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FP Days March 2017
Electron-induced SEUs

story of a new effect

Robert ECOFFET
Space environment and new components office
DSO/AQ/EC

07-03-2017

Timeline - 2010

- **The Impact of Delta-Rays on Single-Event Upsets in Highly Scaled SOI SRAMs**, M. P. King; R. A. Reed; R. A. Weller; M. H. Mendenhall; R. D. Schrimpf; M. L. Alles; E. C. Auden; S. E. Armstrong; M. Asai, IEEE TNS,2010, Vol.57, Issue: 6

- **Evidences MBU in SOI technologies due to delta ray electrons**

- **→ if a secondary delta electron can induce an SEU, why not a primary electron from the environment ?**

KING *et al.*: THE IMPACT OF DELTA-RAYS ON SINGLE-EVENT UPSETS IN HIGHLY SCALED SOI SRAMS 3173

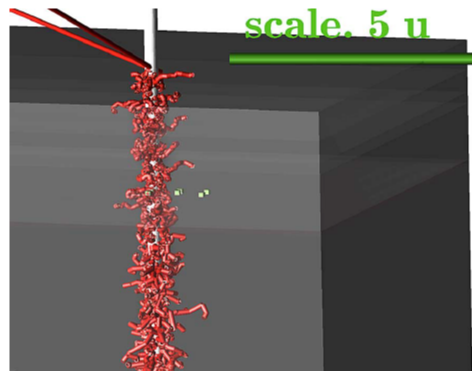

Fig. 6. Simulation of 280 MeV Fe interacting with the simulated SRAM array structure. The solid white tube represents the incident ion track. Red tubes represent generated δ-rays along the ion track. The green structures represent the sensitive volumes of neighboring devices.

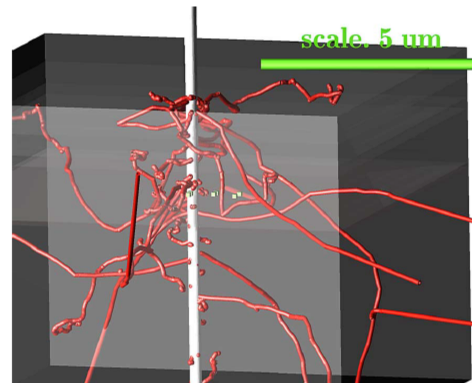

Fig. 7. Simulation of 28 GeV Fe interacting with the simulated SRAM array structure. The solid white tube represents the incident ion track. Red tubes represent generated δ-rays along the ion track. The green structures represent the sensitive volumes of neighboring devices.

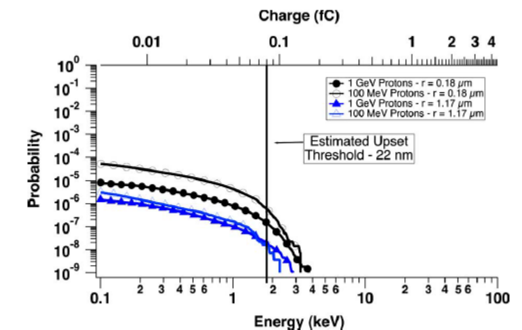

Fig. 5. Cumulative probability distribution for normally incident 1 GeV protons. The color scheme of the plot follows Fig. 3. The distance between SRAM cells is denoted by a distance, r. Values on the x axis represent energy deposited by δ-rays in nearby volumes.

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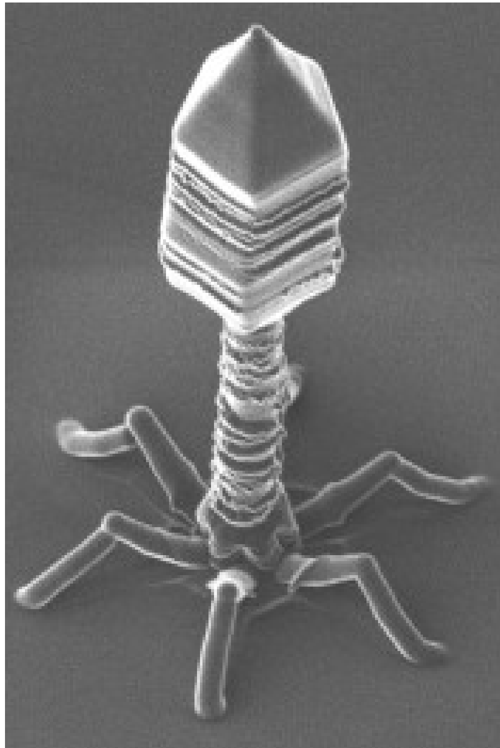
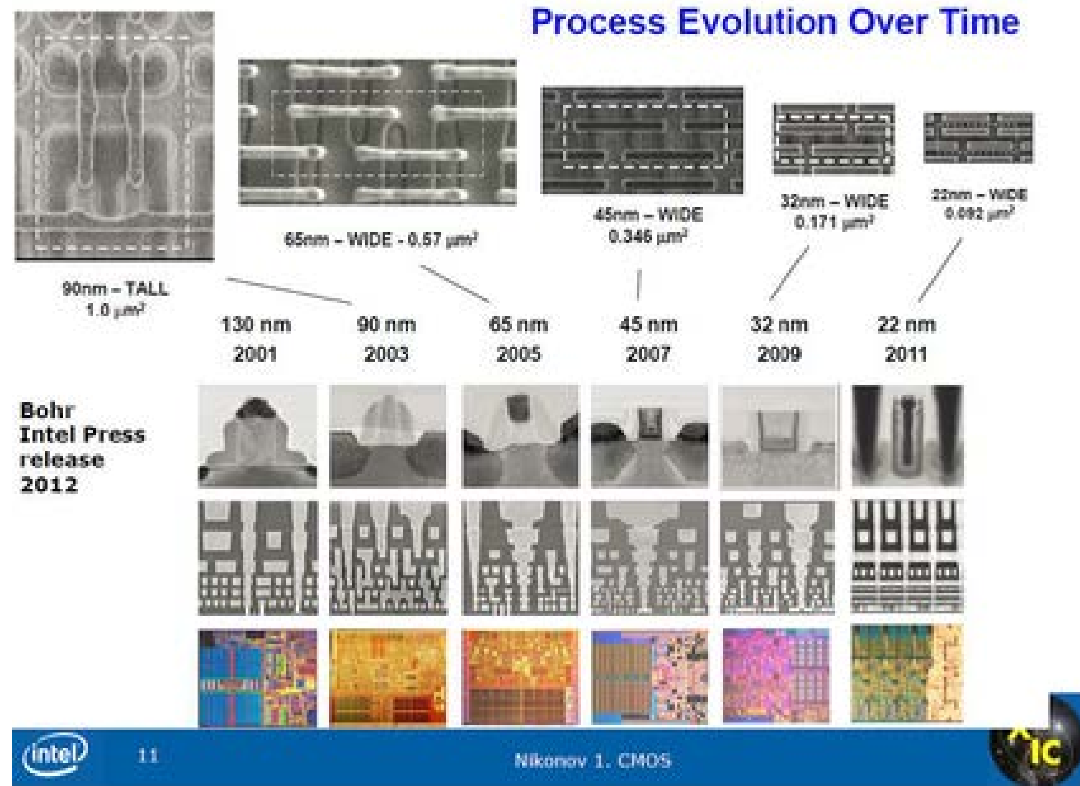
Technology - Dimensions

About the same scale of structuration than elementary living matter





This virus (bacteriophage) is about 200 nm tall and 65 nm wide

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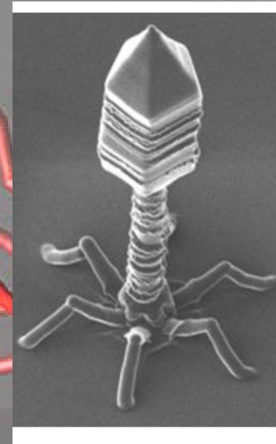
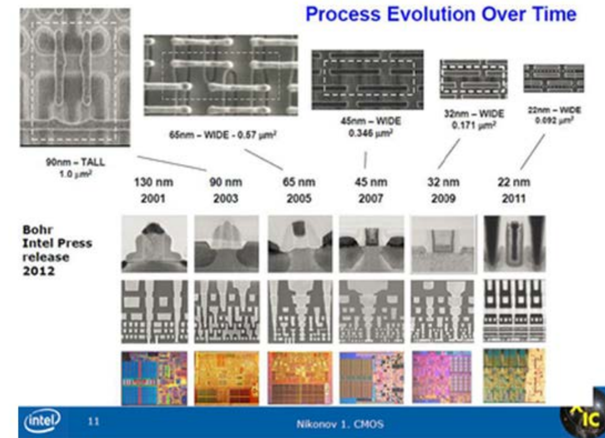
Compared dimensions

scale. 5 um





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Timeline - 2013

- **Anomalies of the ADSP 21060 Onboard the DEMETER Satellite**, C. Inguimbert; S. Bourdarie; D. Falguère; T. Paulmier; R. Ecoffet; N. Balcon, IEEE TNS, 2013, Vol. 60, Issue: 6

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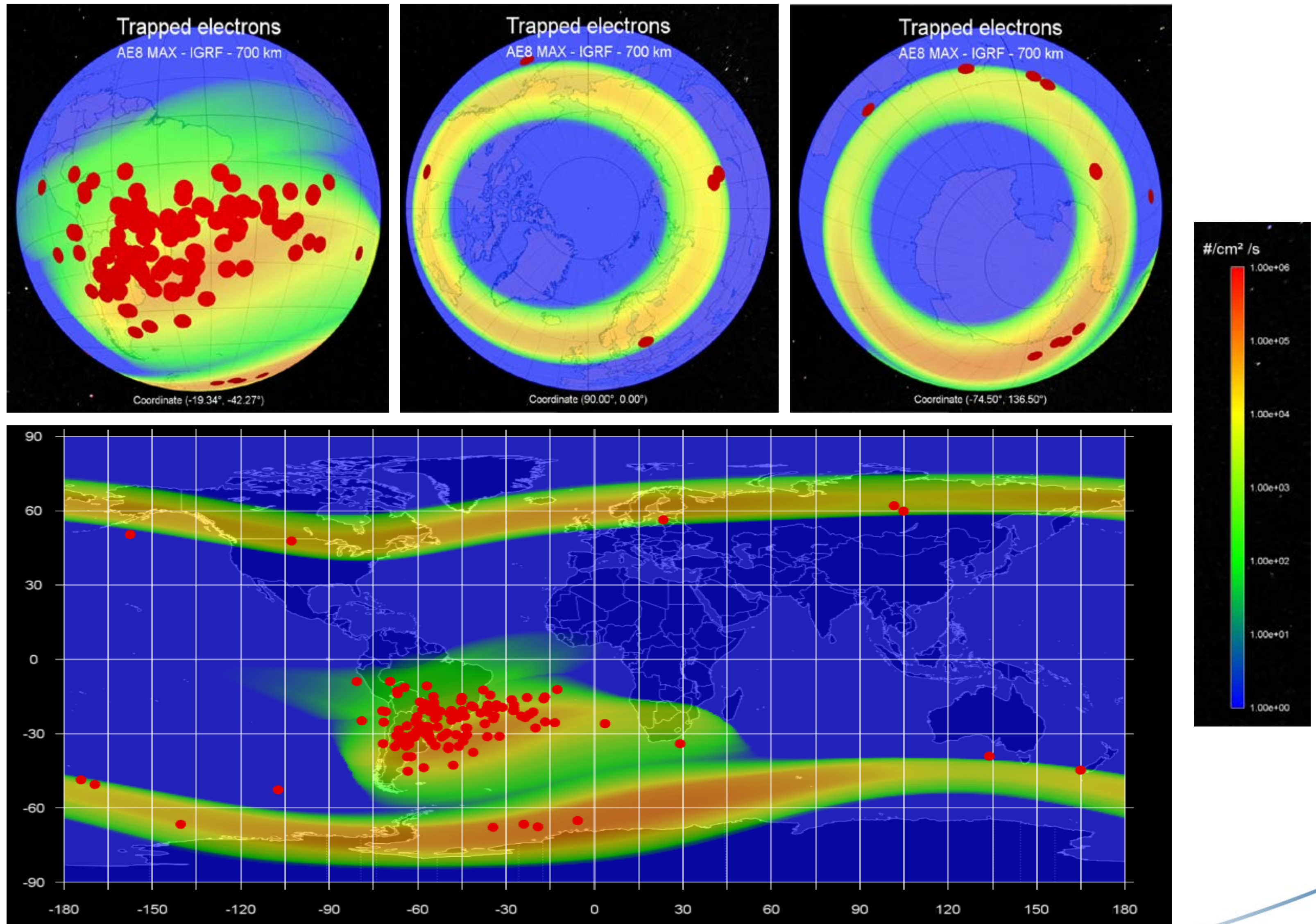
DEMETER OBC, 2004-2007



ADSP 21060 upsets vs > 1 MeV e- flux, OMERE plots

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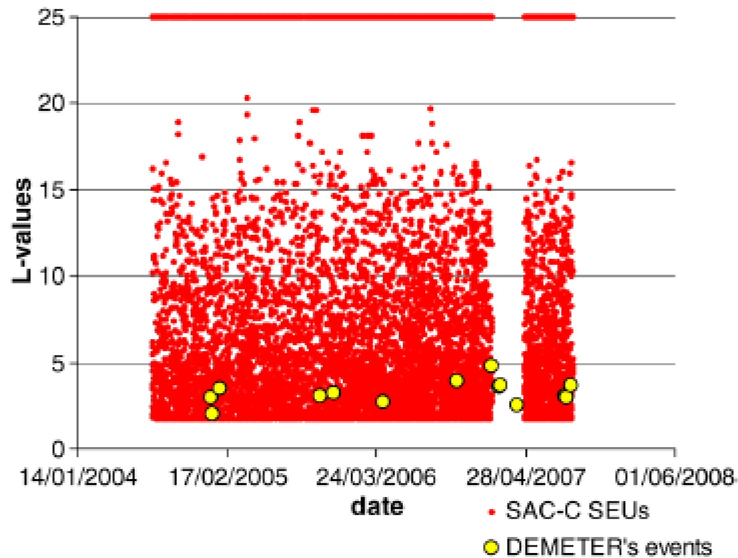
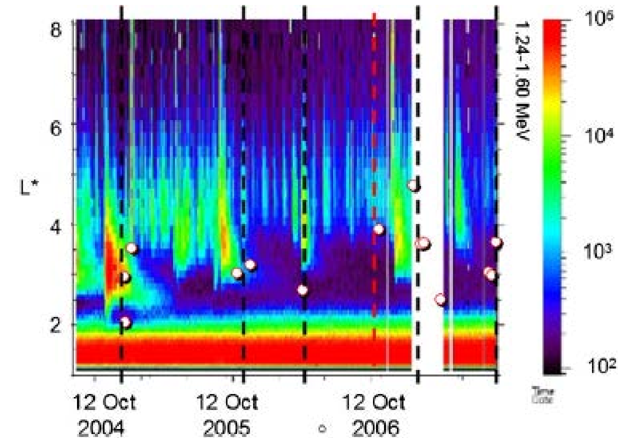
DEMETER OBC, 2004-2007





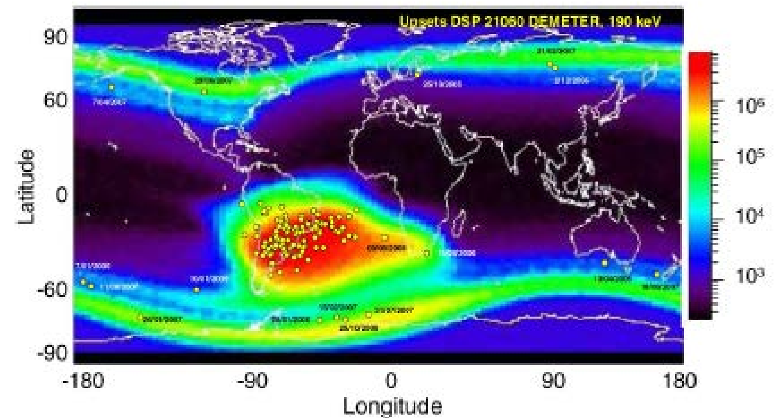
ADSP 21060 upsets vs 190 keV e- ICARE/SAC-C flux, IPSAT plot

SEUs at L>2 in the same time period

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 6, DECEMBER 2013

Anomalies of the ADSP 21060 Onboard the DEMETER Satellite

C. Inguimbert, S. Bourdarie, D. Falguère, T. Paulmier, R. Ecoffet, and N. Balcon



ADSP 21060 upsets vs 1.24-1.60 MeV e- ICARE/SAC-C flux, IPSAT plot

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Timeline - 2013

- **Anomalies of the ADSP 21060 Onboard the DEMETER Satellite**, C. Inguimbert; S. Bourdarie; D. Falguère; T. Paulmier; R. Ecoffet; N. Balcon, IEEE TNS, 2013, Vol. 60, Issue: 6

- → Probably not electron-induced SEEs

- → But demonstrates conditions compatible with possible ESD induced upsets (c.f. Voyager, CRRES)

Timeline - 2013

- **Electron-induced single-event upsets in static random access memory ,** M. P. King, R. A. Reed, R. A. Weller, M. H. Mendenhall, R. D. Schrimpf, B. D. Sierawski, A. L. Sternberg, B. Narasimham, J. K. Wang, E. Pitta, B. Bartz, D. Reed, C. Monzel, R. C. Baumann, X. Deng, J. A. Pellish, M. D. Berg, C. M. Seidleck, E. C. Auden, S. L. Weeden-Wright, N. J. Gaspard, C. X. Zhang, and D. M. Fleetwood, IEEE TNS, 2013, vol. 60, issue 6,

- **First experimental evidence using secondary electrons from an ARACOR 4100 X-ray source + 1 mm aluminium attenuator**

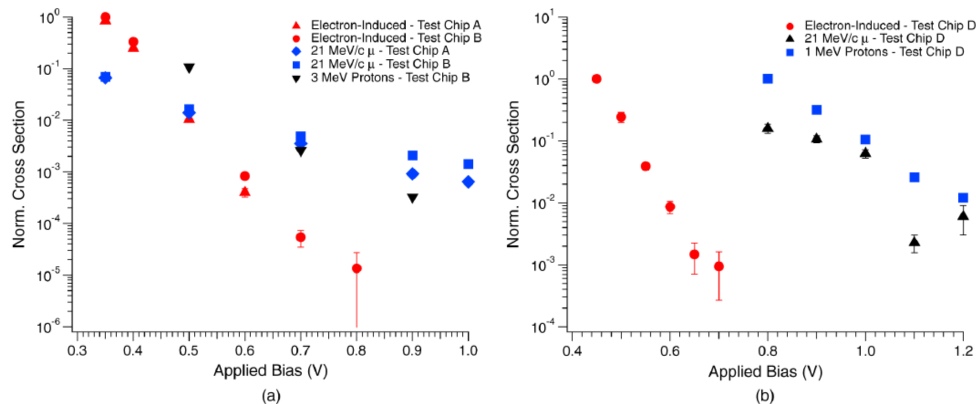

Fig. 9. SEU cross-section dependence on supply voltage for electron-induced SEU cross sections observed during X-ray irradiation, compared with low-energy protons and muons in (a) 28 nm and (b) 45 nm SRAMs. Data shown are normalized to X-ray data at 0.35 V for Test Chips A and B, and 0.45 V for Test Chip D. Results show that, under nominal bias conditions, protons and muons are capable of inducing upsets in 28 nm and 45 nm SRAM while this sensitivity is absent for energetic X-ray electrons generated during X-ray exposure. Under reduced bias conditions, electron-induced SEUs exhibit a larger dependence on supply voltage than muons and protons in the 28 nm and 45 nm technology nodes.

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Timeline - 2014

- **Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology**,
  A. Samaras; P. Pourrouquet; N. Sukhaseum; L. Gouyet; B. Vandevelde; N. Chatry; R. Ecoffet; F. Bezerra; E. Lorfevre, IEEE TNS, 2014, Vol. 61, Issue: 6

- **First experimental evidence using direct mono-energetic beam**

- **Tests performed at NPL, UK using Clinical Elekta Linac (4 to 20 MeV)**
- **Test range 10 to 20 MeV**
- **45 nm FPGA**

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Timeline - 2014

- **Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology**,
  A. Samaras; P. Pourrouquet; N. Sukhaseum; L. Gouyet; B. Vandevelde; N. Chatry; R. Ecoffet; F. Bezerra; E. Lorfevre, IEEE TNS, 2014, Vol. 61, Issue: 6

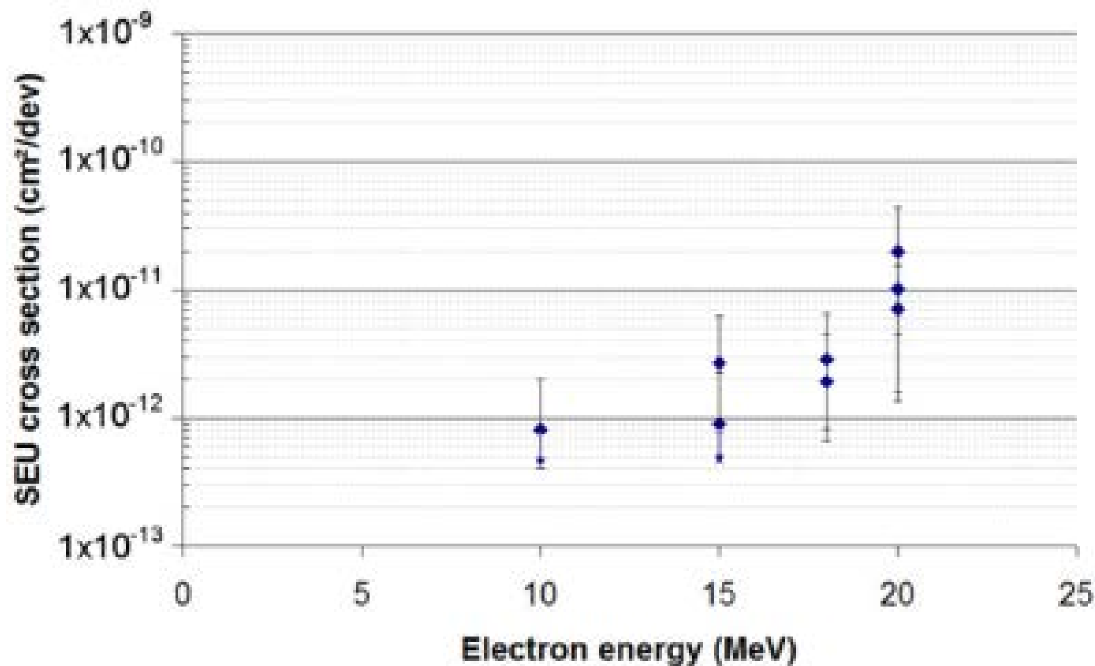

Fig. 5. SEU Cross section curve on FPGA 45 nm embedded RAM under high energy electrons.

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Timeline - 2014

- **Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology**,
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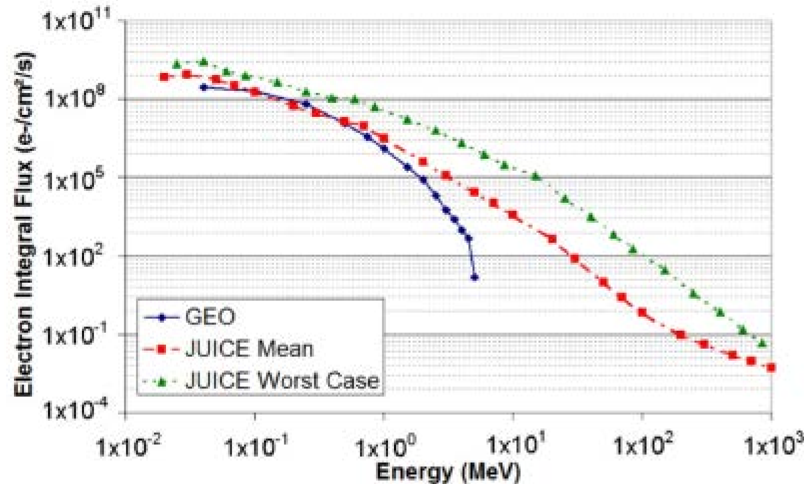

Fig. 7. Electron flux comparison between geostationary and Juice missions.

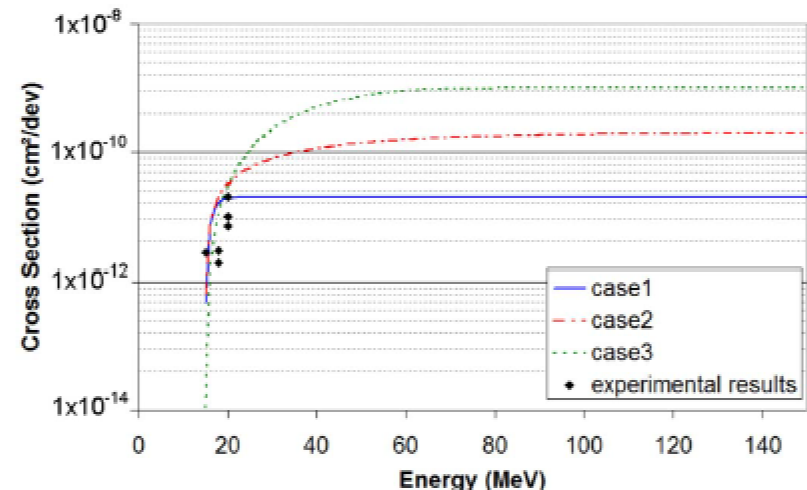

Fig. 9. SEU cross section curves considered for SEU rate calculation with the OMERE Software.

TABLE VI
SEE RATES FOR JUICE ELECTRON ENVIRONMENT FOR THE STUDIED CASES USING OMERE SOFTWARE

	SEE rate for worst case flux (per device per day)	SEE rate for average flux (per device per day)
Case 1	1.07×10^{-1}	2.26×10^{-3}
Case 2	3.8×10^{-1}	7.38×10^{-3}
Case 3	1.34	2.43×10^{-2}

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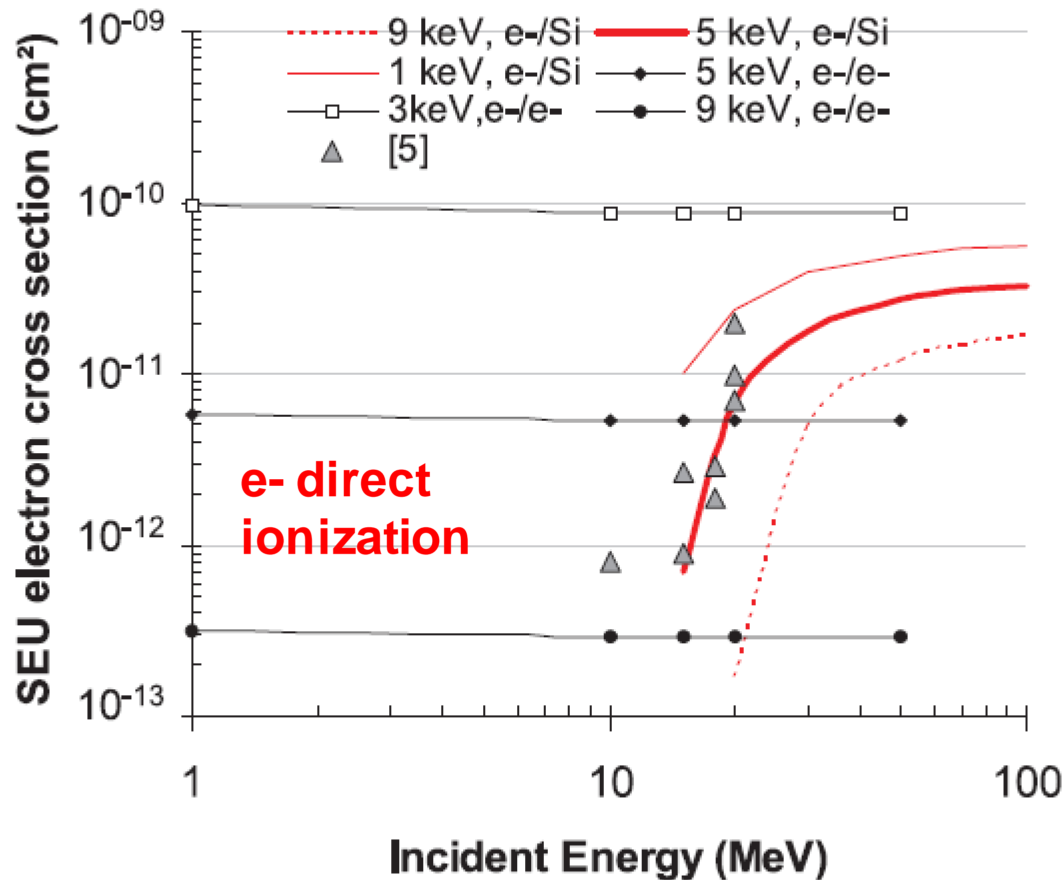
Timeline - 2015

- **Electron-Induced Single Event Upsets in 28 nm and 45 nm Bulk SRAMs**, J. M. Trippe; R. A. Reed; R. A. Austin; B. D. Sierawski; R. A. Weller; E. D. Funkhouser; M. P. King; B. Narasimham; B. Bartz; R. Baumann; J. Labello; J. Nichols; R. D. Schrimpf; S. L. Weeden-Wright, IEEE TNS, 2015, Vol. 62, Issue: 6

- **Electron Induced SEUs: Microdosimetry in Nanometric Volumes**, C. Inguimbert; R. Ecoffet; D. Falguère, IEEE Transactions on Nuclear Science, Year: 2015, Volume: 62, Issue: 6, Pages: 2846 - 2852

Timeline - 2015

- **Electron Induced SEUs: Microdosimetry in Nanometric Volumes**, C. Inguimbert; R. Ecoffet; D. Falguère, IEEE Transactions on Nuclear Science, Year: 2015, Volume: 62, Issue: 6, Pages: 2846 - 2852



e- / Si nuclear reactions

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Recent works

- **CNES continues the works started in 2013**
- **ESA started a similar study in 2015 on 2 test vehicles**
- **Harmonized action :**
  - **Cross test benches**
  - **Cross sources and beams**
  - **Maris Tali Phd works starts 2015**
  - **Pablo Caron PhD works starts 2016**

- **Mono-energetic electron-induced single event effects at the VESPER facility,** Maris Tali et al., RADECS 2016

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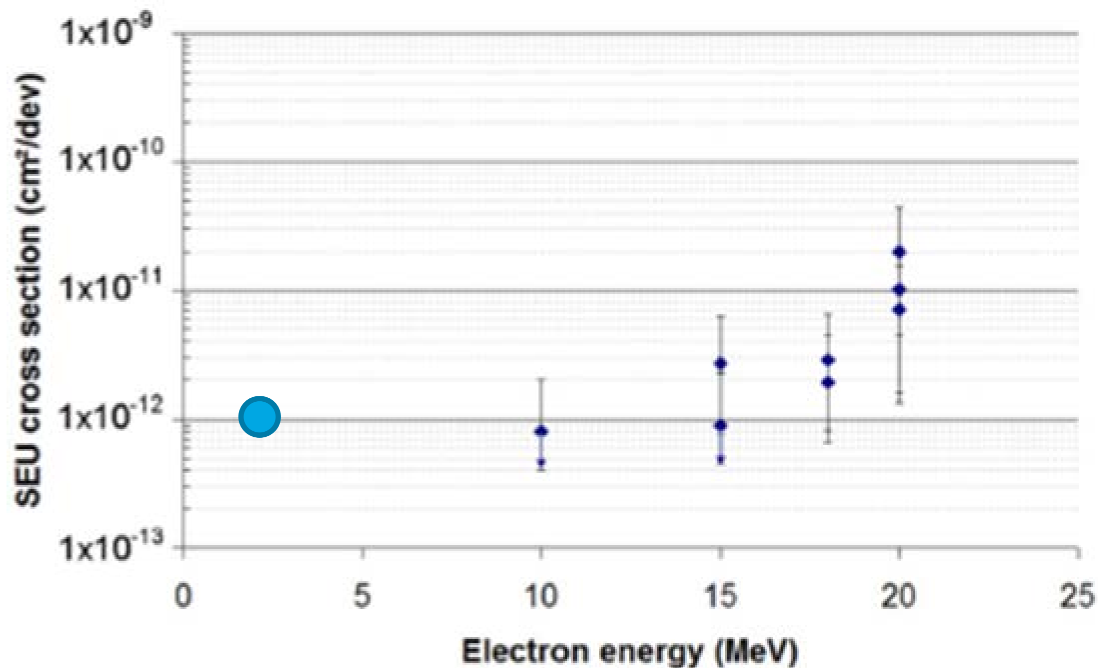
Latest results

- 2 MeV irradiation at ONERA
- Planned 6 – 20 MeV at Carcassonne Hospital



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