



YOSEMITE SPACE

Single Event Effects Induced by High Energy Protons in Gumstix

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<http://yosemitespace.com/>

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Team:

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Benefits of Gumstix in Space

- Small form factor:
 - Gum stick sized
 - Low power consumption (<1W)
 - PoP NAND and RAM enables board size
- Uses OMAP processors with ARM Cortex-A8 architecture
- Worked well in NASA's IPEX Cubesat mission
- Evaluated on ground and in space for radiation effects by Yosemite Space
- Being studied for use in the Dependable Multiprocessor (DM) by Honeywell.



IPEX

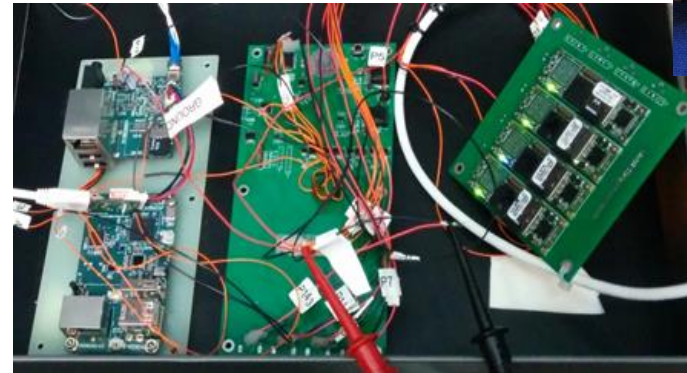
Ref: <http://polysat.calpoly.edu/launched-missions/cp8-ipex/>
<https://directory.eoportal.org/web/eoportal/satellite-missions/>

The Gumstix™ Low Earth Orbit (LEO) study is an important step towards their use in a fault tolerant computers.

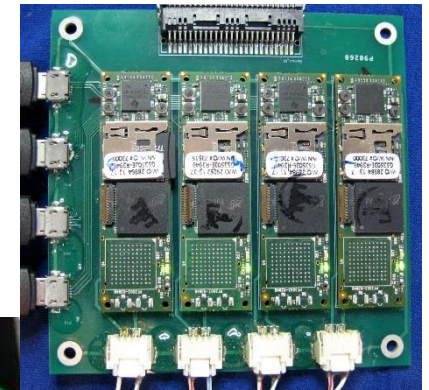
Ground and Space Based Testing

- Models tested include Earth, SandStorm and Water
- External watchdog detects SEEs, records and does a hard reboot
- ***Proton testing complete***
- Space Test on NREP – 9/15
- Payload Return - 2016

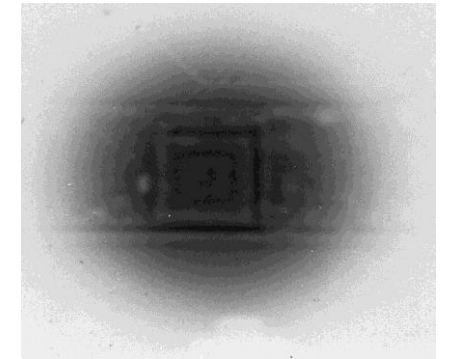
Flight Boards



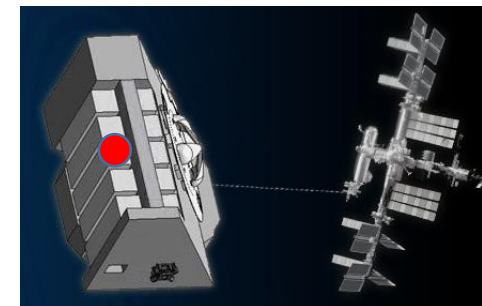
Gumstix Payload



Gumstix Radiograph



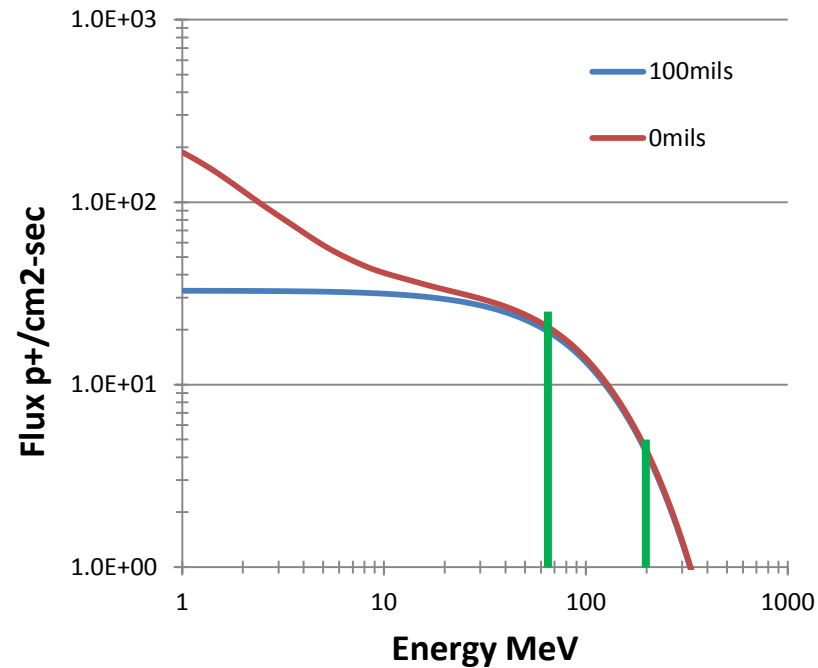
Nanoracks External Platform (NREP)



SEE Testing

Integral Proton Flux for LEO mission:

- Solar Max and Trapped



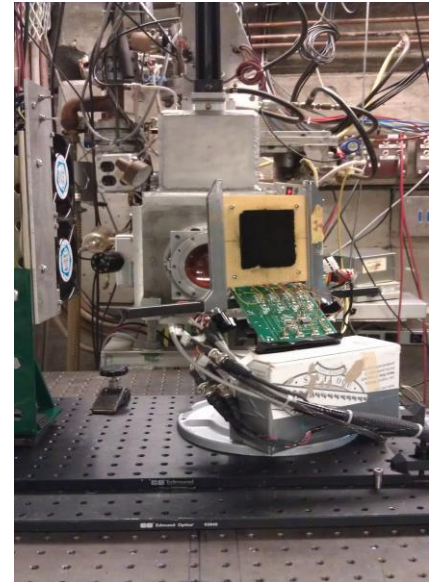
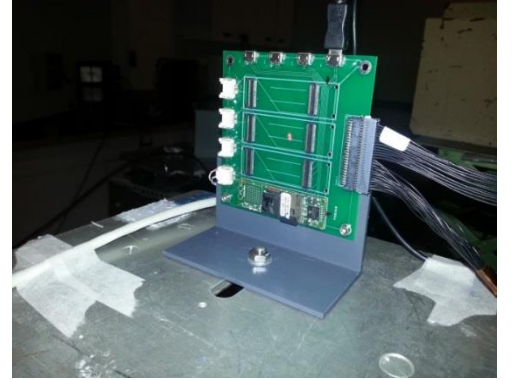
Proton Testing at Crocker Nuclear Labs (CNL) and Mass General Hospital (MGH):

Model	Model ID	Lot Number	Proton Energy (MeV)	Test facility
Water	W3	72949	64.0	CNL
Water	W1	72949	64.8	MGH
Water	W4	72949	200.3	MGH
Earth	E3	73000	64.0	CNL
Earth	E1	73000	64.8	MGH
Earth	E5	73515	200.3	MGH
SandSTORM	S1	72281	64.0	CNL
SandSTORM	S5	72281	64.8	MGH
SandSTORM	S6	72281	200.3	MGH



SEE Testing

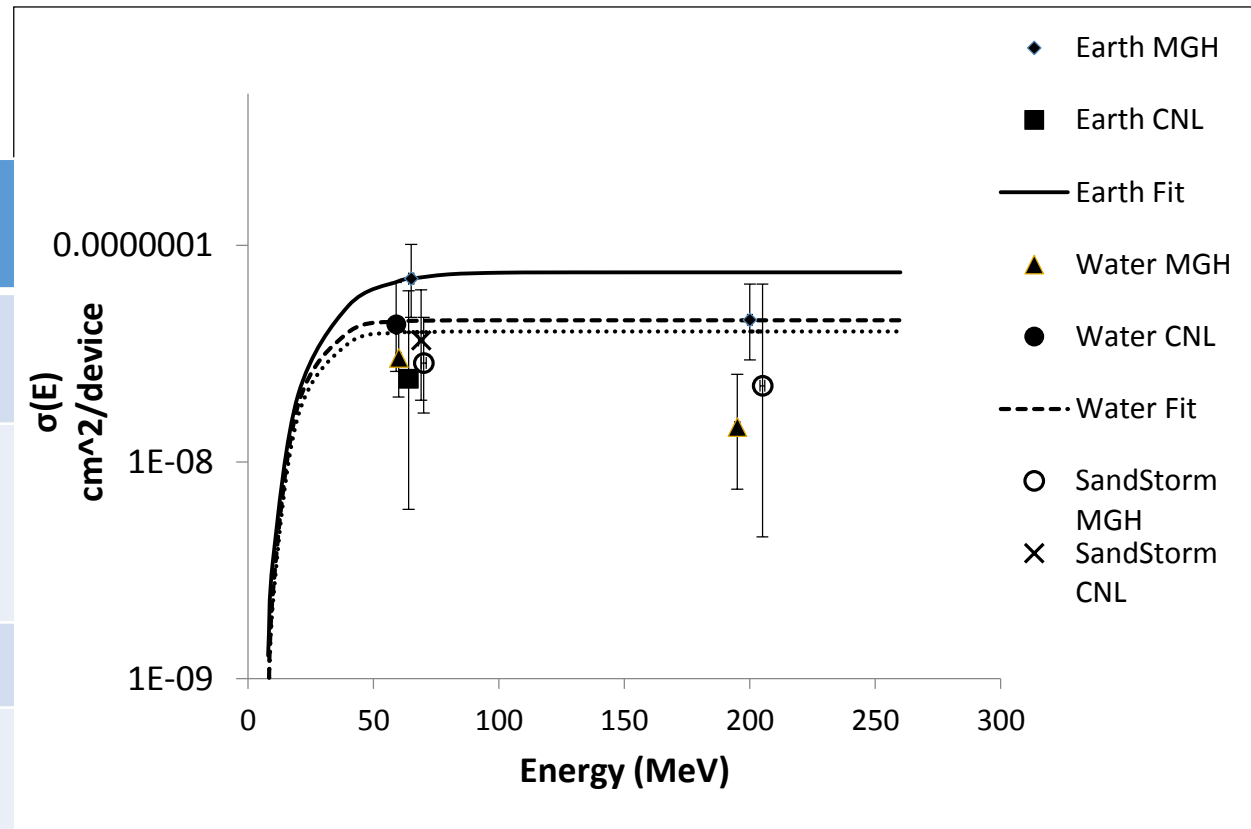
- Real time data acquisition during radiation exposure determines rate of SEEs
- Yosemite Space hardware and software monitors and records current draw (power consumption), application heartbeat (if present) and the SEU test suite results
- SEU Test Suite
 - Includes Matrix Multiply, Workload and NEON tests
 - The suite logs:
 - number of errors generated
 - test duration
 - net time that the system has been running since the last reboot
 - Each log entry is time stamped and written to a microSD card
 - If the SEU test ran but generated no errors, 1 error was assigned to that test



Test Results: Matrix Multiply

Exercised the arithmetic logic unit (ALU) of the CPU.

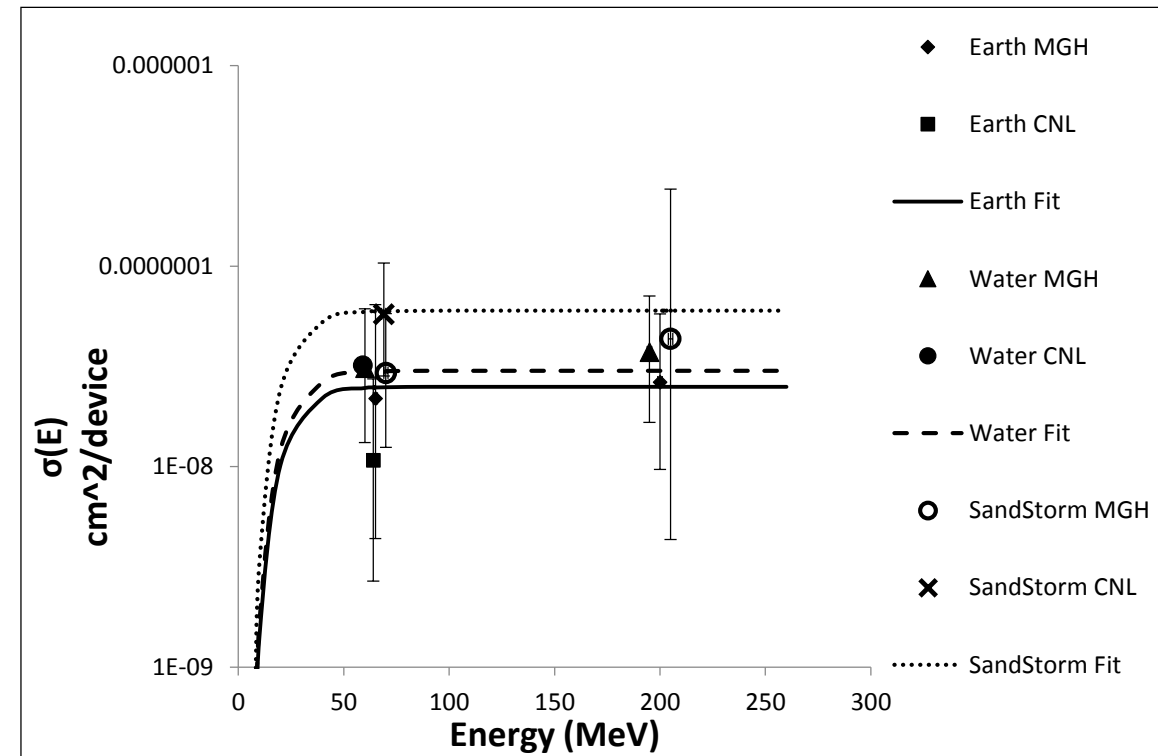
Weibull Fit Parameters	Earth	Water	Sand STORM	Units
Onset Energy	6	7	7	MeV
Saturation Cross-Section	7.50E-8	4.50E-8	4.0E-8	cm ² /device
Width	30.0	20.0	20.0	MeV
Shape Factor	1.5	1.5	1.5	-



Test Results: Workload

- The Workload test exercised the majority of SDRAM, the ALU and the MMU
- Earth and Water accessed 78% of the SDRAM. Only 57% of the SDRAM was exercised on the SandSTORM.

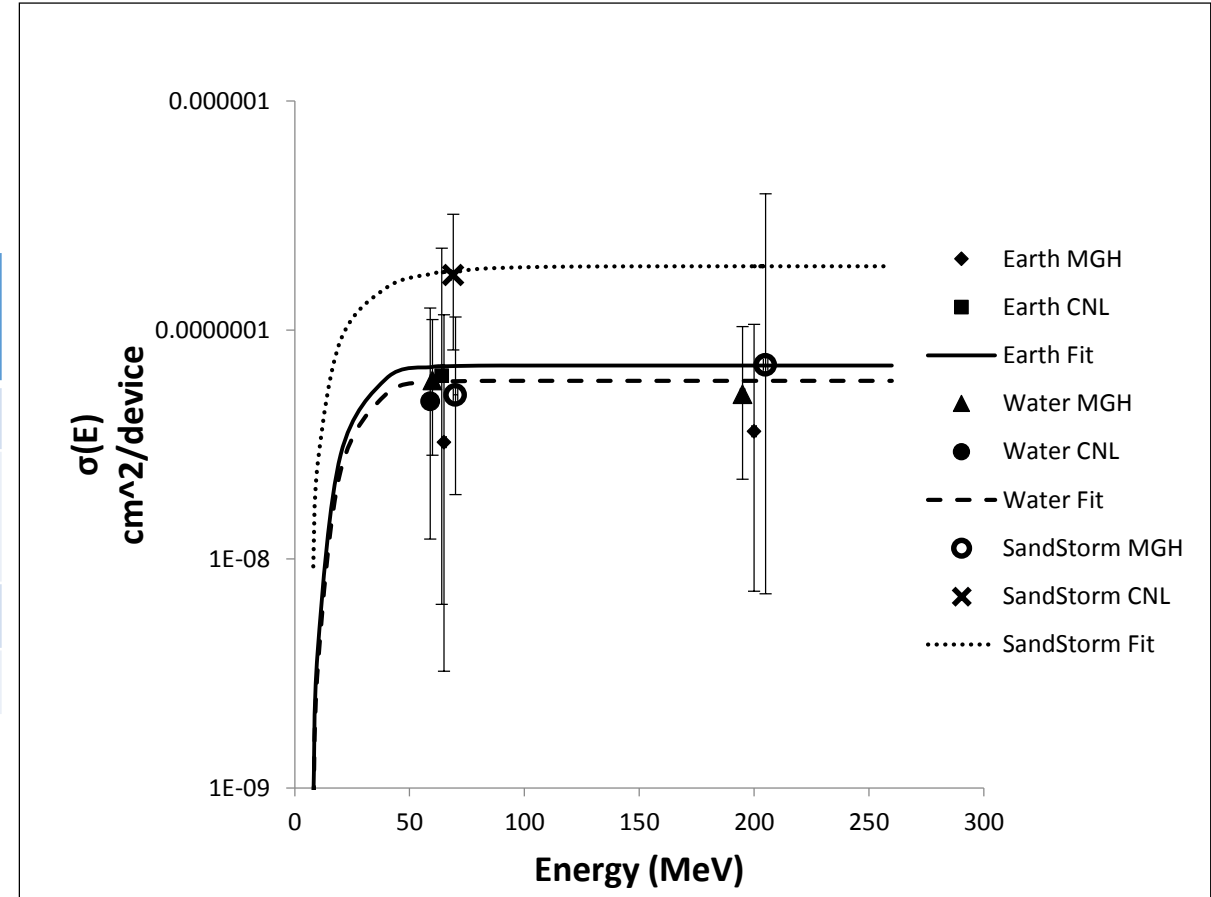
Weibull Fit Parameters	Earth	Water	Sand Storm	Units
Onset Energy	7	7	7	MeV
Saturation Cross-Section	2.50E-8	3.00E-8	6.0E-8	cm ² /device
Width	20.0	20.0	20.0	MeV
Shape Factor	1.5	1.5	1.5	-



Test Results: NEON

- Exercises the NEON and FPU subsystems

Weibull Fit Parameters	Earth	Water	Sand STORM	Units
Onset Energy	7	7	7	MeV
Saturation Cross-Section	7.00E-8	6.00E-8	1.9E-7	cm ² /device
Width	20.0	20.0	20.0	MeV
Shape Factor	1.5	1.5	1.0	-



Estimated SEE rate over 180 Day mission

Gumstix Model	Processor Model	SEU Rate			SEFI Rate	SEL Rate
		Matrix Multiplier	Workload	NEON		
SandSTORM	Sitara AM3703	P: 17, H:35	P: 26, H: 52	P: 82, H:163	P: 1.7	P: 20.4
Water	OMAP 3530	P: 20, H:39	P: 13, H: 26	P: 26, H:52	*	*
Earth	OMAP 3503	P: 31, H:61	P: 11, H:22	P: 31, H:61	P:1.1	*

- Fitted proton data, Crème 96, and SPENVIS are used to predict these rates
- FOM approach estimates 2 SEU from heavy ions for any 1 SEU event from protons
 - An average of 85 SEUs are expected during a 180 day mission.
 - SEFI and SEL rates from heavy ions can only be determined from heavy ion testing and space testing



PoP DRAM Testing: Stuck bits

- DRAM exercised during proton radiation exposure.
- All devices passed their memory tests prior to radiation exposure.
- All devices failed their memory tests after exposure to 64.8MeV and 64MeV proton radiation.
- Months later, the number of stuck bits was quantified.
- Most stuck bit annealed out after 12 hour, unbiased at 85C. This indicates a microdosing mechanism.

GS Label	fluence	Stuck bits			TEST FACILITY	Energy (MeV)	Date of Exposure	Stuck Bits Post Anneal	Date of Analysis
W3	3.22E9	2	3	3	CNL	64	8-1-13	1	12.5 months
W2	2.52E9	2	3	3	CNL	64	8-1-13	0	12.5 months
W1	3.28E9	3	4	4	MGH	64.8	1-25-14	1	8 months
W4	1.63E9	0	0	0	MGH	200.3	1-25-14	0	8 months
E3	1.03E9	0	0	0	CNL	64	8-1-13	0	12.5 months
E2	2.52E9	1	3	1	CNL	64	8-1-13	0	12.5 months
E1	2.23E9	3	1	1	MGH	64.8	1-25-14	0	8 months
E5	1.95E9	0	0	0	MGH	200.3	1-25-14	0	8 months
S1	9.67e8	0	0	0	CNL	64	8-1-13	0	12.5 months
S2	2.52E9	0	0	0	CNL	64	8-1-13	0	12.5 months
S5	2.45E9	1	1	1	MGH	64.8	1-25-14	0	8 months
S6	6.74E8	0	0	0	MGH	200.3	1-25-14	0	8 months
F3	2.52E9	3	2	2	CNL	64	8-1-13	0	12.5 months
F4	1.06E9	0	0	0	CNL	64	8-1-13	0	12.5 months

Conclusions

- No significant difference in SEU cross-sections between Gumstix models
- Earth and SandSTORM had similar SEFI rates. Water did not show any SEFI events at 200.3MeV
- SEL data was only obtained for the SandSTORM and Earth models. Water was tested under similar conditions but latch-up was not observed
- No catastrophic latch-up was observed
- Stuck bits in DRAM observed after proton exposures at 64MeV and 64.8MeV.

Acknowledgements

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- The project will be flown as an ISS National Laboratory flight experiment.
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- The authors would like to acknowledge Drs. Steve Guertin, Larry Edmonds and Philippe Adell for their input of the analysis of stuck bits in RAM.

