VEXAG April 2015: Stratospheric Balloons for Planetary Science

Tibor Kremic April, 2015
Outline

• Why balloons?
• Demonstrations
• Venus application concept
• Assessments / 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 may enable long baseline observations – Unique

- Rapid Response Potential – Not feasible for space missions

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

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

- Technology Maturation (near space environment / recovered) – Advantage

- Reusable. Hardware is generally recovered – can be improved, modified, or replaced per science needs
Why Balloons for Planetary Science

- Unique Obs
- Broad application
- 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>
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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><strong>194</strong></td>
<td><strong>42</strong></td>
<td><strong>21%</strong></td>
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</tbody>
</table>

ModTran results. At 120K, spectrum fully available with low downwelling radiance.
Assessments and Decadal Survey

- Several assessment activities have been implemented
  - Workshop, Community survey and concepts review, Study, Demonstration flights
- Study developed a concept gondola to do a host of planetary science – Gondola for High Altitude Planetary Science (GHAPS)

- Decadal Survey position

“Balloon- and rocket-borne telescopes offer a cost-effective means of studying planetary bodies at wavelengths inaccessible from the ground. Because of their modest costs and development times, they also provide training opportunities for would-be developers of future spacecraft instruments. Although NASA’s Science Mission Directorate regularly flies balloon missions into the stratosphere, there are few funding opportunities to take advantage of this resource for planetary science, because typical planetary grants are too small to support these missions. A funding line to promote further use of these suborbital observing platforms for planetary observations would complement and reduce the load on the already over-subscribed planetary astronomy program.”

Study Defined Driving Features – folded into GHAPS concept

Significant Science is Achievable with Modest System
Recent missions begin to demonstrate potential: BOPPS and OPIS flew in 2014
BOPPS Objectives / Team

• Develop and demonstrate gondola and payload systems for a balloon-borne platform
  – IR imaging of Oort Cloud Comet
  – NUV/Vis imaging and 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
BOPPS Gondola Description

**Estimated MEV Mass**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</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>
</tr>
</tbody>
</table>

Dry mass includes 345 lbs. of CSBF equipment (CIP/MIP, ballast hopper, science stack, live video transmitter with radiator plate, antennas & harness)
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
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
Pointing stabilization tests conducted with/without BIRC cryocooler operating

- Performed fine image motion corrections
  - 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
BOPPS Accomplishments

Demonstrated applicability to planetary science

- 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 Siding Spring at 2.7 µ: \( Q[H_2O] = 5.1 \times 10^{27} \text{ /sec} \)
- Exceeded goals for sub-arcsecond pointing stability
  - Coarse pointing: exceeded goal of 1 arcsecond
  - Fine-steering pointing: exceeded goal of 0.1 arcsecond

BOPPS Level 1 Requirements Were Met
Observatory for Planetary Investigations from the Stratosphere

GSFC Mission
Terry Hurford, Avi Mandell, Eliot Young, Vishnu Reddy
OPIS Team, WASP Team
Mission Goals

- To demonstrate the pointing accuracy as well as short and long term stability of the Wallops ArcSecond Pointing (WASP) system to enable planetary science observations.
OPIS Imaging System

- Built around a refurbished 21” telescope
- OTS Apogee Alta CCD camera
- Translation stage for focusing
- Custom avionics to control the system
Main OPIS Structure

Star Tracker
CCD Camera & Filter Wheel
Translation Stage w/ Stepper Motor
OPIS optic
Batteries
LN-251
Avionics Boxes Mounted Side by Side
Bright Body Camera
C.G.
Trim Weight
Main OPIS Structure
Jupiter Observed

- Obtained non-smeared Jupiter images
- Will process images
- Will analyze the statistics of image quality to assess WASP ability to maintain short-term image quality
- > 2,000 images collected
WASP Short Term Stability

- WASP test flight data shows stability to 1” over 40 minutes

- OPIS pixel FOV is 0.25”
  - Expect that OPIS can image at 0.25”/pixel resolution with short exposures
• WASP quick look results show 0.47” Pitch x 0.39” Yaw RMS pointing performance
• Will be analyzing OPIS star images to determine if there were OPIS-WASP pointing offsets due to flexure
• Main objective to image Jupiter with no jitter induced smear was successful!
  • Plenty of images to reduce and quantify pointing performance

• Secondary objectives of long-term tracking with a star target achieved

• OPIS will provide needed information on the observational conditions and challenges of high-altitude platforms for planetary science investigations
Imagine a Venus Application

Assume a GHAPS platform & appropriate instruments

- Telescope in space like environment – above 99.5% of Earth’s atmosphere

- The capability for diffraction limited observations into the visible
  - Opens up windows to look for water, CO$_2$, organics

- Ability to look at Venus, perhaps continuously for weeks to months during inferior conjunction
Venus Mission Concepts

3D Wind Fields at Lower/Middle/Upper Cloud Decks

- Venus nightside at 1.74 µm: 1 m/s resolution (45-55 km)
- Venus dayside at 0.38-0.9 µm: 0.5 m/s resolution (70 km).

Existence and prevalence of lightning on Venus

- Very high cadence imaging at 777 nm. *Try 10 KHz frame rates.*
- Exploit the 0.15” platescale.

Good spatial and temporal resolutions will improve sensitivity to ephemeral phenomena.

Surface Emissivity

- Maps at windows near 1 - 1.31 µm.
- Extend the VIRTIS maps to the northern hemisphere.
- A single flight (>50 days) near inferior conjunction should provide >500 hours on Venus, enough to time-average over atmospheric variations.
Additional Science Possible

• Properties of Venus' clouds

• Distribution of trace species and the coupling between certain dynamical and chemical processes

• Can complement other assets with additional observing windows
Now What

- Release study and communicate findings

- Experiences affirm that balloon borne observatories offer low cost approach to science and offers more mission opportunities to take science measurements, flight experience, technology maturation…

- Platform is well suited to competed missions / science
  - Broad applicability, short cycles, variety of instruments possible

Compete Science/PI on future flights
What’s Next

• BOPPS hardware is being utilized for Astrophysics mission in winter 2015-16

• After BOPPS hardware is recovered
  • BOPPS instruments and gondola can be re-used
  • Could be re-flown as early as 2017

• GHAPS could be ready for first flight in 2019
  • Designed to optimize science
  • 1m OTA, Pointing <1 arcsec, Light weighted, Modular, Robust
  • BOPPS instruments can be leveraged

• PSD considering options