



# Advanced Power Technology Development Activities for Small Satellite Applications

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# Outline

- I. Introduction
- II. Small Spacecraft Technology Program Smallsat Technology Partnerships
  - a) Demonstration of a Nano-Enabled Space Power System
  - b) Development of a Lightweight CubeSat with Multifunctional Structural Battery Systems
  - c) ALBus Small Sat power demonstrations at NASA
- III. Conclusions
- IV. Questions

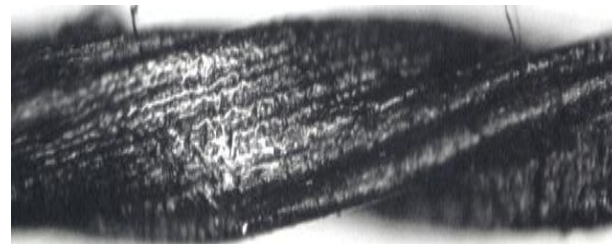
# To Extend Mission Capability

- Challenges: Parasitic Mass, Power Efficiency Limitations
- Advanced power technology for space applications
  - Energy generation
  - Energy storage
  - Power management and distribution
  - Power systems architecture and analysis
- Advancements in such areas will impact the longevity and capabilities of these missions

# Development of a Nano-Enabled Space Power System

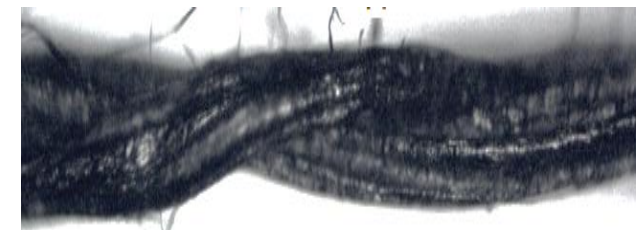
- Nanomaterial-enhanced power system components to allow for reduced weight while maintaining or increasing capability.
  - Quantum dot / Quantum well solar cells
  - CNT enhanced lithium-ion batteries
  - Carbon nanotube (CNT) wire harness
  - CNT thermoelectric energy harvesting
- Nanomaterials
  - ✓ Significant weight saving
  - ✓ Minimal change in cost
  - ✓ Increase in available space

**Optical Microscopy of Twisted and Braided metal-free CNT Harness, exceeding  $1 \times 10^6$  S/m in electrical conductivity**



3 Ply Laid

100μm

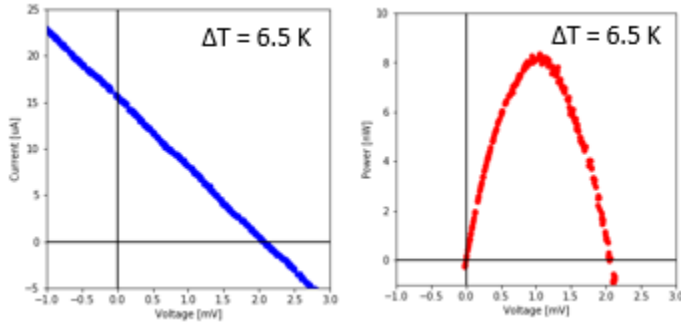


3 Ply Braid

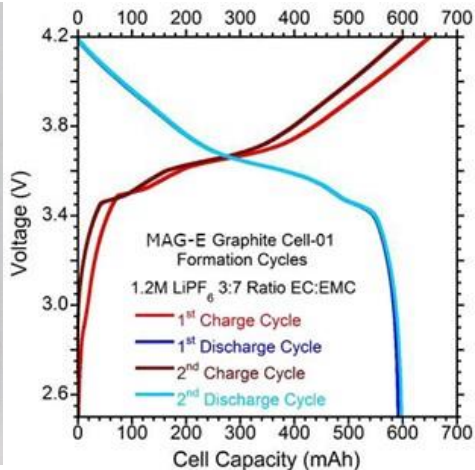
***Evolutionary advancements* in each technology when combined can translate into *revolutionary changes* at the system level to provide higher conversion efficiency and energy density to extend mission capability.**

# Progress to Date

Demonstrated thermoelectric power generation from SWCNT TE device, producing over 8 nW from 3 paired couples against a temperature gradient of 6.5 K



Fabricated pouch cells exceed 250 Wh/kg and will serve as drop-in replacement for Clyde Space batteries (100-150 Wh/kg)



RIT xx3450 Pouch Cell

Heat Management & Energy Harvesting

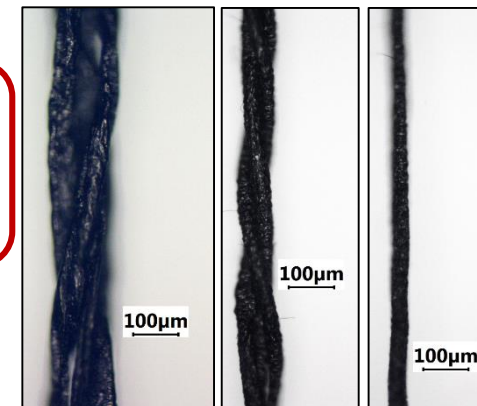
QD/QW Cells

CNT in Li-Ion Batteries

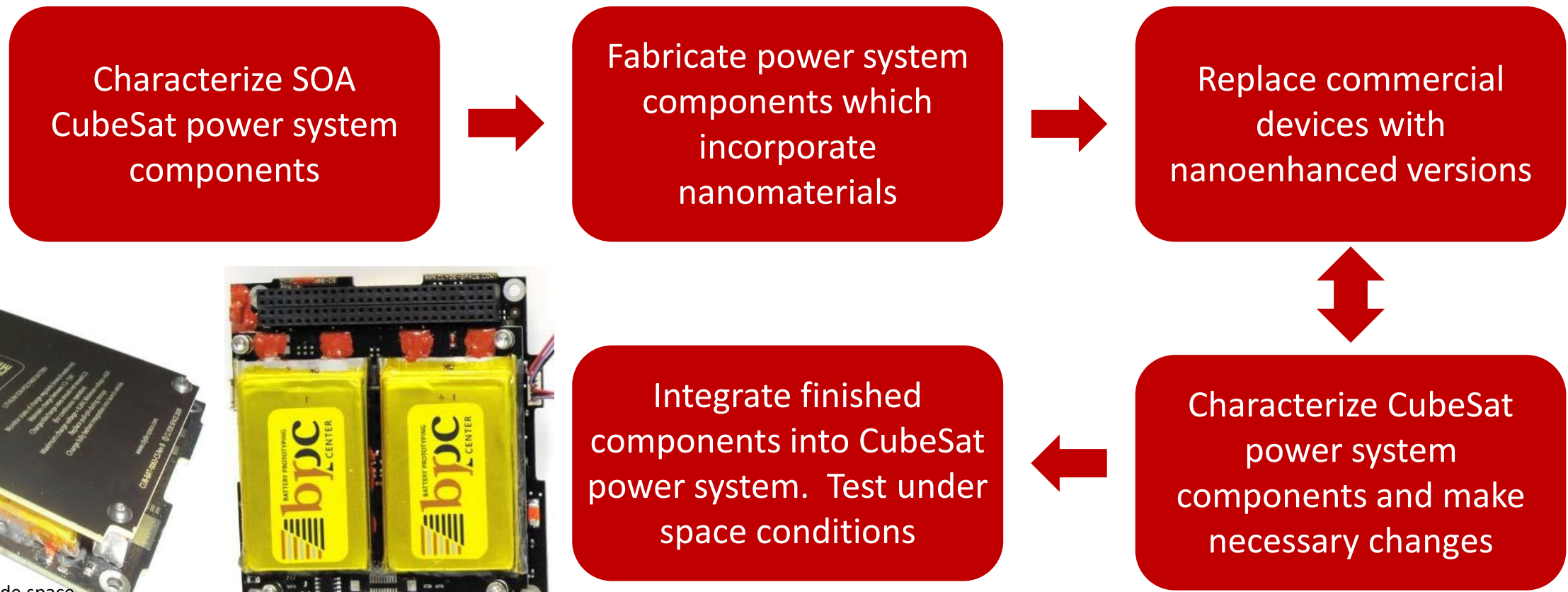
CNT Conductive Wiring

Increased radiation tolerance extending lifetime. Spectrally tuning the middle (GaAs) cell bandgap leading to higher current densities. Highest QD  $V_{OC}$  to date. replacement PV cells to be integrated with Clyde Space boards

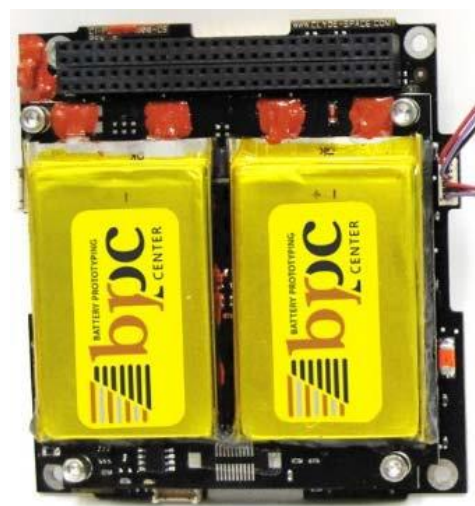
Fabricated Braided Metal Free CNT wires to compare against commercial interconnects



# Approach to Integrating Nanoenhanced Components



www.clyde.space



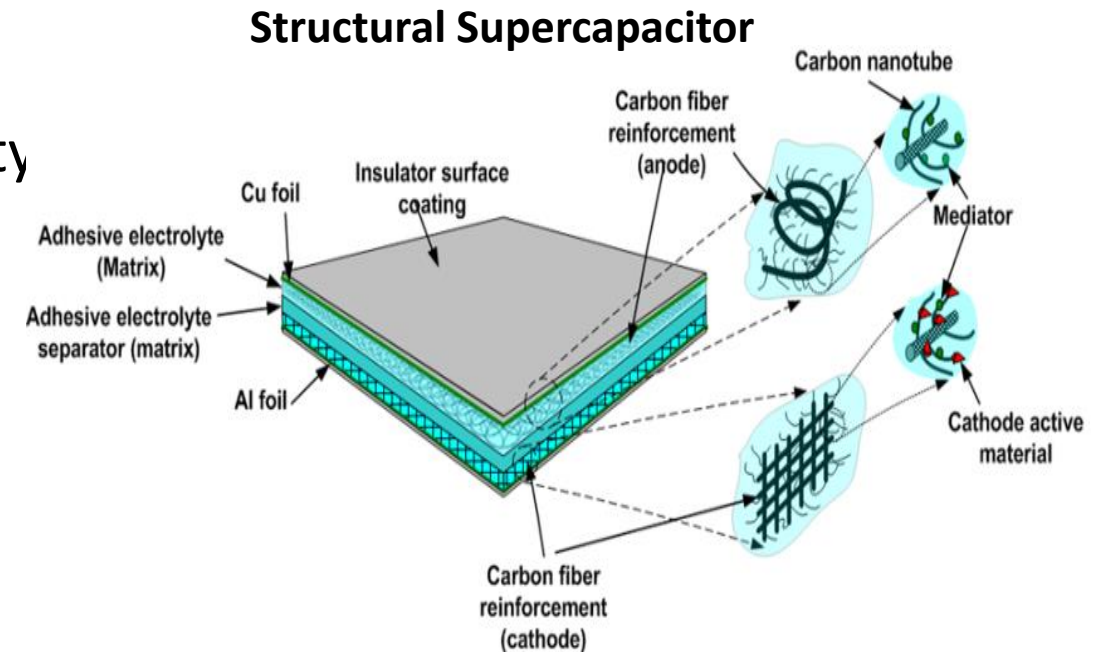
Nano Enhanced

***Benefit of enhancing existing technologies through the use of nanomaterials is that the enhanced products can serve as drop in replacements to existing infrastructure, minimizing the need for new equipment and infrastructure.***



# Development of Lightweight CubeSat with Multifunctional Structural Battery/Supercapacitor Systems

- Lightweight 1U CubeSat which utilizes fully integrated structural battery materials for mission life extension of 200-300%, larger payload capability and significantly reduced mass of 15% or more.
- Mediator-enabled electrolytic polymer
  - ✓ Lightweight load bearing structure and an electrochemical battery system
  - ✓ High specific power and energy with fast charge rate
  - ✓ Significant weight saving
  - ✓ Increase in available volume for payloads



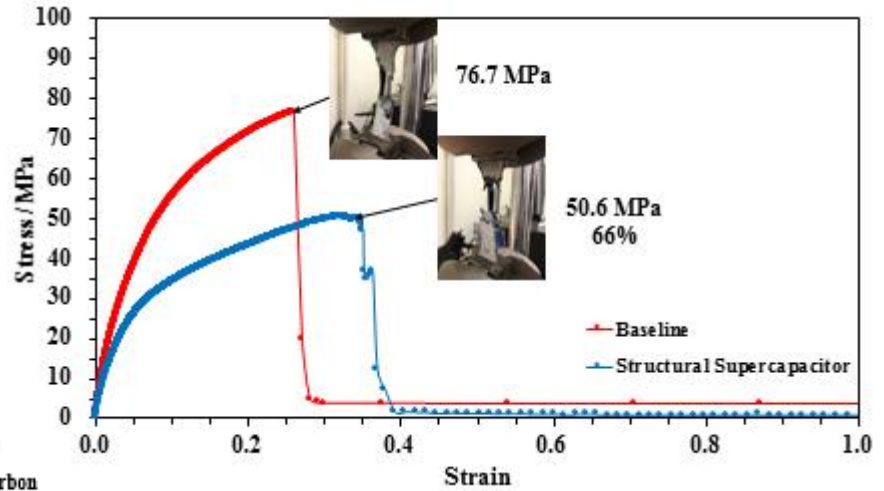
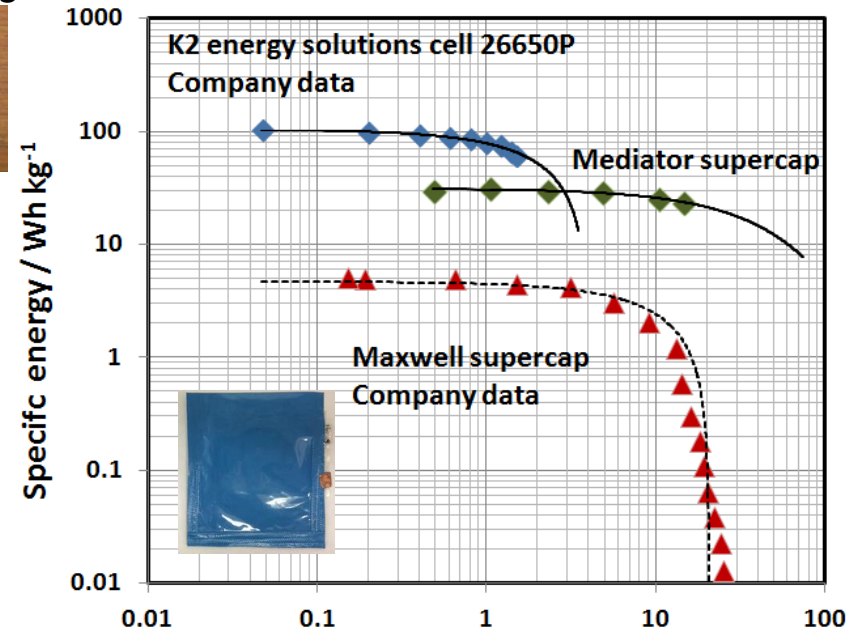
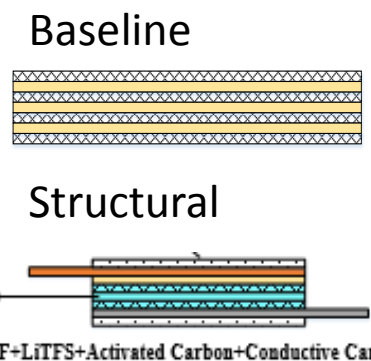
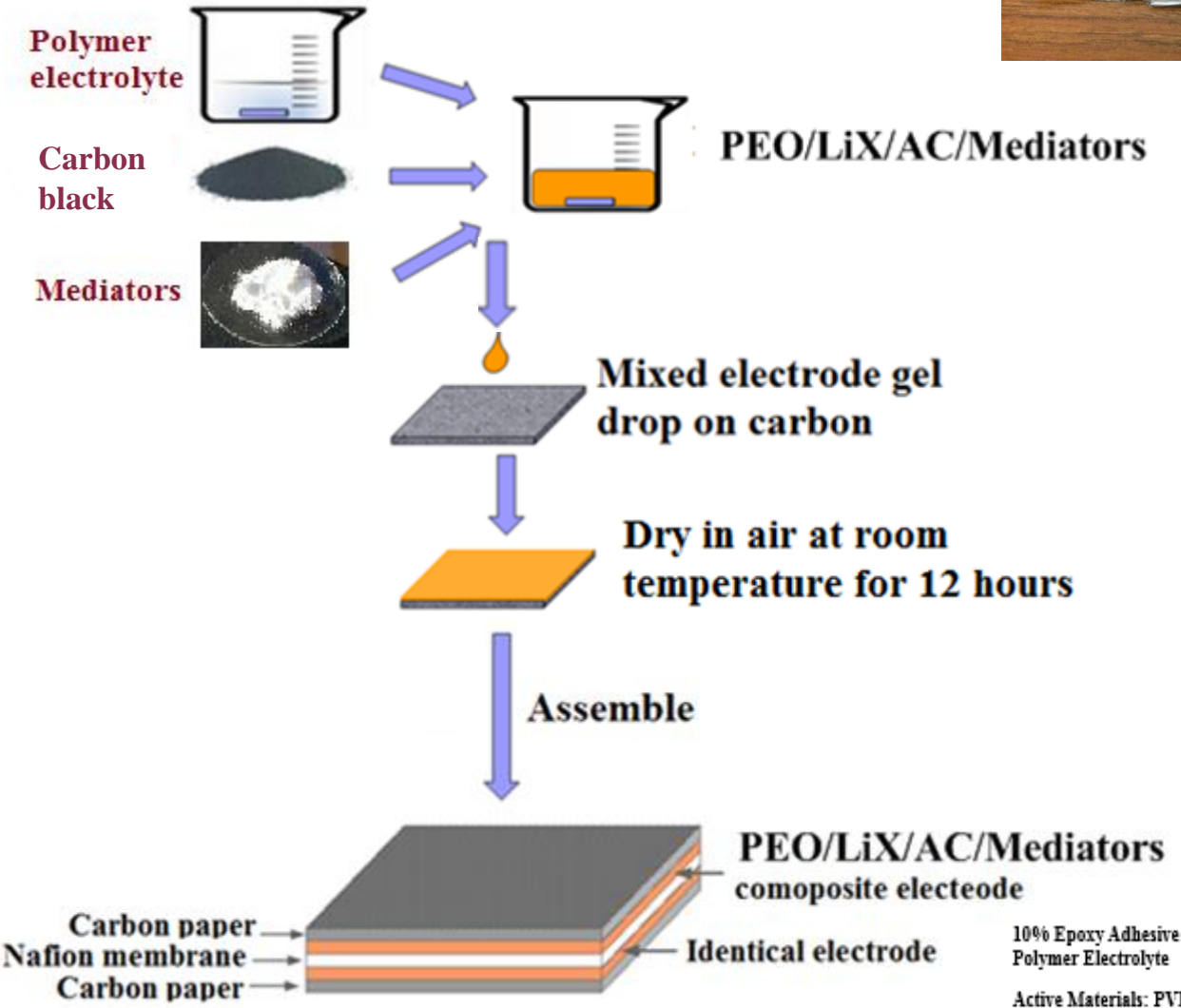
***Advancements* in structural battery technology can replace parasitic structural mass with material that provides additional energy, leading to lighter weigh and extended satellite mission life.**

# Progress to Date

## All Solid-State mediator structural supercapacitor stacks



### Supercapacitor Fabrication







# Advanced Electrical Bus (ALBus) CubeSat Technology Demonstration Mission

- Provide 100 W capable power management system
- Demonstrate regulated high power bus
- On-orbit demonstration of technologies required for 100 W system
- Power system efficiency  $\geq 85\%$
- EPS shall fit in 1U volume (10x10x10 cm )or less
- CubeSat shall not exceed 4.0 kg mass
- Exhibit solar array mechanisms utilizing shape memory alloy materials



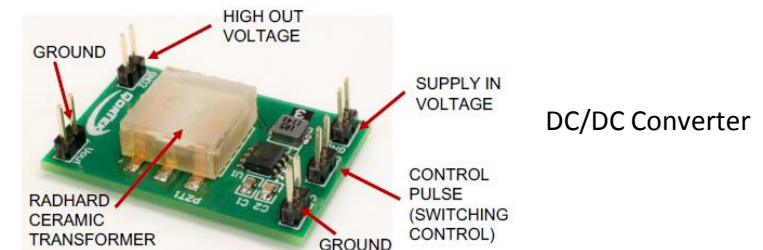
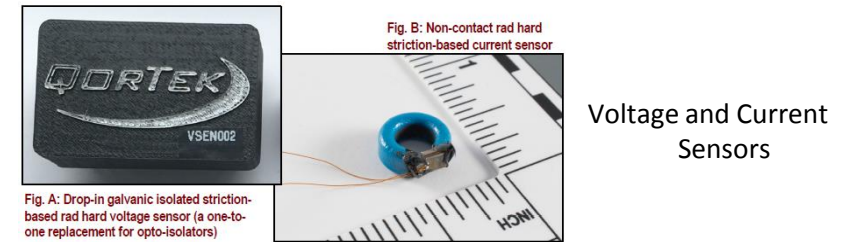
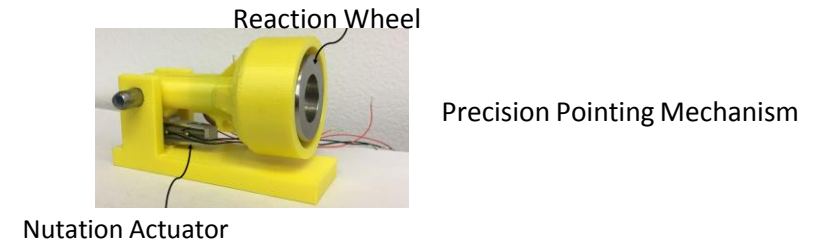
# Advanced Electrical Bus (ALBus) CubeSat Technology Demonstration Mission

- Images from Katie Oriti?



# Power Technologies for SmallSAT

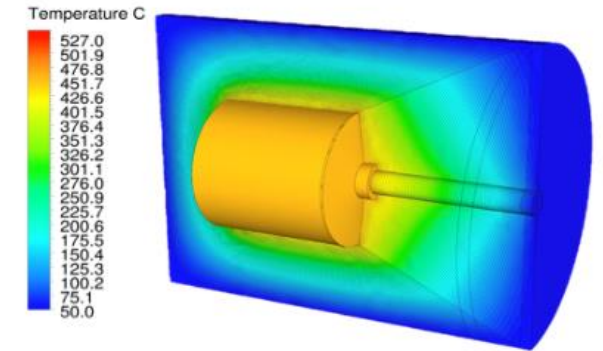
- Power Electronics SBIR work with Qortek:
  - Precision fine attitude tuning of SmallSats (GSFC)
  - Striction based current and voltage sensors for MEO/GEO (GRC)
  - DC/DC conversion – ceramic based power supply for space bus on SmallSats (GRC)
  - Development of SiC and GaN power devices for space applications (GRC with GeneSiC)





# Power Technologies for SmallSAT

- **Super/ultracaps:** In development via GRC SBIRs for power and energy storage
- **Materials:** GRC effort to develop engineering composite materials for high temperature ( $>300$  C) electronic components
- **Power Source:** GRC low power Stirling convertor effort to develop technology for SmallSat applications
- **Testbed:** GRC 28 VDC RSIL testbed developed to test technologies for low power ( $<450$  W) spacecraft



Low Power Stirling Thermal Analysis



RSIL

# Acknowledgements



Questions?

# R·I·T Wire Comparison Chart

Parameter	Clyde Space Copper Wire	Nanocomp MWCNT Yarn (undoped)	Nanocomp MWCNT Yarn (KAuBr <sub>4</sub> doped)	RIT Laser Produced SWCNT (CSA doped)
Resistance/Length (Ohm/m)	3.25	300	70	123
Mass/Length (tex)	2060	12	12	4
Specific Conductivity (S m <sup>2</sup> /kg)	6543	284	1110	2000
# strands to match Clyde Space wire R/L	N/A	92	22	38
# Strands to match 20 AWG equivalent diameter	N/A	10 - 11	10 - 11	30