# **Radiation Tolerant Computing** for Aerospace Applications

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### **Radiation-Hardness for Aerospace Systems**



- Cosmic radiation induces transients in integrated circuits
- Commercial processes are susceptible to Singe-Event-Upsets (SEUs)
- Aerospace systems must address this additional constraint

### **Mitigation Techniques**

- A variety of approaches are used to achieve radiation-hardness:

1) Radiation by Architecture

- Triple Modulo Redundancy, Fault Recovery Processes, COP

2) Radiation by Design/Process

- Substrate doping, Enclosed Layout Transistors, isolation trenches



#### Hasn't this been solved?

- Manned Missions Have Been Underway for 50 years

Mercury 1958-1963 (put a man in orbit)



Atlas

**Gemini** 1965-1966 (long duration in space)

Apollo 1968-1975 (put a man on the moon)



Titan II



Saturn V





 $SRB + O_2/H_2$  Tank



#### Hasn't this been solved?

- Missions to Low Earth Orbits are protected from Radiation by the Earth's Magnetic Field







### **How Did Apollo Do It?**

- Solar events which cause major radiation occur in 12 year periods
- Apollo was timed to occur between solar events







#### Why not time it again?

- it's a different mission now, we want 10 yrs + outside of the magnetosphere



Lunar Surface Systems



#### **Constellation – the next generation...**



Ares I & V Launch Vehicles





Concept image of the Area Y Earth departure stage in orbit, shown with the Orion capaule docked with the Altair lander (NASA MSFC)



Altair Lunar Lander





Orion Crew Exploration Vehicle

Orion Re-entry



#### **The Drawback of Rad-Hard Processors**



Radiation-Hardness translates into slower performance and more power consumption



### **Spatial Avoidance of Radiation Strikes Using Programmable HW**

- Redundant Processors (spares)
- Real Time Reconfiguration







### **Three Processors Run in Synch**

- Triple Modular Redundancy (TMR)
- Voter Circuit Checks for Errors

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#### If Errors Are Detected in a Processor, Another One is Brought Online

- TMR is still in tact

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### System Continues to operate in the presence of radiation

- Damaged regions can sometimes be repaired.

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### What happens during a recovery?

- Processors must be rebooted, reinitialized, and resynched





#### **Integrated Sensor Can Be Coupled with FPGA For More Robustness**







## Questions







