Essentials for electronics in the space radiation environment - Test methods and facilities

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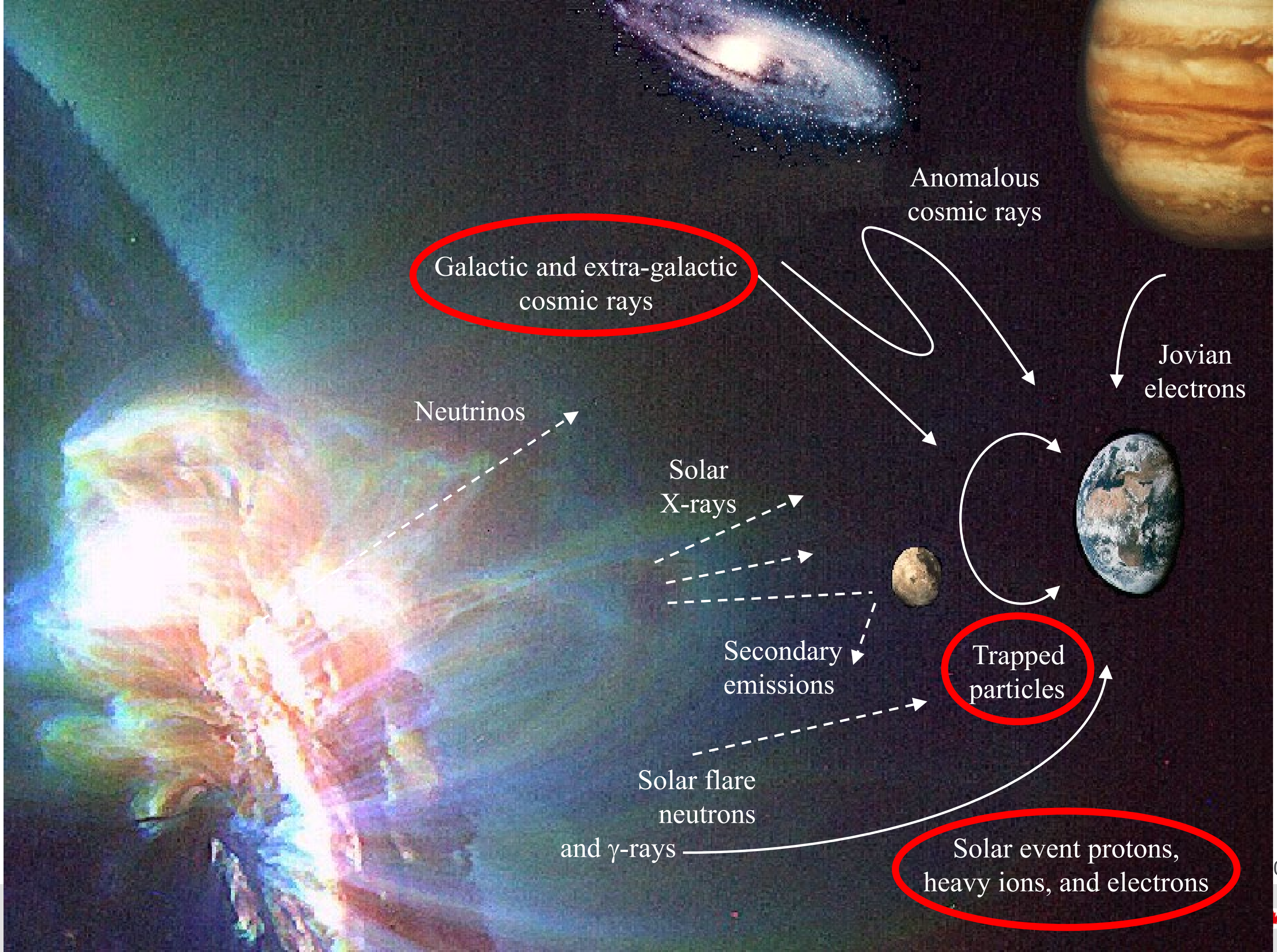
European Space Agency

- **8 sites in Europe**
- **about 2200 staff**
- **4.4 billion Euro budget**

- **Space science**
- **Human spaceflight**
- **Exploration**
- **Earth observation**
- **Launchers**
- **Navigation**
- **Telecommunications**
- **Technology**
- **Operations**

ESA has 22 Member States
Seven other EU states have Cooperation Agreements with ESA
Canada takes part in programmes under a long-standing Cooperation Agreement.



Space Environnements

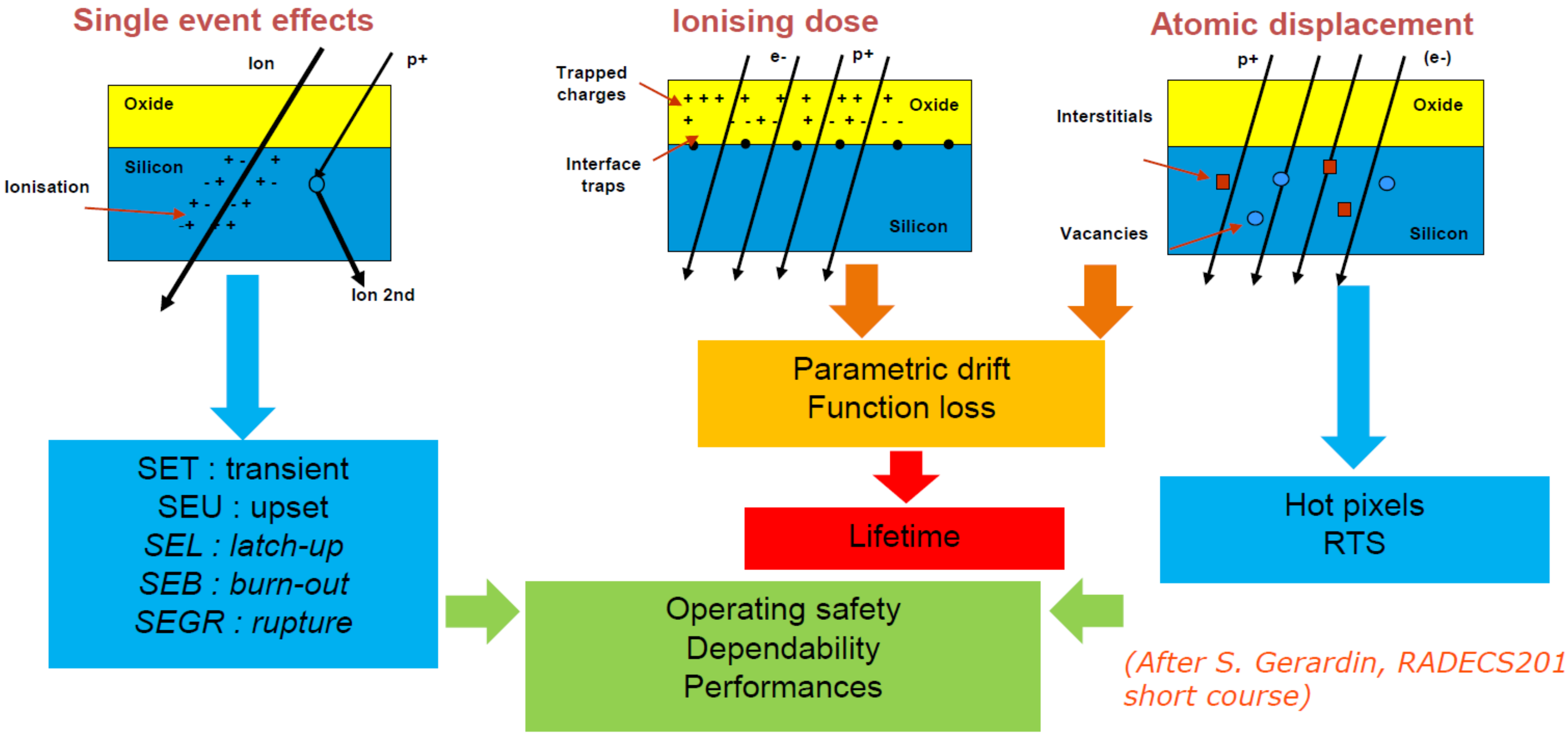
After Petteri Nieminen and Hugh Evans

ESA Internal Radiation course (TEC-QEC and EPS)
11 Nov. 2014

Guaranteed for Flight

- **Testing**

Main radiation effects in EEE – focus on SEE



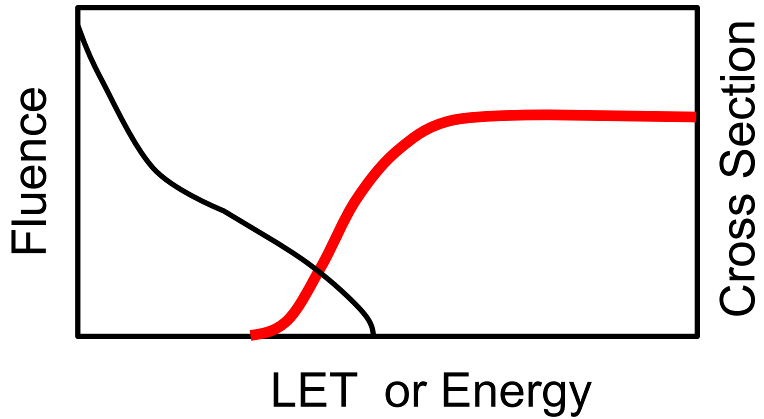
(After S. Gerardin, RADECS2015 short course)

Why SEE testing? For SEE rate prediction and mitigation

Need to know:

a. Space Environment: Integral flux as a function of LET or energy

b. Cross-section vs. ion LET or proton energy



Guidelines and Standards – space segment

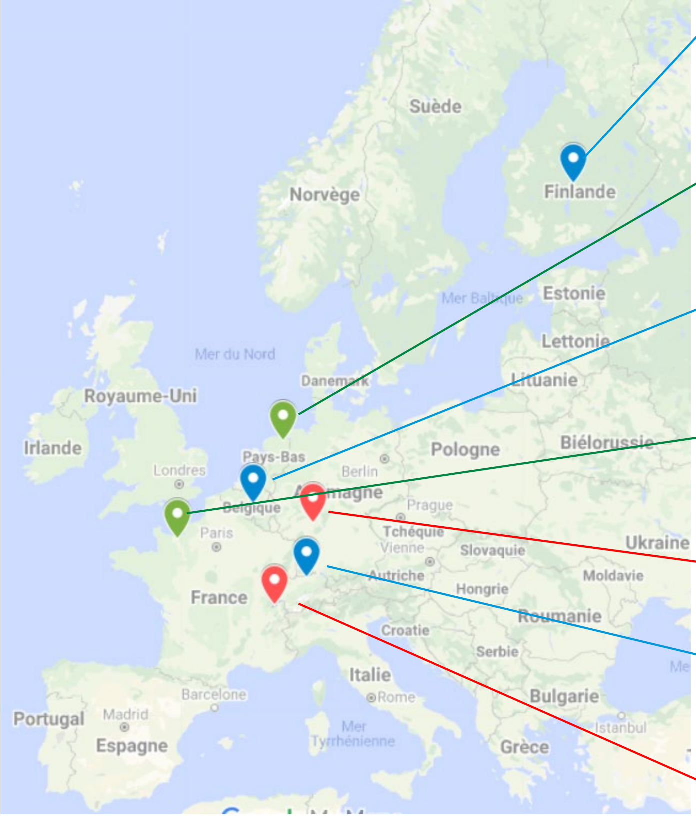
by European space agencies & Industry

- ESCC 25100 Single Event Effects Test Method and Guidelines, Iss. 2 Oct. 2014
- ESCC 22500 Guidelines for Displacement Damage Irradiation Testing, Iss. 3, Nov. 2019
- ESCC 22900 Total Dose Steady-State Irradiation Test Method, Iss. 5, June 2016
- ➢ ECSS-Q-ST-60-15C, Radiation Hardness Assurance – EEE Components, Oct. 2012

ESCC
European Space Components Coordination

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Main heavy ion & proton facilities in Europe used for SEE testing



RADEF, Jyväskylä, FI, **ESA support** since 2004-2007, ~900€/h, ~12 weeks/y
Heavy Ions, Cocktails 9.3 MeV/n, 16.3-22 MeV/n (2019), range 155-257 µm

KVI, Groningen, NL, ~900€/h, ~ few weeks/y, Protons up to 190MeV
Heavy Ions, Cocktail 4 species, ~ 30 MeV/n, range 333 µm

UCL, Louvain-la-Neuve, BE, **ESA support** since 1995-1997, ~900€/h,
~16 weeks/y, Heavy Ions, Cocktail 9 species, ~ 9 MeV/n, range 73 µm

GANIL, Caen, FR, high E., Heavy Ions ~ -45-50 MeV/n, ~ 1000 €/h,
availability 1-2 week/y, One species per experiment (Xe, Kr)

GSI, Darmstadt, DE, Very-high E., Heavy Ions 1-2 GeV/n, Protons 4.5 GeV,
One species per experiment (p+ to U), 5.7 k€/h, availability < 1 week/y

PSI, Villigen, CH, **ESA support** since 1990-1992, ~900€/h
Protons, up to 230 MeV, Nearly all weekends

CERN, Geneva, CH, Ultra-high E., 30-150 GeV/n, Xe (2017) Pb (2018)

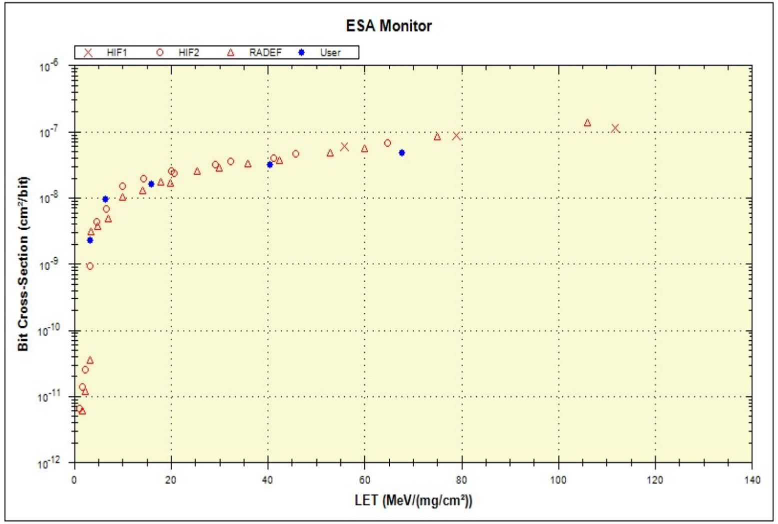
Irradiation SEE test facilities for space should be/have

- Technical parameters (energy, flux) in line with the requirements of test guidelines and Radiation Hardness Assurance standards for EEE components (ECSS, ESCC) for space applications
  - protons up to ~200 MeV (+/- 10%), and heavy ions ≥ 9MeV/n (range)

- For space industry and institutional users: Availability, lead time, cost, dosimetry and practicality for EEE tests

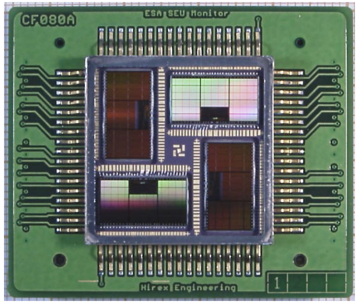
- Viability, sustainable economic model
  - Facilities are often part Universities, Institutions, supporting other activities (Scientific research, medical treatments, isotopes, industrial applications)
  - Ex. US Indiana closed Oct 31, 2014, Eu TSL Upssala 2010 (re-opening)

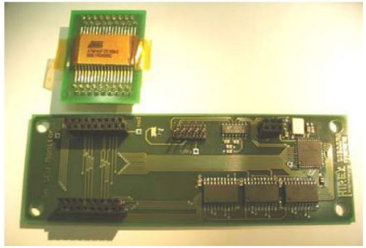
Checking the beam: the ESA SEU monitor



[F-X Guerre, HIREX, 2013]

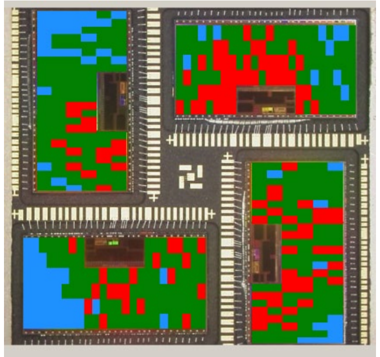
4 dies module of the 0.25um ATMEL AT60142F 4Mbit SRAM



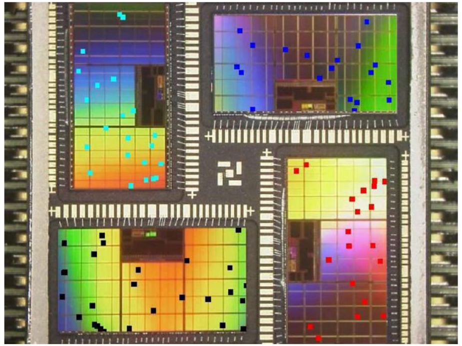


[Harboe Sorensen Radecs 2005]

Kr, 305 MeV, +/-10%

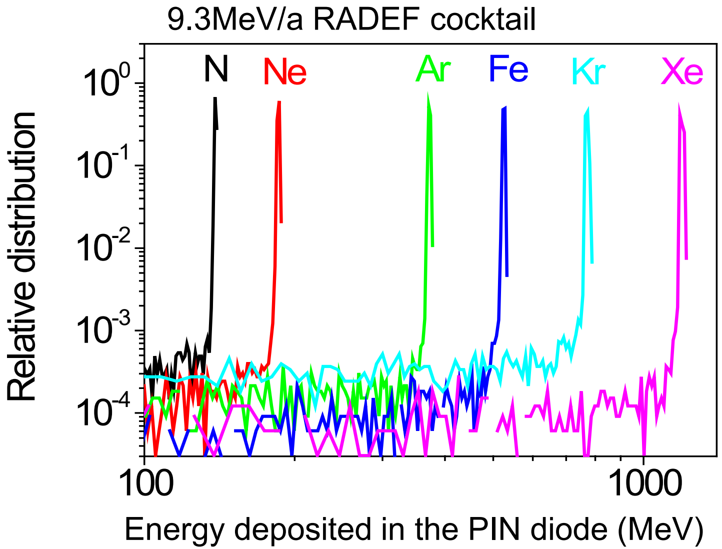


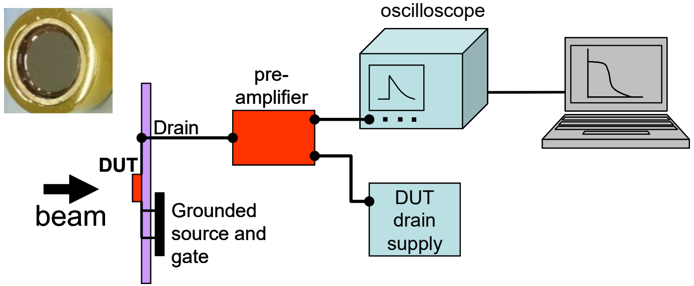
[Harboe Sorensen Proba2 TDM TNS Aug 2012]

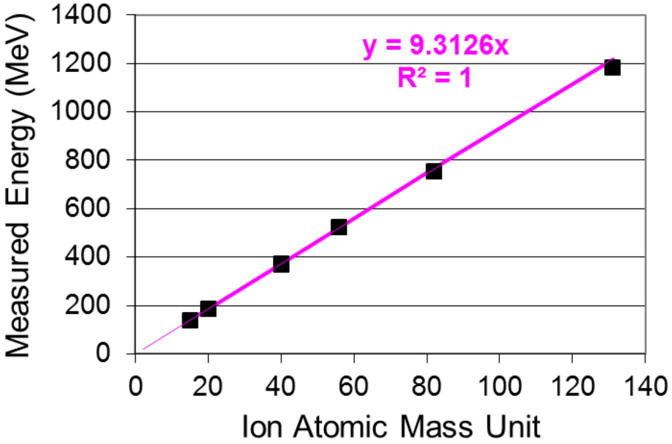


Checking the beam: the ESA calibrated PIN diode system

Energy peak is very narrow < 0.5% FWHM

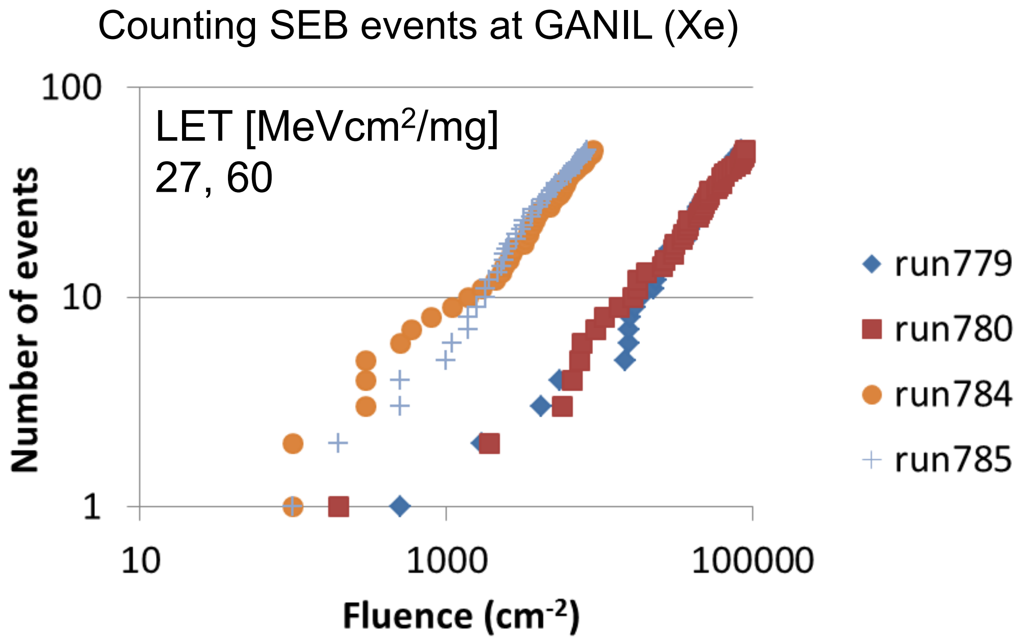






After V. Ferlet-Cavrois, TNS Dec 2010 and 2012

Experimenters: Use Statistics by counting events

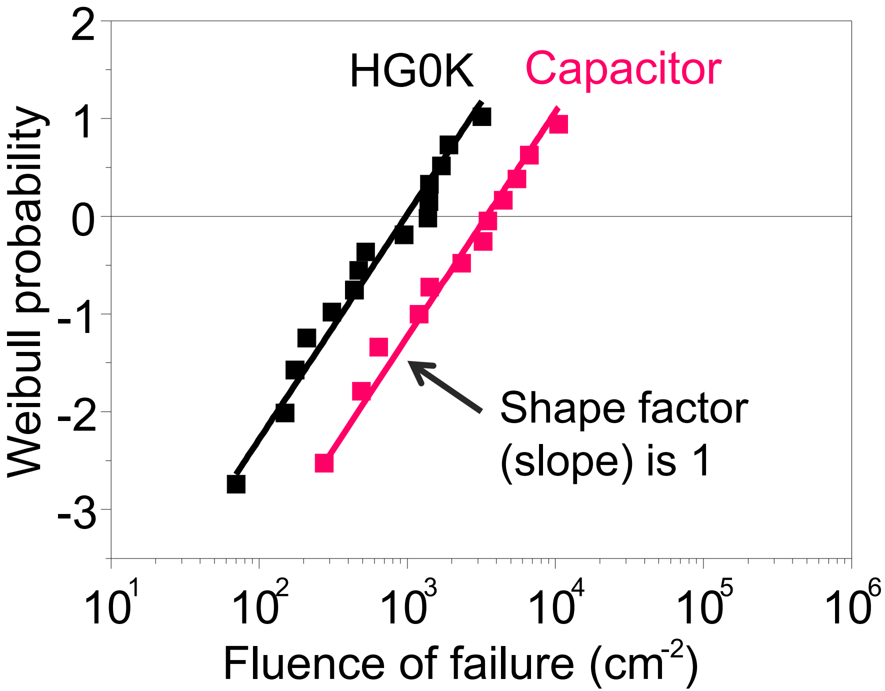


[Binois, Carvalho, 2013, Airbus under ESA contract]

V. Ferlet-Cavrois, ESA Internal Course, EEE Component Radiation Hardness Assurance Tutorial, ESTEC, 22 Nov. 2013]

The distribution of fluences of events follows a Weibull statistics with a shape factor (slope) of 1

E.g. Gate oxide rupture is a random single event effect



A shape factor of 1 is observed for both planar large area capacitors and power MOSFETs

This statistical behaviour is expected for **all single event effects**
[Ladbury05], [Petersen]

After V. Ferlet-Cavrois, TNS Dec 2012

What about EEE COTS in Space

- The Radiation Hardness Assurance (RHA) requirements are the same for COTS than for Rad-Hard components (as per ECSS or MIL-STD)
  - the test facilities should be high energy /range, esp for COTS in complex packages
  - Alternative tests (pulsed focused X-rays, laser, Cf252) only for debugging, analysis or assessment, **NOT** for qualification

- COTS in Space are not new: all ESA missions include COTS, business as usual as long standards are followed
  - ECSS-Q-ST-60C (EEE, rev.) and ECSS-Q-ST-60-13 (COTS, Oct 2013)
  - Significant work to **prove homogeneity**, between tested parts and Flight Model parts
  - Worth cost/effort when: performance needed, not Rad-hard alternative, or large number of parts needed (e.g. 1000 vs. 100)

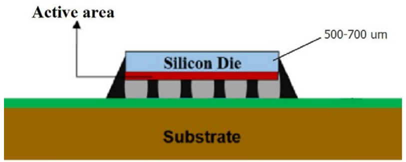
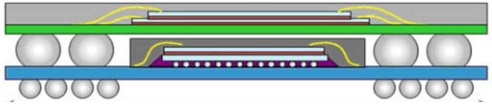
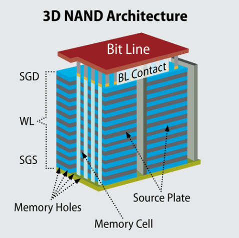
COTS EEE components, often dense packaging

Examples:

- Multi chip modules
- Flip chip construction
- Hybrids
- Plastic package with Cu bondwires

The exposure of the dies is either impossible or difficult,
And there is the risk to modify the device response.

need of more energetic heavy ions to have more range
(despite lower LET)

		
Flip chip: Active area facing package Backside irradiation -> die thinning to ~200 um	**System in package:** Test separately	**Dense structure:** Higher beam penetration range

After A. Costantino, 2020

Conclusion (1)

- Test is mandatory to know the radiation behavior of component (flight lot)
  - ➢ no possible replacement by modelling or simulations

- In space, high energy particles: protons, heavy ions, electrons
  - ➢ No possible replacement of heavy ions by any other species
  - ➢ If there is only one SEE test to be done, it should be heavy ions, as it envelops all others

Conclusion (2)

- The Radiation Hardness Assurance (RHA) requirements are the same for COTS than for Rad-Hard components (as per ECSS or MIL-STD)
  - User is responsible of beam quality / check your beam

- COTS in Space are not new, however modern packaging are often difficult to open, and more frequent
  - No problem for high energy protons, SEE from nuclear interaction recoils
  - Heavy ions have limited range at standard energies

- Needs High Energy Heavy Ion facilities (range 1-10 mm), sustainable business model, affordable and accessible
  - Proposal to RADNEXT to conduct a similar investigation (Testing at the speed of light, 2018, and AoA 2019) to quantify the need of beam time (kilo-hours/year) at high Energy (≥ 100 MeV/n) in Europe

Thanks and References

Big thanks to my ESA colleagues, M. Muschitiello, A. Costantino, C. Poivey, M. Poizat, C. Boatella Polo, V. Gupta, T. Borel, A Pesce, H. Evans, P. Nieminen, A. Zadeh, K. Lundmark, F. Tonicello

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CERN CHARM and North Area
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