CubeQuest CHALLENGE

Advanced CubeSat Technologies for Affordable Deep Space Science and Exploration Missions

Ground Tournaments, the Moon, and Beyond

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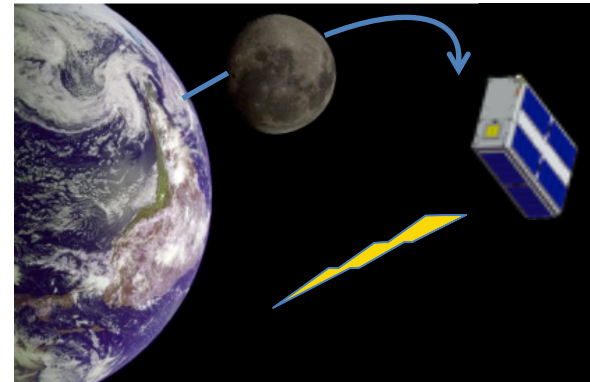
ISSC - 1 May 2017

Outline

- CubeSats and Future
- What is Cube Quest?
  - Why a Cube Quest?
  - Rules and Prize Structure
- Today’s Status
  - GT4 Competitors
  - Emerging Technologies
- Next Steps
  - GT4 winners
  - SLS PSRs
  - In-space Competition



Get your CubeSat to the moon,
work the best
survive the longest
win big prizes!

CubeSats in Deep Space

- Advantages over traditional satellites:
  - Low cost
  - Low mass
  - Standard LV interface
- Developed, deployed in fraction of time, cost, of traditional “high-stakes” satellite
- Interchangeable secondary payloads
  - increased launch opportunities
- Array of small CubeSats > single conventional probe:
  - asteroid seismographs
  - array of Mars weather stations
  - distributed , temporally correlated measurements
  - redundancy at the system level; robust system of systems
  - nodes for antenna arrays or telescope arrays

Current CubeSat Limitations

To-date, CubeSats haven't ventured beyond LEO:

Limitation	SoA	Deep Space Missions Need
Limited comm range	Low-gain dipoles or patches mainly used	high gain directional antennas needed
Limited comm data rate	Low power, amateur band transmitters mainly used	High-power, high frequency, wide bandwidth transmitters needed
Lacking radiation tolerance	COTS, low-cost parts used; more benign environment of LEO	Radiation shielding, fault detection, fault tolerance
Lacking in-space propulsion	Not demonstrated (except solar sails); chemical fuel/pressurized containers prohibited	High thrust, high ISP needed; chemical, electrical, solar
Depend on Earth-based nav references	Passive magnetorquers used; GPS or magnetometers sense Earth's magnetic field	Start trackers, moon/sun sensors, radar altimeters and other sensors needed for deep space

Can CubeSats Enable More Affordable Science and Exploration Missions in Deep Space?

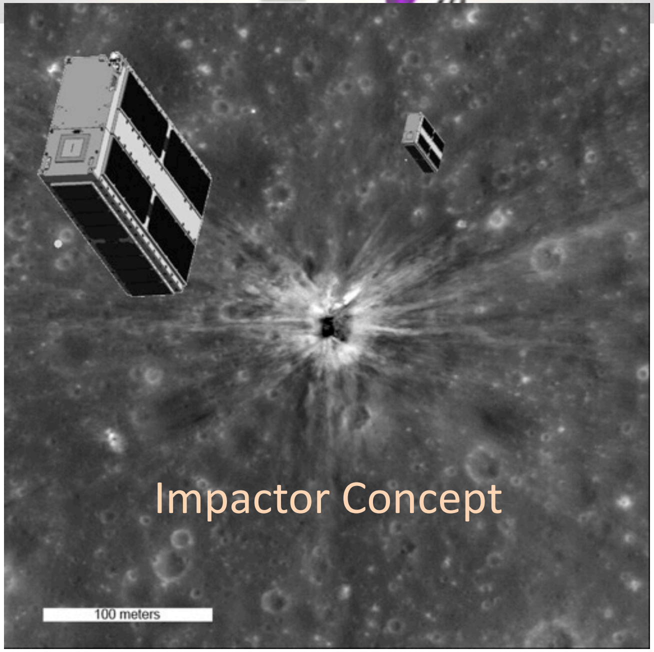
Why a CubeSat Centennial Challenge?

- Achieve goals of NASA, other Government Agencies, industry?
- More affordable science and exploration missions?
- Unique missions (swarms, cooperative operations)
- Take advantage of payload capacity; launch unobtrusively?

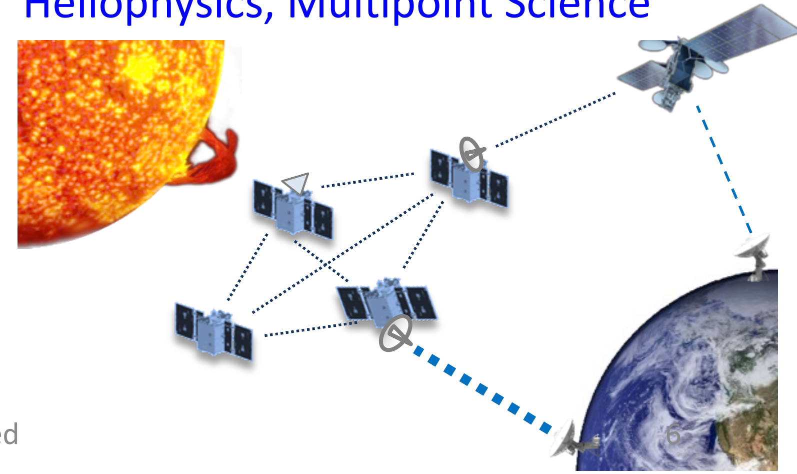
Future Mission Needs of Stakeholders Drive the Challenge

Trace Capabilities to NASA Roadmaps

- Astrophysics:
  - Distributed RF and Optical Arrays on affordable satellite constellation
  - Affordable, time-correlated (simultaneous) multi-point observations of NEOs (mass density, albedo, etc)
- Planetary Explorations:
  - Distributed measurements (Ex: surface seismographic; Mars “weather systems”, multi-site impactors to detect lunar subsurface volatiles, etc.)
  - Co-ordinated assets (Ex: landers paired with orbiting relays)
- Heliophysics:
  - Global coverage
  - Multiple observations of transient events (Ex: radio occultation)
  - Geographically distributed time-correlated “space weather” measurements
- Earth Science
  - Global coverage (multiple)
  - Time correlated weather, oceanic observations



Heliophysics, Multipoint Science



Designing Cube Quest

- Considered 5 competitive scenarios
  - * Lunar flyby long-distance comm
  - Lunar Impactor
  - * Lunar Orbiter
  - 2 Sat Comm Relay
  - Proximity ops in cisLunar environment
  - (Lunar Lander not evaluated, as impractical dV req’t)
- Each scenario depends, relatively more or less, on these subsystems:
  - Propulsion
  - Deep space survival
  - Comm
  - Power
  - Pointing
- Each scenario applies, relatively more or less, to future needs/goals
  - Precursor missions
  - Earth Science
  - Heliophysics/Space Weather
  - NEO surveys

* Selected Scenarios that develop the most capabilities, with greatest applicability to needs/goals

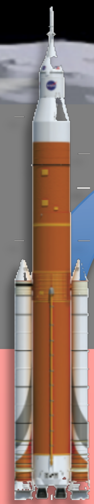
Combined Long-distance comm, Lunar Orbiter, as optimal Cube Quest “missions”

Stimulating Advanced Tech for Deep Space CubeSat Operations

- Objective: Achieve Lunar Orbit
- Requires:
  - Propulsion, high dV
  - Navigation without GPS or Earth's magnetic field
- Objective: Hi Data Rate, Large Data Volume, Far Comm Distance
- Requires:
  - High power transponder; high gain antenna; long & frequent ground station passes; deployable antennas; stable ACS; precise knowledge of Earth direction
- Objective: Longevity (survival)
- Requires:
  - Rad hardening, redundancy, shielding

- All are critical capabilities for deep space operations

Prize Structure



Ground Tournaments (GT)

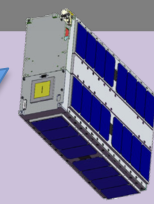
4 Rounds
Approx every 6 months

GT-1 - top 5 win $20k
GT-2 - top 5 win $30k
GT-3 - top 5 win $30k
GT-4 - top 5 win $20k
Total $500k

Top 3 qualified GT-4 teams launch free on EM-1

Qualify for 1 of 3 EM-1 launch slots
- *or* –
get your own ride

Total $5.0M Prize Money



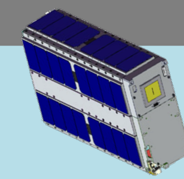
Lunar Derby

While in lunar orbit

Achieve Lunar Orbit*$1.5M/shared,*
$1M max per team

Error-free Communication
Burst Rate- $225k/25k
Total Volume- $675k/75k

Longevity
$450k/50k



Deep Space Derby

While range ≥4M km

Farthest Distance
$225k/25k

Error-free Communication
Burst Rate- $225k/25k
Total Volume- $675k/75k

Longevity
$225k/25k

Ground Tournaments

Teams submit GT documents

5 Judge Panel

- 2 NASA
- 3 Non-NASA leaders
  - Industry
  - Academic
  - DoD

GT Winners:

Top 5 Teams

Scoring > 3.0/5.0

- Rules
- GT Workbook
- SLS IDRD
- SLS Safety Rqts (or equiv. launch provider rqts)

Team of technical SMEs

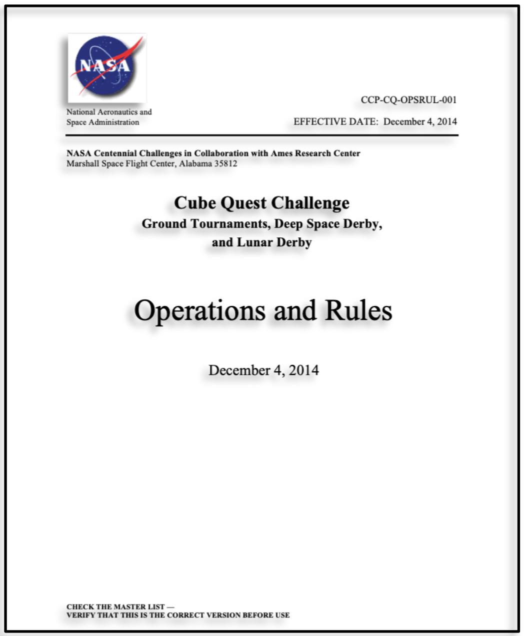
40% Likelihood of Mission Success

\+

60% Compliance with Rules, SLS IDRD, SLS Saftey Rqts

Total GT Score

Rules and Constraints


National Aeronautics and Space Administration

CCP-CQ-OPSRUL-001

EFFECTIVE DATE: December 4, 2014

NASA Centennial Challenges in Collaboration with Ames Research Center
Marshall Space Flight Center, Alabama 35812

Cube Quest Challenge
Ground Tournaments, Deep Space Derby, and Lunar Derby

Operations and Rules

December 4, 2014

CHECK THE MASTER LIST —
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

SLS Safety and Interface Requirements

- SLS Payload Safety Reviews (to fly on EM-1)
- Or equivalent, for 3rd-party launches

Any allowable part of the spectrum

- subject to FCC public freq. alloc. and licensing regs

Comm data eligible for prizes

- May use NASA DSN – at your cost
- DSN tracks all trajectories; checks lunar orbit, 4M km range
- Comm data format per Rules, to qualify

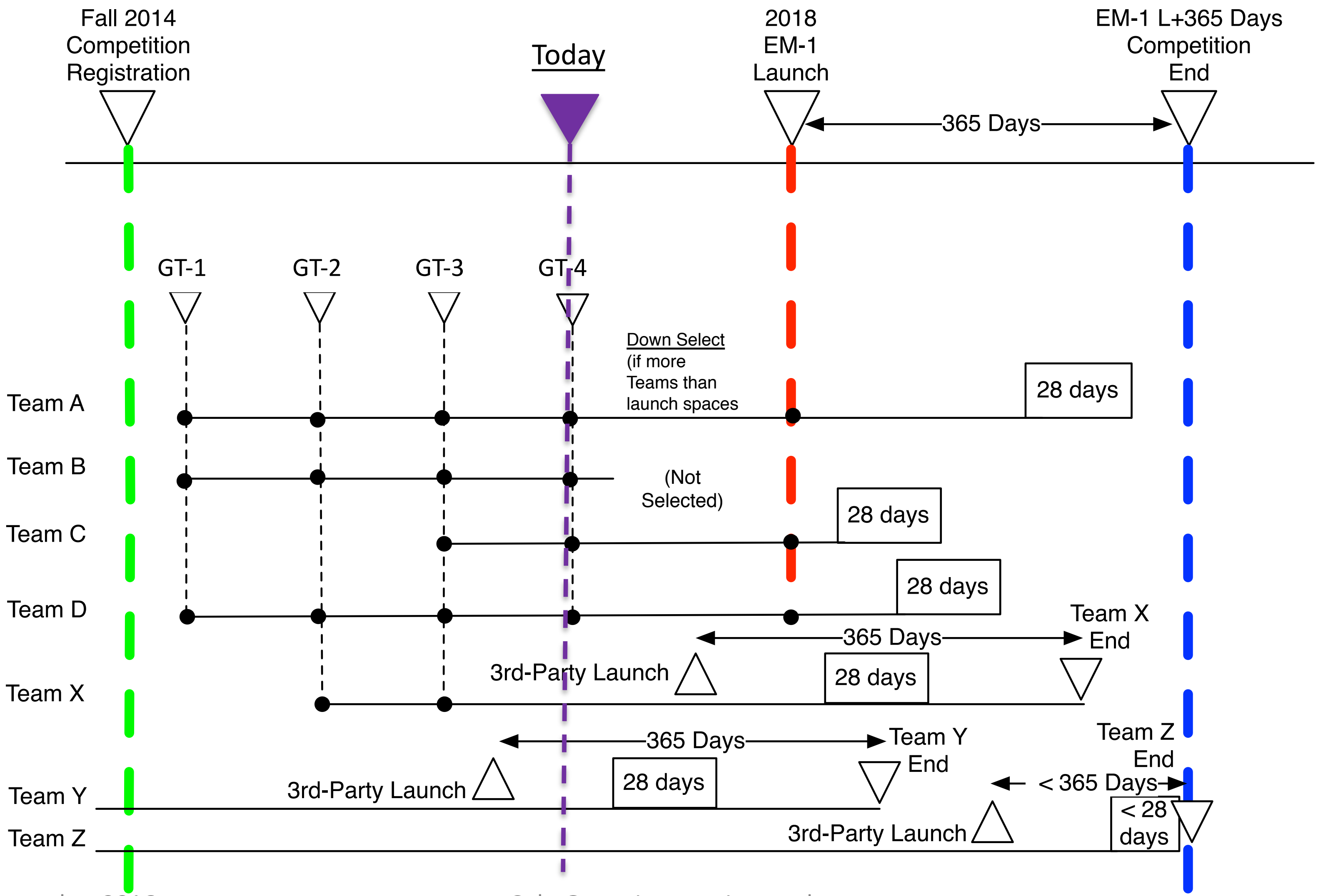
Comply with Orbital Debris and Planetary Protection laws and regs

http://www.nasa.gov/cubequest/reference

Versatility of CubeQuest Rules

- EM-1 or procure your own launch
- Propulsion or no propulsion
  - Deep Space Challenge does not require propulsion
  - 365-day time rule should allow exotic trajectories to lunar orbit
- Use NASA SCaN (NEN, DSN) at your own cost
  - NASA uses DSN to enforce rules
  - DSN costs and limited aperture time incentivize teams to develop alternative ground stations
- Competition start date is EM-1 launch or 3rd party launch date
  - End date is 365 days after EM-1 launch or 356 days after 3rd party launch, whichever occurs first

Current Status



Centennial Challenges Program

- NASA STMD’s Centennial Challenges Program, initiated in 2005, named after Wright Brothers’ Kitty Hawk flight
- Engages public in advanced technology development
- Prizes for solving problems of interest to NASA and the nation
- Competitors based in US; not supported by government funding.
- Since 2005, there have been eight challenge categories, resulting in more than 20 challenge events to date.
- More than $6 million in prize money has been awarded to more than 17 different teams
- Summer 2013, work began on Cube Quest Challenge

Current
Centennial Challenges:

- Sample Return Robot
- 3-D Printed Habitat
- Mars Ascent Vehicle
- Cube Quest

Ground Tournaments Lead to EM-1 Launch

GT1	GT2	GT3	GT4	EM-1
1. Alpha Cubesat - Xtraordinary Innovative Space Partnerships, Inc 2. Cislunar Explorers - Cornell University 3. HuskySat - University of Washington 4. Lunar CubeQuestador - Missouri University of Science and Technology 5. MIT KitCube - Massachusetts Institute of Technology 6. Novel Engineering - Novel Engineering Inc. 7. OpenOrbiter Lunar I - University of North Dakota 8. ERAU Eagles - Embry-Riddle Aeronautical University 9. Project Selene - Flintridge Preparatory School 10. Heimdallr- Ragnarok Industries, Inc. 11. SEDS UC San Diego - University of California - San Diego 12. Team Miles - Fluid & Reason LLC 13. True Vision Robotics - Isakson Engineering	1. Alpha CubeQuest, XISP Inc 2. CisLunar Explorers, Cornell University 3. Eagles-Quest, Embry-Riddle Aeronautical University 4. Earth Escape Explorer (CU-E3), University of Colorado 5. Goddard Orbital and Atmospheric Testing Satellite (GOATS), Worcester Polytechnic Institute 6. Lunar CubeQuestador, Missouri University of Science & Technology 7. MIT KitCube, Massachusetts Institute of Technology 8. Heimdallr, Ragnarok Industries Inc. 9. SEDS Triteia, SEDS University of San Diego 10. Team Miles, Fluid & Reason LLC	1. Team Miles Fluid & Reason, Tampa, Florida (placed first in GT-1 and fifth in GT-2) 2. Cislunar Explorers - Cornell University, Ithaca, New York 3. CU-E3- University of Colorado, Boulder 4. KitCube - Massachusetts Institute of Technology, Cambridge, Massachusetts 5. SEDS Triteia - University of California, San Diego 6. Ragnarok, Ragnarok Industries Inc. 7. MIT KitCube, Massachusetts Institute of Technology 8. Goddard Orbital and Atmospheric Testing Satellite (GOATS), Worcester Polytechnic Institute	1. Team Miles Fluid & Reason, Tampa, Florida 2. Cislunar Explorers - Cornell University, Ithaca, New York 3. CU-E3- University of Colorado, Boulder 4. SEDS Triteia - University of California, San Diego 5. Heimdallr, Ragnarok Industries Inc.	?

Current Teams – GT4 April-May 2017

*** - indicates EM-1 Qualifier**

Industry

***Heimdallr**
Ragnarok Industries, Inc

***Team Miles**
Fluid & Reason LLC

Academia

***Cislunar Explorers**
Cornell University

*** SEDS UC San Diego**
University of California- San Diego

*** CU-E3**
University of Colorado – Boulder

Lunar Derby | Deep Space Derby | Lunar & Deep Space Derby

CubeQuest Emerging Technologies

- Comm
  - UHF, S-, X-, C- band
  - Mainly patch antennas – from moon and beyond
  - Deployable antennas
- Ground Stations
  - DSN
  - WFF UHF
  - AMSAT X- and S-band
  - Commercial
  - Univ dishes
  - Arecibo
- Propulsion
  - Busek green monoprop
  - EP (Xenon and Iodine)
  - 3D printed thrusters
  - Electrolysis of water for fuel
- Other Technologies
  - Rad hardened CPU, memory, error checking and redundancy
  - Blue Canyon GNC / ADCS
  - Custom design:
    - Sun sensors
    - Star trackers
    - Reaction wheel
    - Imagers / quaternions

Emerging Technologies – Propulsion, Other

- Propulsion
  - COTS
    - Busek green monopropellant
    - ConstantQ plasma thruster (Iodine)
    - Phase Four plasma (Xenon) spin off from U of Michigan
    - Standard Micro Propulsion System from Vacco, cold gas, for attitude control
  - Custom In-House
    - 3D printed cold gas for attitude control
    - Electrolysis of water for H2 and O2, for 3D printed titanium thruster fuel and oxidizer
    - Hydrogen peroxide monopropellent for 3D printed Inconel 716
- Other Tech
  - Rad-hard components
    - deep space radiation, longer mission lifetimes intensify effect. Lunar orbit provides a proving ground for radiation-based experiments or technology demonstrations.
    - 1 team plans Resilient Affordable CubeSat Processor (RACP), a microcontroller and 3 ARM 15 SoC uPs., with a health monitoring and management system to check processors and subsystems
  - Navigation Systems
    - No GPS or magnetic field in cis-lunar space
    - Clue Canyon Technologies XACT star tracker, sun sensor and reaction wheels.
    - Or combinations of their own sun sensors, and COTS inertial sensors for ADS.
    - GEO-hard Miniature Integrated Star Tracker (MIST) from Space Micro,
    - In-house ADCS, with in-house reaction wheels, in-house star tracker and sun sensors
    - Navigate using Raspberry Pi camera to image Earth, Sun and Moon,and gyro using transformation matrix to spacecraft body from and inertial frame.

Emerging Technologies - Communications

- Communication Technologies
  1. RF Bands Utilized
     - S-Band
       - Commonly used but cutting-edge for CubeSats
       - Teams plan S-band for radio comm and trajectory determination
     - X-Band
       - DSN primarily uses X-band, but CubeSats haven't the power to use before
       - Teams plan X-band to commercial gnd stns or DSN
     - C-Band
       - Has some use in general sat comms; 5cm band is amateur band
       - Team plans AMSAT in C-band
     - UHF
       - Often used in CubeSats in amateur bands, to lots of amateur gnd stns
       - Team plans UHF for long distance using WFF 18m dish
  2. Antenna Design
     - Patch Antennas
       - Commonly used on CubeSats due to small size and low cost; but lacking in gain
     - Deployables
       - 1 team plans to use a reflectarray on reverse side of solar panel, fed by deployable feed horn

What's the Status?

- **GT-4 the final Ground Tournament underway!**
  - Document submittals received April 6
  - Supplemental submittals April 19 (test results)
- GT-4 winners to be announced at SmallSats-Deep Space Symposium

SmallSats – Deep Space June 7-8 at ARC

- Co-Produced by Small Satellite Technology Program, Small Satellite Systems Virtual Institute, and Centennial Challenges Program
- Invited speakers include:
  - Leaders from SMD, HEOMD, STMD
  - SSSVI and SSTP Program Managers
  - EM-1 payload developers
  - Cube Quest Teams
  - More!
- The event culminates in the prize awards to the winners of the Cube Quest Challenge Ground Tournament and top 3 winners selected for EM-1

Summary

- CubeSats will soon enable affordable science and exploration missions in deep space
- Cube Quest Challenge rewards citizen inventors to help NASA, stimulate and industry, for the public benefit
- Competitors already advancing CubeSat technology
- Cube Quest Challenge may serve as pathfinder for other ambitious prize challenges

CubeQuest CHALLENGE

Advanced CubeSat Technologies for Affordable Deep Space Science and Exploration Missions

Questions?