Commute: CubeSat Swarm Orbital Maneuvers for a Mission to Study Uranus’s Atmospheric Environment

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Why Uranus?
- Recommended by the 2023-2032 Planetary Science and Astrobiology Decadal Survey
- Answer questions about “the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres”

Thermal
- Worst-case heat loss at viable temperature is 197 W
- Would be sustained by 7.2 kg of Radioisotope Heater Units
  - This disregards the significant waste heat from power generation, as well as planetshine
- Actual heater requirements would be lower

Power
- Emerging technology - Thermoradiative Cells
  - Utilizes a separate heat source to generate electricity through a temperature differential
- Generates ~34 W
- Minimum average excess power is ~10 W

Radiation
- Similar missions project 100 mils (2.54 mm) thick Aluminum shielding is sufficient for external radiation mitigation
- Internal worst-case lifetime radiation dose reduced to 1 krad with 0.445 cm thick Al shielding

Communications
- High gain antennas
- Radio power amplifier
- UHF band — lower bit rate, lower noise
- Link margin of 6.4 dB with mothership

Why CubeSats?
- More diversity of design – greater specialization
- Increased rate of observation
- Simultaneous observations of the same phenomena from different angles
- Smaller total mass – transfer time is halved, able to observe the end of the solstice

Instrumentation Comparison

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Power Requirements (W)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAG</td>
<td>3.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Magnetometer (3)</td>
<td>1.3 - 3.0</td>
<td>0.3</td>
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<tr>
<td>CAPS</td>
<td>14.5</td>
<td>12.5</td>
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<tr>
<td>Plasma Sensor</td>
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<td>0.1</td>
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<tr>
<td>Huygens SSP</td>
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<td>4.2</td>
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<tr>
<td>Thermometer</td>
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<td>&lt;1*</td>
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<tr>
<td>Multispectral Imager</td>
<td>2.6 - 4.6</td>
<td>0.5</td>
</tr>
<tr>
<td>MKI</td>
<td>&gt; 3</td>
<td>3.0</td>
</tr>
<tr>
<td>K-band Transmitter</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

CubeSat Group 1 – Multispectral Imager
- Atmospheric circulation and process for banded patterns
- Heat and moist convection influence on atmosphere structure
- Atmospheric interactions

CubeSat Group 2 – Plasma Sensor and Thermometer
- Atmospheric temperature profile
- Atmospheric composition
- Atmospheric chemistry variability and haze production

CubeSat Group 3 – K-Band Transmitter
- Bulk abundances of major species and ice-to-rock ratios
- How interior composition changes with depth
- Deep rotational and dynamic state

CubeSat Group 4 – Triple Magnetometer
- Interior composition, state, and evolution
- Magnetosphere generation, content, dynamics, stratospheric interactions, and differences from gas giants

Mothership Communications
- Mothership’s purpose is to be a communications relay
- Three CubeSat antennas, one Earthlink antenna
- Able to link with CubeSats at any point in the orbit
- Earthlink antenna design based on the New Horizons antenna – similar size, similar capabilities

Fuel and Sizing
- Total spacecraft mass calculated based on launch vehicle characteristics
  - Assuming a specific impulse of 341 s; we estimate requiring ~1435 kg of fuel
- CubeSats have a worst-case mass and volume buffer of ~29% and ~15%, respectively

Acknowledgments
- We thank Artist Miranda Barnes for her mission concept illustration