PLANETARY SCIENCE WITH BALLOON-BORNE TELESCOPES

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Outline

• Why a balloon-borne observatory for Planetary Science
  • Advantages and driving features

• BOPPS Summary

• What’s Next

Photo from BOPPS Onboard Camera
Why Balloons for Planetary Science

- Enables observations not possible from the ground or aircraft (mid IR, NUV) - Unique

- Ultra-Long Duration Balloon (ULDB) flights would enable uninterrupted observation campaigns for weeks if not months – Unique

- Rapid Response – Unique to balloon and ground

- Allows high value observing time at relatively low cost – Advantage

- Engage science community in frequent new missions and broad science, especially good for early career stages – Unique

- Technology Maturation (near space and recovered) – Advantage
Why Balloons for Planetary Science

- Broad application
- Observing in NUV through IR
- Temporal Science

### IR Observing

<table>
<thead>
<tr>
<th>Category</th>
<th>Total # of DS “Important Questions”</th>
<th># Answered or significantly addressed</th>
<th>% Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Bodies</td>
<td>23</td>
<td>10</td>
<td>43%</td>
</tr>
<tr>
<td>Inner Planets</td>
<td>39</td>
<td>11</td>
<td>28%</td>
</tr>
<tr>
<td>Major Planets</td>
<td>39</td>
<td>6</td>
<td>15%</td>
</tr>
<tr>
<td>Icy Satellites</td>
<td>75</td>
<td>12</td>
<td>16%</td>
</tr>
<tr>
<td>Mars</td>
<td>48</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td>Total</td>
<td>194</td>
<td>42</td>
<td>21%</td>
</tr>
</tbody>
</table>
Driving Features

Significant Science is Achievable with Modest System
The Balloon Observation Platform for Planetary Science (BOPPS) Mission and Results
BOPPS Objectives / Team

- Develop and demonstrate gondola and payload systems for a balloon-borne platform
  - IR imaging of Oort Cloud Comet
  - Demonstration of Fine Steering Mirror (FSM) for obtaining sub-arcsec pointing stability
- Achieve high-value planetary science objectives
  - Measure CO\textsubscript{2} and H\textsubscript{2}O in an Oort Cloud comet
  - Observe other high-value targets as available

- Team
  - Project management, gondola, and integration - APL
  - BIRC payload - APL; UVVis payload - SwRI
  - Program Management and support - GRC
• Two comet reservoirs, Kuiper Belt and Oort Cloud
• Oort Cloud Comet ISON in 2013, the BRRISON target
• Oort Cloud Comets as targets in 2014

Oort Cloud
5,000-100,000 AU

Kuiper Belt
30-55 AU

Sun
BOPPS Gondola Description

Estimated MEV Mass

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>4134 lbs.</td>
</tr>
<tr>
<td>LN2</td>
<td>178 lbs.</td>
</tr>
<tr>
<td>Ballast</td>
<td>750 lbs.</td>
</tr>
<tr>
<td>Total Wet</td>
<td>5062 lbs.</td>
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</tbody>
</table>

Dry mass includes 345 lbs. of CSBF equipment (CIP/MIP, ballast hopper, science stack, live video transmitter with radiator plate, antennas & harness)

- Suspension Point
- Azimuth Reaction Wheel
- Roll Reaction Wheel
- Telescope Baffle Extension
- STO 0.8 m Telescope
- Star Cameras (x2)
- Science Instruments Suite
  - UVVis
  - BIRC
- LN2 Dewars (x2)
- Avionics and Power bay
- CIP/MIP Package
- Antenna boom

NASA GRC
BIRC Instrument Overview

- BIRC is a multispectral IR imager with cryogenic HgCdTe detector
- Cooled filter wheel and relay optics
- Filters at:
  - 2.47 μm
  - 2.70 μm
  - 2.85 μm
  - 3.05 μm
  - 3.20 μm
  - 4.00 μm
  - 4.27 μm
  - 4.60 μm
  - R band (600 – 800 nm)
- FOV 3 arcmin
- 1.16 arcsec/pixel plate scale with 18 μm pixel pitch
- 12 bit images
**Science channel**
- CCD camera with filter wheel
- 4 bandpass filters (300 – 450 nm)
- Broad band (< 300 – 600 nm)
- Frame format 1024x1024 with optional EMCCD
- AR coated window
- Plate scale 0.19 arcsec/pixel with 13 μm pixel pitch

**Guide channel**
- Fast framing CMOS imager
- 600 – 850 nm broad band
- sCMOS detector with image format 2560x2160
- Plate scale 0.096 arcsec/pixel with 6.5 μm pixel pitch
- Controls a fine steering mirror for fine image stabilization to ~ 0.1 arcsec

**Inset fold mirror**
- Movable into the telescope light beam
- Divert light from telescope into UVVis optic
- Open lets light reach BIRC instrument
BOPPS Pointing

- Pointing with FSM
  - Stabilization tests conducted with/without BIRC cryocooler operating
  - Performed fine image motion corrections, <5 Hz
    - RMS pointing errors were reduced to 280 & 165 mas (AZ and EL) with the cryocooler ON
    - RMS was 33.3 & 58.1 mas with the cryocooler OFF

- Coarse Pointing

- Achieved 0.5 arcsec RMS stability

**Pointing performance exceeded mission goals**
BIRC Observations

<table>
<thead>
<tr>
<th>Target</th>
<th>$r_H$ [AU]</th>
<th>$\delta$ [AU]</th>
<th>Phase [deg.]</th>
<th>Calibration star (type) mag</th>
<th>Detections [band center in µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siding Spring C/2013 A1</td>
<td>1.46</td>
<td>1.12</td>
<td>43</td>
<td>HD163761 (A0V) V=6.69</td>
<td>R, 2.7, 2.47, 4.0</td>
</tr>
<tr>
<td>Jacques C/2014 E2</td>
<td>1.72</td>
<td>1.15</td>
<td>34</td>
<td>HD196724 (A0V) V=4.82</td>
<td>R, 2.7, 2.47, 3.05, 3.2, 2.85, 4.0, 4.27, 4.6</td>
</tr>
<tr>
<td>1 Ceres</td>
<td>2.75</td>
<td>3.37</td>
<td>15</td>
<td>HD133772 (A0V) V=7.47</td>
<td>R, 2.7, 2.47, 3.05, 3.2</td>
</tr>
</tbody>
</table>

- Siding Spring and Ceres were twilight targets; Jacques was a night time target
Demonstrated planetary science applicability of balloons:

• Unique science observations
  - First observations of 2.7 µ and 4.27 µ fluxes from an Oort Cloud comet revealed cool, silicate dust population
  - First observation of 2.7 µ flux from Ceres to characterize water / hydroxyl infrared absorption
  - Measured water production of comet Siding Spring

• Exceeded goals for sub-arcsecond pointing stability
  - Coarse pointing: exceeded goal of 1 arcsecond
  - Fine-steering pointing: exceeded goal of 0.1 arcsecond

• Successful Secondary Payload
NEXT STEPS
What’s Next

• Demonstrated that desired planetary decadal science can be achieved from balloon-based platforms

• Platform offers low cost approach to science - offering more mission opportunities to take science measurements, flight experience, technology maturation...

• Well suited to competing missions / science
  • Broad applicability

• Competed science is the approach for future
What’s Next

• Continue to define a platform optimized for planetary science – Gondola for High Altitude Planetary Science (GHAPS)
  • 1m OTA, Course pointing <1 arcsec, Light weighted, Modular, Robust
  • Working to make available for first flight in 2019

• BOPPS was successfully recovered
  • Hardware would be available for re-flight

• BOPPS instruments can be leveraged

• Interested in discussing potential collaborations