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The Opportunities and Challenges for Future Space Processing

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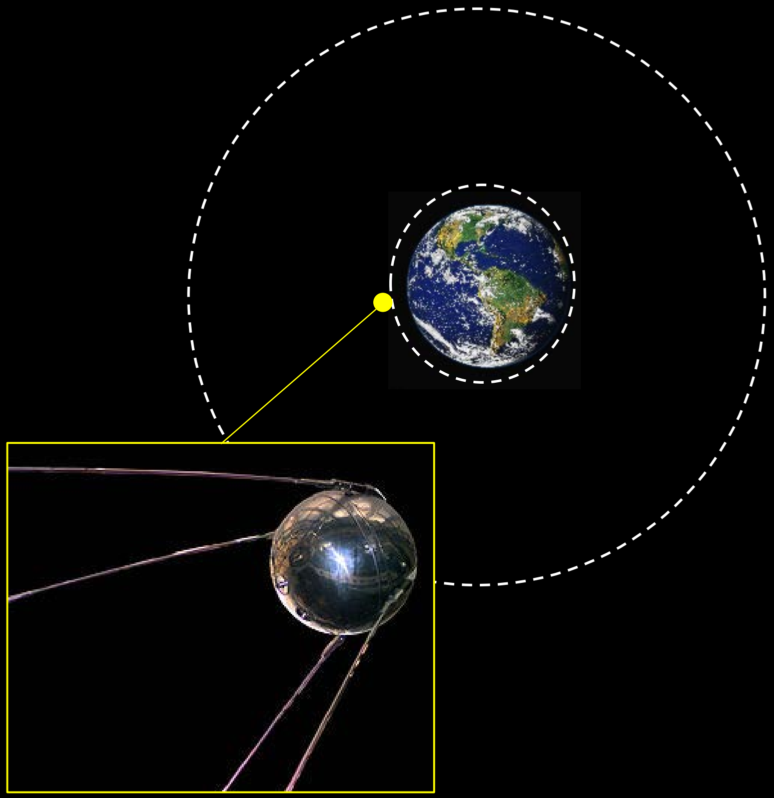
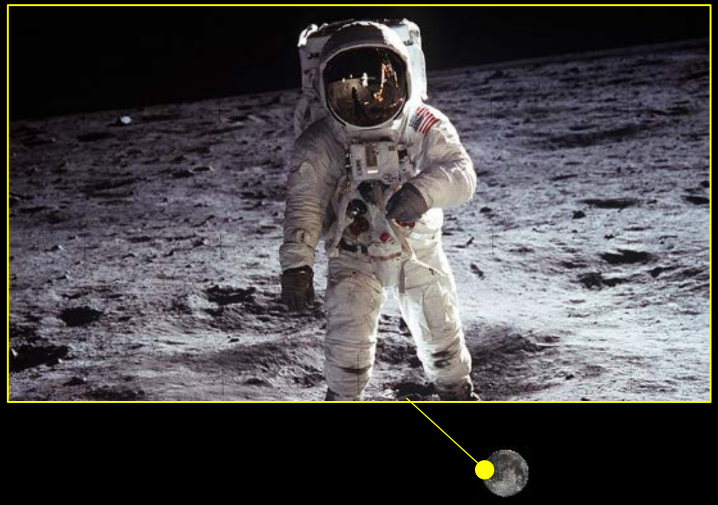
Agenda

- Trends in Space
- Drivers for advanced processing in space
- Space electronics challenges
- Quantifying our processing requirements
- Leverage commercial processors in space

In the Mid-20th Century, the US and USSR raced to space





1969:
~1500 objects
7 nations in space
2 nations to the moon

In the 21st Century, economic interests are driving a second space age

amazon

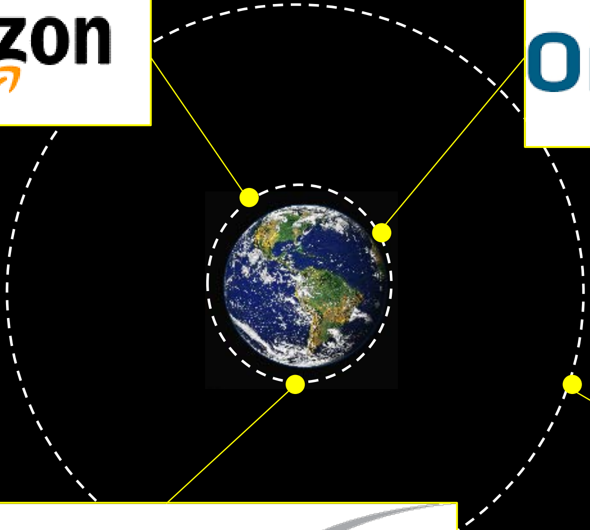
x3200

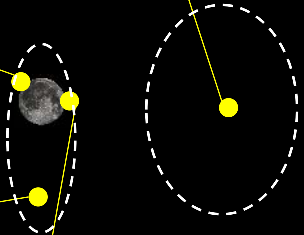
OneWeb

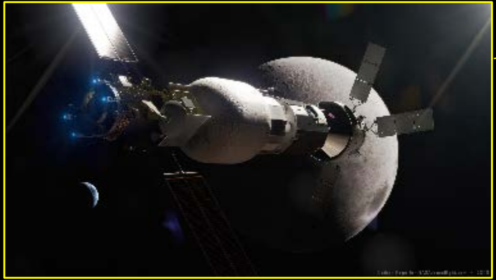
x2500

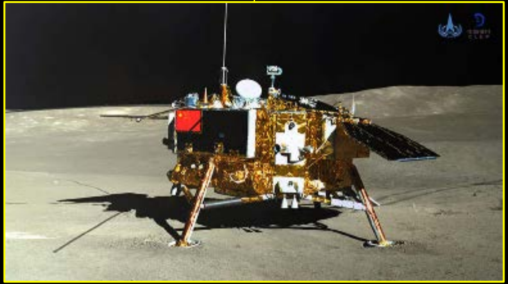
SPACEX

x12,000







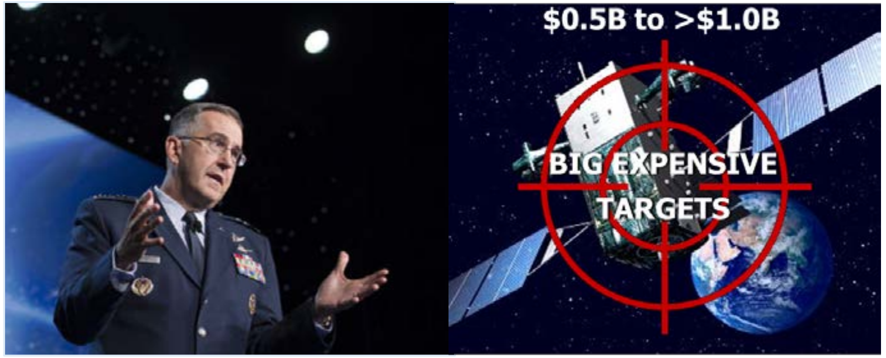


1969:
~1500 objects
7 nations in space
2 nations to the moon

2019:
~20,000 objects
<80 nations in space
7 nations to the moon

Defense Space Enterprise has been given a clear message to do space differently

*"I won't support the development …of **large, big, fat, juicy targets**"*
-Gen John Hyten



Breaking News

Pentagon officially stands up Space Development Agency, names first director

By: Aaron Mehta and Valerie Insinna March 13

A powerful Delta 4 Heavy rocket carrying a U.S. spy satellite lifts off from Vandenberg Air Force Base in California on Jan. 19, 2019. (Matt Hartman/AP)

WASHINGTON — The Pentagon has formally stood up the Space Development Agency, and named its new director, according to a memo obtained by Defense News.

The memo, signed out by acting Defense Secretary Patrick Shanahan March 12, immediately stood up the SDA as a new office under the direction of Under Secretary of Defense for Research and Engineering Mike Griffin.

Space Development Agency (SDA)

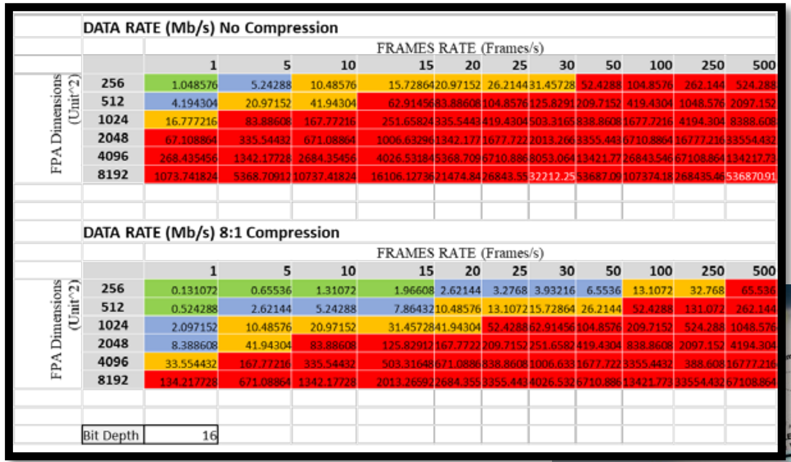
*"Keeping its competitive edge will require… **execution at the 'speed of relevance'**…It's time to take risks...'*
Sec Heather Wilson

- Commercial, Proliferated LEO (p-LEO) offers a unique opportunity to explore these changes through smart risk
- Looking to leverage commercial technologies to close technology gap

Drivers for Advanced Communication and Processing Electronics in Future Space Systems

Huge growth in sensor data rates coupled with limited communication bandwidth to ground

Proliferated "mega-constellations" at Low Earth Orbit & the pivot to autonomous operations



DATA RATE (Mb/s) No Compression

FPA Dimensions (Unit^2) / FRAMES RATE (Frames/s)

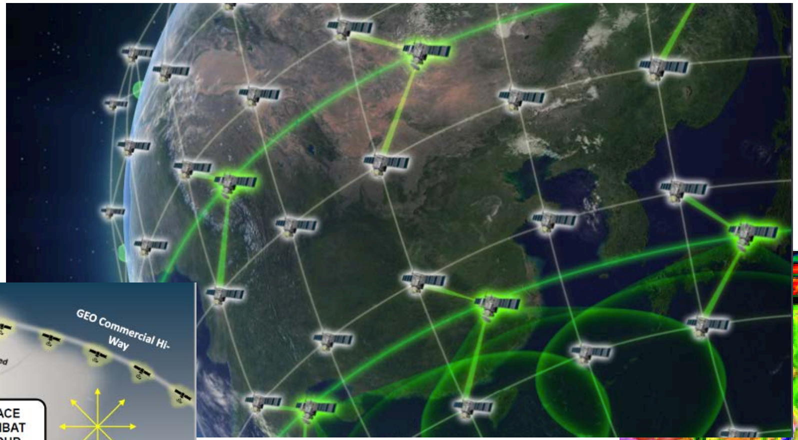
	1	5	10	15	20	25	30	50	100	250	500
256	1.048576	5.24288	10.48576	15.7286	20.97152	26.2144	31.45728	52.4288	104.8576	262.144	524.288
512	4.194304	20.97152	41.94304	62.91456	83.88608	104.8576	125.8291	209.7152	419.4304	1048.576	2097.152
1024	16.777216	83.88608	167.77216	251.65824	335.5443	419.4304	503.3165	838.8608	1677.7216	4194.304	8388.608
2048	67.108864	335.54432	671.08864	1006.63296	1342.177	1677.722	2013.266	3355.443	6710.8864	16777.216	33554.432
4096	268.435456	1342.17728	2684.35456	4026.53184	5368.709	6710.886	8053.064	13421.77	26843.546	67108.864	134217.73
8192	1073.741824	5368.70912	10737.41824	16106.1273	21474.84	26843.55	32212.25	53687.09	107374.18	268435.46	536870.91

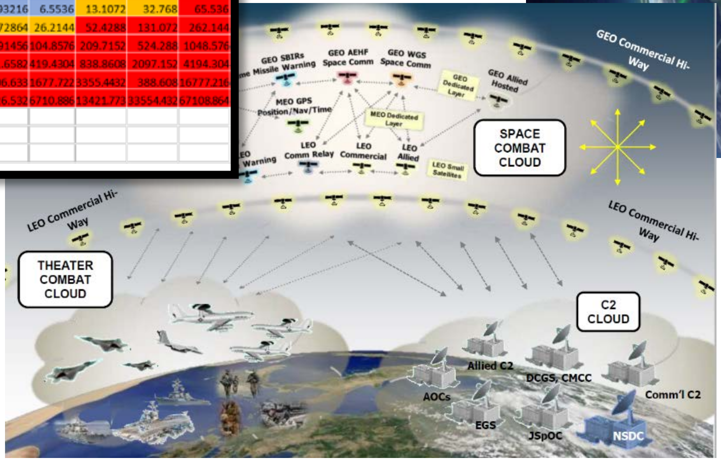
DATA RATE (Mb/s) 8:1 Compression

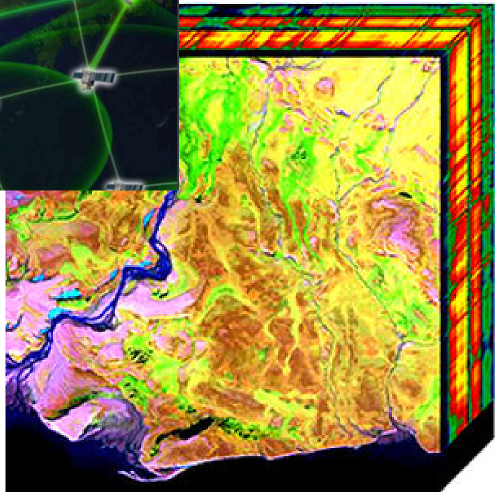
FPA Dimensions (Unit^2) / FRAMES RATE (Frames/s)

	1	5	10	15	20	25	30	50	100	250	500
256	0.131072	0.65536	1.31072	1.96608	2.62144	3.2768	3.93216	6.5536	13.1072	32.768	65.536
512	0.524288	2.62144	5.24288	7.86432	10.48576	13.1072	15.72864	26.2144	52.4288	131.072	262.144
1024	2.097152	10.48576	20.97152	31.4572	41.94304	52.4288	62.91456	104.8576	209.7152	524.288	1048.576
2048	8.388608	41.94304	83.88608	125.82912	167.7722	209.7152	251.6582	419.4304	838.8608	2097.152	4194.304
4096	33.554432	167.77216	335.54432	503.31648	671.0886	838.8608	1006.633	1677.722	3355.4432	388.608	16777.216
8192	134.217728	671.08864	1342.17728	2013.2659	2684.355	3355.443	4026.532	6710.886	13421.773	33554.432	67108.864

Bit Depth: 16





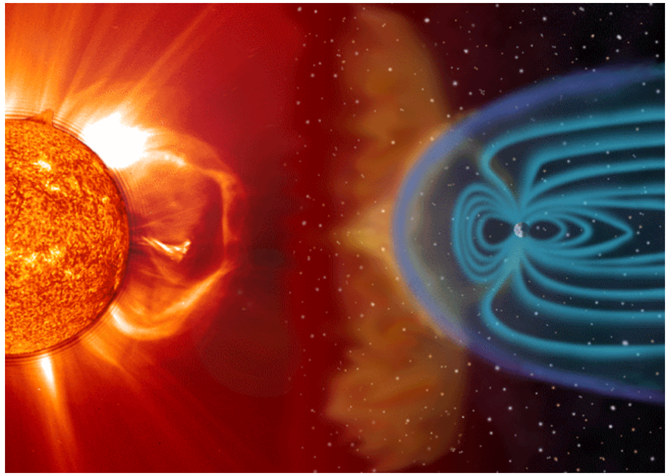


Space Enterprise Vision driving new tech objectives: Short duration missions with rapid tech refresh, & Multi-domain Combat Cloud

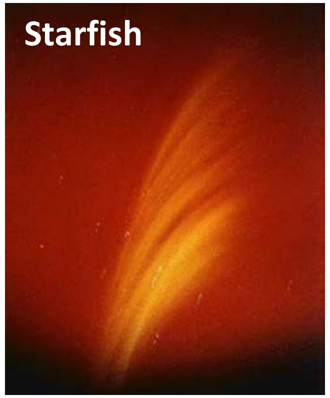
Opportunities to leverage Advanced Data Processing techniques

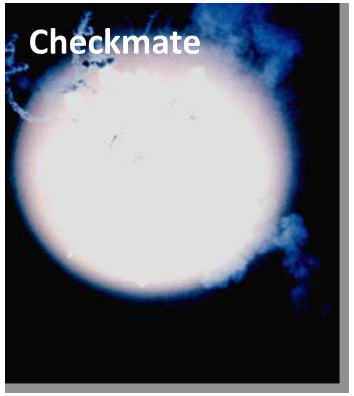
Challenges for Advanced Electronics in Space

Natural Space Radiation Environment



Enhanced Space Radiation





Power Constraints

ROSA

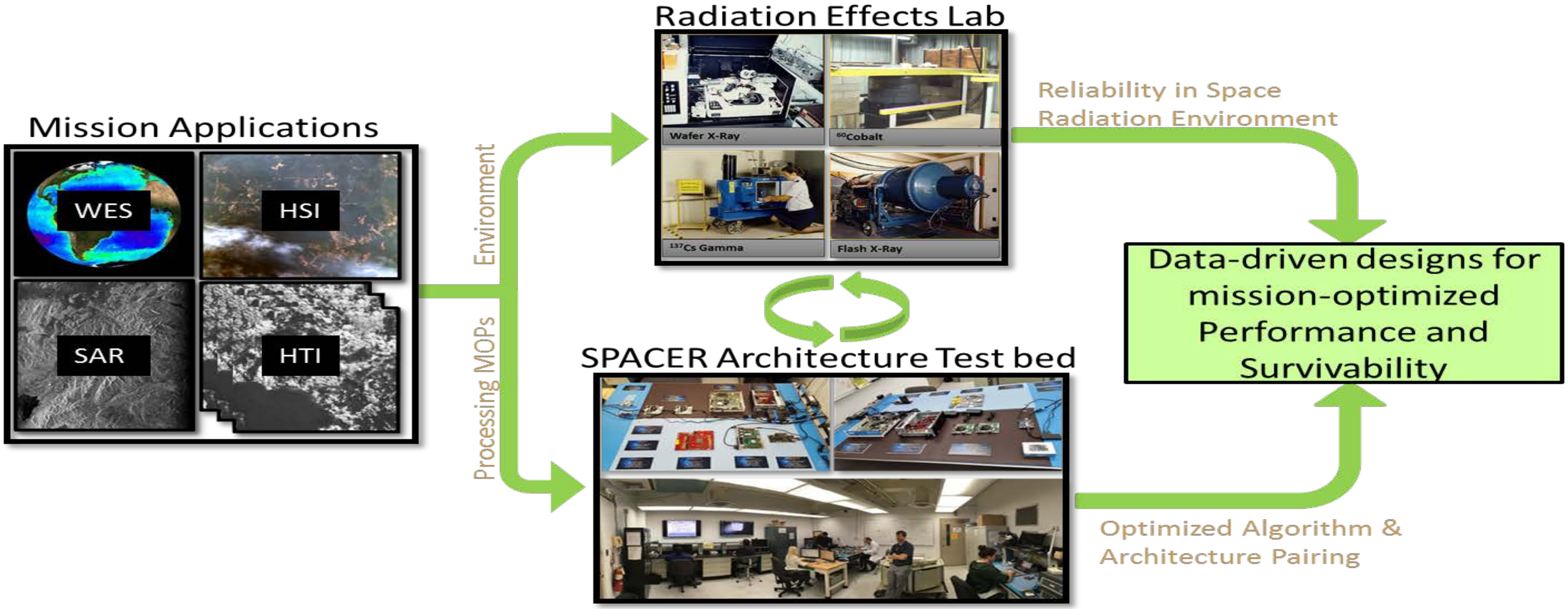
Size and Weight Constraints

SpaceX - 60 Starlink Satellites!

High-Performance Space Electronics are critical for national security space & missile systems, civil and commercial satellites

How do we quantify our processing requirements?

Electronics Assessments Are Needed to Determine Mission Suitability and Provide Options



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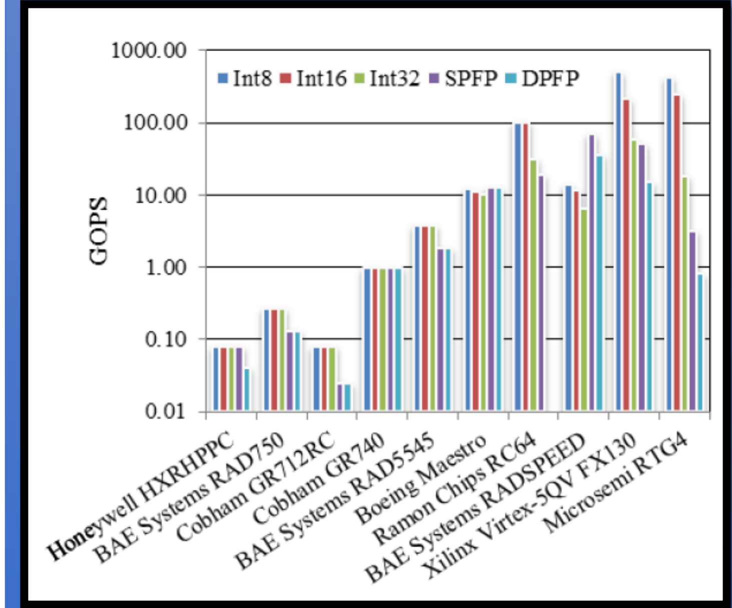
Theoretical Capabilities vs. Realizable Utilization

Peak Performance Metrics



Commercial (Rad-Hard)

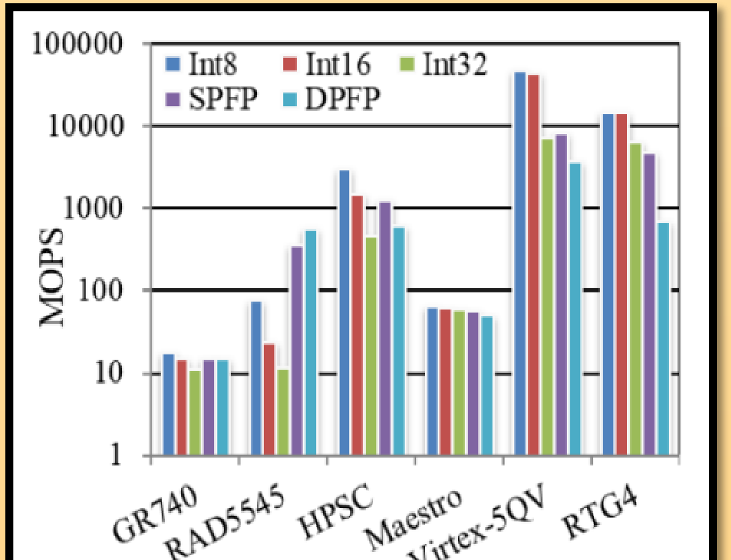
Max GPP (SPFP): 110.0 (12.74) GFLOPS
Max GPP (int8): 626.6 (12.0) GOPS

Max DSP (SPFP): 198.4 (70.8) GFLOPS
Max DSP (int8): 1459.2 (14.2) GOPS

Max FPGA (SPFP): 224.3 (51.9) GFLOPS
Max FPGA (int 8): 2295.0 (503.7) GOPS

Max GPU (SPFP): 384.0 (none) GFLOPS
Max GPU (int8): 1152.0 (none) GOPS

Compute Kernel Benchmarking



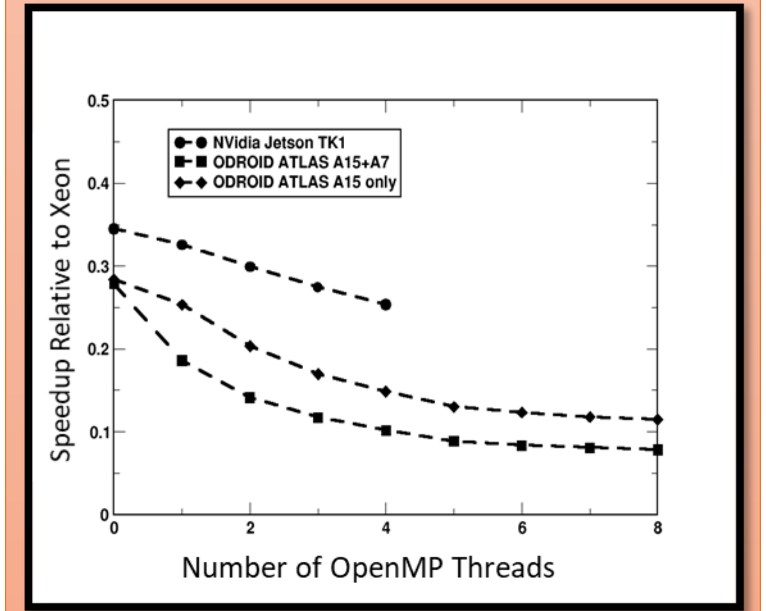
Matrix Multiplication

Matrix Multiplication
Max GPP (SPFP): 1.24 GFLOPS
Max GPP (int8): 3.04 GOPS
Max FPGA (SPFP): 7.94 GFLOPS
Max FPGA (int 8): 46.7 GOPS

Matrix Convolution
Max GPP (SPFP): 0.408 GFLOPS
Max GPP (int8): 0.460 GOPS

Matrix Addition
Max GPP (SPFP): 0.413 GFLOPS
Max GPP (int 8): 1.51 GOPS

Application Porting & Optimization



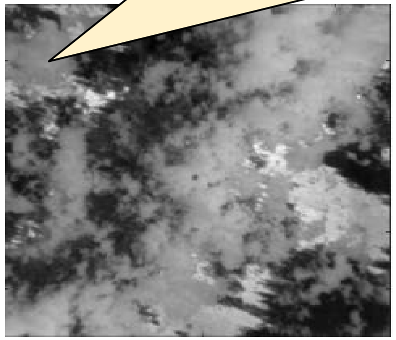
Parallel performance of the 32-bit ARM implementations relative to the 64-bit Xeon (0.35 to 0.08)

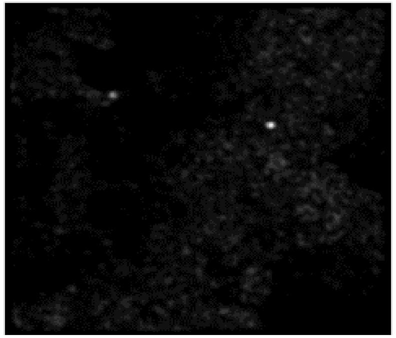
4x to 30x lower than peak

GPP=General Purpose Processing
DSP=Digital Signal Processor
FPGA=Field Programmable Gate Array
GPU=Graphics Processing Unit

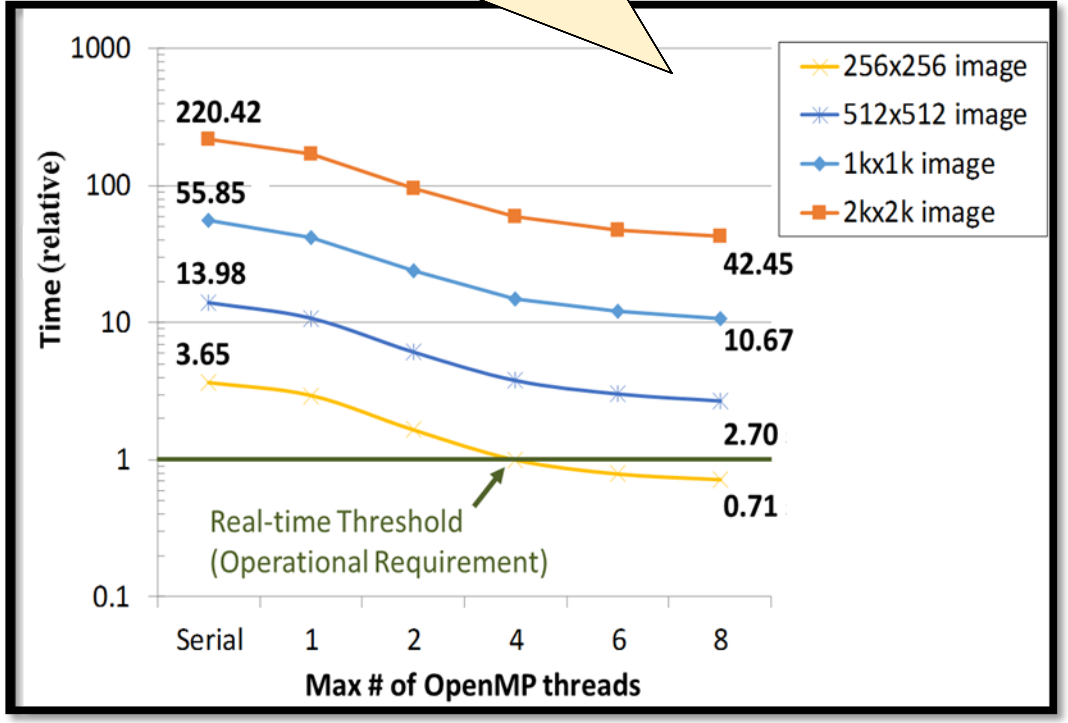
Real-time Threshold Requirements for an Advanced Image Processing Algorithm

Opportunity: Enhance national missile warning capability with advanced sensors and processing techniques for dim target detection

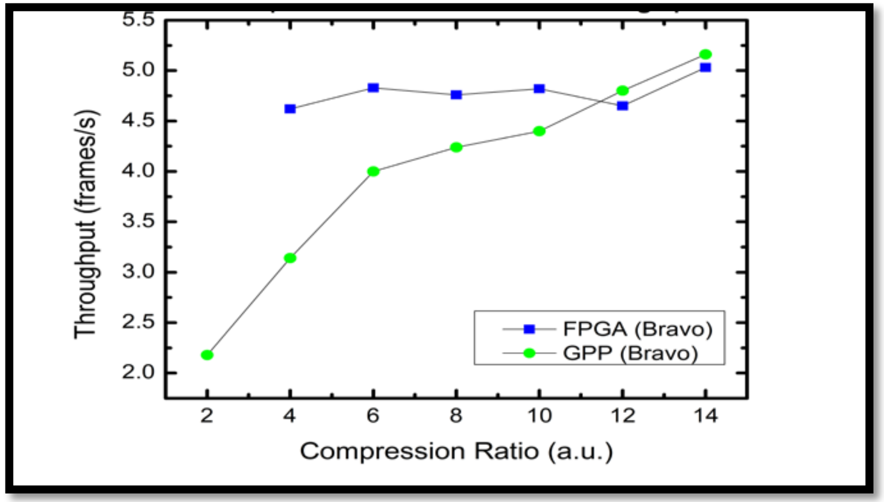


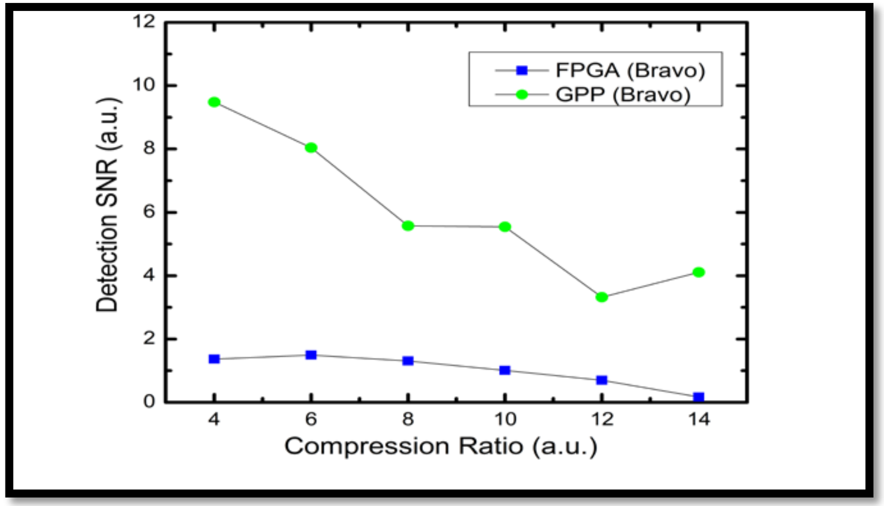


Challenge: Very difficult to meet real-time processing time requirements, even with SOTA commercial HW



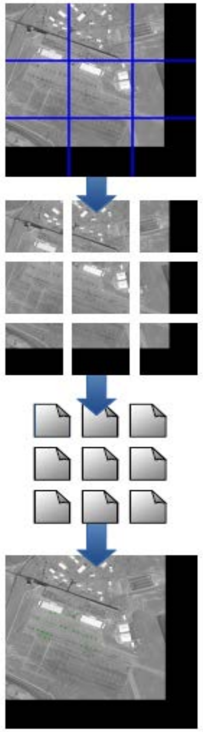
Challenge: High-performance compression has low throughput and/or loss of quality





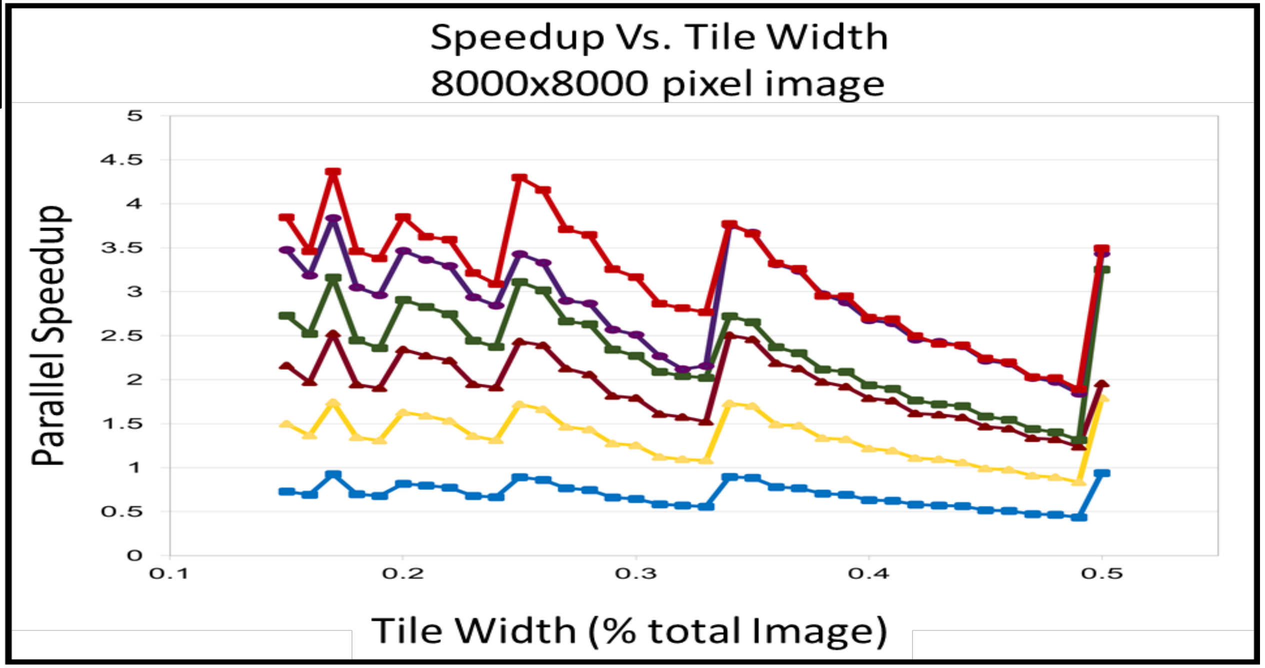
Artificial Intelligence in Space

Opportunity: Advancements in machine learning have potential to enable low power, low latency, high accuracy classification of objects in E/O image data, and resiliency in radiation environment.



Sliced image into square tiles with overlap

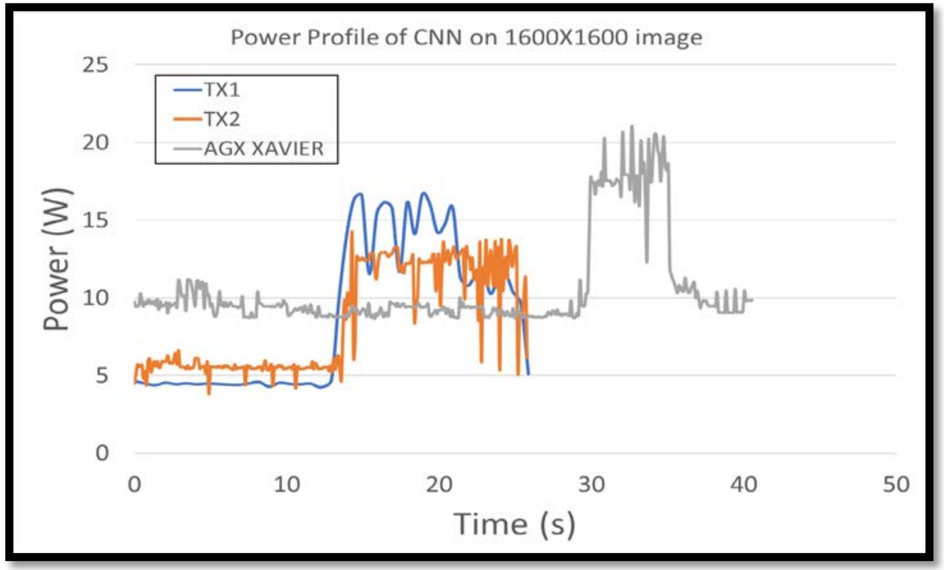
Challenge: Non-semantic meaning, access to data, cost of training, limited memory resources



Inference on array of up to 6 NVIDIA TX2 boards

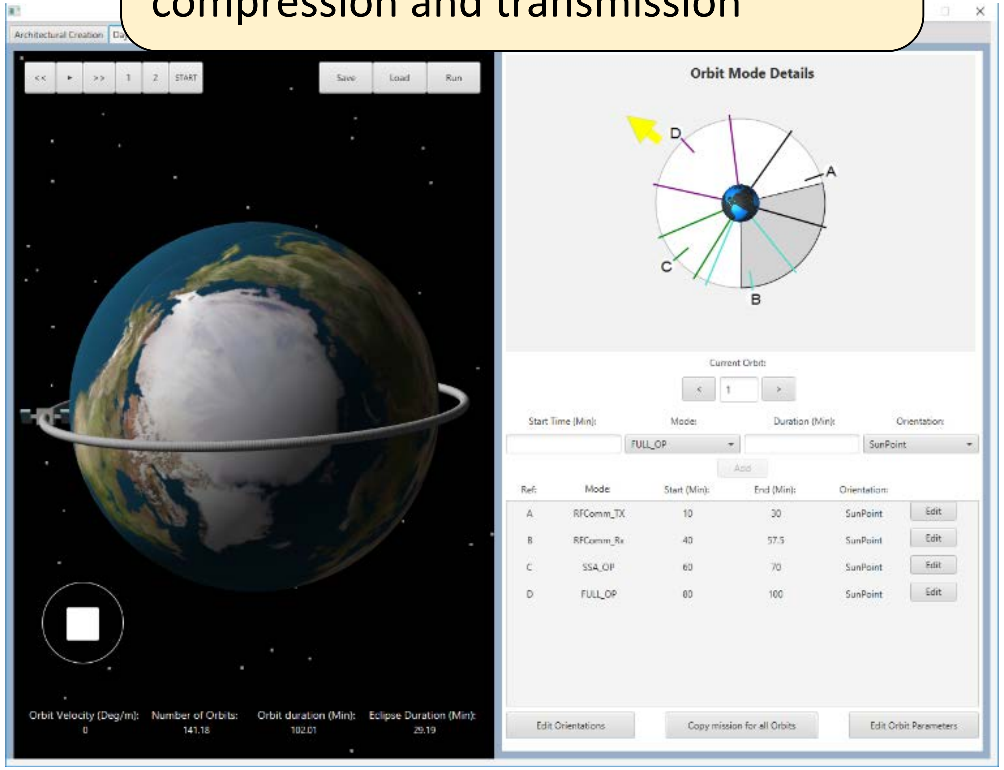
Max Parallel Speedup of 4.5x on 6 TX2 boards (0.73 of max theoretical)

Trade-space between On-orbit Processing and Transmission

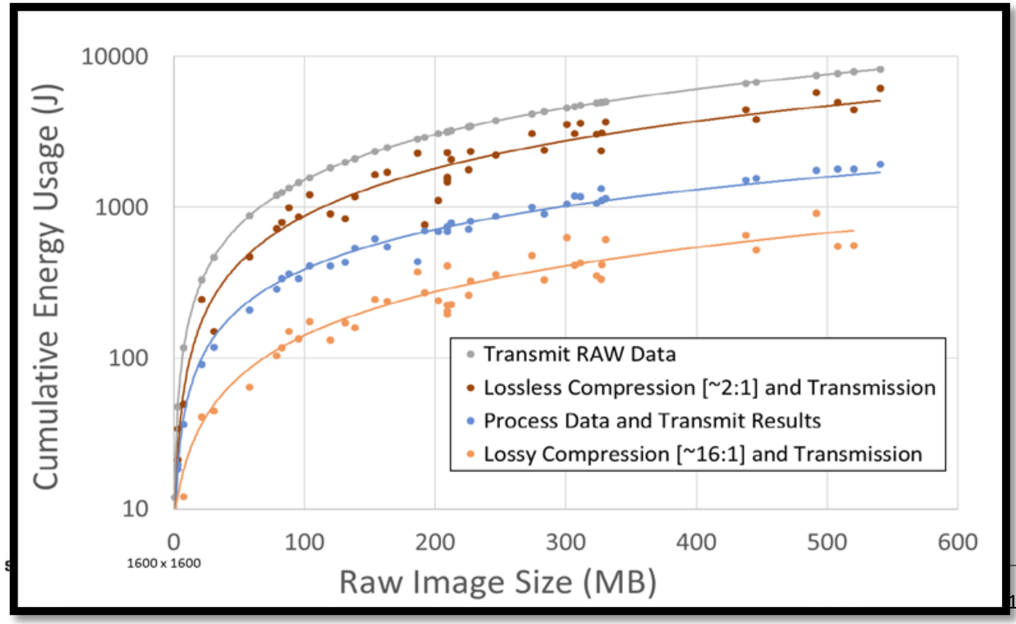


(1) Profiled the CNN detection algorithm

(2) Modeled trade-off (time & energy) between on-orbit processing vs. compression and transmission



(3) Analyze the time & energy consequences of different profiles



ID'd key performance and energy advantages for on-orbit processing

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Opportunities to Leverage Commercial Processors in Space

A New Approach: Radiation Tolerant by System

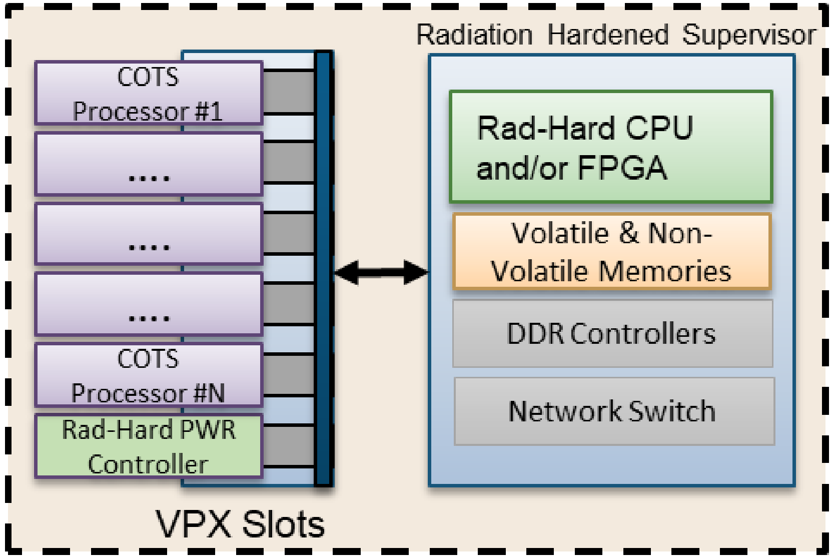
GOAL: Performance of *Commercial* with the reliability of *Rad-Hard*

- How is this done today?
  - Wait for fully RH processors to be developed – costly in time, money and performance
  - Custom solutions combining RH peripheral components with commercial processors
- Challenge: Create a generalized *Rad-Tolerant by System (RTBS)* approach
  - Utilize system elements to mitigate radiation effects in an array of "unmodified" commercial boards
- Why has no one done this before?
  - Sensitivity and "Smarts" of detection
  - Time to mitigate before destruction
  - Isolate observed effects to a single board or component on the board

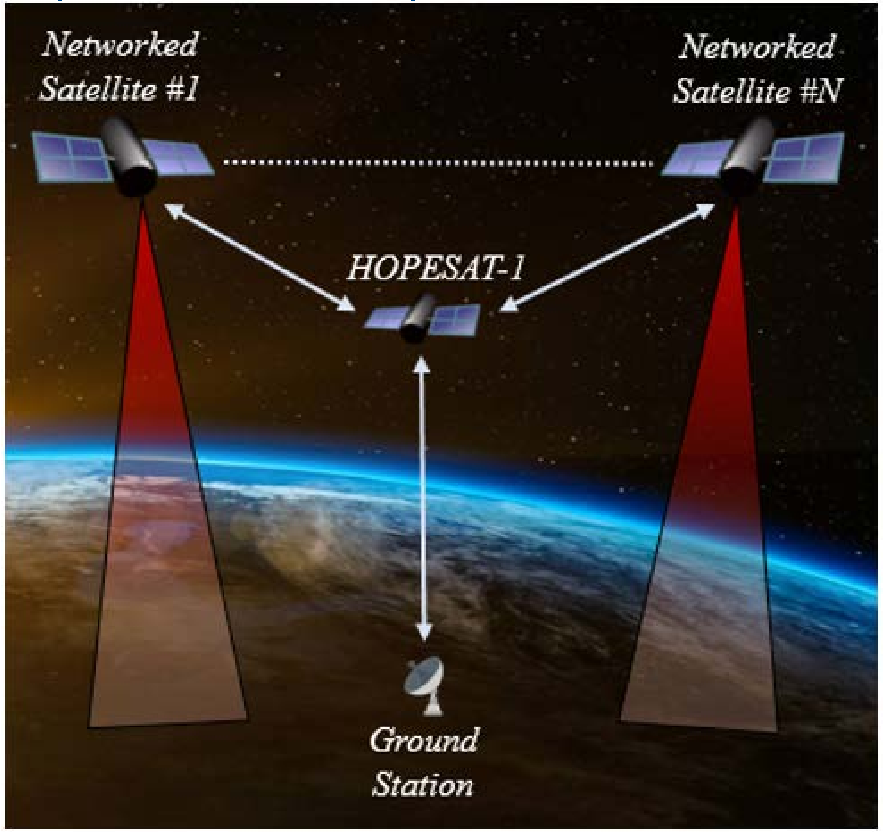
Concept for a Rad Tolerant by System Heterogeneous Processing Architecture

Need to demonstrate, in a relevant environment, a distributed computing architecture that leverages commercial computing solutions and prove the feasibility of a Rad-Tolerant by System approach.

- *Heterogeneous On-orbit Processing Engine (HOPE)*
- *Cluster of commercial processors*
- *Rad-hard supervisor/experiment manager*



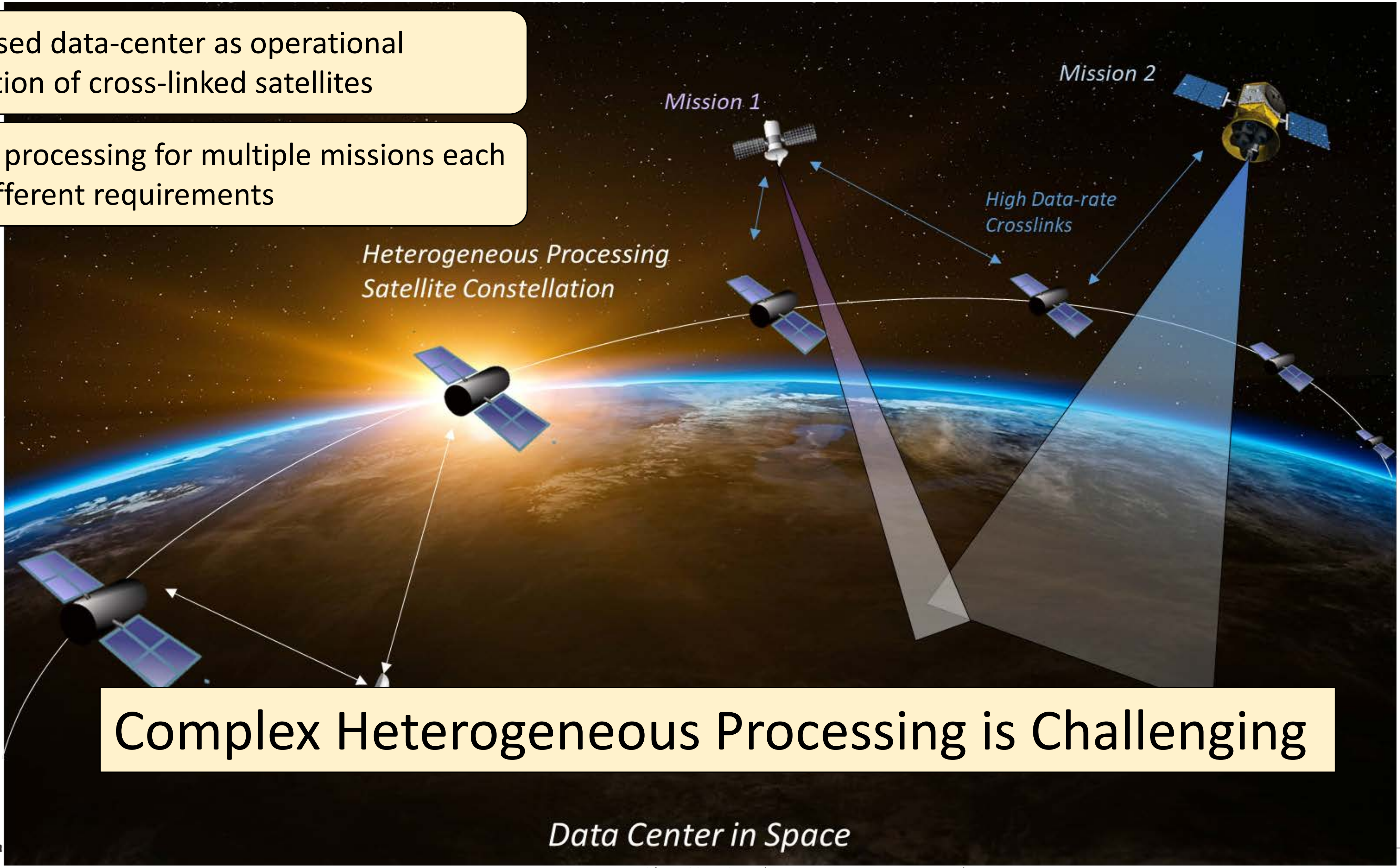
Experimental Demo planned for Q4 CY2021



Sensor-data Processing Layer in Space

Space-based data-center as operational constellation of cross-linked satellites

Augment processing for multiple missions each having different requirements

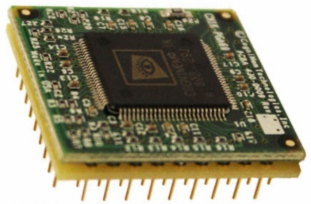


Complex Heterogeneous Processing is Challenging

Summary

- Growing need for advanced processing and communication electronics in future space systems
- The space environment places challenging constraints on the electronics
- There is a need to quantify algorithm requirements, architecture capability and realizable utilization
- Opportunities exist to leverage commercial processing technologies in space to enhance our capability

Evolving Landscape of Processing Options

	CPU	GPU	FPGA	Neuromorphic
				
Processor Type	General Purpose	Graphics Processor	Reconfigurable Logic	Special Purpose (Machine Learning)
Number of Processing Elements	1-10's cores	100's-1000's cores	1,000,000's configurable logic blocks	Analog/Digital emulation of Bio-inspired Computer
Computing Resources	Fixed computing resources, Low to moderate parallelism	Fixed computing resources, Highly Parallel	Flexible computing resources (Programmable Logic Blocks), Parallelism at user control	Digital/analog, Highly connected layers
Power	Low to High	Low to High	Very Low	Very Low
Development tools	Well-understood Highly Flexible Programming Model, 50+ years of compiler development	Less well-understood programming model, Rapidly evolving tools and library frameworks	Highly Specialized Programming Model (circuits), Some tools for translating conventional code to circuits.	Specialized vendor specific tool support, some support for popular ML frameworks
Advantages	Complex Functions	Simple Functions, Vector Processing	Digital Hardware Circuitry	Deep Learning, Great for detection and classification
Limitations	Minimum number of compute cores	Memory & Communications Constrained	Floating point uses large amounts of resources, Lower productivity	Limited Application Support

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