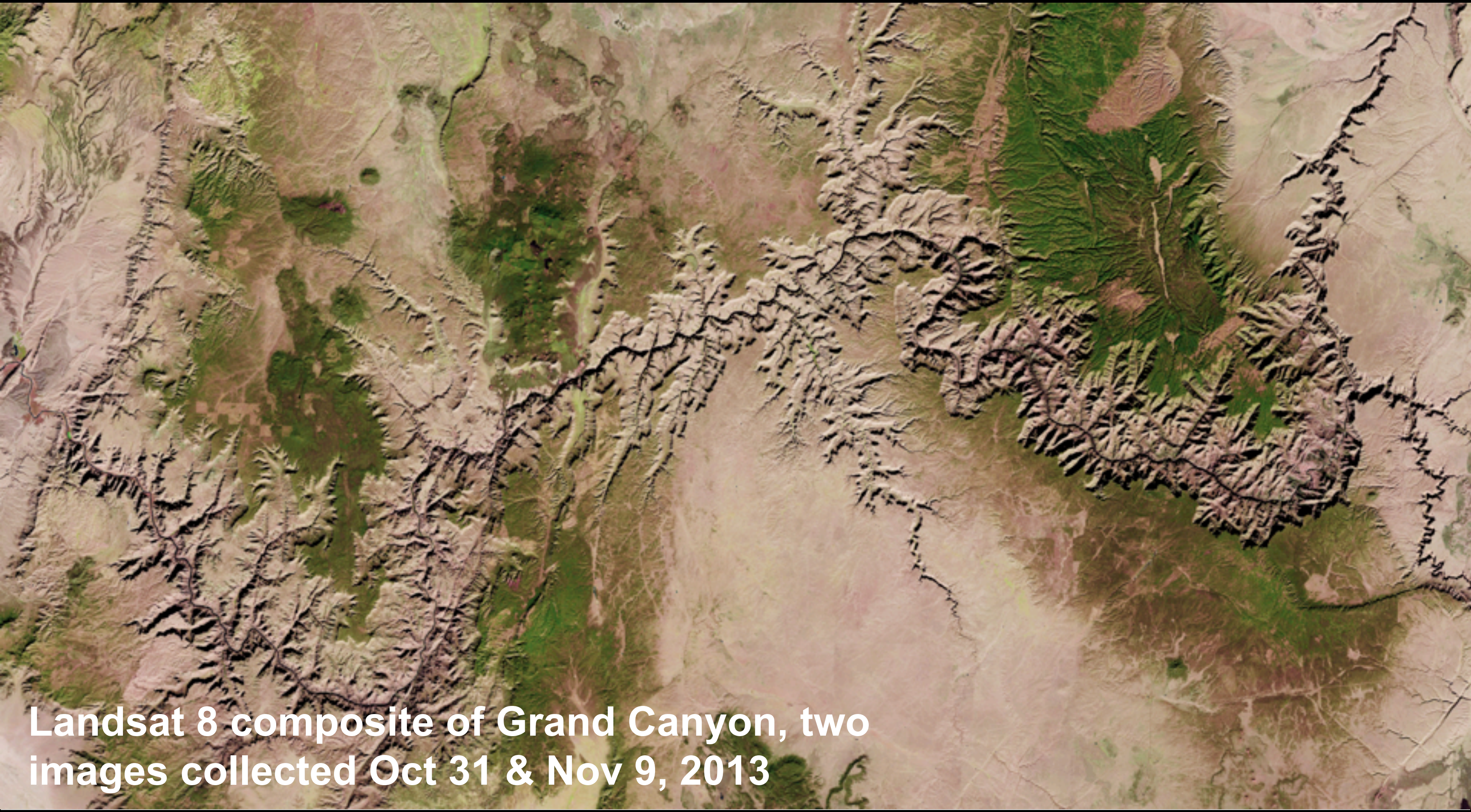
NASA Sustainable Land Imaging Program
Progress Report & Path Forward


Landsat 8 composite of Grand Canyon, two images collected Oct 31 & Nov 9, 2013

24 January 2014 Checkpoint Briefing for Public Release

Overview of what we are going to cover

- We will present NASA's implementation of the Sustainable Land Imaging (SLI) charter we received in 2013 from the OSTP.

- We will show the methodology we are employing to
  - Define the study trade space, including establishing target measurement and program objectives
  - Methodically evaluate architecture approaches
  - Understand the current and projected technology capabilities
  - Conduct comprehensive mission, instrument, science and ground system cost estimates

- Our plans are being updated based on developing events
  - Study schedule is being updated to comply with FY14 Congressional appropriations guidance
  - Some conclusions can be made based on the first 4 months work by the AST

PROGRAM OBJECTIVES DEFINITION

OMB/OSTP Direction to NASA

- $30 million in FY14 for NASA to study options for a future sustained land imaging system, in collaboration with USGS.
- The study shall define a system for sustained global land-imaging multispectral and thermal infrared information for an approximately 20-year period starting in 2018.
- The study should provide options which consider various weightings of near-term capability, continuity/gap risk mitigation, and technology infusion over the system's lifetime.
- While the basic system requirement is the continuation of global data and information having the quality of Landsat-8 products, the study should consider refined capabilities requested by the user communities.
- The study should also consider a range of implementation strategies that could spur innovation and increase efficiencies.
    - Options should include possible international and private sector collaborations
    - Options should also include integration of hyperspectral capability as appropriate.
- The study should recognize that lowering the cost of the system is an important goal.
    - For example, cost of the options developed under this study should not exceed $120 million in average annualized costs to NASA over the life of the system, including development, launch, and commissioning, and should take into account the likely highly-constrained budget outlook over the current 5-year NASA budget horizon.
- NASA should report the results of the study to OSTP and OMB by August 15, 2014.

Additional Guidelines For the Study Team

Three Basic Study Tenets for the Program

- Sustainability
  - The SLI program should provide the data products for the long haul, without extraordinary infusions of funds, within the budget guidance provided.
  - It should also ensure the technology required for the program is available and appropriate for the long haul

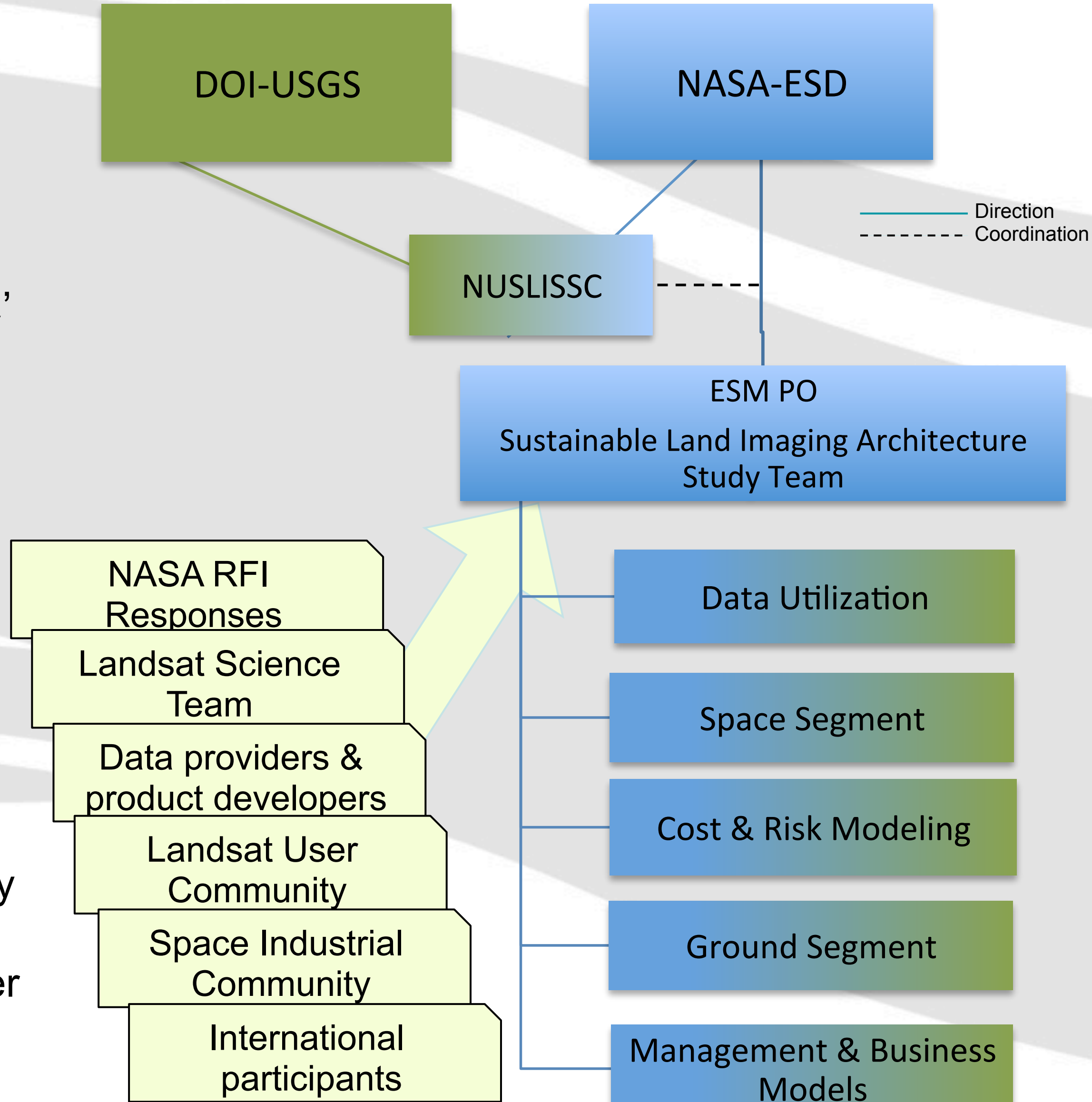
- Continuity
  - The SLI program should continue the long term Landsat data record. This does not necessarily mean the imagery per se, but the usable products that define the utility of the data record.
  - Understanding how the data are used is essential when considering potential architectures.

- Reliability
  - The SLI program should exhibit a form of functional redundancy. The data sets should be able to draw on equivalent or near equivalent deliverables from different sources to provide the data for the highest priority land imaging data products.
  - With these “near equivalent” data sources identified in advance, the loss of a single satellite or instrument on orbit should not cripple the program or significantly impact users, and the program will exhibit graceful degradation.

Sustainable Land Imaging Study Execution

- NUSLISSC = **N**ASA/**US**GS **S**ustainable **L**and **I**maging **S**ystem **S**teering **C**ommittee
  - NASA Members: Dave Jarrett, Brad Doorn, Woody Turner
  - USGS Members: Tim Newman, Tom Cecere, John Crowe, Ray Byrnes, Steve Covington

- Landsat Science Team (LST) also will provide the AST with technical evaluation of:
  - Applications requirements
  - Possible contributed measurements (Sentinel 2, for example)
  - Status on radiometric sensitivity analyses
  - Architecture trade spaces under consideration



AST Charge and Process

- Land Imaging AST Charge (September 2013)
  - Define a Sustainable Land Imaging (SLI) system delivering global land-imaging multispectral and thermal infrared information for a 20-year period starting in 2018
  - Provide options which consider various weightings of near-term capability, continuity/gap risk mitigation, technology infusion over the system's lifetime, and cost
  - Consider refined capabilities requested by the user communities
  - Include consideration of new measurement approaches, as well as potential international and private sector partnerships

$K	FY14	FY15	FY16	FY17	FY18	FY19 & Beyond
Sustainable Land Imaging (SLI)	30,000	84,000	94,800	117,900	117,900	120,000

- AST Study Process
  - Establish study trade space via expert knowledge, intensive AST discussions, and RFI responses
  - Trade space is explored via several design cycles, and adjusted through each
  - Appealing architectures that are likely to satisfy budget constraints are further refined and assessed

ARCHITECTURE STUDY TEAM EXECUTION

Sustainable Land Imaging (SLI) Study Timeline

✧ Establish Architecture Study Team (AST)	Sep 2013
✧ Initiate Community outreach	Sep 18, 2013
✧ AST Design Cycle 1	Nov 1, 2013 – Jan 10, 2014
✧ Checkpoint Review 1 with NASA ESD	Jan 21/22, 2014
✧ NASA/USGS Stakeholders Briefing	Jan 24, 2014
✧ AST Design Cycle 2	Jan 27 – Mar 15, 2014
✧ Coordination with NASA ESD on best path(s) forward	mid-Mar 2014
✧ SLI Community/Industry Forum	Late Mar/Early Apr 2014
✧ AST initial SLI architectures report to NASA ESD	Apr 15, 2014
✧ NASA SLI Interim Report to Congress	May 2014
✧ AST completion of full SLI program options	May 15 – Jul 15, 2014
✧ Completion of SLI study report	Jul 2014
✧ Agency review and concurrence	Aug 1-15, 2014
✧ NASA ESD Sustainable Land Imaging report and recommendations delivery to OMB/OSTP	Aug 15, 2014

AST Focus Group Organization

- Exploration of the Land Imaging trade space has been divided into the focus group areas, with each major area led by members of the AST
  - Requirements development and prioritization
  - Instrument and observatory design metrics, including current and future instrument capabilities, and spacecraft & launch vehicle factors
  - Architecture technical concepts, including orbits, FOV, single vs. multiple spacecraft, and mission operations
  - Business models, including procurement models, commercial options, block buys, and international partnerships
  - Architecture gap analysis
  - Cost assessment

Collection of Inputs and Information

- USGS NLIR Pilot Project elicited over 150 distinct, representative user applications where Landsat data is used routinely to produce and provide consistent services or informational products
  - Pilot study is part of a planned larger effort by the USGS that will continue for 1-2 years, so this elicitation continues, but even as a Pilot it provides useful insights to guide our architecture evaluations

- USGS-chartered Landsat Science Team (LST) consulted for their insight into past, current, and desirable future capabilities
  - Addressing specific questions on Applications-specific data requirements, Continuity definition, assessment of Sentinel-2 capabilities relative to Landsat, among others

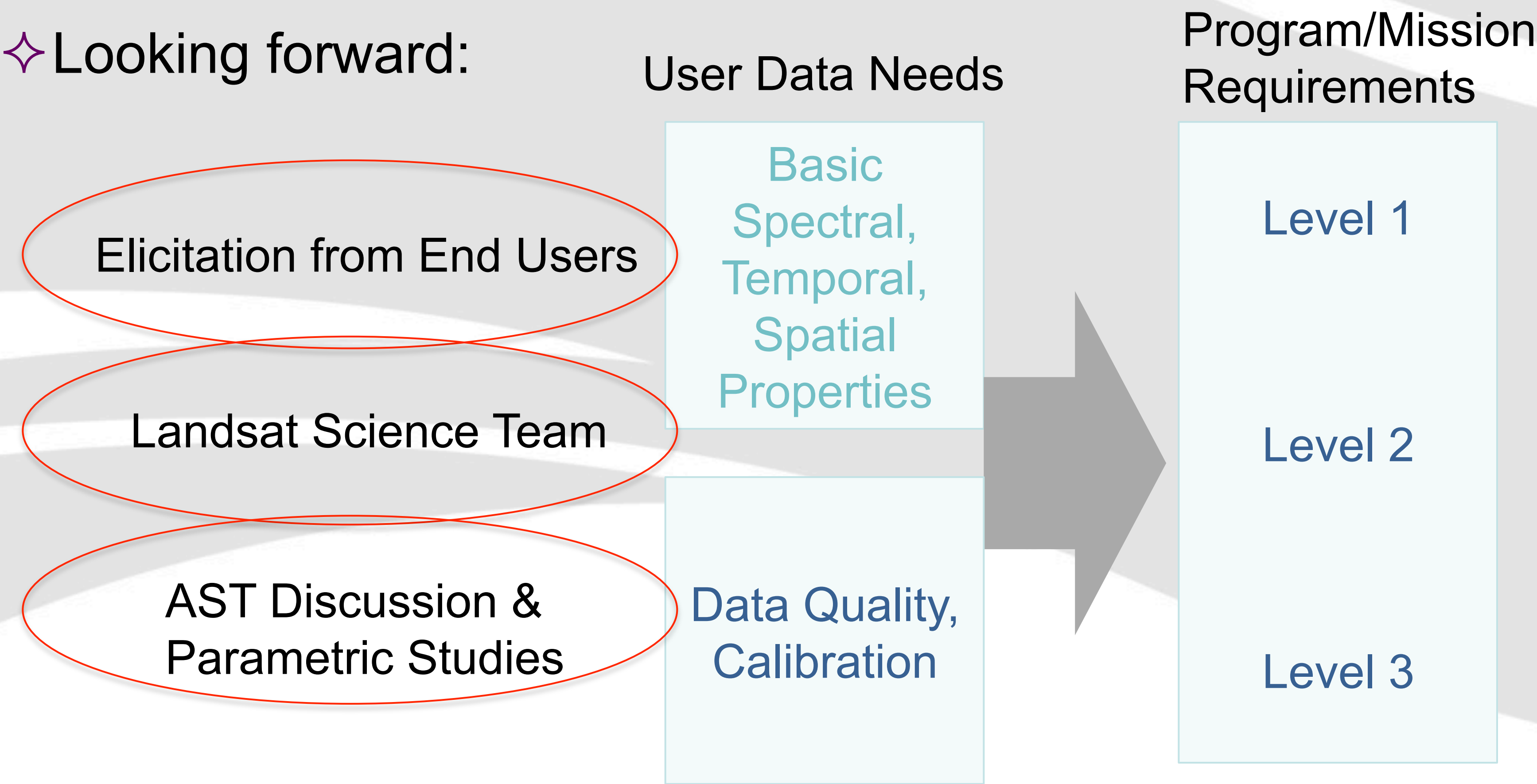
- NASA released an open RFI for industry ideas on how to address the SLI program objectives
  - ~35 responses covering a broad range of proposed solutions, industry capabilities, and data processing approaches

Legacy Landsat Performance

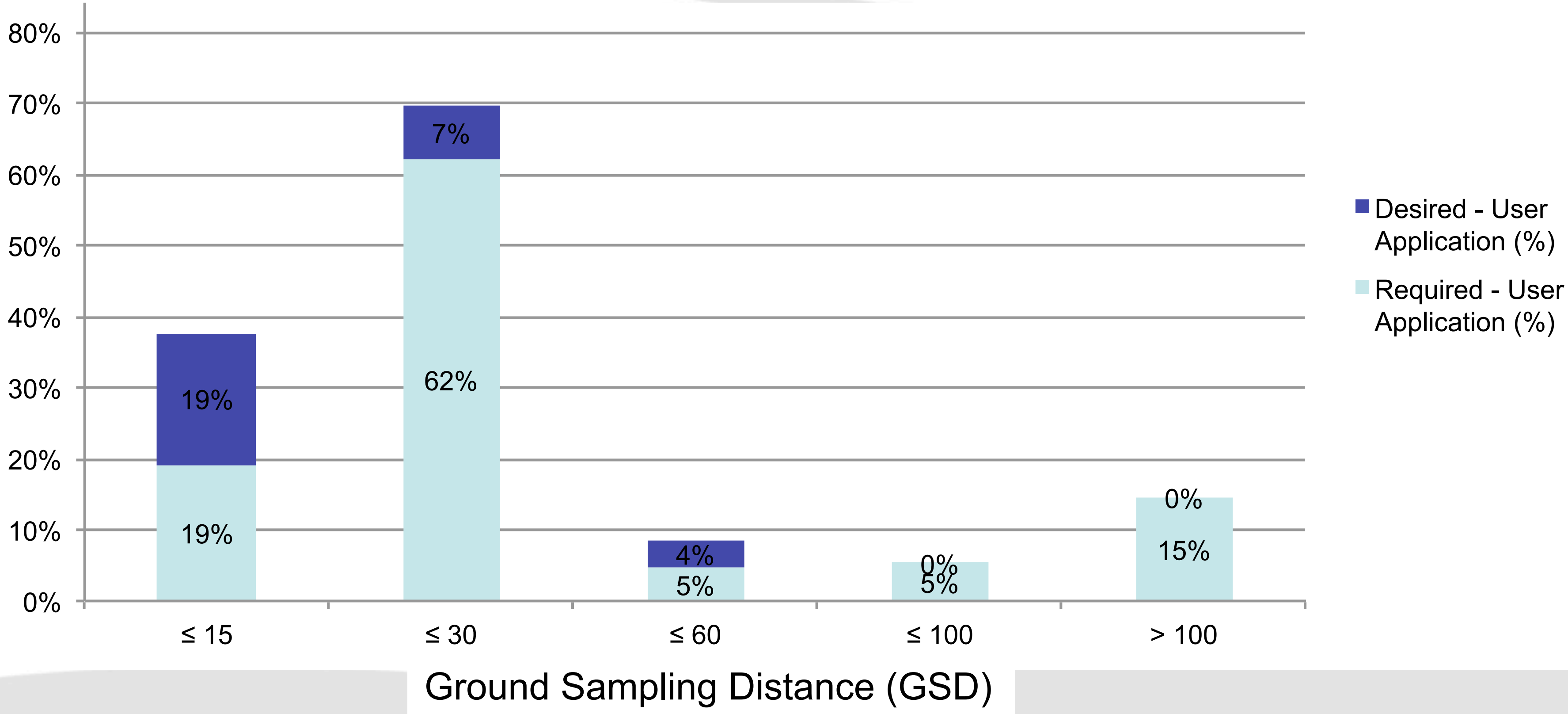
Performance Parameter	Rationale
Spectral coverage across VNIR, SWIR, and TIR	• *Most applications require multiple spectral regions*
30m (120m) spatial resolution for VSWIR (TIR)	• *Spatial resolution supports land management, land use, and ecosystem studies;* • *Broad area coverage supports regional/continental monitoring*
Ability to image each point on the globe every 16 days (8 days realized for majority of Landsat history)	• *Time series needed to characterize seasonal change* • *More frequent observations help mitigate cloud cover*
Sun-synchronous orbit, ~10 AM crossing time	• *Radiometric continuity with existing Landsat record*
Near co-incident imaging of spectral bands (VSWIR within seconds; TIR within minutes of VSWIR)	• *Near-simultaneous VSWIR required for multi-band indices;* • *TIR and VSWIR coincidence supports ET, water resources applications*
Global coverage of land area	• *Required for global land science & applications*
Less than 5% uncertainty in absolute spectral radiance	• *Provides radiometric continuity for long-term monitoring and change detection*
View angles < +/- 15 degrees	• *Limit BRDF variability within archive*
Free and open data distribution	• *Hallmark of Landsat program*

Framework for Establishing Program Performance Metrics

- Start with the 40+ year Landsat data record
  - Established the historical record and the legacy performance
  - Back compatibility with data record is an essential element of the SLI
- Looking forward:



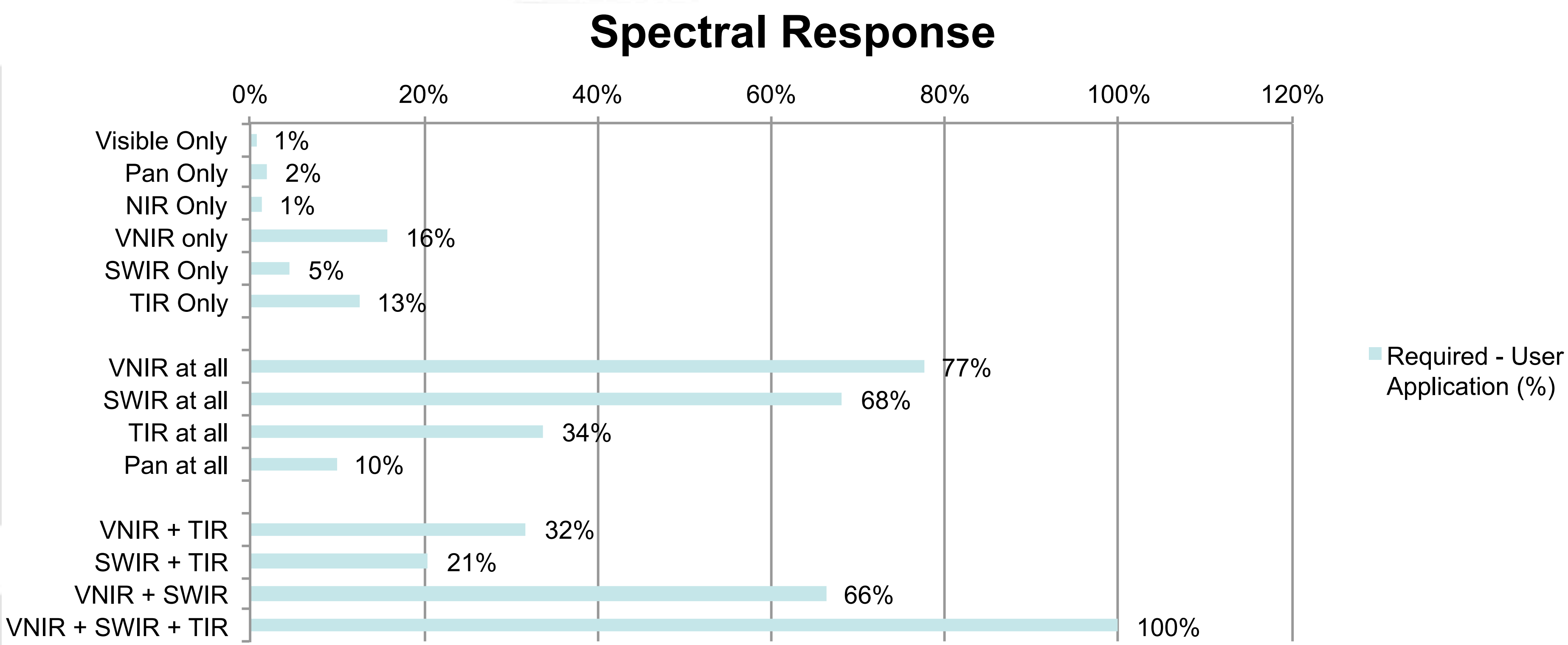
Example Input: Application Statistics-Resolution



- Majority of routine user applications require ≤ 30 meter GSD
- Note these are desired User needs, not direct mission requirements

*Totals will exceed 100% as GSD was not directly correlated to band selection for 2012 USGS RFI (users were allowed to select more than one required GSD)

Example Input: Spectral Coverage Utilization



- User applications rely heavily on band combinations
  - Combinations of VNIR and SWIR comprise the significant majority aggregate need while TIR is used in 34% of user applications
  - TIR only applications comprise 13% of applications

Architecture Trade Space

Aerial Systems	Space-based Systems						
Platforms	**Instrument Configuration**	**Spacecraft Platform**	**Risk Class**	**Launch Vehicle**	**Potential Technology Infusion**	**Partnerships**	**Business Models**
UAVs	3+ Separate Instruments	Dedicated Spacecraft	Class B	Dedicated	Hyperspectral	International	Separate Contracts
Airplane	Two Separate Instruments	Hosted Payload	Class C	Shared	Micro-bolometer	Commercial	Observatory Contract
	Combined Instrument	Minisat/ Microsat Constellations	Class D+		Enabling Instrument Technologies	Federal Agencies	Prime Payload
		CubeSat Constellations					Commercial Turn-Key
		International Space Station					Block Buys
							Data Buy
							Sole Source
							IOO Space

Removed aerial systems from trade space… Coverage, FOV, illumination and imaging geometry incompatible with land imaging requirements

Technically not mature enough to meet imaging requirements in the near-term. Feasibility for future infusion is under investigation.

Removed International Space Station as a platform for VSWIR instruments from trade space because not sun sync. Limited applicability for TIR gap filler. ISS potential platform for technology demonstration.

Four Classes of Candidate Architectures

- Architecture 1: Full Capability Observatories
  - Two instrument (or combined instrument) strategies on same spacecraft
  - No international partnership – U.S. Government covers all costs
- Architecture 2: Disaggregated System
  - Alternate building of thermal and reflective imagers on dedicated spacecraft
  - Viability of mini-sat and micro-sat constellations
  - No international partnership – U.S. Government covers all costs
- Architecture 3: International Participation
  - Reliance on International partners to provide reflective imagers and/or data to preserve continuity
  - International partnership a must – U.S. Government covers portions of cost
- Architecture 4: Commercial Approach
  - Reliance on commercial partners to provide hosted or data buy opportunities
  - Partnerships with Commercial or other Federal Agencies
- Common Features for All:
  - Launch vehicle can be shared or dedicated
  - Consider various risk classes
  - Consider precursor full-spectrum or thermal-only “gap filler” mission
  - International/commercial systems assessed for backup role
  - Technology infusion is an option in this architecture

Design Cycle #1

- Design Cycle #1 concentrated first on
  - Understanding the critical user needs to maintain continuity with the historical data record
    - Contributes to the value measures used to guide the creation of and assess the performance of each candidate architecture
  - Identifying the subset of architecture concepts that are easier to characterize in the first design cycle while more challenging concepts are being further investigated
- Architecture Class 1 as well as some of the simpler Architecture Class 2 concepts were characterized in Design Cycle #1
  - Developed representative instrument designs and candidate spacecraft as building block envelopes (e.g., mass, power, volume, data, etc.)
    - Drew on Landsat 8 as well as recent instrument study and development work performed at NASA Centers and in industry to reduce the size and cost of instruments while ensuring imaging performance is maintained
  - Parametric and analogy cost models were used in conjunction with various risk classes and business models to explore the sustainability and performance of each architecture
- Architecture Class 4 was also investigated by exploring potential hosted payload and commercial opportunities, capabilities, and business models

Cost & Schedule Methodology Overview

Cost

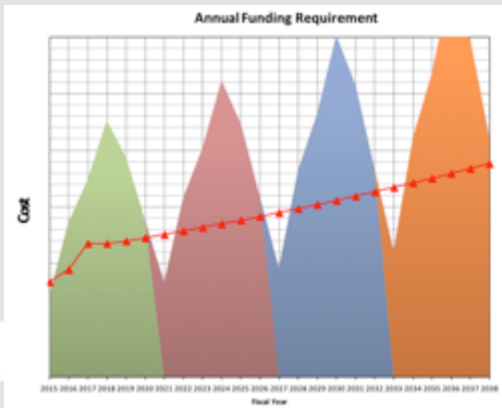
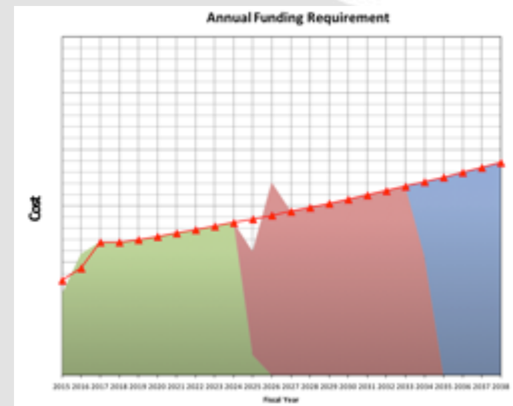
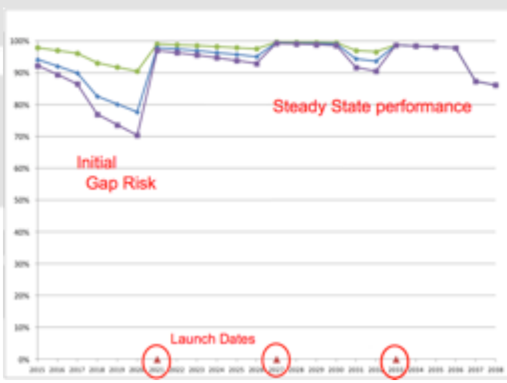
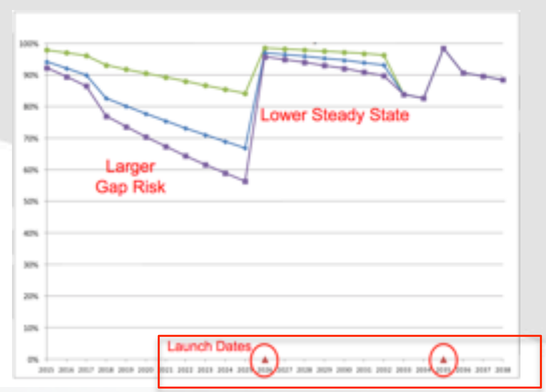
- Standard Aerospace Independent Cost Estimate (ICE) methodology utilized
  - Spacecraft and Instrument cost based on use of models and analogies
  - Pre-launch Science & GDS/MOS utilizes same percentage of hardware cost as LDCM
  - Launch Vehicle cost provided by KSC LSP
- Costing based on analogies within Class

Schedule

- Mission Class also assumed to influence development schedule.
- Aerospace Independent Schedule Estimate (ISE) process used to set representative schedule using analogies from representative mission classes
- Funding spread over development schedule using methodology based on on historical funding profiles

Adjusting to Constraints

✧ Requirement to fit within the allocated budget (i.e. “Sustainability”) requires that launches be spread further apart, which affects launch cadence and overall system availability*

	Prior to Fitting Budget	After Fitting Budget
Budget		
Availability		

Fewer Launches

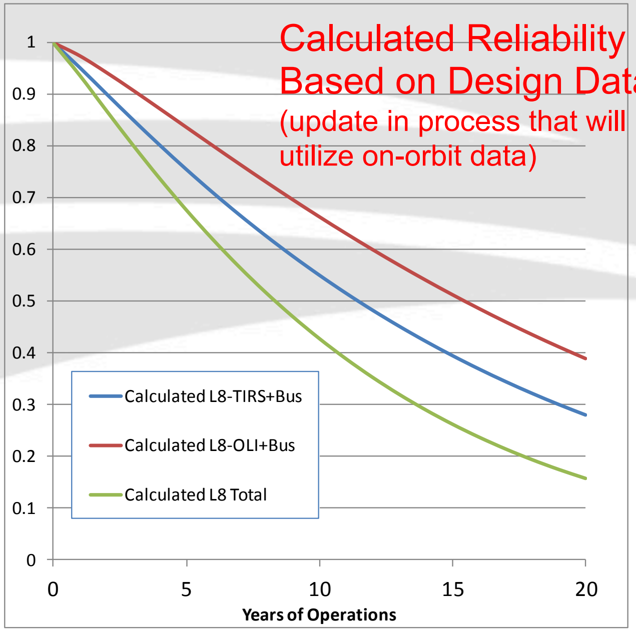
* Note: Cost profiles in this illustration are based on isolated projects, not a continuum of missions

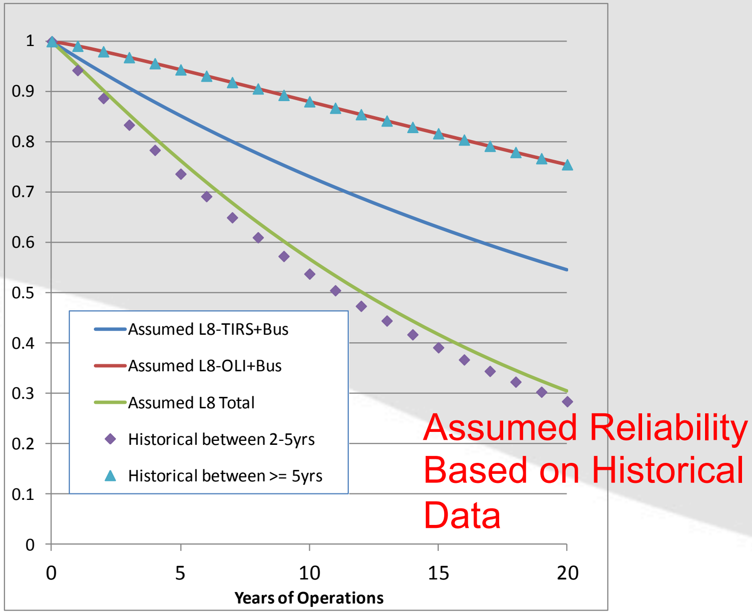
Design Cycle #1 Metric Considerations

- Design Cycle #1 explored a subset of the trade space consisting of full spectrum sats (similar capability to Landsat 8), disaggregated sats, and several other excursions
  - In our costing and availability analyses, we did not yet consider impacts of block buys, swarms of microsats, international partnerships, hyperspectral systems, launch failure impacts
- Given the annual budget constraints imposed on the program under study, total cost is not a metric as cost of any architecture will fully fill up the budget wedge
  - Cost peaks that exceed annual budget are pushed over into the future with an efficiency penalty applied
- **Launch cadence (availability) is the dependent variable**
- Cost is influenced by the development class (and business model) of the mission which, in turn, dictates the reliability of each concept which rolls up into an overall system availability
  - Currently, cost profiles assume sequences of independent satellite projects since block buys have not yet been investigated
- Architecture value to user community can then be assessed relative to satisfaction of historical and desire performance measures

Example: Mission Class Reliability

- Reliability based on historical performance of Government LEO satellites is significantly higher than reliability based on design calculations
  - Class B assumed design life greater than equal to 5 years
  - Class C assumed design life ~3 years
  - Class D assumed design life less than 2 years
- On-orbit lifetime data beyond 15-20 years becomes sparse, increasing uncertainty in models
- AST assessing how best to characterize reliability and consumable lifetime limits in architecture comparisons





Other Parameters & Features Being Considered

- The long term nature of the study means we cannot just look at current capabilities, but we must also look into future capabilities
- Current and evolving capabilities of small satellites, including nanosats (<10 kg) to minisats (100-200 kg)
  - Include constellations or swarms
  - Capabilities are limited by physics (*e.g.* aperture) and enabled by technology (*e.g.* detectors & ROICs, ASICs, mini cryo-coolers)
  - Shrinking telescopes/instruments enable smaller spacecraft; assessing performance trades and their impact
- Hyperspectral capabilities
  - Data could simulate OLI data; for example, convolving AVIRIS data sets to OLI resolution and spectral bands
- Detailed investigations of these options to be deferred until after the May 2014 deliverable to Congress

Architecture Trade Space – Design Cycle #2

Design Cycle #2 will focus on:

- Completion of Architecture Classes #1 and #2 investigations
  - Improved instrument and spacecraft building block cost models
  - Considering alternate business strategies, such as block buys and ridesharing
  - Refined value measures including satisfaction of user needs, robustness, and risk
- Architecture Class #3 – International partnerships for both full capability and disaggregated systems
- Near term bridging approaches that lead to a sustained implementation
- Technology Infusion
  - Identification of promising techniques and technologies for potential later infusion to reduce cost or improve performance

AST Initial Assessments (1 of 2)

- Landsat 8 is healthy and meeting all needs, projections show the satellite is likely to exceed the 5 yr lifetime, and TIRS the 3 yr lifetime
- Analysis of historical and expected user needs indicates
  - Close simultaneity of calibrated full spectral band coverage (within a few seconds for Vis-NIR-SWIR and within minutes for VSWIR to thermal) needed for large majority of data users to support routine data products
  - Partial spectral vicarious-calibrated solutions can augment, but do not negate need for backbone architecture providing calibrated near-simultaneous full-spectrum synoptic coverage
- We have narrowed our trade space for our more detailed immediate assessment
  - Focusing on architectures most likely to address near term issues ***and*** lead to a sustainable capability
  - Downsizing and decimation of instruments to enable microsat/nanosat constellation implementations is under study, but not considered a near-term solution due to performance risk
  - Full analysis will be included in complete report planned for August 2014
- Too few hosted payload opportunities exist in appropriate orbits to form basis of sustainable program
  - May be appropriate for targeted demonstrations
- The thermal IR measurements have the highest risk of a gap in the near term

AST Initial Assessments (2 of 2)

- Sentinel 2 satellites may serve as a reflective band component of or backup to a near-term capability
  - "… Sentinel-2 may augment Landsat capabilities, especially in frequency of (some) observations, and it may provide a bridge between Landsat 8 and 9 should Landsat 8 not exceed its five-year design life …" (From the Landsat Science Team summary assessment, Jan 23, 2014)
  - Even while it is not necessarily a long term replacement for a USG solution
- Preliminary cost assessment conclusions are:
  - The program budget profile is the dominant factor constraining launch cadence
  - Sustainable architectures appear to exist that meet most program needs within the budget profile
    - Block buy efficiencies and robustness to launch failure may be difficult to achieve within budget constraints
  - A thermal-only near-term mission can address near-term thermal gap risk, but significantly delays soonest full capability USG architecture
  - Program budget constraints can amplify the inherent inefficiencies of disaggregated approaches (e.g., separate satellites for thermal and reflective band imagers) by delaying component launches, resulting in low availability of on-orbit full spectrum capabilities
    - Smaller microsat secondary-launch approaches may overcome this inefficiency if challenges to capturing and assembling full spectrum, calibrated, synoptic imagery can be overcome and demonstrated
  - A USG full spectral coverage capability likely not feasible until 2021 or later within our budget profile

Next Steps for the AST (by March 2014)

For the AST:

- For all candidate architectures:
  - With the ESD and the USGS, refine a simple set of valuation parameters with which to compare the quality of the different architectures
  - Provide programmatic value assessments of these cases against a common performance metric
  - Complete program level budget analyses for all options
  - Prepare assessments of the ground system and science utilization requirements to allow full exploitation of the Sentinel 2 data set
  - Support for ESMPO in developing necessary potential procurement materials
  - Understanding of the possible instruments to achieve the USG solution
  - Careful assessment of gap filler options and approaches
  - Support for ESD in partnership discussions
  - Prepare for community/industry forum in late March time frame

Next Steps for the NASA ESD (by March 2014)

For NASA ESD:

- ✧ With the Earth Systematic Missions Program Office, conduct the assessment of and preparatory work for procurement approaches to support likely study outcomes.
- ✧ Explore, with the USGS, the partnership details with the Sentinel 2 program (ESA or EC or EU, as appropriate), to be able to quantify the risk associated with such a partnership. Including
  - Addressing mission design questions provided by AST
  - Data use and utilization
  - Mission management and CONOPS
- ✧ Prepare draft architecture assessment for communication with external stakeholders prior to completion of report to Congress and OSTP