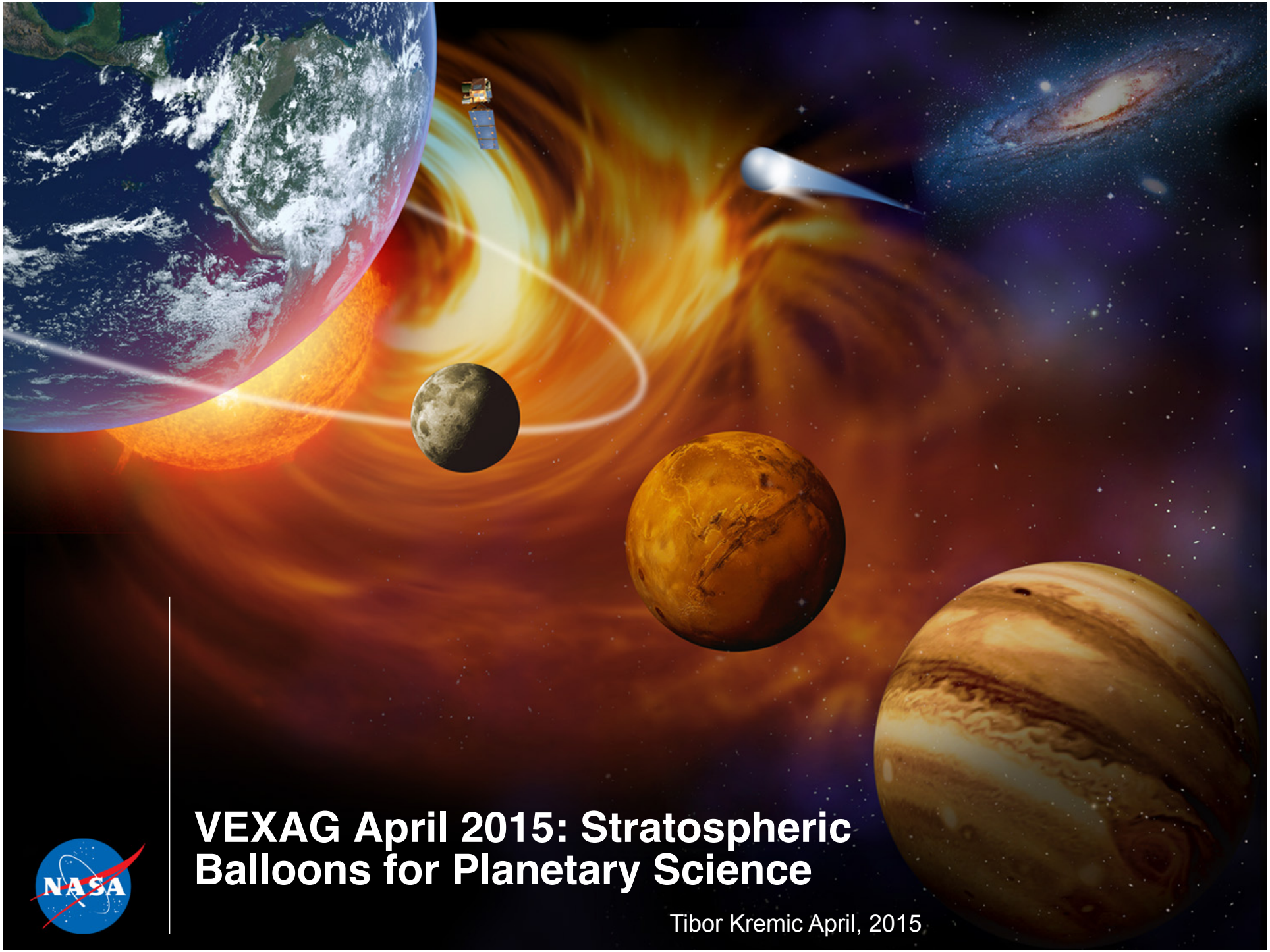


VEXAG April 2015: Stratospheric Balloons for Planetary Science

Tibor Kremic April, 2015

Outline

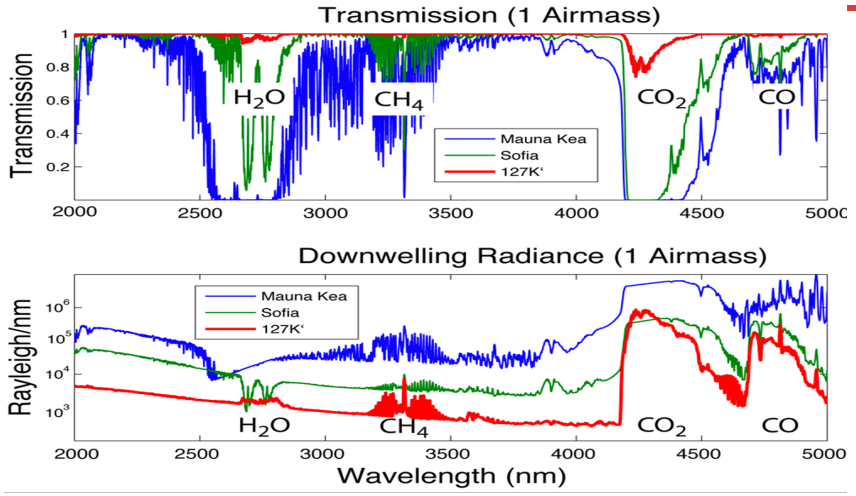
- Why balloons?
- Demonstrations
- Venus application concept
- Assessments / What's Next

Photo from BOPPS Onboard Camera

Why Balloons for Planetary Science

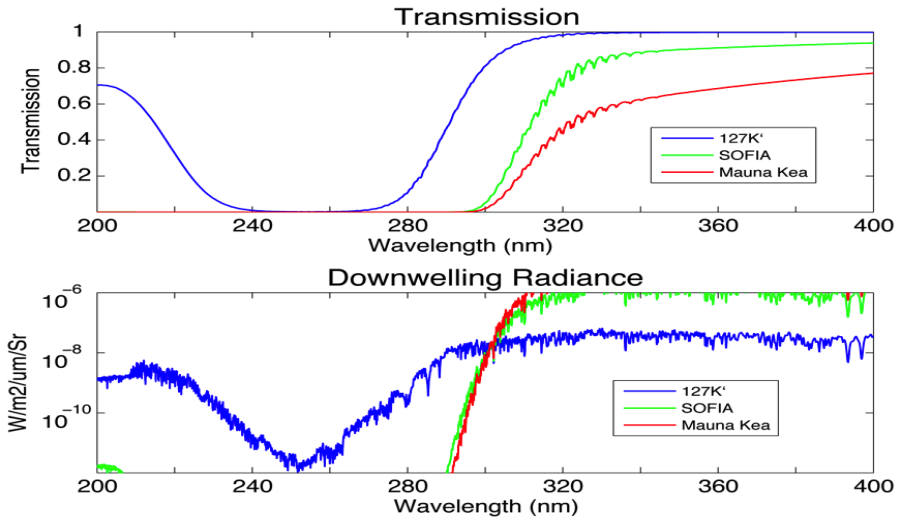
- Enables observations not possible from the ground or aircraft (mid IR, NUV) - Unique
- Ultra-Long Duration Balloon (ULDB) flights may enable long baseline observations – Unique
- Rapid Response Potential – Not feasible for space missions
- Generates high value observing time at **relatively low cost** – 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



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

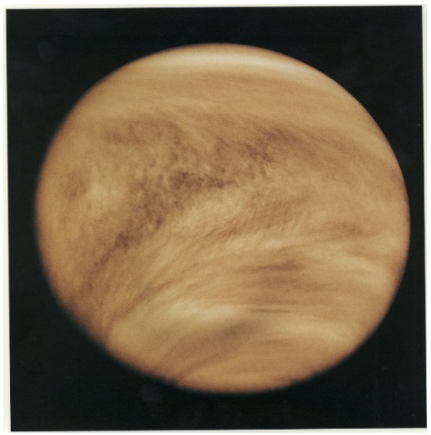
IR Observing

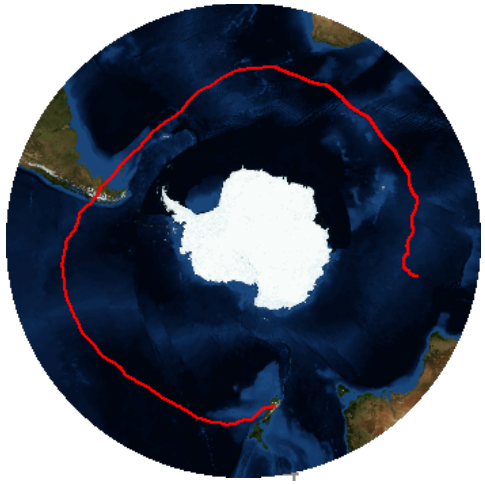


UV Observing

- Unique Obs
- Broad application
- Temporal Science

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%





Assessments and Decadal Survey

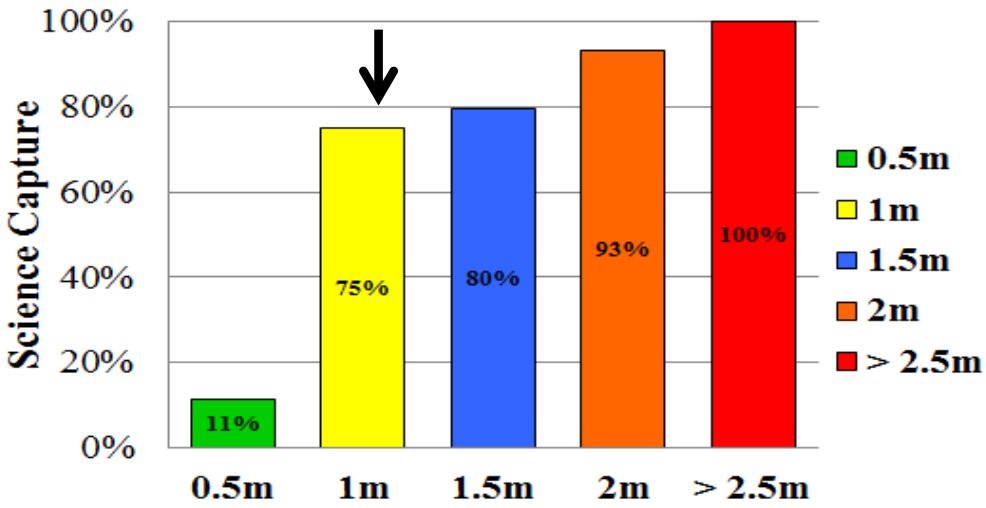
- Several assessment activities have been implemented
  - Workshop, Community survey and concepts review, Study, Demonstration flights
- **Study developed a concept gondola to do a host of planetary science – Gondola for High Altitude Planetary Science (GHAPS)**

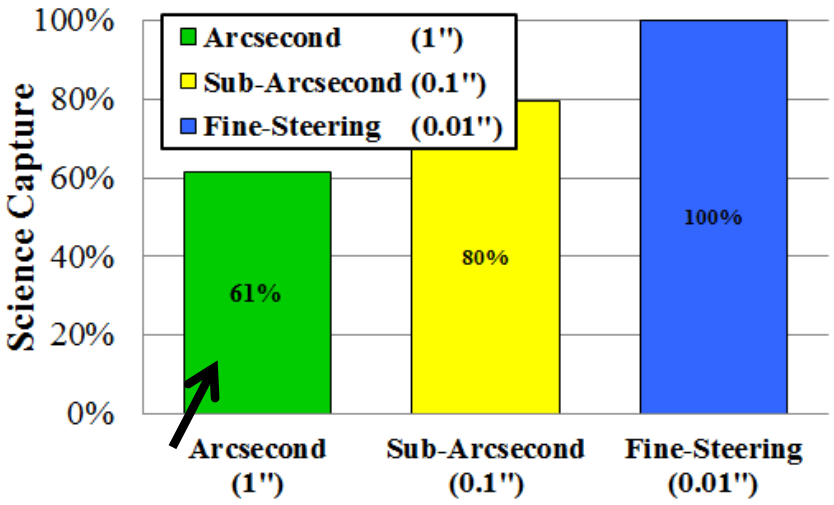
- Decadal Survey position

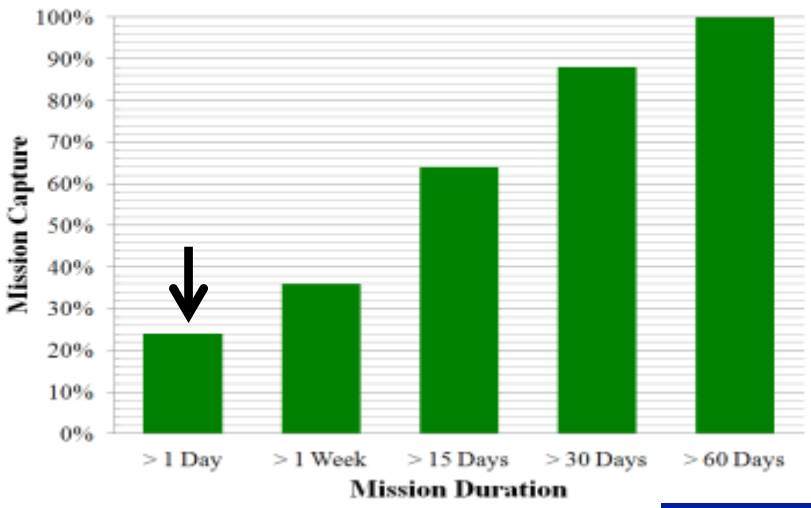
"Balloon- and rocket-borne telescopes offer a cost-effective means of studying planetary bodies at wavelengths inaccessible from the ground. Because of their modest costs and development times, they also provide training opportunities for would-be developers of future spacecraft instruments. Although 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."

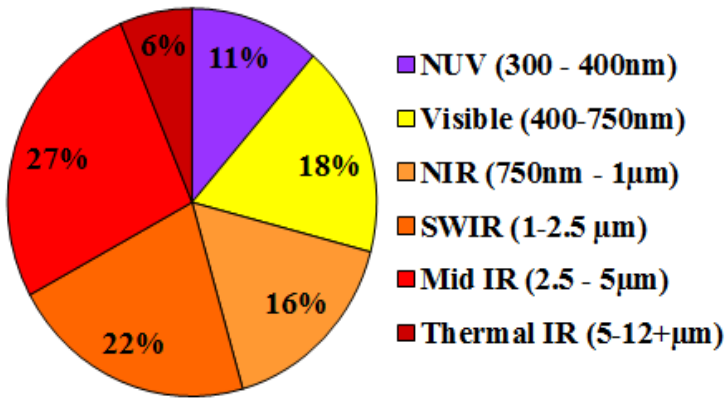
National Research Council. "Vision and Voyages for Planetary Science in the Decade 2013-2022," Washington, DC: The National Academies Press, 2011.

Study Defined Driving Features – folded into GHAPS concept





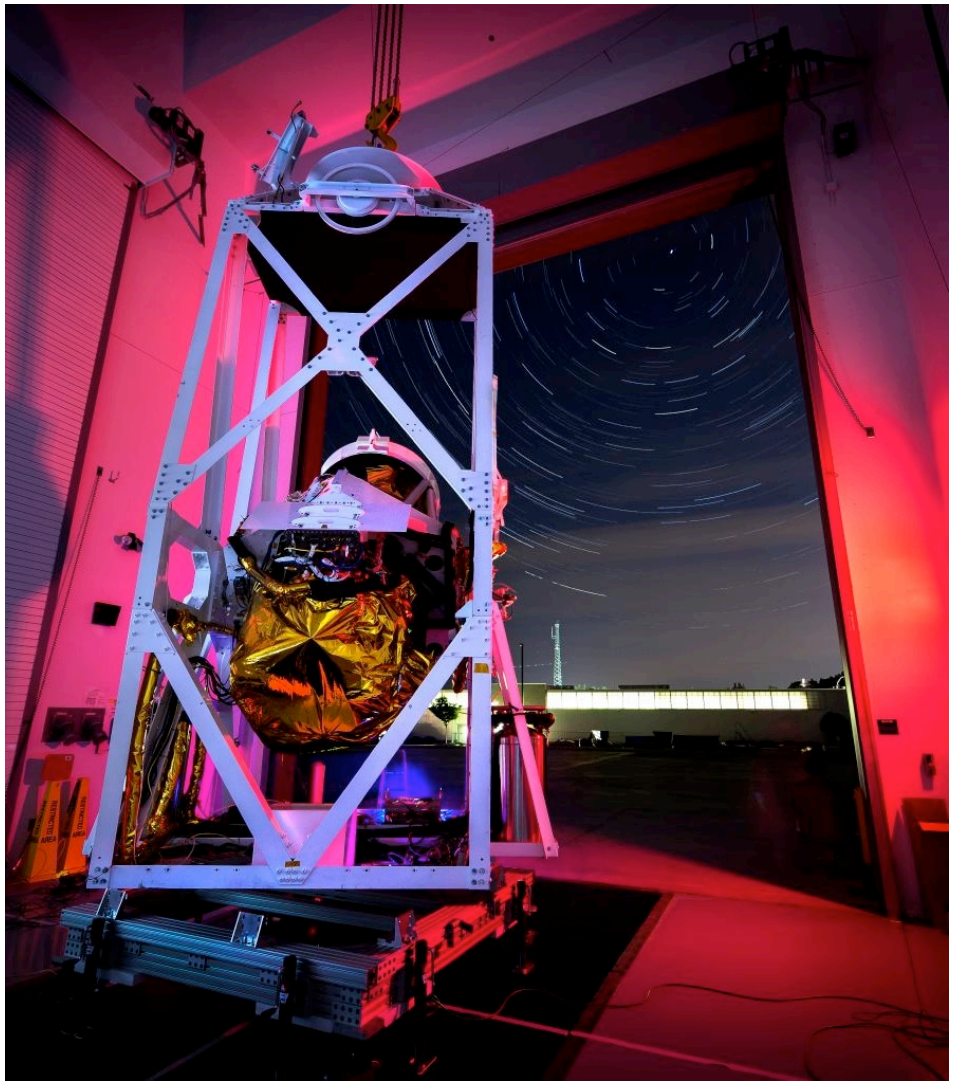




Significant Science is Achievable with Modest System

Demonstrations

Recent missions begin to demonstrate potential: BOPPS and OPIS flew in 2014



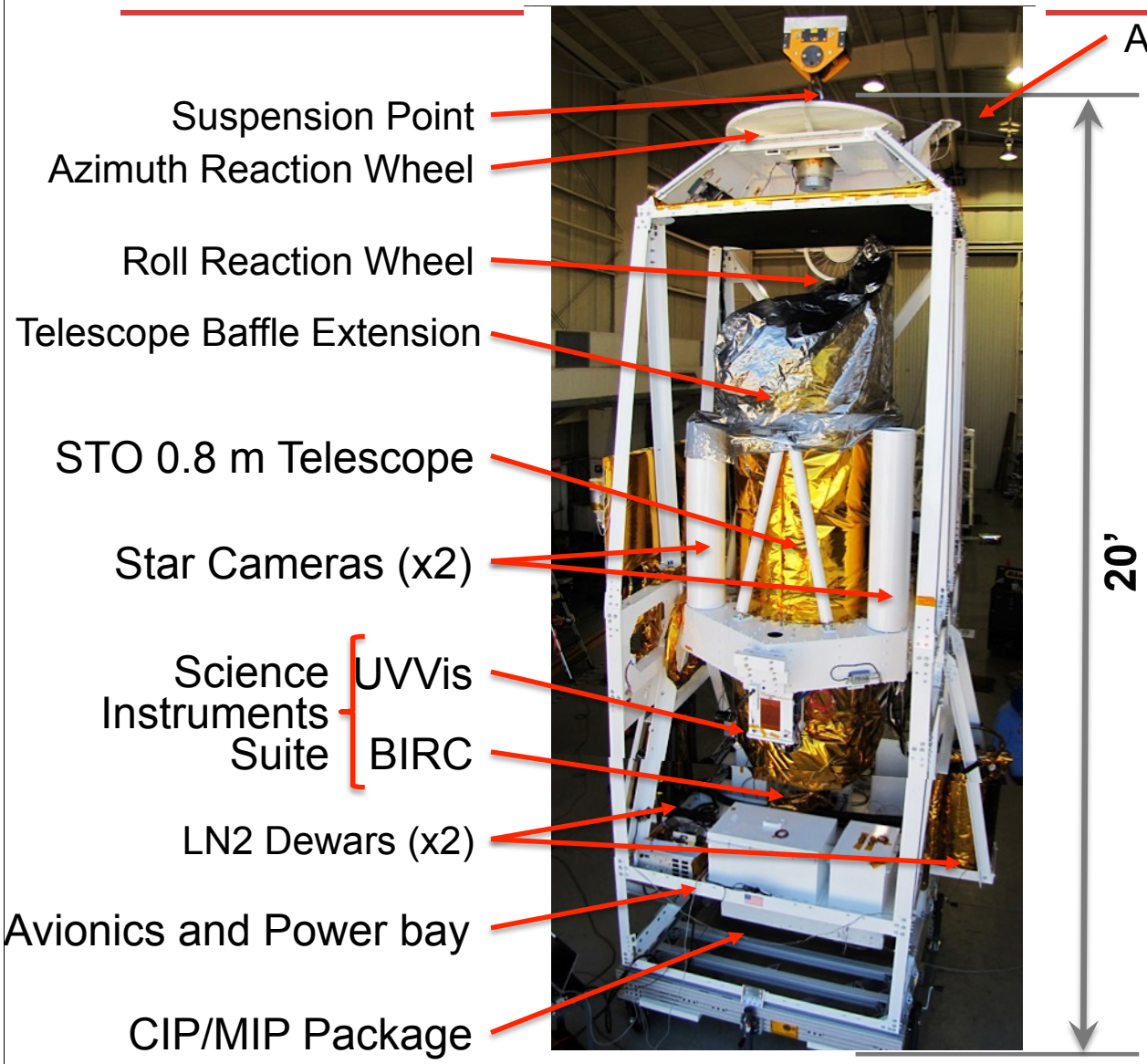
BOPPS Objectives / Team

- **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_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

BOPPS Gondola Description



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

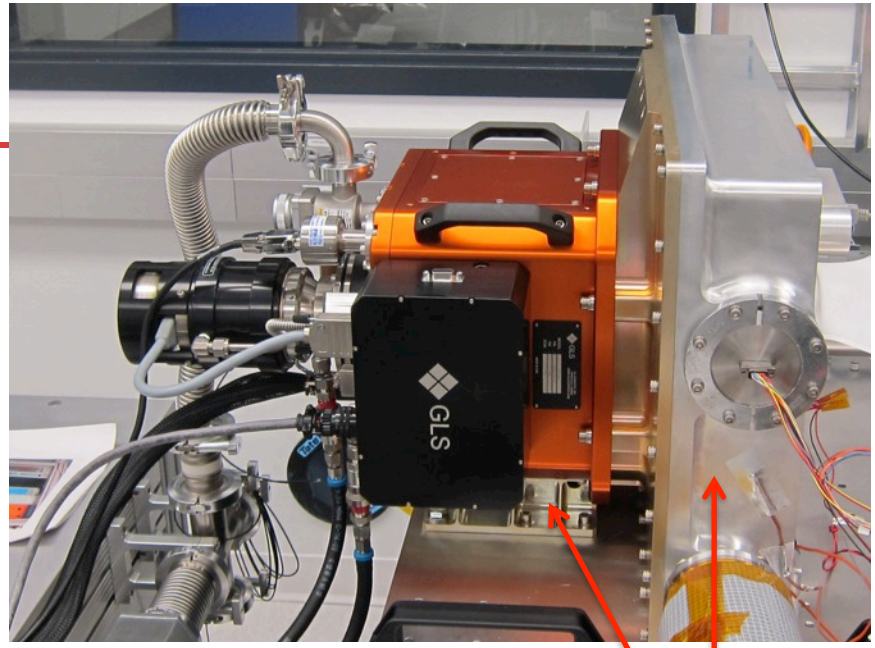
Dry mass includes 345 lbs. of CSBF equipment (CIP/MIP, ballast hopper, science stack, live video transmitter with radiator plate, antennas & harness)

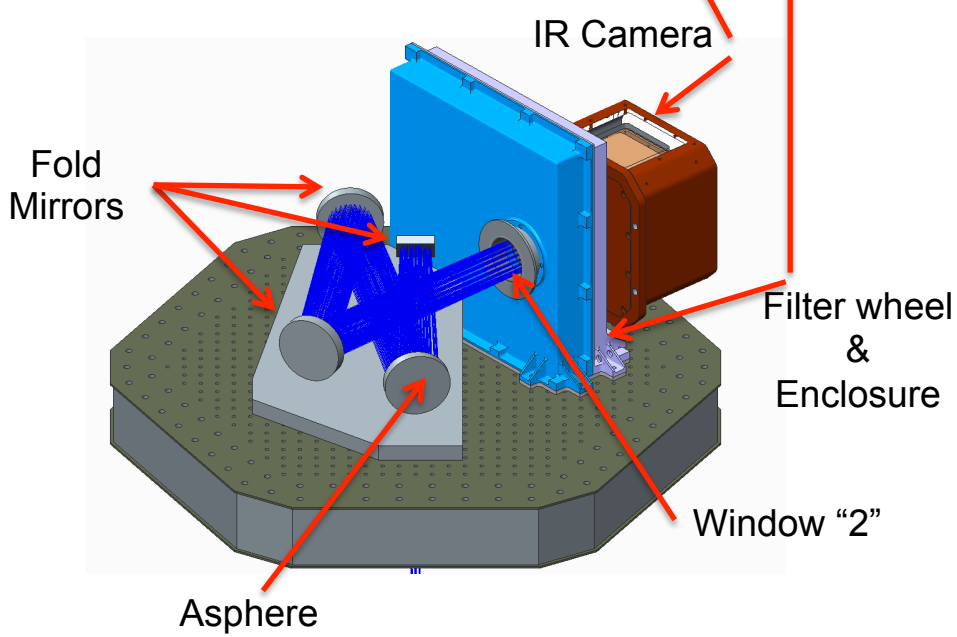
BIRC Instrument Overview

- **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

  water and continuum
  - 3.20 μm
  - 4.00 μm
  - 4.27 μm
  - 4.60 μm

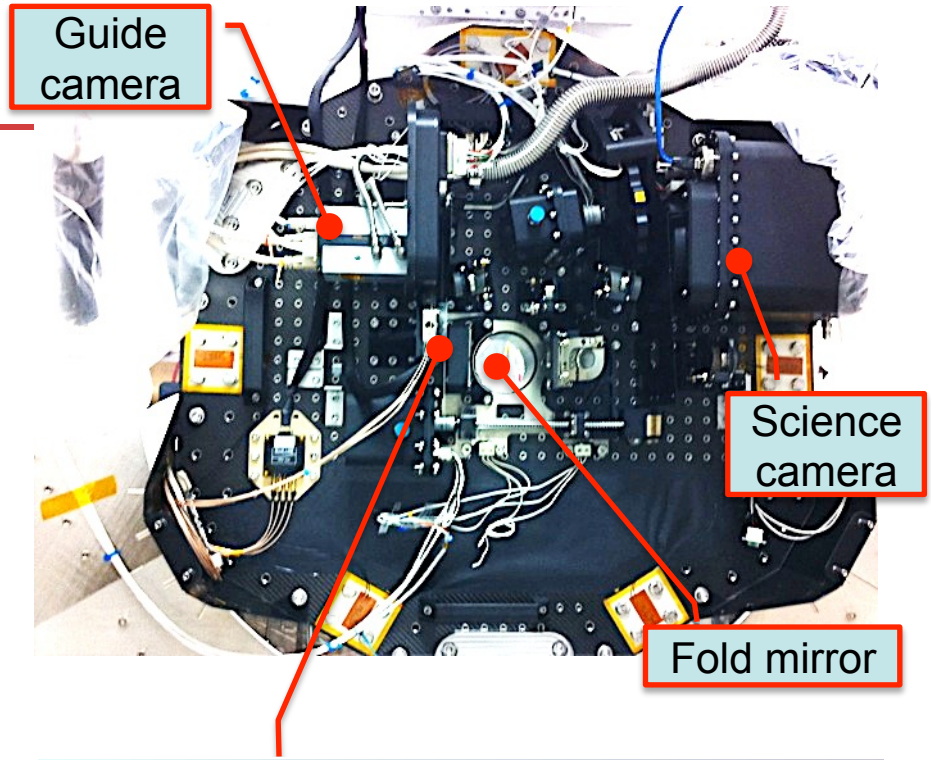
  CO_2 and continuum
  - R band (600 – 800 nm)
- **FOV 3 arcmin**
- **1.16 arcsec/pixel plate scale with 18 μm pixel pitch**

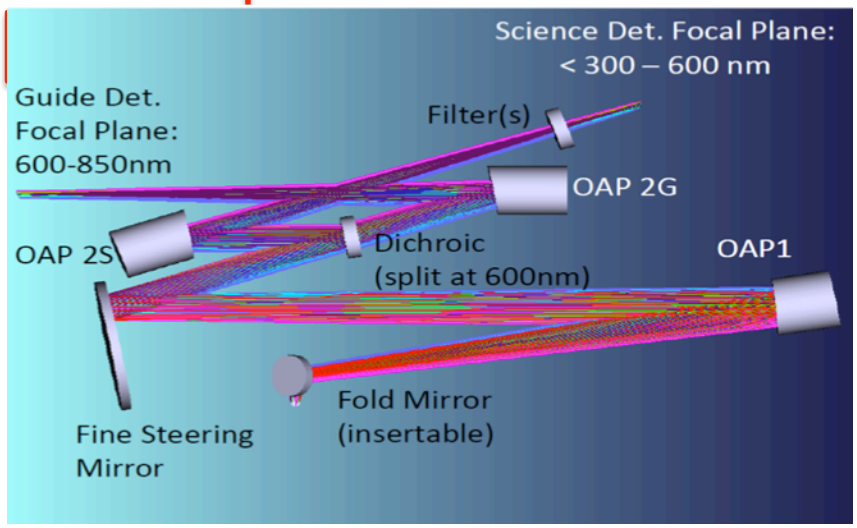




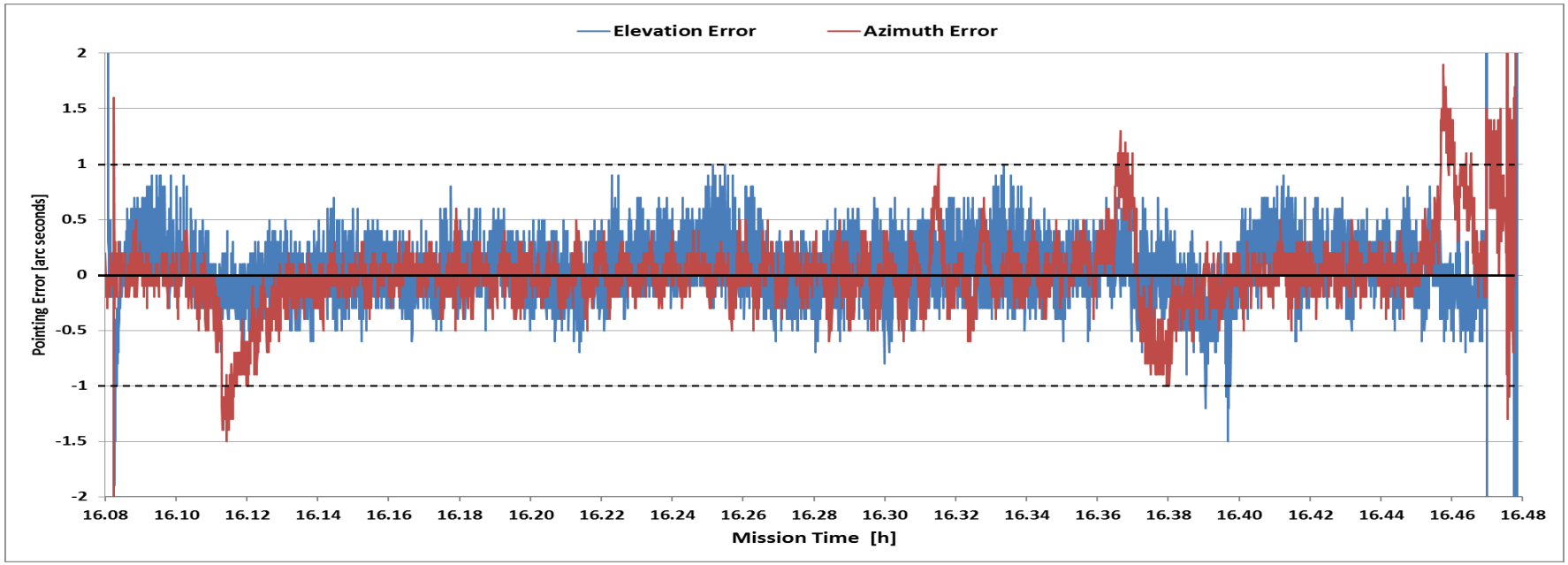
UVVis Instrument Overview

- **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





BOPPS Pointing



- 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

2014 BOPPS - Successful Flight

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: $Q[H_2O]=5.1e27$ /sec
- 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

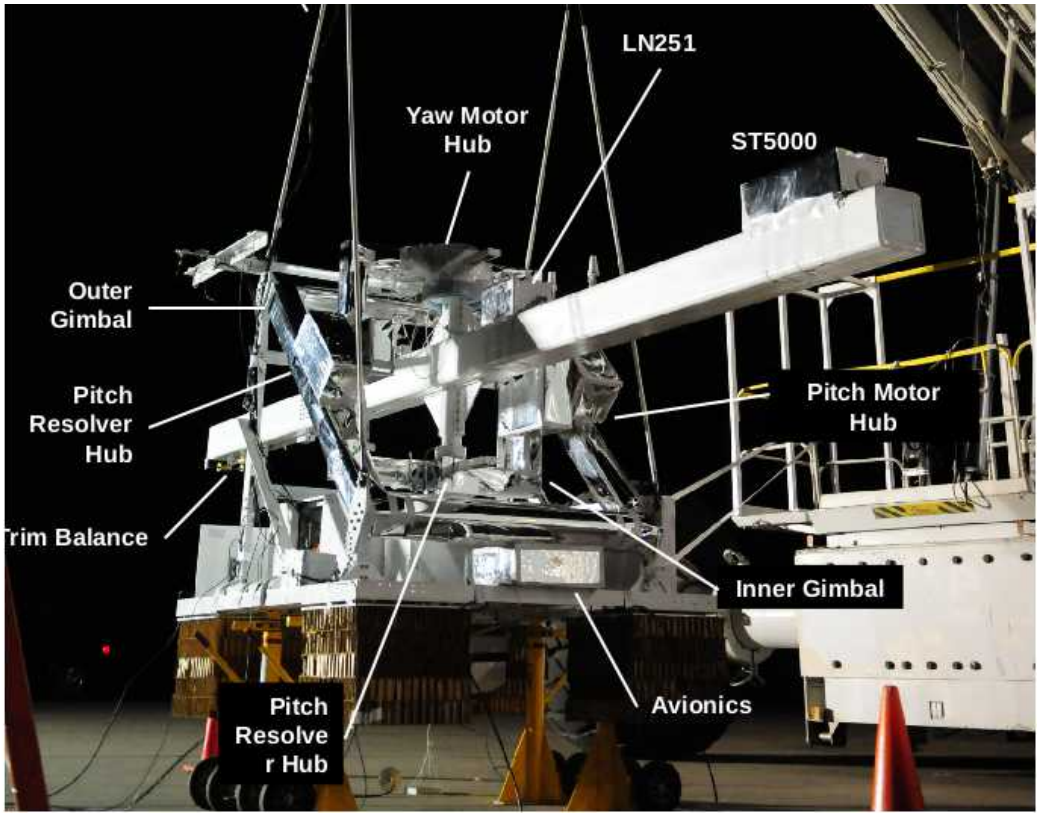
BOPPS Level 1 Requirements Were Met

Observatory for Planetary Investigations from the Stratosphere

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

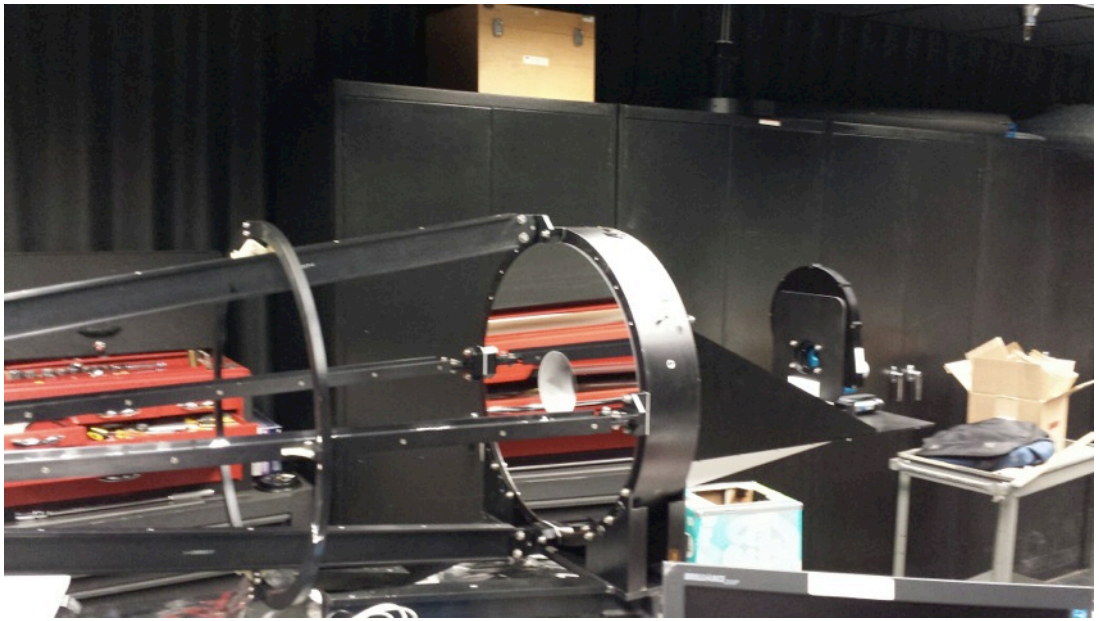
Mission Goals

- 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

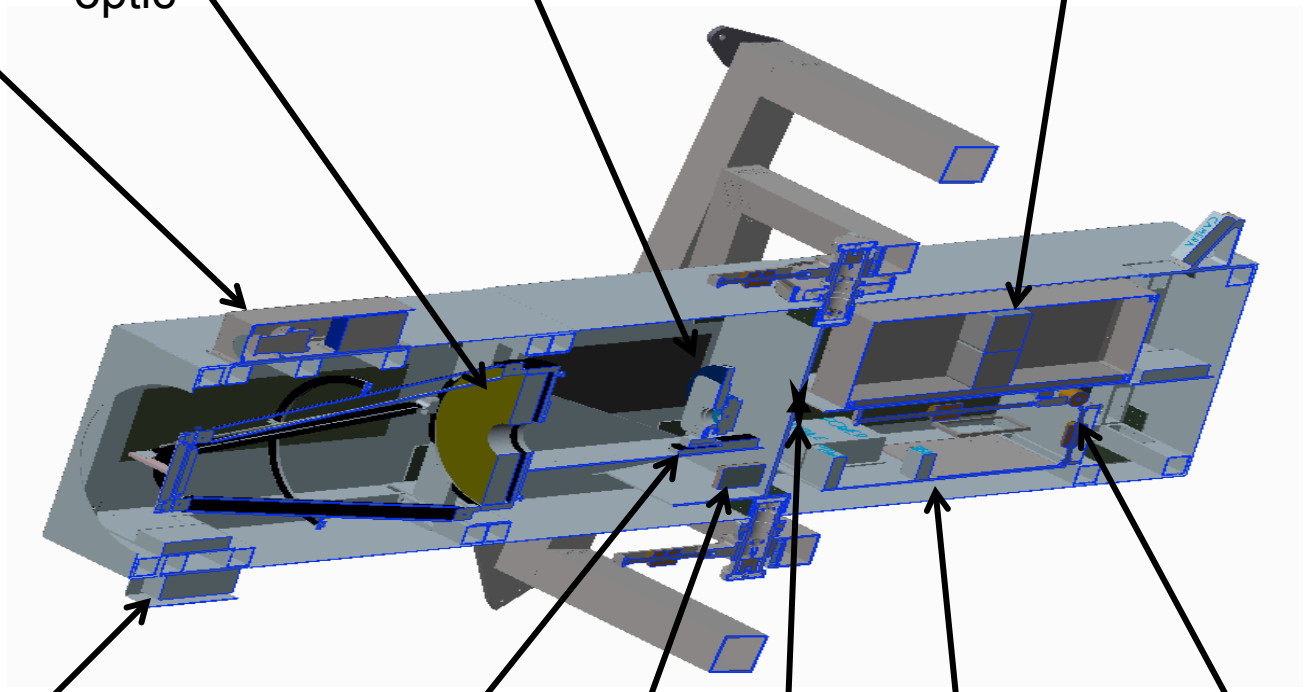


OPIS Imaging System

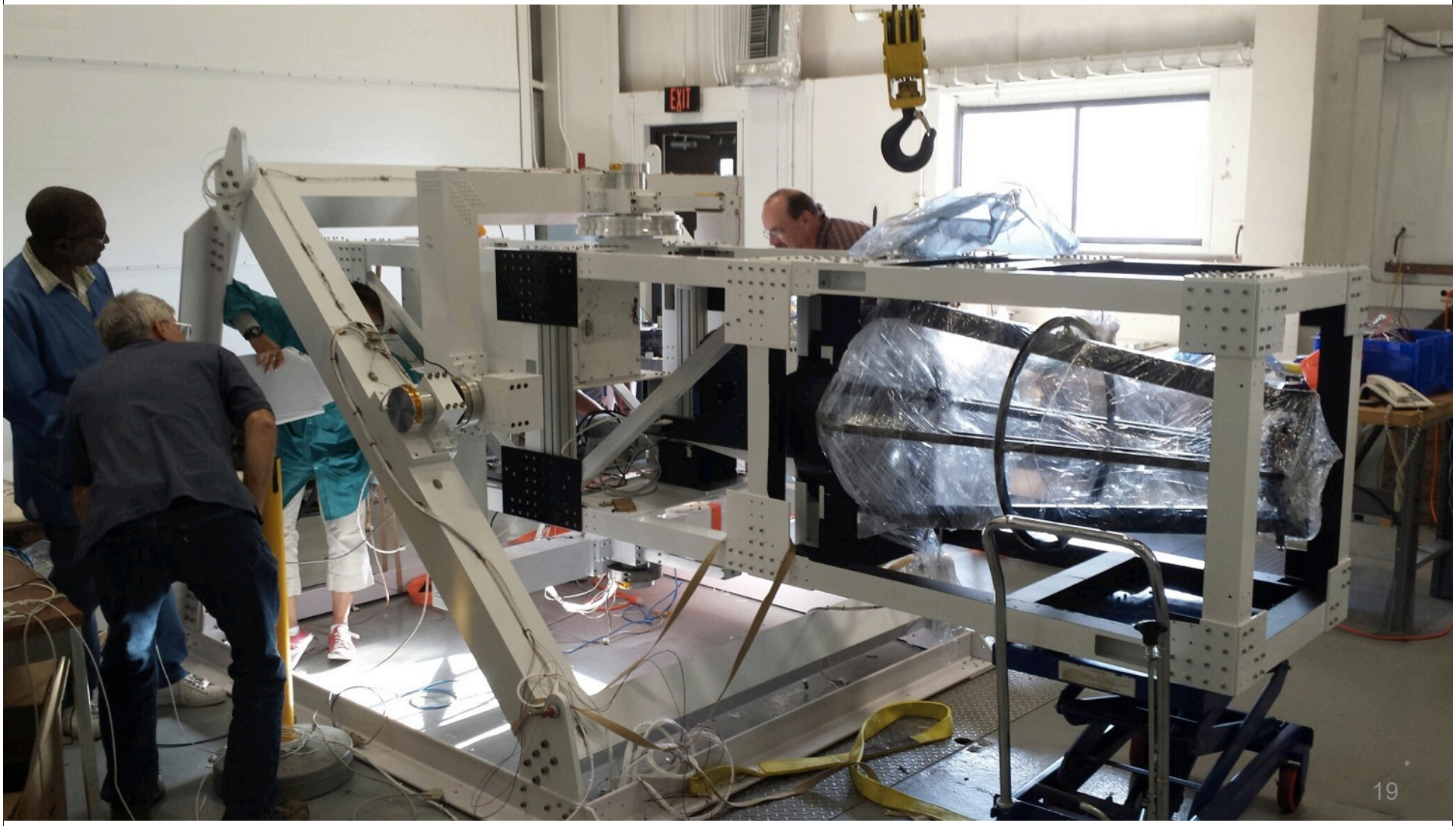
- Built around a refurbished 21” telescope
- OTS Apogee Alta CCD camera
- Translation stage for focusing
- Custom avionics to control the system



Main OPIS Structure

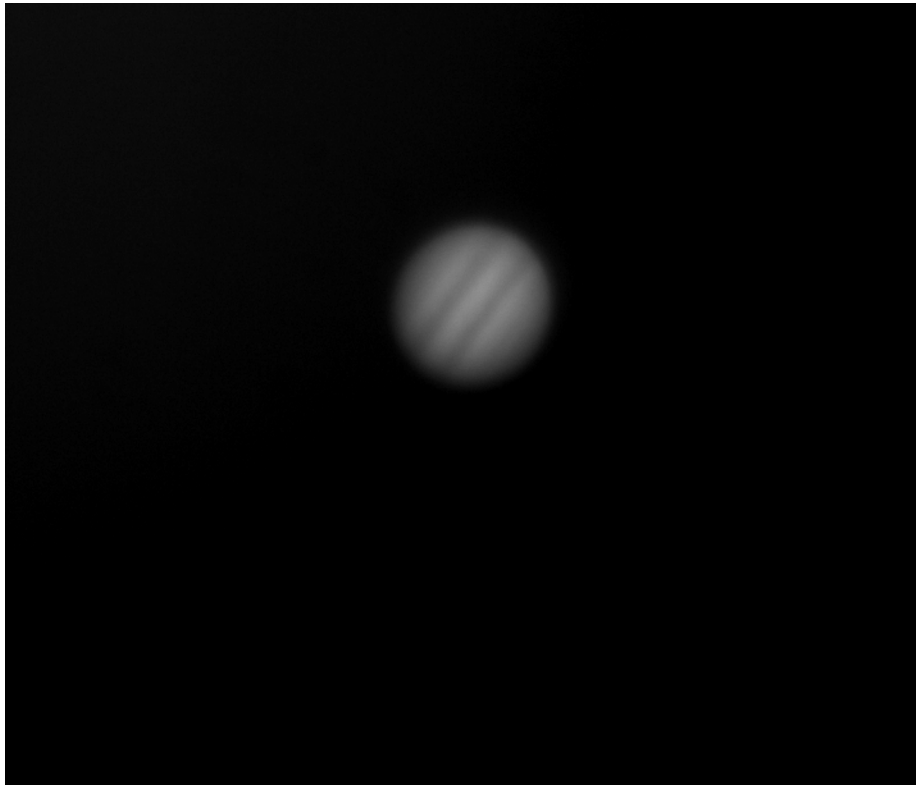


Main OPIS Structure



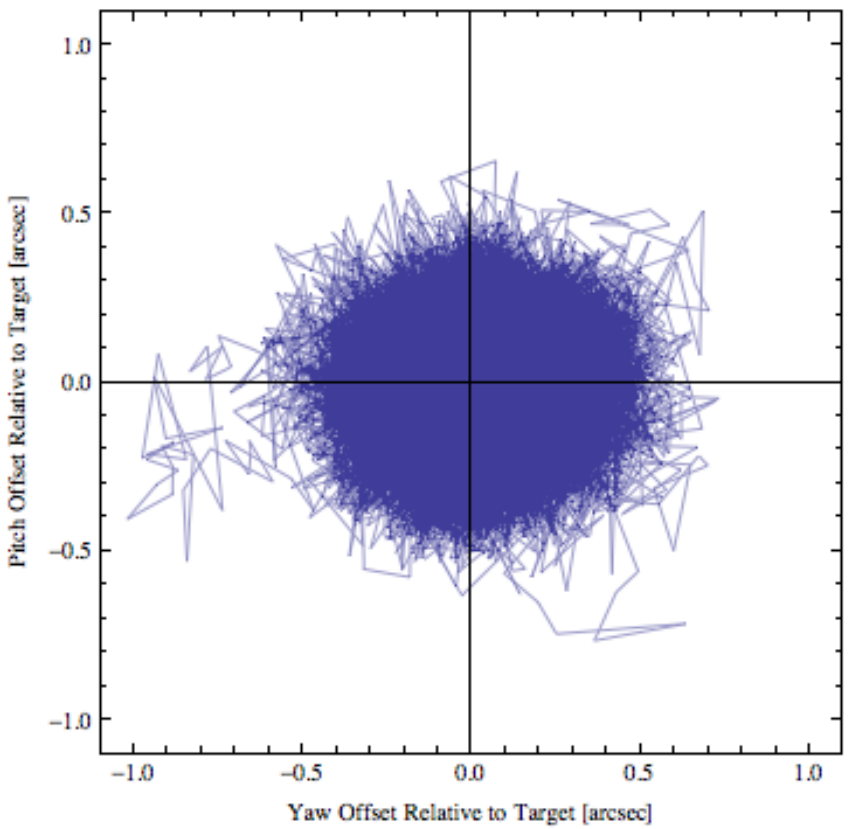
Jupiter Observed

- 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



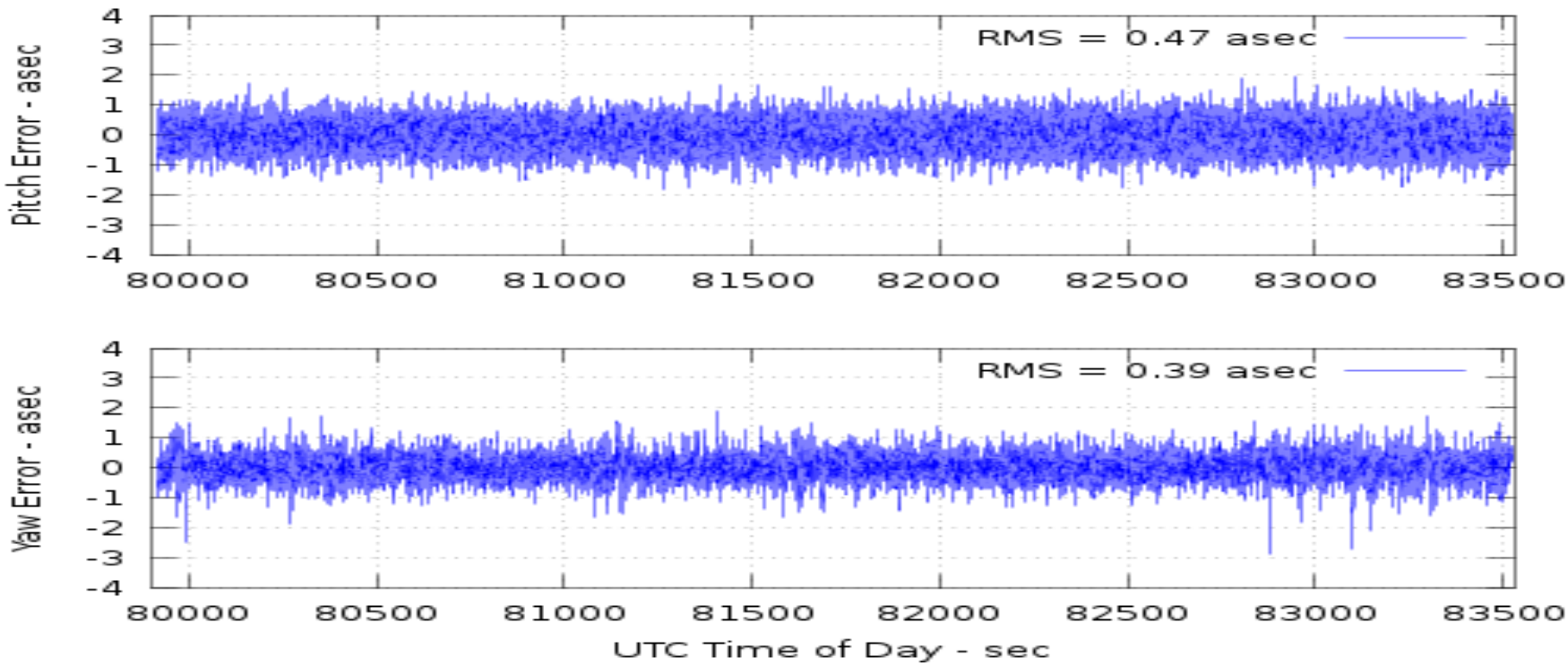
WASP Short Term Stability

- 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



Bright Star Observations

- **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**



OPIS Mission Summary

- **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**

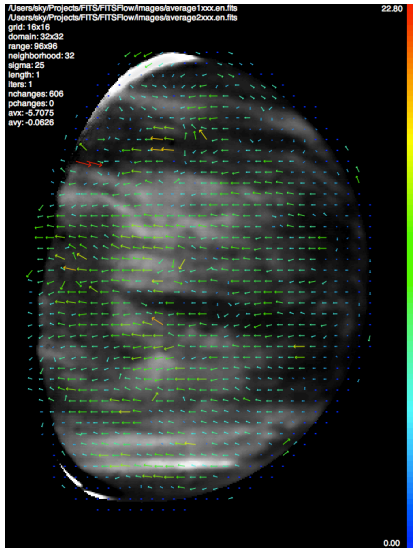
Imagine a Venus Application

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

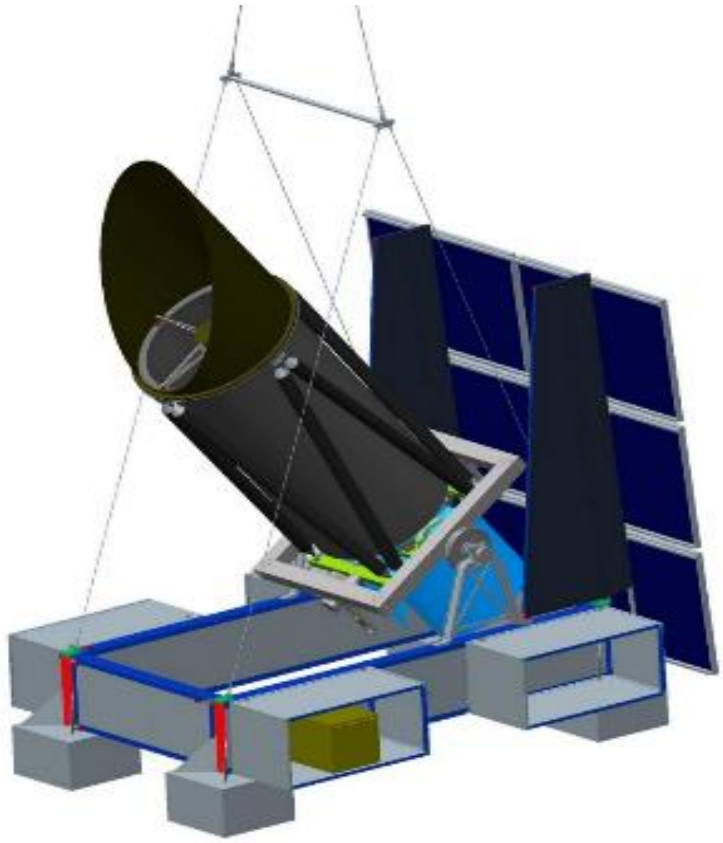
Surface Emissivity

- 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**

NEXT STEPS



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