Overview of Small Spacecraft Technology Activities at the NASA Glenn Research Center

32ND AIAA/USU Conference on Small Satellites, 4 to 9 August 2018, Logan, Utah (SSC18–PI–15)

Frederick W. Elliott | frederick.w.elliott@nasa.gov | 216–433–2322
NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135

National Aeronautics and Space Administration

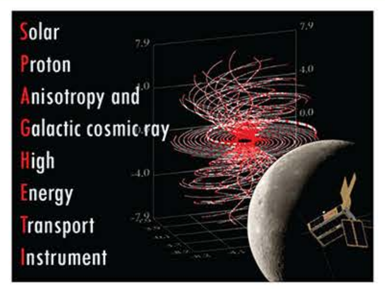
The NASA Glenn Research Center (GRC) in Cleveland, Ohio, designs and develops innovative technologies to advance NASA's missions in aeronautics and space exploration. The Center's expertise includes that in power, energy storage, and conversion; in-space chemical and electric propulsion; communications; and instrumentation technologies. GRC is currently managing and/or developing a number of these technologies for small spacecraft applications. Small spacecraft propulsion efforts include efforts with Tethers Unlimited, Inc. (TUI), and Busek Co., Inc. Power systems technology efforts include the Advanced Electrical Bus (ALBus) CubeSat in-house development as well as efforts with the Rochester Institute of Technology (RIT), the Kennedy Space Center, and University of Miami. In the area of communications, NASA GRC continues to explore the potential capabilities and advantages of using Ka-band for low-Earth-orbit (LEO) spacecraft communications with both NASA and commercially owned geosynchronous Earth orbit (GEO) relays and direct-to-ground (DTG) terminal networks. GRC has also proposed a number of small spacecraft instrumentation technology demonstrations such as SPAGHETI and CFIDS.

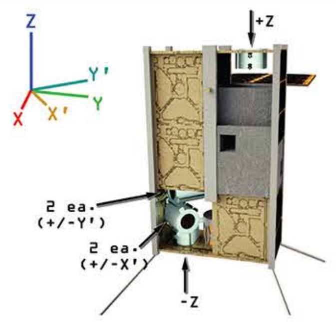
ACKNOWLEDGMENTS

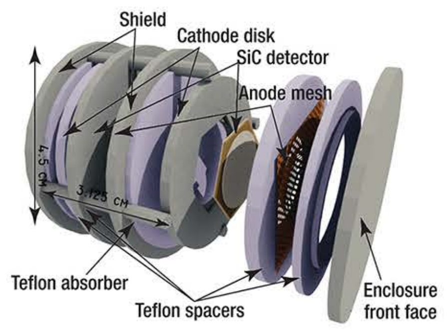
Gabriel F. Benavides, Geoffrey A. Landis, Thomas B. Miller, Dale J. Mortensen, Kathryn J. Oriti, Charles J. Sarmiento, Wensheng Huang, and John D. Wrbanek	NASA Glenn Research Center, Cleveland, OH
Luke B. Roberson	NASA Kennedy Space Center, Titusville, FL
Larry Byrne and Dr. Mike Tsay	Busek Co., Inc., Natick, MA
Ryne Raffaelle, Chris Schauerman, and Matthew Ganter	Rochester Institute of Technology, Rochester, NY
Mason Freedman and Karsten James	Tethers Unlimited, Inc, Bothell, WA
Xiangyang Zhou and Ryan Karkkainen	University of Miami, Coral Gables, FL

INSTRUMENTS

SPAGHETI: Proposed Deep-Space CubeSat





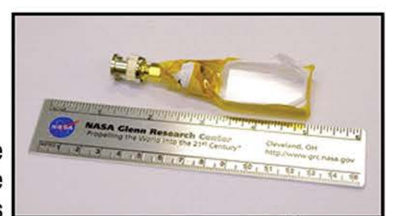


SiC LET detector stacks

- SPAGHETI would explore the transient variations in ion flux anisotropy in deep space and near the lunar surface
- SPAGHETI would contain six packages of SiC LET detector stacks, arranged to provide simultaneous multidirectional measurements
- Detector insensitivity to temperature changes would allow compact, low-power operation

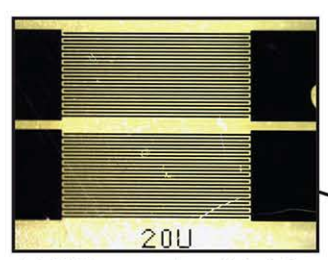
Future Concept: Compact Full-Field Ion Detector System (CFIDS)

Space radiation detector with spherical geometry
Technology covered by U.S. Patents 7,872,750 (January 18, 2011) and 8,159,669 (April 17, 2012)

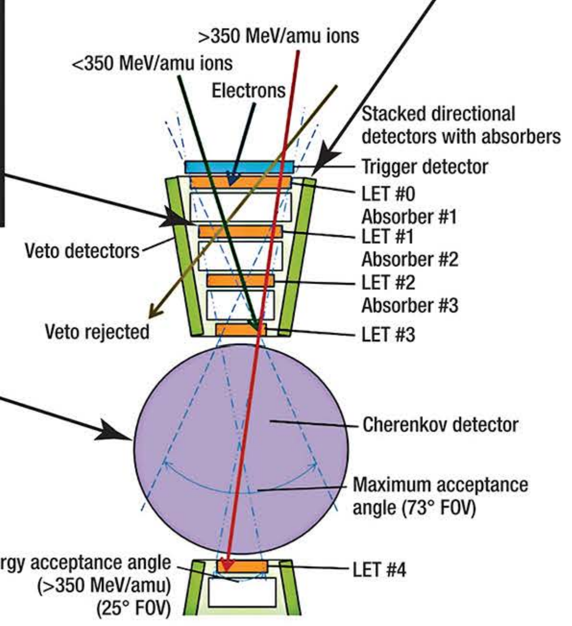


GaP diode for solid-state coincidence/anticoincidence detectors

Large-area SiC diode for LET detectors



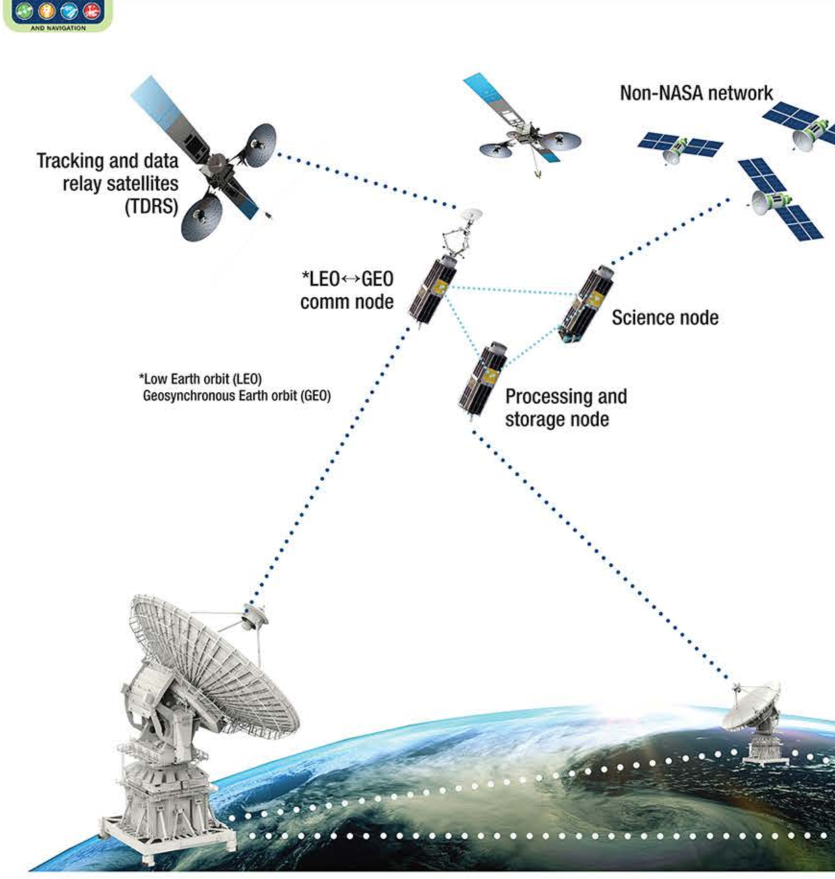
ZnO UV sensor for solid-state Cherenkov detector



- Mapping of heavy ions >100 MeV/amu
- High radiation flux rates for 10+ year missions
- Low-noise, multidirectional measurements at single locations

COMMUNICATIONS

Candidate CubeSat Mission



Candidate Mission Demonstrations
- User initiated service
  - Space network (SN) and near-Earth network (NEN) service
  - Commercial service(s)
- Cognitive data routing
  - Decentralized, service-based
  - Drop data anywhere
- Link optimization
  - Interference mitigation
  - Spectrum sharing
- Cognitive space hardware
  - Neuromorphic/memristive
  - GPU or multicore processors
  - Cognitive antenna

Software-Defined Radio (SDR) and Transceiver Examples

Attributes	Functions and Benefits
• Software defined and reprogrammable compatible with NASA Space Telecommunication Radio System (STRS) standard • Adaptive modulation and coding compatible with CCSDS and DVB-S2 standards MOD/COD family of waveforms • Variable data rates from 10s to 100s M/s via relays; 100s to 1000s Mb/s via DTG links • Low mass/power/volume and operational complexity	• High rate DTG for latency-tolerant missions and high-capacity relay links for latency-sensitive missions • Standards compatibility enables waveform sharing and helps ensure interoperability among commercial SDR suppliers • Dual band (26- and 30-GHz transmit) enables data return via TDRS KaSA and/or commercial Ka-band GEO relays, and/or DTG links • Smart SDRs enable near-optimal use of link margin

Operational | Under Development

JPL ~2 Gb/s Near-Earth Ka-band Modulator for Universal Space Transceiver

Harris AppSTAR™ 3rd Generation Micro Space Software Defined Platform for ~1 Gb/s Coded Modulation

Harris AppSTAR™ 3rd Generation Micro SDR and Ka-Band RF Assemblies

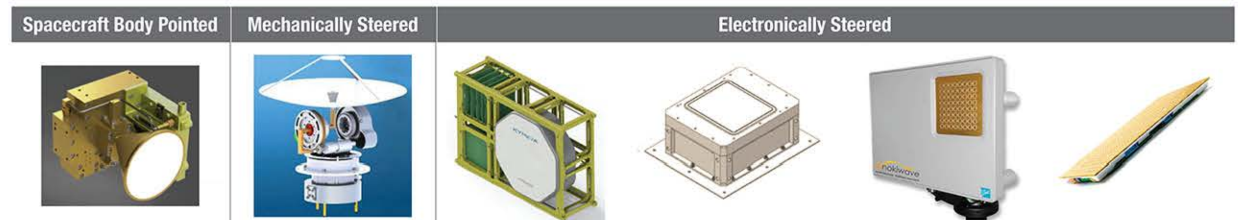
Space Micro S- and X/Ka-Band Software-Defined Near-Earth Space Transceiver SBIR Phase III

Tethers Unlimited OpenSWIFT-SDR for STRS SBIR Phase II

Commercial Ka-Band User Terminal Antenna Examples

Attributes	Functions and Benefits
• Single aperture transmit only or transmit and receive capability • Potential for dual-band Ka-band compatibility (Government 26/22 transmit/receive GHz and non-Government 30/20 GHz) • Electronically scanned beams over at least ±60° field of regard • EIRP of 30 to 36 dBW to enable 10s to 100s M/s via relays; 100s to 1000s Mb/s via DTG links • Two to three types of antennas based on mass, power, volume, and complexity	• Instantaneous electronically steered beams eliminate vibration and spacecraft disturbances on sensitive instrumentation • High rate DTG for latency-tolerant missions and high-capacity relay links for latency-sensitive missions • Dual band (26- and 30-GHz transmit) enables data return via TDRS KaSA and/or commercial Ka-band GEO relays, and/or DTG links • Helps enable transition to commercially provided services

Spacecraft Body Pointed | Mechanically Steered | Electronically Steered



Astro Digital Ka-Band CubeSat DVB-S2 Transmitter, 21 dBW

Surrey Satellite Ka-Band Antenna Positioning System (APS), e.g., 26-cm antenna, >25 dBi, 34 dBW with 8-W SSPA

Kymeta Liquid Crystal Ka-Band Transmit Antenna, 23 to 26 dBi, 32 to 35 dBW with 8-W SSPA

Boeing Proposed Space-Qualifiable 256-Element Ka-Band (26 GHz) Transmit Phased Array Antenna, 36 dBW

Anokiwave 64-Element Ka-Band (27.5 to 30 GHz) Terrestrial 5G Wireless Phased-Array Antenna

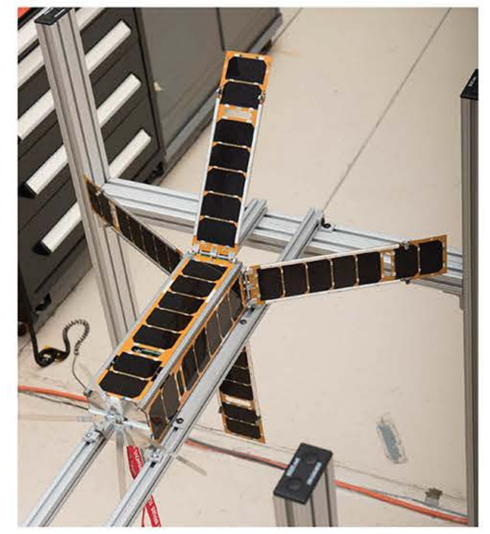
Phasor Solutions Ku-Band (14/12 GHz) Flat Panel Antenna With Potential for Redesign in Ka-Band

POWER

Advanced ELectrical Bus (ALBus) CubeSat

Pathfinder Technology Demonstration for High-Power Density CubeSats and Resettable Mechanisms

Glenn's first fully in-house CubeSat project • Designed and developed by early career engineers
Set to launch on ELaNa XIX mission

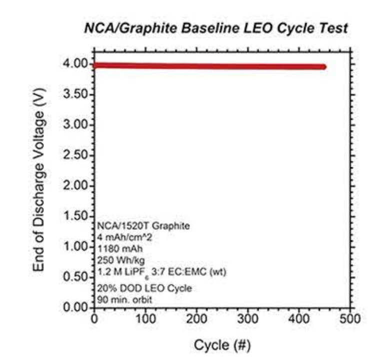


Mission Objectives
- Demonstration of resettable Shape Memory Alloy solar array release mechanisms
  - Activated Nitinol release mechanism
  - Passive superelastic Nitinol hinge springs open arrays and conduit for solar array power
- On-orbit characterization of high-power density system performance in LEO environment
  - Transient distribution of ~100 W of electrical power in 3U volume
  - Passive thermal control
  - Characterize and quantify limitations to duty cycle in changing orbital thermal conditions
- Demonstration of GRC design, 100 W capable power distribution system
  - Battery charging algorithm
  - 3.3 V, 5 V, and raw battery voltage distribution

R·I·T Development of a Nano-Enabled Space Power System

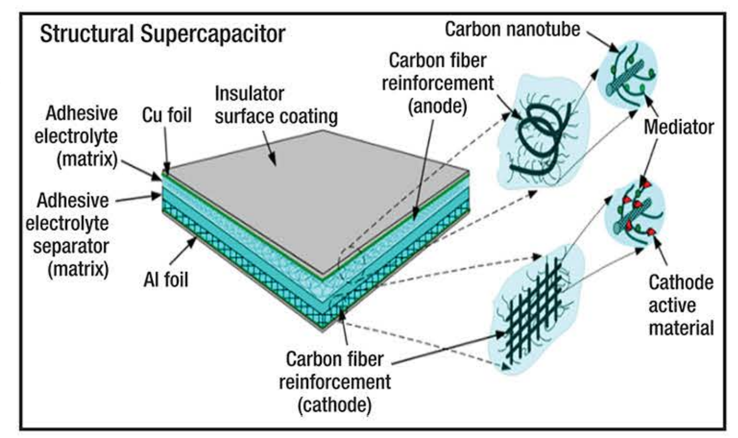
Developing nanomaterial-enhanced power system components that allow for reduced weight while increasing capability in power systems for CubeSats and other small satellites:
- Carbon nanotube (CNT)-enhanced lithium-ion batteries
  - Improved power/weight ratio of 301 W-hr/kg
  - Demonstrated LEO cycling of >1000 cycles with no change in voltage
- **Quantum dot/quantum well solar cells** with improved efficiency and radiation tolerance
- **CNT wire harnesses** with reduced weight and increased strength
- **CNT thermoelectric materials** with improved efficiency of energy harvesting and cooling
- Demonstrate function with high-altitude balloon launch to near space conditions (July 2018)

High-capacity "pouch" cell



UNIVERSITY OF MIAMI Development of Lightweight CubeSat with Multifunctional Structural Battery/Supercapacitor Systems

- Lightweight 1U CubeSat that utilizes fully integrated structural battery materials for mission life extension of 200 to 300 percent, larger payload capability, and significantly reduced mass of 15 percent 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



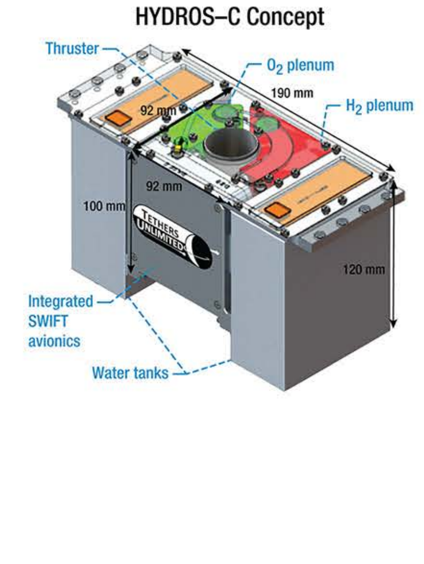
Advancements in structural battery technology can replace parasitic structural mass with material that provides additional energy, leading to lighter weight and extended satellite mission life.

PROPULSION

STMD Small Spacecraft Technology Program (SSTP) Tipping Point—Tethers Unlimited, Inc., HYDROS–C

A space technology is at a "tipping point" if an investment in a ground development/demonstration or a flight demonstration will result in 1) a significant advancement of the technology's maturation, 2) a high likelihood for utilization of the technology in a commercially fielded space application, and 3) a significant improvement in the offerers' ability to successfully bring the space technology to market.

HYDROS–C Concept



Source: http://www.tethers.com/HYDROS.html

HYDROS™ Description
- Propellant at launch is water
- On orbit, a compact electrolysis cell that operates in microgravity generating hydrogen and oxygen propellants which are fed to a simple bipropellant thruster

Specifications

Metric	2U "Saddlebag" Configuration	Base Thruster
Mass	2.86 kg wet (1.87 kg dry)	1.02 kg (dry)
Size	~2U (190 x 120 x 92 mm)	~1U (92 mm²)
Power	5 W – 25 W	

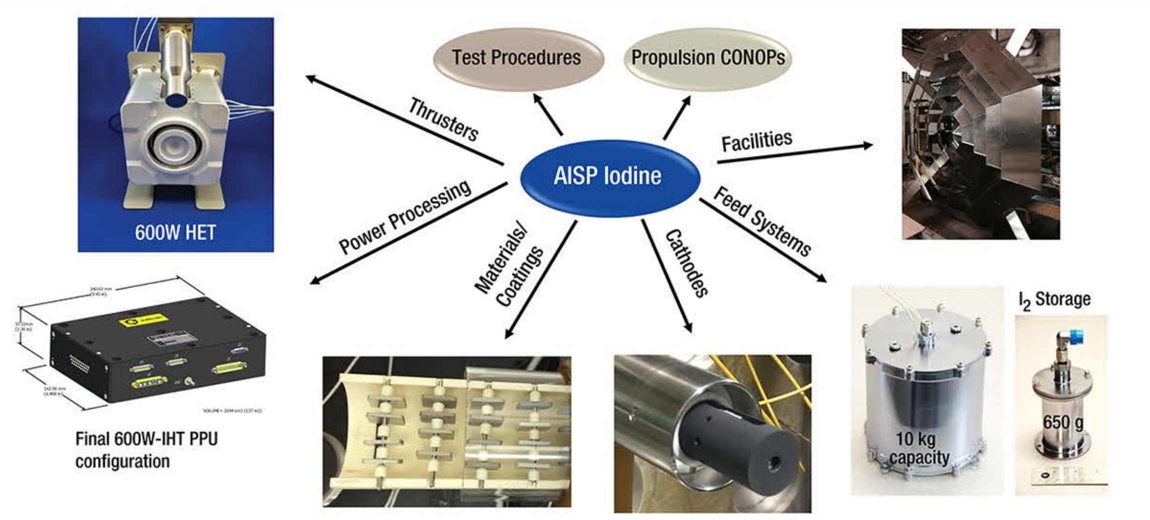
Performance

Metric	Value
Impulse per thrust event	> 1.75 Ns
Isp	> 310 s
Average thrust	> 1.2 N
Minimum time to refill plenums	825 s
In 2U "Saddlebag" Configuration	
Water capacity	0.67 kg
Total number of thrust events	1114
Total impulse delivered	> 2036 Ns

Tipping Point HYDROS–C Qualification Unit

To be flown and demonstrated on NASA Pathfinder Technology Demonstrator-1 in 2019.

STMD Game Changing Development (GCD)—Advanced In-Space Propulsion (AISP)



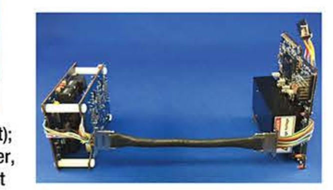
AISP endeavors to systematically advance iodine electric-propulsion technology across a wide range of components and systems toward risk reduction for future missions seeking to benefit from the benefits of high-density iodine propellant.

BIT–3 and HEOMD AES Lunar IceCube

- Busek's BIT–3 provides ultra-high performance in a 1.6U package
  - Lightweight, rad-tolerant PPU
  - Innovative iodine feed system with up to 1.5 kg propellant; xenon backwards compatibility
  - 3-cm gridded RF ion thruster and 1-cm RF cathode
  - 2-axis gimbal with +/-10º slew
- System undergoing integration and qualification testing
- SBIR ph2-X recently awarded for extended life and integration testing
- Test duration up to 4,000 hr
- BIT–3 flight hardware delivery to both flight missions Q3 CY18
- Iodine-fueled BIT–3 RF ion propulsion system will be flying on Lunar IceCube and LunaH-Map (SLS EM–1 launch)

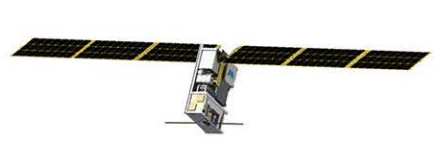
BIT–3 QM and FM units (1.6U/3kg wet); each unit includes thruster, neutralizer, power processing, gimbal, propellant feed, and propellant tank

BIT–3 and cathode at max. power on iodine



Power processing unit (500g)

BIT-3 System Characteristics	
Thrust	0.88 mN nom., 1.24 mN max.
Total Isp	1,870 sec nom., 2,640 sec max.
Input power	65 W nom., 80 W max.
Mass	1.5 kg dry / 3 kg wet
Volume	1.6 U
Delta-v	~2 km/s for 6U CubeSat



Lunar IceCube in flight configuration

PS–02600–0718