Balloon Based Planetary Science Capability

Science Traceability to System Requirements

Planetary Science Balloon Study Interim Report:

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Agenda

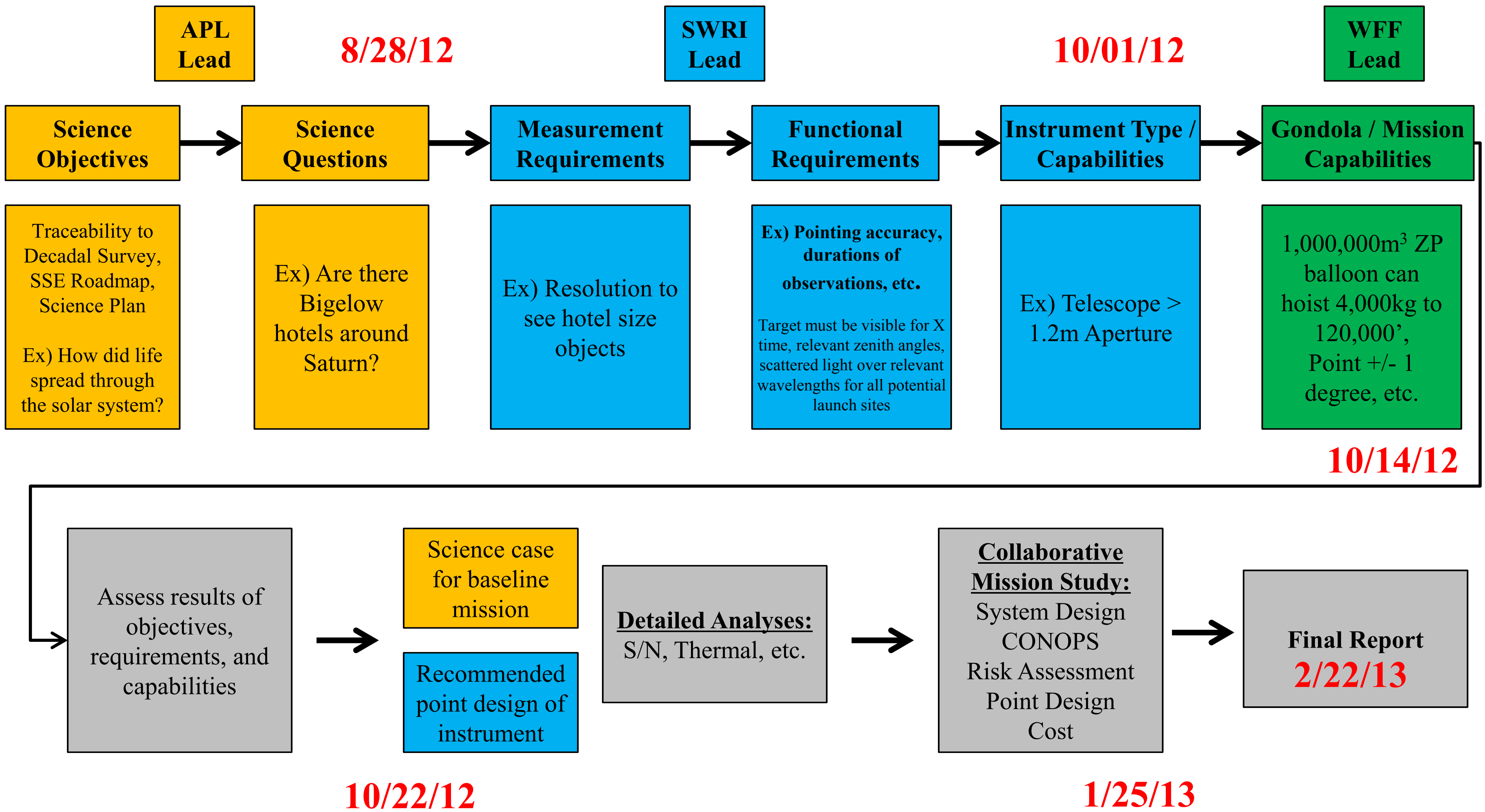
Team Introductions	All
Study Objective	Tibor Kremic
Study Plan and Products	John Dankanich
Science Traceability to Decadal	Karl Hibbitts
Instrument / System Requirements	John Dankanich
Existing System Capabilities	Rob Landis
Recommended Baseline Instrument	Eliot Young
Recommended Demonstration	Tibor Kremic
Architecture Science Capability	Karl Hibbitts
Paths for Growth	Tibor Kremic
Near-Term Plan	John Dankanich
Summary	Tibor Kremic

Study Objectives

1) Confirm the science potential of a balloon based telescope – deeper exploration of earlier concept ideas, traceability to Decadal Survey
   - Understand and document "Why a balloon platform?"
2) Develop requirements for balloon based telescope to meets NASA's planetary science goals and objectives (aperture, durations, altitudes, locations)
3) Develop requirements for general instrument systems (optical characteristics, pointing, etc.)
   - Assess gondola systems/subsystems to meet the requirements.
   - Assess near-term and mid-term instruments and subsystems.
4) Develop schedule and cost estimates to field near-term and mid-term technologies.
5) Identify the feasibility of a near-term mission with sufficient science justification:
   - Science traceability
   - Risk assessment and mitigation plan
   - Detailed analysis and point design of a baseline instrument
   - Detailed point design of gondola
   - System level integration assessment
   - Concept of operations
   - Cost assessment and development schedule

Develop an early success concept that validates platform as planetary science contributor.

Study Plan and Products



Balloon-Based Planetary Science Workshop held Jan. 25-26, 2012.

C-2012-256

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field

- Over 70 attendees

- Break–out sessions
  - Venus: Sanjay Limaye
  - Small Bodies: Mark Sykes
  - Giant Planets & Icy Satellites: Kevin Baines
  - Other: Steve Mackwell
  - Discipline – Composition, Dynamics, etc.

- 40 + vetted mission concepts from sun-grazing comets to KBOs.

- Followed with systematic approach matching desires to the Decadal Survey
  - Vetting TRL of balloon capabilities
  - Initial determination of high level system requirements
  - Resulted in 6 architectures and 41 missions traced to explicit decadal science

Continued workshop momentum and filled in gaps.

Priorities of the Decadal Survey

Supported potential of balloon based science.

Mission oriented

Stratospheric Balloons can offer '**mission science**'.

TABLE 3.1 The Key Questions and Planetary Destinations to Address Them

Crosscutting Themes	Priority Questions	Key Bodies to Study
Building New Worlds	1. What were the initial stages, conditions and processes of solar system formation and the nature of the interstellar matter that was incorporated?	Comets, Asteroids, Trojans, Kuiper belt objects (See Chapter 4)
	2. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?	Enceladus, Europa, Io, Ganymede, Jupiter, Saturn, Uranus, Neptune, Kuiper belt objects, Titan, Rings (See Chapters 4, 7 & 8)
	3. What governed the accretion , supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?	Mars, Moon, Trojans, Venus, Asteroids, Comets (See Chapters 4, 5 & 6)
Planetary Habitats	4. What were the primordial sources of organic matter, and where does organic synthesis continue today?	Comets, Asteroids, Trojans, Kuiper belt objects, uraniaun satellites, Enceladus, Europa, Mars, Titan (See Chapters 4, 5, 6 & 8)
	5. Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?	Mars and Venus (See Chapters 5 & 6)
	6. Beyond Earth, are there modern habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?	Enceladus, Europa, Mars, Titan (See Chapters 6 & 8)
Workings of Solar Systems	7. How do the giant planets serve as laboratories to understand Earth, the solar system and extrasolar planetary systems?	Jupiter, Neptune, Saturn, Uranus (See Chapter 7)
	8. What solar system bodies endanger and what mechanisms shield Earth's biosphere?	Near-Earth objects, the Moon, Comets, Jupiter (See Chapters 4, 5 & 7)
	9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres lead to a better understanding of climate change on Earth?	Mars, Jupiter, Neptune, Saturn, Titan, Uranus, Venus (See Chapters 5, 6 & 8)
	10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	All solar system destinations. (See Chapters 4, 5, 6, 7 & 8)

Small bodies Science Traceability condensed

Goals	Specific Objectives	Important questions	Possible Measurement	Unique/Advantageous Balloon Observable	Instrument Requirements	Mission Requirements
Decipher records of epochs and processes						
	Condensation, accretion, and formative processes in the solar nebula	Time sequence, evaporation and condensation location, isotopes, meteorite-asteroid link, comet hetereogeneity	Comet Volatiles, D/H ratios, CO, methane, water,CO2,OH band min position in asteroids, CO2 on Trojans?	CO2 in coma and surface Enabled over ground and SOFIA. 2.6-2.8 µm region unavailable from ground, still some extinction on SOFIA	Imaging spectroscopy. 10nm spectral resolution. 4 – 4.5 um. Spatial resolution, near arcsec?? Capability in 2.5-2.8 µm region without grating break	*determine # of comets per year or predictability. Duration: 1 hr. for detection. 1mo for evolution. Daytime okay. ~1m fine. Arcsec pointing, no latitude req., 120K', mission concept #19, 17, 23
		Abundance and distribution of asteroids, Oort cloud comets, KBOs,	Survey	A. Survey with very large VNIR detector. 24th or 25th mag(weak case). Good seeing. B. Detect Oort cloud objects. And use 2 wavelengths. Stable photometry.	A. N/A B. 40Hz calibrated imaging. 6degx6deg FOV. IFOV: (TBD just looking at lightcurve)	Accuracy: +-2deg. Stabiliy: 1/100 pixel over 40Hz. -→ 2 arcsec/sec. Nighttime. Several nights. 1m aperture. #11
		Composition of Oort cloud comet vs. KBO	Organics, ices, volatiles (also see asteroids above)	Fundamental IR absorption bands of volatiles, ices, organics,incl amino acid precursors. Enabled by low background and atm. transmission. However, SOFIA should be able to do this except CO2. SOFIA can not look at many given time available..	Spatially unresolved spectroscopy 2 – 5 um, 10nm spectral resolution.	1 arcsec (~ diffraction limit of 1m aperture at 5um) IFOV. RMS stability of 0.5arcsec. Daytime okay for longer wavelengths. Nightime required for full wavelength coverage. 1m aperture. 120K'. Hours per object. #20,22
	Effects and timing of secondary processes on the evolution of primitive bodies	Spin up effects on binary objects and space weathering effects	NUV-Vis slope effects	NUV-Vis multispectral, low resolution spectroscopy. NUV atmospheric transmission. Main belt binaries have sufficient separation to resolve with 1m aperture.	300- 500 nm multispectral/low resolution spectroscopy measurements. 1/10 arcsec spatial resolution.	30min for object max. 1/20th of a arcsec for 5min. Nighttime only. 1 day to several weeks (just changes the number of objects). 120K'. . 1m aperture. #21,24
As building blocks for planets and life						
	Determine the composition, origin, and primordial distribution of volatiles and organic materials in the Solar System	What are the chemical routes leading to organic molecules of complexity in regions of star and planet formation	Spectroscopy of KBOs, asteroids, Trojans, irregular satellites	Low background. (if you have the sensitivity to do KBOs, you have the sensitivity to do a lot of these other populations)	Low resolution spectroscopy 2.5 – 5 um	"Telescopic spectral observations of primitive bodies provide at best a tantalizing buy incomplete picture of the orbital distribution of organic matter in the early solar system" DS2010 p4-9. My comment: DS focus is on in-situ and sample return. 1m, 1", 100K', 10s of minutes to hours per observation. Can observer continuously from object to object for duration of mission.. daytime okay #16
		What was the proportion of surviving presolar organic vs. locally produced organics?	Presolar is IDP composition.	Dust collection.	MCR. Moving sticky pad. MSP.	Altitude not matter too much. Duration, not matter too much. 100K'. 1 day or so. #18
		Why are differentiated asteroids/planets volatile poor?	Measure/constrain OH on differentiated asteroids	2.6-2.8 µm region unavailable from ground, still some extinction on SOFIA	2.5 – 3.8 micron, 10nm resolution	1 arcsec IFOV. RMS stability of 0.5arcsec. Daytime okay. 1m aperture. 120K'. Minutes to hours per object. #16
	Understand how/when planetesimals formed planets	Are there systematic chemical or isotopic gradients	Compositional information	High and Low resolution spectroscopy (how is this an "advantage for balloons"?)	Low resolution (10nm) spectroscopy of solid surfaces 2.5-5um, high resolution (10000 lambda/delta lambda) spectroscopy of comet comas for CO2.	1 arcsec pointing. 1m aperture. Minutes to hours for observations especially for smaller bodies or distant objects. #16
		How did earth get its water and other volatiles?	Modeling and remote sensing	Organics and volatiles in small bodies	Low resolution (10nm) spectroscopy of solid surfaces 2.5-5um, high resolution (10000 lambda/delta lambda) spectroscopy of comet comas for CO2.	1 arcsec pointing. 1m aperture. Minutes to hours for observations especially for smaller bodies or distant objects. # 16,26,27
	Dynamics	What are the sources of asteroid groups (trojans, centaurs) that remain to be explored by S/C	Observations in spectral regions with diagnostic absorptions	2.6-5 µm region unavailable from ground for dim objects, still some extinction on SOFIA, observe to 5 µm	Low resolution (10nm) spectroscopy of solid surfaces 2.5-5um, spectroscopy	1 arcsec pointing. 1m aperture. Minutes to hours for observations especially for smaller bodies or distant objects. 120K'. # 16,26,27.

Priorities of the Decadal Survey

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%

- 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 greatest likelihood, a single mission will answer and/or address multiple questions.

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

Top Priority Balloon Missions Derived from the Decadal Survey

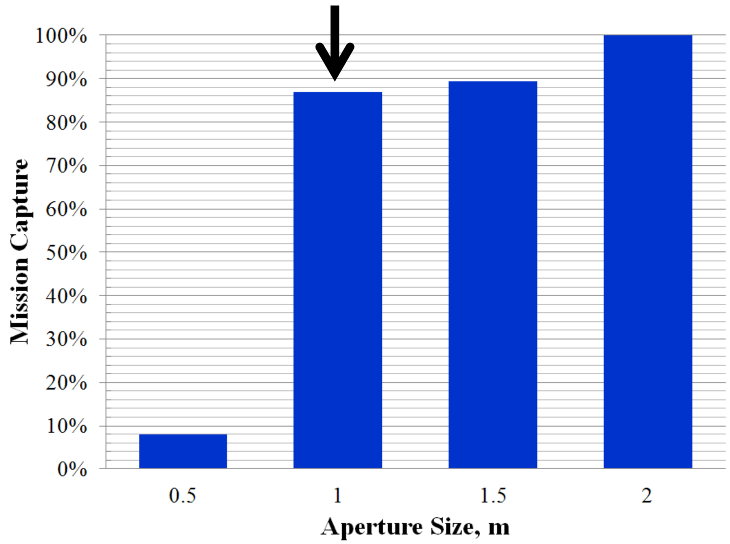
Small Bodies: 2.5 – 5-um spectroscopy, 10nm resolution, 1-m aperture, responds to five “Priority Questions” under the the Objective “Determine the composition, origin, and primordial distribution of volatiles and organic materials in the Solar System”.

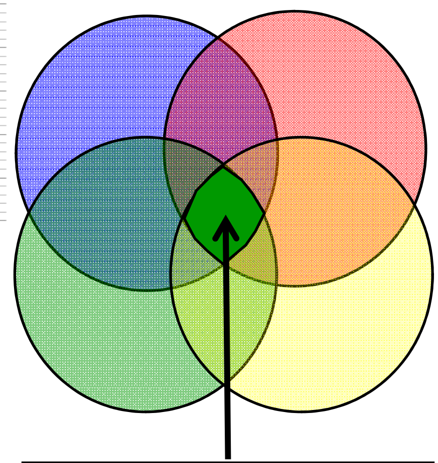
Icy Satellites: 1 – 5-um spectroscopy, 10nm resolution, 1-m aperture, responds to one “Priority Question” under the the Objective “Composition and distribution of volatiles ” – for the satellites of Uranus and Neptune.

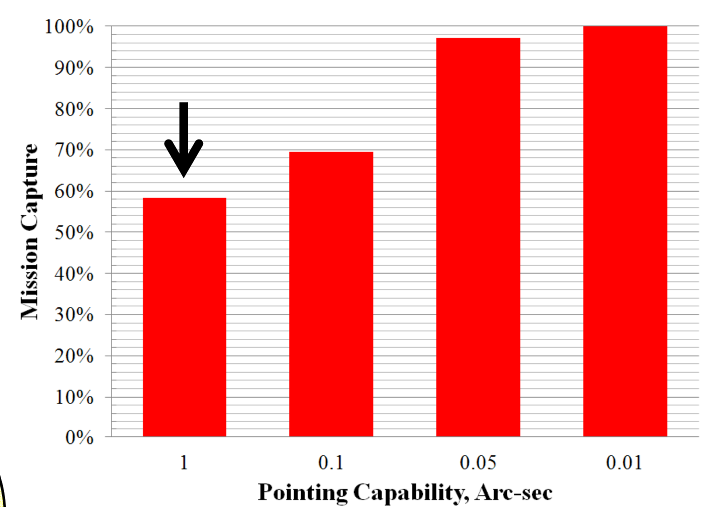
Inner Planets: high spatial resolution NUV – NIR imaging, 1-m aperture, responds to two “Priority Questions” under the Objective “Determine how solar energy drives atmospheric circulation, cloud formation, chemical cycles on Venus”.

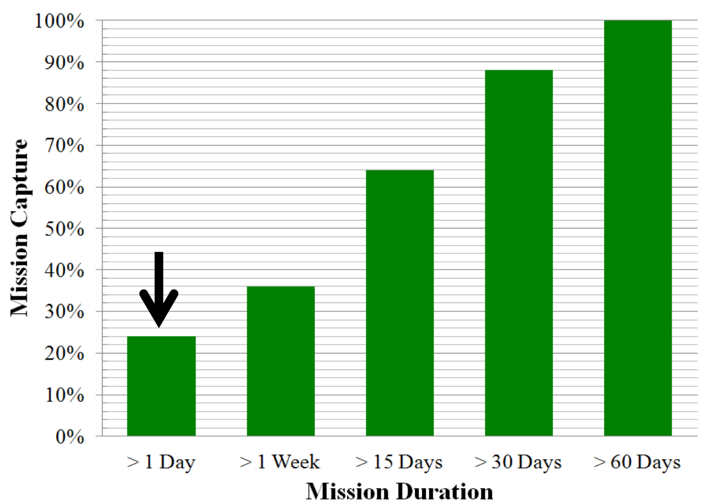
Giant Planets: high spatial resolution Vis imaging, 2-m aperture responds to one “Priority Question” Why and how does the atmospheric temperature and cloud composition vary with depth and location on the planet?”

Balancing Science with Near-term Success



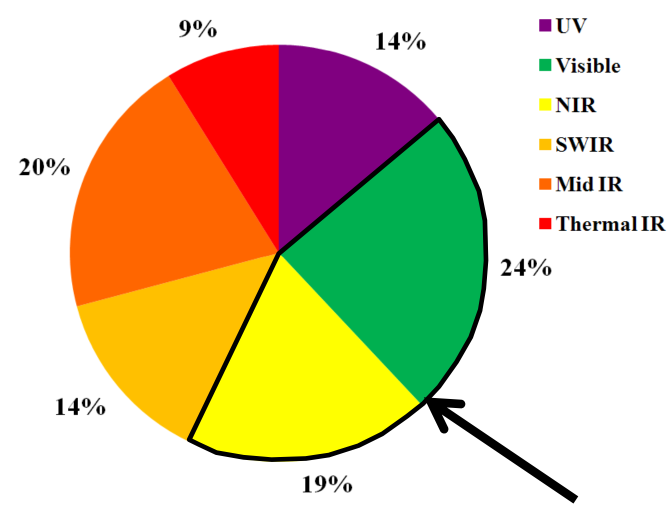






~20% of Planetary Balloon missions possible with baseline system

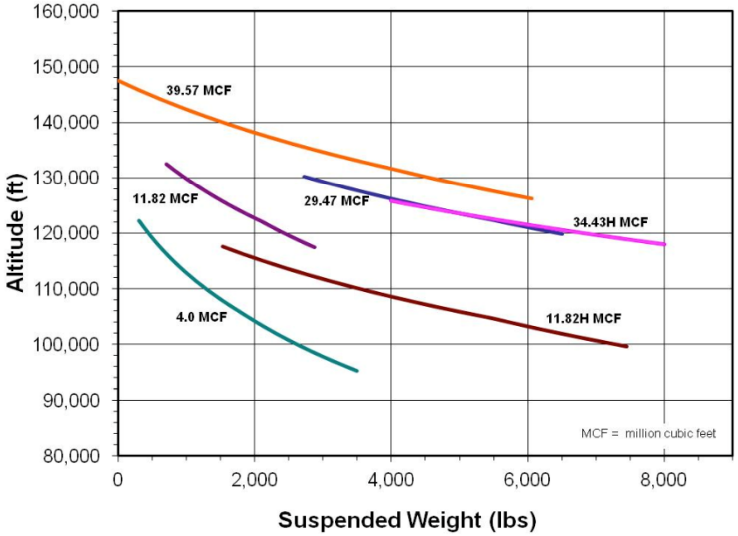
Addresses 15% of Decadal Survey "Important Questions"



Significant science is achievable with modest system.

Gondola Subsystems Existing from BPO

Pitch Error RMS was 0.24 arc-sec
Yaw Error RMS was 0.22 arc-sec
Design accommodates a 1m aperture



Better than 1 arc-sec pointing demonstrated

WASP design supports 1m aperture w/o engineering change

Altitude > 120,000ft achieved with sufficient mass

Super-pressure balloon demonstrated 54 day flight; 100 day goal

Recent and near-term developments enable planetary balloon science.

Requirements vs. Alternative Options

	SOFIA	HST	Ground	Balloon
Time Allocation				
Above telluric absorption and background				
Spatial Resolution / Pointing				
Observing Efficiency				
Cost per Mission				
Aperture				

More than 35% of the Cycle 19 HST proposals could have been performed from a balloon-borne 2-m telescope with a stabilized visible camera.

- Only Balloons & HST have the capability of imaging visible targets at the 0.05” level.
- Balloons have no measurable wavefront errors at 120,000 ft (ref: Barthol/SUNRISE) and could perform diffraction-limited visible imaging at the 0.05” level with a 2-m aperture.
- HST allocates 2800 orbits per cycle. → A single 100-day balloon mission can provide about 1000 hours of dark time, more than TEN TIMES the annual SS allotment.

Balloons offer a cost-effective addition to HST imaging and enables capabilities beyond alternative assets.

Requirements vs. Alternative Options

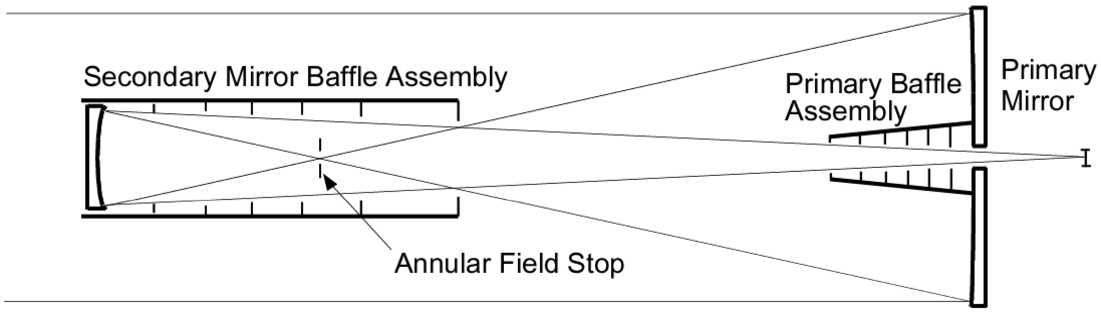
	SOFIA	HST	Ground	Balloon
Time Allocation				
Above telluric absorption and background				
Spatial Resolution / Pointing				
Observing Efficiency				
Cost per Mission				
Aperture				

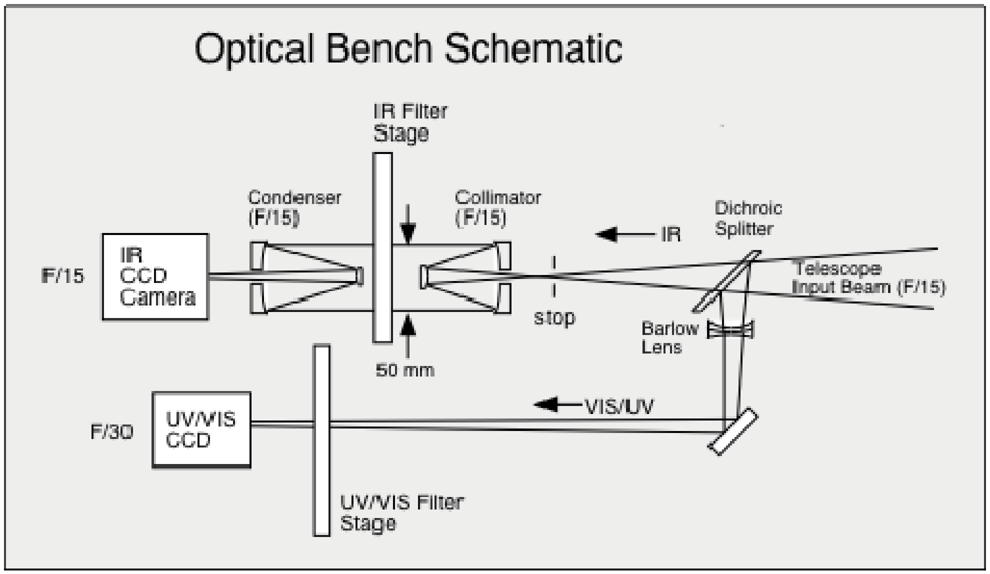
Balloon Platforms can conduct observations not possible by ground-based telescopes, SOFIA, or HST.

- Only Balloons and SOFIA can conduct observations in the ‘water-bands’.
- Only balloons can conduct daytime mid-IR observations.
- Only balloons can measure CO_2 and have 10x lower downwelling radiance than SOFIA and near 100% transmission at other mid-IR wavelengths.

Balloons enable mid-IR capabilities beyond alternative assets.

Recommended Baseline Capability





Baseline Aperture: At least 1-m. Provides 0.12” diffraction limit at 0.5 µm. A 50-cm aperture only provides 0.25” resolution, about 2x better than the best ground-based sites.

Baseline Pointing (VIS and IR): Long exposures require 0.05” RMS pointing. For IR imaging (J-H-K), 0.25” RMS is sufficient. For IR spectroscopy, 1.0” stability is good enough to keep light in the slit; depends on instrument design.

Notes on the Baseline Design:
1) The 1-m Gregorian is straightforward, and has a balloon legacy.
2) The OTA’s weight and inertia are well-suited to WASP.
3) Dual channels can be separately optimized for VIS and IR diffraction limits.

Baseline demo mission would address or answer 30 of the Decadal’s 194 ‘important questions”.
De-scope Options: NUV-VNIR alone addresses 17, IR addresses 13.

Simultaneous VIS and IR channels with platescales matching their respective diffraction limits

Recommended Mission Concept to Evaluate

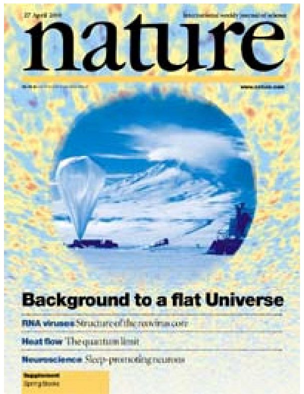
Recommending the simplest / lowest risk mission demonstration that achieves significant science

- Based on 1m, 1" pointing capability

- Utilize Day and Night observations

- LOS communications

- Possibly a 24 hrs mission out of Ft. Sumner



- Goal of at least two peer review papers

- Develop detailed CONOPS, risk assessment, cost, development schedule, modularity, survivability/ recovery, etc.

Demonstrating the concept will highlight practicality of balloon based planetary science, yield significant science return, and open the door for more aggressive science campaigns.

Path for Growth and Evolution

The platform allows for graceful growth in capability and science return

- Low risk improvements, many of which are or will be demonstrated before we'd need them

Exciting new science can be achieved as new features are added

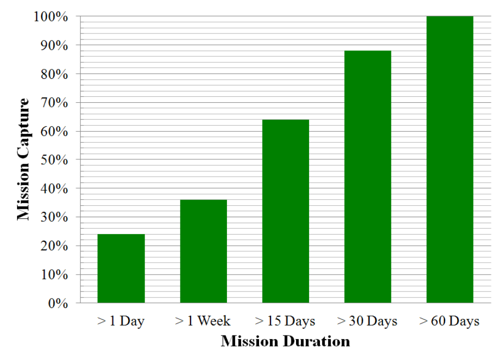
The BPO continues investment with significant near-term mission expansion capabilities

E.g. Standard Instrument Package (SIP) over mini-SIP

Enables satellite communication over Line-of-Sight with proven subsystem

Balloon program is working longer duration balloons and more launch site options

The will open up new planetary science observations and science



Additional Enhancements to add life cycle value and lower cost may also be possible: Survivability, modularity, etc.

Evolutionary path leverages existing BPO efforts and other mission successes. Will open up new planeteray science with little risk and low cost

Near-Term Plans

With approval:

1-m Class observing system concept design

- thermal, structure, cost, schedule, risks, etc.
- Maturation cost, schedule

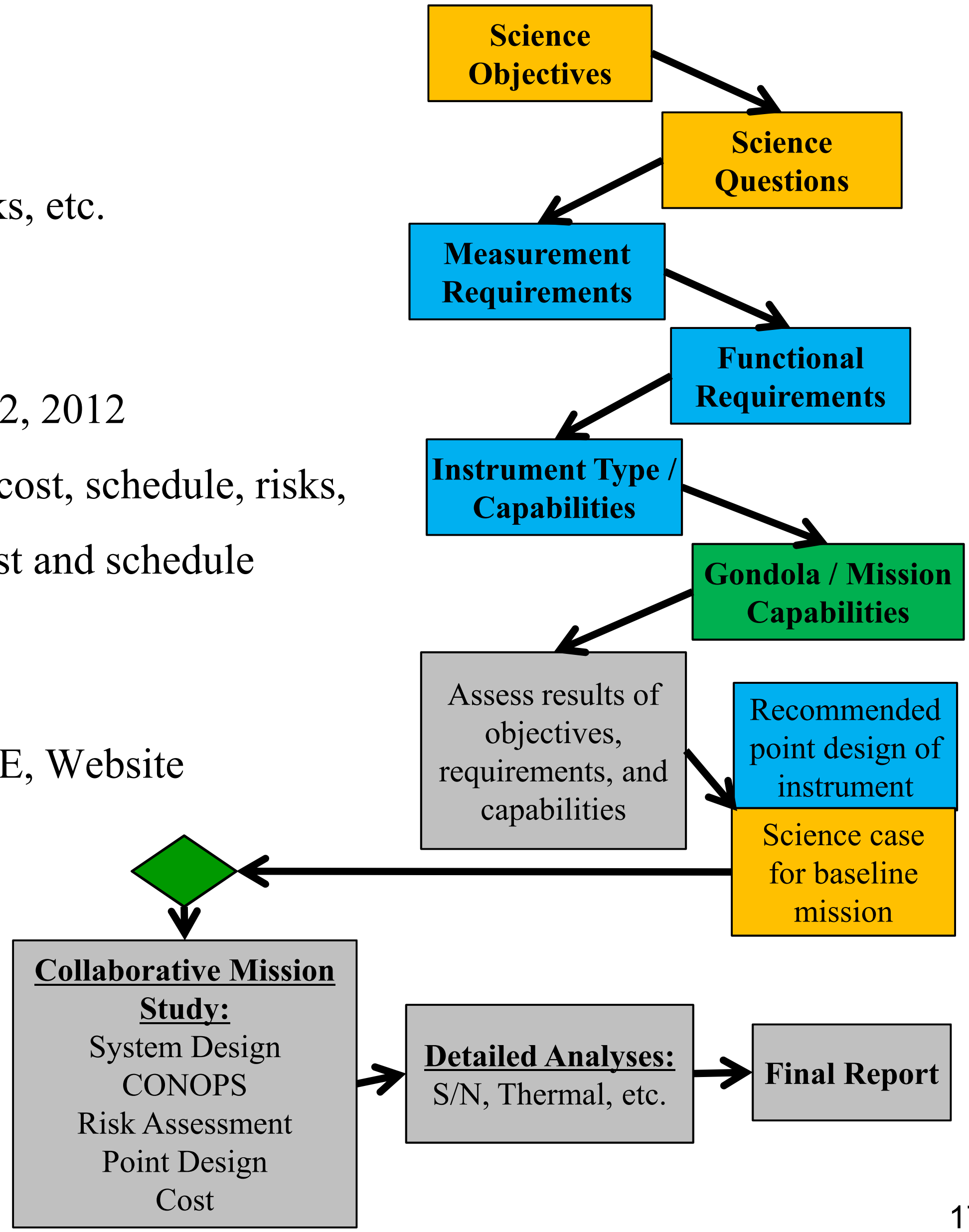
Initiate the Mission Concept Study – October 22, 2012

- CONOPS, gondola design, analyses, cost, schedule, risks,
- Development and maturation risk, cost and schedule

Continue to engage community

- DPS (October 14th – 19th), AGU, IEEE, Website

- Targeting final briefing February
- Final Report February / March



Summary

Significant science potential through balloon based asset

- Addresses significant fraction of Decadal science
- Compliments existing ground based and airborne assets
- Significant cost savings over space based or future flight missions

Baseline recommended concept is near-term, achievable and leverages existing BPO capabilities

Will continue to engage the science community (DPS, IEEE, LPSC and AG papers and/or posters,)

The team recommends this initial modest / low-risk system for additional analyses through COMPASS and engineering efforts

The team is requesting HQ concurrence on the concept to develop and plan forward