National Aeronautics and
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Rapid Spacecraft Development
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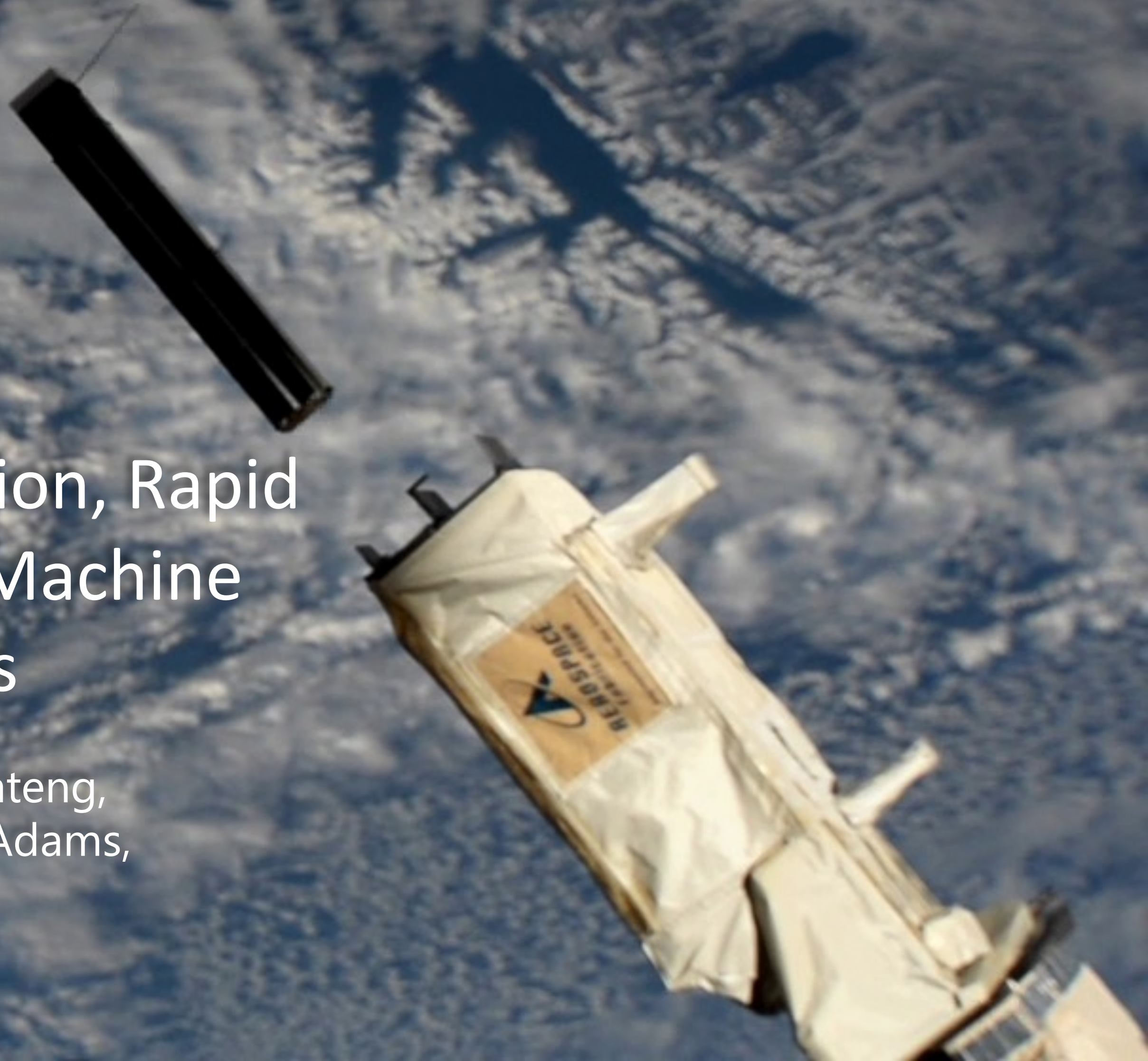

Advances in Cognitive Communication, Rapid Devices, and Artificial Intelligence/Machine Learning (AI/ML) Flight Experiments

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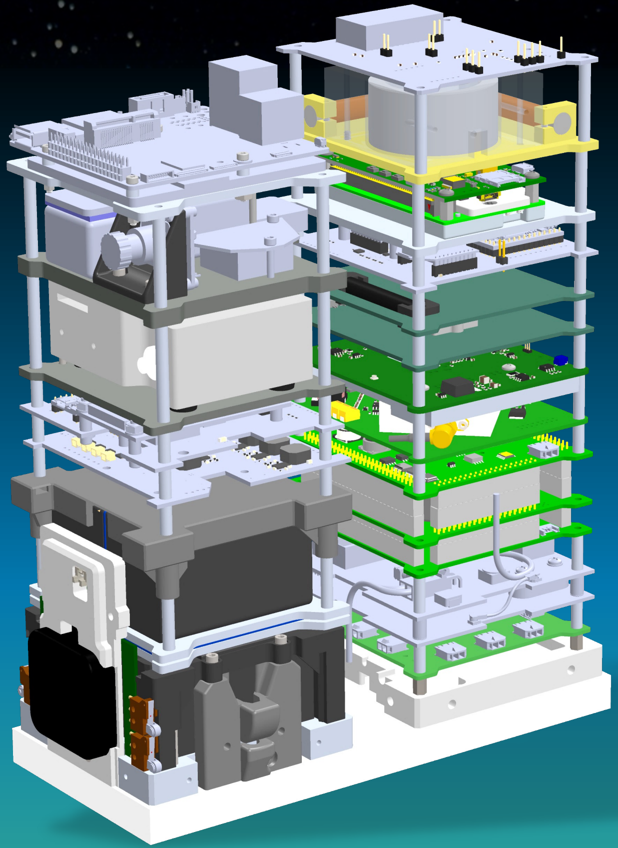
Logo:
Stanley Krześniak

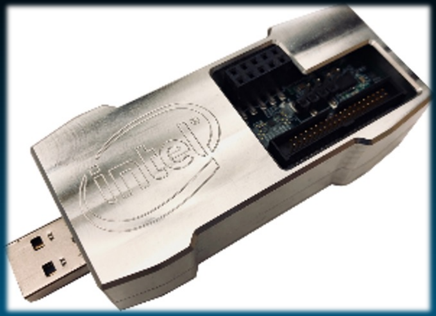
BrainStack

An orbital testbed for AI/ML processors and software

- Previous TES-n/NOW AI/ML experiments (GPUs, neuromorphic processors), expanding to multi-element stack
- Permits different software experiments on each layer of the stack:
  - Spacecraft autonomy/prognostics
  - Radiation damage accommodation
  - Extension of EOL for the spacecraft
  - Celestial Navigation (Earth zenith pointing)
  - Earth surface object identification
  - Remote sensing optimization
  - Cognitive communication / autonomously scheduled data downlink

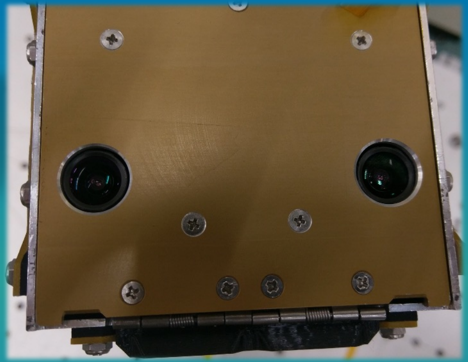


Notable Payloads



INTEL Kapoho Bay

- Loihi Neuromorphic Processor
- Power-efficient AI/ML



NVIDIA Jetson TX2

- GPU Video Processing
- Cameras in stack (pictured) for on-orbit video

Images courtesy of NASA

Initial BrainStack Flights: TES-8 and TES-10

- First tests of an AI/ML payload for the program
- Selected Payload: NVIDIA Jetson TX2 + stereoscopic camera system meant to record the ExoBrake ejection event from the ISS

TechEdSat-8

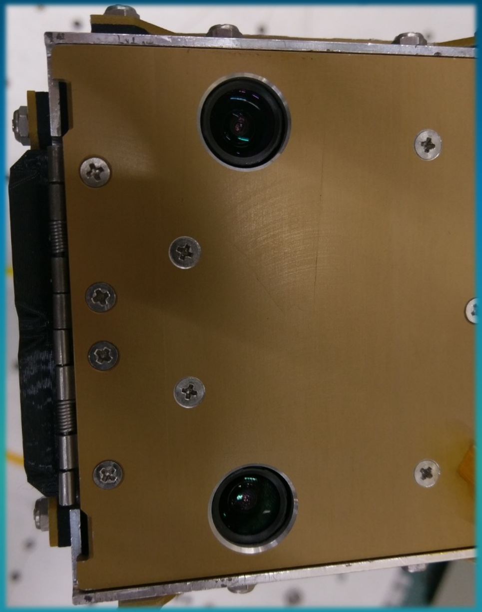
- Launched in 2019 from the ISS
- First flight of the NVIDIA Jetson TX2 Image processing payload

TechEdSat-10

- Launched in 2020 from the ISS
- Re-flight of the NVIDIA Jetson TX2 Payload from TES-8

TES-8 Avionics Stack

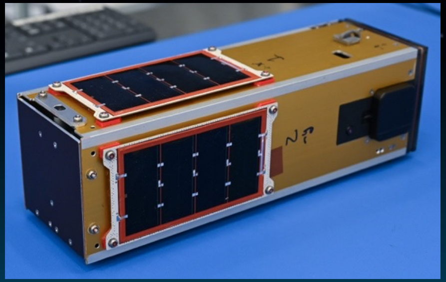
NVIDIA Jetson TX2 payload and Camera



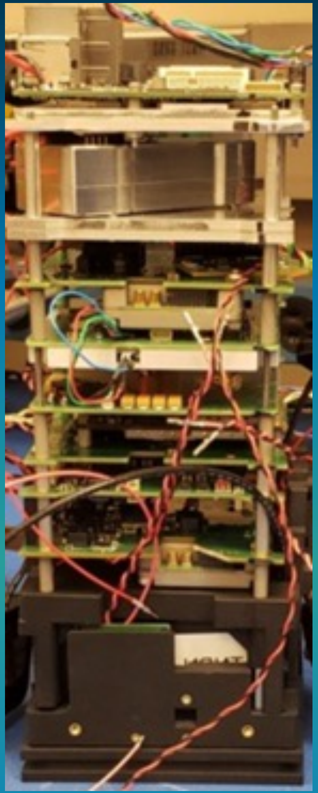
Developed in conjunction with San Jose State University

Neuromorphic BrainStack: TES-13

TechEdSat-13



TES-13 Avionics Stack



Launched January 13, 2022

- Virgin Orbit *Above the Clouds* mission

Status

- Satellite fully operational
- Mission comprehensive success achieved

AI/ML Experiment

- **Intel Loihi** neuromorphic processor

Objectives

- Establish the hardware, electrical, and software interfaces necessary to build an on-orbit neuromorphic platform
- Run simple AI/ML applications that utilize the **Intel Kapoho Bay**

The “So What” Factor:

Neuromorphic/DNN processor

↓

100x-1000x power efficiency vs. CPUs/GPUs

↓

Higher performance learning/computation for small spacecraft with limited power

↓

Potential to greatly improve nano-sat data processing while decreasing power consumption

Future BrainStack Options

AI/ML Architectures					
Processor	Developer	Dimensions	Power	Supported APIs	Comments
Tegra X2	NVIDIA	256-core NVIDIA Pascal™ GPU architecture with 256 NVIDIA CUDA cores	15W	TensorFlow (TF), CUDA	Flown on TES-8/10 Ready for TES-11 flight
Loihi 1 Kapoho Bay	Intel	128K neurons per chip in 2D mesh of 128 neural cores	<1.5W	NxSDK	TES-13 in orbit (first test flight) TES-12 in dev.
Loihi 2	Intel	1M+ neurons per chip in 3D mesh of 128 neural cores	<1W	LAVA	TES-17 in dev. Core capacity significantly higher than Loihi 1
Akida	Brainchip	1.2 million neurons, 256 nodes	<4W	TF, Keras, BrainChip MetaTF	Minimal CPU intervention needed, mini PCIe board with Brainchip
Movidius™ Myriad™ X Vision	Intel	16 SHAVE cores (916 billion operations per second)	1.5W TDP	Flic Hub SDK	14mm x 14mm x 0.84mm 105°C max & -40 °C min
Coral TPU	Google	85x56mm	2 TOPS/W	TFLite	Low power usage
Apple A16 Bionic	Apple	16 Apple neuron Engine cores	17 TOPS 8W TDP	Swift	iPhone GPU, not tested for flight, very small size
HPSC	NASA	8x X280 at 4.6TOPS/c 4x TBD RISC-V cores	7W	TFLite, ROS	Scalability: less than 1W or up to 10 cores 2025 delivery