RADSAGA

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Electron-induced SEEs in SDRAMs and dosimetry of a pulsed electron beam

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RADSAGA Final Conference and Industrial event

Daniel Söderström, RADSAGA ESR 2, Work Package #1

RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators (RADSAGA) is a project funded by the European Commission under the Horizon2020 Framework Program under the Grant Agreement 721624.
RADSAGA began in Mars 2017 and will run for 5 years.

Presentation outline

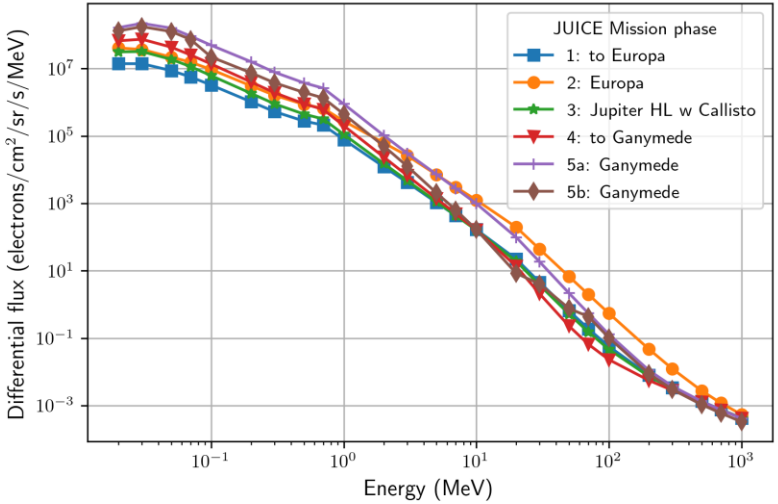
- ESR 2 project
- Electron-induced stuck bits in SDRAMs
  - Irradiation facilities
  - Electron-induced SEE
  - Jovian environment
- Optical fiber-based dosimetry
  - Response to a pulsed electron beam
  - Emission spectra
  - Dose rate dependence

Project of ESR 2

- Based in the University of Jyväskylä, Department of Physics, RADEF
- Project surrounding electron environments
  - Electron radiation effects studied in SDRAMs
  - Dosimetry using optical fiber-based systems
- Co-supervised from and collaboration work with
  - Laboratoire Hubert Curien, Saint Etienne
  - LIRMM, Montpellier

Electron irradiation of SDRAMs

- Motivated by the JUICE mission
- A mission candidate component tested

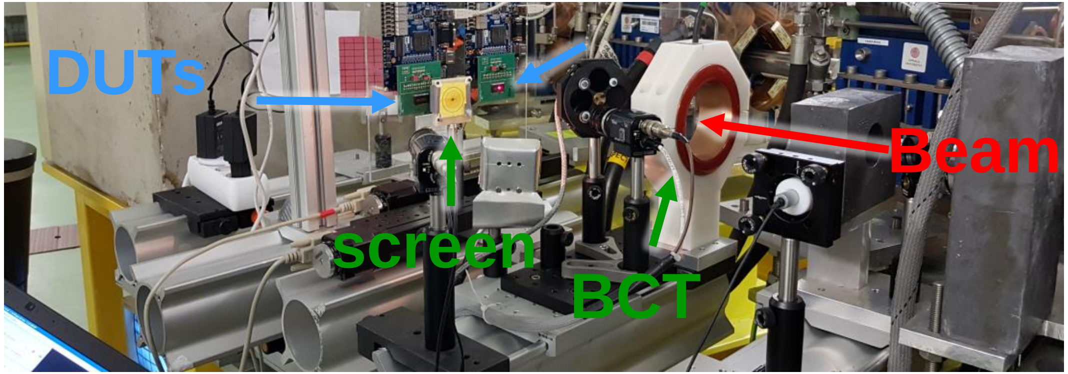


Hard energy spectrum in the Jovian electron environment

Data from JUICE environment specification, European Space Agency (ESA)/ESTEC, Revision 5 Issue 5, Feb. 2017, reference JS-14-09.

Test facilities: VESPER at CERN

- ❑ Electron energy: 60 – 200 MeV



VESPER beam parameters	Pulse frequency	Pulse length	Bunch frequency	Beam dosimetry
	10 Hz	100 bunches	3 GHz	Beam current measured by a beam current transformer, beam spot shape from a scintillating screen

Test facilities, Clinac at RADEF

- Electrons:
  6 – 20 MeV
- Photons:
  Bremsstrahlung

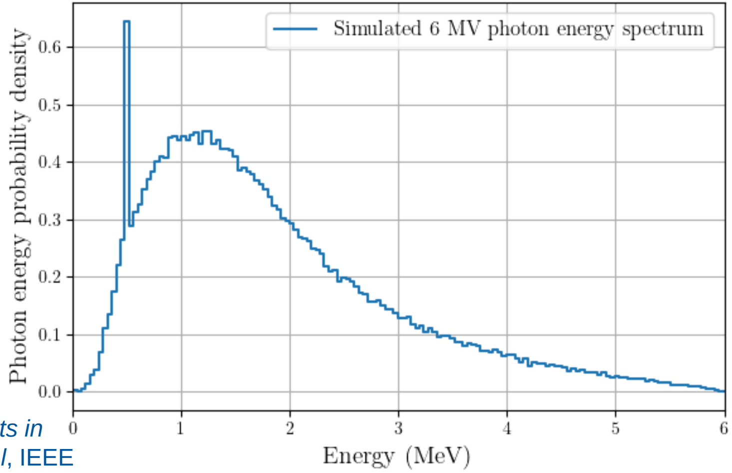


Figure source: *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021.

RADEF beam parameters	Pulse frequency	Pulse length	Beam dosimetry
	< 200 Hz	5 µs	In-beam ionization chambers, calibrated against absolute dosimeters in water.

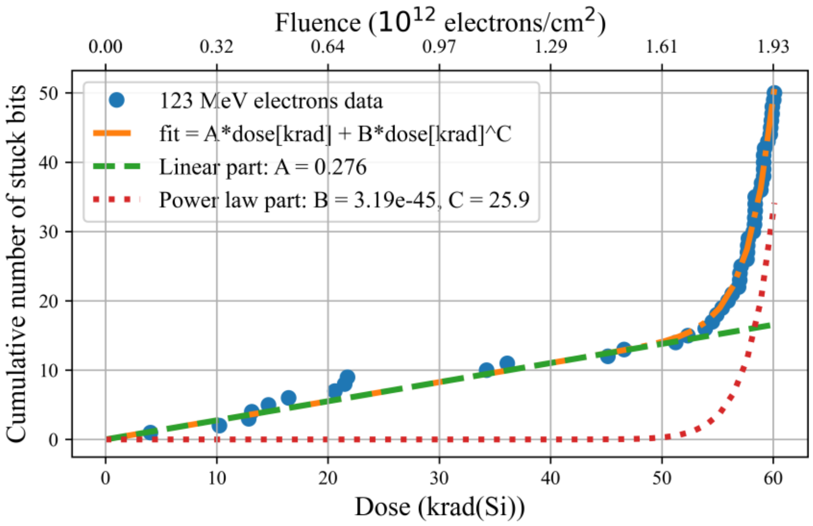
Tested components

- ❑ 512 Mb ISSI SDRAMs
  - ❑ IS42S86400B most tested and most sensitive

Memory	Node size	Irradiation field	Irradiation energies
IS42S86400**B**	110 nm	Electrons Photons	6 – 200 MeV 6 MV
IS42S16320**D**	72 nm	Electrons	200 MeV
IS42S16320**F**	63 nm	Electrons	200 MeV

SEE induced by high-energy electrons

❑ Stuck bits and bit-flips

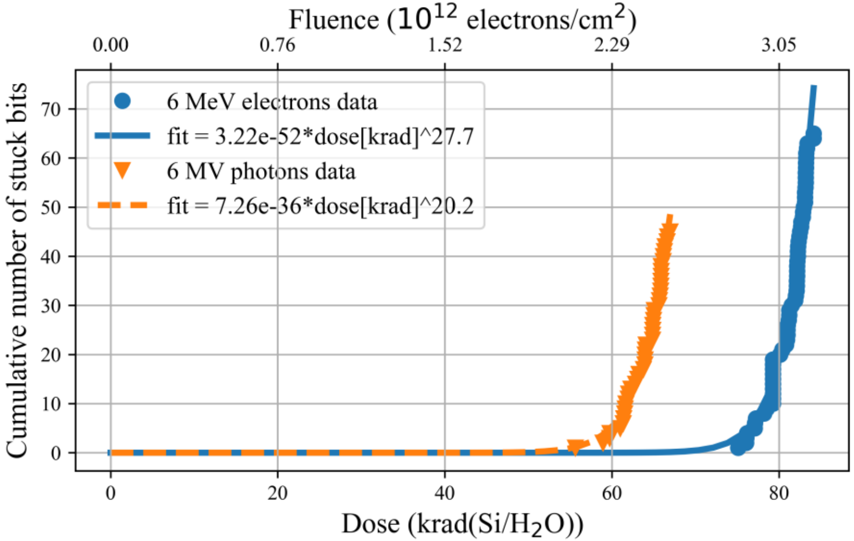


- Sample IS42S86400**B**
- Stuck bits as a function of 123 MeV electron fluence.
- Similar look for bit-flips
- Linear part from SEE
- Power law increase from cumulative effects

Figure source: *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021.

Low-energy electron irradiation

- ❑ No SEE observed, only cumulative effects

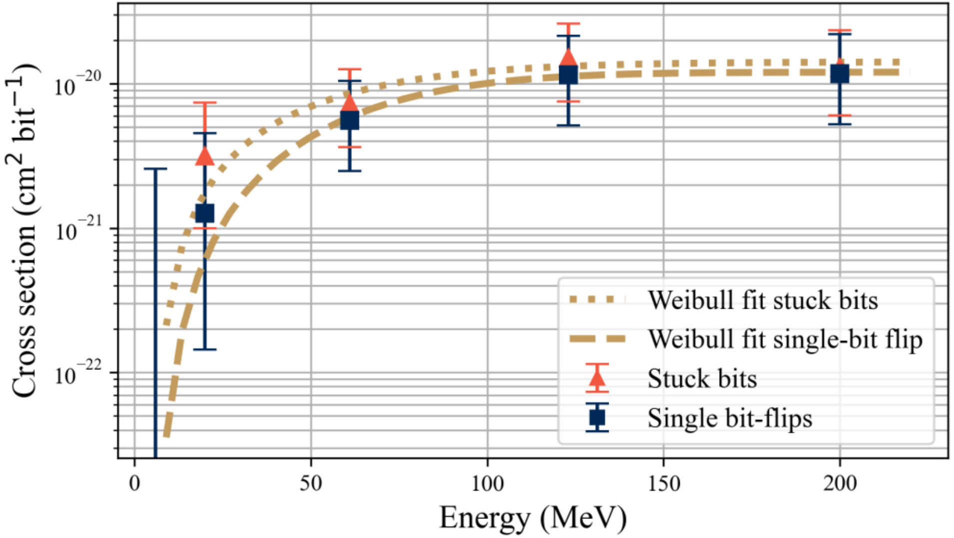


- Dose in krad(Si) for electrons, and krad(H_2O) for photons

Figure source: *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021.

Electron SEE cross sections

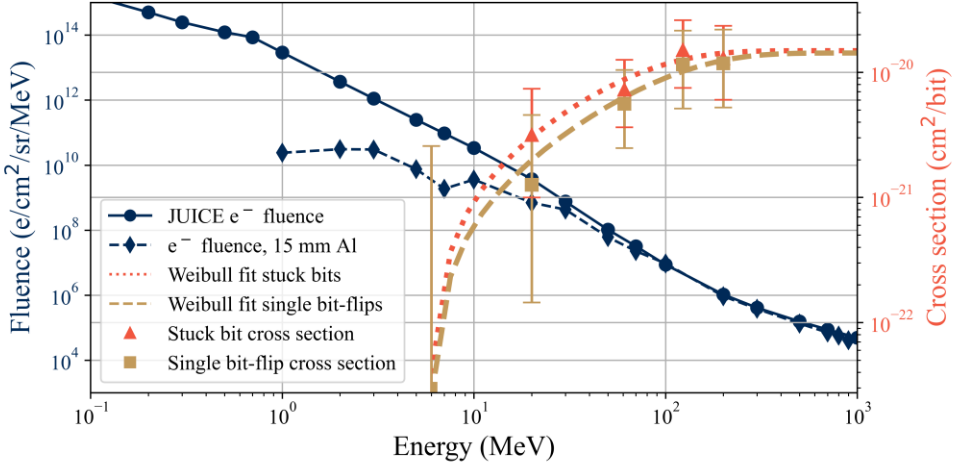
- Similar values for stuck bits and bit-flips



Weibull parameter	Stuck	Bit-flip
A (10^{-20} cm^2/bit)	1.41	1.20
E_0 (MeV)	6.0	6.0
W (MeV)	57.9	68.3
s	1.41	1.86

Projected electron SEE on board JUICE

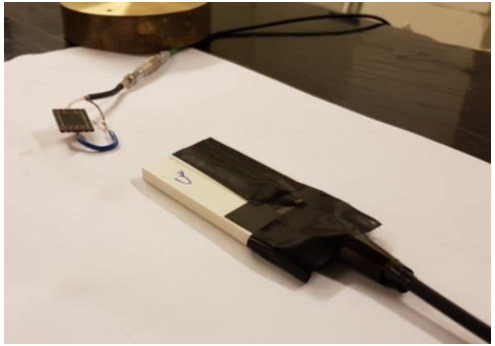
Fault	Errors without shielding	Errors with 15 mm Al shielding
Stuck bits	4.2	0.86
Bit-flips	4.0	0.81

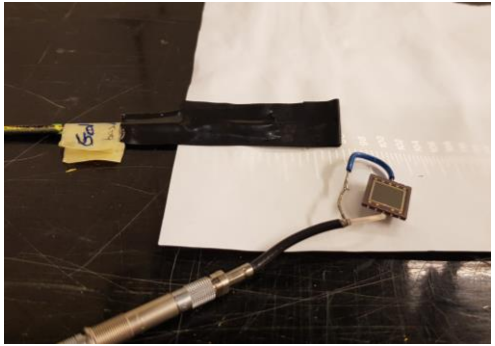


(Different fitting procedure than in *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021, but the results are similar.)

Fiber-based dosimetry in pulsed electron beams

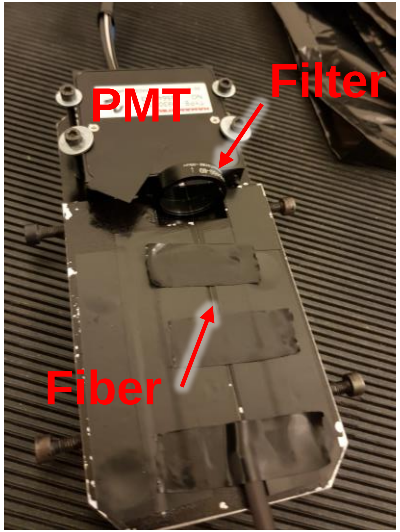
- ❑ Samples are doped silica rods connected to a transport fiber
- ❑ Dopants: Ce, Cu, and Gd





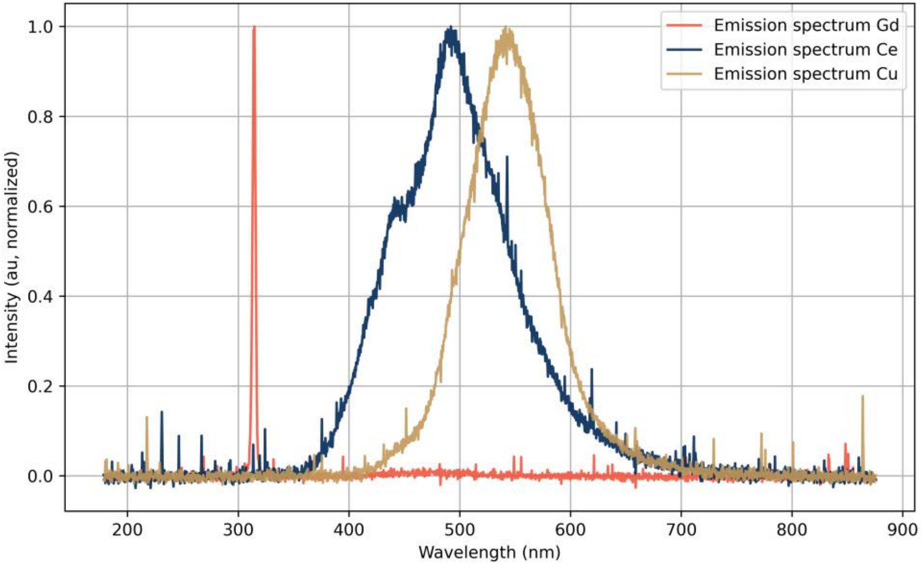
Tests and setups

- ❑ Readout systems for different purposes
  - ❑ Photomultiplier tube (PMT) to oscilloscope
    - ❑ Analyze traces with many pulses
  - ❑ PMT to digitizer
    - ❑ Analyze the structure of individual pulses
  - ❑ Light signal to spectrometer
    - ❑ Analyze the optical emission spectra



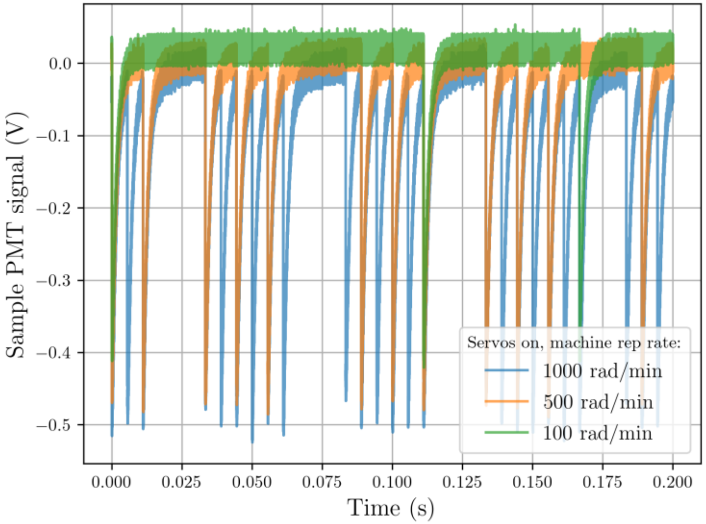
Emission spectra

- ❑ Excited by 20-MeV electrons
- ❑ Peaks at
  - ❑ Gd: 314 nm
  - ❑ Ce: 494 nm
  - ❑ Cu: 543 nm

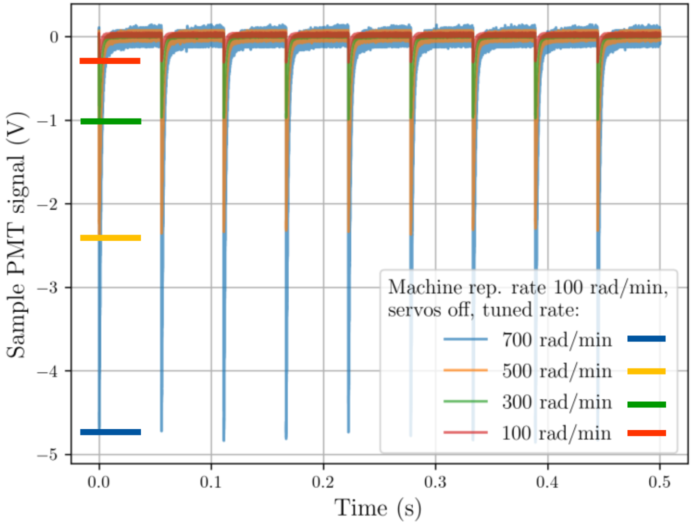


Accelerator parameters

- ❑ Non-standard operation of the accelerator



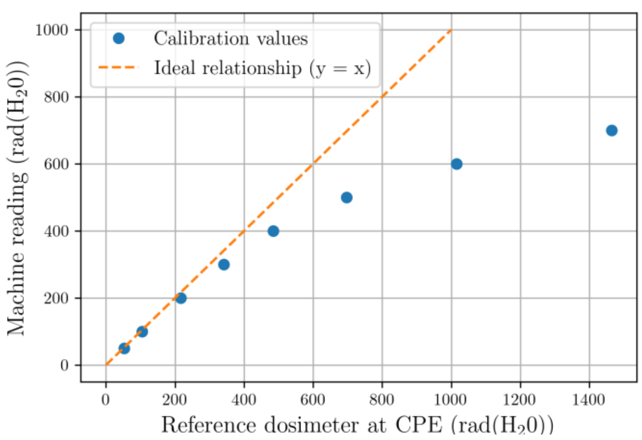
Normal dose rate tuning

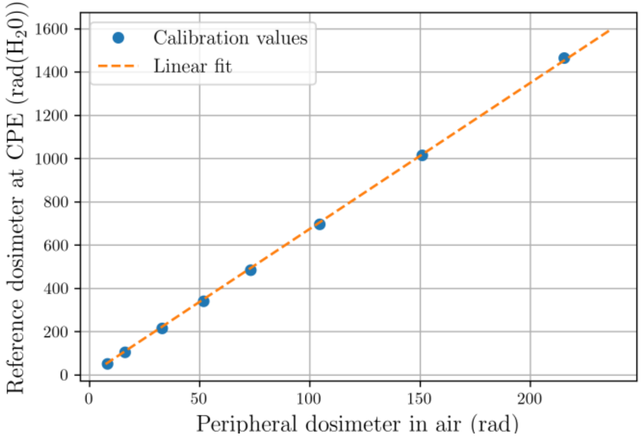


Dose rate tuning here

Machine dose calibration

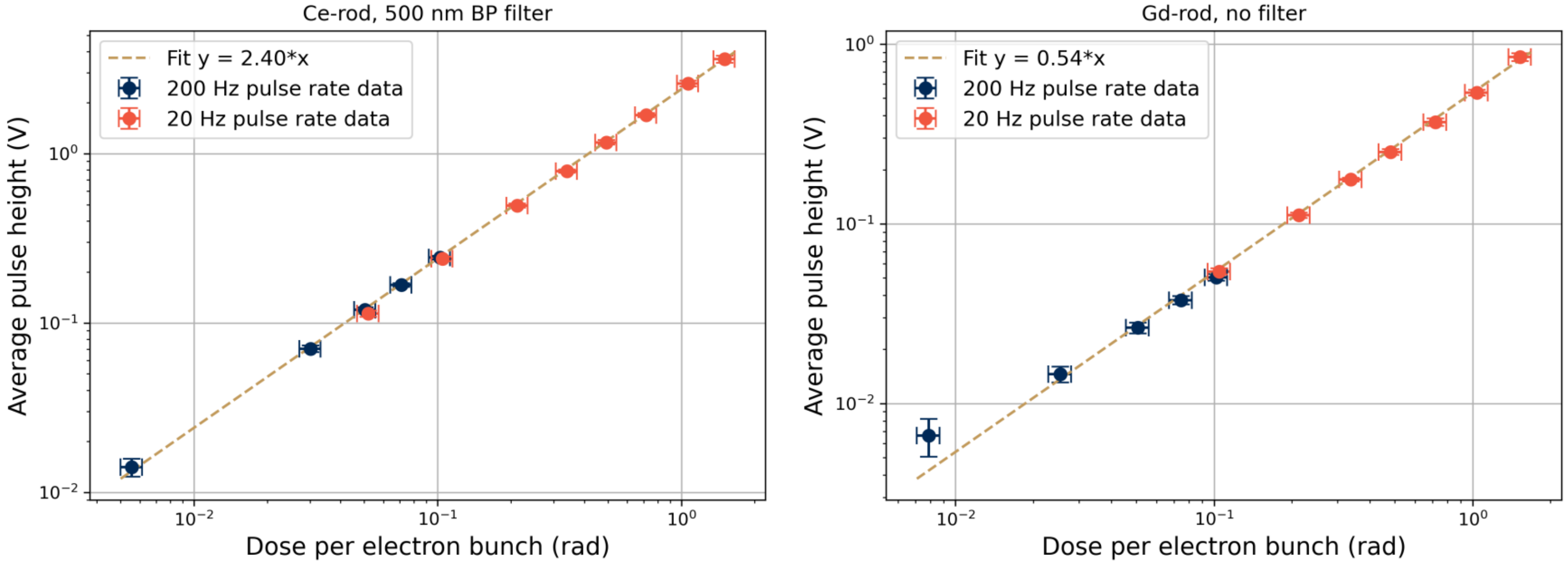
- ❑ Built-in ionization chambers diverted from linearity at larger electron pulses
- ❑ Data for tests of one minute duration, with increasing electron bunch sizes at a constant frequency





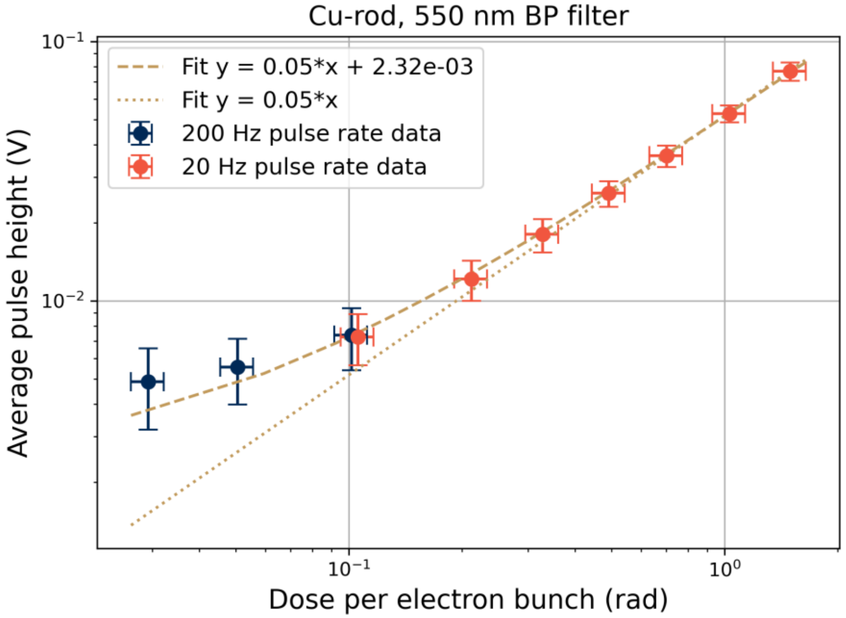
Fiber signal at different electron bunch sizes

- Pulse height as a function of bunch size



Fiber signal at different electron bunch sizes

- ❑ Pulse height with thin transport fiber (50 µm)



Small bunches are dominated by the noise.

Conclusion

- Electrons can cause stuck bits in SDRAMs as SEE
- Electron SEE is not a big problem for the tested device in the Jovian environment
- The doped silica rods have a linear response of luminescence vs electron bunch size (mrad – rad)
  - Can be used to monitor pulsed radiation from a Clinac

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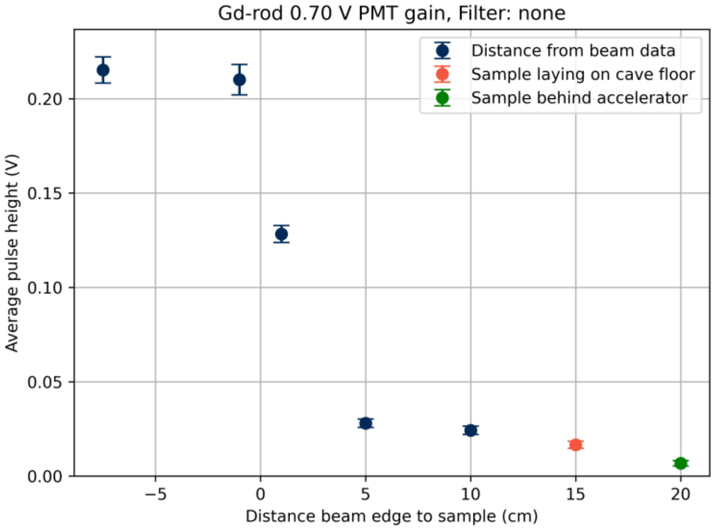
Thank you for your attention

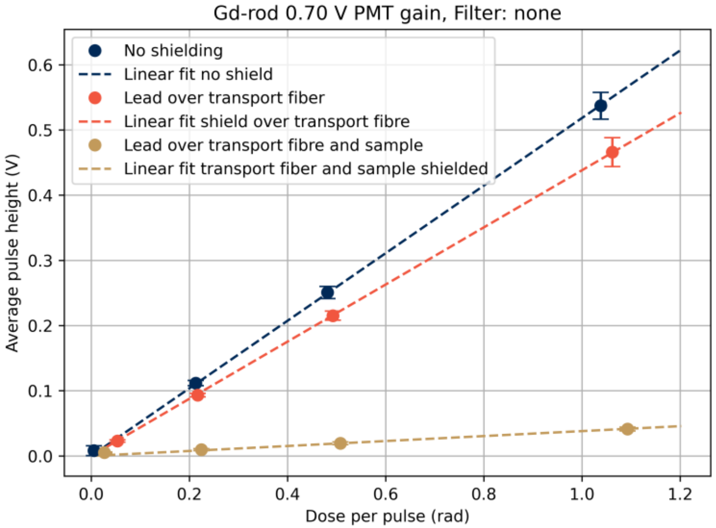
Thanks to all collaborators who have
helped in experiments and analysis.

Backup slides

Rods in clinac beam

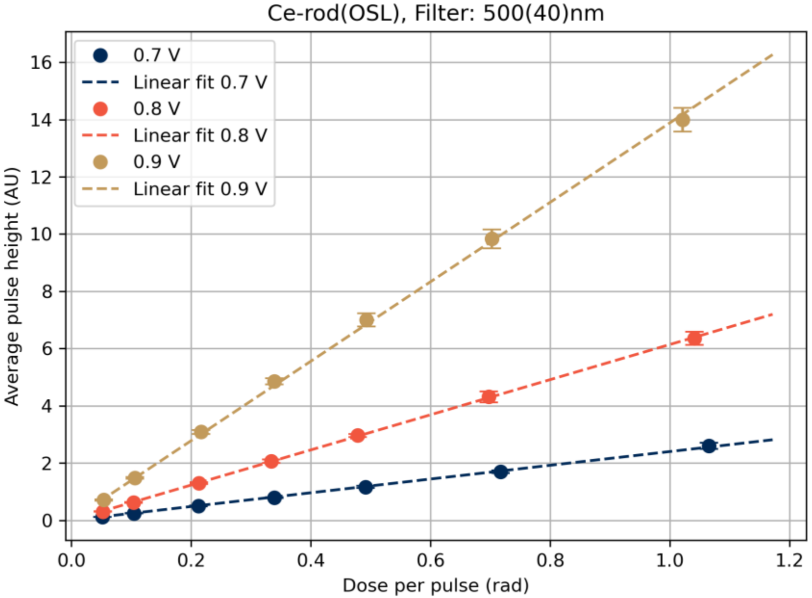
❑ Sample in different configurations


Gd-rod 0.70 V PMT gain, Filter: none


Gd-rod 0.70 V PMT gain, Filter: none

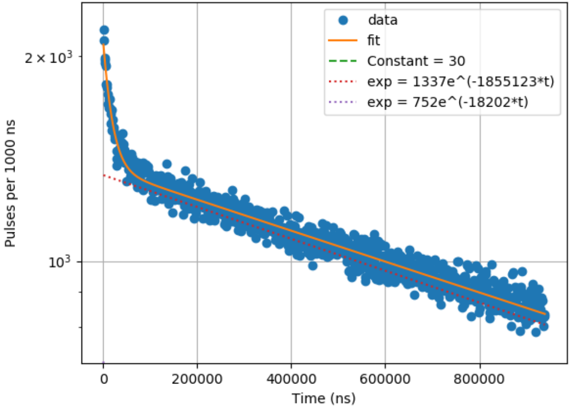
Impact of PMT gain voltage

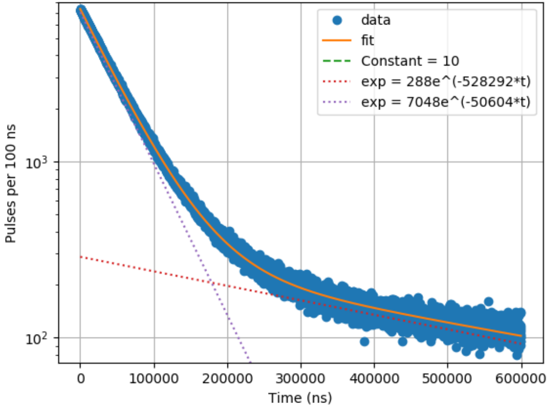
- The PMT gain might affect linearity

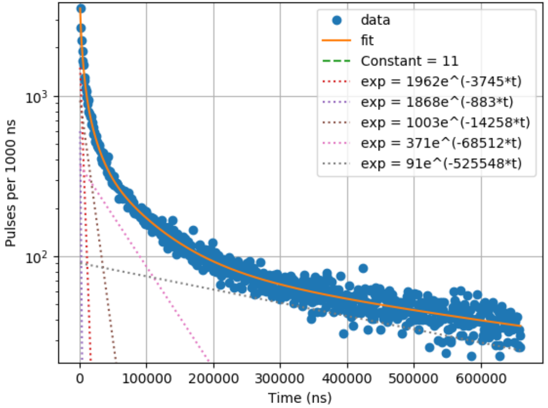


Decay time plots

- Gd, Cu, and Ce samples

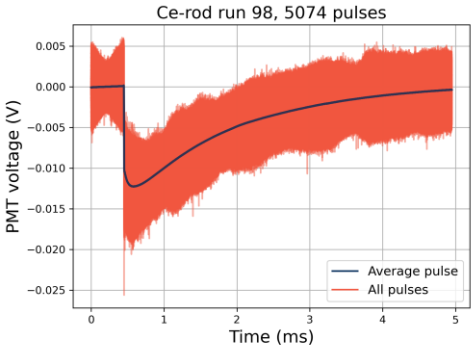


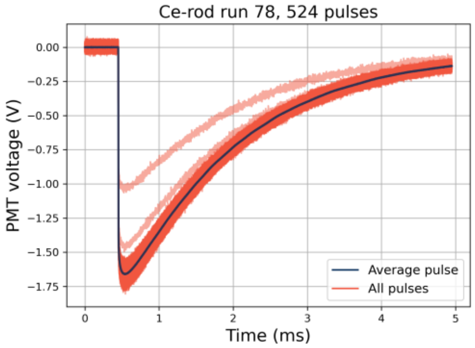




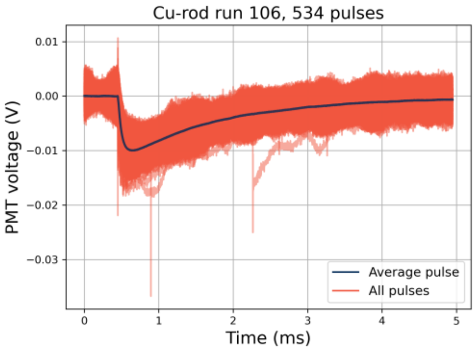
Collected pulses in oscilloscope

Ce sample


Ce-rod run 98, 5074 pulses

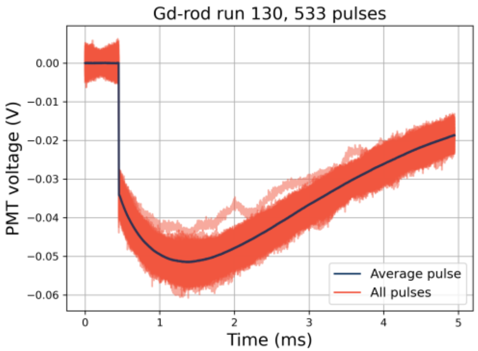

Ce-rod run 78, 524 pulses

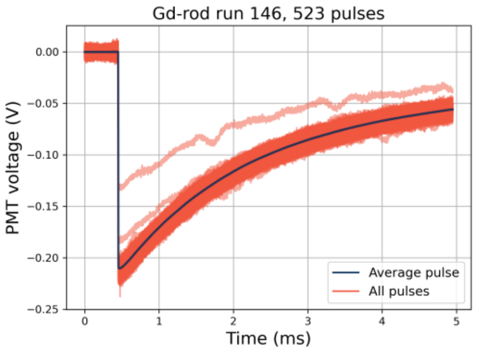
Cu sample


Cu-rod run 106, 534 pulses


Cu-rod run 123, 524 pulses

Gd sample


Gd-rod run 130, 533 pulses


Gd-rod run 146, 523 pulses

Memory cell damage in different bit populations

- ❑ Comparison of three different populations:
  - ❑ Stuck bits (SEE)
  - ❑ Single bit-flips (SEE)
  - ❑ All bits
- ❑ Bits which were either stuck or had a bit-flip show reduced data retention capabilities compared to the global population
- ❑ The stuck bits generally fail at higher refresh frequencies than the flipped
- ❑ The stuck and flipped populations show signs of being damaged in a similar fashion during irradiation
- ❑ The mechanism behind both failure modes is likely one and the same, differing mainly in the severity of the event.

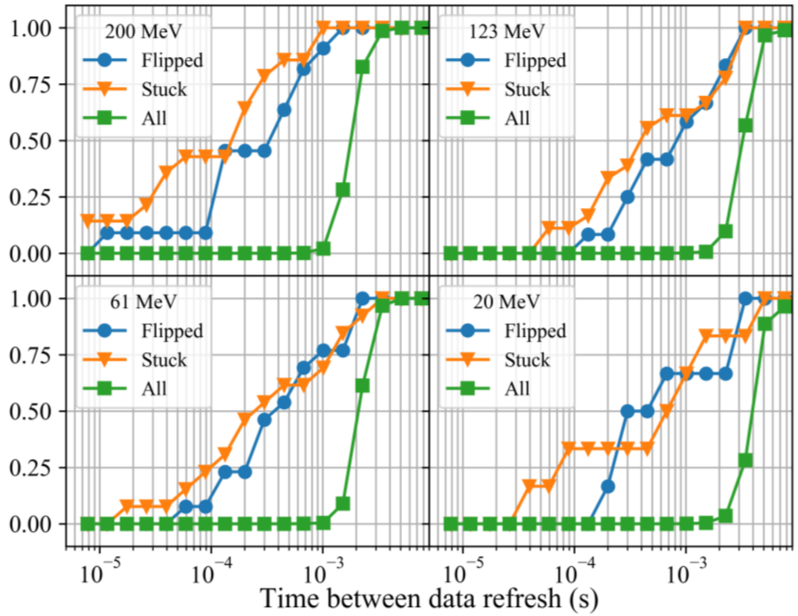


Figure: Fraction of the total number of words containing failing bits in different populations in the memory in a post-irradiation test, performed using different refresh frequencies in the memories. Data from four model B memories tested with different electron energies.

Figure source: *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021.

SDRAM annealing

❑ Annealing of irradiated samples

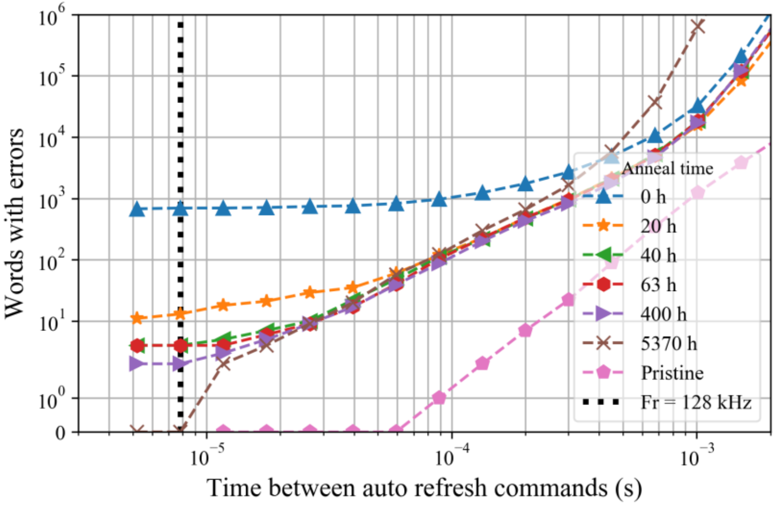


Figure source: *Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment*, Söderström *et al*, IEEE TNS, Early access, 10.1109/TNS.2021.3068186, 2021.