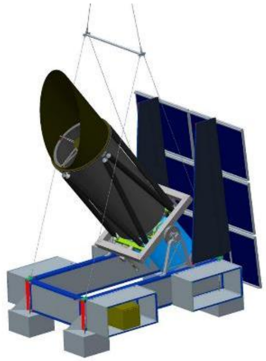
2015 ESA Balloon and Rockets Symposium

PLANETARY SCIENCE WITH BALLOON-BORNE TELESCOPES



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- Karl Hibbitts (APL)

Andy Cheng (APL)
Eliot Young (SWRI)

Outline

- Why a balloon-borne observatory for Planetary Science
  - Advantages and driving features
- BOPPS Summary
- What's Next

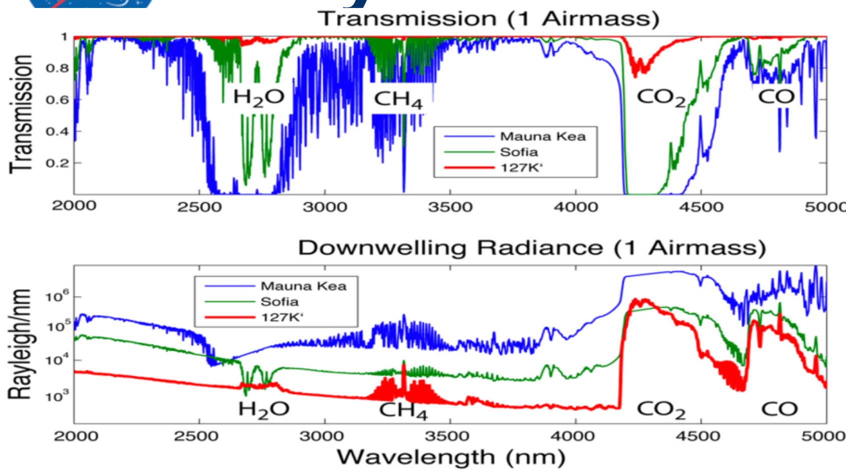
Photo from BOPPS Onboard Camera

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 un-interrupted 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

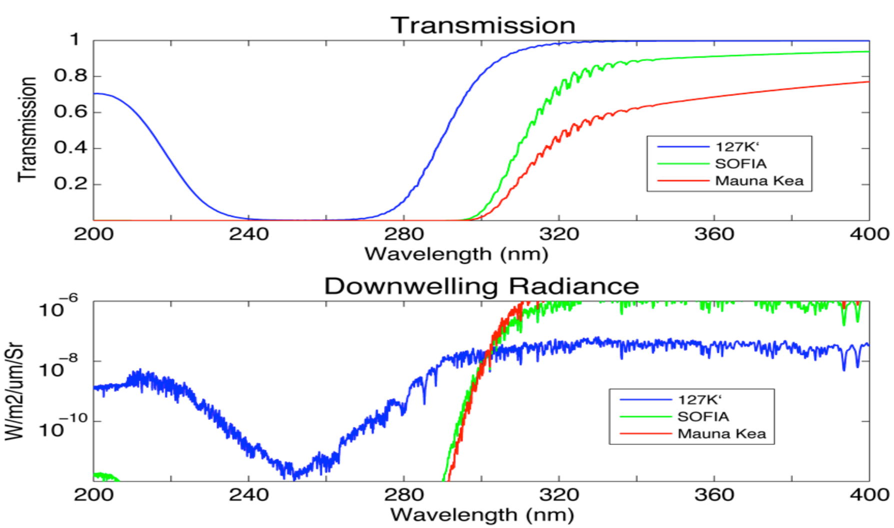
Why Balloons for Planetary Science

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



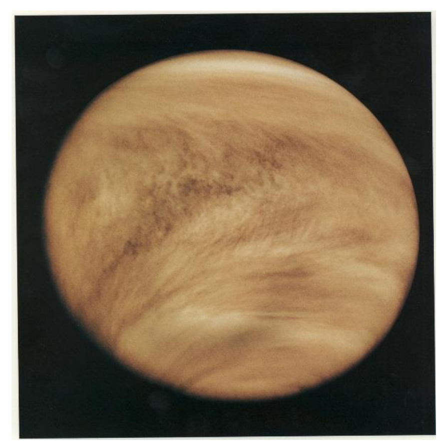
ModTran results. At 120K', spectrum fully available with low downwelling radiance.

IR Observing

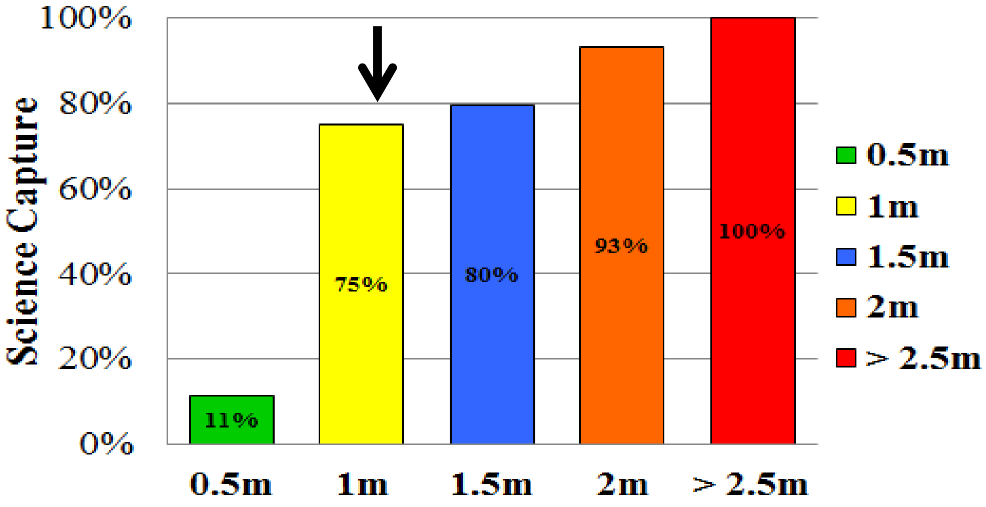


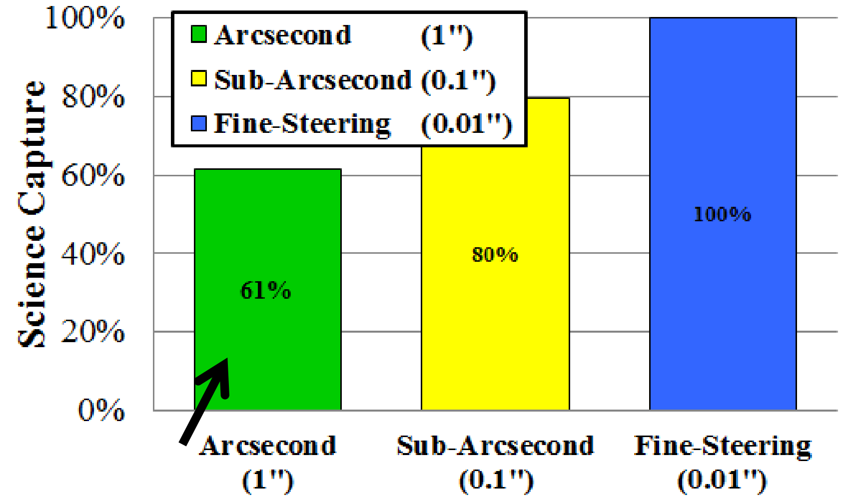
UV Observing

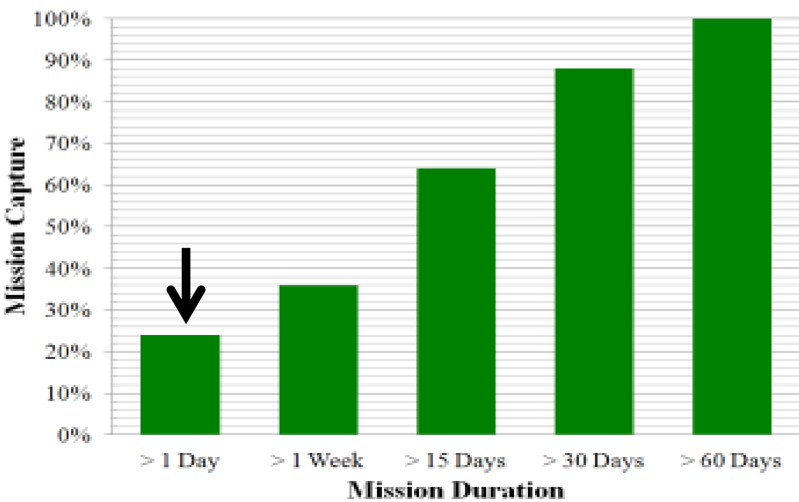
Category	Total # of DS "Important Questions"	# Answered or significantly addressed	% Addressed
Small Bodies	23	10	43%
Inner Planets	39	11	28%
Major Planets	39	6	15%
Icy Satellites	75	12	16%
Mars	48	3	6%
Total	194	42	21%

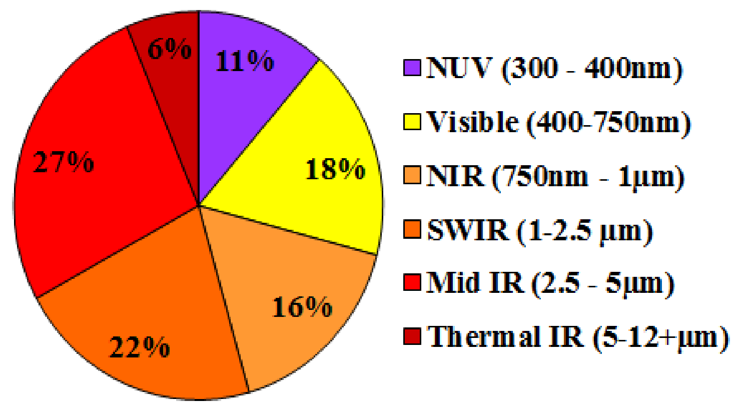


Driving Features



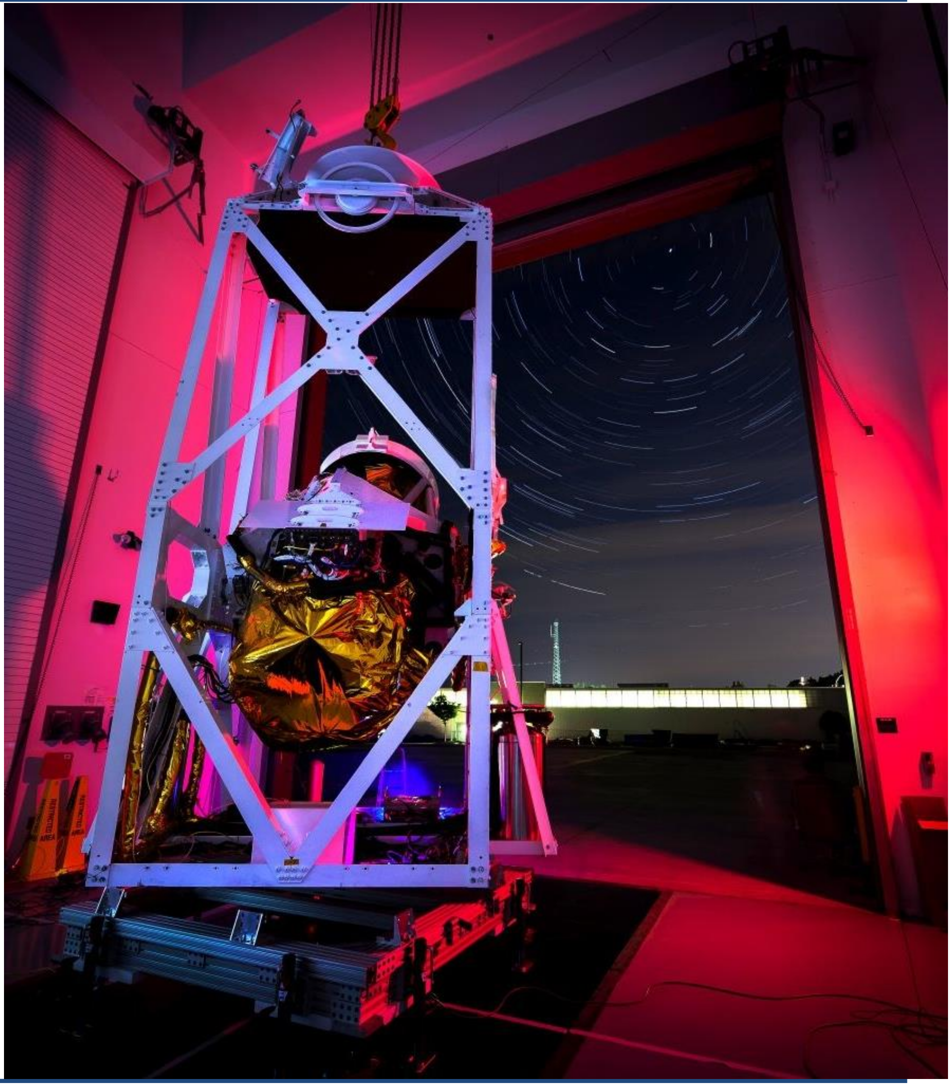






Significant Science is Achievable with Modest System

The Balloon Observation Platform for Planetary Science (BOPPS) Mission and Results



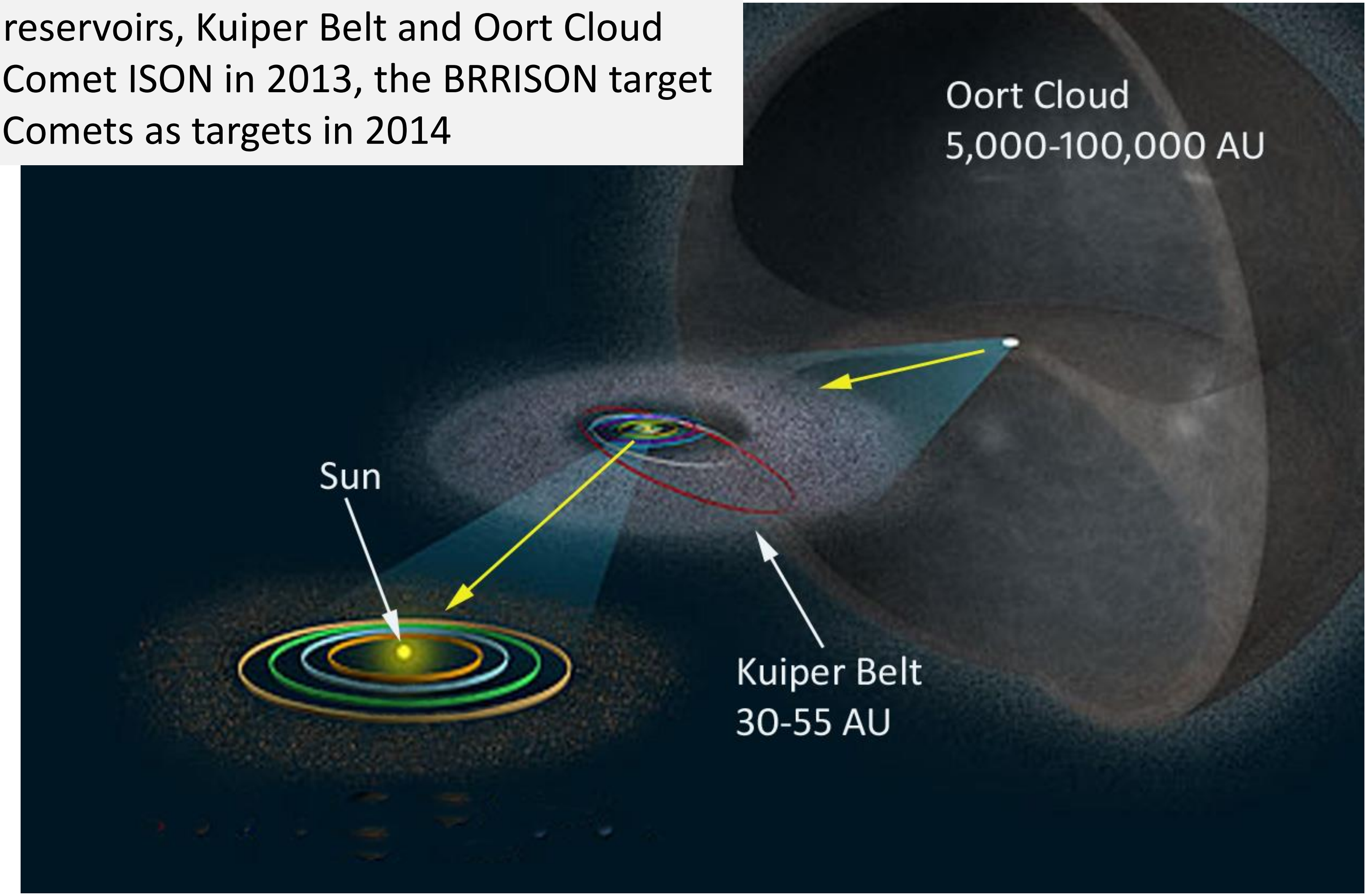
BOPPS Objectives / Team

- 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_2O in an Oort Cloud comet
  - Observe other high-value targets as available

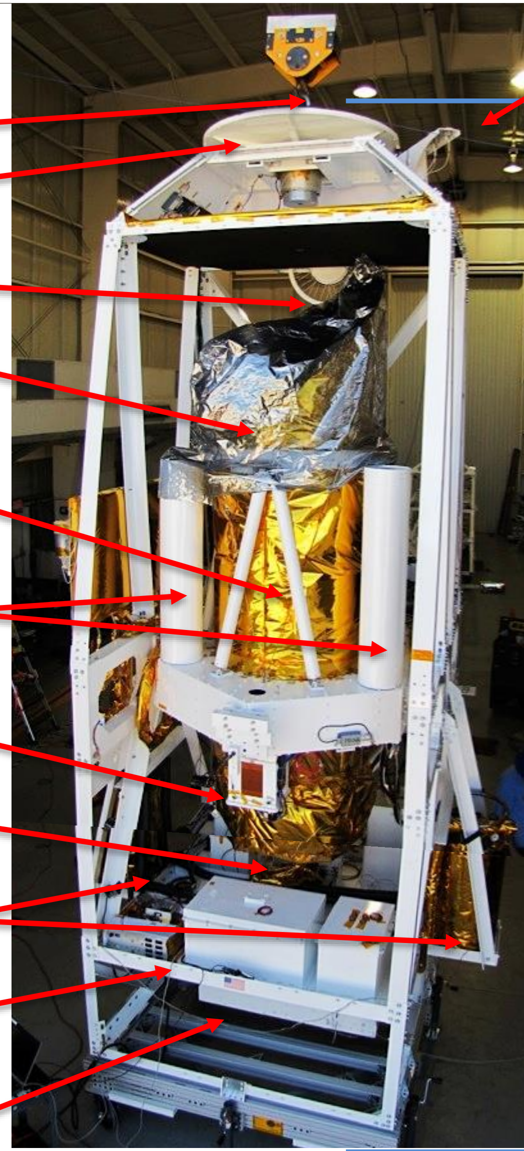
- Team
  - Project management, gondola, and integration - APL
  - BIRC payload - APL; UVVis payload - SwRI
  - Program Management and support - GRC

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



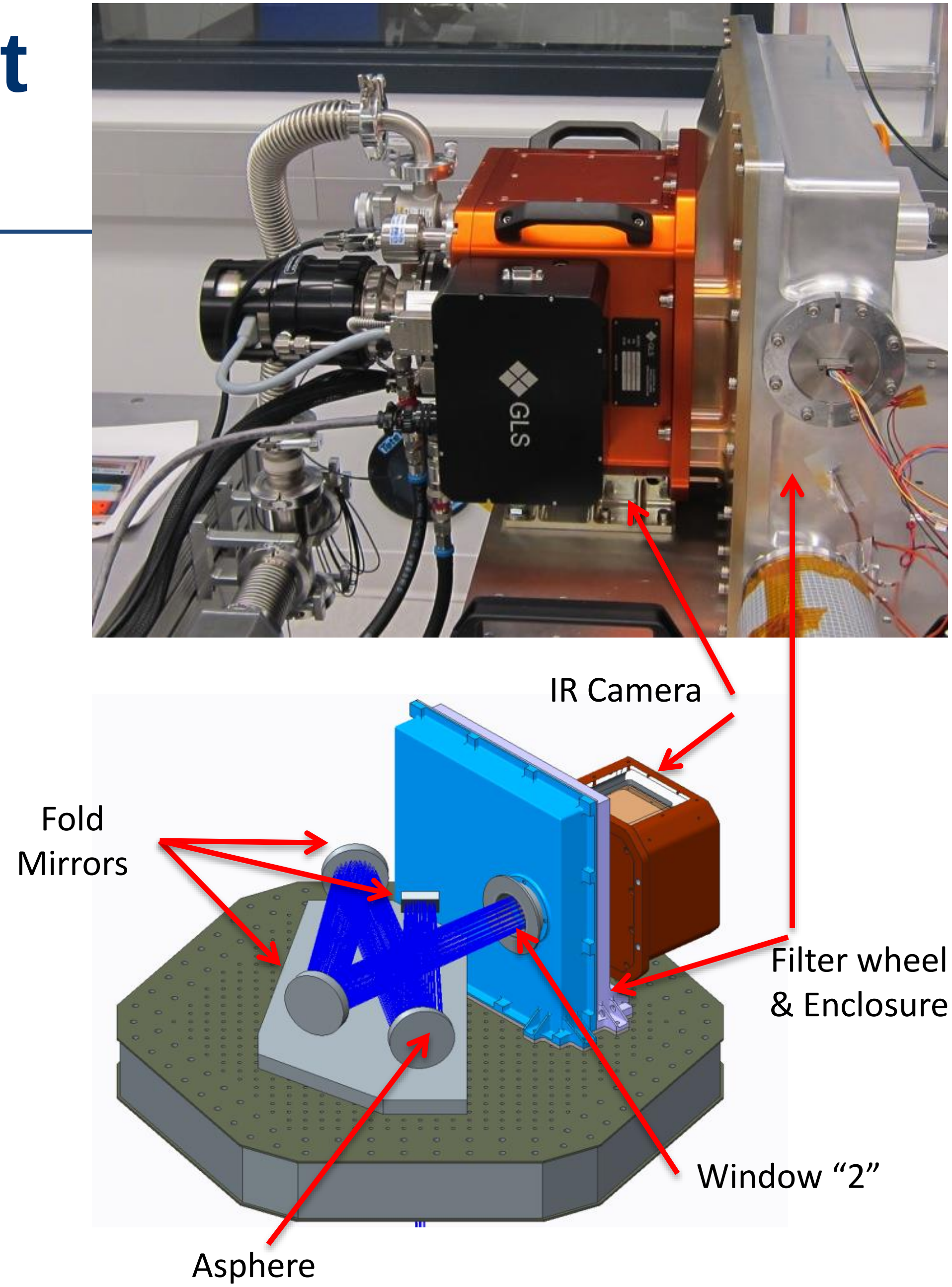
Estimated MEV Mass	
Dry	4134 lbs.
LN2	178 lbs.
Ballast	750 lbs.
Total Wet	5062 lbs.

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

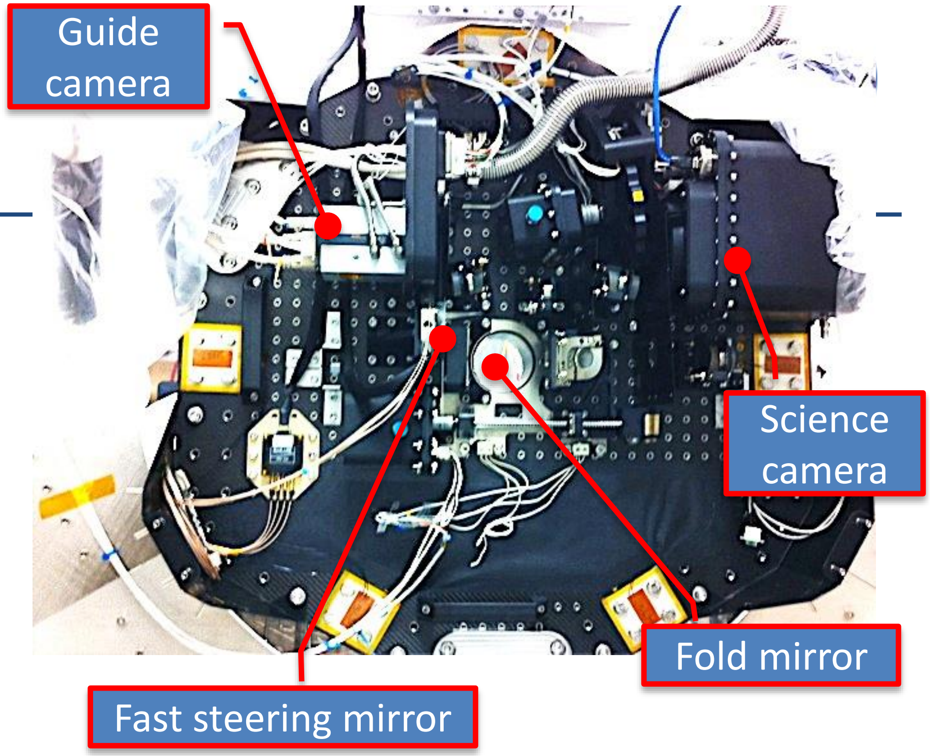
- BIRC is a multispectral IR imager with cryogenic HgCdTe detector
- Cooled filter wheel and relay optics
- Filters at
  - 2.47 μm
  - 2.70 μm
  - 2.85 μm
  - 3.05 μm
  - 3.20 μm
  - 4.00 μm
  - 4.27 μm
  - 4.60 μm
  - R band (600 – 800 nm)

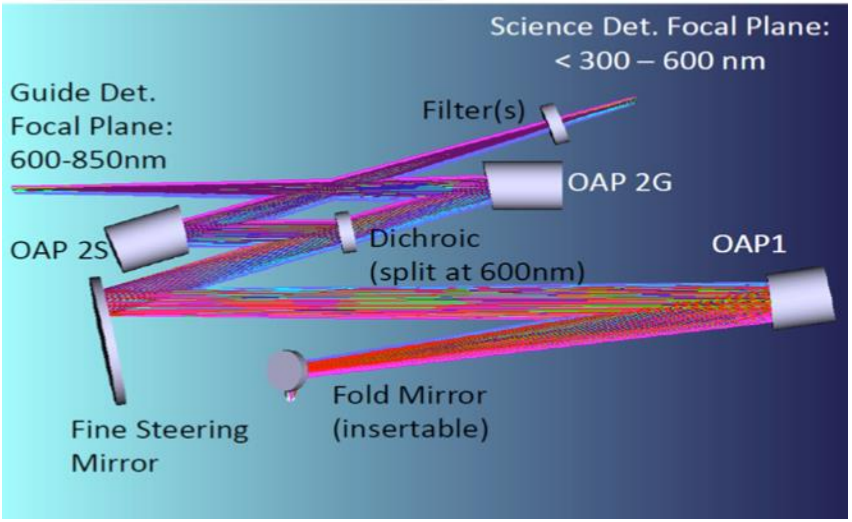
  (2.47–3.05 μm: water and continuum; 3.20–4.60 μm: CO_2 and continuum)
- FOV 3 arcmin
- 1.16 arcsec/pixel plate scale with 18 μm pixel pitch
- 12 bit images



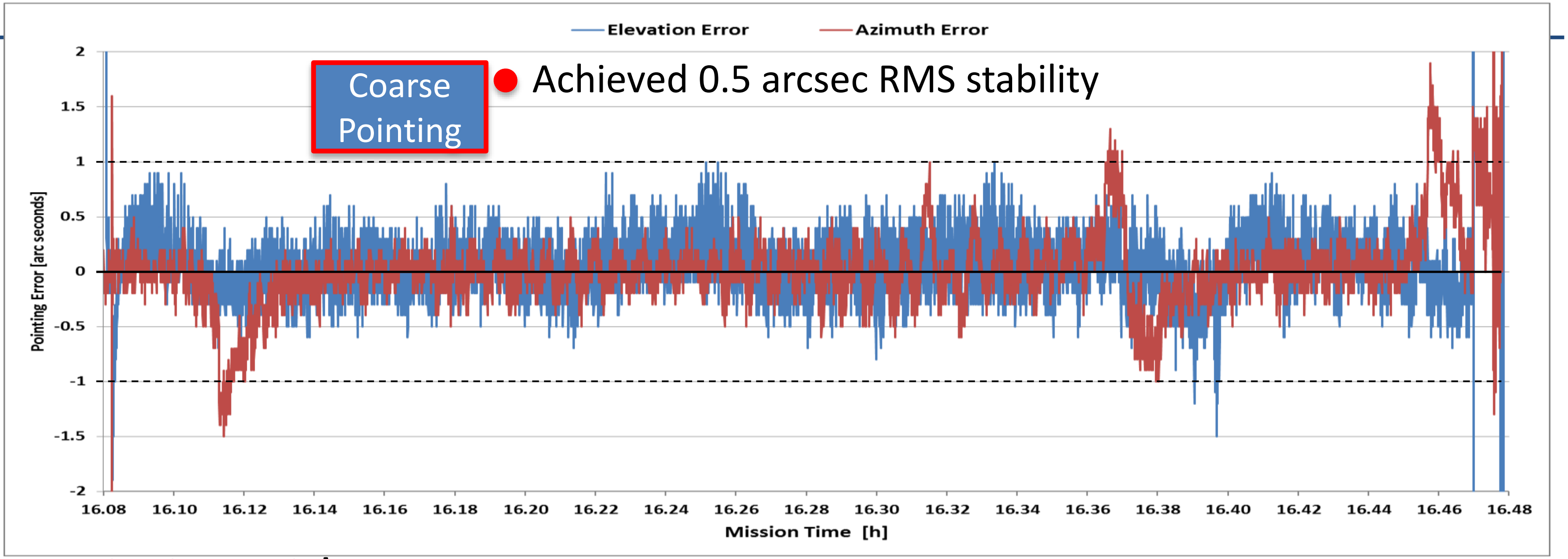
UVVis Instrument Overview

- **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

Pointing performance exceeded mission goals

BIRC Observations

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

- 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

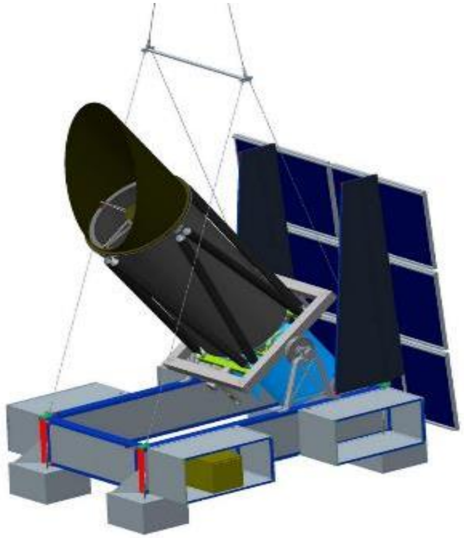
NEXT STEPS

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