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
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

<table>
<thead>
<tr>
<th>Category</th>
<th>Total # of DS “Important Questions”</th>
<th># Answered or significantly addressed</th>
<th>% Addressed</th>
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<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>
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<tr>
<td>Major Planets</td>
<td>39</td>
<td>6</td>
<td>15%</td>
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<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><strong>Total</strong></td>
<td>194</td>
<td>42</td>
<td>21%</td>
</tr>
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</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$_2$ and H$_2$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
Oort Cloud and Kuiper Belt

- Two comet reservoirs, Kuiper Belt and Oort Cloud
- Oort Cloud Comet ISON in 2013, the BRRISON target
- Oort Cloud Comets as targets in 2014
BOPPS Gondola Description

Estimated MEV Mass

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
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</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)

STO 0.8 m Telescope

UVVis

BIRC

Science Instruments Suite

Star Cameras (x2)

Avionics and Power bay

Suspension Point

Azimuth Reaction Wheel

Roll Reaction Wheel

Telescope Baffle Extension

20’ Antenna boom

LN2 Dewars (x2)

CIP/MIP Package

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
UVVis Instrument Overview

- **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

- **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 $\mu$m]</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
BOPPS Accomplishments

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

BOPPS Level 1 Requirements Were Met
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