

Jet Propulsion Laboratory

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CubeSat Microcontrollers

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Outline

- **Status and Updates**
- **Microcontrollers Review**
- **MSP430**
- **PIC**
- **2016 plans**
- **Conclusions**



Status and Updates

- **Continuation from 2015**
- **Planned TID and SEL on non-EPI MSP430FR5739 for 2016**
- **Task Objectives**
 - **Provide SEE and TID test data on microcontrollers of interest for CubeSat and Small Missions**
 - **CubeSat Kit devices**
 - **Devices either flying or in designs being built**
 - **(and if enough interest, devices people would like to fly)**
 - **Future-looking devices**
 - **Focus is primarily on devices that are in designs right now – these are essentially the embedded market**



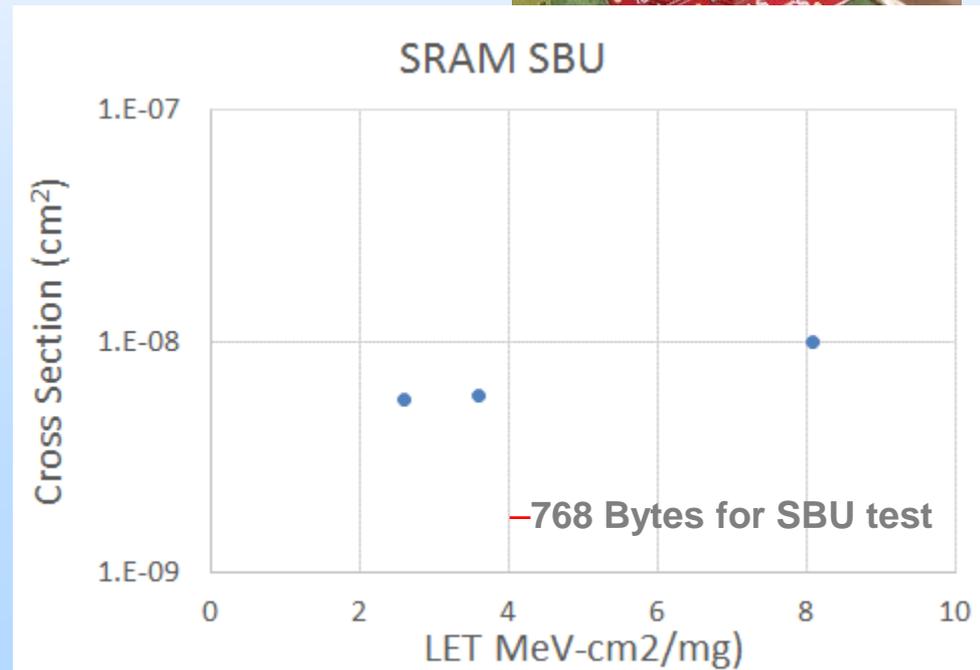
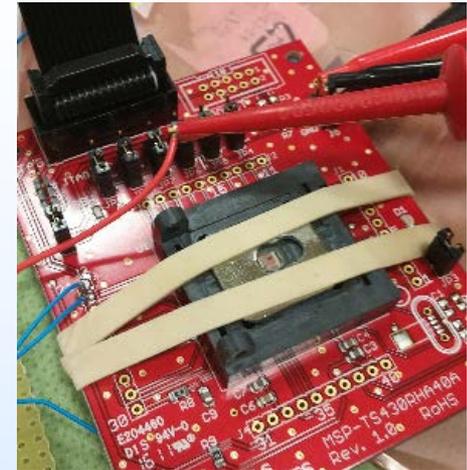
Microcontroller Review

Device	Manufacturer	CubeSat Kit	NASA Sats	Others	2015 Tests	TID conditions	2016 Tests	TID conditions
MSP430F1611	TI	X			SEE/SEL/TID	Unbiased/biased, Dynamic, reprogramming		
MSP430F1612	TI	X			SEE/SEL/TID	Unbiased/biased, Dynamic, reprogramming		
MSP430F1618	TI	X						
MSP430F2619	TI		X					
MSP430FR5739	TI			X	SEE/SEL			
MSP430FR5739 non-EPI	TI			X			SEL/TID	Unbiased/biased, Dynamic, reprogramming
C8051F120	Silicon Labs	X						
PIC24FJ256GA110	Microchip	X			SEE/SEL/TID	Unbiased/biased, Dynamic, reprogramming		
dsPIC33FJ256GP710	Microchip	X			SEE/SEL/TID	Unbiased/biased, Dynamic, reprogramming		
AT91SAM9G20	Atmel	X	X		SEE/SEL			
AT91SAM7	Atmel	X						
ATMEGA1281	Atmel	X						
ATMEGA164P	Atmel		X					
ATMEGA32U/8	Atmel		X	X				
ATMEGA16U2	Atmel			X				
Cortex-M3 MCU	ARM/General	X						
Other ARM9	ARM/General		X	X				
PX32A	Parallax	X	X					
ColibriPXA270	Intel/Marvel			X				
Sitara AM3505	TI		X					
Sitara AM3703	TI		X	X				



SEE/SEL performance of MSP430FR5739 EPI

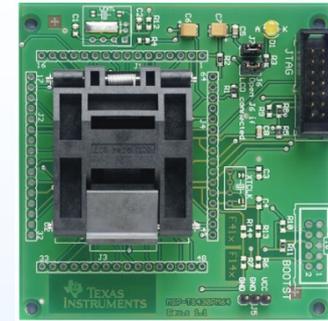
- Testing performed at TAMU on 6/18
- No SEL was observed
 - Exposed to $2 \times 10^6 / \text{cm}^2$ Au at 86 MeV-cm²/mg
 - Tested at 3.6V and 85C (both max)
 - 85C took out the UART
- We did observe permanent damage
 - $\sim 1 \times 10^{-5} \text{cm}^2$ at LET 86 – event not seen with 1.5×10^6 at LET 8.1
 - Device does not function
 - Cannot be reprogrammed (“Inconsistent configuration information, discard unit and replace”)



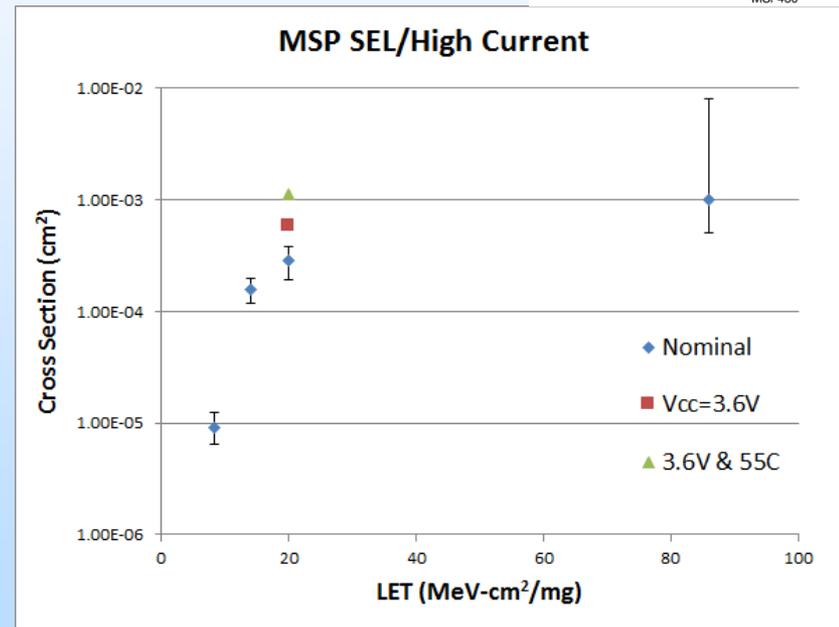


SEL/SEE Results – MSP430F1611 and 1612

- **SEL Characterization**
 - 0.05 A threshold
 - $LET_{TH} \sim 8 \text{ MeV-cm}^2/\text{mg}$
 - Large σ by LET 20
- **Not recovered by reset (power cycle required)**
- **At about $1 \times 10^6/\text{cm}^2$ (@ LET 86) test devices unprogrammable**



MSP430 64-pin Target Board
MSP-TS430PM64
TEXAS INSTRUMENTS
MSP430



– **Error bars (nominal only) $\sim 2\sigma$, and include beam uncertainty**



TID Testing of MSP430F1611 & 1612

- **Test procedure: between irradiation tested with characterization programs – requires being able to reprogram devices:**
 - LED blinker
 - Flash memory test program
 - Whetstone test program

Device Type	Condition	# Tested	TID Result
1611	Unbiased	5	Good > 20 krad(Si)
1611	Biased	5	Fail between 5 and 10 krad(Si)
1612	Unbiased	5	Good > 20 krad(Si)
1612	Biased	5	Fail between 5 and 10 krad(Si)



PIC Overview

- **PIC24 and dsPIC 33 devices have been tested for SEL, SEE, and TID**
- **Devices generally show relatively high SEL rate (about 10x higher than MSP430F1611)**
 - No indication of damage
- **TID performance (biased) is around 10krad(Si) with failures due to inability to reprogram.**
 - Again, results may be different if we don't require reprogramming



PIC TID

- **Performed unbiased testing of PIC24 and both biased and unbiased testing of dsPIC33**
- **Test Programs:**
 - Flash memory test program
 - Whetstone test program
 - SRAM test program
- **Unbiased devices failed at 20-50 krad(Si) – Failures due to inability to reprogram for post-rad evaluation.**
- **During biased testing, 2 out of 3 DUTs failed to reprogram at 10 krad(Si)**



TID issues of PICs

Better Approach:

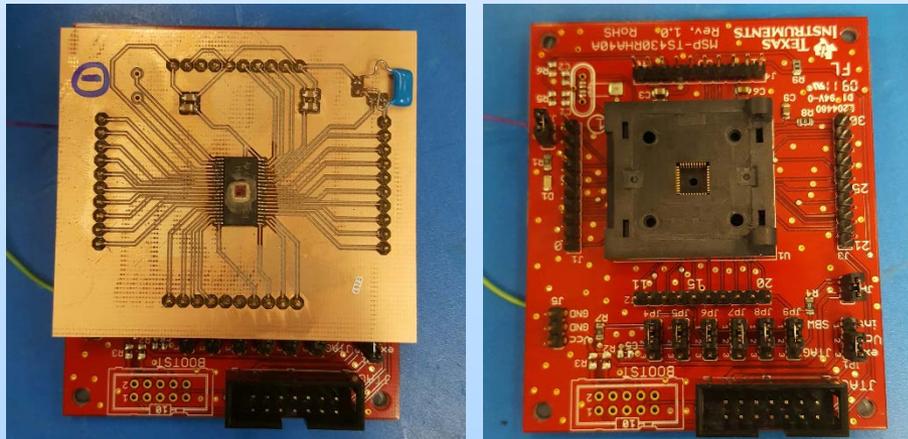
- TID test of devices without reloading of test code
 - More flight like application
 - Avoid test code reprogramming issues
- Issues:
 - Needs controller circuit to implement RTSP (run-time self-programming) using a bootloader to load firmware from external EEPROM or Flash



2016 Plans

Planned Tests

- **SEL test of MSP430FR5739IDAR (Non-Epi version)**
 - Identified by Busek, needed by some 5739 users
 - TSSOP-38 Package compared to RHA
 - Different die inside from 3 manufacturing sites
 - No Epi version released by TI





2016 Plans

Planned Tests

- **TID test of MSP430FR5739IDAR (Non-Epi version)**
- **Test procedure: between irradiation tested with characterization programs – requires being able to reprogram devices:**
 - LED blinker
 - FRAM test program
 - Whetstone test program



Expected Results

- **SEL test of MSP430FR5739IDAR (Non-Epi version)**
 - **Lower latch-up cross section compared to MSP430F1611 and 1612**
- **TID test of MSP430FR5739IDAR (Non-Epi version)**

Part	# tested	Bias condition	Test Programs	Results
MSP430FR-5739IDAR	2	Biased	Whetstone,LED,FRAM	Good up to 50 krad(Si)
MSP430FR-5739IDAR	2	Unbiased	Whetstone,LED,FRAM	Good up to 50 krad(Si)



Conclusion

- **NEPP is moving forward to identify current and potential future microcontrollers and microprocessors**
 - Developing SEE and TID data to support various missions
 - Creating a basis of device response data for different families of devices
- **Have tested several different devices to date**
 - TID and SEE on TI MSP430 1611/12; and MSP43FR5739 EPI (non-EPI planned for 2016)
 - TID and SEE on PIC24 and dsPIC33



End



Backup Slides



Cubesat Controller Survey

- Reviewed many Cubesat system architectures
 - Primary devices on this list: MSP430F1611, 1612, 1618; PIC24, dsPIC33; AT91SAM9G20; ATMEGA1281; C8051; AT91SAM7

CubeSat Provider	Processor	Availability	Development Board
Pumpkin	TI MSP430F1612	Yes	Yes
	TI MSP430F1611	Yes	Yes
	TI MSP430F1618	No	No
	Silicon Labs C8051F120	Yes	Yes
	Microchip PIC24FJ256GA110	Yes	Yes
	Microchip dsPIC33FJ256GP710	Yes	Yes
Tyvak (Intrepid)	AT91SAM9G20 (ATMEL, ARM9 Based)	Yes	Yes

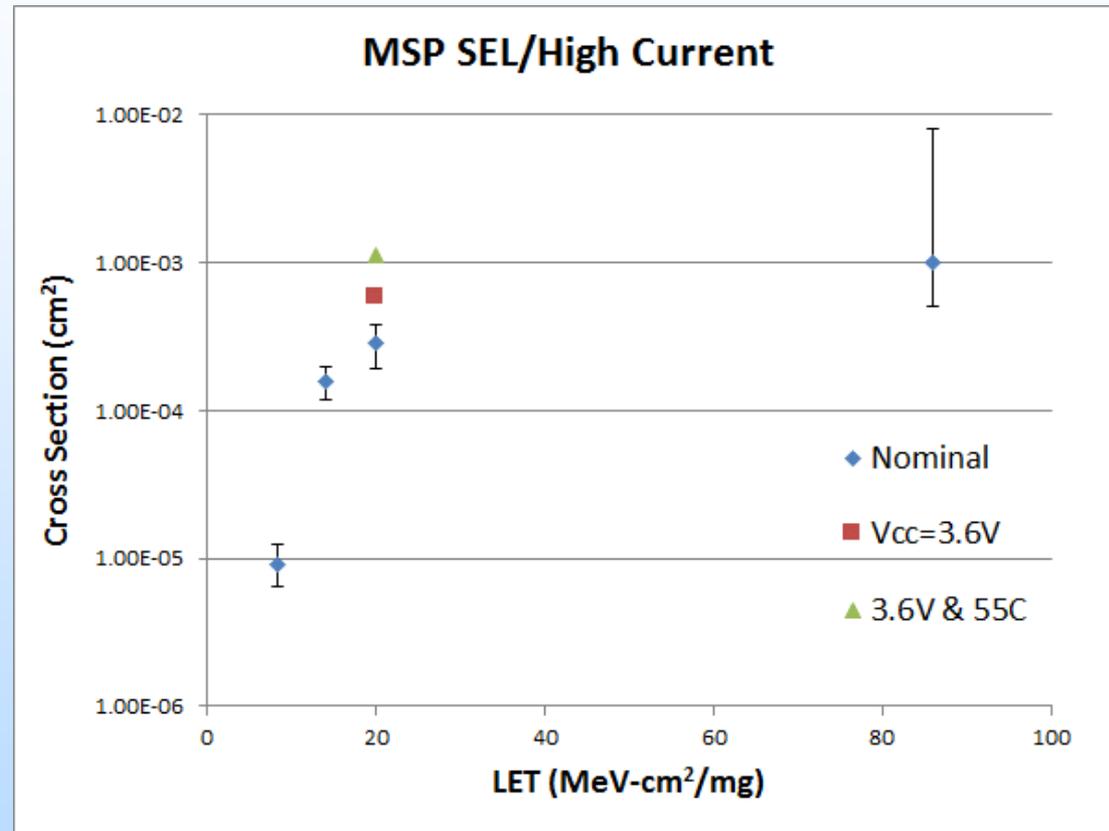
CubeSat Provider	Processor	Availability	Development Board
GOMspace (NanoMind)	AT91SAM7 series (ATMEL, ARM7 Based)	Unknown	Unknown
	ATMEL ATMEGA1281	Yes	Unknown
Gaussteam (ABACUS)	TI MSP430 series	Yes	Yes
ESL/ISIS (Cube Computer)	ARM Cortex-M3 MCU	Unknown	Unknown
ISIS (OBC)	AT91SAM9G20 (ATMEL, ARM9 Based)	Yes	Yes
Clyde Space Use Pumpkin CubeSat OBC		Yes	Yes

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SEL/SEE Results – MSP430 – 1611 and 1612

- **SEL Characterization**
 - 0.05 A threshold
 - $LET_{TH} \sim 8 \text{ MeV-cm}^2/\text{mg}$
 - Large σ by LET 20
- **Not recovered by reset**
- **ISS event rate estimated between 2×10^{-5} and $4 \times 10^{-4}/\text{day}$**
 - $\sim 10 \times$ higher for GCR
- **SRAM SBU (limited eval)**
 - $\sigma \sim 4 \times 10^{-8} \text{ cm}^2/\text{bit} @ \text{LET } 20 \text{ MeV-cm}^2/\text{mg}$
 - Testing 2048 bytes

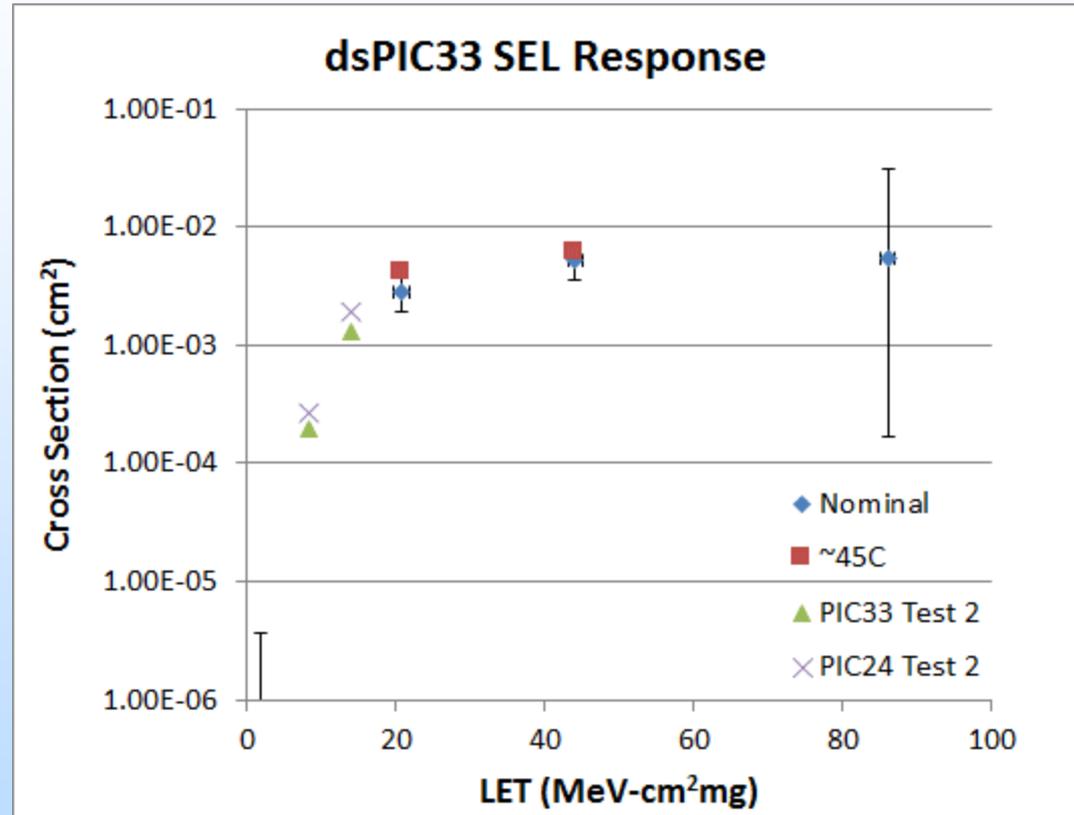


- **Error bars (nominal only) $\sim 2\sigma$,**
- **and include beam uncertainty**



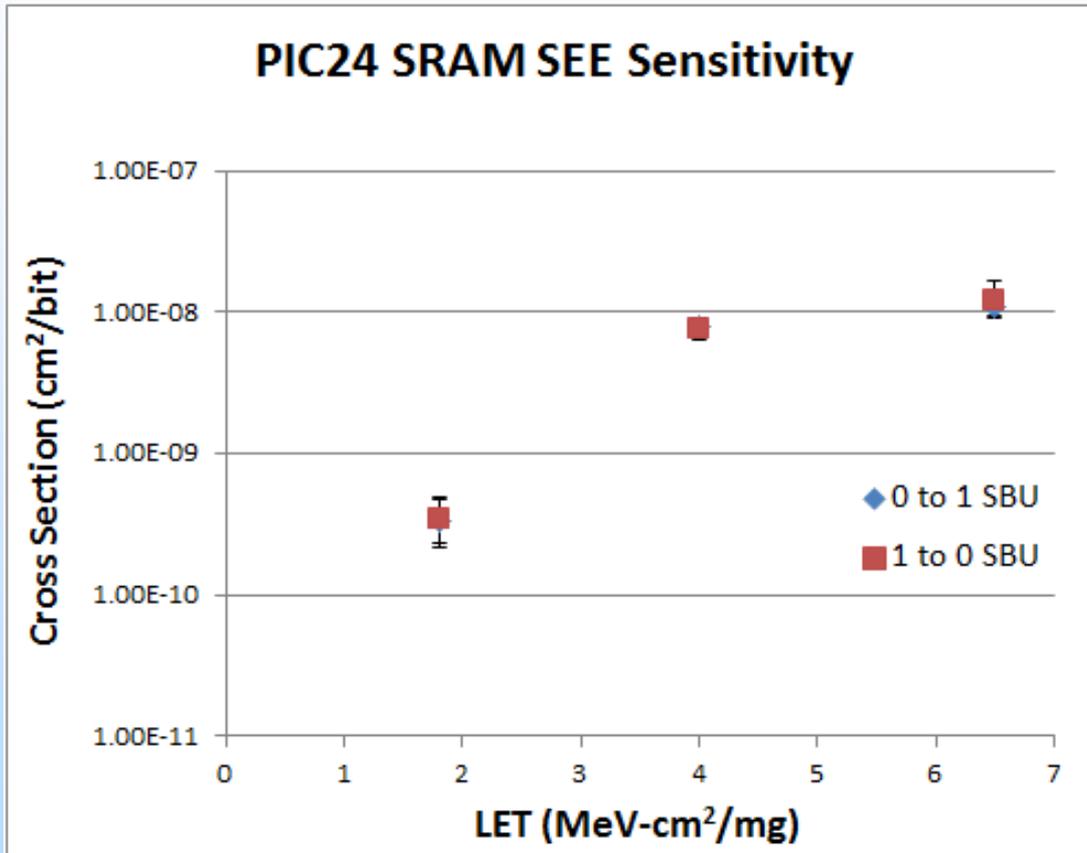
SEL Cross Section

- Used 0.25 A as threshold for SEL
- When heated, the SEL current trips on-board regulation
- Both points (slightly) higher σ for high T
- ISS event rate estimated between 2×10^{-4} and 4×10^{-3} /day
 - ~10x higher for GCR
- dsPIC33 and PIC24 devices very similar





PIC SEE Results



- **Flash Results**
 - No upsets observed with $6 \times 10^5 / \text{cm}^2$ ions at LET = 86
 - Limiting cross section of $\sim 6 \times 10^{-12} \text{ cm}^2/\text{bit}$
- **SRAM Results**
 - SEL behavior interfered at higher LETs