OSIRIS REx
Science Processing & Operations Center (SPOC) and Science Engineering Peer Review

OSIRIS-REx™
ASTEROID SAMPLE RETURN MISSION

13 – Science Operations Overview

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Agenda

- Requirements
- Overview of science
- Previous reviews
- Science Production Plan
- Staffing and Risks
- Minimum Mission and Plans to Preserve Schedule

Science Processing and Science Operations

- Science Operations
  - Observations Planning and Commanding
  - Ingest
  - Calibration and Observation Verification, Instrument monitoring
- Science Processing
  - Science products for navigation
  - Maps production
  - Near- and Long-term Science
  - Archiving
- *Science Processing is the focus of this presentation*

OSIRIS-REx Science Objectives

- All directly traceable to major questions in the NASA Solar System Exploration Roadmap and four Key Questions in the NRC New Frontiers in the Solar System document.
  1. Return and analyze a sample of pristine carbonaceous asteroid regolith in an amount sufficient to study the nature, history and distribution of its constituent minerals and organic material.
  2. Map the global properties, chemistry, and mineralogy of a primitive carbonaceous asteroid to characterize its geologic and dynamic history and provide context for the returned samples.
  3. Document the texture, morphology, geochemistry, and spectral properties of the regolith at the sampling site *in situ* at scales down to the sub-centimeter.
  4. Measure the Yarkovsky effect on a potentially hazardous asteroid and constrain the asteroid properties that contribute to this effect.
  5. Characterize the integrated global properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the entire asteroid population.

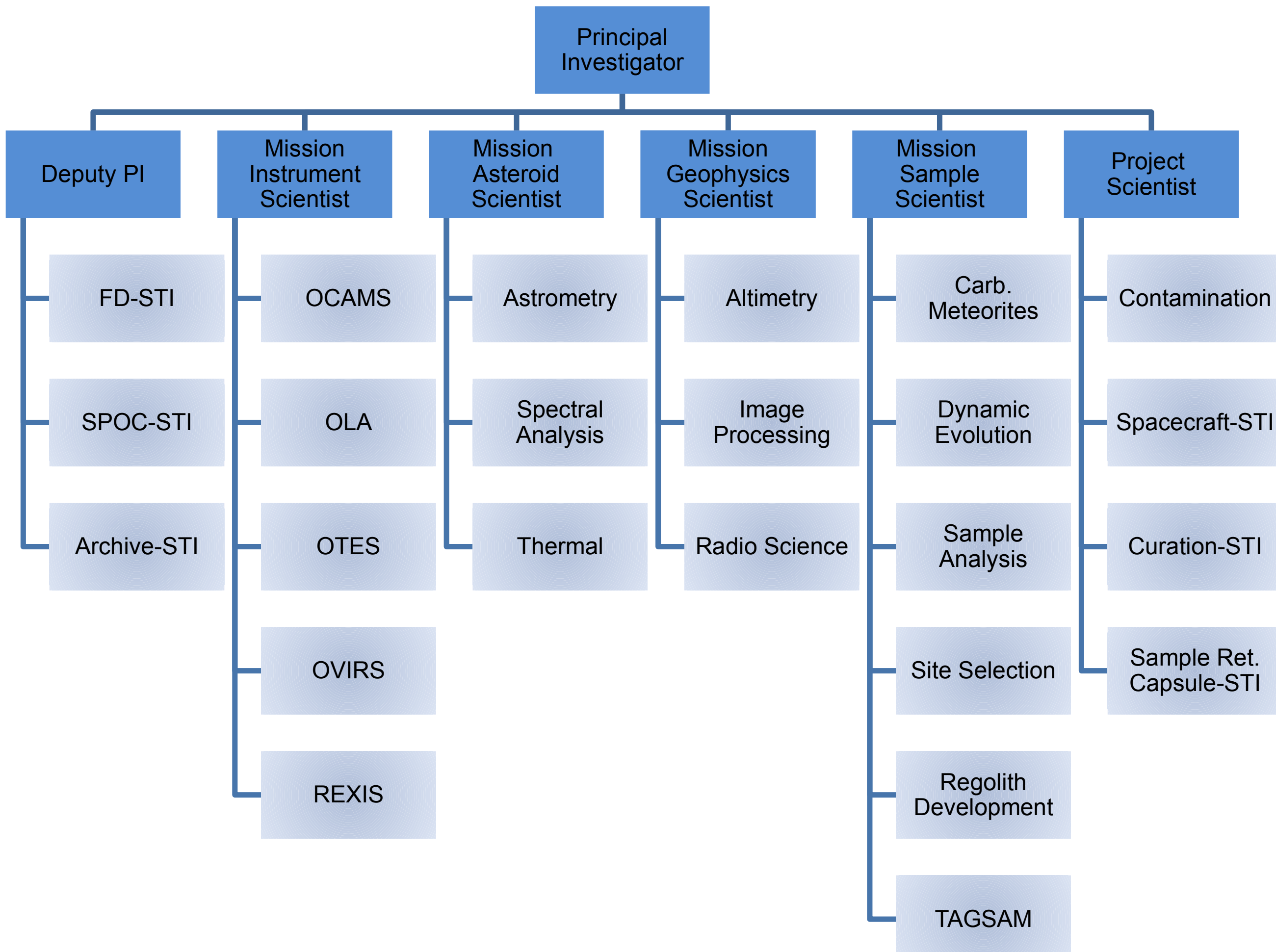
Science Requirements Flow Down

- Fifteen Level-1 Baseline Science Requirements appear in the Program Level Requirements Agreement (PLRA, Completed May, 2013)
  - Twelve threshold requirements incorporate six baseline requirements unchanged, modify six, and fully descope three.
- Level-1 Requirements flow down to 70 Level-2 Science Requirements in Mission Requirements Document (MRD)
  - Details sample mass allocation and contamination limits, key site selection decision criteria, specific science products, coverage, etc.
  - Latest MRD version in approval cycle is Rev J, which incorporates eight new requirements from Flight Dynamics and ten from GN&C (Natural Feature Tracking)
    - Explicit requirements for ground sample distance, accuracy, precision, and timing of shape models
  - Numerous mission system requirements dictate observing circumstances needed to obtain science observations
- MRD Rev H plus Rev J requirements on science wiki.

Science Team Responsibilities Phase C/D

- Develop a plan for meeting the mission science objectives through observations and analysis
  - Assist in developing the DRM and observing plan
  - Define and document science products
  - Develop and deliver analysis software and test cases to the SPOC
  - Develop appropriate testing and training materials for operations
  - Assist in the definition of top map products used to select a sample site
- Provide information about Bennu to assist in the development of the flight system
- Support development contingency plans where appropriate
- Communicate our plans and progress to the public

Science Team Now



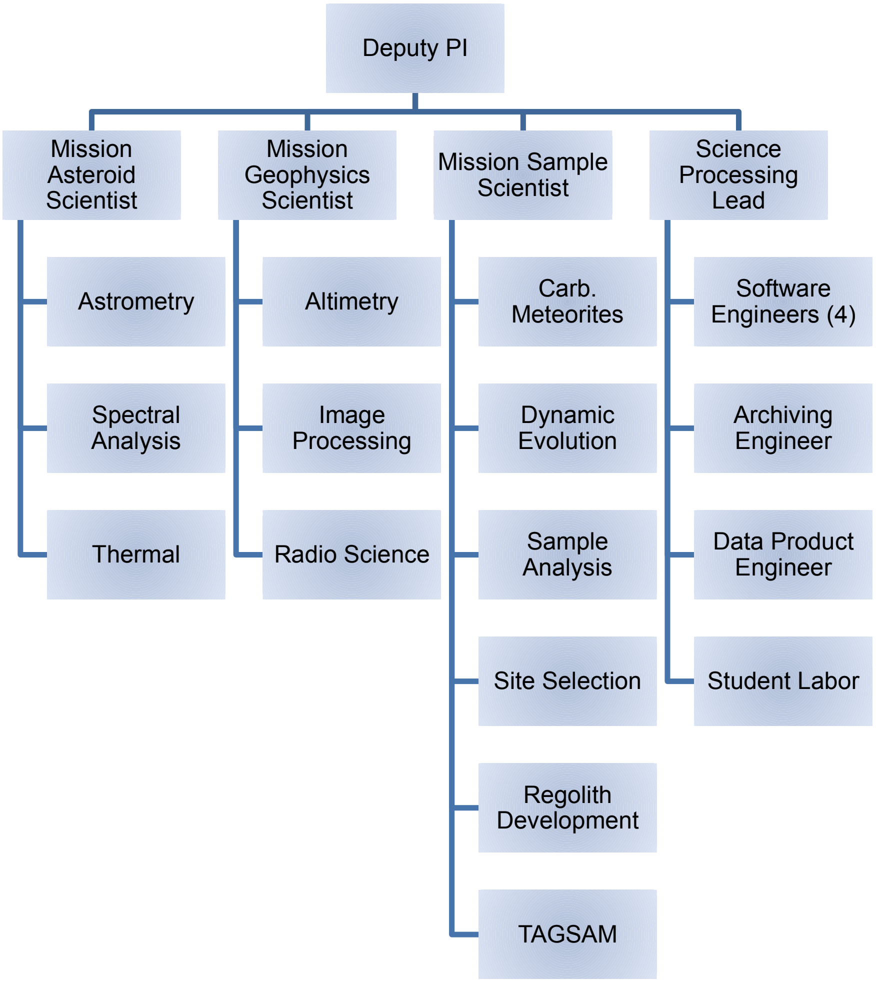
Science Team Responsibilities Post Launch

- Make formal observations requests based on the Mission Plan
- Produce and interpret science data products
  - Emphasis on products that service sample site selection
  - Products for navigation and guidance through TAG phase
  - Quick-look and long-term science investigations that address mission science requirements
  - Sample analysis (Phase F)
- Play a deliberative role in the site selection process
- Support engineering assessments and contingency operations
- Certify that mission science requirements have been met
- Communicate scientific progress and discoveries to the public

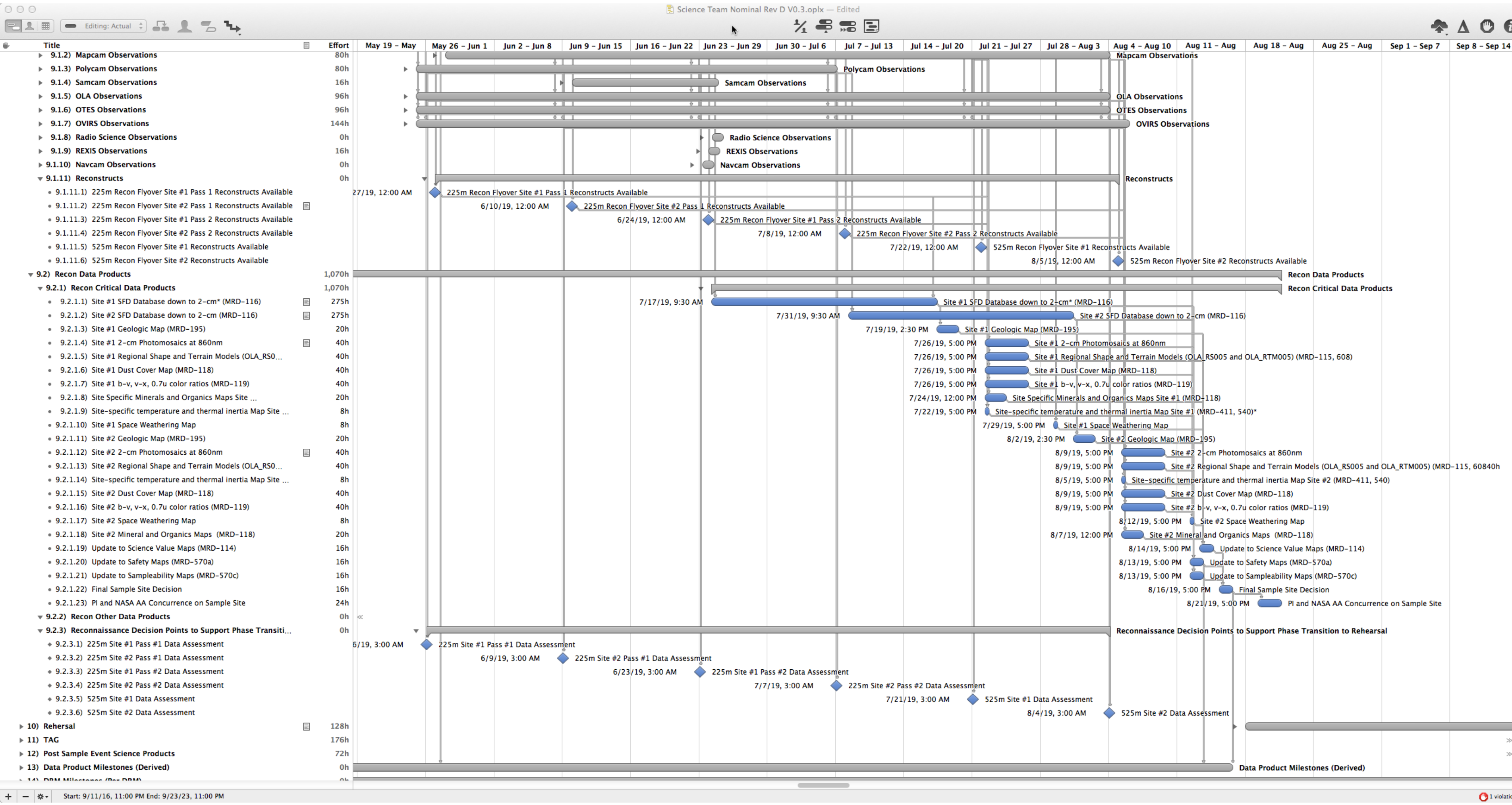
Science is an Operational Part of the Mission

- OSIRIS-REx science team must deliver operational products during every campaign through TAG
  - Examples
    - Navigation — satellite search, shape model, spin state assessment
    - Sample site selection — sampleability maps
    - TAG — TAG reconstruction and TAG imaging
- Requires full participation by the science team in preparing for operations
  - Understanding of requirements
  - Product timing
  - Resource management
  - Science participation in operational tests
  - Certification and training

Phase E Science Processing Organization



Phase E Schedule — Science



Previous Reviews

- ✓SPOC/Science PDR Engineering Peer Review (11/2012)
- ✓Preliminary Design Review (3/2013)
- ✓SPOC/Science CDR Engineering Peer Review (1/2014)
- ✓Critical Design Review (4/2014)
- ✓Ground Engineering Peer Review (12/2014)

Status at CDR

- Science team Phase C/D and E responsibilities presented
- Operations organization and positions documented
- Science Team operational communications plan described
  - Meeting schedules and agendas
  - Including interactions with SPOC team
- Concept for science product generation and management presented
  - Data products and algorithms documented
  - Documentation and release of results
  - Configuration control
  - Resolving discrepancies
  - Buying off science requirements
- High-fidelity science product production schedule based on DRM published

Progress and Changes Since CDR for Science Team (1/3)

- Worked with MSA, SPOC, and FD teams to develop observations and planning scenarios for each mission phase
  - Supports timeline and con-ops development
  - Define planning cycles
  - Defines role and timing of science input to planning
  - Meeting schedules during con-ops
- Refined J-Asteroid feature set
  - Developed case studies to help define planning, commanding, and visualization capabilities
  - Presented to science team in series of telecons in Dec and Jan
- Delivered first builds of science software to the SPOC
- Proposed science playbooks
  - Details operations for science team members
  - Identifies risk reduction observations opportunities (where available)
  - Documents off-nominal analysis strategies

Progress and Changes Since CDR for Science Team (2/3)

- Refined science product production schedule
  - Met with science working groups to identify disconnects
  - Planned software delivery, V&V, training and certification in close collaboration with SPOC
  - Added a small number of new products to support top-level maps, contingencies
- Investigated standards for interchange of map products
  - Identifying common utilities to accelerate maps development
- Worked with top maps teams to develop map requirements based on available science products
- Development of science decision points based on critical observations and processing

Progress and Changes Since CDR for Science Team (3/3)

- Science team meeting half-day splinters that focused on operational topics
  - Tucson (4/14)
    - *Pointing, SPICE, and Geometric Correction*
    - *Earth Gravity Assist and In-flight Calibration Plans*
    - *Maps Requirements, Algorithms, and Logistics*
  - Toronto (10/14)
    - *Science Products via DRM Rev C*
    - *OCAMS Calibration, Pipeline and Science*
    - *Science Operations Tools and Processes*
  - Pasadena (3/15)
    - *Making Maps*
    - *Boulder Counting and Hazard Detection*
    - *Dr. SPOC is IN!*

Progress and Changes Since Ground Engineering Peer Review

- Adjusted delivery of Photometric Model and Role of Bond Albedo on Thermal Model Development and reordered equatorial stations
  - Provides relief in delivery of initial site selection from global data
- Altimetry WG fully engaged in supporting products destined for NAV and Guidance
- Initiated development of science playbooks
- Finalized requirements for J-Asteroid visualization functionality
- Began delivering Build 2 science software to SPOC
- Finalized standards for interchange of map products
  - SIS signed (UA-SIS-9.4.4-324, Rev. 1.0)
  - Settled on common utilities to accelerate maps development
- Draft requirements for all maps delivered
- Held Geophysics TIM at Science Team Meeting #8 (March, 2015)
  - Covered a number of topics to provide status and/or set plans for
    - Coordinate system management
    - Rotation State and Wobble
    - Reprocessing
    - Support from imaging
    - Interfaces

Science Lessons Learned

- Rosetta
  - Visits with Rosetta team prior to comet operations have provided valuable insights into establishing long-term, reasonable routines for their operations teams.
  - Recommended that science and operations focus on planning around a single TAG attempt — detailed plans beyond that are difficult to make
  - Visited in early 2015 to review lessons learned during their approach, proximity operations, and site selection activities (among others).
- DAWN
  - Have science backup opportunities and descopes (documented in playbooks) when schedule is compromised
- Iterative Review of Science Production Plans
  - Many interfaces
  - First round reviews with working groups Summer of 2014
  - Dedicated splinters at Science Team meetings
  - Scheduling another round of reviews for 2015

Science Risks

LIKELIHOOD	1	2	3	4	5
5	4, 5	2			
4					
3		1,3			
2					
1					

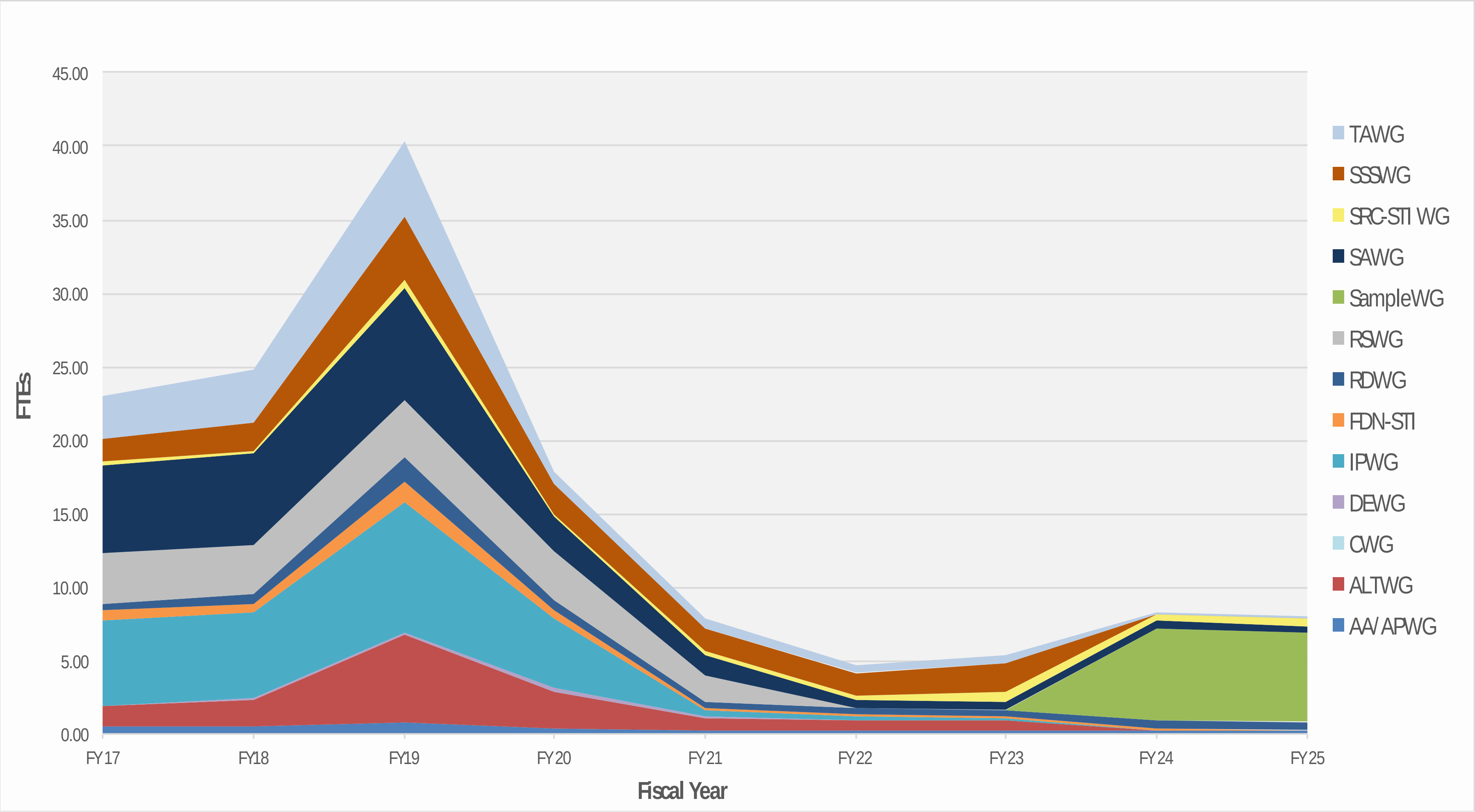
CONSEQUENCES

Trend	Rank	Risk ID	Approach	Risk Title
Unchanged	1	SCI-16	Mitigate	Science Team FY 17 & 18 Staffing may be too low
Worsening	2	SCI-26	Mitigate	Additional Science support needed for NFT implementation
Unchanged	3	SCI-22	Watch	Additional data products may be needed for sample site selection
Worsening	4	SCI-25	Mitigate	Additional modeling and analysis to support Regolith and TAGSAM response studies Phase D
Worsening	5	SCI-24	Mitigate	Bridge funding for Christian Dubigny

High
Med
Low

L x C Trend	Approach	Likelihood
Improving	M - Mitigate	5 - Likely
Worsening	W - Watch	4- Probable
Unchanged	A - Accept	3 - Possible
New Since Last Period	R - Research	2 - Unlikely

Phase E Science Team Working Group



Science Team Staffing profile is well aligned with Science Data Production Schedule

Phase E Challenges: Schedule

- Top-level science objectives dictate that the returned sample remains *pristine*.
  - Excessive sample (>75□) heating occurs after ~12/11/2015 if not in SRC (violates MRD-84, and L1 requirement to obtain a pristine sample.)
  - This date has been called “the line in the sand.”
  - Analysis related to this have been, or are being, carefully re-examined
  - Tests and analysis in early 2016 are expected to move date to the right
- Waiting until after perihelion passage (~mid-2020) to attempt a TAG and stowage resolves the problem, but
  - Would increase operational costs
  - Spacecraft exposed to continued threats with close proximity to Bennu
  - Failed first TAG after mid-2020 would compress time for subsequent attempts
- *We want a sample stowed by late 2019*

Dealing with Schedule Challenges

- Careful attention to avoid commanding errors, excessive complexity, operations fatigue, etc. will improve prospects for a schedule that tracks the DRM, with all planned science observations complete and sample stowage before December of 2019.
- We will prepare a set of descopes to be reviewed at specific points in the mission, when the future is more predictable. These descopes will be designed to buy back schedule, or budget, or both.
- We must understand what triggers a descope and the decision pathway for taking it.

Understanding Descopes Requires That We Understand Our Priorities

- *Complete Baseline Mission*
  - Meets all MRD requirements (short- and long-term science)
- *Science driven sample* — The return of a substantial, pristine sample with science value
  - Meet only the MRD requirements to build Deliverability, Safety, Sampleability, and Science Value maps in advance of site selection
  - Collect >60 g of pristine sample before the *Line in the Sand*
- *Sample with context* — The return of a substantial, pristine sample with science context
  - Meet only the MRD requirements to build Deliverability, Safety, and Sampleability maps in advance of site selection
  - Analyze data to produce Science Value map after sample collection
  - Collect >60 g of pristine sample before the *Line in the Sand*
- *Pristine sample* — The return of a substantial, pristine sample
  - Meet only the MRD requirements to build Deliverability, Safety, and Sampleability maps in advance of site selection, with science input as available
  - Collect >60 g of pristine sample before the *Line in the Sand*
- *Required Sample* — The return of ≥ 60g of bulk sample, but may not be pristine
  - Meet only the MRD requirements to build Deliverability, Safety, and Sampleability maps in advance of site selection, with science input as available
  - Collect >60 g of sample anytime during encounter
- *Minimum Mission Success* — successful return of any sample
  - Meet only the MRD requirements to build Deliverability and Safety maps in advance of site selection
  - Collect any amount of sample anytime during encounter with minimal analysis

Possible Descopes in Response To Schedule Pressure (1/2)

- Goal
  - Preserve margin between TAG and “Line in the Sand” date for rehearsal
- Delays suffered in Navigation Campaign will be absorbed in Detailed Survey
  - Schedule-preserving changes should be taken early
  - We propose equatorial stations in a week-for-week trade based on science priorities
    - Baseball diamond remains untouched since it provides high resolution imaging for safety and is best way to obtain global maps for SPC
    - Preserves margin to deal with delays that might be suffered later in the site selection campaign
    - We want to identify early risk-reducing observations early to cover for, or supplement observations that might be lost later.

Possible Descopes in Response To Schedule Pressure (2/2)

- Delays during Detailed Survey made up with an expedited Orbital B/ Reconnaissance campaign.
  - Reduce number of candidate sites in initial downselect
  - In worst case, deprioritize science value assessments and go directly for the safest, sampleable site
  - Orbital B might become a combined Orbital B/Recon campaign that prioritizes safest sites based on Detailed Survey and Orbital B observations
  - 225m Recons for final safety and sampleability assessments
  - 525m Recons could be reduced to a single flyover for science context or dropped entirely
  - A 225m Recon that failed to identify a safe site followed by 225m Recon at the next best site, etc. until a site is found
- Keep new plans tied to DRM elements to reduce need for analysis and extensive replanning

“Minimum” Mission Scenario: Observation Assumptions

- Navigation and TAG Campaign unchanged from DRM Rev C
  - Add OVIRS & OTES data collection to Preliminary Survey
  - Add TBD nadir-pointed data collection to Orbital A: OLA, OCAMS, OTES, & OVIRS
- Detailed Survey reduced to Baseball Diamond Observations
  - Add OVIRS & OTES data collection
  - Requires new trajectory design to transition from BBD to Orbital B
- Orbital B: only observe 2 sites
  - OLA & REXIS nadir-pointed observations occur after LTR thruster calibration
- Recon: reduce to two 225m passes (two passes over prime site or one pass over both prime & backup)
  - Preference to use OLA to focus PolyCam so that OLA can collect science data
  - Includes risk-reduction test of LIDAR-based on-board navigation
- Site selection product development and decision-making drive both LIDAR-guided and NFT-guided TAG timelines: 115 days less than DRM Rev C timeline
  - 23 days required for ground data processing & decision-making beyond what is required for observations

Work to Go

- Support development/refinement of tools and processes to produce science products
  - Emphasis on critical products for site selection and navigation
  - Review science operations processes to identify schedule and process disconnects
  - Fully develop the Science Playbooks
- Support V&V of Science Products at the SPOC
- Work with systems engineering to define descopes and triggering decision points for minimum mission
  - Refine minimum mission that addresses the requirements of science and engineering
  - Identify risk reduction observations that can minimize impact of later descopes or lost datasets
  - Document off-nominal science observations and processing plans to lessen impact of descopes or lost datasets
  - Document other impact of minimum mission
    - Define must-have products and the observations/processes that deliver them
    - Document staffing levels
    - Identify impact on L1 and L2 requirements

Next Topic (This slide will be done for you)

#	Start Time	Topic	Presenter
	7:45 AM	Coffee/Refreshments	
1	8:00 AM	Welcome	E. Beshore
2	8:10 AM	OSIRIS-REx Mission Overview and Priorities	D. Lauretta
3	9:10 AM	DRM Science Collection Overview	B. Boynton/J. Kidd
	9:55 AM	Break	
4	10:10 AM	Ground System Overview	J. Gal-Edd
5	11:10 AM	SPOC Overview	C. Shinohara
	11:55 AM	Lunch	
6	12:55 PM	Operations Overview	S. Barnes
7	1:40 PM	SPOC/Science Planning Process	B. Boynton/C. Hergenrother
	2:40 PM	Break	
8	2:55 PM	SPOC Implementation Process	S. Barnes
9	4:25 PM	SPOC Downlink Process	S. Balram
	4:55 PM	Board Caucus	Board

Backup

Summary of Categories

- PI Office/Admin/Facilities/CPE
  - PI, DPI, PPCO, Bus Mgr, Prog Coordinators, Exec Asst, Communications Lead and Social Media Lead
- Science Processing and Planning
  - UA: MIS, Strategic/Tactical Observation Lead (.50 FTE), Post Doc, Sci Processing Lead, Archive Engr, Data Product Engineer, 4 SW Engineers
  - Science Team: AA/APWG, ALTWG, IPWG, RDWG, RSWG, SSSWG, TAWG (FY 17 – 19)
- IS/DIS
  - OCAMS: Rizk & D'Aubigny only (IE in 7.4 Science Operations)
  - OTES: Full instrument staff (will revise for cost summit)
  - OVIRS: Full instrument staff (will revise for cost summit)
- Science Operations
  - Science Ops Lead, Systems Administrators, Documentarian
  - Operations and Instrument Engineers (Includes 2 OCAMs IEs)
  - IS/DIS (Includes OTES and OVIRS IEs – we will adjust pre MOR and move the IE's to Science Ops rather than in the IS/DIS profile.
- Long Term Science
  - Science Analysis and Archiving (FY 17 -25: CWG, DEWG, FDN-STI, SampleWG, SRC-STI)
  - Science Analysis: (FY20-FY25: AA/APWG, ALTWG, IPWG, RDWG, RSWG, SAWG, SSSWG, TAWG)
  - Postdoc FY 20-25
- Student Labor
  - Undergraduates: Facilities, Science Processing, Operations support
  - Graduate Students: SE/CM, Operations Support, Science Analysis

Phase EF Science Team Working Group FTE Backup Data

	FY 17	FY18	FY19	FY 20	FY 21	FY 22	FY 23	FY 24	FY 25	Phase EF Total
AA/APWG	0.54	0.45	0.78	0.38	0.26	0.20	0.20	0.18	0.18	**3.16**
ALTWG	1.30	1.85	5.92	2.52	0.76	0.66	0.66	0.00	0.00	**13.67**
CWG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.01**
DEWG	0.11	0.13	0.20	0.20	0.11	0.11	0.11	0.11	0.00	**1.11**
IPWG	5.78	5.79	8.82	4.71	0.44	0.25	0.13	0.00	0.00	**25.92**
FDN-STI	0.65	0.65	1.50	0.65	0.20	0.10	0.10	0.10	0.10	**4.05**
RDWG	0.52	0.62	1.56	0.69	0.40	0.40	0.45	0.57	0.57	**5.78**
RSWG	3.39	3.31	3.97	3.29	1.75	0.00	0.00	0.00	0.00	**15.71**
SampleWG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.25	6.07	**12.32**
SAWG	6.04	6.28	7.65	2.38	1.42	0.52	0.53	0.44	0.46	**25.73**
SRC-STI WG	0.20	0.20	0.52	0.17	0.24	0.35	0.65	0.50	0.50	**3.34**
SSSWG	1.58	1.85	4.23	2.04	1.62	1.57	1.95	0.00	0.00	**14.83**
TAWG	2.83	3.61	5.17	0.81	0.64	0.54	0.54	0.18	0.18	**14.51**
	22.94	**24.75**	**40.33**	**17.84**	**7.84**	**4.71**	**5.31**	**8.33**	**8.05**	**140.12**