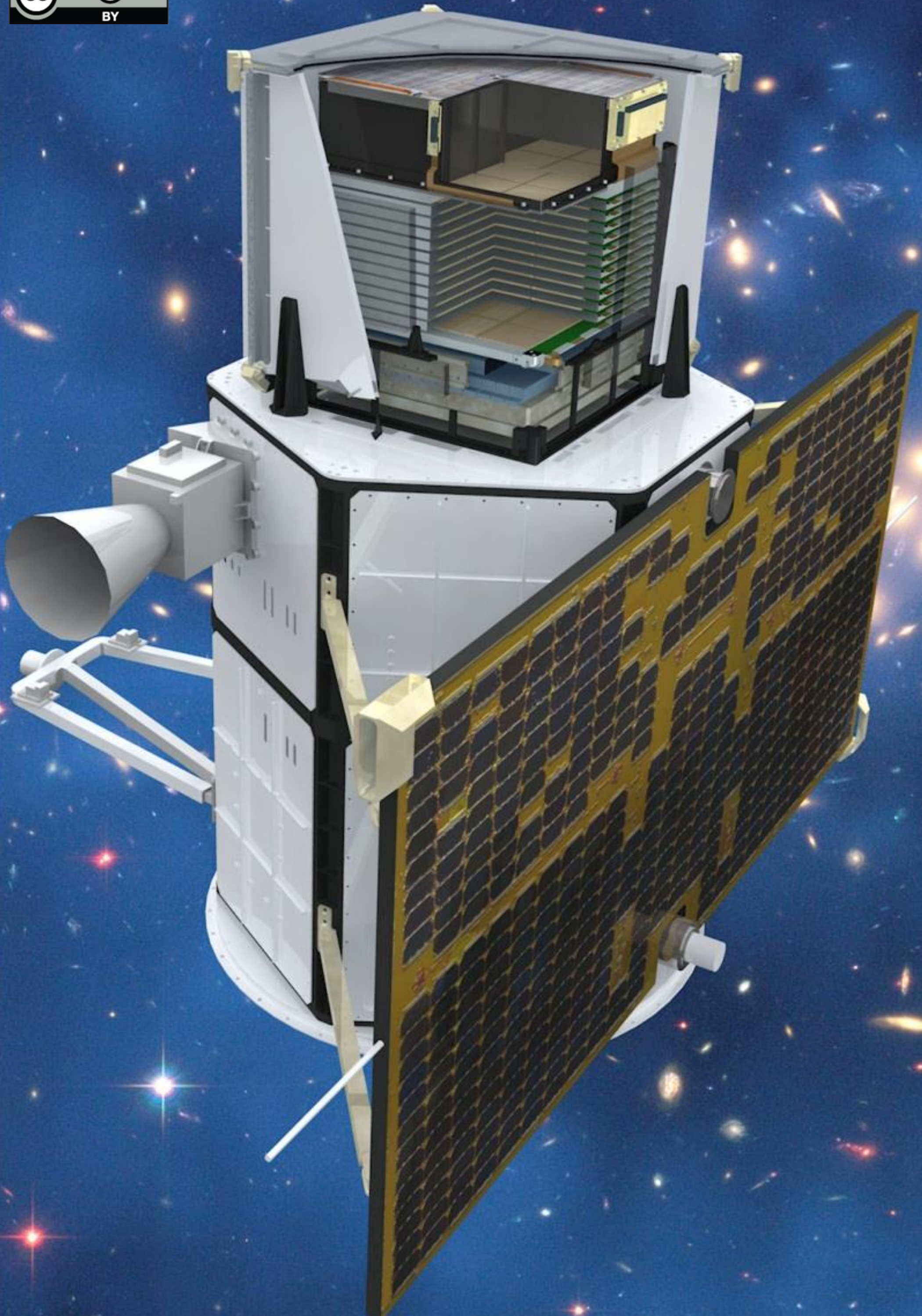
AGILE Satellite (IABG, Munich 16 June, 2006)

350 kg satellite

asi agenzia spaziale italiana

INAF

INFN



The AGILE Small Mission:

It combines for the first time a **gamma-ray imager**

(50 MeV- 30 GeV)

with a **hard X-ray imager**

(18-60 keV)

with large FOVs (1-2.5 sr) and optimal angular resolution

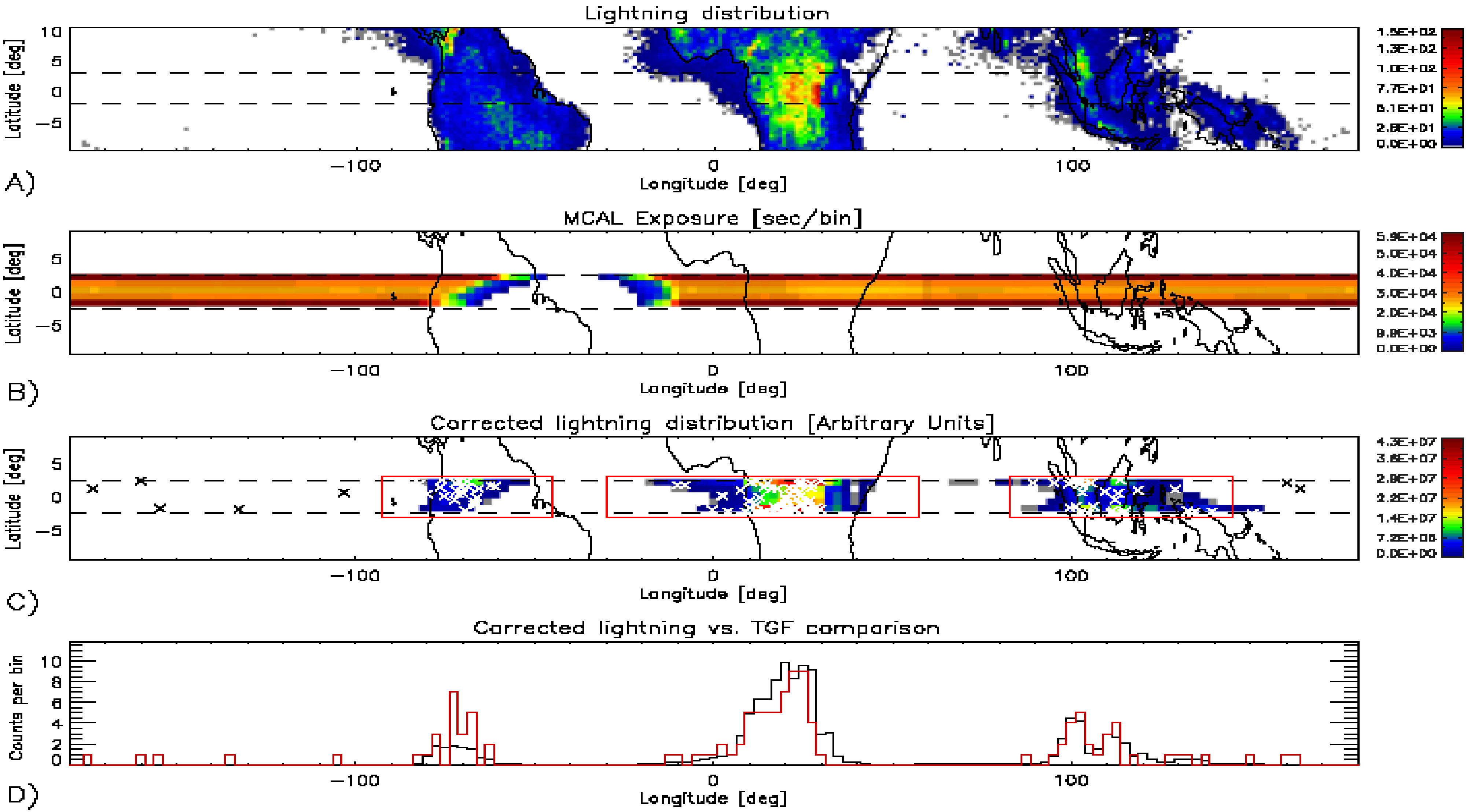
- AGILE special trigger capability
- MCAL burst search from sub-ms to seconds
  - TGFs detected by the trigger logic working in the timescale range $0.3 \text{ ms} < \tau < 16 \text{ ms}$

*** about 500 TGFs detected since 2009

*** about 300 are with good S/N ratio

energy range 0.4 – 100 MeV

TGF-lightning correlation

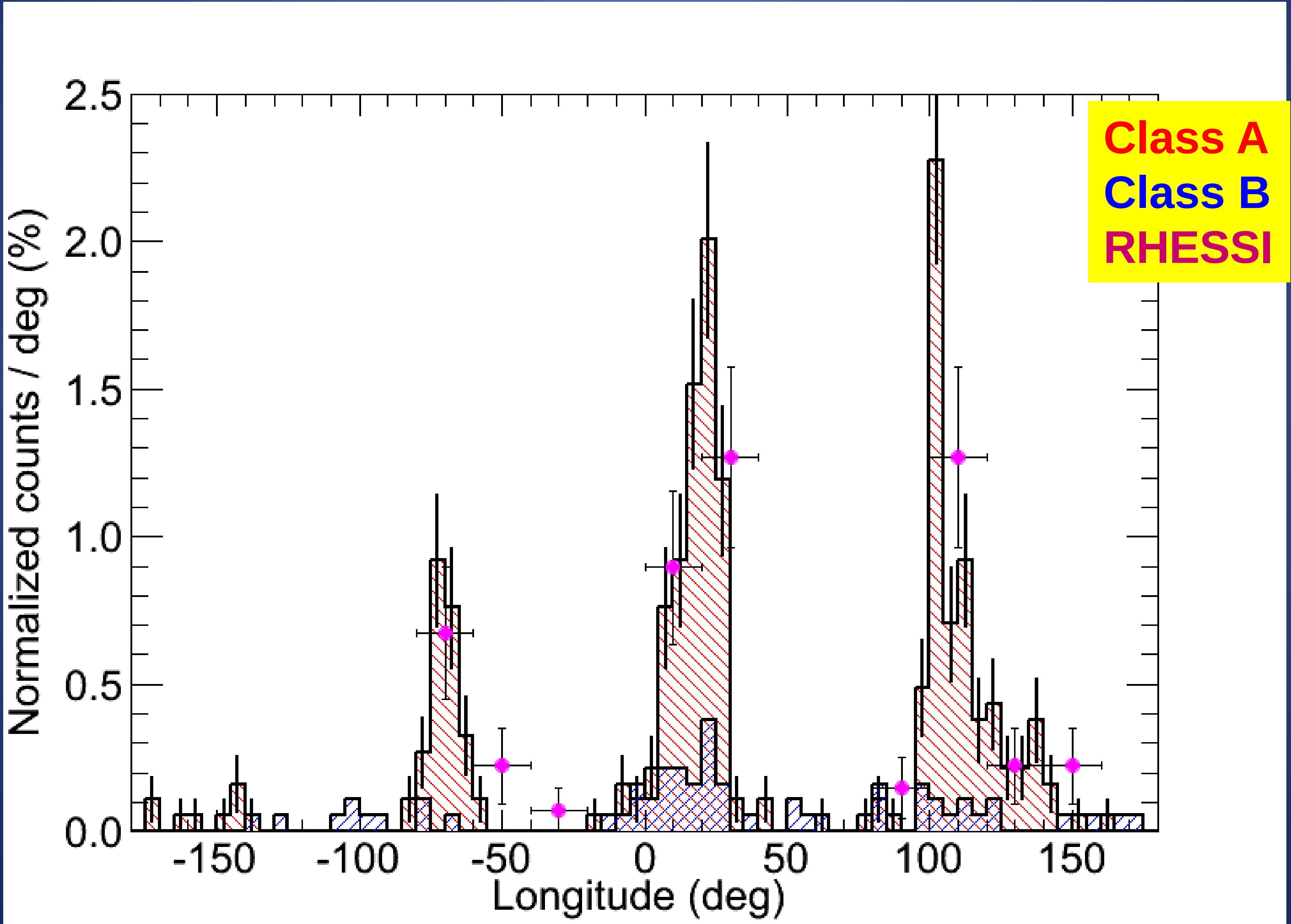


0.68 correlation coefficient for a global fit F. Fuschino et al. 2011

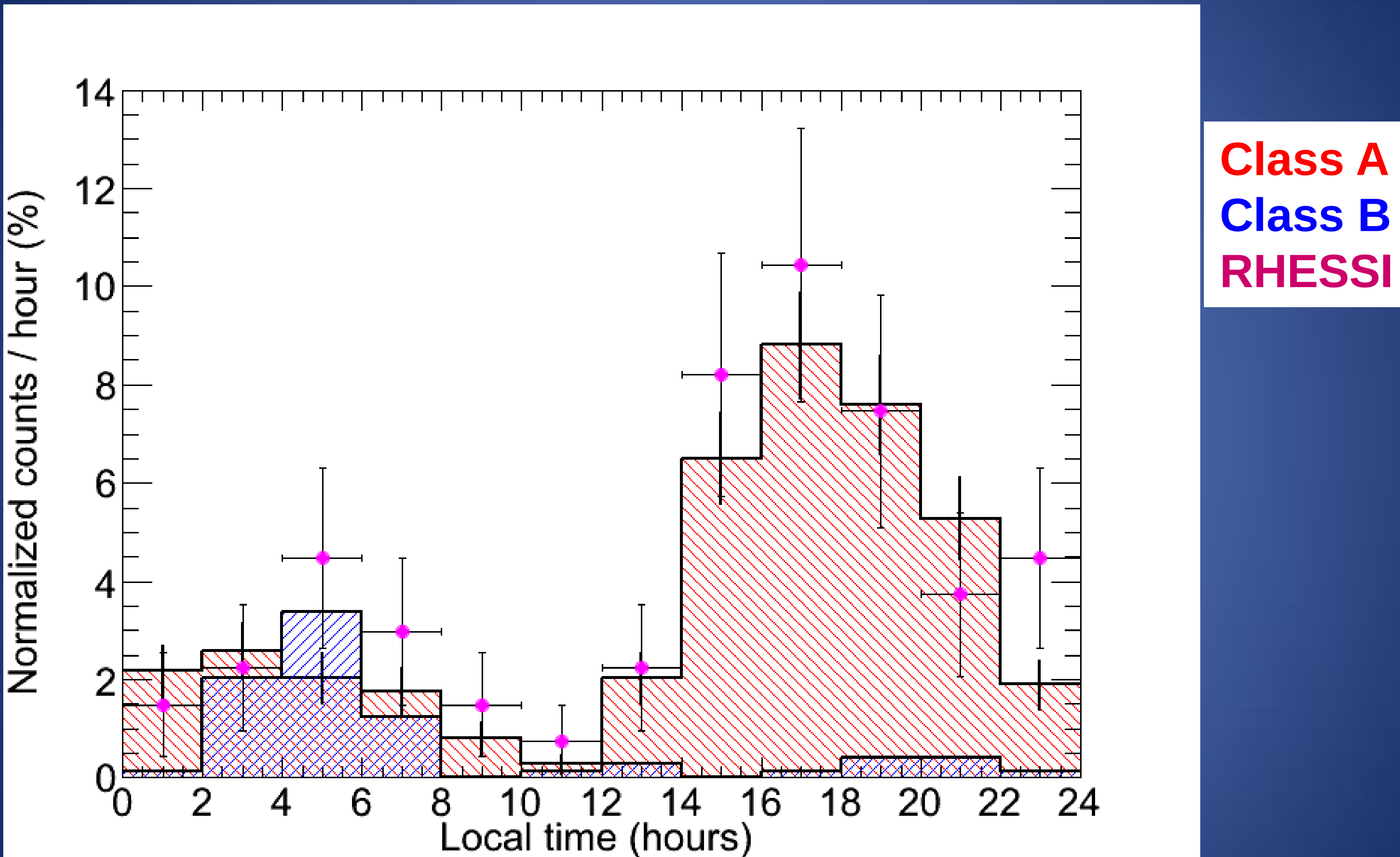
LIS-OTD high resolution full climatology available at http://thunder.msfc.nasa.gov/

Continental region	TGF / flash ratio
America	$1.5\ 10^{-4}$
Africa	$6.0\ 10^{-5}$
South East Asia	$7.5\ 10^{-5}$
All	$7.8\ 10^{-5}$

Longitude distribution
$E_{MAX} < 30$ MeV



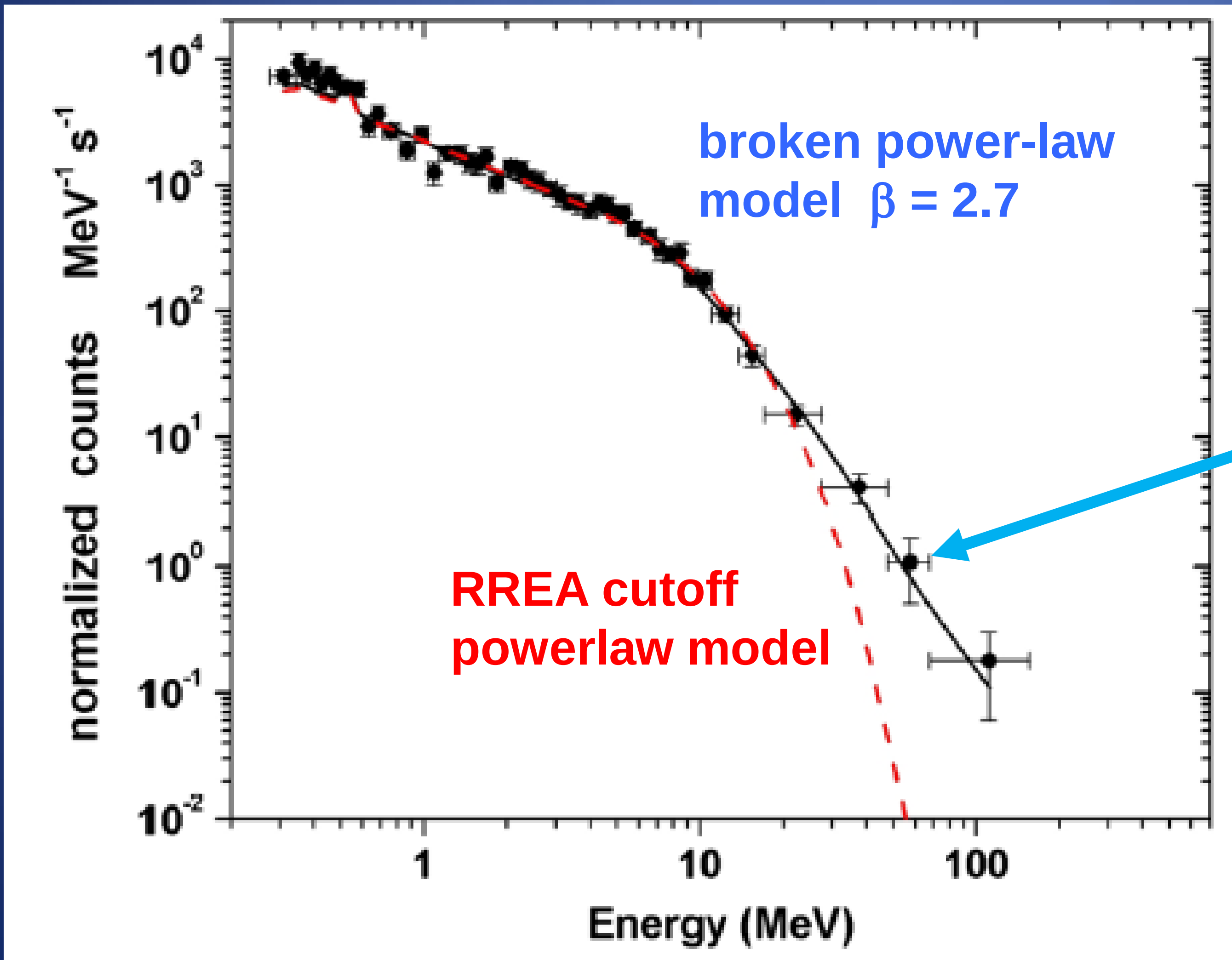
Local time distribution



TFG cumulative spectrum

Tavani et al., Phys. Rev. Letters 106, 018501 (2011)

110 TGFs 26 events E_{max} > 20 MeV



significant detection of γ–rays with E>40 MeV unexplained by standard RREA models: a challenge for emission models

Nat. Hazards Earth Syst. Sci., 13, 1–7, 2013
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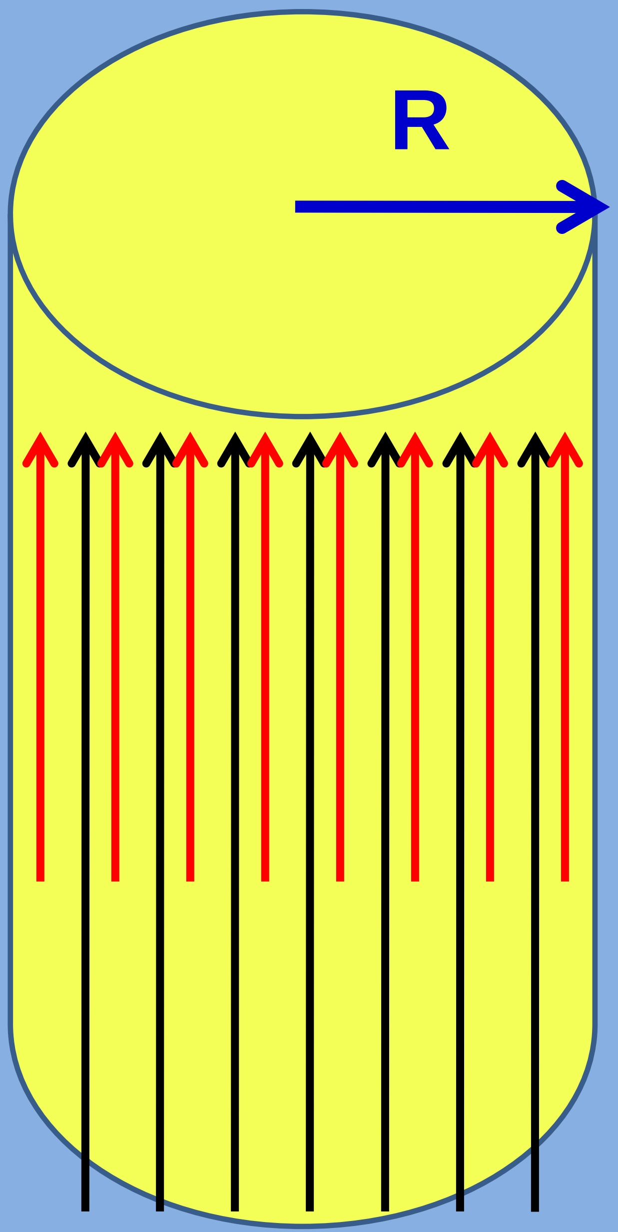
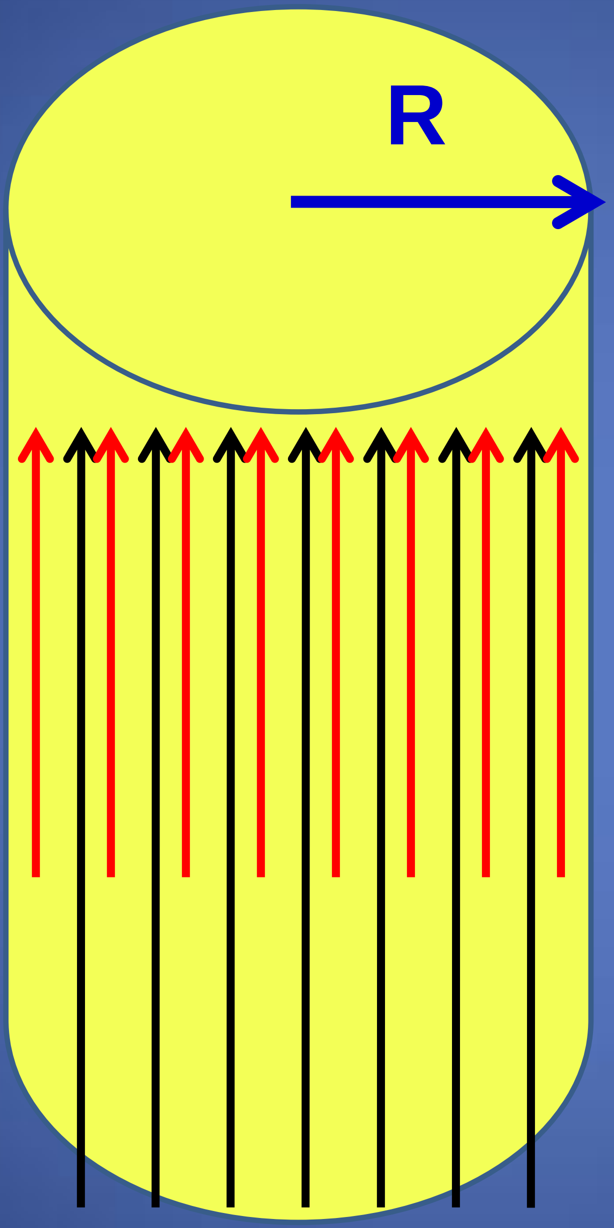
Possible effects on avionics induced by terrestrial gamma-ray flashes

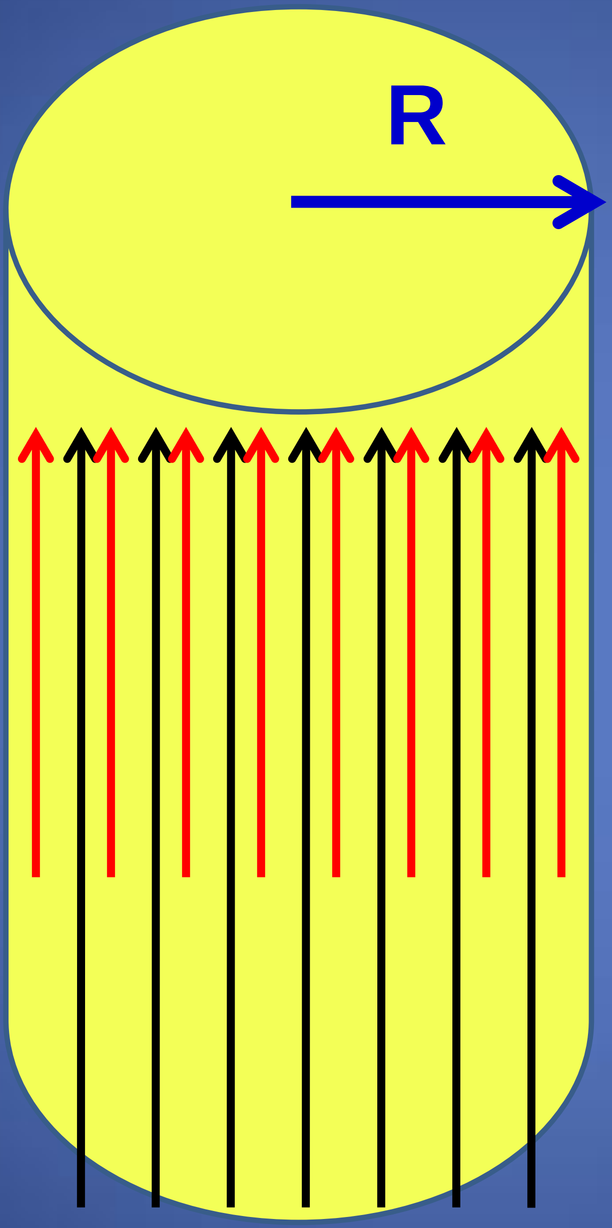
M. Tavani[1,2,3], A. Argan[4], A. Paccagnella[5], A. Pesoli[2], F. Palma[2], S. Gerardin[5], M. Bagatin[5], A. Trois[6], P. Picozza[2,3], P. Benvenuti[7], E. Flamini[8], M. Marisaldi[9], C. Pittori[10,11], and P. Giommi[11]


R

TGF active channel



TGF active channel

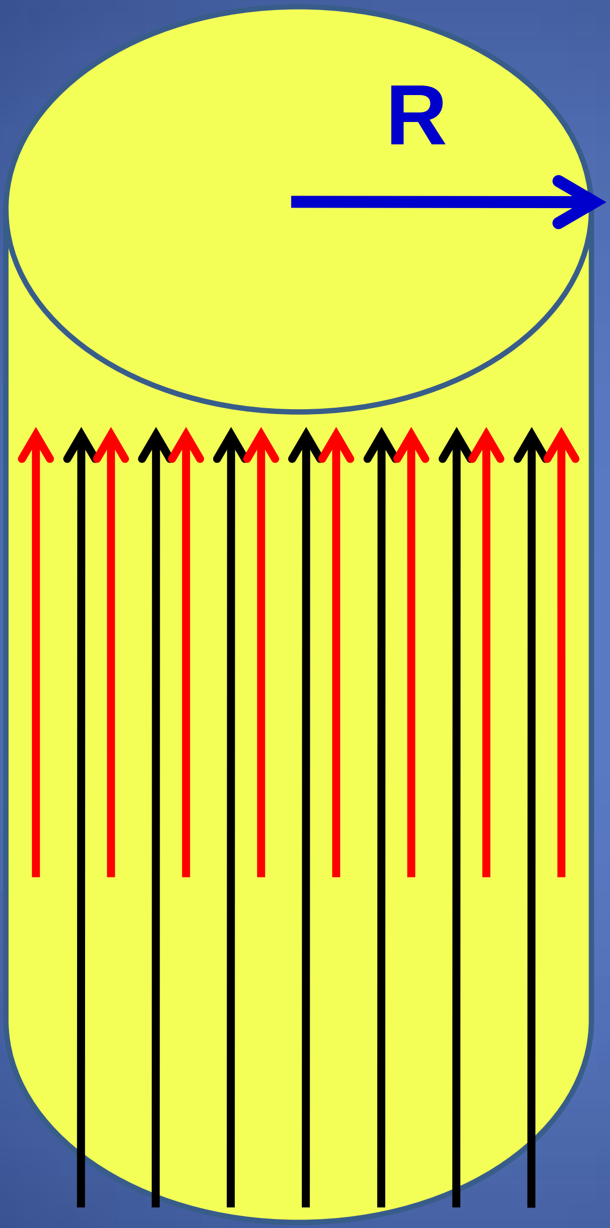


$N = N_{17}\ 10^{17}$

$R = R_3\ 10^{3}$ cm

$\tau = \tau_{-5}\ 10^{-5}$ sec

TGF active channel



$N = N_{17}\ 10^{17}$

$R = R_3\ 10^3$ cm

$\tau = \tau_{-5}\ 10^{-5}$ sec

define

$X = N_{17}\ R_3^{-2}$

2 main components of radiation/particles within the aircraft

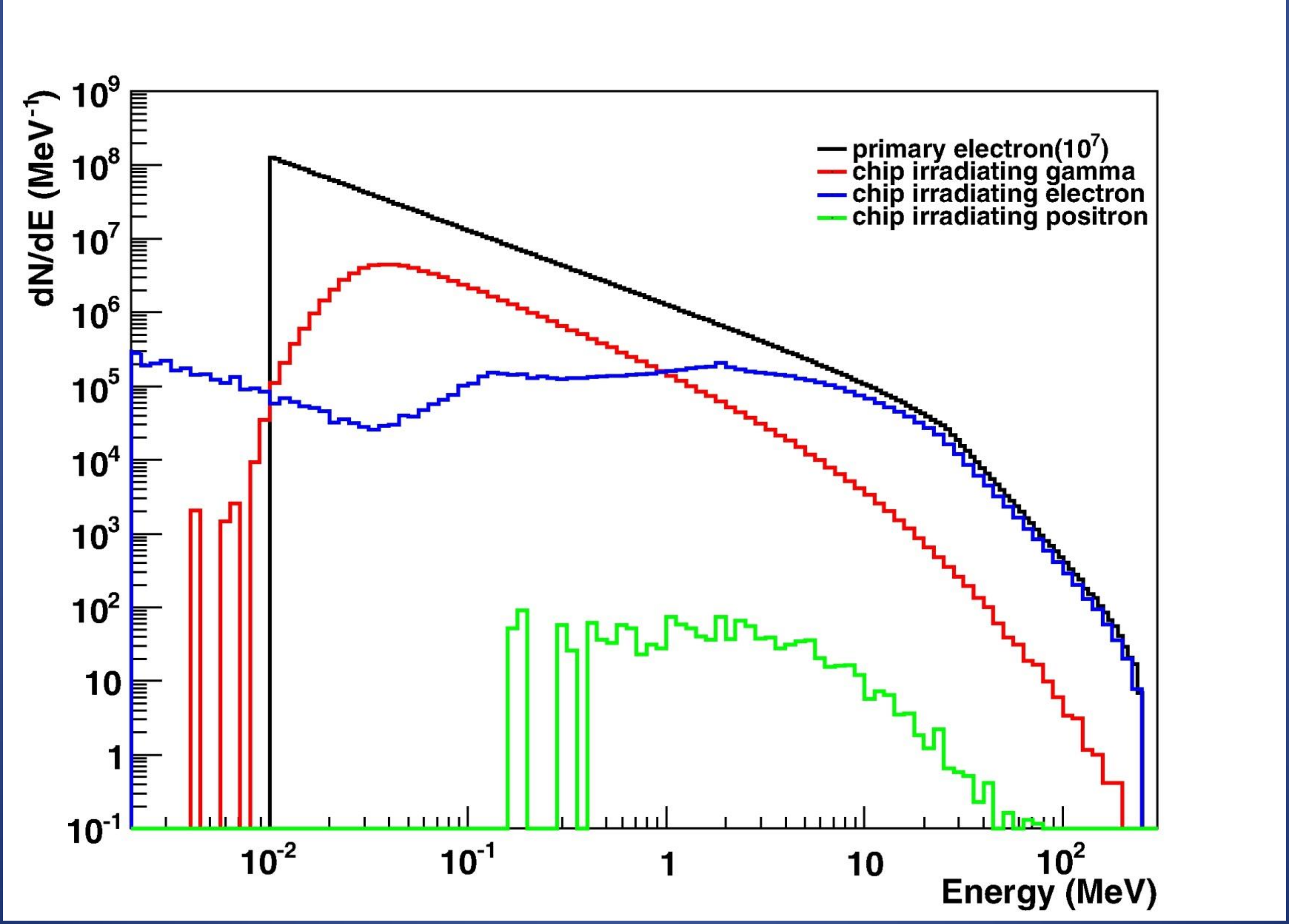
- electromagnetic component
  - electrons/positrons
  - gamma-rays

- neutron component

Possible effects on aircraft electronics

- **TID (total ionizing dose) effects**, cumulative effects causing charge trapping and interface state generation in dielectric layers.
- **DD (displacement damage) effects**, cumulative effect of ionizing and non-ionizing radiation displacing lattice atoms with parametric variations.
- **DR (dose rate) effects,** produced by intense bursts of ionizing radiation delivered within a few tens of microseconds causing upsets and latch-ups;
- **SEE (single event) effects**, caused by a single ionizing particle hitting a sensitive device.

Transport of primary electrons producing secondary electrons, positrons, gamma's [L(Al) = 0.5 cm]



- For shielded electronic components the total e.m. dose is **$D = (200\ \mathrm{rad})\ N_{17}\ R_3^{-2}$**
- for unshielded components, D is ~30 % higher (see also Dwyer et al. 2011)

- this dose is accumulated within **τ**
- **the dose rate is**

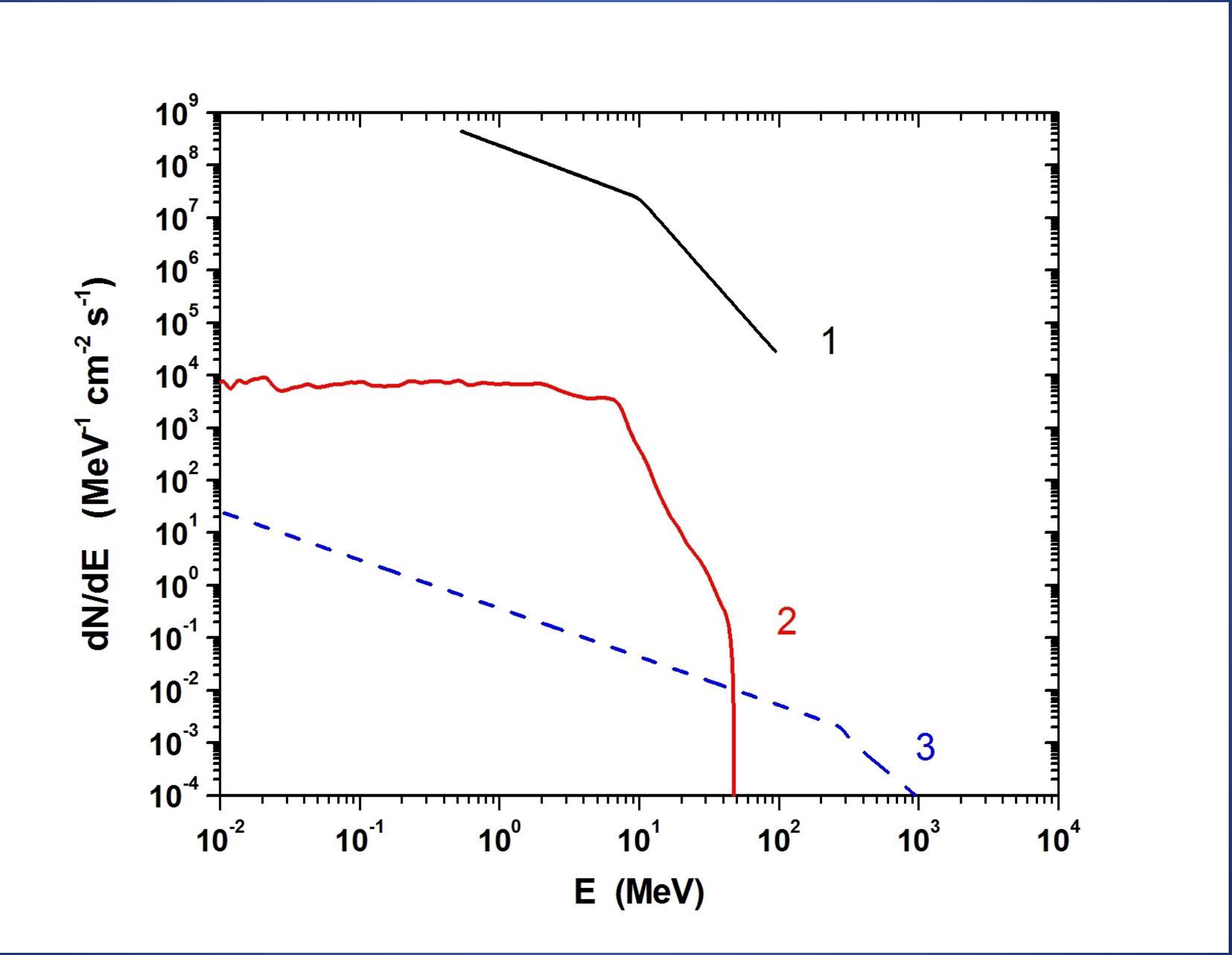
$$dD/dt = (2 \times 10^7\ \mathrm{rad\ s^{-1}})\ N_{17}\ R_3^{-2}\ \tau_{-5}$$

Neutrons

- neutrons induced in the atmosphere by lightning and TGFs were considered by, e.g. Babich et al (2008…) and Carlson et al. (2010).
- **we consider here neutron photo-production in an aircraft structure (of equivalent Al depth L): probability = 6×10^{-4} (L/1cm)**
- **Prompt photo-produced neutron (PPN) spectrum and total flux**

$$F_n = (10^{10}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1})\ N_{17}\ R_3^{-2}\ \tau_{-3}^{-1}\ (L/1\ \mathrm{cm})$$

Neutron (PPN) flash (red, 2)



Possible effects

- DD and TID are usually not relevant for X < 1, they may become relevant for **X > 25** (in this case the dose can be very high also for humans, $D > 5 \times 10^3$ rad(Si), see Dwyer et al. 2010).

- **Dose rate (DR) and SEE effects** can be produced by very rapid and collective effects (circuit upsets, latchups and burnout if delivered within a timescale shorter than 1 ms).

Possible effects

- Assuming a critical level of malfunction ($D = 10^8$ rad(Si) s^{-1}), we obtain a DR malfunction condition

$$X \tau_{-5}^{-1} \sim 5$$

Possible effects

- **SEU (single event upset) effects** on aircraft electronics are mostly due to neutrons (Normand et al. 2006).
- For TGF irradiation, we consider PPN on benchmark electronics such as SRAMs., SEU cross-sections per bit for 4 Mbit SRAMs for neutron energies near 10 MeV

$$\sigma\,(\text{SEU cross-section/bit}) \simeq \alpha\, 3 \times 10^{-13}\ \text{cm}^2 \qquad (4)$$

$$\sigma\,(\text{SEU cross-section/device}) \simeq \alpha \times 10^{-6}\ \text{cm}^2, \qquad (5)$$

where α $(0 < \alpha < 1)$ takes into account the measurement scatter for different SRAM manufacturers. From Eq. (5) and

Possible effects

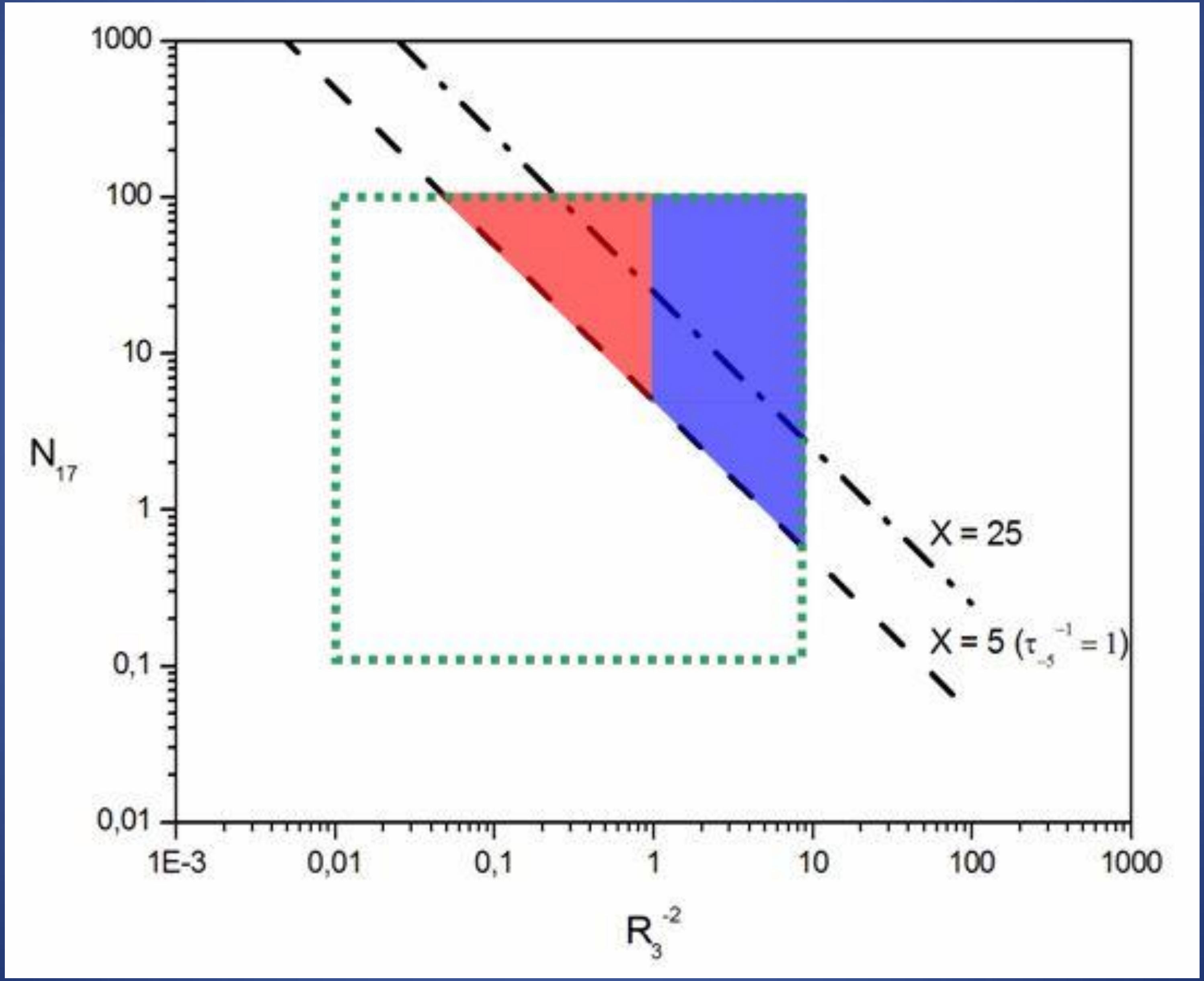
- The SEU probability per SRAM device induced by TGF PPN is

$$P \sim 10\,\alpha\,X\,L$$

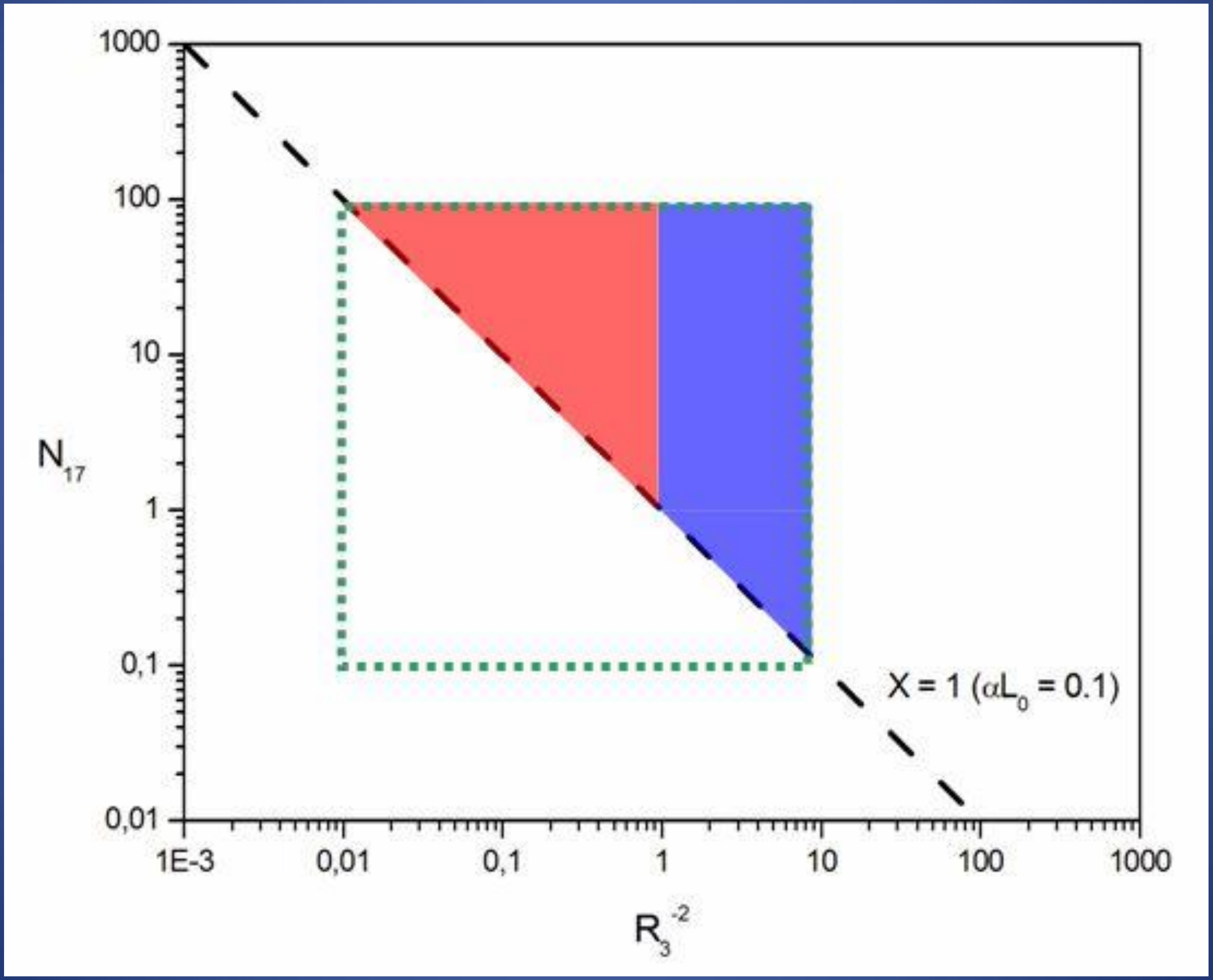
Table 1. Susceptibility to TGFs.

TGF strength	Radiation effects
$\alpha\, X\, L_o > 0.1$	significant neutron-induced SEEs
$X \geq 25$	total dose effects in sensitive components
$X\, \tau_{-5}^{-1} \sim 5$	dose rate effects

Possible critical parameter space (e.m. irradiation)



Possible critical parameter space (neutron irradiation)



Conclusions

- Depending on TGF strength and geometry of possible interaction with aircraft, critical susceptibility of simultaneously affected electronic equipment can be reached:
  - for PPN neutrons for $\alpha X L \sim 0.1$;
  - for the e.m. component for $X > 25$ or $X \tau_{-5}^{-1} \sim 5$.
- Depending on internal redundance and protection, the overall aircraft electronic system may recover or possibly be affected.
- Definitely, additional work is needed:
  - improved measurements (ground, aircraft, satellite);
  - susceptibility studies for highly variable regimes;
  - realistic simulations.