SBG Community Webinar July 15, 2020
Rules of Engagement

- Turn off your video
- All will be muted
- Please use chat to ask a question to "Everyone" (Kerry Cawse-Nicholson to read)
- Following the presentations, we’ll answer questions.
- Any questions we don’t get to will be answered within a week in writing and the answers posted: https://sbg.jpl.nasa.gov/news-events
- Please also send questions about the final architectures you’d like to hear about at the 15 July presentation
- Contact Dave Schimel or Ben Poulter directly by email or to set up a phone call: dschimel@jpl.nasa.gov or benjamin.poulter@nasa.gov

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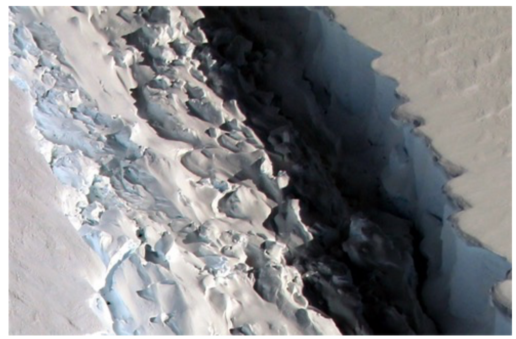

SBG Community Webinar 3: Preview of architecture recommendations

Jamie Nastal, JPL/Caltech
Dave Schimel, JPL/Caltech
Christine Lee, JPL/Caltech
Jon Chrone, NASA LaRC
Charles Miller, JPL/Caltech
Dave Bearden, JPL/Caltech

Outline

Previous Webinars:

1. Study status update (May 202)
2. Study process (June 2020)

Objective for Webinar 3:

1. Community preview of recommendation for HQ on July 29th
2. Review community feedback and input
3. Solicit community perspective on final recommendation

Vote: SBG Study Logo ***Theme***

https://tinyurl.com/SBGlogo

https://tinyurl.com/SBGlogoresults

A Surface Biology & Geology Designated Observable

Surface Biology & Geology Designated Observable

Surface Biology & Geology (SBG) Designated Observable

SBG

B Surface Biology & Geology Designated Observable

Surface Biology & Geology Designated Observable

Surface Biology & Geology (SBG) Designated Observable

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C Surface Biology & Geology Designated Observable

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Surface Biology & Geology Designated Observable

SBG

- **Logo Theme – Voting!**
- Study Overview
- Science and Applications Overview
- Science and Applications Scoring
- International Partnership Opportunities
- Architecture Study
- Science and Applications Appraisal
- NASA HQ Next Steps
- Stay Engaged

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SBG DO Study Overview

Jamie Nastal, JPL/Caltech
Study Lead




SBG Overview

- The SBG Study has three core objectives:
  1. Identify and characterize a diverse set of high value SBG observing architectures
  2. Assess the performance and cost effectiveness of architectures against SBG research and applications objectives
  3. Perform sufficient in-depth design of one or more candidate architectures to enable near-term science return

- Decadal Survey gave clear direction on SBG Observing priorities:
  1. Terrestrial vegetation physiology, functional traits, and health
  2. Inland and coastal aquatic ecosystems physiology, functional traits, and health
  3. Snow and ice accumulation, melting, and albedo
  4. Active surface changes (eruptions, landslides, evolving landscapes, hazard risks)
  5. Effects of changing land use on surface energy, water, momentum, and C fluxes
  6. Managing agriculture, natural habitats, water use/quality, and urban development

- SBG Science and Applications Traceability Matrices (SATM)
  - Science Objectives have traceability capability categories and applications
  - Observing architectures options, with associated capability categories, are mapped back to Science Objectives
- Value Framework will assess each candidate architecture by performance, cost and risk value criteria
- Selected architectures from the Value Framework will then be further developed in preparation to support a Mission Concept Review (MCR)

SBG Study Scope

Surface Biology and Geology (SBG) Designated Observable Study Plan
2017 Earth Science Decadal Survey

1. **Candidate architectures**. Development of candidate architectures based on synthesis of Decadal Survey science and application recommendations related to SBG, surveys of community capabilities, and initial architectural designs of the options,
2. **Assessment of Architectures**. Assessment of potential observing architectures for providing cost-effective SBG observations,
3. **Architecture Design**. Design of a recommended observing system architecture and preparation of preliminary Mission Concept Review (MCR) material
4. **Deliverable Preparation**. Preparation of the End Study Report.

Observations:

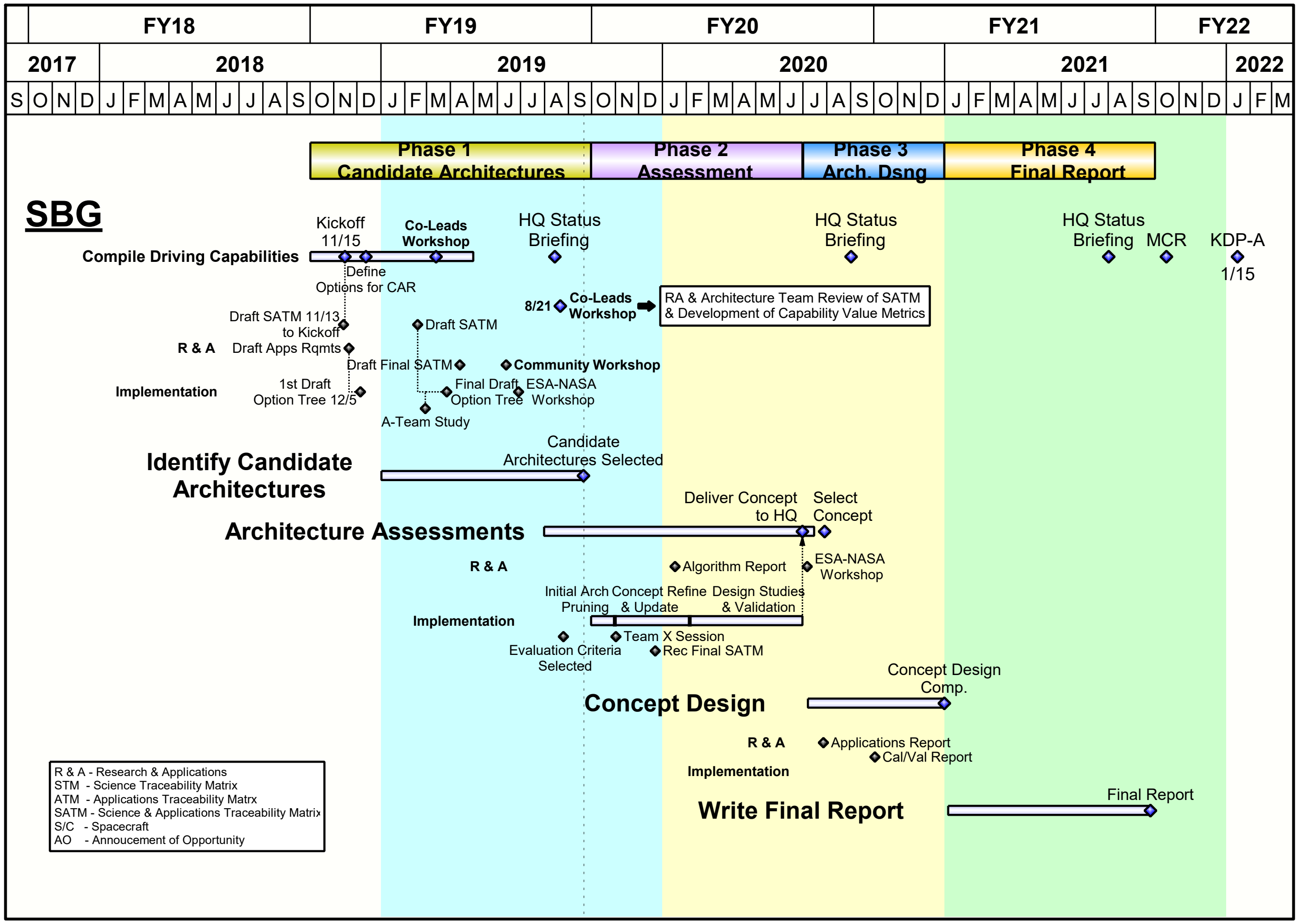
- Science value assessment based on community vetted SATM and science metrics
- The team is confident that a meaningful down-select can occur in the July timeframe, resulting in one preferred architecture with alternates
- The study has significantly evolved such that the original study plan should be modified to incorporate a more focused MCR prep phase that begins in FY21.

Recommendation:

Once Preferred Architecture is selected, recommendation is to enable an MCR team in Fall 2020 to move towards a scheduled review and Key Decision Point (KDP-A)

Study Phase 3-4 could be combined to both complete study material and provide final report

SBG Study Schedule



SBG Organization

NASA HQ
Woody Turner
Ben Phillips
Marissa Herron
Laura Lorenzoni

Center Executive Steering Committee
Ryan Spackman- NASA ARC
James Irons- NASA GSFC
Randy Friedl- JPL Chair
David Young- NASA LaRC
Gary Jedlovec- NASA MSFC

SBG Study Coordinator
Jamie Nastal- JPL

International Collaborations Coordinator
Chip Miller- JPL

Research & Applications Team
Dave Schimel- JPL, Coordinator
Betsy Middleton- GSFC
Ben Poulter- GSFC
Science Steering Committee
Working Groups:
Algorithms
Cal/Val
Modeling
Applications
Science System Engineering

Architecture Teams

Architecture Formulation Team
Kelley Case- JPL,
Co- Coordinator
Belgacem Jaroux- ARC,
Co-Coordinator

(A-Team Workshops for Candidate architectures, Architecture Assessment and Detail Architecture)

Phase 1: Identify Candidate Architectures
Tony Freeman- JPL, Lead
Ben Poulter- GSFC, Deputy Lead

Phase 2: Architecture Assessment
David Bearden- JPL, Lead
Jon Chrone- LaRC, Deputy Lead

Phase 3: Architecture Design
Amit Sen- JPL, Lead
Kurt Thome- GSFC, Deputy Lead

Cost Estimation Team
Jim Hoffman-JPL,
Co-Coordinator
Jordan Klovstad- LaRC,
Co-Coordinator

Deliverable Preparation
Phase 4: Final Report, MCR material
Jamie Nastal- JPL, Lead

Key SATM Performance Objectives

- Derived from the Decadal Survey and shown in the SATM
- Provided in the RFI to identify all candidate observing architectures

Performance Parameters	Spectral Range	Spectral		GSD	Revisit	Coverage	Local Time for Acquisition
VSWIR	0.35 or 0.4 to 2.5µm	Resolution: 10nm or better Coverage: Continuous	SNR: VNIR: >400 SWIR: >250	30-45m	2-16 days	Global	10:30am to 1:30pm
TIR	8 to 12µm 3 to 5µm	Bands: >5 desired	NEdT: <0.2 K	40-60m	1-7 days	Global	Can vary across the diurnal cycle

The primary goal of the architecture study is to determine the extent to which any given architecture meets all, most, or some of the objectives derived from these priorities within the budget and schedule constraints recommended in the Decadal Survey. All observational architecture concepts and measurement capabilities achieving performance parameters within the ranges in this table are considered. An observational system can include any combination of a program of record, space and/or airborne systems.

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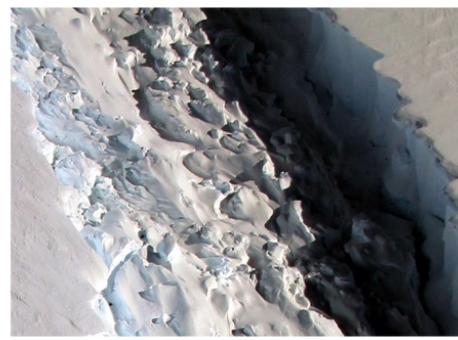
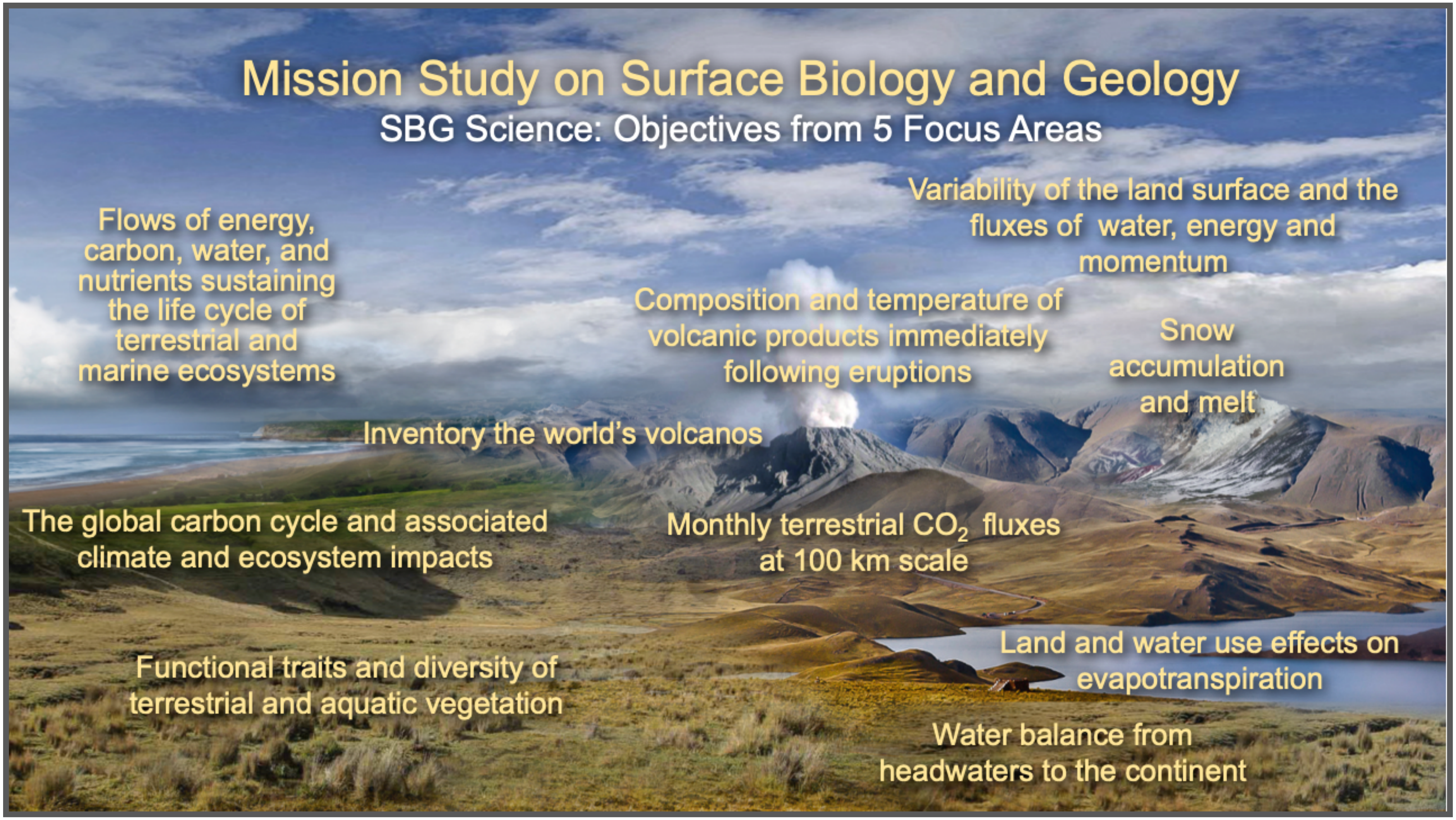


Research and Applications Overview

Benjamin Poulter, GSFC, Deputy Co-Lead


Mission Study on Surface Biology and Geology
SBG Science: Objectives from 5 Focus Areas
Flows of energy, carbon, water, and nutrients sustaining the life cycle of terrestrial and marine ecosystems
Variability of the land surface and the fluxes of water, energy and momentum
Composition and temperature of volcanic products immediately following eruptions
Snow accumulation and melt
Inventory the world's volcanos
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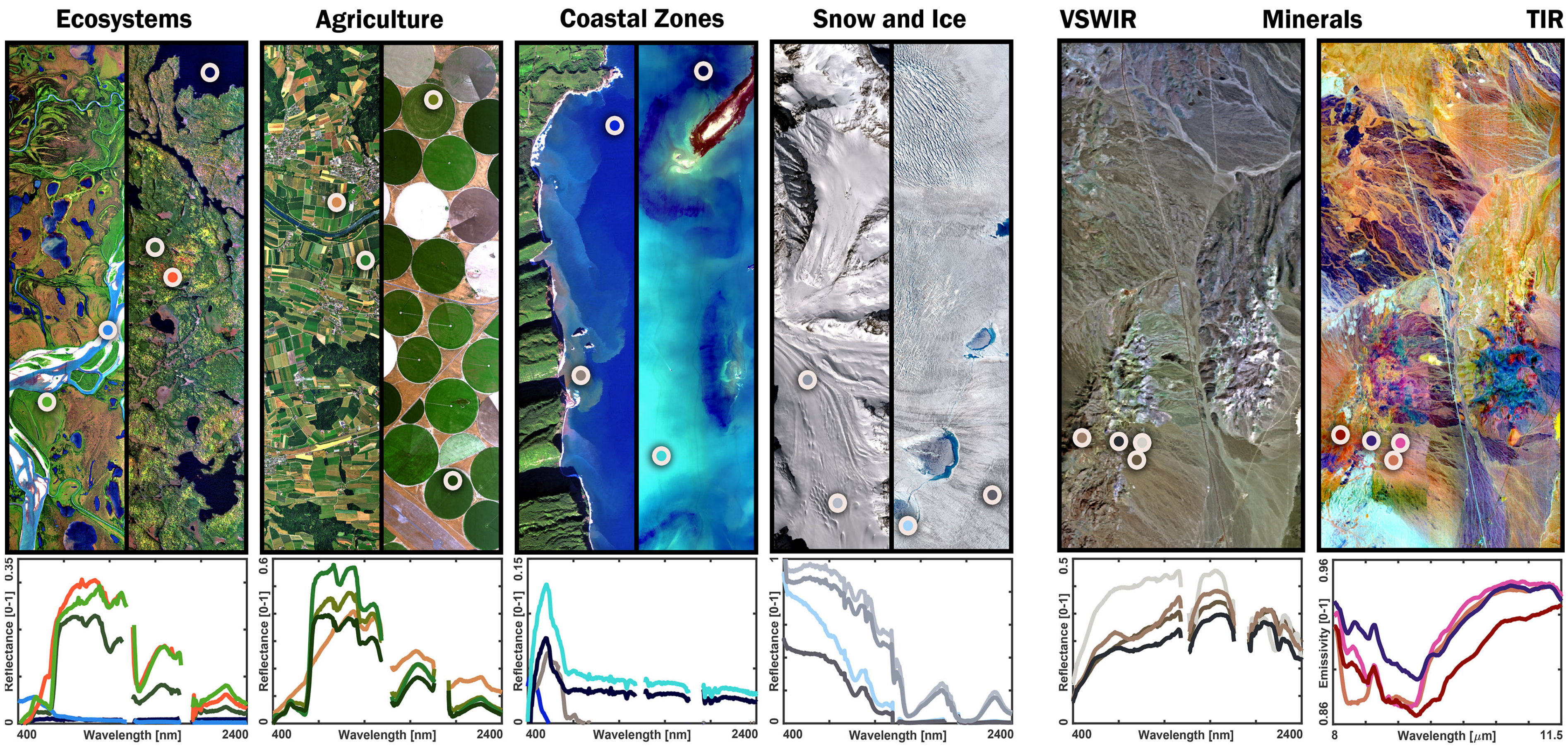
Monthly terrestrial CO_2 fluxes at 100 km scale
Land and water use effects on evapotranspiration
Functional traits and diversity of terrestrial and aquatic vegetation
Water balance from headwaters to the continent

SBG Science: critical data for new science and applications in two critical spectral regions

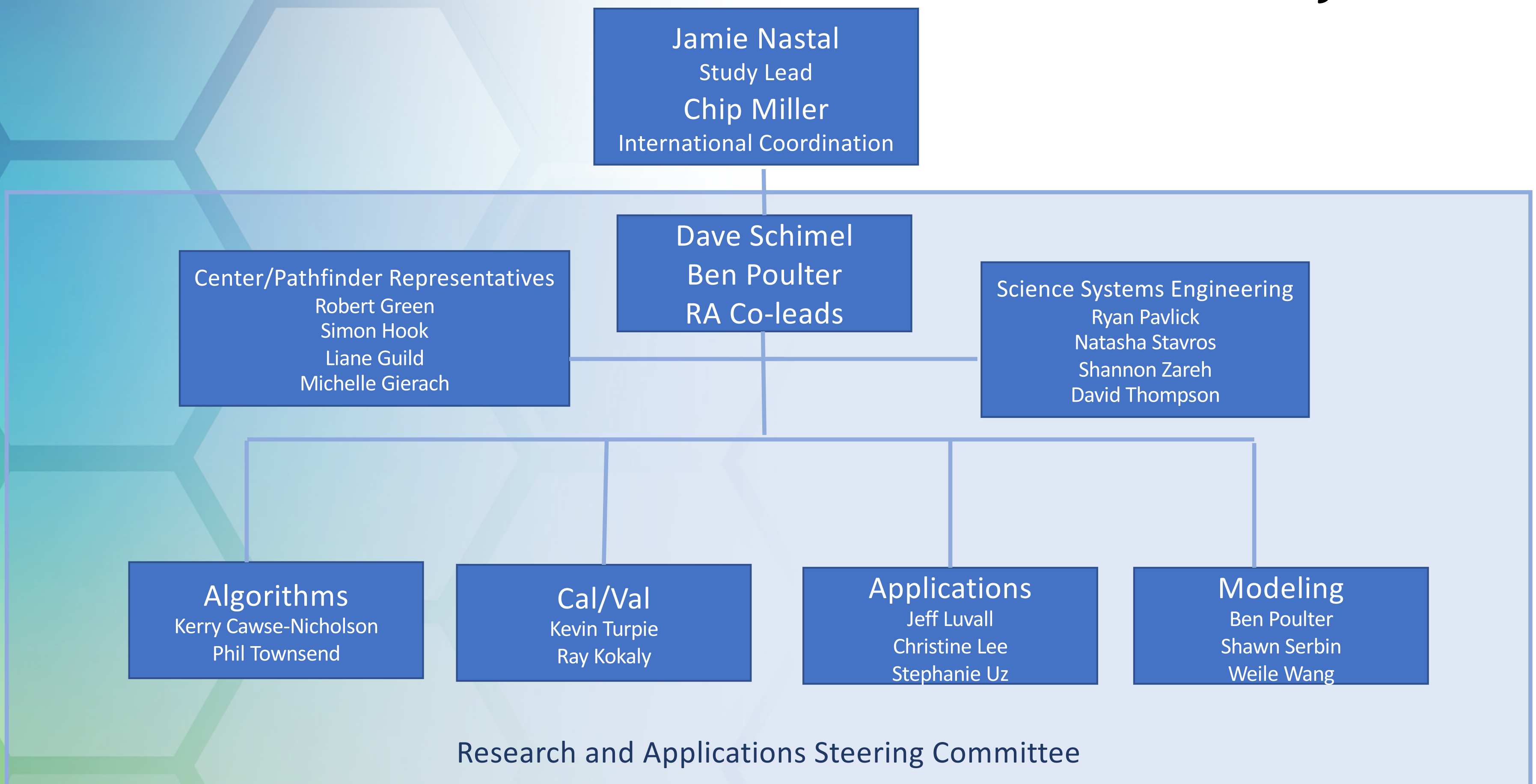


Decadal Survey observing priorities interleave Research **and** Applications

- Changes to terrestrial vegetation physiology, diversity, traits, and health
- Inland and coastal aquatic ecosystems physiology, traits, and health
- Snow and ice accumulation, melt, and albedo
- Geology (vulcanism, minerals, landslides, evolving landscapes, hazards)
- Effects of land use on surface carbon, energy, water, momentum, fluxes
- Agriculture, conservation, water use/quality, urban development, wildfire




SBG Research and Applications Team provided science value to inform architecture study



SATM Capability Codes identify measurement objectives to achieve specific science priorities

Capability Code	VSWIR Spatial	VSWIR Temporal	VSWIR Range	VSWIR Sensitivity	TIR Spatial	TIR Temporal	TIR Range	TIR Sensitivity
A	30 m	≤8 days for global coverage*	≤380 - ≥2500 nm, @ ≤10nm	SNR ≥400 VNIR, SNR ≥250 SWIR, accuracy ≤5%	60 m	≤1 day for global coverage*	≥5 bands in 8-12 um, ≥ 1 band in 3 -4.5 um	≤1K Absolute, ≤0.2K NeDT / band
B	<60 m	≤16 days for global coverage*	≤380 nm - ≥1000 nm, @ ≤10nm	≤10% Absolute accuracy	60 m – 100 m	≤3 days for global coverage*	≥5 bands in 8-12 um	≤1.5% Absolute, <1K NeDT / band
C			VNIR multiband		≥ 100 m	≤5 days for global coverage*	≥3 bands in 8-12 um	

Phase 1 Analysis of ESAS 2017 to define >70% solution, which converge on capability priorities

	VSWIR				TIR				coincidance
	spatial	Temporal	Range	Sensitivity	spatial	Temporal	Range	Sensitivity	
H1-a	A	A	A	-	A	B	B	A	-
H1-c	A	A	A	B	A	B	B	A	-
H2-a	A	A	A	-	A	B	B	A	B
H4-a	A	A	A	B	A	B	B	A	-
w-3a	-	-	-	-	B	A	B	A	-
E-1a	A	B	A	A	-	-	-	-	-
E-1c	A	B	A	A	-	-	-	-	-
E-3a	A	A	A	A	A	B	B	A	-
S1-a	A	A	A	A	A	A	B	A	-
S1-c	A	A	A	A	A	C	B	-	-
S-2b	A	A	A	A	A	A	A	-	-
Satisfier	A	A/B	A	A	A	B	B	A	B

Capability Codes Needed by SBG L3 Algorithms

Requirements per product suite

Product Suite	VSWIR spatial	VSWIR temporal	VSWIR Range	VSWIR Sensitivity	TIR spatial	TIR temporal	TIR range	TIR Sensivitity	Will be met by ABAA/ABBA?	Cliff/gradual	Science questions answered
Snow		A				A			0	Gradual	H1, H4
Water biogeochemistry			B	A					1	Cliff VNIR sensitivity; Gradual VSWIR range	E1, E3
Water biophysics			B	A					1	Steep slope with cliff at the end (sensitivity)	E1, E3
Aquatic classification			B	A					1	Steep slope with cliff at the end (sensitivity)	E3
Substrate composition	A		A				B		1	Gradual in spatial, cliff for spectral (need SWIR)	E1, S1, S2
Volcanic SO2 and ash		A			B	A	A	A	0	Gradual in time; Cliff in spectral (Need midIR)	S1, S2
High temperature features		A	A			A	A	A	0	Gradual in time; Cliff in TIR spectral (Need midIR); cliff for VSWIR range for plumes/high temperature features	S1
ET			C		B		B	A	1	Gradual; Coincidence of VNIR/TIR cliff	H1, H2
Plant functional traits	A	B	A						1	Gradual on spatial and temporal, Cliff on VSWIR range(need SWIR)	E1, E3
Proportional cover	A		A						1	Gradual	E3

Optimal SATM Performance Objectives

- Derived from the Decadal Survey and shown in the SATM
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	Spectral Range	Spectral Resolution	Sensitivity	GSD	Revisit	Coverage	Local Time for Acquisition
VSWIR	0.35 or 0.4 to 2.5µm	10nm or better, Continuous coverage	VNIR >400 SWIR >250	30 m	16 days	Global	10:30-11:00
TIR	8 to 12µm 3 to 5µm	>5 Bands desired	NEdT <0.2 K	60m	3 days	Global	Afternoon

Measurement consensus

VSWIR				TIR			
Spatial	Revisit	Range	Sensitivity	Spatial	Revisit	Range	Sensitivity
94% A	54% B	76% A	64% A	77% A	46% B	46% B	54% na (46% A)

Distance from AAAA-AAAA is used to rank science value

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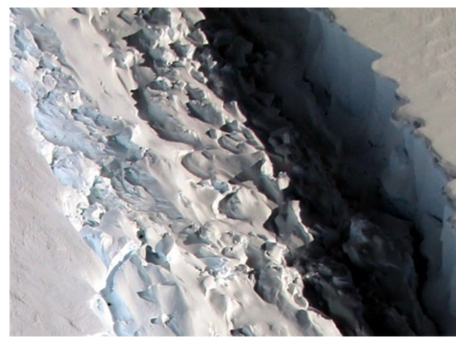
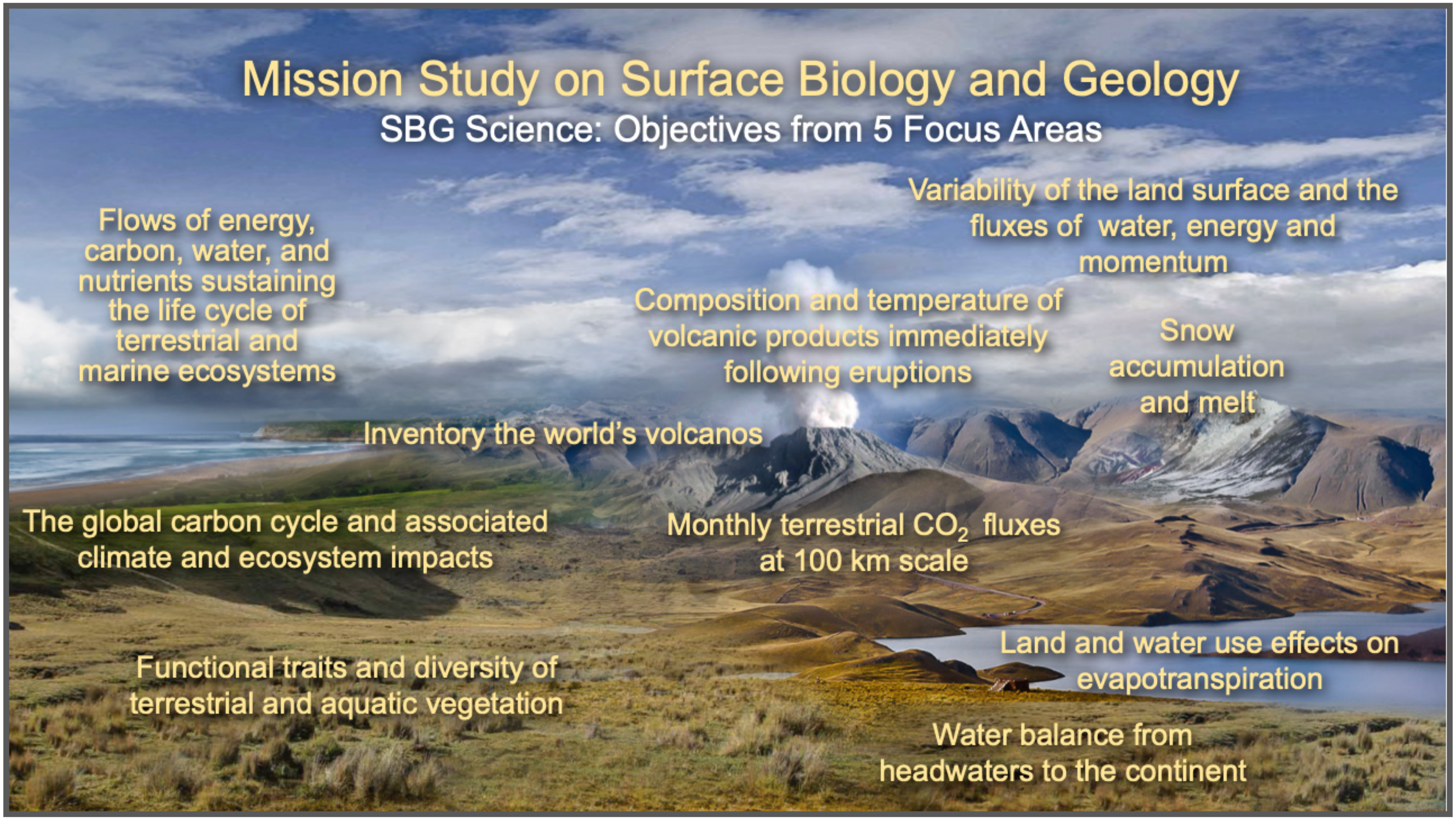


SBG Research and Applications Value Scoring

Dave Schimel, JPL/Caltech
Co-lead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	Spectral Range	Spectral Resolution	Sensitivity	GSD	Revisit	Coverage	Local Time for Acquisition
VSWIR	0.35 or 0.4 to 2.5µm	10nm or better, Continuous coverage	VNIR >400 SWIR >250	30 m	8 days	Global	10:30-11:00
TIR	8 to 12µm 3 to 5µm	>5 Bands desired	NEdT <0.2 K	60m	1 days	Global	Afternoon

Scoring Approach

- Score based on capability codes $\frac{A\ Reference}{Actual}$ ratioing the actual score (except range) and the A capability code value
- Use a linear score with the A code as maximum for the NASA assets (maximum score of 1)
- Can get additional revisit value from international constellations (NASA + partner could exceed 1)
- Calibration/validation, optimal overpass, coincidence between TIR and VNIR, other features considered qualitatively
- Two international collaborations considered numerically (CHIME and TRISHNA), others, commercial collaborations less well specified or uncertain (funding, timing) noted qualitatively

Scoring

Spatial	Temporal	Sensitivity	Spectral range
$\frac{A\ Reference}{Actual}$	$\frac{A\ Reference}{Actual}$	$\frac{A\ Reference}{Actual}$	$\frac{A\ Actual}{Reference}$

eg: VSWIR

$$\frac{30\ m}{30\ m} \qquad \frac{8\ days}{16} \qquad \frac{450/250}{450/250} \qquad \frac{380-2500}{380-2500}$$

1 + 0.5 + 1 + 1 = 3.5

eg: TIR

$$\frac{60\ m}{60\ m} \qquad \frac{1\ day}{3\ Days} \qquad \frac{0.2\ NeDT}{0.2\ NeDT} \qquad \frac{8\ Bands}{6\ Bands}$$

1 + 0.33 + 1 + 1* = 3.33

* Maximum score is 1 (no 'extra' credit for exceeding the 'A' value)

Additional Value from International Collaboration

- Score from international collaboration for reduced revisit.
- NASA VSWIR co-orbiting with CHIME is scored as follows:

		SBG		CHIME						
$\frac{30\ m}{30\ m}$		$\frac{8\ days}{16}$	+	$\frac{8\ days}{22}$		$\frac{450/250}{450/250}$		$\frac{380-2500}{380-2500}$		
1	+	0.5	+	0.4	+	1	+	1	=	3.9 (was 3.5)

Two-platform options can get value from CHIME (ESA), 0.4 and TRISHNA (CNES/ISRO), 0.33

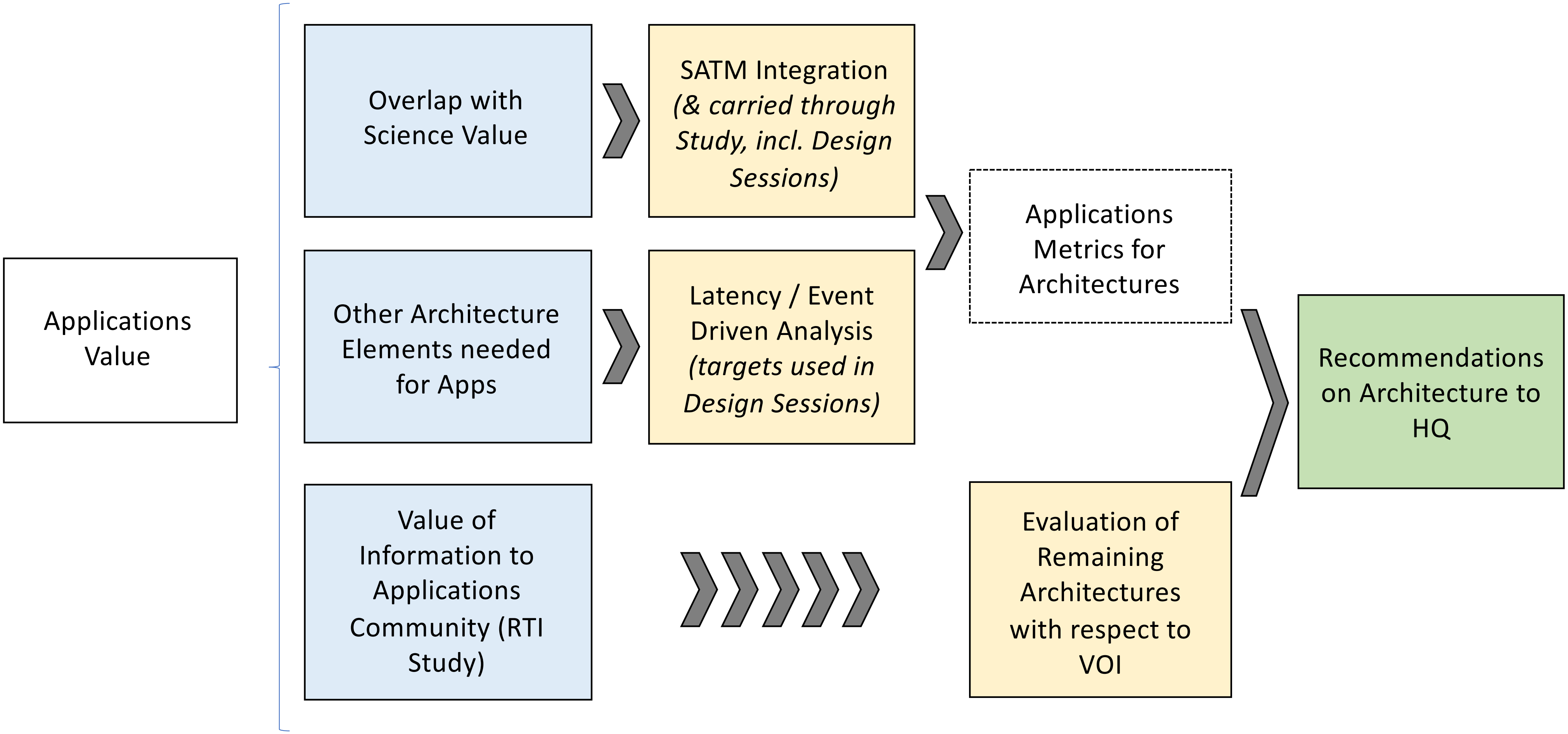
One platform options considered could only add value from either CHIME or TRISHNA due to conflicting overpass times.

Final options were selected from high science, applications and international partnership value architectures

- All instruments were scored A for spatial resolution (30, 60 m)
- All architectures were scored B for revisit (TIR and VSWIR),
- A for revisit only obtainable with international partners (VSWIR, TIR instruments too costly to replicate)
- All instruments were scored A on sensitivity (SNR or NeDT)
- All instruments were scored A on spectral coverage (380-2500 nm VSWIR, 8 to 12µm, 3 to 5µm, thermal)
- Two-platform solutions, with instruments as above, get 0.73 points for collaboration
- Architectures scoring lower than the above were rejected once ABAA, ABBA solutions closed on cost

Applications have been central to SBG Architecture Study

Doing so would allow application needs to be accounted for, alongside other key metrics such as cost, risk, science value, in the final architecture set. We evaluated the success of this in the applications scoring framework.



Sneak Peek: RTI Value of Information Study / Community Assessment

<u>Two main components to study</u>

(1) Broad: Survey (open for one week)
  - 562 Unique Respondents
  - Academia and federal government

(2) In-Depth: Key Informant Interviews for value assessment
  - Conducted over 40 interviews
  - Industry

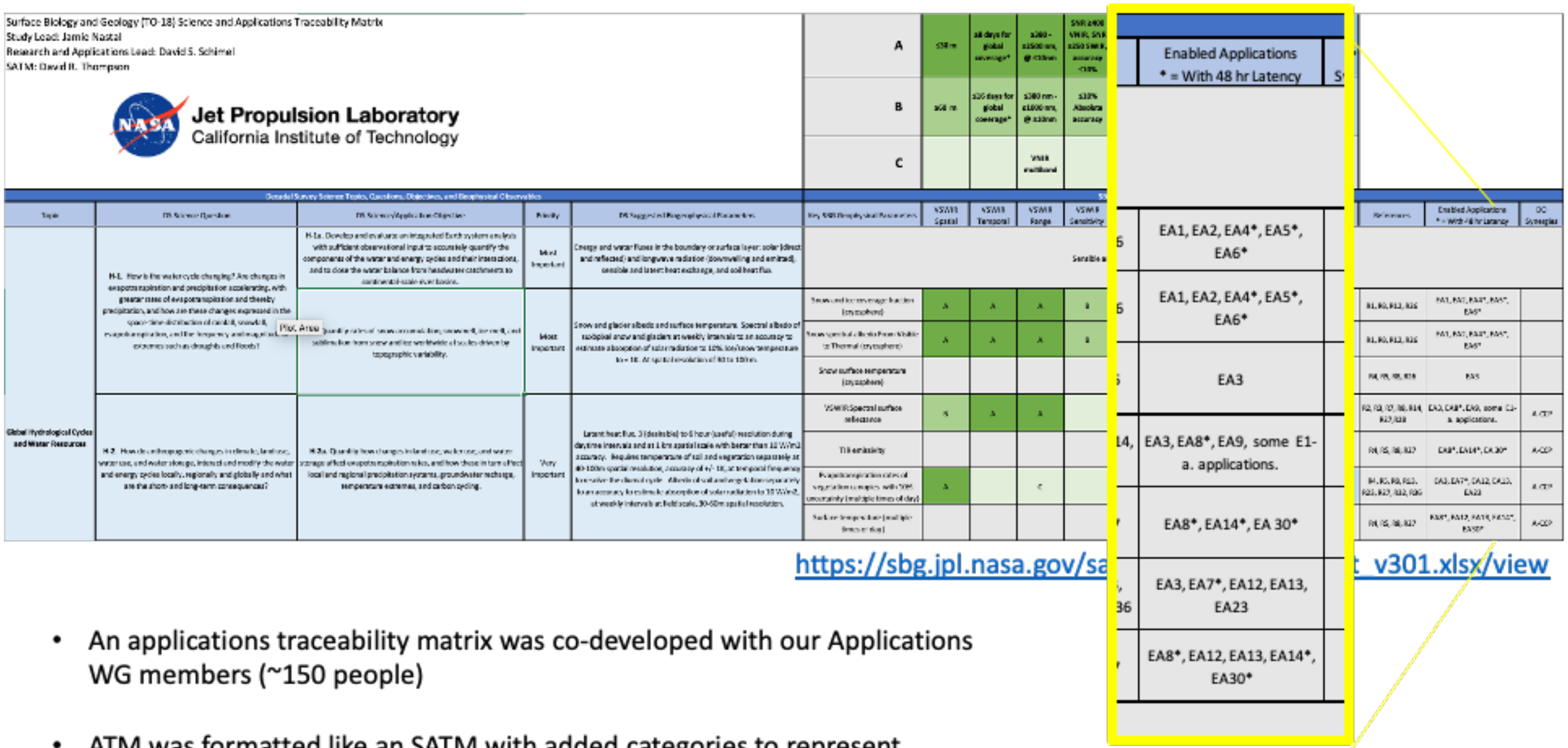
Fire Ecology Applications Users
Top priorities: Spectral (VNIR, SWIR, TIR), Temporal Revisit, Coincidence
Lower priorities:

Agriculture and Water Resources Users
Top priorities: Spectral (VNIR, TIR), Temporal Revisit, Latency, Coincidence
Lower priorities:

Algal Bloom / Water Quality Applications Users
Top priorities: Spectral (VNIR, TIR), Temporal Revisit, Latency
Lower priorities: Global / Large Area Coverage

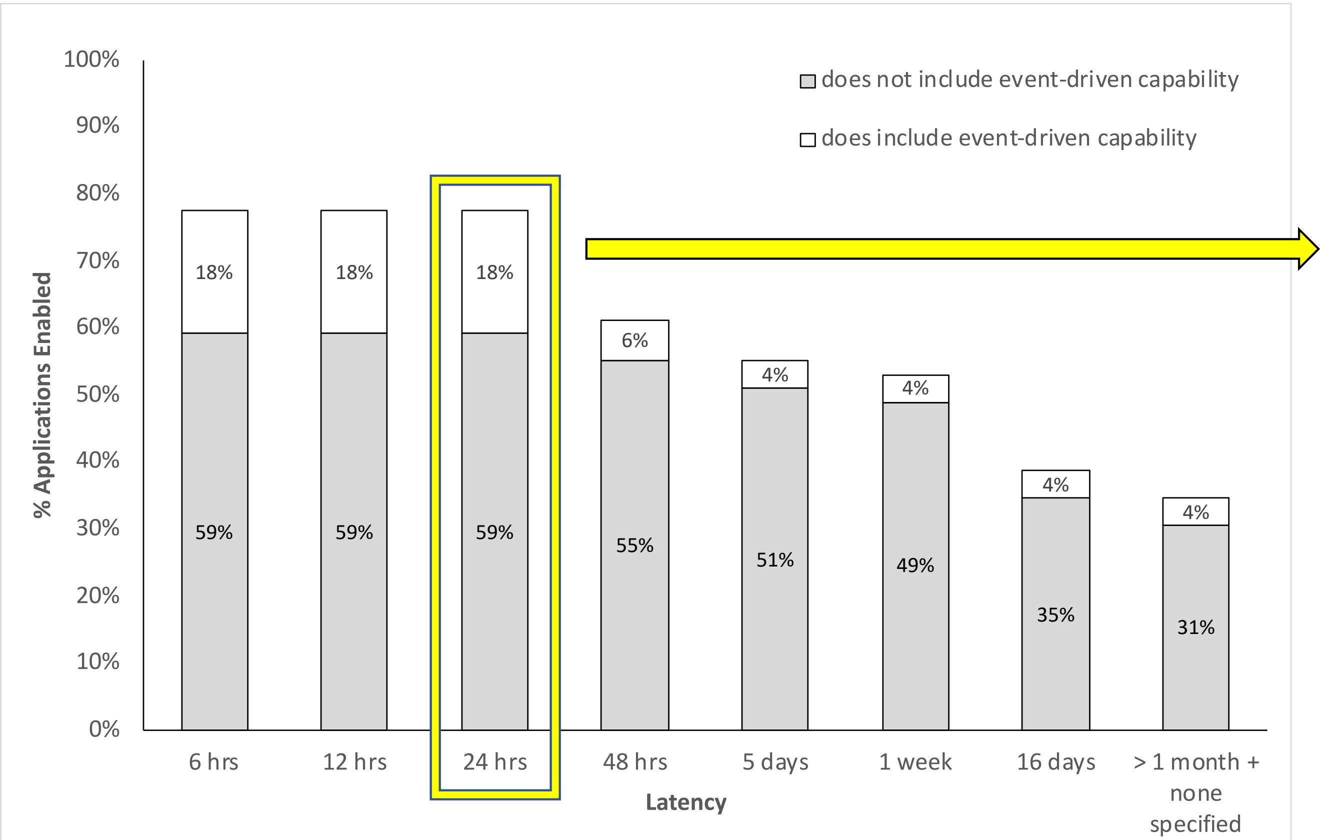
Mineral Mapping Applications Users
Top priorities: SNR, Spectral (VSWIR & TIR), Spatial
Lower priorities: Temporal Revisit, Latency

Science Value to includes Applications Value



- An applications traceability matrix was co-developed with our Applications WG members (~150 people)
- ATM was formatted like an SATM with added categories to represent decision context and application of data, partners
- ATM was integrated into SATM, with initial latency assessments denoted

Other factors of applications value needs chart, which was used in the Architecture Study design targets for latency



<u>How this input was used</u>

- 24 hour latency with event-driven capability enables 77% of SBG SATM applications
- 24-hour latency target used in architecture design sessions
- Event-driven needs considered, determined challenging to achieve within current cost cap

Architecture abilities evaluated using three core applications metrics; no differentiation in architectures observed

capability code	Application Value Metrics						
A	< 24 hrs		possible, costed		responsive		
B	> 24 hrs		possible, not costed		limited responsive		
Architecture Options	Latency		Priority Downlink		Event Detection		Code Score
Arch1 - 12	A	A	A	B	B	B	AA/AB/BB
Instrument	VSWIR	TIR	VSWIR	TIR	VSWIR	TIR	

Three applications metrics:

- Latency: time from acquisition to ground
- Priority Downlink: on-board processing that would allow higher priority datasets to be downlinked in less than 24 hours
    - *Possible, costed*: on-board processing built into design and cost
    - *Possible, not costed*: possible for design but not costed yet
- Event Detection: ability to acquire an event within one day or on-demand
    - *Responsive*: spaceborne observing system can acquire within one day or on-demand
    - *Limited Responsive*: non-spaceborne elements of observing system can acquire over select events within one day or on-demand

Applications needs, having been embedded in science value (SATM) and engineering sessions, became part of the design targets for architecture study and are thus “built-in” to the remaining high scoring architectures.

This is confirmed by the absence of differentiation in the remaining, high scoring and feasible architectures.

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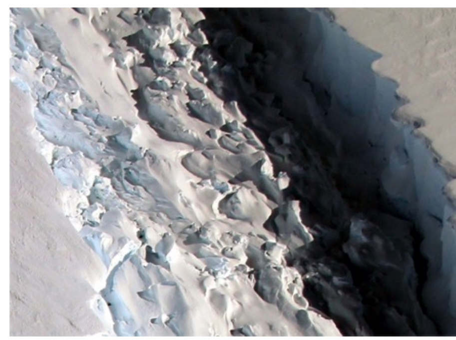

International Partnership Opportunities

Charles Miller, JPL/Caltech

International Collaborations Are Essential to the SBG Observing System

Developing contribution options for the SBG flight segments

- **VSWIR**: ISRO – PSLV launch of a NASA VSWIR instrument/satellite + ISRO VSWIR instrument/satellite and launch
- **TIR**: ASI – Accommodation of a NASA TIR instrument on a PLATINO+ satellite bus, VNIR camera, VEGA launch

Cultivating collaborations for coordinated on-orbit sampling strategies, data sharing, and cal/val

- **VSWIR**: CHIME (ESA), Unnamed (ISRO)
- **TIR**: TRISHNA (CNES + ISRO), LSTM (ESA)
- **Cal/Val**: Australian Space Agency, ESA, CEOS

Creating pre-SBG time series through the Pathfinder activity to provide greater sensitivity to Earth System change

- **VSWIR**: HISUI (JAXA), DESIS (DLR), PRISMA (ASI), EnMAP (DLR), Sentinel (ESA)
- **TIR**: ASTER (JSS), Sentinel (ESA)

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Architecture Study

Dave Bearden, Phase 2 Lead, JPL/Caltech
Jon Chrone, SBG Phase 2 Deputy Lead, LaRC

- Logo Theme – Voting!
- Study Overview
- Science and Applications Overview
- Science and Applications Scoring
- International Partnership Opportunities
- **Architecture Study**
- Science and Applications Appraisal
- NASA HQ Next Steps
- Stay Engaged

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4. **Deliverable Preparation**. Preparation of the End Study Report.

Architecture Evaluation Objectives

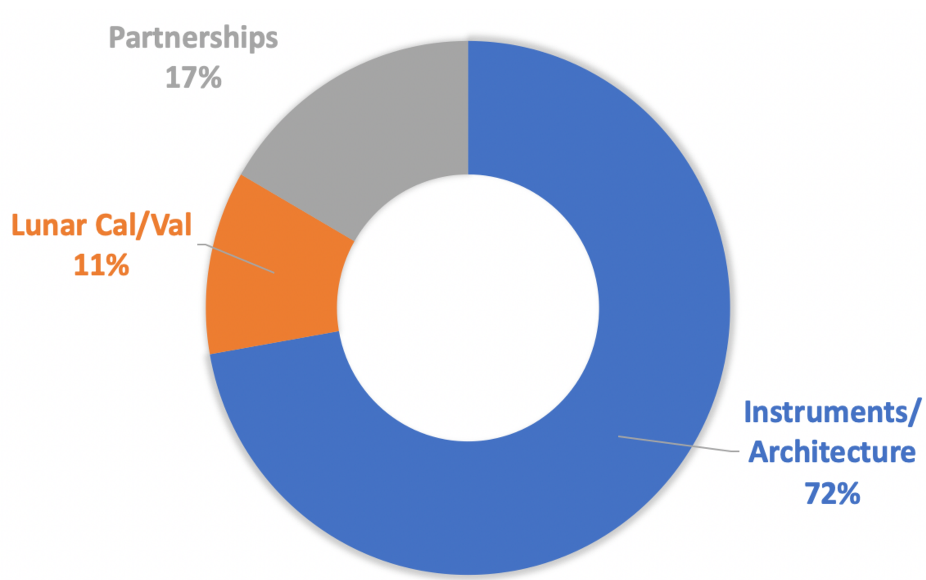
- Identify architectures to support research and applications objectives
- Develop Value Framework to evaluate architecture solutions to most/very important science and applications objectives performance, risk, cost, schedule
- Assess a diverse set of high RA value SBG observing architectures and reduce down to a few promising architectures
- Provide justification for eliminating candidate architectures

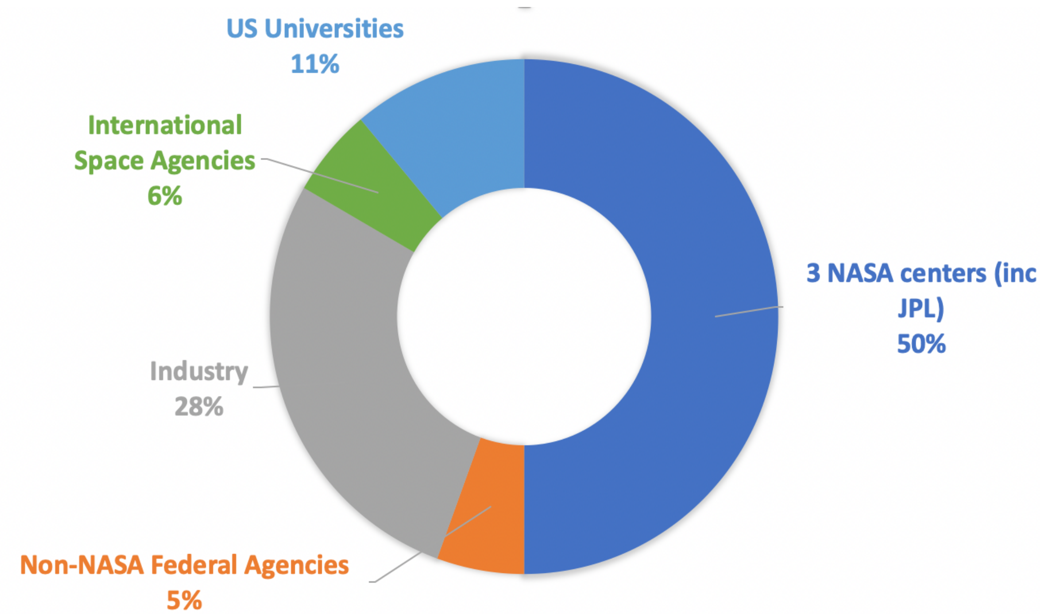
Value Framework Overview

- SBG Value Framework assesses key features relevant to decision criteria while providing the ability to discriminate between alternatives
- Quantitative features
  - Capability (Science & Applications)
  - Cost / Affordability
  - Schedule
  - Risk
- Qualitative features
  - Programmatic factors
  - International Partnerships

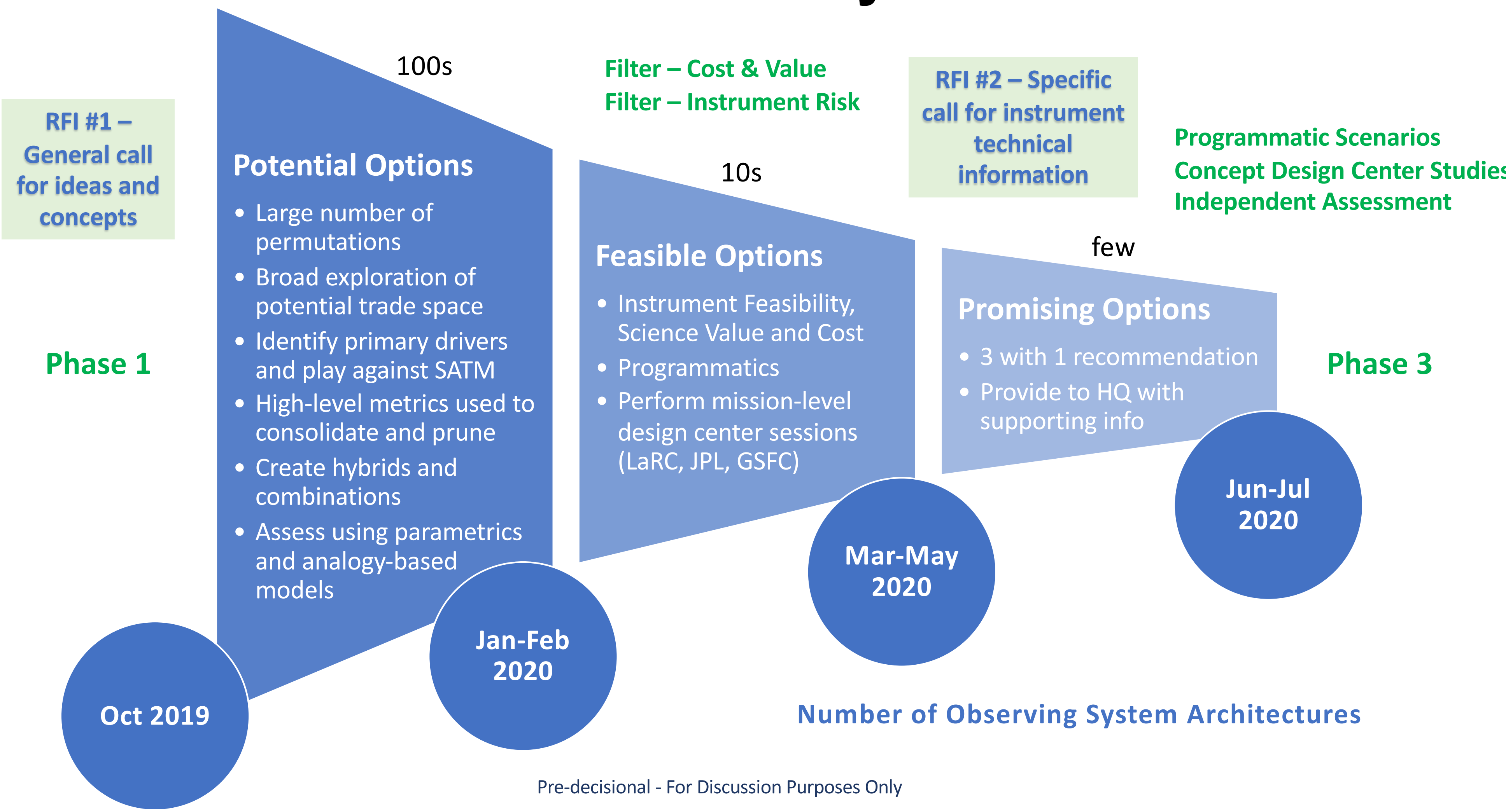
Summary of RFI Responses

- Two SBG RFIs seeking expertise and information from across the spectrum of Earth Science research, applications, technology, mission formulation and implementation
- Input from major stakeholder organizations in government (NASA and non-NASA), academia, industry and the international community





Funnel - from “Many” to “Few”



Architecture Definition and Capabilities

Options for Space-based Systems

Observing System Class	Launch Vehicle	# Platforms	Instrument Configuration	Calibration	Data Latency	Mission Duration
Flagship	Falcon-9 or Vulcan	1	VNIR 0.4 – 1.0 µm	OnBoard	High	3 yrs
Large-Class	Electron or Virgin	2	VSWIR 0.4 – 1.7 µm	Vicarious	Medium	5-7 yrs
Medium-Class	Secondary	Multiple	VSWIR 0.4 – 2.5 µm		Low	
Small-Class	Vega or PSLV		TIR Whisk-Push			
Constellation			TIR PushBroom			
			Micro bolometer			
			TIR Hyperspectral			
			Non-SBG instruments			

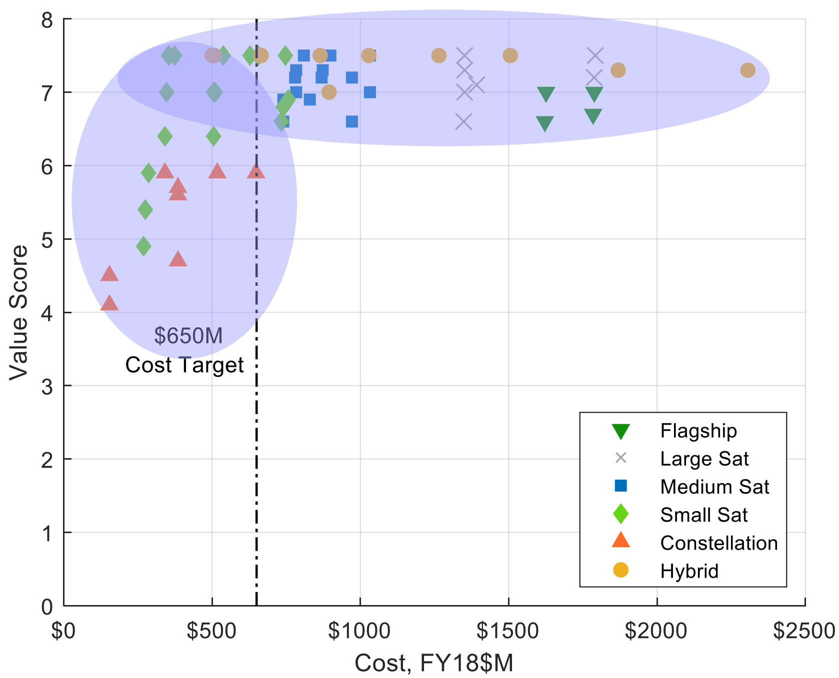
Additional Features

- Off-nadir Pointing
- International Contributions
- Flight Spares
- Airborne Component
- MOps Coordination
- OnBoard Processing
- Hosted Payloiad

- 5 Classes
- 60 Variants
- 765 permutations

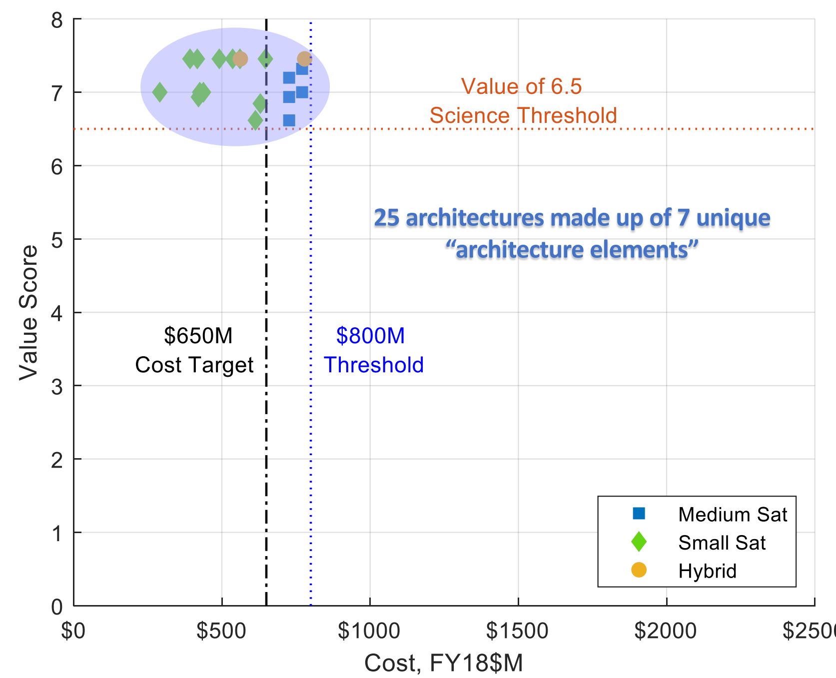
Architecture Down-Select Status (1 of 3)

Winnowed down the number of options from 100s to ~25 high value, affordable architectures



January 2020 (complete)

Applied a series of down-select criteria (value, cost) and refined the concepts



February 2020 (complete)

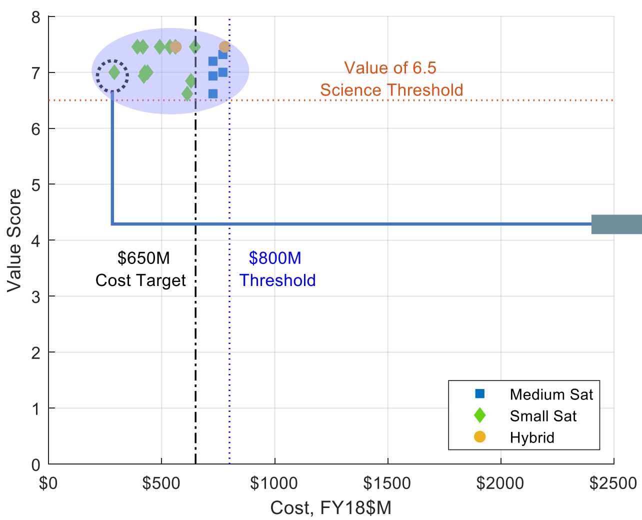
Process - Design Study Candidates

- Feb 2020: Approximately 25 candidate architectures composed of 7 unique “architecture elements” remain in the architecture trade space
  - Pruned based on initial architecture cost estimates and updates following the Team-I study incorporating Subject Matter Expert findings
- Mar – May 2020: The remaining candidates were decomposed into individual architecture elements
  - Design studies focused on sizing and costing architecture elements, not full architectures
- June - July 2020: The products for each architecture element focused design study are combined to rebuild the full candidate architectures
  - Updated and refined estimates for cost effectiveness

Architecture Down-Select Status (2 of 3)

Reassembled the best combination of elements into Promising Architectures

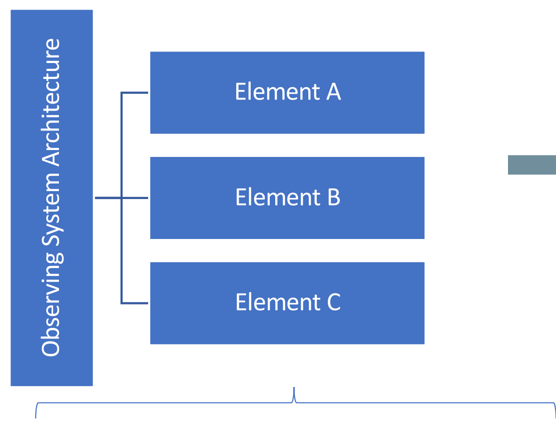
Multiple High Value, Affordable Architectures are made up of common elements

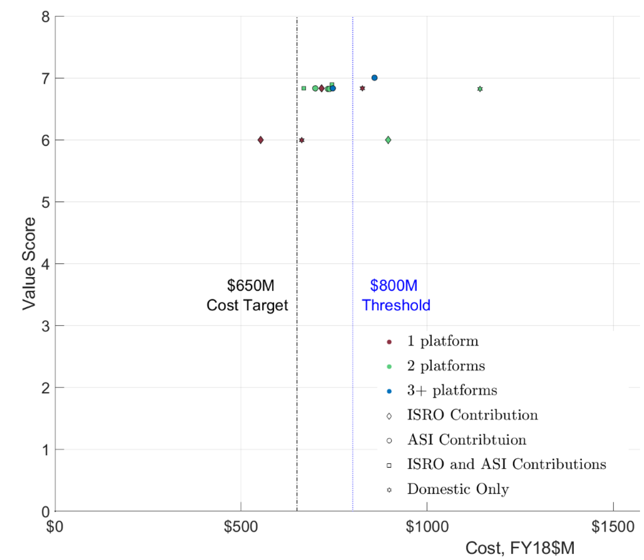


Complete February 2020

Complete July 2020

Design Center Studies focused on sizing and costing these foundational elements





- Small spacecraft with wide-swath (ws) VSWIR
- Small spacecraft with Whisk Push (W/P) TIR
- Small spacecraft with Push Broom (P/B) TIR
- Medium spacecraft with wide-swath (ws) VSWIR and W/P TIR
- Medium spacecraft with wide-swath (ws) VSWIR and P/B TIR
- Constellation spacecraft with TIR bolometer
- Constellation spacecraft with narrow-swath (ns) VSWIR/VNIR

Architecture Elements

Design Study	Element Description	Cost Affordability	Technical Feasibility	Comment
JPL 7/7	**WS VSWIR FreeFlyer**	**Medium**	**High**	**Technically feasible, but challenging to pair with a TIR under cost target**
JPL 7/7	**WS VSWIR FreeFlyer w/ ISRO**	**High**	**High**	**Potential cost reduction with contributed launch vehicle**
	NS VSWIR Constellation	Medium	High	Technically feasible, but challenging to pair with a TIR under cost target
	NS VSWIR Constellation w/ ISRO	High	Medium	Concerns about technical compatiblity with contributed LV
JPL 6/18	**WP TIR FreeFlyer**	**Low**	**High**	**Technically feasible, but challenging to pair with a VSWIR under cost target**
JPL 6/18	**WP TIR FreeFlyer w/ ASI VNIR**	**High**	**Medium**	**Cost allows pairing with VSWIR, some concerns about compatibility with contributed elements**
LaRC 6/15	**WS VSWIR & WP TIR Spacecraft**	**Low**	**High**	**Cost unlikely to be compatible with target**
LaRC 6/15	**WS VSWIR & WP TIR Spacecraft w/ ISRO**	**Medium**	**Low**	**Concerns about compatiblity due to mass**
	PB TIR FreeFlyer	Low	High	Cost does not allow pairing with a VSWIR
	WS VSWIR FreeFlyer (Ind.)	Medium	Medium	Cost makes it challenging to pair with a TIR
	WS VSWIR FreeFlyer (Ind.) w/ ISRO	High	Medium	Data rates require further examination
	NS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	WS VSWIR (Ind) & PB TIR Spacecraft	Low	High	Cost for combined platform well above the target
	NS VSWIR & WP TIR Spacecraft	Medium	High	Cost for combined platform near the target
GSFC 6/23	**PB TIR FreeFlyer**	**Medium**	**High**	**Cost makes it challenging to pair with a VSWIR**
	NS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	Calibration Cubesat	High	High	Could be included as part of observing system as an ehancement
	WS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	WS VSWIR & PB TIR Spacecraft w/ ISRO	High	Low	Concerns about compatiblity due to mass
	VNIR Cubesat	High	Medium	Concerns about pointing compatibility
	TIR Cubesat	High	High	Could be included as part of observing system as an ehancement
	VNIR & TIR Cubesat	High	Medium	Concerns about pointing compatibility

Full set of architecture elements was examined in multiple dedicated sessions in April

Architecture Elements

Recommendation: Two-Platforms

Alternate 1: Single

Alternate 2: Constellation

Design Study	Element Description	Cost Affordability	Technical Feasibility	Comment
JPL 7/7	**WS VSWIR FreeFlyer**	**Medium**	**High**	**Technically feasible, but challenging to pair with a TIR under cost target**
JPL 7/7	**WS VSWIR FreeFlyer w/ ISRO**	**High**	**High**	**Potential cost reduction with contributed launch vehicle**
	NS VSWIR Constellation	Medium	High	Technically feasible, but challenging to pair with a TIR under cost target
	NS VSWIR Constellation w/ ISRO	High	Medium	Concerns about technical compatiblity with contributed LV
JPL 6/18	**WP TIR FreeFlyer**	**Low**	**High**	**Technically feasible, but challenging to pair with a VSWIR under cost target**
JPL 6/18	**WP TIR FreeFlyer w/ ASI VNIR**	**High**	**Medium**	**Cost allows pairing with VSWIR, some concerns about compatibility with contributed elements**
LaRC 6/15	**WS VSWIR & WP TIR Spacecraft**	**Low**	**High**	**Cost unlikely to be compatible with target**
LaRC 6/15	**WS VSWIR & WP TIR Spacecraft w/ ISRO**	**Medium**	**Low**	**Concerns about compatiblity due to mass**
	PB TIR FreeFlyer	Low	High	Cost does not allow pairing with a VSWIR
	WS VSWIR FreeFlyer (Ind.)	Medium	Medium	Cost makes it challenging to pair with a TIR
	WS VSWIR FreeFlyer (Ind.) w/ ISRO	High	Medium	Data rates require further examination
	NS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	WS VSWIR (Ind) & PB TIR Spacecraft	Low	High	Cost for combined platform well above the target
	NS VSWIR & WP TIR Spacecraft	Medium	High	Cost for combined platform near the target
GSFC 6/23	**PB TIR FreeFlyer**	**Medium**	**High**	**Cost makes it challenging to pair with a VSWIR**
	NS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	Calibration Cubesat	High	High	Could be included as part of observing system as an ehancement
	WS VSWIR & PB TIR Spacecraft	Medium	High	Cost for combined platform near the target
	WS VSWIR & PB TIR Spacecraft w/ ISRO	High	Low	Concerns about compatiblity due to mass
	VNIR Cubesat	High	Medium	Concerns about pointing compatibility
	TIR Cubesat	High	High	Could be included as part of observing system as an ehancement
	VNIR & TIR Cubesat	High	Medium	Concerns about pointing compatibility

Low science value, but …

Full set of architecture elements was examined in multiple dedicated sessions in April

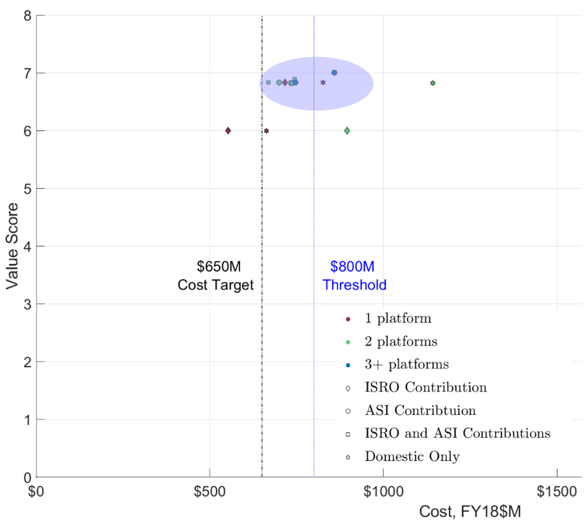
Design Studies

- JPL TeamX – Completed over 2 sessions (4/14–16 and 4/28-30)
  - Conducted high level assessment of multiple architecture elements
- LaRC Engineering Design Studio – Completed (4/21-23 and 5/5-7)
  - Conducted focused assessment of a combined VSWIR and TIR platform
- GSFC Mission Design Lab – Completed (5/11-15)
  - Conducted focused assessment of a TIR-only platform
- ARC Smallsat Study – Completed (2/17 – 6/19)
  - Conducting assessment of cubesat/microsat VSWIR and TIR platforms
- JPL TeamX – Completed in 2 sessions (6/16-18 and 7/7-9)
  - Conducted focused assessment of TIR (ASI) and VSWIR-only (ISRO)

Architecture Down-Select Status (3 of 3)

Deep Dive Design Sessions and Independent Assessment to arrive at 3 finalist Architecture Classes

Design Center studies resulted in final architectures for consideration



Aerospace Independent Cost and Schedule Evaluation

ICE/ISE by Aerospace

Update with Aerospace

Finalist Architectures

1. Two Platform
VSWIR-ws +
TIR w/VNIR +
International Collaboration

2. Single-Satellite
VSWIR-ws & TIR on same SC +
International Collaboration

3. Constellation
VSWIR-ns Constellation +
TIR w/VNIR +
International Collaboration

Other elements considered

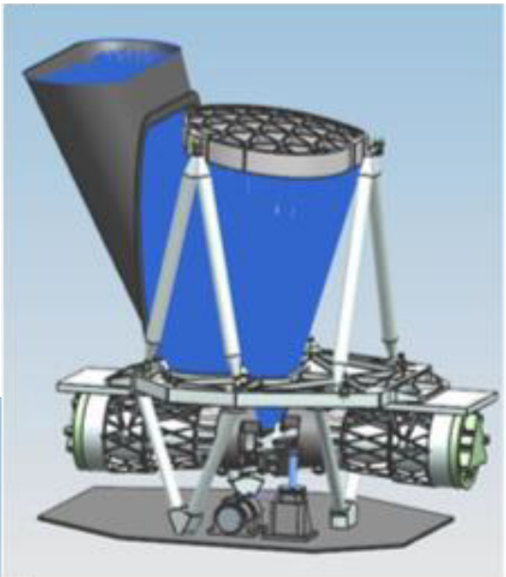
- Microsats for niche roles / improve revisit
- Smallsat-based calibration
- Airborne components
- International Collab to improve revisit

What we have learned along the way

- SBG science & applications community priorities used to assess science value
  - High spatial resolution, high SNR spectral imaging
  - Global sampling of land and coastal ocean
  - Shortest possible revisit frequency
- Cast the net wide and now have 1-3 high-value, affordable (~$650M) architectures
  - A single flagship/large VSWIR/TIR platform (HyspIRI Model) is cost prohibitive
  - Architectures with separate VSWIR and TIR components on smaller spacecraft provide best value and flexibility
  - "Coincidence" TIR and VNIR overlap within minutes (derived from LANDSAT) provides added value
  - Microsats may provide incremental capability/value or pathfinders to sustainable future continuity mission
  - Applications value can be assessed as a function of latency and other factors (on-board processing, downlink, etc.)
  - Airborne component may be included to provide cal/val for L2, L3 and L4 products
  - Calibration (both on-board and vicarious) can be accommodated as applicable to specific architectures
- International partnerships are <u>critical</u> to achieving objectives within the budget guideline
  - Cost sharing and launch opportunities
  - Data sharing to reduce revisit time and improve quality

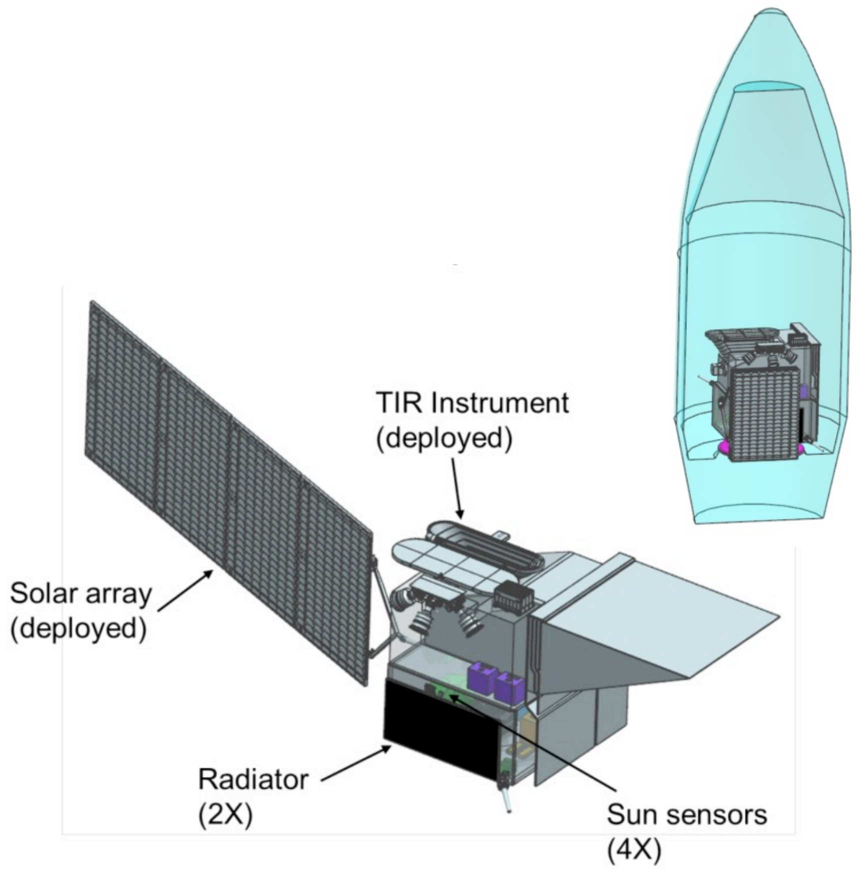
Recommended Architecture – VSWIR Freeflyer (1 of 2)

- Wide-swath VSWIR instrument accommodated on a dedicated spacecraft
- Launch into orbit compatible with ESA CHIME
- JPL Team X designed and sized spacecraft
  - Commercial spacecraft acquisition
- Compatible with potential contributed launch vehicle for cost savings
- Technically closed with costs of approximately 400-500 FY18$M (Phase A-E)
- Investigating partnerships which would reduce the cost to NASA
  - Other spacecraft is separate from a ISRO built and operated VSWIR platform
- Launch Readiness: late 2026 to mid-2027



Recommended Architecture – TIR/ASI Freeflyer (1 of 2)

- Whiskpush TIR instrument and VNIR context camera on a single platform
- This element is completely enabled by the ASI partnership
  - Spacecraft bus and VNIR instrument contributed by ASI
  - Launch on Vega vehicle, also contributed by ASI
- Five thermal IR bands, two mid-IR bands and one short-wave IR band
- JPL TeamX reviewed and confirmed compatibility with the instruments
- Orbit altitude 665-km, GSD <60m and 935-km swath provides global coverage with 3-day revisit
- Technically closed and costs of approximately 200 FY18$M (Ph.A-E)
- Launch Readiness: late 2026 to mid-2027



Architecture Technical Descriptions

- Architecture variants studied (e.g., payload options)
- Key observation performance parameters - Instrument capability
- Nominal acquisition approach (e.g., commercial vs. NASA vs. international partner) and timeline
- System-of-systems analysis and considerations: downlink and data management, combined revisit time including international collaboration
- Which lend themselves to upgrades for applications and why

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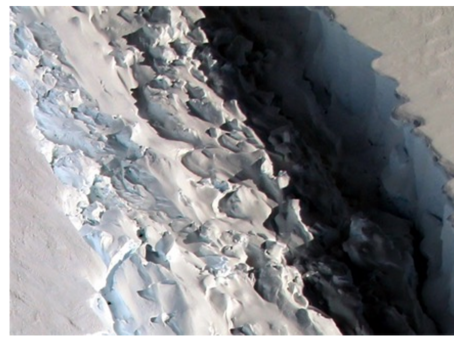
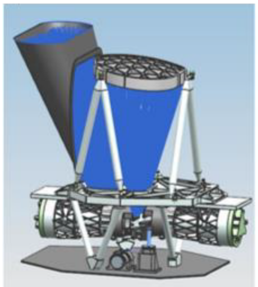


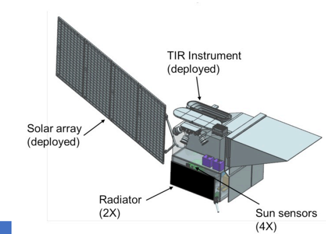
Science and Applications Appraisal

Dave Schimel, JPL, Caltech
Co-lead

Research and Applications >20 Interviews

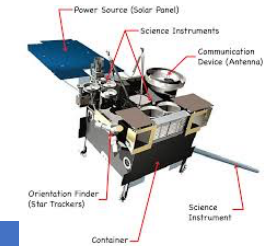


Recommended: Two Platforms



	Two Platforms (TIR + ASI VNIR + ASI LV) + (VSWIR + ISRO LV)
Capability Score-NASA assets	6.83/8
Capability score-with international constellation	7.56/8
Applications Value-NASA assets	High (low latency enabled)
Community assessment-benefits	High for revisit, performance, coincidence for ET, two platforms allow optimizing orbit and LCT
Community assessment-concerns	• Data sharing - will data system support NASA and non-NASA products? • Cal/Val
Cost (A-E), FY18$	600–650 $M (w/o PSLV 700–750 $M)
Risk posture	• TIR enabled by ASI-provided spacecraft and launch – potential schedule risk. • VSWIR enhanced by ISRO-provided LV – risk additional cost if need to procure US launch vehicle. • Ability to decouple development of the two platforms reduces development risk and interdependencies.
Industrial content	• Commercial spacecraft bus • NASA/commercial/hybrid VSWIR (make/buy prior to MCR) • Commercial downlink and data distribution. • Dependence on international contributions
Flexibility/descope	• Assuming ISRO-provided PSLV, may be able to afford adjunct microsat or pathfinder or significant airborne campaigns. • Provides flexibility to align with international collaborators.
Schedule	Date TBD – late 2026 to mid 2027
Comments	ASI partner brings VNIR simultaneity, Potential ISRO spectrometer

Alternate 1: Single-Satellite



	<u>One Platform VSWIR + TIR</u>
Capability Score-NASA assets	6.83/8*
Capability score-with international constellation	7.23/8
Applications Value-NASA assets	Reduced due to LCT, no coincidence for ET
Community assessment-benefits	Partial TIR/VSWIR coincidence for new science on partial swath
Community assessment-concerns	LCT, no VNIR coincidence for ET, reduced revisit for TIR because only one partner orbit
Cost (A-E), FY18$	700 – 800 $M
Risk posture	• All domestic reduces partner risk at increased cost. • Larger, coupled complex satellite with two developments
Industrial content	• Commercial spacecraft bus, • NASA/commercial/hybrid VSWIR (make/buy prior to MCR) • Commercial downlink and data distribution
Flexibility/descope	• Limited flexibility with respect to international partners • Larger, more capable spacecraft may allow hosted payload. • Less flexibility to align with international collaborators.
Schedule	Date TBD – 2027 to early 2028
Comments	Only partial swath overlap between TIR and VSWIR, TIR at suboptimal Local Crossing Time, reduced international collaboration.

Alternate 2: Constellation

	Constellation (TIR + ASI VNIR + ASI LV) + 5-satellite VSWIR narrow-swath constellation
Capability Score-NASA assets	6.83/8
Capability score-with international constellation	7.56/8
Applications Value-NASA assets	May have fewer options for rapid downlink and data sub-setting on orbit
Community assessment-benefits	Maybe sustainable model, if extra copies or parts, then launch on failure is a new sustainability model
Community assessment-concerns	• Unproven approach • May not achieve cross-sensor calibration targets without anchor flagship sensor for reference • Data inhomogeneity, instrument striping causes problems for coverage of rapidly changing phenomena
Cost (A-E), FY18$	600–650 $M (w/o PSLV 700–750 $M)
Risk posture	• TIR enabled by ASI-provided spacecraft and launch – potential schedule risk • VSWIR enhanced by ISRO-provided LV – risk additional cost if need to procure US launch vehicle. • Ability to decouple development of the two platforms reduces dev. risk and interdependencies
Industrial content	• Commercial spacecraft bus –utilize smallsat or “new space” industry • NASA TIR (based on RFI) • NASA/commercial/hybrid VSWIR (make/buy prior to MCR) • Commercial downlink and data distribution • Dependence on international contributions
Flexibility/descope	• Descope or up-scope number of spacecraft with implications for cost/ performance • Future supplemental spacecraft leading to sustainment or continuity • Provides flexibility to align with international collaborators
Schedule	Date TBD – late 2026 to mid 2027
Comments	Cal/Val a major concern, sustainability an intriguing option

Summary

	Recommendation: Two-Platforms	Alternate 1: One-Platform	Alternate 2: Constellation
Science value	7.56 out of 8	7.23 out of 8	7.56 out of 8
Applications value	Highest	High	Intermediate
Community assessment	Optimal	Acceptable	Unknown science risk (Cal/Val)
Risk	Schedule risk depends on partners	Complex development	Unknown level of science risk
NASA Cost (FY$18)*	600-650	700-800	700
Schedule - Launch Readiness Date	2026-2027	2027-2028	2026-2027
Comments	ASI VNIR for coincidence	Partial swath overlap	Cal/Val concerns

* Best-case

Website: www.sbg.jpl.nasa.gov

Mentimeter (Closes 20 July 2020): https://tinyurl.com/SBGlogo

Slack: https://tinyurl.com/SBGslack
@nasa_sbg and #nasasbg

Twitter:
Questions/Feedback please email sbg@jpl.nasa.gov, Dave Schimel (David.Schimel@jpl.nasa.gov), or Ben Poulter (benjamin.poulter@nasa.gov)

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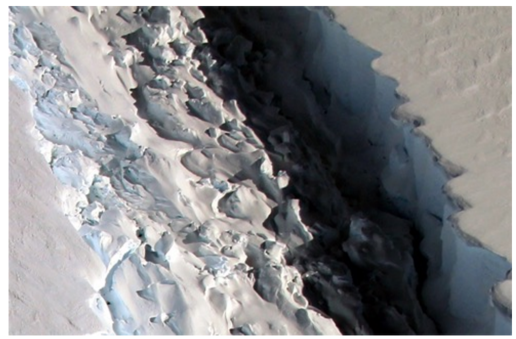
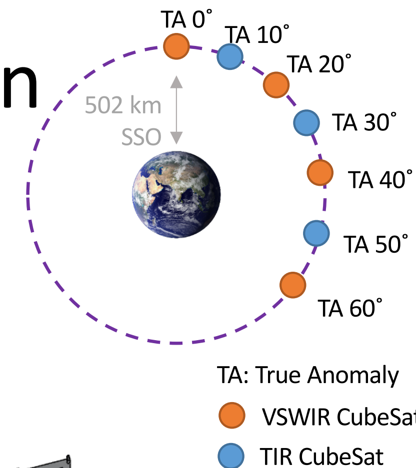
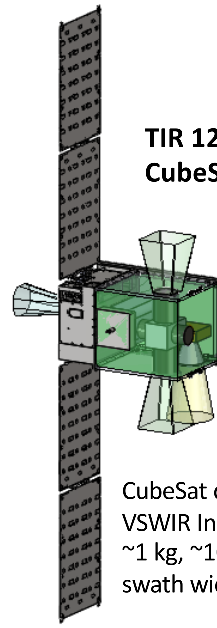


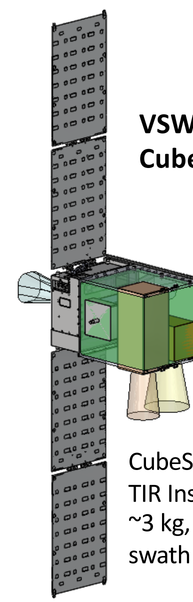

Backup

ARC Design Study – CubeSat Constellation Augmentation to Backbone Architecture



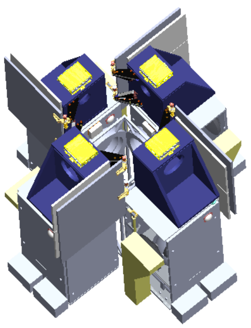
- CubeSat Constellation augmentation to SBG Backbone Architecture
- Provides greater revisit and taskable event-driven measurement opportunities
- Baseline eight spacecraft: four 12U VSWIR CubeSats and four 12U TIR spaced CubeSats spaced 10˚ in true-anomaly (TA)
- Technical report completed, cost estimates finalized
  - Mission Duration: 1-3 yrs
  - MEV each S/C ~16 kg
  - MEV launch mass ~ 128 kg
  - Single commercial rideshare launch

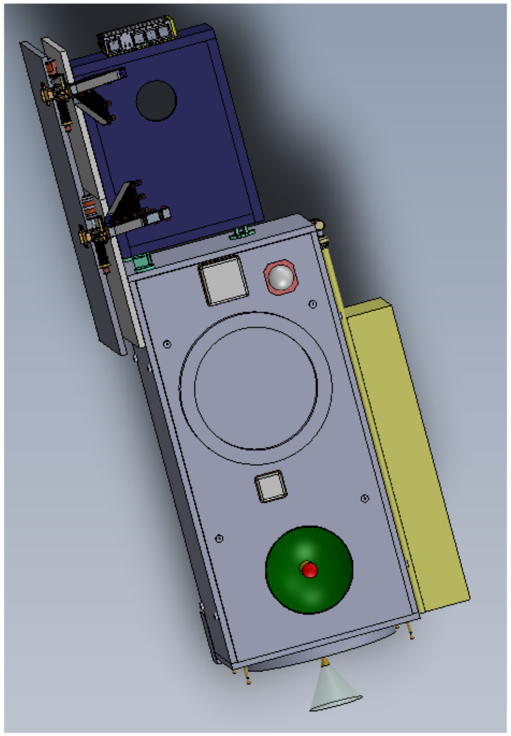




GSFC MDL Design Study – TIR Constellation

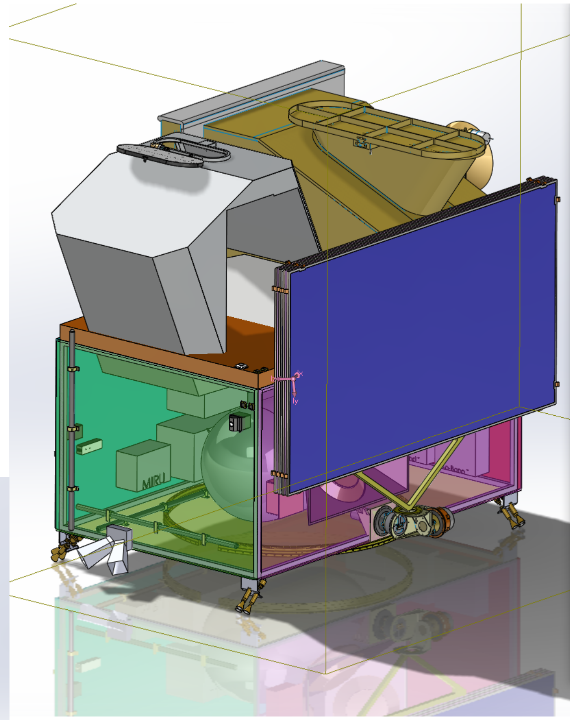
- Landsat derived TIR instrument
- Up to 4 spacecraft on a single launch
- Generic LV interface leveraging Moog Flat Plate Adapter
  - Compatible with Firefly Beta as primary payload or multiple other LVs as secondary
- Technical closed, but 4-satellite constellation cost prohibitive
  - MEV launch mass ~525 kg per spacecraft

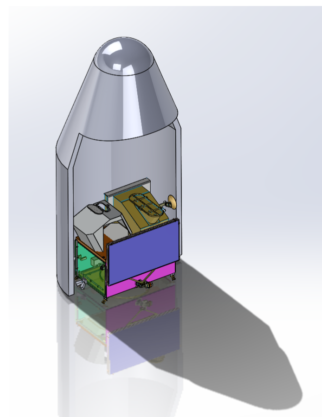




LaRC Design Study – Combined VSWIR/TIR Spacecraft

- Accommodates both a wide-swath pushbroom VSWIR and wide-swath whiskpush TIR on a single spacecraft
- Unlikely to be compatible with co-manifest on an ISRO PSLV assuming 50% mass allocation
- Technical report completed, cost estimates finalized
    - MEV launch mass ~ 1,180 kg





Representative value proposition of an SBG observing system for 4 archetype applications

Mining	Algal Blooms Water Quality	Fire Ecology	Agriculture and Water Resources
"There is a very strong, and established expert need for SBG, particularly if it can be free."'	"Public health is job #1, protecting industry is job #2. But I need help."	"Improved fuel and moisture maps are the biggest unmet need, and they can't come soon enough."	"I rely on scientists to develop production ready ET models, so we have defensible decision-making."
"If there were finally an HSI up there, it would be huge!"	"Monitoring for HABS is great, but not much you can do about them. But finding new sites for high growth shellfish farms will create a new industry."	"Right now most people are not great at even looking at multi-spectral maps or understanding what ET models are telling them."	"Digital agronomy is new for our business, but it is the future of business opportunities and improving farming practices"
"ASTER already gives us most of what we need, for SBG to be a game changer <10 m and high SNR HSI should be the goal."	"There have been other HSI research efforts. We need operational missions we can count on."	"Prescribed fire reduce wildfire, but without better data to support that, we can't shape better policies and oversight."	"60 bands at 5 meters, or every 2 days, could be better than 200 bands at 30m every two weeks."