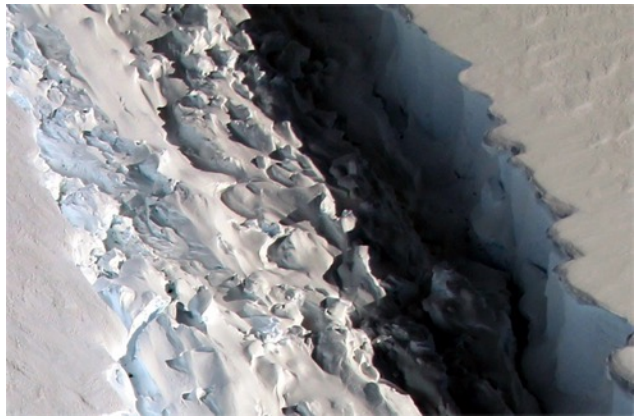
SCIENCE






The Surface Biology and Geology DO is ready to begin pre-Phase A study towards MCR

David Schimel, Jet Propulsion Laboratory, California Institute of Technology

The Surface Biology and Geology DO is defined with considerable detail in the Decadal Survey

SBG is key to understanding in five science and applications focus areas:

- Functional traits, diversity and health of terrestrial vegetation and inland and near-coastal aquatic ecosystems
- Physiology of primary producers, productivity and stress
- Effects of changing land use on surface energy, water, momentum, and carbon fluxes
- Snow and ice accumulation and melt, surface water availability and management
- Active geological surface changes, natural hazards

The Decadal Survey defines the implementation as two sensors "*Hyperspectral imagery in the visible and shortwave infrared; multi- or hyperspectral imagery in the thermal IR*":

1. "….a moderate spatial resolution (30-45 m GSD), hyperspectral resolution (10 nm; 400-2500 nm), high fidelity (SNR = 400:1 VNIR/250:1 SWIR) imaging spectrometer is needed for characterizing land, inland aquatic, coastal zone, and shallow coral reef ecosystems"
2. "….30-60 m TIR observations in the 10.5-11.5 µm and 11.5-12.5 µm spectral regions are needed with a 2-4 day revisit frequency" [1]

1) Note, this specification was updated based on recent work and community engagement to optimize for the DS-specified science and applications.

Key assumptions

- SBG will follow an implementation path to an early launch
  - Community supports Decadal Survey performance targets, no “re-litigation of the science” needed
  - No space-segment technology development for primary VSWIR and TIR instruments due to existing high TRL solutions
  - Builds on capabilities at 5 NASA centers.
- Availability of CEOS RadCalNet and other domain-specific ground calibration networks; airborne sensors for cross-calibrating the international constellation;
- Lunar model for instrument trending.

Key Science and Mission/DO Synergism

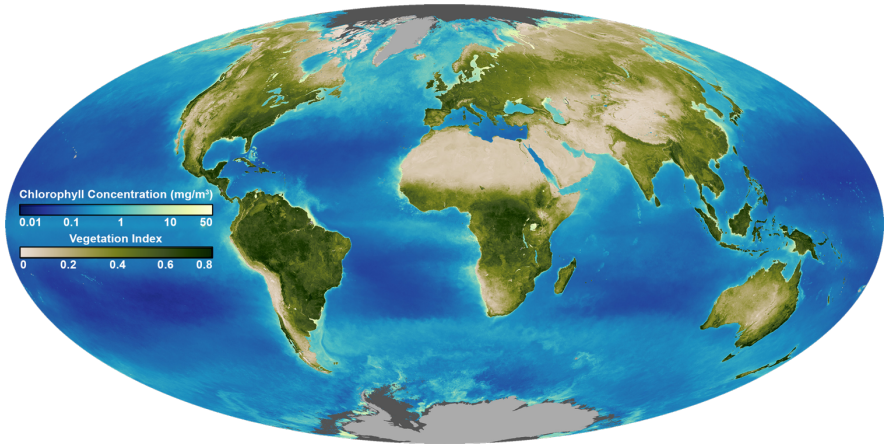
Carbon Cycle and Ecosystems, Hydrology, Weather and Climate, and Geology

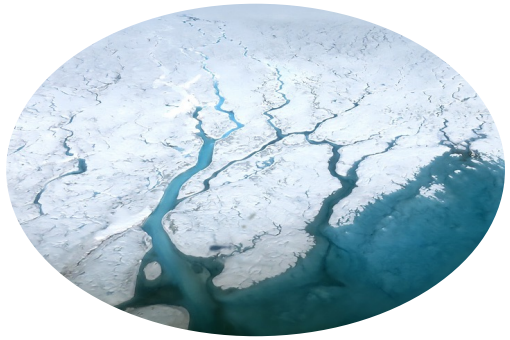
- Changes to the diversity and health of terrestrial vegetation (with NISAR and Sentinel 5/FLEX/GeoCarb) and inland and near-coastal aquatic ecosystems (PACE/GLIMR)
- The diversity of life on Earth, function and functional diversity of land and phytoplankton physiology (with PACE/GLIMR and Sentinel 5/FLEX/GeoCarb)
- Changing land use and the surface energy, water, momentum, and carbon fluxes, albedo, improvements to forecast models (with A-CCP)
- Snow, albedo and evapotranspiration in the water cycle, surface water reservoir management (with MC)
- Active surface changes (eruptions, volcanic lakes, volcanic gases), science to improve forecasting (with NISAR/SDC)
- Hazard risks in rugged topography (landslides, threats to water supply), forecasting and mitigation (with SDC)

SBG at a Glance
Surface Process Foci

Surface Processes

DS Science Questions





Snow melt

Water use

H-1,2 Flows of water and energy

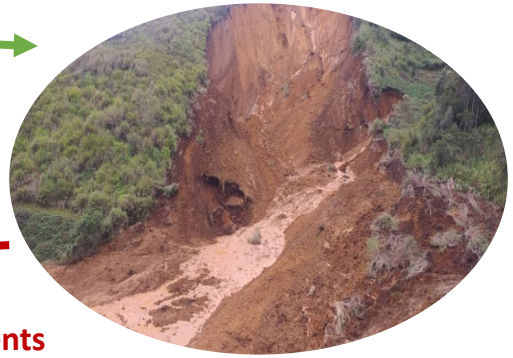
Surface water

Fluxes through watersheds

Sediments Nutrients

E-1,2,3 Earth's ecosystems

Vegetation state Fire



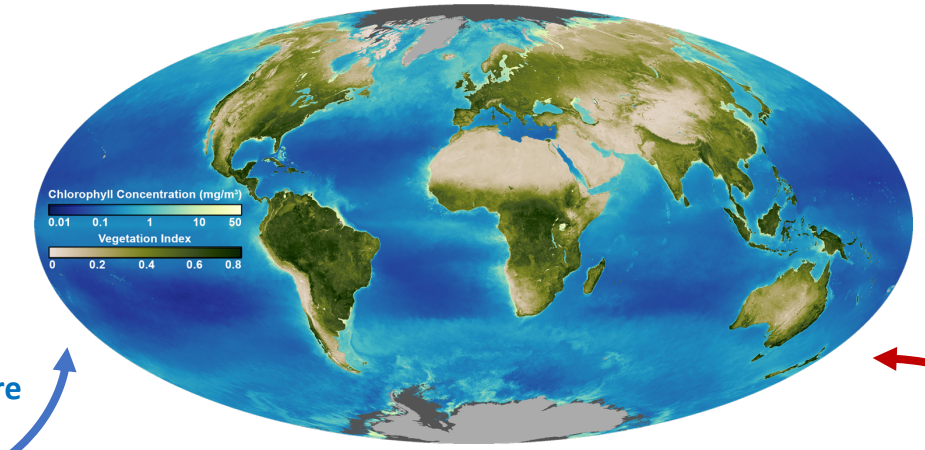
Sediments Nutrients

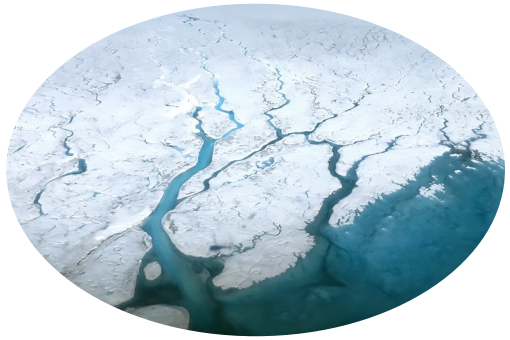
S-1,2 Geological disasters

SBG at a Glance
Earth System Foci

Surface Processes

DS Science Questions





Snow melt

Temperature
Albedo

Water use

Surface water

H-1,2 Flows of water and energy

Fluxes
through
watersheds

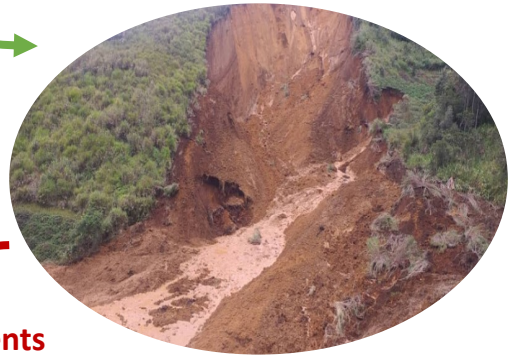
Greenhouse
gases

E-1,2,3 Earth's ecosystems

Sediments
Nutrients

Volcanic emissions

Vegetation state
Fire



Sediments
Nutrients

S-1,2 Geological disasters

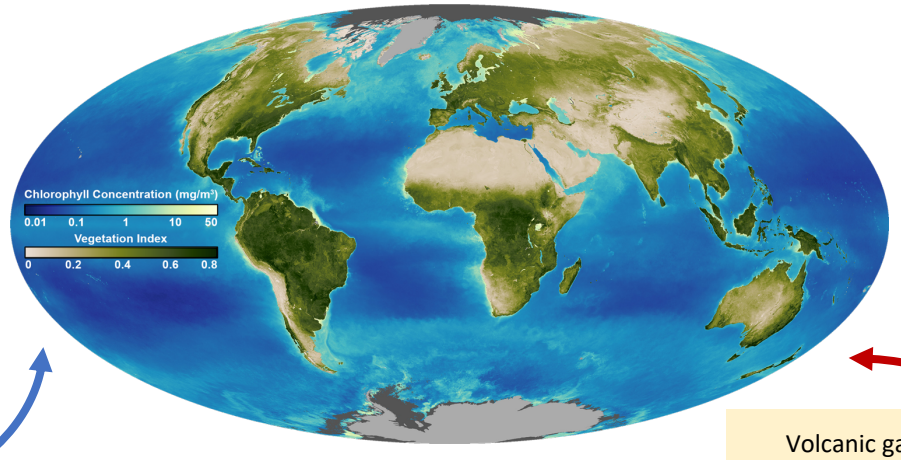
SBG at a Glance Geophysical Observables

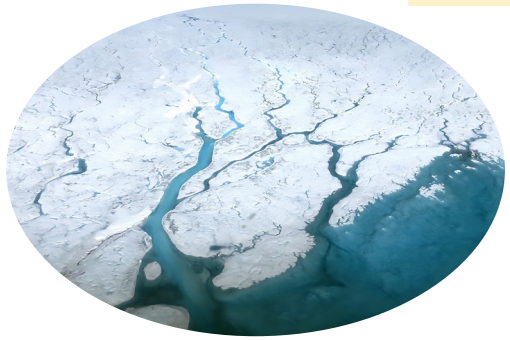
Measurement Needs

Synergy

DS Science Questions

Albedo
Light absorbing impurities
Snow Grain size
Land surface temperature
Eavapotranspiration
Water quality





Temperature
Albedo

Snow melt

Water use

A-CCP
MC

H-1,2 Flows of water and energy

Surface water

Plant functional traits
Canopy structure
Leaf Area Index
Fire severity
Sediment
Chlorophyll
CDOM
Coral cover
Kelp

Greenhouse gases

E-1,2,3 Earth's ecosystems

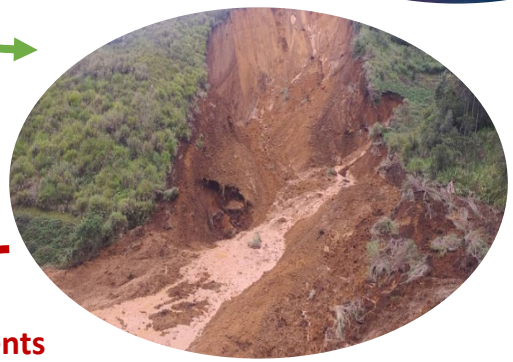
Sediments
Nutrients

PACE
GLIMR

Vegetation state
Fire

Volcanic emissions

Volcanic gases
Lava temperatures
Volcanic lakes
Mineral composition
Newly exposed substrate



Sediments
Nutrients

NISAR
SDC

S-1,2 Geological disasters

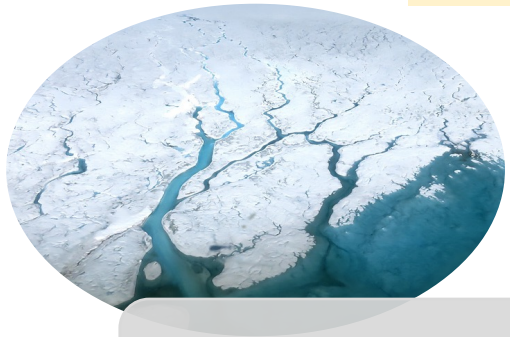
SBG at a Glance
Societal Benefits

Measurement Needs

Surface Processes

DS Science Questions

Albedo
Light absorbing impurities
Snow Grain size
Land surface temperature
Eavapotranspiration
Water quality



Temperature
Albedo

Air Quality
Public Health

Volcanic emissions

Plant functional traits
Canopy structure
Leaf Area Index
Fire severity
Sediment
Chlorophyll
CDOM
Coral cover
Kelp

Greenhouse gases

Volcanic gases
Lava temperatures
Volcanic lakes
Mineral composition
Newly exposed substrate

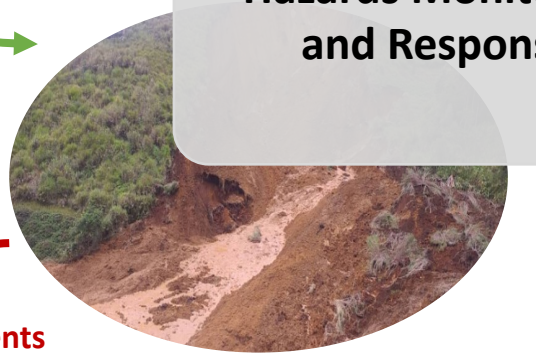
Water Resources
Agriculture
Drought Monitoring

Fire Risk and Response
Conservation and Ecoforecasting
Land Management

Vegetation state
Fire

Hazards Monitoring and Response

Surface water



Sediments
Nutrients

Water Quality
Coastal Resource Management

Sediments
Nutrients

H-1,2 Flows of water and energy

E-1,2,3 Earth's ecosystems

S-1,2 Geological disasters

Key applications: users, importance and economic valuation

Primary Application	Example Potential Users of SBG Data/Products	Key Use Cases of SBG Data/Products
Fire	• State and local fire authorities/responders • Commercial utility companies • Fire risk map/model developers/providers • Prescribed burn companies and regulators • Insurance companies	• Pre-/post-fire fuel mapping of vegetation type, live/dead, moisture for risk severity • Fire risk model via better fuel/moisture data • Utility vegetation management, risk mitigation, and operations/planning changes
Agriculture	• Ag input and equipment companies • Crop consultants, large-farm managers, commodities traders, and insurers • Ecosystem market communities • Ag/water resource/policy managers	• Ag and water resource, drought monitoring • Crop type/composition/health monitoring (for ag policies, supply chain, input optimization) • Crop residue/monitoring (e.g., for credits, monitoring, reporting, and verification [MRV]) • National food security/yield forecasting
Algal Blooms	• Local health/environ./water agencies • Aquaculture (fish/shellfish) companies • Drinking water utilities/engineering firms • Forestry/lake management companies/orgs	• Regional-scale water body quality monitoring • Early warning of harmful algal blooms (HABs) • Shellfish site water chemistry for growth/health • Watershed/source pollution/nutrient monitors
Mining	• "Spectral geologists" and exploration consultants for large mining companies • Regulatory/compliance organizations • VASPs serving the energy and mineral resources sectors	• Greenfield/brownfield large-area explorations • Geologic process, mineral/vegetation surveys • Mine opening/operations baseline/monitoring • Environmental/health/regulatory monitoring on-site and in surrounding environs

Draft Community Assessment Completed

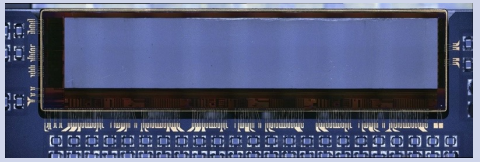
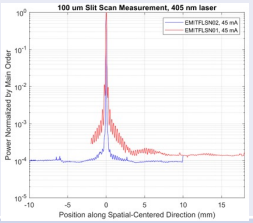
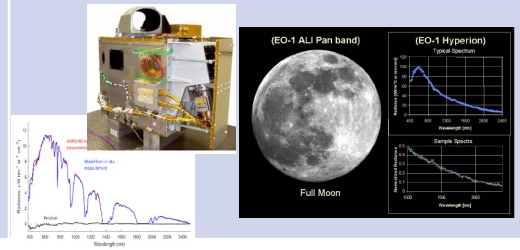
https://sbg.jpl.nasa.gov/doc_links/user-needs-and-valuation-study/view

Measurement targets

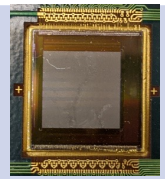
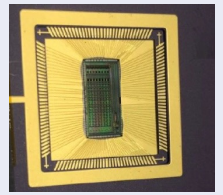
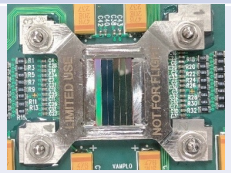
Nearly all of the Most/Very Important objectives from SBG's five science focus areas and multiple applications area needs can be met with:

Parameter	Spatial Resolution	Revisit (Swath)	Spectral range and resolution	Radiometric performance and SnR
VSWIR	30 m for vegetation, snow, agriculture, minerals	16 days to resolve natural and crop timing, snowmelt, aquatic communities and health	400-2500 nm with 10 nm bands to retrieve vegetation, aquatic composition, minerals, crop type, snow grain size and albedo	5% radiometric uncertainty, SnR 400 (VNIR), 250 (SWIR) @ 25% Reflectance
TIR	60 m to resolve land cover, water bodies	3 days to resolve land surface temperature, evapotranspiration	4 TIR channels to resolve T vs emissivity, 1 or more mid-wave for high temperature features	0.2 NEdT or 1K for LST
TIR + VNIR	60 m for ET applications	simultaneous to resolve crop ET, uncertainty and coverage decrease with temporal separation	TIR as above, two VNIR channels for vegetation index normalization	As above for TIR, not demanding for VNIR (commodity sensor)

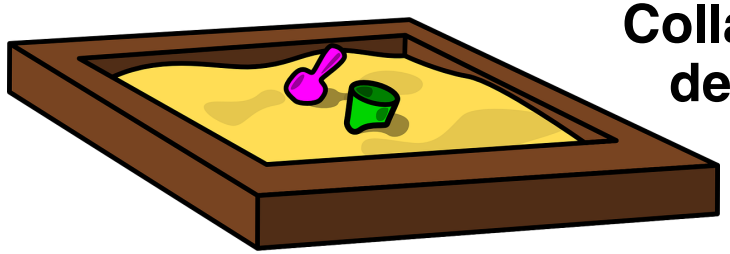
Key technologies: VSWIR

Technology	TRL	Heritage (Justification)	
Focal Plane Arrays: Two Teledyne CHROMA-D: 3072x512 digital focal planes deliver wide swath imagery with 30m spatial resolution	5/6	Recent testing; flight qualification of similar GeoSnap detector	
Gratings: Large, concave, low scatter, full spectral range gratings that support optically fast, high signal-to-noise VSWIR spectrometers	≥ 6	EMIT Earth Venture, MISE (Europa Clipper), and airborne sensors	 
High uniformity optical designs: Ultra uniform optical slit to support SBG VSWIR requirements	≥ 6	EMIT, MISE, and airborne sensors	
Precision ultra-black light trap for stray light control.	≥ 6	EMIT, MISE and other sensors	
Calibration/Validation: Technologies for instrument, on-orbit, and vicarious calibration, trades related to spectral, radiometric, spatial, uniformity performance.	≥ 6	Solar diffuser, vicarious RadCalNet, airborne, etc.	

Key technologies: TIR

Technology	TRL	Heritage (Justification)	
Focal Plane Array (FPA) and readout integrated circuit (ROIC): Mercury Cadmium Telluride (MCT)	5/6	ECOSTRESS (same form and fit, 2x function)	
High speed application specific integrated circuit (ASIC) readout electronics	5/6	Landsat/Sidecar (2X the maximum speed of Sidecar)	
Low power cryocooler and electronics	9	ECOSTRESS (same focal plane temperature)	
High fidelity focal plane spectral filtering	5/6	ECOSTRESS (same fit and function but with 2 more filters)	
Lightweight, high emissivity blackbodies	9	ECOSTRESS (same form, fit and function)	

Key technologies: Data Science

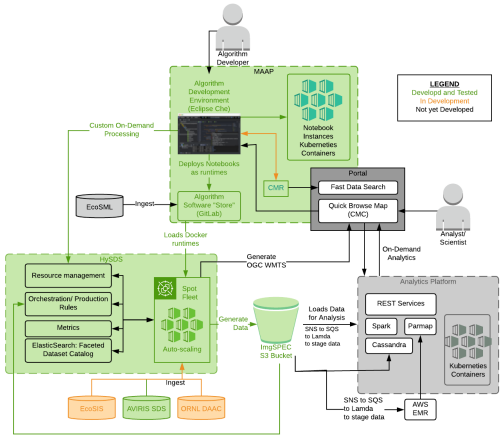


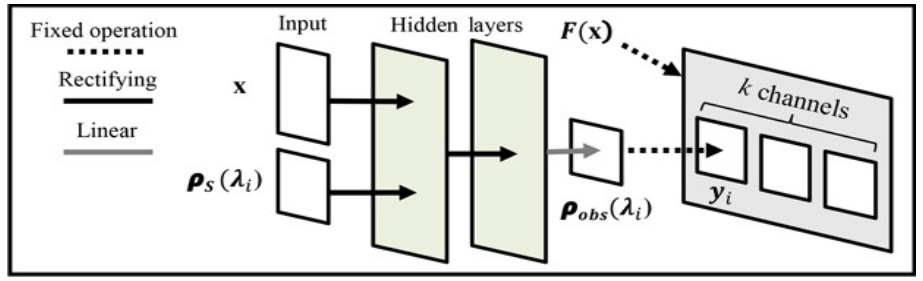
Collaborative algorithm development and test environment

- All relevant data accessible in one place (data integration).
- Data preprocessed and harmonized for common access.
- Ability to develop and test ~200 candidate Level-2+ algorithms at scale, and make comparative trades.
- Open science: share and reuse algorithms

Observing system data production service

- On demand and configurable data processing.
- Tight integration with the archive and partner decision support systems
- Quantify uncertainty in data products
- Scalable cloud-based infrastructure
- Open science (transparent algorithms and reproducible data)
- Low latency production option





Data analytics

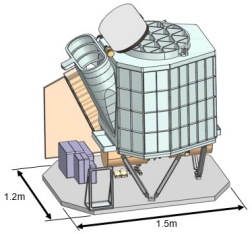
- Tools to calibrate and validate the science data products.
- Analysis tools next to the data
- Machine learning for data understanding and interpretation
- Fast algorithms for global fields
- Multidimensional data visualization for high dimensional data

SBG Architecture Approach

Surface Biology Geology (SBG) Observing Architecture consisting of 3 elements

1 - VSWIR

- Wide swath hyperspectral instrument
- Observation swath of 185 km
- 6000 cross-track samples
- VSWIR 632 km Sun-Sync Orbit, 10:45 local time

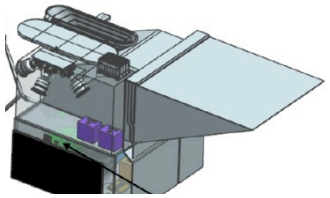


NASA VSWIR on industry bus

- NASA/Industry Payload
  - RFI indicates interest/capability. Make/Buy/Hybrid prior to MCR
- Industry Spacecraft
  - consistent with existing capabilities and heritage configurations
- Domestic Launch
- Commercial downlink and data distribution
  - Large SBG data volumes can leverage commercial solutions for cloud based data storage and computing

2 - TIR

- Wide swath thermal instrument
- Observation swath of 935 km
- TIR 665 km Sun-Sync Orbit, 13:30 local time

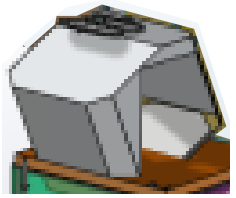


NASA TIR hosted on ASI PLATiNO

- NASA TIR Payload
  - RFI did not indicate industry interest/capability
- ASI VNIR Payload
  - Fulfills threshold capability for TIR/IS coincidence
- Italian Industry Spacecraft
- Foreign Launch - Vega
- ASI downlink and data distribution

3 - VSWIR Smallsat Demo

- Narrow swath tech demo/pathfinder
- Observation swath of <20 km
- Fly leading or trailing VSWIR

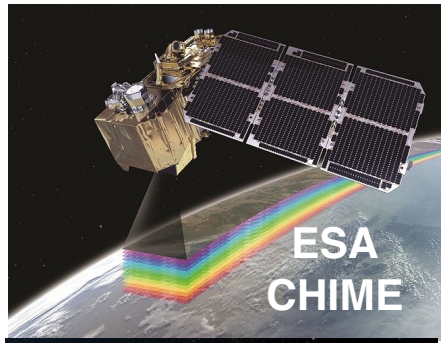


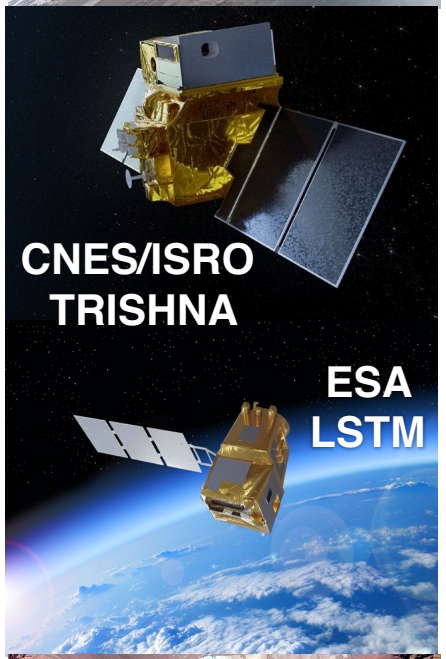
VSWIR-demo built by industry

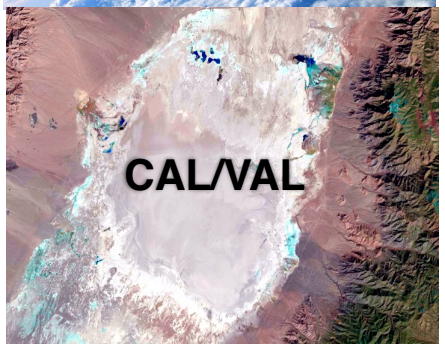
- Industry Payload
- Industry Spacecraft
  - SBG Request for Information focused on small scale, innovative VSWIR solutions
- Ride-along VSWIR Domestic Launch
  - Compatible with Venture class LVs or as secondary on SBG
- Commercial downlink and data distribution

Data Communications

- **Petabyte class mission**
  - 5 Petabytes of uncompressed L1 data over 3-year primary mission lifetime
- **Direct broadcasting**
  - Near instantaneous downlink after data collection for regional, real time applications
- **Ground architectures**
  - GDS facilities for concurrent big-data DO missions.
  - Networks for international data sharing and direct into the cloud
  - Cyber security
- **On-board processing**
  - Downlink data prioritization
  - Data reduction including onboard cloud screening and 4x lossless compression
  - Event detection







Key partnerships and NASA leadership in open data

- **Enabling: maximize science strength and cost effectiveness:** Joint mission with ASI provides science strength, VNIR camera, launch and spacecraft for TIR instrument.
- **Enhancing: improve science and applications value:** Open data harmonization with CHIME (VSWIR), LSTM and TRISHNA (TIR) reduces revisit, improves latency, and increases science and applications opportunities.
- **Data quality: unprecedented data quality and access** through use of terrestrial and aquatic networks for vicarious calibration and validation activities on six continents.

What did we learn

- A large Science and Applications community is ready and eager to deploy these new technologies
  - 300+ attend webinars, 1700+ registered on SBG email list
  - Strong desire and potential for MSI/HBCU/Tribal participation in science and applications
  - Private sector interest in SBG data, particularly in developing new, value-added products for their customers
  - Leadership from five NASA centers (JPL, GSFC, ARC, LaRC, and MSFC)
- The recommended approach achieves a threshold level of performance against science and application needs
  - Spectral performance needs are met, revisit partially met, could be fully met with successful international collaboration
- Collaborating with international missions can reduce revisit to optimal needs for science and critical applications, e.g., water quality and wildfire

What did we learn (cont)

- Meeting Decadal Survey performance target for both wavelength ranges led to a constrained trade space within resources available.
- No space-segment technology development needed for primary VSWIR and TIR instruments due to existing high TRL solutions
- Algorithms and workflows for spectroscopy are not mature, algorithmic complexity and data volume, combined lead to low TRL for GDS/SDS—investment is required (eg, MEET-SBG, SISTER pathfinders)
- Technology for constellations of high-performance low-cost instruments to enable continuity remains low TRL, investment is required (tech demo)