Lunar Flashlight and Near Earth Asteroid Scout: Exploration Science Using Cubesats

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EM1 Secondary Payloads

- EM1 launch opportunity (2018) will have 11 6U cubesat dispensers
- Three payloads manifested from the Advanced Exploration Systems (AES) program
  - Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
  - Synergistic use of previously demonstrated technologies
  - Life-cycle cost and optimal use of available civil servant workforce
- Other secondary payloads will be added
  - NASA – SIMPLEX, LCAS, Cubesat Challenge
  - Others – universities, research centers, DOD, etc?

<table>
<thead>
<tr>
<th>Payload</th>
<th>Strategic Knowledge Gaps Addressed</th>
<th>Mission Concept</th>
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<tbody>
<tr>
<td>BioSentinel ARC/JSC</td>
<td>Human health/performance in high-radiation space environments</td>
<td>Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth</td>
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<tr>
<td></td>
<td>• Fundamental effects on biological systems of ionizing radiation in space environments</td>
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<tr>
<td>Lunar Flashlight JPL/MSFC/MHS</td>
<td>Lunar resource potential</td>
<td>Locate ice deposits in the Moon’s permanently shadowed craters</td>
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<td></td>
<td>• Quantity and distribution of water and other volatiles in lunar cold traps</td>
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<tr>
<td>Near Earth Asteroid (NEA) Scout MSFC/JPL</td>
<td>NEA Characterization</td>
<td>Slow flyby/rendezvous and characterize one NEA in a way that is relevant to human exploration</td>
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<tr>
<td></td>
<td>• NEA size, rotation state (rate/pole position)</td>
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<td></td>
<td>How to work on and interact with NEA surface</td>
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<tr>
<td></td>
<td>• NEA surface mechanical properties</td>
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**Biosentinel**: DNA Damage-and-Repair Experiment Beyond Low Earth Orbit

- **What**: Yeast radiation biosensor measures DNA damage caused by space radiation: specifically, double strand breaks (DSBs)
- **Why**: Space radiation’s unique spectrum cannot be reproduced on Earth
  - Various high-energy particles/energy spectra; omnidirectional; continuous; low flux
  - Health risk for humans over long durations beyond LEO
- **How**: Before launch, engineered S. cerevisiae cells (brewer’s yeast) are dried & placed in arrays of microwells
  - In space, a group of wells is rehydrated every few weeks
  - Cells remain dormant until growth is activated by a DSB + gene repair
  - Yeast repair mechanisms in common with human cells; well studied in space
Near Earth Asteroid Scout
Marshall Space Flight Center/Jet Propulsion Lab/LaRC/JSC/GSFC/NASA

One of three 6U Cubesats sponsored by Advanced Exploration System, Joint Robotic Program to fly on SLS EM-1

GOALS
Characterize one candidate NEA with an imager to address key Strategic Knowledge Gaps (SKGs)
Demonstrates low cost capability for HEOMD for NEA detection and reconnaissance

Measurements: NEA volume, spectral type, spin and orbital properties, address key physical and regolith mechanical SKGs
Sunlight is reflected off the sail to the lunar surface in a 3° beam. Light diffusely reflected off the lunar surface enters the spectrometer to distinguish water ice from regolith.

**Lunar Flashlight JPL/MSFC**

- One of three 6U Cubesats sponsored by Advanced Exploration Systems to fly on SLS EM-1
- Addresses NASA Strategic Knowledge Gap to understand water and other volatiles in lunar polar regions
- Identifies surface ice deposits and maps favorable locations for in-situ utilization

**Demonstrates low cost capability for lunar measurements**

- 18 month nominal mission, 30 month max
- <11.4 kg 6U Cubesat
- ~80 m² sail
- <40W solar power (BOL)
- 1 kbps data link from lunar orbit

![Graph showing reflectance vs. wavelength for ice and regolith at different water content percentages](image)
Lunar Strategic Knowledge Gaps

I. Understand the lunar resource potential

D. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.

Narrative: Required “ground truth” in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

- Lunar Flashlight will illuminate permanently-shadowed and detect water ice absorption bands in the near-infrared – **Measurement goal**
- By repeating this measurement over multiple points, Lunar Flashlight will create a map of surficial ice concentration that can be correlated to previous mission data and used to guide future missions – **Mapping goal**
Lunar ice frost as a human resource

- Locations where Diviner measures the coldest year-round temperatures also show high albedo in LOLA at 1.064 μm, consistent with water frost

- Ultraviolet albedo data from LAMP also show evidence for water ice at the lunar surface, but are not yet definitive
• Four-channel point spectrometer
• Off-axis parabola telescope design
• Judson (Teledyne) strained-lattice InGa:As PVs detectors
  – Passively cooled operation at -65C
• 10% of PSRs within 10° of pole observed over 60 orbits, covers Shoemaker Crater and LCROSS site with <2 km/px
<table>
<thead>
<tr>
<th>HEO-Defined Strategic Knowledge Gaps</th>
<th>Expected Performance</th>
<th>Risk Reduction or Benefit</th>
</tr>
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<tbody>
<tr>
<td>Location (position prediction/orbit)</td>
<td>OCC decrease to 0</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
</tr>
<tr>
<td>Size (existence of binary/ternary)</td>
<td>High accuracy on size, detection of satellites</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<tr>
<td>Rotation rate &amp; pole orientation</td>
<td>High accuracy on pole and velocity</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<tr>
<td>Particulate environment/Debris field</td>
<td>Characterization of particle density in target vicinity</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<td>Regolith mechanical &amp; geotechnical properties</td>
<td><em>Indirect</em> (imagery interpretation)</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<td>Mass/density estimates (internal structure)</td>
<td><em>Indirect</em> (based on taxonomic characterization)</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<td>Surface morphologies and properties</td>
<td>Morphology at resolution of astronaut’s foot</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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<tr>
<td>Mineralogical &amp; chemical composition</td>
<td><em>Indirect</em> from taxonomic characterization</td>
<td><img src="image" alt="Crew/Mission" /> <img src="image" alt="Operations" /> <img src="image" alt="Cost" /> <img src="image" alt="Performance" /> <img src="image" alt="Science/Engineering" /></td>
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Ref – Abell and Castillo, After SKG Report (Rivkin et al. 2012)
Baseline Target: 1991 VG

- $H = 28.4 \pm 0.7$  \ D~ 5-12 meters  \ Albedo = unknown
- Position is known within 2700 km ($1\sigma$) but optical observation opportunity in July ‘17 will decrease uncertainty to a few 100s km
- Rotation period between a few minutes and less than 1 hr
- Unlikely to have a companion
- Unlikely to retain an exosphere or dust cloud
  - Solar radiation pressure sweeps dust on timescales of hours or day

<table>
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<tr>
<th>Secondary Targets</th>
<th>Absolute magnitude</th>
<th>30% albedo Diameter (m)</th>
<th>5% albedo Diameter (m)</th>
<th>Orbit Condition Code</th>
<th>Observation Opportunity prior to launch</th>
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</thead>
<tbody>
<tr>
<td>2001 GP$_2$</td>
<td>26.9</td>
<td>10</td>
<td>25</td>
<td>6</td>
<td>Depends on launch date 2020-10 (Optical)</td>
</tr>
<tr>
<td>2013 BS45</td>
<td>25.9</td>
<td>11</td>
<td>51</td>
<td>0</td>
<td>2015-01 (Optical)</td>
</tr>
<tr>
<td>2008 EA$_9$</td>
<td>27.7</td>
<td>7</td>
<td>17</td>
<td>5</td>
<td>none</td>
</tr>
<tr>
<td>2012 UV$_{136}$</td>
<td>25.5</td>
<td>19</td>
<td>47</td>
<td>1</td>
<td>2014-08 (Optical) 2020-05 (RADAR)</td>
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NEAS Science Products

Target Detection and Approach
Light source observation
SKGs: Ephemeris determination and composition assessment

Target Reconnaissance
50 cm/px resolution over 80% surface
SKGs: volume, global shape, spin rate and pole position determination

Close Proximity Imaging
High-resolution imaging, 10 cm/px GSD over >30% surface
SKGs: Medium-scale morphology, regolith properties, and local environment characterization
NEAS Proximity Science

Flyby velocity ~ 20m/s

- Local morphology
- Morphology, Environment
- Rotation
- Size

Distance (km)

Solar phase angle (deg)

- COTS Schneider ruggedized lens, 20MP sensor
- Inherited from EECAM on Mars 2020 rover and OCO-3 programs
- Strip filters provide 40nm bandpass in 4 wavelengths

Low phase angles for geology imaging
### Fitting into 6U is challenging

<table>
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<tr>
<th>Category</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Payload</strong></td>
<td>• Lunar Flashlight: Custom spectrometer built in-house</td>
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<td></td>
<td>• NEA Scout: Heritage JPL MSL/Mars 2020 imager (400-900 nm)</td>
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<tr>
<td><strong>Mechanical &amp; Structure</strong></td>
<td>• “6U” CubeSat form factor (~10x20x30 cm)</td>
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<td>• &lt;12 kg total launch mass</td>
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<td></td>
<td>• Modular flight system concept</td>
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<tr>
<td><strong>Propulsion</strong></td>
<td>• ~85 m² aluminized Kapton solar sail (based on NanoSail-D2)</td>
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<tr>
<td><strong>Avionics</strong></td>
<td>• Radiation tolerant LEON3-FT architecture</td>
</tr>
<tr>
<td><strong>Electrical Power System</strong></td>
<td>• Simple deployable solar arrays with UTJ GaAs cells (~35 W at 1 AU solar distance)</td>
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<tr>
<td></td>
<td>• 6.8 Ah Battery (3s2p 18650 Lithium Cells)</td>
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<td></td>
<td>• 10.5-12.3 V unregulated, 5 V/3.5 V regulated</td>
</tr>
<tr>
<td><strong>Telecom</strong></td>
<td>• JPL Iris 2.0 X-Band Transponder; 1 W RF, supports doppler, ranging, and D-DOR</td>
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<tr>
<td></td>
<td>• 2 pairs of INSPIRE-heritage LGAs (RX/TX)</td>
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<td></td>
<td>• Lunar Flashlight: ~500 bps to 34m DSN at all times.</td>
</tr>
<tr>
<td><strong>Attitude Control System</strong></td>
<td>• 15 mNm-s (x3) &amp; 100 mNm-s RWAs</td>
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<td>• Zero-momentum slow spin during cruise</td>
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<td></td>
<td>• VACCO R-236fa (refrigerant gas) RCS system</td>
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<tr>
<td></td>
<td>• Nano StarTracker, Coarse Sun Sensors &amp; MEMS IMU for attitude determination</td>
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**Diagram:**
- LF Spectrometer or NEAS Camera (JPL)
- 18650 Lithium Batteries (SDL/Panasonic)
- TRAC Boom Assy x2 (MSFC)
- Solar Sail x2 - Stowed (MSFC)
- Solar Panels x4 (MMA)
- LGA (JPL)
- Rad Tolerant C&DH (JPL)
- EPS (TBD)
- Iris 2.0 Transponder (JPL)
- RWA x4 (Blue Canyon)
- RCS (VACCO)
Solar sailing is challenging

200 m² IKAROS
JAXA
Bus mass / Sail area = 1.6 kg/m²

32 m² Lightsail-1
Planetary Society
Bus mass / Sail area = 0.15 kg/m²

~1200 m² NASA (STMD)
Sunjammer

85 m²
LF / NEA Scout
NASA AES
Bus mass / Sail area = 0.14 kg/m²

3.5 m NanoSail-D2
(2010)
Bus mass / Sail area = 1.1 kg/m²

20 m ground demo (2005)
Summary

• NASA is using cubesat missions to address Exploration SKGs and conduct science
• These missions further the maturity of CubeSats
  – Long-lived CubeSat bus for deep space missions (C&DH, EPS, ADCS, Deep Space Transponder)
  – Characterization of deep space environment effects on CubeSats (building on INSPIRE)
  – Mature CubeSat propulsion methods
• Future potential of small missions for science & exploration
  – Part of 1st generation of cubesat-style planetary missions to conduct real science measurements
  – Secondary spacecraft hosted on interplanetary missions
NEAS Rendezvous Target Search

Telecom Distance (AU)
- blue < .25
- green < .5
- orange < .75
- red < 1

OCC
- △ under 2
- □ under 4
- ▽ under 7

Appx diameter
- small < ~15 m
- med. < ~30 m
- large < ~50 m