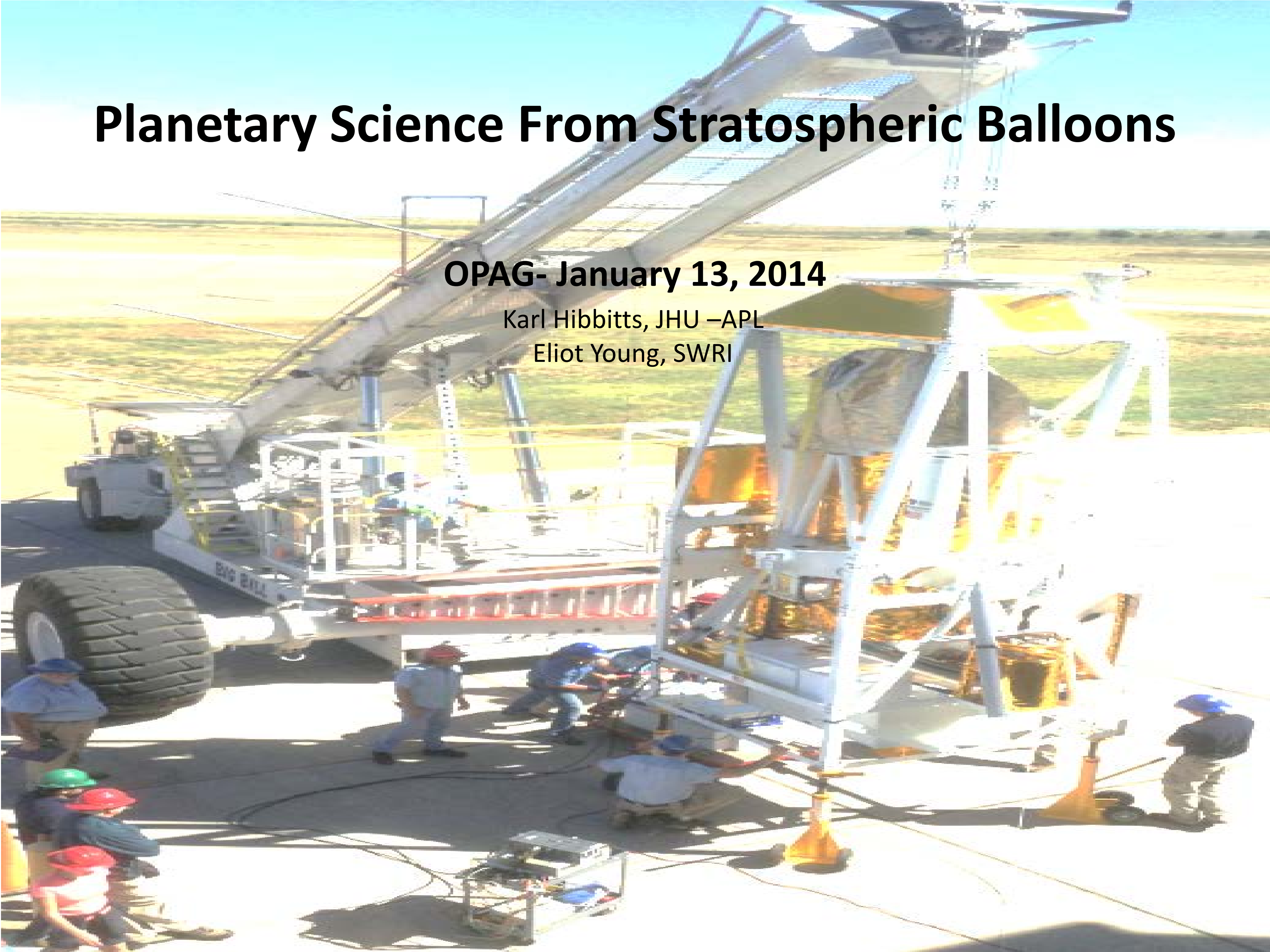
Planetary Science From Stratospheric Balloons



OPAG- January 13, 2014

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Addressing Decadal Survey Science

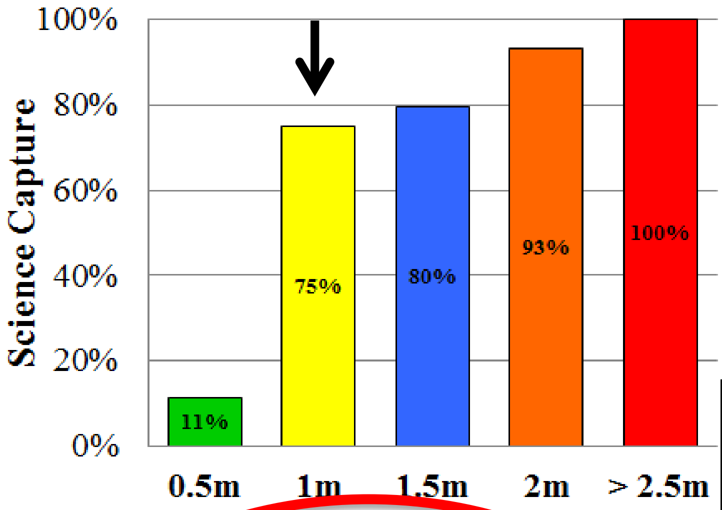
- being summarized in a report to the PSD -

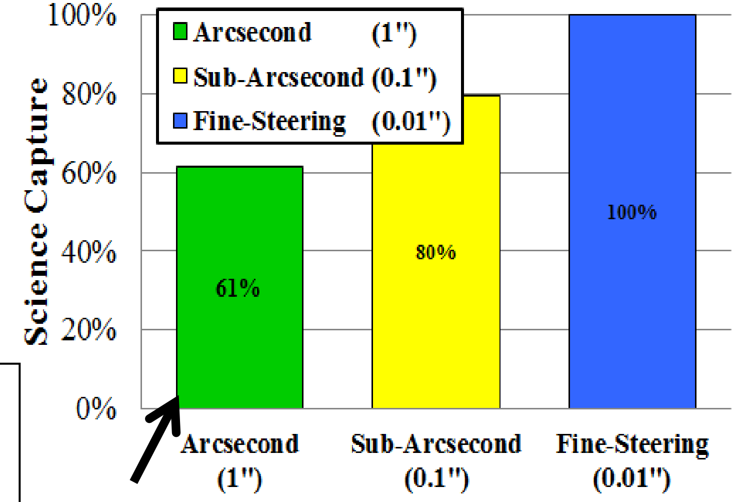
Category	Total # of DS "Important Questions"	# Answered or significantly addressed	% Addressed
Primitive Bodies	33	10	30%
Inner Planets	34	10	29%
Giant Planets	39	7	18%
Satellites	75	13	17%
Mars	18	4	22%
Total	**199**	**44**	**22%**

- The number of questions does not account for importance or priority. Answering a single question may justify an entire mission.
- Each question does not require a separate mission. In all likelihood, a single mission will address multiple questions.

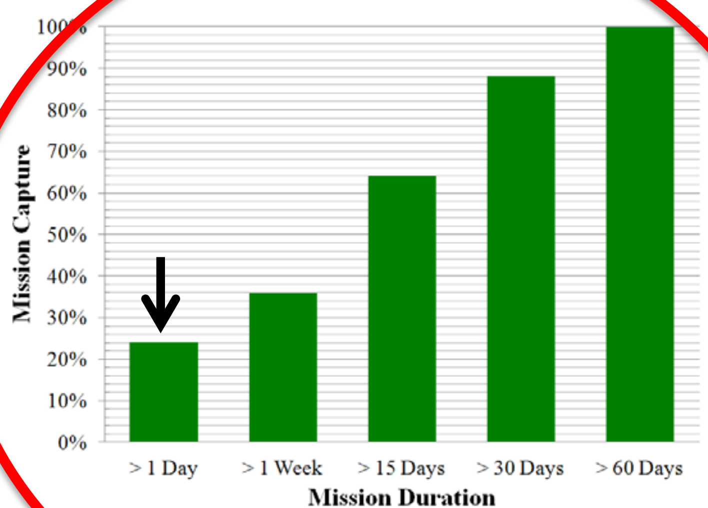
A balloon platform offers a multi-target / crosscutting capability to address a wide range of decadal science objectives

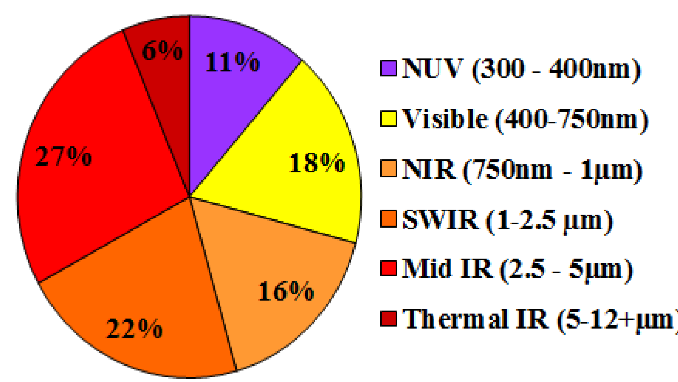
Science Achievable vs Platform Capability





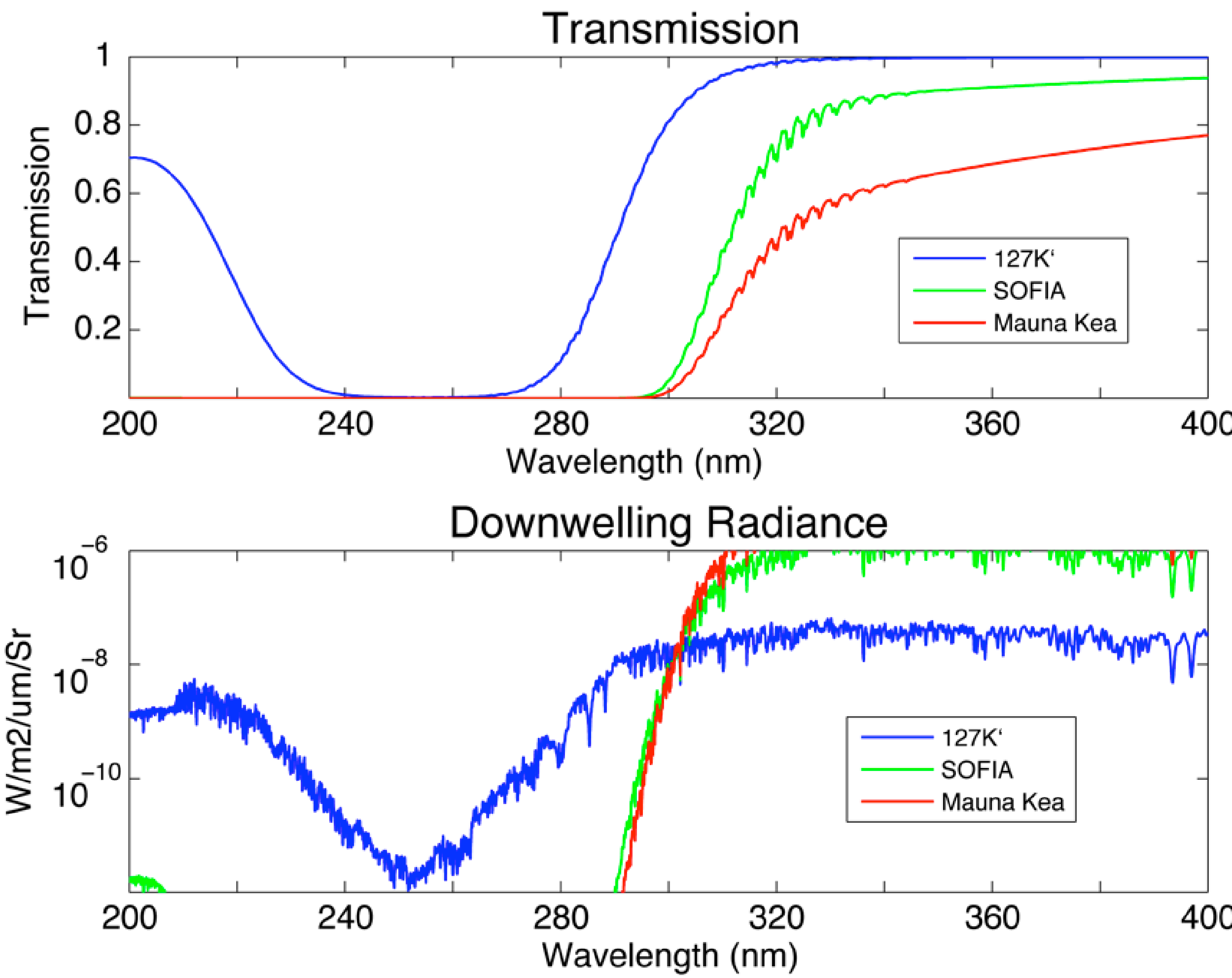
A system with the indicated features could addresses 15% of Decadal Survey "Important Questions"





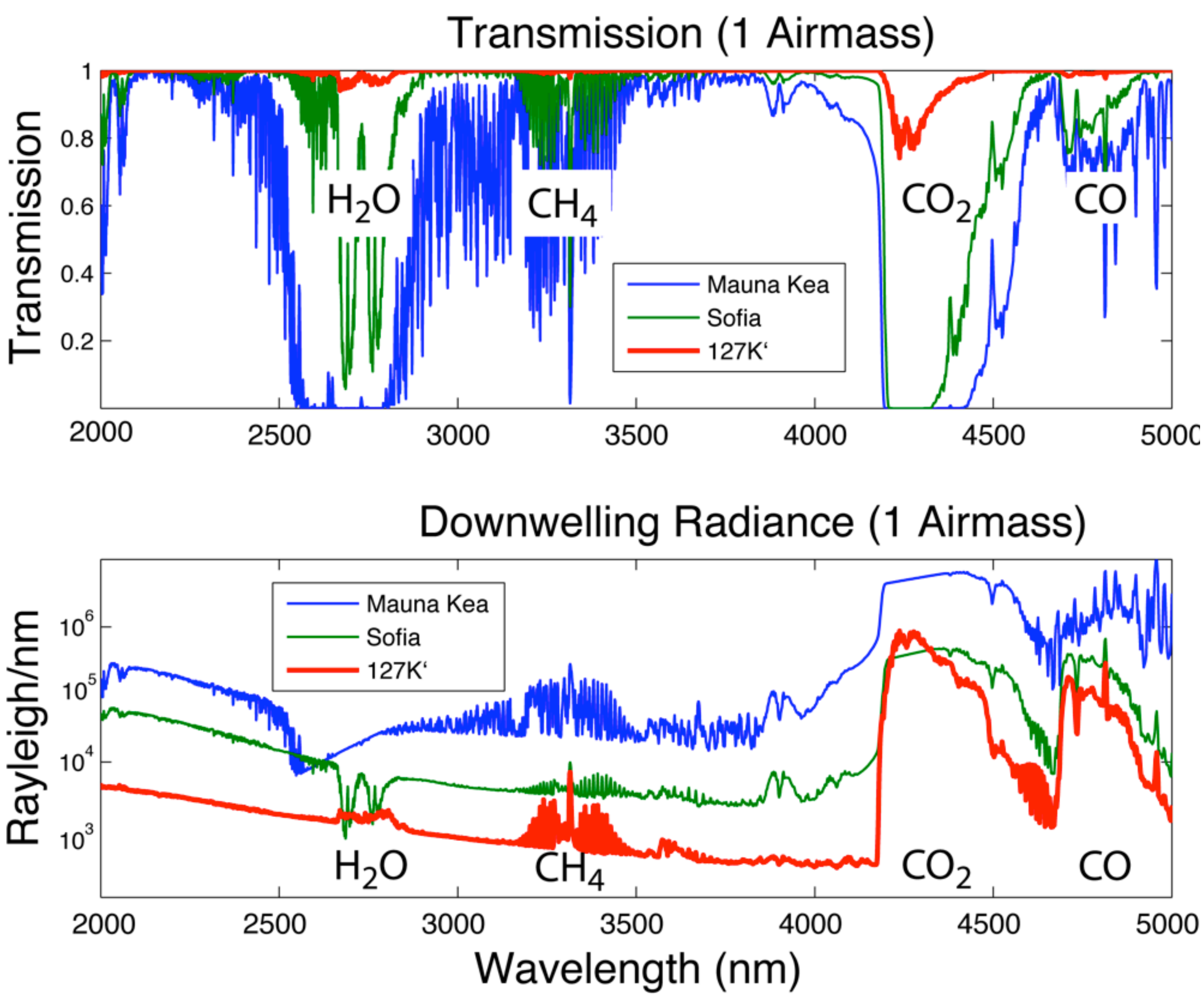
Significant science is achievable with modest system

The Stratospheric Advantage
I. Near Ultraviolet - Visible



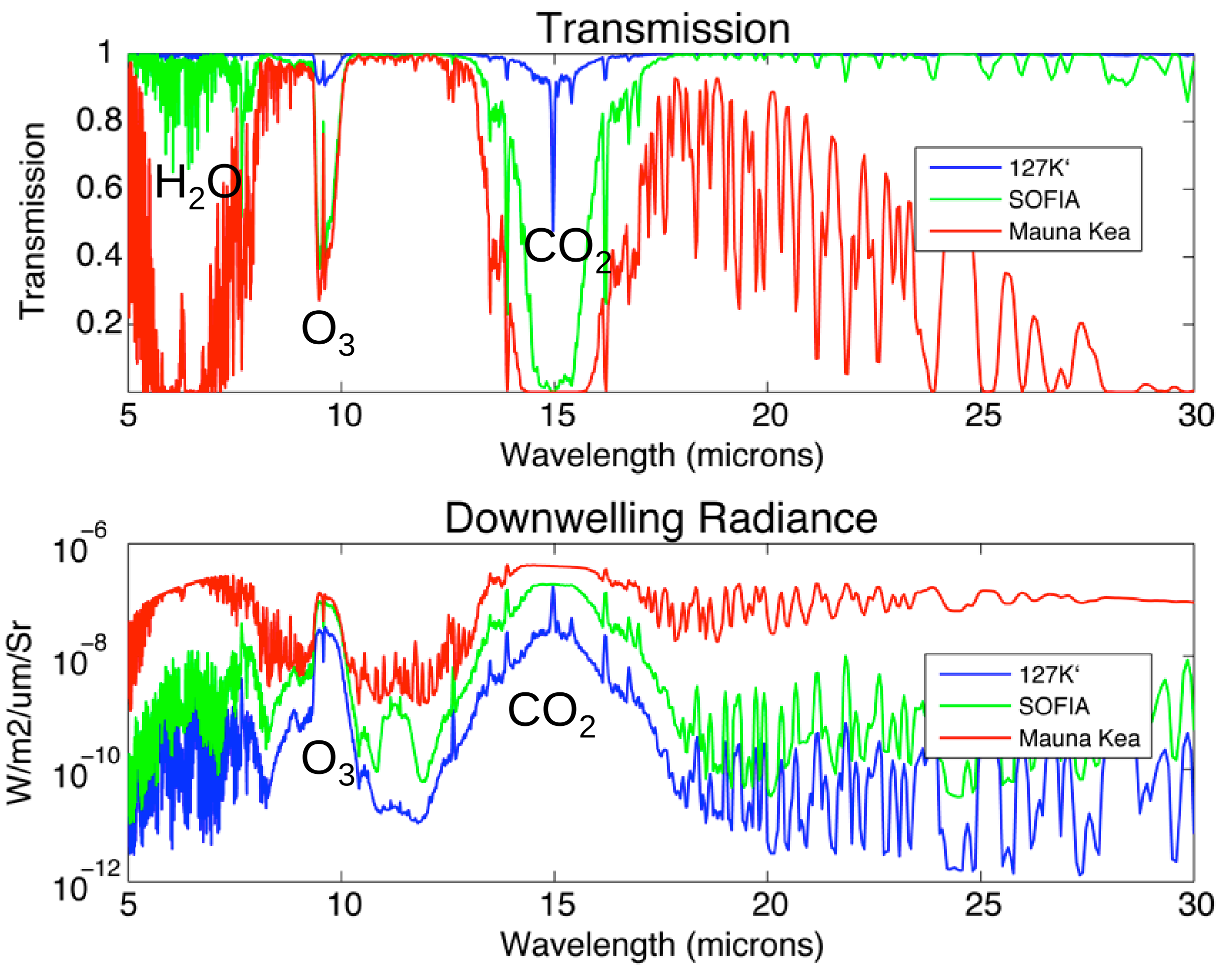
- Space like seeing.
- The near UV from ~ 195nm to 225nm and from ~ 285 nm and longward.
- Reduced Rayleigh scattering may enable daytime observations.

The Stratospheric Advantage
II. Shortwave - Mid IR



- Excellent transmission.
- Considerably lower downwelling radiance → long integration times.
- Typical aperture (1-2m) well-suited for diffraction level imaging.

The Stratospheric Advantage
III. Thermal IR



- Transmission ~ 100%
- Downwelling << than for airborne/ground → long integration times.
- Low TSE with optics temperatures ~ -50C.

Disadvantage: Limited light gathering and spatial resolution of 1-2 m aperture.

Current Status

- PSD has been assessing stratospheric balloon platforms and is moving toward a goal of:

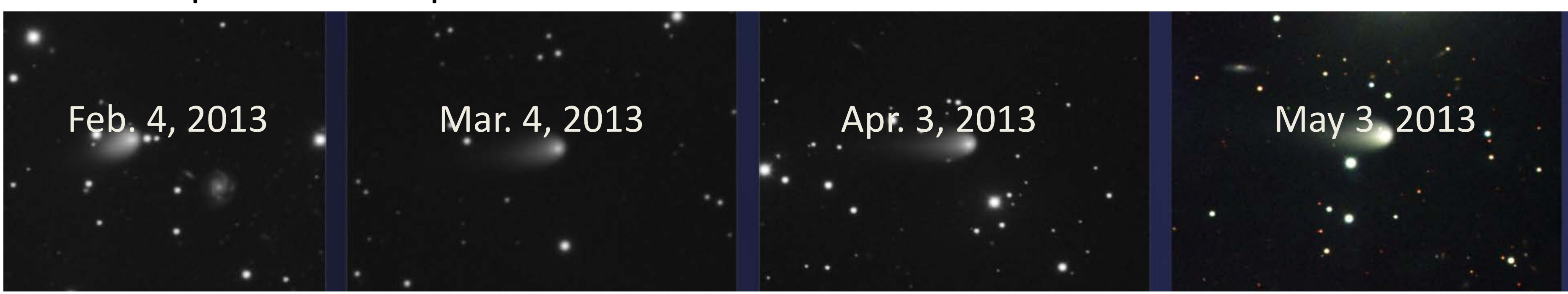
Developing a reusable platform to achieve high-value planetary science which takes advantage of the extremely high altitude, advanced pointing capabilities, and the low cost of balloon-borne missions. BRRISON is a part of that effort.

  - Relatively low cost
  - Enables observations not otherwise possible
  - Engages planetary science community, especially valuable at early career stages

Balloon Rapid Response for ISON (BRRISON) Mission Overview

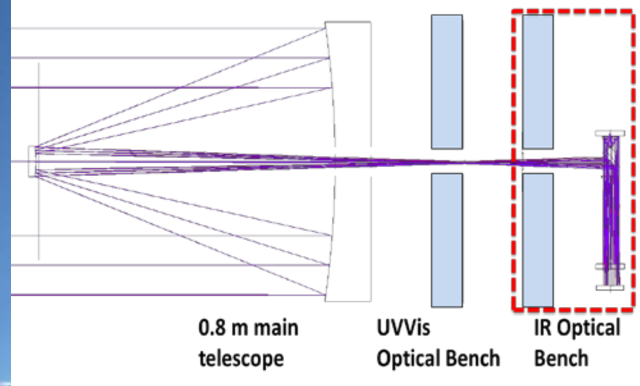
BRRISON Objectives

- Develop and demonstrate gondola and payload systems for a balloon-borne platform designed to achieve planetary science.
- Demonstrate NUV/Vis imaging and operation of Fine Steering Mirror (FSM) for obtaining sub-arcsec pointing stability.
- Provide high-value science
  - Primary: Measure CO_2 and H_2O and determine their ratio for ISON
  - Secondary: Repeat for Encke; Characterize the water in asteroids, Jupiter’s atmosphere.

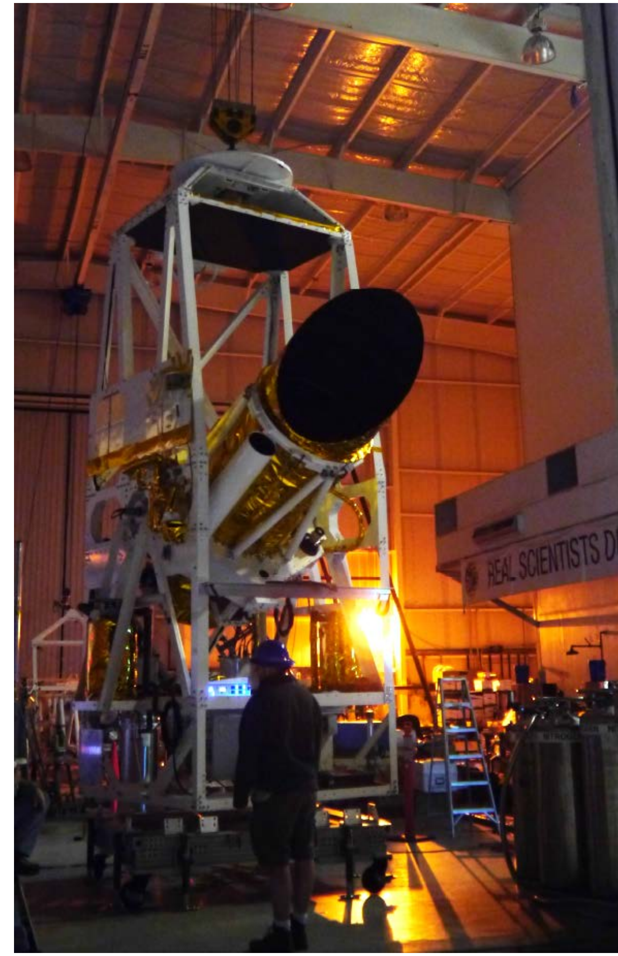


ISON imaged by Gemini Multi-Object Spectrograph, Gemini North

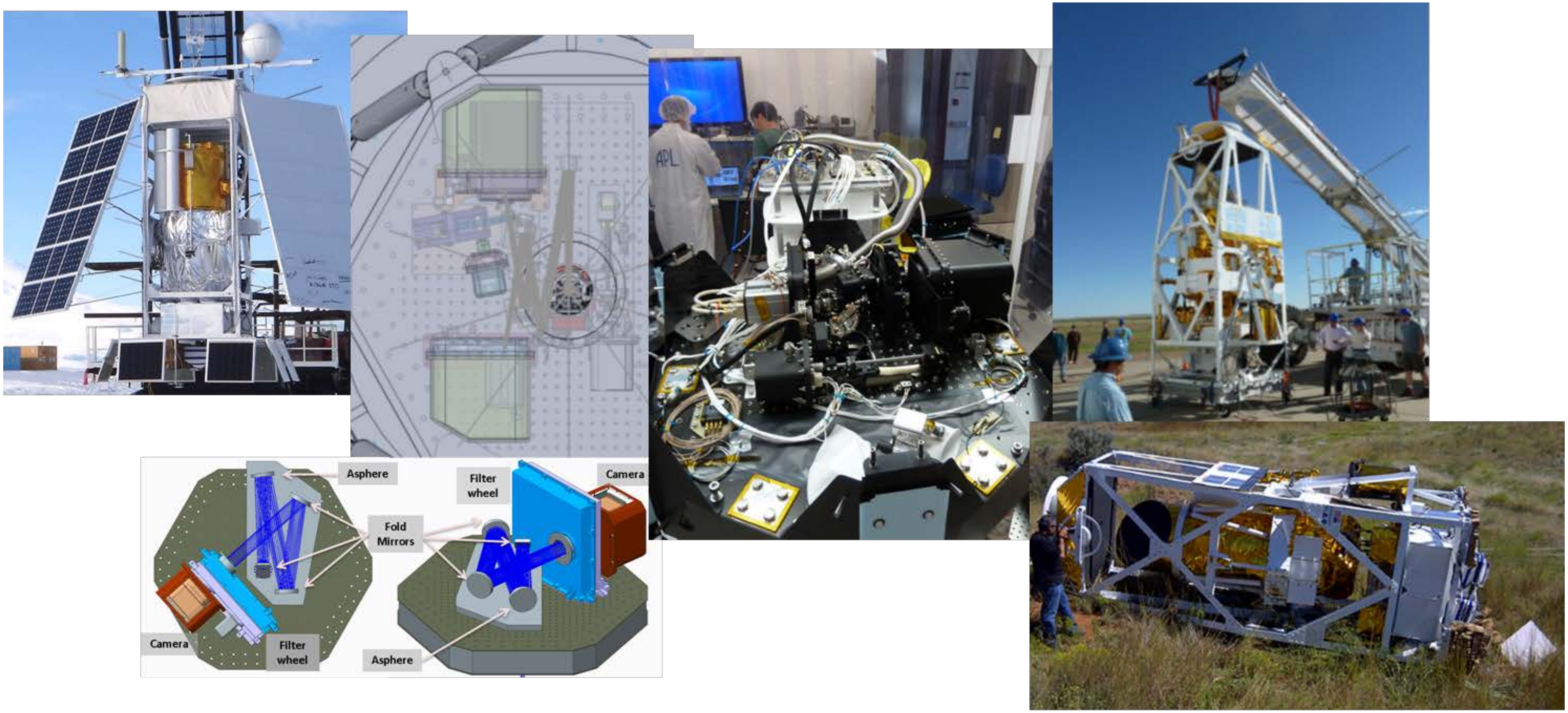
BRRISON Gondola



- Azimuth and Attitude stabilized gondola with 80-cm telescope
- Two instruments on separate optical benches
  - APL developed IR camera (BIRC) for imaging 2.5 μ to 5μ
  - SWRI developed UV-Vis camera (UVVis) with fast steering mirror and fine guidance system
  - Light is sent to either UVVis or BIRC (not both)
- Payload in stowed position is enclosed within gondola frame



Rapid Response Development



STO flight Jan 2012 → BRRISON Review Mar 2013 → June-July 2013 → Sept-Oct 2013

BRRISON Flight

- Arrived at Ft. Sumner, NM on 9/9
- Performed telescope alignment & reassembly of the gondola. Finalized testing
- Hang tests on 9/26
  - All systems performed well
- Flight Readiness Review on 9/27
  - Launched 9/28, a rare afternoon launch due to weather
- Experienced a telescope position anomaly early in flight which prevented ISON and other science observations

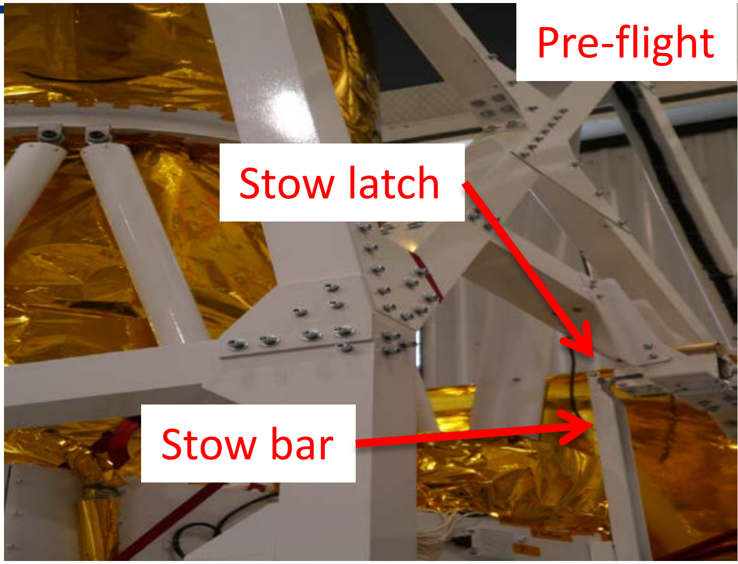
APL GRC

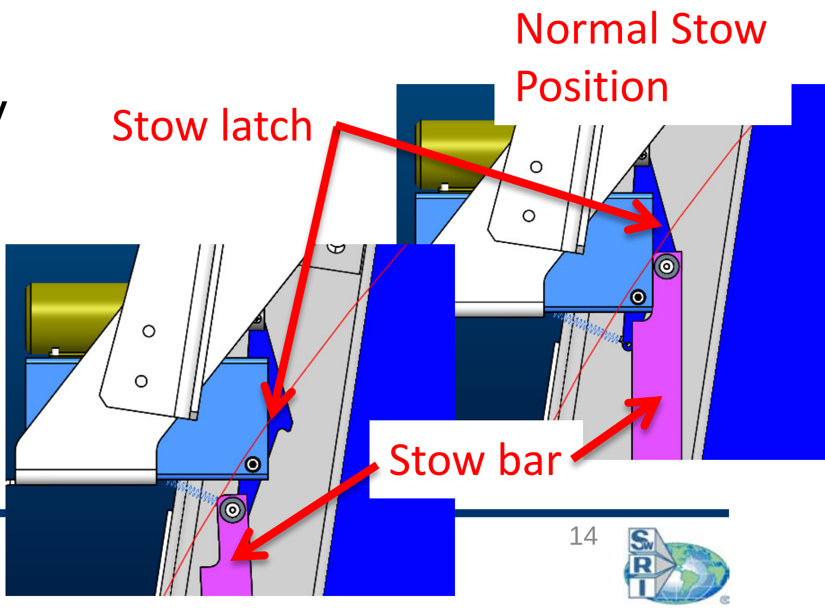
BRRISON Accomplishments

- Demonstrated required gondola performance during hang tests.
- Demonstrated required FSM performance during hang test.
- During float, operated VNIR and MIR cameras as designed for extended period providing calibration information.
- During float, demonstrated ability to point with telescope and acquired sidereal target.
- During float, demonstrated successful operation of gondola components other than telescope.

Anomaly and Proximate Causes

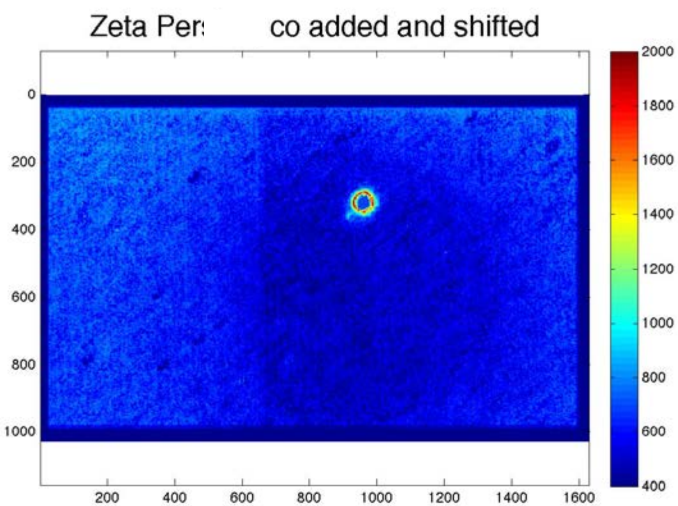
- The Optical Telescope Assembly (OTA) became trapped in its stowed position
- Anomaly was due to combination of three causes
  - Communication between gyros and heritage computers was interrupted (connection integrity).
  - The loss of data resulted in software incorrectly driving the telescope assembly into its stowed position at full torque
  - The latch mechanism, while a heritage design, had insufficient structural strength to handle this anomaly condition, deflecting and trapping the stow bar



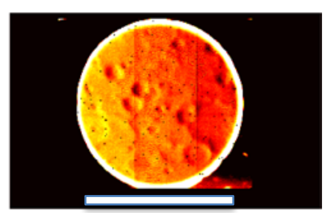


IR Camera (BIRC)

- “Hang” tests at launch site demonstrated arc second pointing platform
  - The IR camera imaged the bright star ζ Pers and its companion BD+31 666C. Companion is 8.5 mag fainter and ~15 arc sec away.
- IR camera imaged Polaris (α UMi) in flight

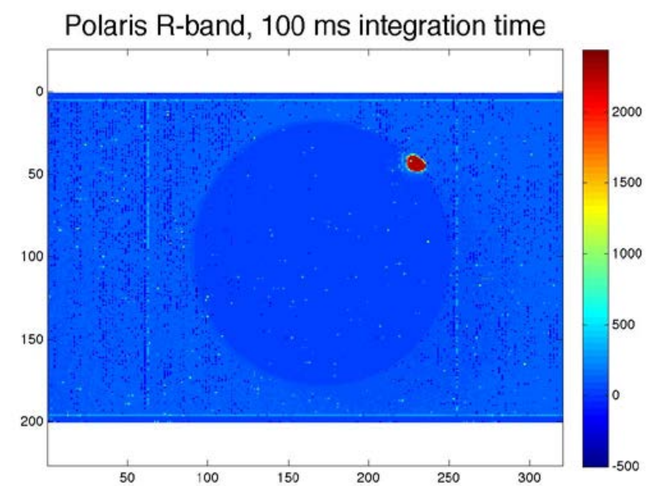


Moon 2.47 & 4.0 μ



340 km (BIRC FOV = 3’)

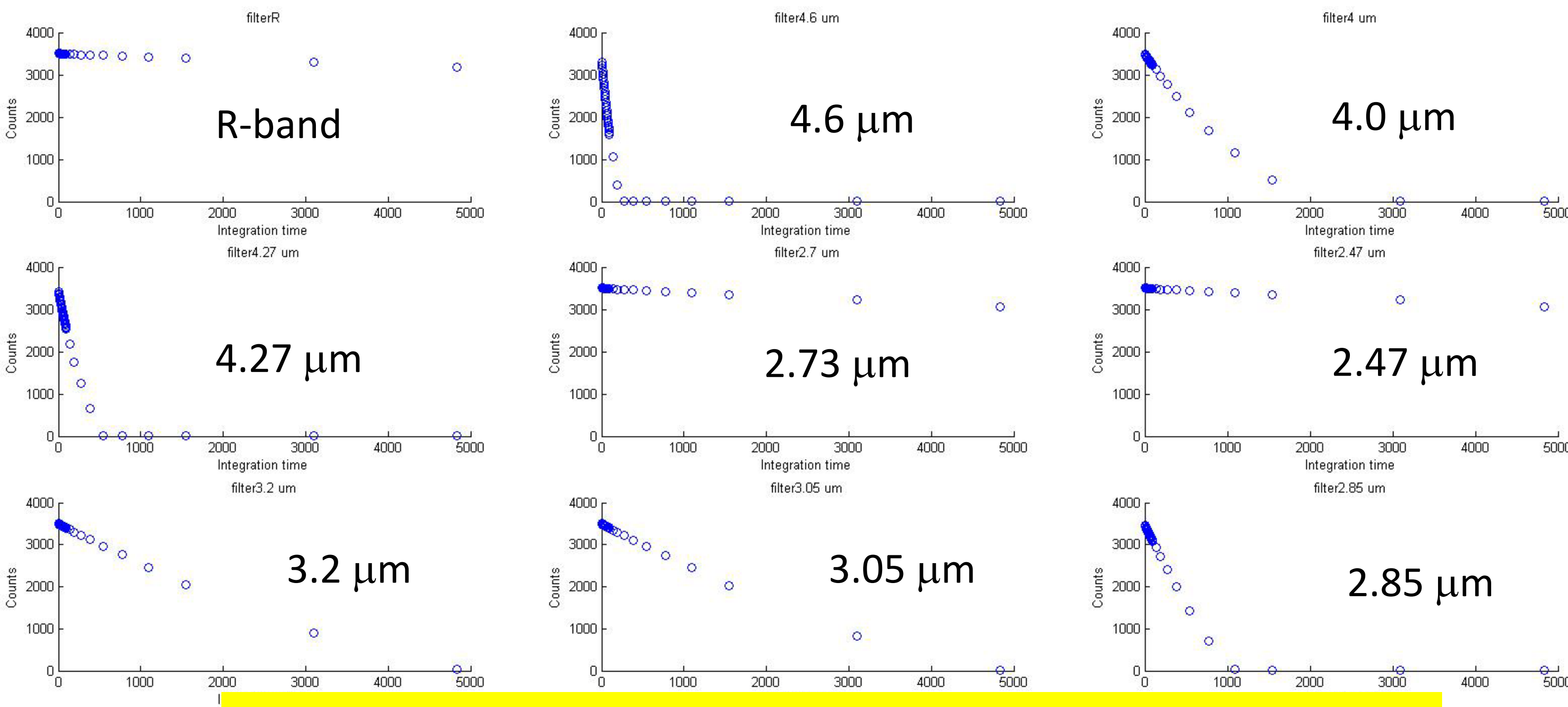
Stars and Moon imaged during hang tests



Star imaged in flight by IR camera (star is saturated)

IR Camera (BIRC)

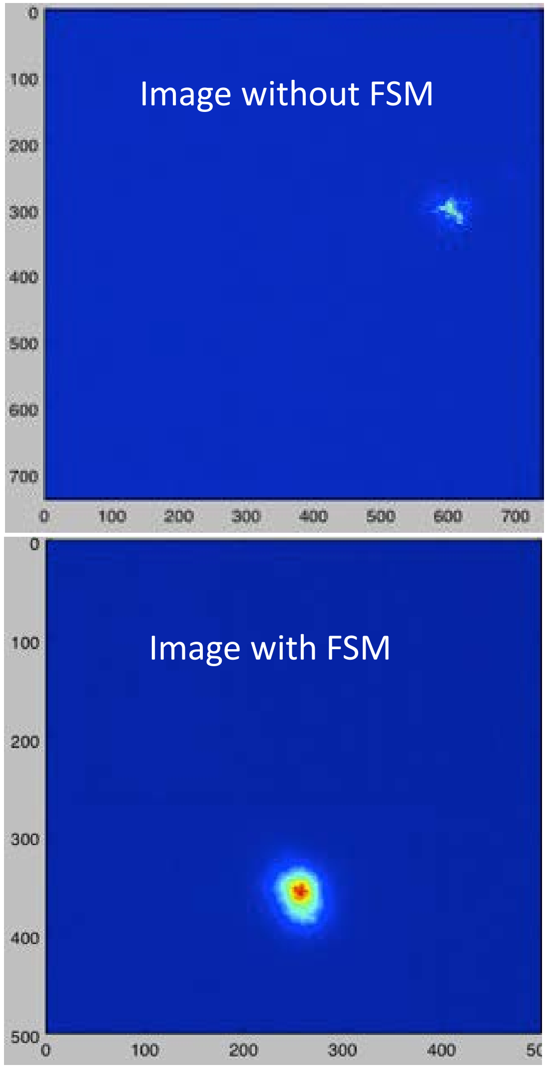
- Ground calibration tests → time to saturation ranges from 100s millisecond (CO_2 band) to many seconds, especially long at 2.45 to 3.2 microns.



with Target Plate: -73C. X – axis scale: 0 to 5 seconds.

BRRISON UV/VIS Camera

- The UVVis Guide Camera and Fine Steering Mirror corrected two types of errors:
  - Image blur due to atmospheric turbulence. From focus sweeps, we find a minimum image FWHM of 3” at best focus.
  - Pointing errors due to telescope motion (RMS motion was about ±15” during the hang test).
- Results:
  - Pointing errors for the full field (60”) were determined at 50 Hz (100 Hz for a 40” FOV) and sent to the FSM. This is much faster than the goal of 20 Hz.
  - The FSM corrected all detectable telescope image motion and, further, reduced the blur due to seeing to 1.5”. This 50% reduction of the FWHM is the theoretical improvement that can be attained by a tip-tilt system!



Expected Imaging Acuity

- Super-pressure balloons float near 110,000 ft; zero-pressure balloons float near 125,000 ft (above 99.3 or 99.6% of the atmosphere, respectively).
- Best evidence for space-like image acuity at Visible and UV wavelengths: results from the Sunrise balloon missions.

Expected Imaging Acuity

- The Sunrise balloon missions carried a *Correlating Wavefront Sensor* to control a tip-tilt fine steering mirror, but the CWS also measured other distortions.

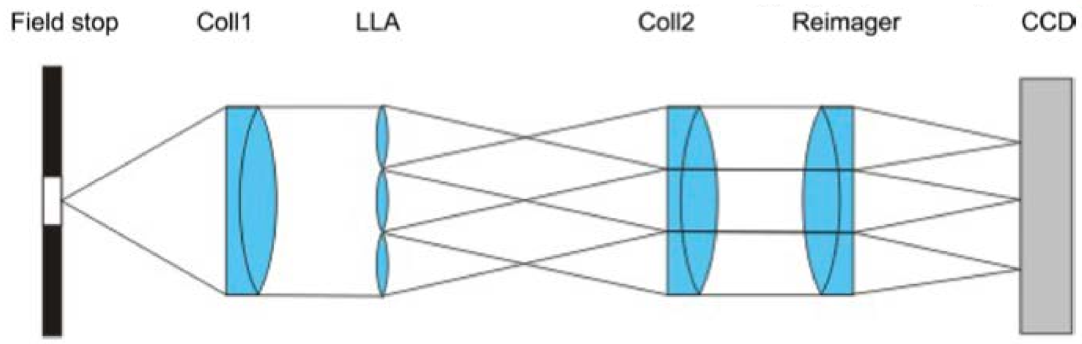
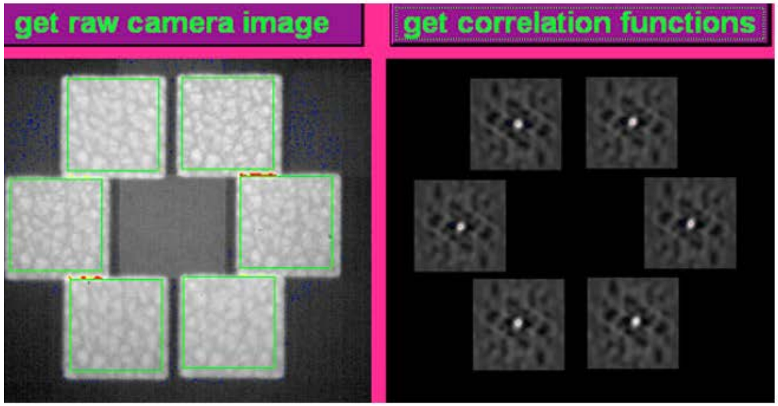


Figure 3 Scheme of the wave-front sensor of *Sunrise*. The field stop coincides with a focal plane of the telescope.



- CWS results: no atmospheric degradation was seen – the telescope might as well have been in space.
- Diffraction limited PSF width: 0.12” at 0.5 µm for a 1-m mirror.

Challenges to Balloon Imaging

- Two main obstacles to diffraction limited imaging:
  - Pointing and stabilization of the telescope & focal plane.
  - Overcoming thermal distortions.
- Several groups (WASP, Sunrise, STO) have demonstrated telescope stabilization at the few arcsecond level plus FSM correction to tens of mas.
- Day/night thermal effects:
  - MLI is not very effective in the stratosphere – you need thicker insulation.
  - Preliminary modeling indicates that 20 cm of “Styrofoam” can lower the OTA temperature by about 40 K.
  - Two potential advantages of thermal blanketing schemes: possible use of cheap COTS telescopes, and reduced thermal background for IR spectroscopy in L and M bands.

Thermal Stabilization

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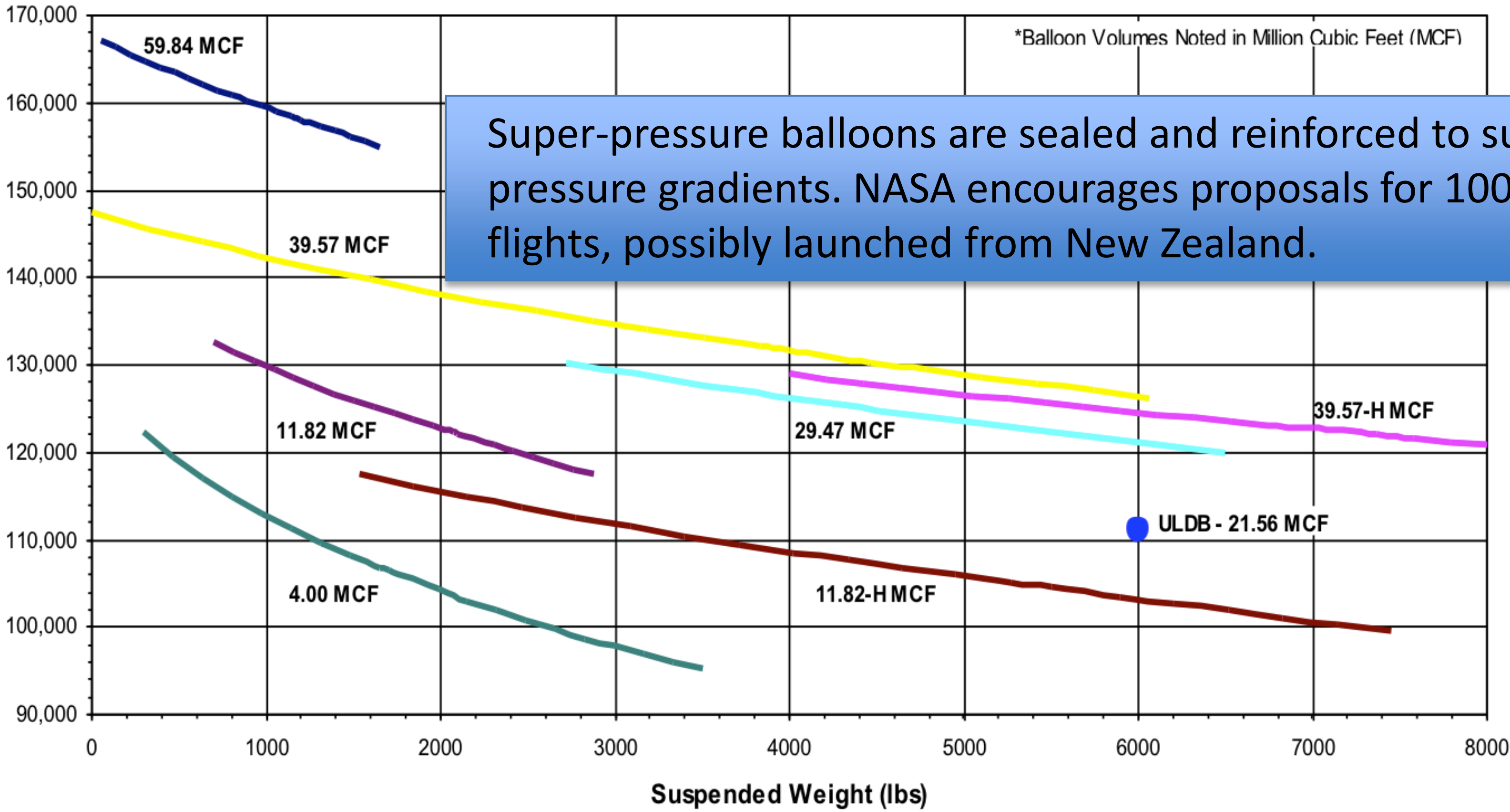
  - OTA at 235 K: a 1-m aperture beats the 3-m IRTF at 4.8 µm.

2014 Potential Science Return

- Observable from Kiruna in summer: Oort Cloud comet C/2012 K1; Ceres, Vesta, Uranus, Neptune; Moon (depending on launch date)
  - Comet C/2012 K1 (PanSTARRS) is observable continuously 24/7; allows first-ever measurement of rotational light curves in water and CO_2 emissions from an Oort Cloud comet
- Observable from Fort Sumner in fall: Oort Cloud comets C/2013 A1 & C/2012 K1; Ceres, Vesta, Uranus, Neptune; Moon (depending on launch date)
  - Comet C/2013 A1 (Siding Spring) is observable within a few weeks of the Mars close encounter which will be observed by Mars spacecraft; and Comet C/2012 K1 (PanSTARRS) is observable, but neither can be observed continuously
- Both Kiruna and Fort Sumner flights offer excellent science
  - Kiruna flight offers discovery potential from a first-ever observation
  - Fort Sumner flight offers two comets and night time (dark sky) observations for UVVis extended exposures
  - Both Oort Cloud comets are much brighter than ISON for both flight opportunities
  - Both flights can observe Ceres and Vesta in support of the Dawn mission shortly before the Ceres encounter

Super-pressure Balloons

- Zero-pressure balloons are vented. They loose helium (and must drop ballast) every day/night cycle.



Super-pressure balloons are sealed and reinforced to sustain pressure gradients. NASA encourages proposals for 100-day flights, possibly launched from New Zealand.

Conclusions

- Decadal class planetary science can be achieved from stratospheric balloons
  - Unique contributions, low cost, opportunity for frequent and long duration flights.

- Rapid cadence & low costs present potential for young career scientists to participate on missions and demonstration of new measurement approaches.

- A reflight in 2014 would be a second opportunity to demonstrate unique and compelling science can be realized for a very low cost by leveraging the gondola and instrument systems developed for Comet ISON.

- Comments to 2014 science options?   Or Questions?