LANL CubeSat Reconfigurable Computer (CRC)

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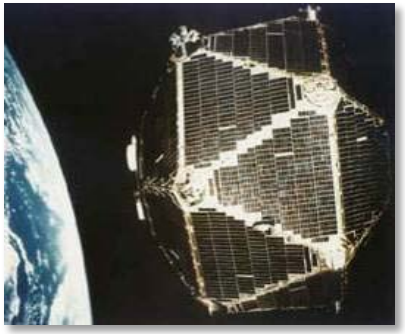
LANL History in Space

Operational Sensors



Vela W-Sensor

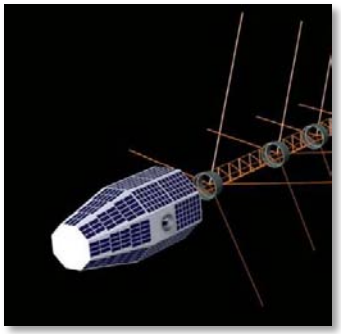
GPS IIA/IIR W-Sensor

GPS IIF V-Sensor

CubeSats

R&D Sensors

ALEXIS/Blackbeard



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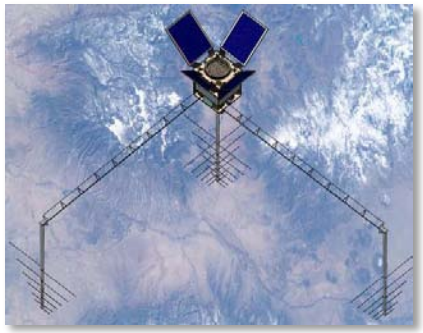


Cibola Flight Experiment

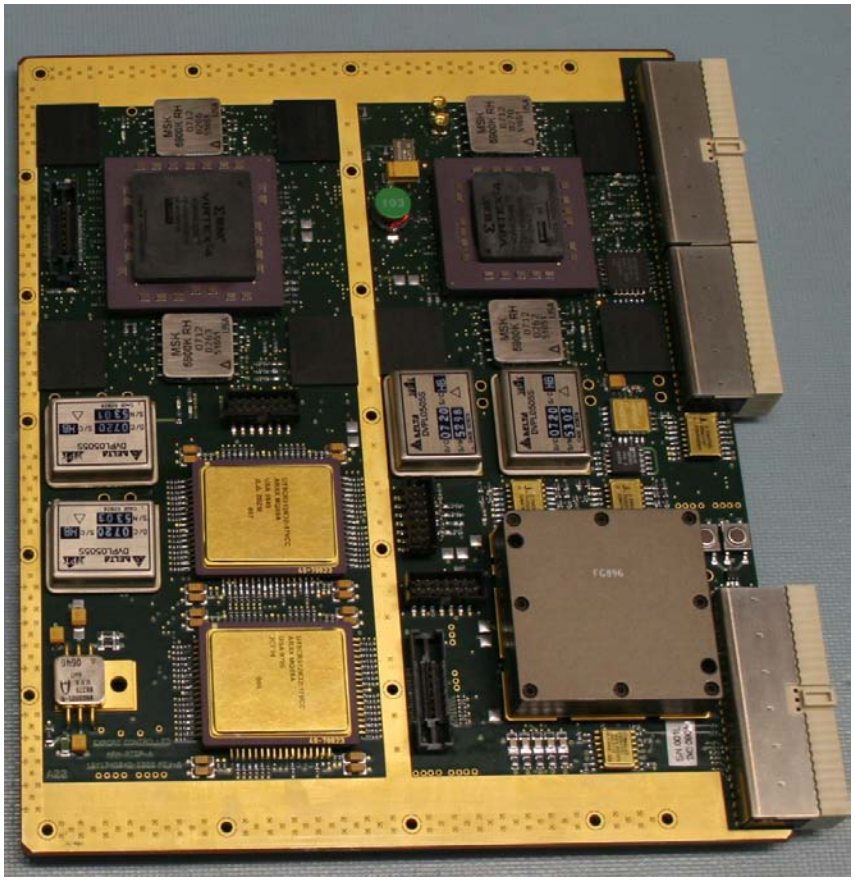
TeraOps SDR

LANL Reconfigurable Computing History (1 of 3)

- **Cibola Flight Experiment (CFE)**
  - Experimental Satellite for DOE
  - Project Objectives
    - Technology Demonstration: responsive, flexible multi-mission RF payload with continuous data processing
    - Adaptability: Re-configurable post-launch
    - Smart and adaptive reconfigurable computing at sensor for super-computer processing speeds, enhanced sensitivity and reduced data downlink
  - Technical Approach
    - On-board data processor using COTS parts
    - Processor includes a network of Xilinx Field Programmable Gate Arrays (FPGAs)
    - FPGAs allow post-launch reconfiguration to meet new and changing program requirements
    - Tailor processing application to each theater of interest
    - Algorithm swap time <1 min
  - Payload Description
    - 4-Channel Software Radio
    - Tunable 100-500 MHz with 20 MHz bandwidth
    - Dual 12-bit ADC @ 100 MSPS
  - Status
    - Operated for more than 3.5 years
    - Uploaded 50+ new experiments
    - Configured FPGAs 50K+ times

LANL Reconfigurable Computing History (2 of 3)

- **LANL TeraOps SDR**
  - Experimental payload on an operational spacecraft
  - Project Objectives
    - Prove a number of new COTS parts for operational use in space by demonstrating their on-orbit reliability in a radiation environment
    - Test experimental radio applications for DOE treaty monitoring missions, as currently performed in the NDS payload on GPS
  - Technical Approach
    - Real-time Signal Processor (RTSP) includes two Virtex-4 FPGAs
    - FPGAs allow post-launch reconfiguration to meet new and changing program requirements
    - Tailor processing application to each theater of interest
  - Payload Description
    - Software-defined Radio (SDR)
    - 16-bit ADC @ 120 MSPS
  - Status
    - Expected launch in 2011

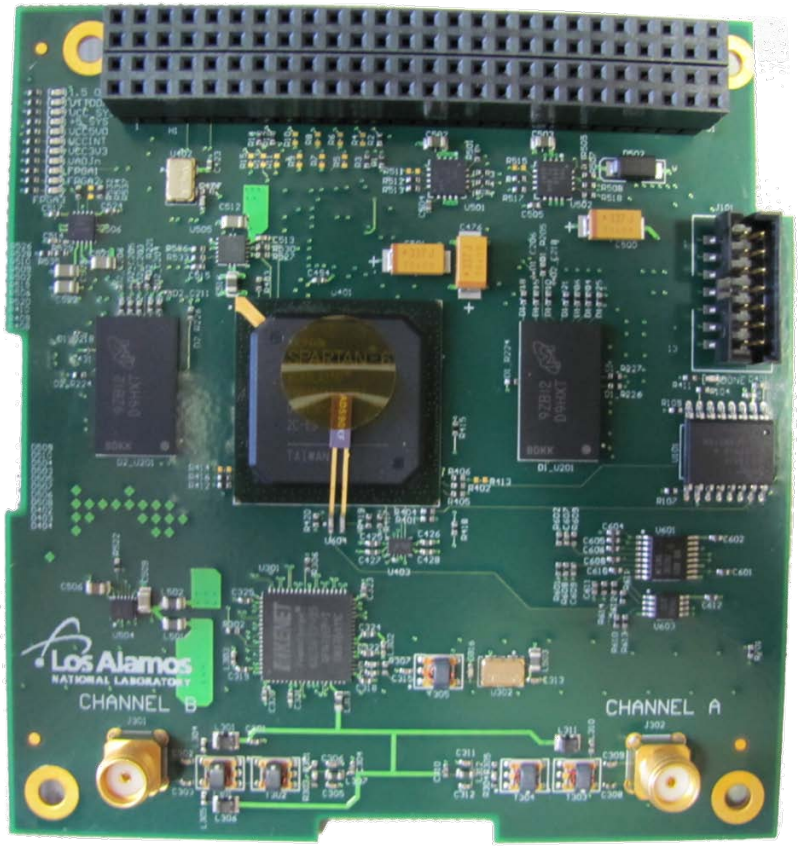


LANL Reconfigurable Computing History (3 of 3)

- **FPGA Radiation Effects Research**
  - DOE/LANL has funded more than a decade of research through the CFE, TeraOps SDR, DAPS, SOPRANO and JAS programs
  - LANL partnered with Xilinx to perform the first radiation effects experiments on commercial Xilinx FPGAs
  - Founding member of the Xilinx Radiation Test Consortium (XRTC)
  - Funded development at Brigham Young University (BYU) of BLTMR, an open-source TMR tool (http://sourceforge.net/projects/byuediftools/ or http://reliability.ee.byu.edu/)
  - Dozens of peer-reviewed journal articles, conference papers, invited talks, etc.
    - Cross-section Measurements
    - Fault-injection
    - Persistence
    - Multi-bit Upsets (MBUs)
    - Multiple Independent Upsets (MIUs)
    - SEU Mitigation Methods
      - TMR
      - Partial TMR
      - Duplication with Compare
      - Alternative approaches (Quadded Logic, State Machine Encoding, Temporal Redundancy)
      - Smart Models
      - etc.
    - High-speed Serial (MGT)
    - etc.

LANL CubeSat Reconfigurable Computer (1 of 2)

- **Project Objectives**
  - IRAD for future LANL projects
  - Demonstrate reconfigurable computing capability within the constraints of a CubeSat
  - Reduce size, weight and power (SWAP) i.e. miniaturize CFE / TeraOps SDR
- **Technical Approach**
  - Single board with low-power/high-performance FPGA, memory and ADC
    - Xilinx Spartan-6 LX150 FPGA
    - 2x 2-Gbit Micron DDR3 SDRAM chips
    - 2 Channel ADC; 12-bit @ 250 MSPS
    - 102 pin connector to on-board computer; compatible with Pumpkin CubeSat Kit
    - 128-Mbit on-board Flash bitstream storage
- **Status**
  - Received CRC from manufacturing 7/26/2010
  - Built-in self test (BIST) complete
  - Demo application in progress



LANL CubeSat Reconfigurable Computer (2 of 2)

Comparison of CRC with CFE and TeraOps SDR

		CFE	TeraOps SDR	CRC
Size		16” x 8” x 12”	10.5” x 3.4” x 9”	4” x 4” x 1”
Weight		20 Kg	5.5 Kg	100 g
Power		100 W	25 W	10 W
# FPGAs		9	2	1
	Logic Cells	249K[1]	255K[1]	150K[2]
	On-chip RAM	1 Mb	13.6 Mb	5 Mb
	DSP Slices	0	608	180
# ADCs		1	1	1
	Sample Rate	100 MSPS	120 MSPS	250 MSPS
	# bits	12	16	12
	# channels	2	1	2
System memory		.86 GB[3]	.25 Gb[4]	.5 GB[5]

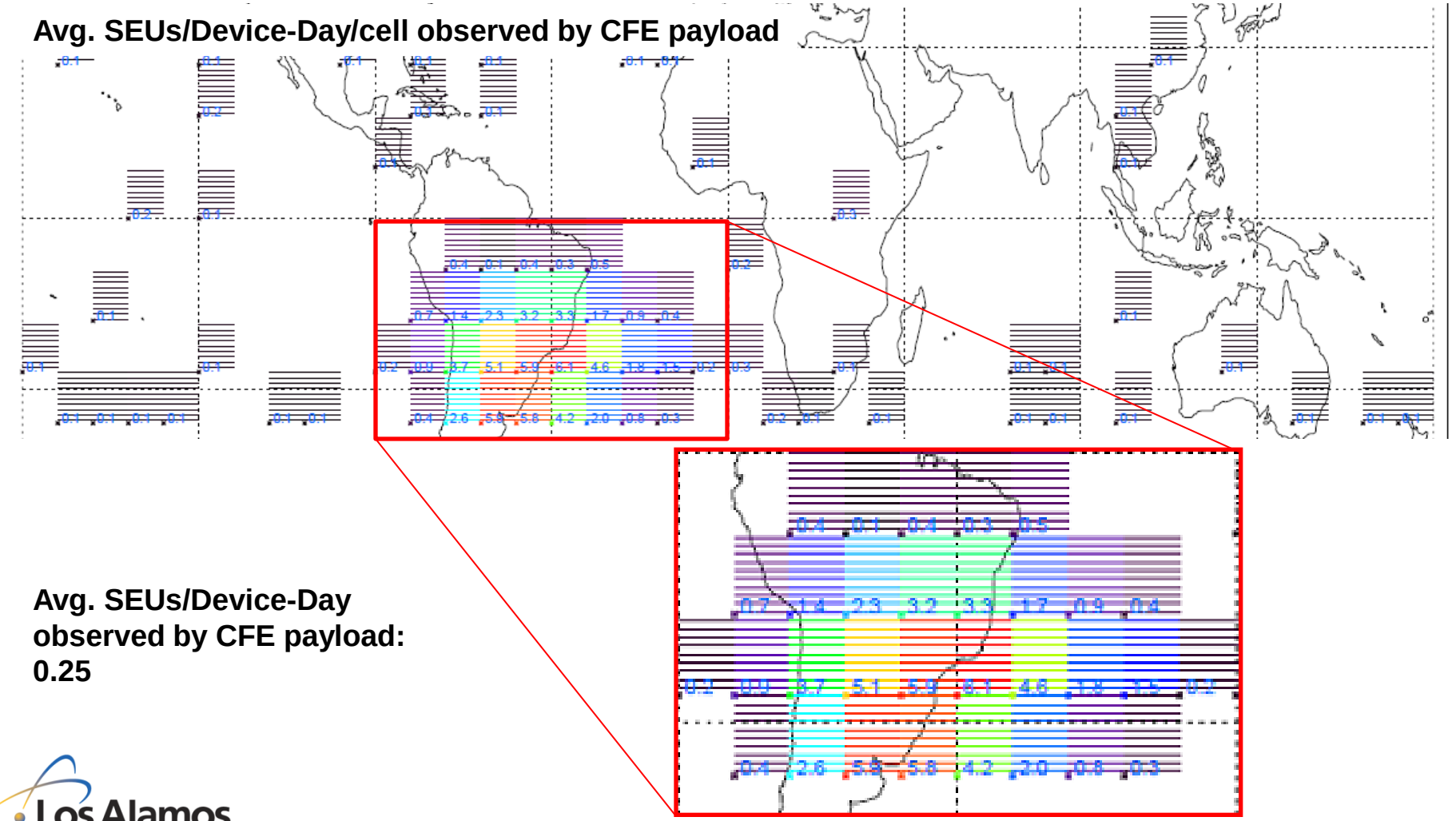
[1]4-input LUT [2]6-input LUT [3]SDRAM [4]QDR SRAM [5]DDR3 SDRAM

Benefits of Reconfigurable Computing and CubeSats

- **High performance, low-power computing in a small form factor**
- **Upgrade or add functionality after launch**
- **Hardware Reuse**
  - Enhances reliability
  - Decreases cost
  - Increases code base
  - Accelerates development time
- **Simplifies hardware design for CubeSat constellations**

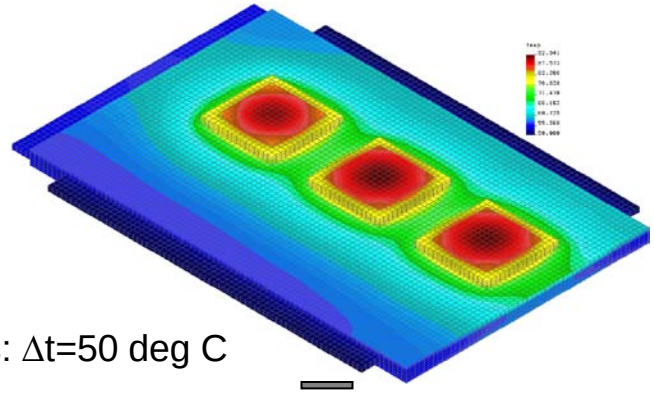
Challenges of Reconfigurable Computing and CubeSats: Single Event Upsets (SEUs)

Avg. SEUs/Device-Day/cell observed by CFE payload

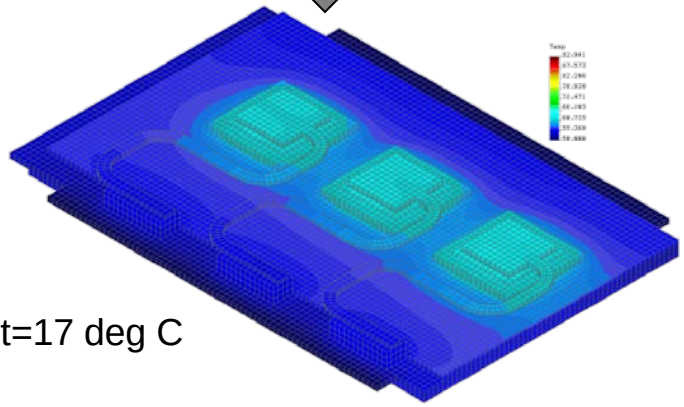


Avg. SEUs/Device-Day observed by CFE payload: 0.25

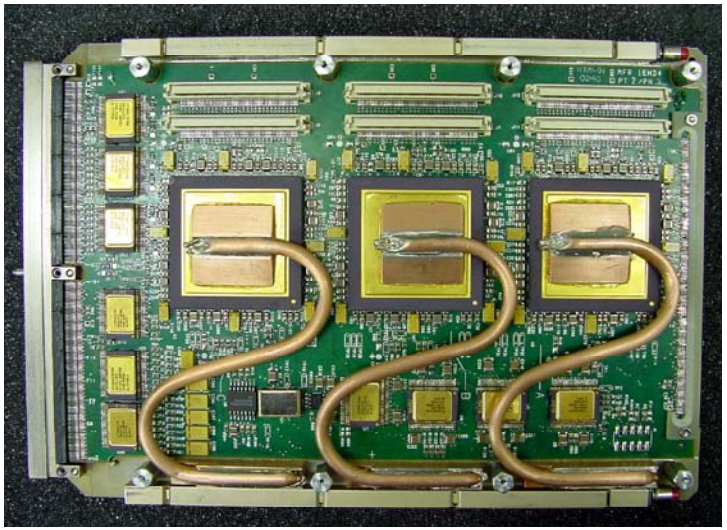
Challenges of Reconfigurable Computing and CubeSats: Thermal Management



Without heat pipes: ∆t=50 deg C

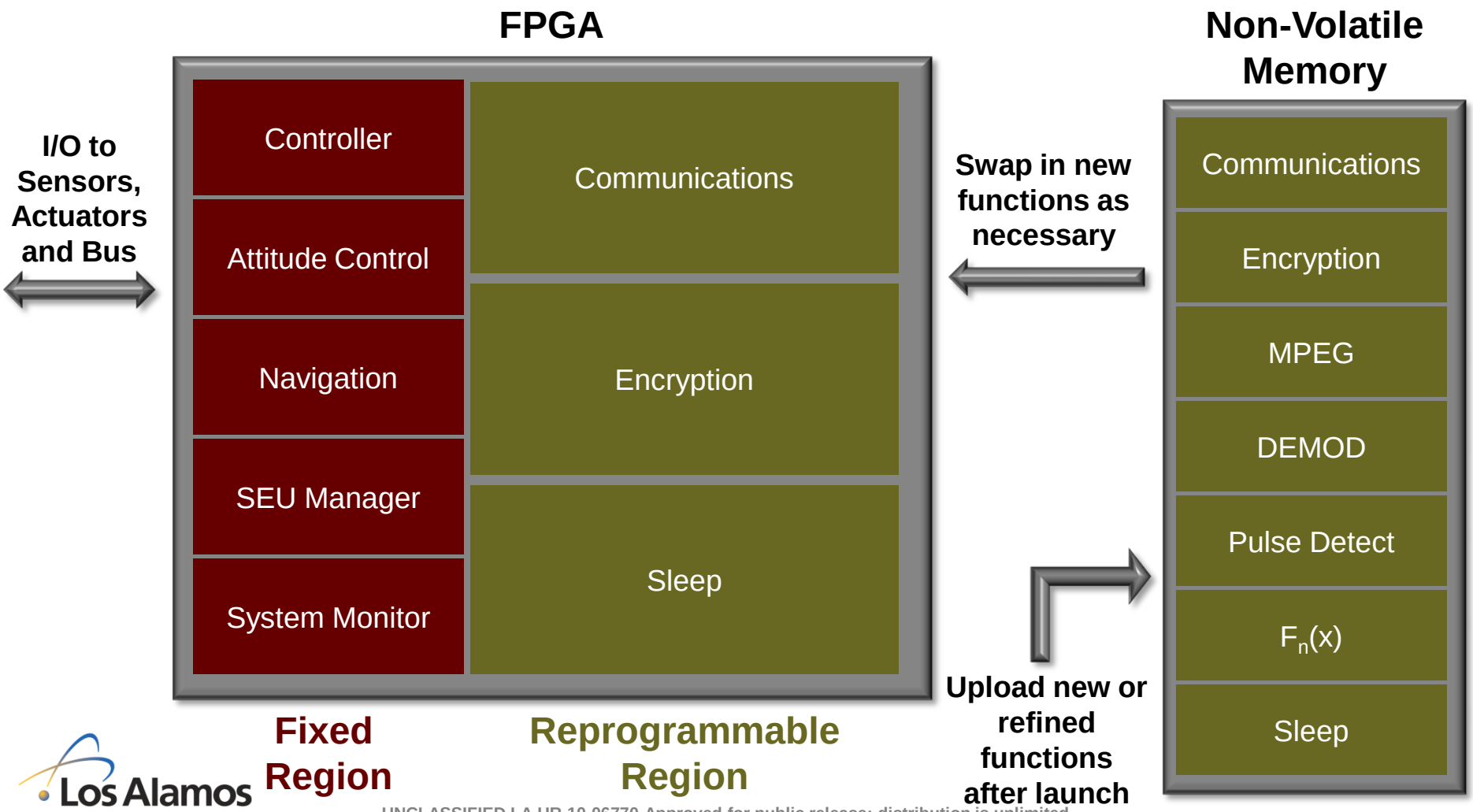


With heat pipes: ∆t=17 deg C



Proto-Flight CFE reconfigurable computing board with heat pipes

“Software-defined Satellite”



Future Work

- **Example Science Missions**
  - Wide band RF pulse detection
  - Total Electron Content (TEC) in Ionosphere
- **Constellations**
  - Numerous inexpensive satellites replace larger expensive satellites
  - Paradigm shift allows new functions to be performed
  - Spatial separation
  - Unit replacement
  - True global and persistent observation

Summary

- **LANL has decades of experience with satellites/payloads and reconfigurable computing**
- **The LANL CFE and TeraOps SDR programs demonstrated the feasibility of reconfigurable computing in space**
- **LANL CubeSat Reconfigurable Computer (CRC)**
  - High performance, low-power reconfigurable computing in a small form factor
  - Upgrade or add functionality after launch
  - Hardware Reuse
- **SEU and thermal challenges are manageable**
- **Technology enables inexpensive & interesting science missions and constellations for true global persistent surveillance**