NEPP Processor Enclave

NEPP ETW 2023

Ed Wyrwas[1], Steve Guertin[2]

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NASA Electronic Parts and Packaging (NEPP) Program

[1]Space Systems and Applications, Inc. (SSAI, Inc.), Lanham, MD 20706 work performed for NASA GSFC, NEPP Program
[2]NASA JPL Caltech

Acronyms

- Advanced Micro Devices (AMD)
- Application Specific Integrated Circuit (ASIC)
- Artificial Intelligence (AI, Ai)
- Applied Physics Laboratory (APL)
- Ames Research Laboratory (ARC)
- Advanced RISC Machine (ARM)
- Capture, Containment, and Retrieval System (CCRS)
- Complementary metal oxide semiconductor (CMOS)
- Central Processing Unit (CPU)
- Commercial off-the-shelf (COTS)
- Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS)
- Confidential Unclassified Information (CUI)
- Comma Separated Values (CSV)
- Compute Unified Device Architecture (CUDA)
- Dual Data Rate (DDR)
- Device under test (DUT)
- Electrical, Electronic and Electromechanical (EEE)
- Field programmable gate array (FPGA)
- Goddard Space Flight Center (GSFC)
- Graphics Processing Unit (GPU)
- Graphical User Interface (GUI)
- High Performance Computing (HPC)
- Input / Output (IO)
- Intellectual Property (IP)
- Johnson Space Center (JSC)
- Key Process Indicators (KPI)
- Low Earth Orbit (LEO)
- Linear energy transfer (LET)
- LINear equations software PACKage (LinPack)
- Machine Learning (ML)
- Magnetoresistive random-access memory (MRAM)
- Materials Extrusion Additive Manufacturing (MatEx AM)
- Mean time to failure (MTTF)
- Message Passing Interface (MPI)
- Military and Aerospace Programmable Logic Devices (MAPLD)
- Multi-Bit Upset (MBU)
- National Aeronautic and Space Administration (NASA)
- NASA Electronic Parts and Packaging (NEPP)
- NEPP Processor Enclave (NPE)
- Nuclear and Space Radiation Effects Conference (NSREC)
- Open Compute Language (OpenCL)
- Other Government Agencies (OGA)
- Open Graphics Language (OpenGL)
- Operating System (OS)
- Printed Circuit Board Assembly (PCBA)
- Procurement Request (PR)
- Radiation tolerant and Reliable Electronic Displays: a Preliminary Assessment Necessary for Deep-spaceflight ApplicationS (2REDPANDAS)
- RApid Machine-lEarned Triage (RAMjET)
- Scientific and Technical Information (STI) Program
- Single-Bit Upset (SBU)
- Single-Event Effect (SEE)
- Single-Event Functional Interrupt (SEFI)
- Single-Event Upset (SEU)
- Single-Event Upset Cross-Section (σ_{SEU})
- Stereolithography (SLA) Additive Manufacturing
- System on Chip (SOC)
- System on Module (SOM)
- Taiwan Semiconductor Manufacturing Company (TSMC)
- Transiting Exoplanet Survey Satellite (TESS)
- Technical Operation Report (TOR)
- University of Georgia (UGA)
- Universal Serial Bus (USB)
- User Interface (UI)

Agenda

- Quad Chart
- Big Picture Notes
- AI Thoughts
- AMD e9173 GPU (<50W) – SEE Results
- NPE Test Bench / Workflow Updates

- Steve Guertin's slides

To be presented at the NASA Electronic Part and Packaging (NEPP) Program's Electronic Technology Workshop 2023
by Edward Wyrwas (SSAI, Inc.) and Steve Guertin (JPL)

FY23-4: NEPP Processor Enclave (NPE)

Processors and Artificial Intelligence:

Testing includes total dose, single event and reliability. Test vehicles will include CPU, SOC, and GPU devices from NVIDIA, AMD, and other vendors as available. Test vehicles will include 'simple interface' devices with USB or similar connectivity, and Single Board Computers.

- Compare to previous generations
- Investigate failure modes/compensation for increased power consumption
- Identifies viable suppliers and provide insight into product obsolescence roadmaps

Description:

- This is a task over all device topologies and processes
- The intent is to determine inherent radiation tolerance and sensitivities
- Identify challenges for future radiation hardening efforts
- Investigate new failure modes and effects
- Electrical characterization pre, during and post-rad

FY23-4 Plans:

- Continue to deploy AI and Machine Learning test suite, making refinements as required.
- Update "Command Center" GUI, building interfaces for all command-line/terminal scripts.

Collaboration:

- OGA, Industry, and NASA Center partners are asked to contribute "code" to the software repository in order to have access to it. [as permitted]
- "Code" can be their own published or CUI items since the repository is not public:
  - Science payload workflows (but not real data)
  - Flight-like applications, scripts, and source code
  - Instrumentation and monitoring frameworks

Team Members

- Steve Guertin
- Scott Stansberry
- Carl Szabo
- Jim Forney
- Seth Roffe

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Big Picture Notes:

- Additional work performed by team at UGA on NEPP+JHU APL TX2i DUTs as acknowledged in E. Miller, C. Heistand and D. Mishra, "Space-operating Linux: An Operating System for Computer Vision on Commercial-Grade Equipment in LEO," 2023 IEEE Aerospace Conference, Big Sky, MT, USA, 2023, pp. 1-12, doi: 10.1109/AERO55745.2023.10115703. https://ieeexplore.ieee.org/document/10115703
- Significant uptick in inquiries regarding NVIDIA Jetson TX2i. Data anticipated from the radiation effects community (i.e., Troxel Aerospace at IEEE NSREC in July '23) will discuss some SEL associated with newer, higher performing successors to the TX2i.
  - Community discussions indicate that the High-Performance Tier Xavier devices and Orin devices have not shown good radiation performance thus far.
- Radiation Effects Support for MRAM and Ai Devices with ARC are ramping up.

Big Picture Notes:

- NEPP has published 200 MeV proton test results for the AMD v1202b SOC. Published with STI 20230000488 on ntrs.nasa.gov
- AMD Radeon e9173 GPU 16MeV/u heavy ion test – preliminary results follow.
- Radiation Tolerant Displays (2REDPANDAS) papers accepted to IEEE Space Computing Conference, SEE MAPLD and NSREC - Heavy Ion SEE effects on display drivers; Pixel dosing data; Susceptibility of layout and protection elements on substrate of each display type.
- NEPP Rapid Prototyping Lab now has Materials Extrusion Additive Manufacturing (MatEx AM) capabilities as well as Stereolithography (SLA) Additive Manufacturing for anti-static material systems.
  - We're actively in discussions with materials companies with offerings of conductive filaments with either limited and no-post processing requirements… for additively manufactured printed wiring boards.

Confusion Makes AI Scary

- Automation:
  - Y = mx + b (standard function for a line)
  - Inputs relate to known outputs (discrete variables)
  - Expected stimulus results in a response by the system, but noise and extraneous signals (unexpected signals) are typically ignored or suppressed
- Artificial Intelligence:
  - f(x,y,z) = 3xy + 2.5y - 7z (example multilinear polynomial function of degree 2)
  - Inputs may be their own functions or may be constantly changing (continuous variables)
  - Unexpected stimulus is the desired primary input.
    - The framework black-boxes the computations required to optimize a model that can produce an output similar to the training data.
    - The black-box is effectively a big linear algebra equation (aka the AI model).
    - The training process attempts convergence of the linear algebra so we can “solve” the equation.

https://en.wikipedia.org/wiki/Multilinear_polynomial#:~:text=For%20example%20f(x%2Cy,variables%20occurring%20in%20any%20monomial.

AI is a Workflow Problem, Not a Model Problem



- When deploying AI, a system designer will face one true question:

  Where within the compute system and its memory hierarchy should we take a resource hit?

  - to load the AI framework/engine (i.e., TensorFlow),
  - to store the model's weights,
  - to hold the model's weights during inference,
  - to acquire the input data,
  - to transform the input data into something usable by the Ai model,
  - to perform the inference,
  - to save the output telemetry into a meaningful format schema

- A variation to this question is:

  Which device(s) in the system will consume the clock cycles to do the aforementioned tasks?

  - Within an AI system, "Somebody has to do it," and some devices do each task better than others.

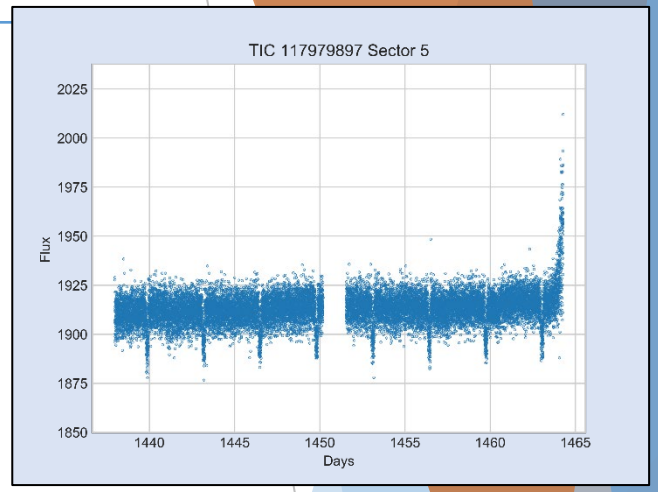
Test Benches Codify a Teaching Moment

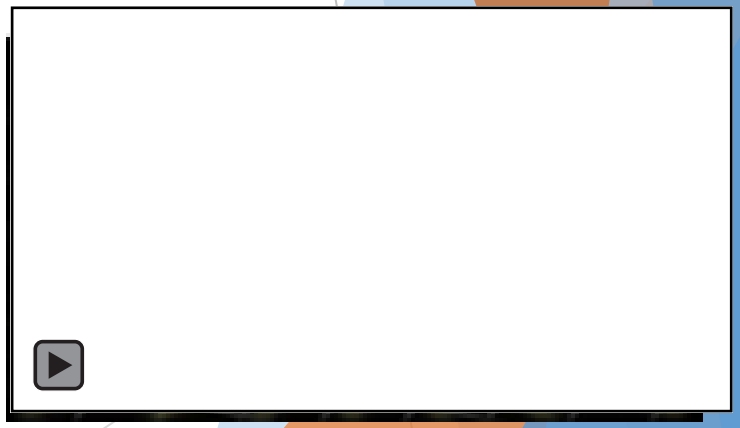
- Automation and AI are both required for an AI workflow.
  - Setting up a dataset can rival the time it takes to train a model.
  - The first pass through, to create the data automation workflow, is a very tedious process.
  - Training is a very iterative process and is usually GPU intensive.

- Convolutional Neural Network end-to-end tutorial (*Sun vs Moon*) has been included in the NPE test suite for a few years now containing Python scripts for:
  - Dataset image acquisition
  - Dataset image file renaming
  - Dataset inventory CSV file creation
  - Dataset preprocessing workflow to standardize training inputs
  - Neural Network configuration
  - Training routine
  - Model file exports
  - Requantization of Model
  - Inference routine for multiple device types

More Complexity, but on Public GitHub

- A microlensing classifier using Greg Olmschenk (667)'s RApid MachinE-learned Triage (RAMjET) has been included in the test bench for a few years as a Deep-Preprocessing Workflow Example.
  - RAMjET is a framework for producing neural networks to characterize phenomena in astrophysical photometric data.
  - The resources required to preprocess the light curve dataset is not small. However, training could be done on orbit and has been evaluated on various low power compute hardware.
  - If another device in the system can preprocess the light curve from a telescope instrument, then the inferences could be performed in real-time using low power AI Accelerator hardware.





https://astroramjet.readthedocs.io/en/latest/

https://exoplanets.nasa.gov/resources/2168/gravitational-microlensing/

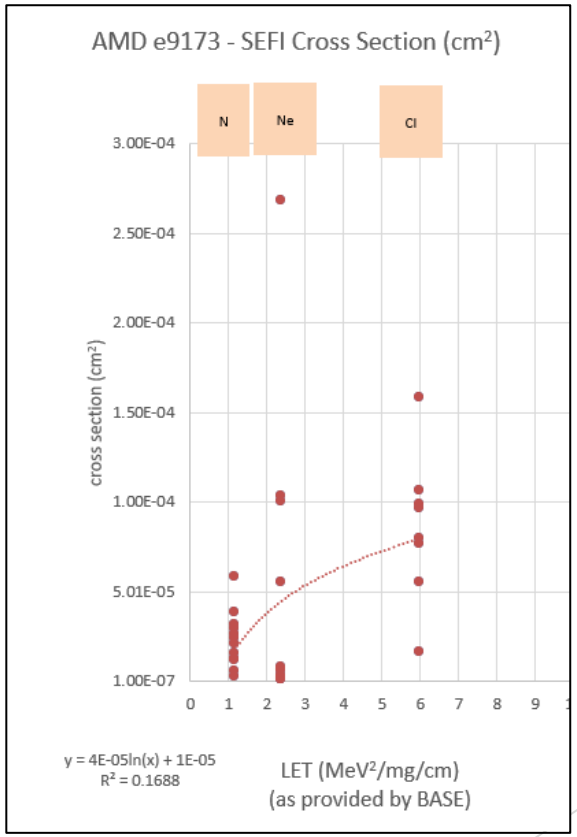
AMD e9173 GPU (<50W) – SEE Results

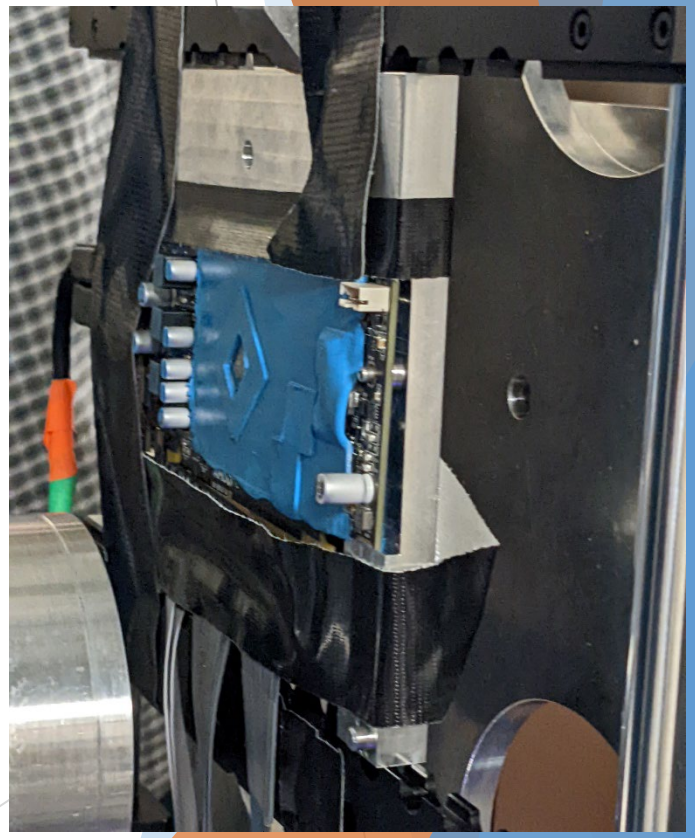
NPE Test Suite elements:

- Ubuntu OS 20.04 – [Idle Test]
  https://releases.ubuntu.com/20.04/
- ROCm 3.7 open-source stack for GPU computation -
  https://rocm.docs.amd.com/
- TensorFlow ROCm 2.3 – [Matrix Math Test]
  https://pypi.org/project/tensorflow-rocm/2.3.0/
- RAMjET Microlensing Ai – [Ai Dynamic Test with LSTM]
  https://github.com/golmschenk/ramjet,
  https://astroramjet.readthedocs.io/en/latest/
- NEPP Processor Enclave Sun vs Moon Classifier Ai – [Ai Static Test]
  https://ntrs.nasa.gov/citations/20205003132
- Mesa GLXGears Benchmark – [OpenGL Graphics Test (60 fps)]
  https://packages.debian.org/stretch/mesa-utils

Tests prepared but not utilized due to test constraints:

- JSC's prototype software for JARVIS [Vulkan and OpenGL Graphics]
  https://www.nasa.gov/feature/nasa-empowers-workforce-to-advance-deep-space-technologies
- HPC MPI, Ruby, Fortran and LinPack [Open-source MPI]
  https://www.open-mpi.org/software/ompi/v4.1/
- NEPP Processor Enclave's OpenCL Matrix Math Tester





AMD Radeon Embedded e9170 GPU (e9173 PCIE variant)
Thinned to ~150um and cooled using conduction and convection

Engineering Test Bench Additions

- GSFC NPE Team
  - Post processing script(s) to identify errors in Linux Kernel logs
  - Next revision to the Radiation Effects Testing Workflow app for the RealWear headset will be anchored by Seth Roffe (561)
  - Python UI for Automation scripts used with AI are in development
- JSC JointAR display interface software is being tested on the AMD x64 architecture
  - Official deployment target is ARM though package is considered portable
  - Permits both GPU and Display testing
  - Tyler Garrett (JSC) will be presenting on this software application topic at the IEEE Space Computing Conference. July 18th-21st, 2023. “Towards a Radiation-Tolerant Display System” https://smcit-scc.space/
- AMES / UGA Computer Vision Pipeline written in C – for CubeSat Flight Experiment
  - A Hardware Accelerated Computer Vision Library for 3D Reconstruction Onboard Small Satellites
  - Evaluating robustness of software for both test bench and flight
  - https://ieeexplore.ieee.org/document/9438159

Radiation Effect	Displacement Damage Dose (DDD)	Total Ionizing Dose (TID)	Non-Destructive Single Event Effects (NDSEE)	Destructive Single Event Effects (DSEE)
Technologies Dominated by the Effect	Opto-electronics, Bipolar	Analog, CMOS, MOSFETs	All	All (e.g., CMOS→SEL, MOSFETs→SEB & SEGR)
Type of Effect	Cumulative (total particle fluences)	Cumulative (total particle fluences)	Instantaneous (one particle)	Instantaneous (one particle)
Why?	Damage cascades, disruption of the semiconductor lattice	Charge trapping (oxide/passivation/interface trapping especially)	Transient conditions: recombination and drift of charge carriers. Upsets that are persistent. Charge collection.	Semiconductor tolerances exceeded internally (current density, electric field strength, etc.)
What does that lead to?	Photonics and transparent material degradation	Threshold voltage shifts, leakage current	System and functionality drop-outs, some may require power cycle or reset	System and functionality failure
Radiation Source that Exhibits the Effects in an Isolated Fashion	Mid-energy protons (50-63 MeV p+)	Gamma source to create electron-hole pairs uniformly throughout the DUT	High energy protons or heavy ions for sufficient local charge deposition	Heavy ions
Other Sources that can also create the effect	Neutrons (difficult to count) or other energy protons (competing Coulombic interactions)	Protons, electrons, x-rays, heavy ions (physical coverage uniformity in question)	Protons, pulsed laser	Protons (competing with dose effects)

Radiation Effects and Analysis Lessons: a Scientist's Field Instruction to Explain Radiation Testing.
https://ntrs.nasa.gov/citations/20220002512

NPE Rapid Prototyping Lab

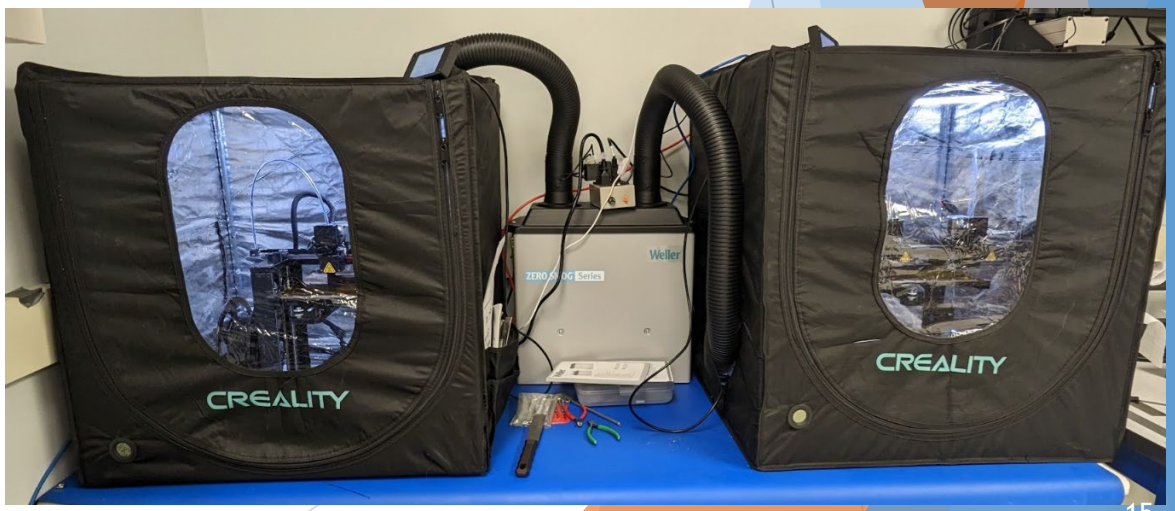
- Fixtures for DUTs and cable harnesses, parts of engineering test benches,
  - FormLabs 3L printer back in action
  - Two MakerGear M3-ID material extrusion printers have been installed and calibrated
    - We are using generic and anti-static thermoplastic for DUT fixturing and test setup components
    - NPE has designed and fabricated ETB parts for: 2REDPANDAS and CCRS, CUVIS, Dragonfly, others
- Community Engagement
  - ASME committee member for Materials Extrusion “3D Printing” of non-metals
  - NASA’s Community of Practice for Additive Manufacturing of Electronics (AME)
    - Presently creating a ‘printing profile’ for Kupros Inc.’s Cu-29 copper filament



2REDPANDAS –
Right-angle DUT brackets for LBNL



CCRS –
LED testing “Light Meter” test box



MakerGear M3-ID printers with Creality Enclosures and Weber Fume Extractor

<20nm Technologies

*Radiation Testing (RT)
*Cold Block (CB) Adapter Development
*Test Feasibility Evaluation (FE)
*Continuation or
*Termination or

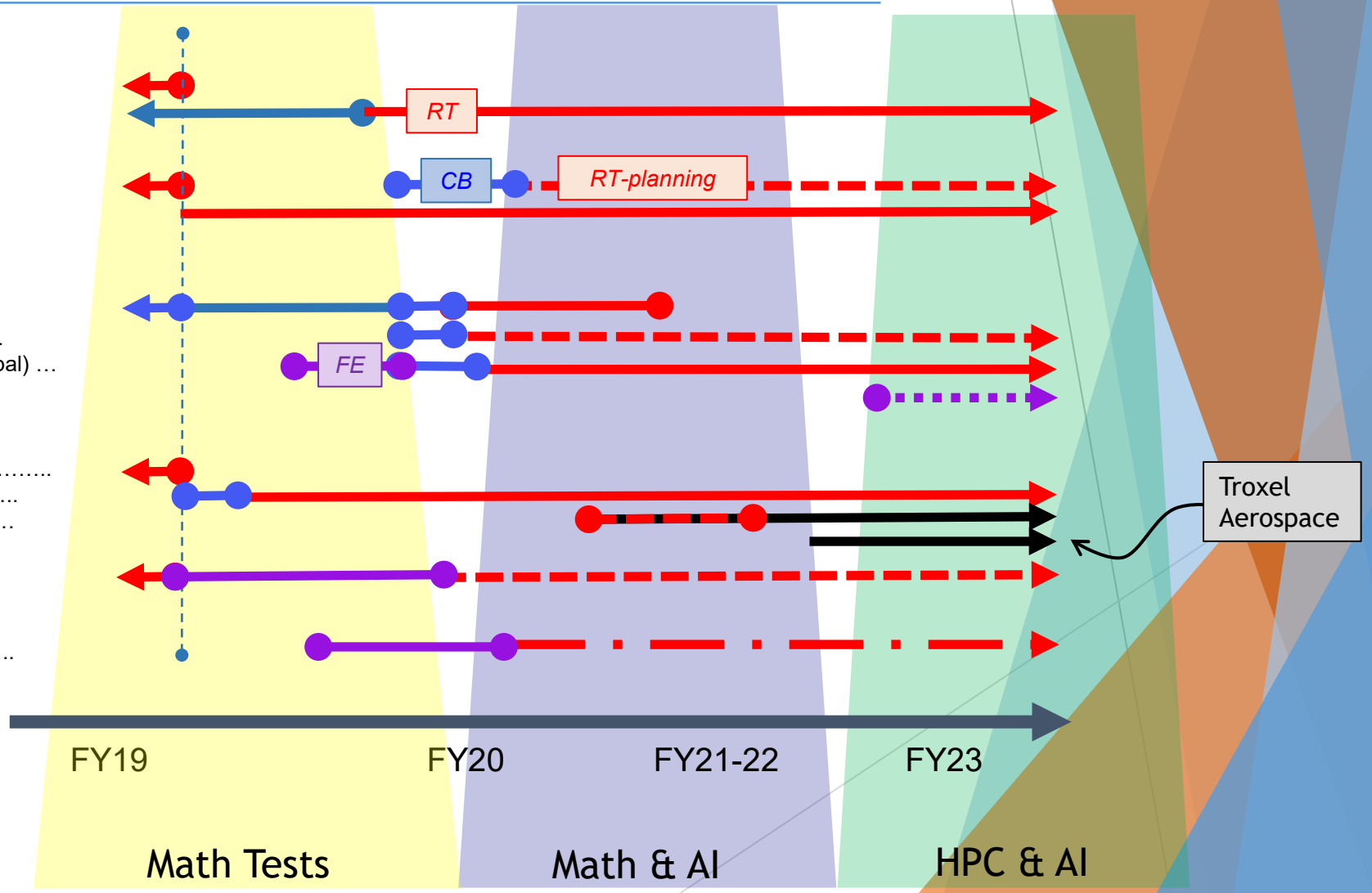
Microprocessors
Intel ……
AMD (Global) ……

Microprocessors with embedded GPUs
Intel ……
AMD (Global) ……

GPUs
NVIDIA GTX (TSMC) ……
AMD (Global) ……..
14nm Low Power, AMD Radeon e917x (Global) …
NVIDIA RTX (TSMC) ……..……

System on Chip
NVIDIA Tegra X1, X2 (TSMC) ……..
NVIDIA Tegra X2i (TSMC) ……..
NVIDIA Tegra Xavier (TSMC) ……
NVIDIA Tegra Orin (TSMC) ……
Qualcomm (Samsung) ……..

Neural Network Devices
Google, Intel Myriad/ Loihi……..



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NPE Engagements

- Polaris projects with JSC - **2REDPANDAS** (Displays) and **JARVIS**/STARK (GPUs)
- GSFC **Radiation Effects and Analysis Group -** Design and Fabrication
- **NASA** and **ASME Additive Manufacturing** (AM) Working Groups for non-metallic materials for extrusion
- NASA **Additive Manufacturing of Electronics** Community of Practice
  - Kupros, Inc. (& DoD) – Conductive filaments
  - Multi3D, LLC – Conductive filaments
- **NASA Generative Design Team** (Autodesk Fusion 360 workflow support)
- **NPE Rapid Prototyping Lab** - Cooling Solutions for high power devices
- Office of Safety and Mission Assurance (**OSMA**) Physics of Failure handbook
- Data sharing activities: **S3VI**, **Aerospace** Corporation,
- **Avionics Architecture** Community of Practice
- **JPL** (Steve Guertin) is handling the ARM piece of the NPE
- **JourneyApps + RealWear** – software platform enabling standardized radiation test records
- **JHU + UGA** – Continuation of TX2i testing
- **ARC** – Planned TX2i flight for AI test bench evaluation

NPE Working Group Telecon

- 1st and 3rd Fridays of each month at 11am Eastern
  - Contact Ed Wyrwas (edward.j.wyrwas@nasa.gov) if you would like to attend
  - Our next meeting is Friday, June 16th

Acknowledgements

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  NASA Electronic Parts and Packaging (NEPP) Program

  NASA Office of Safety & Mission Assurance

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