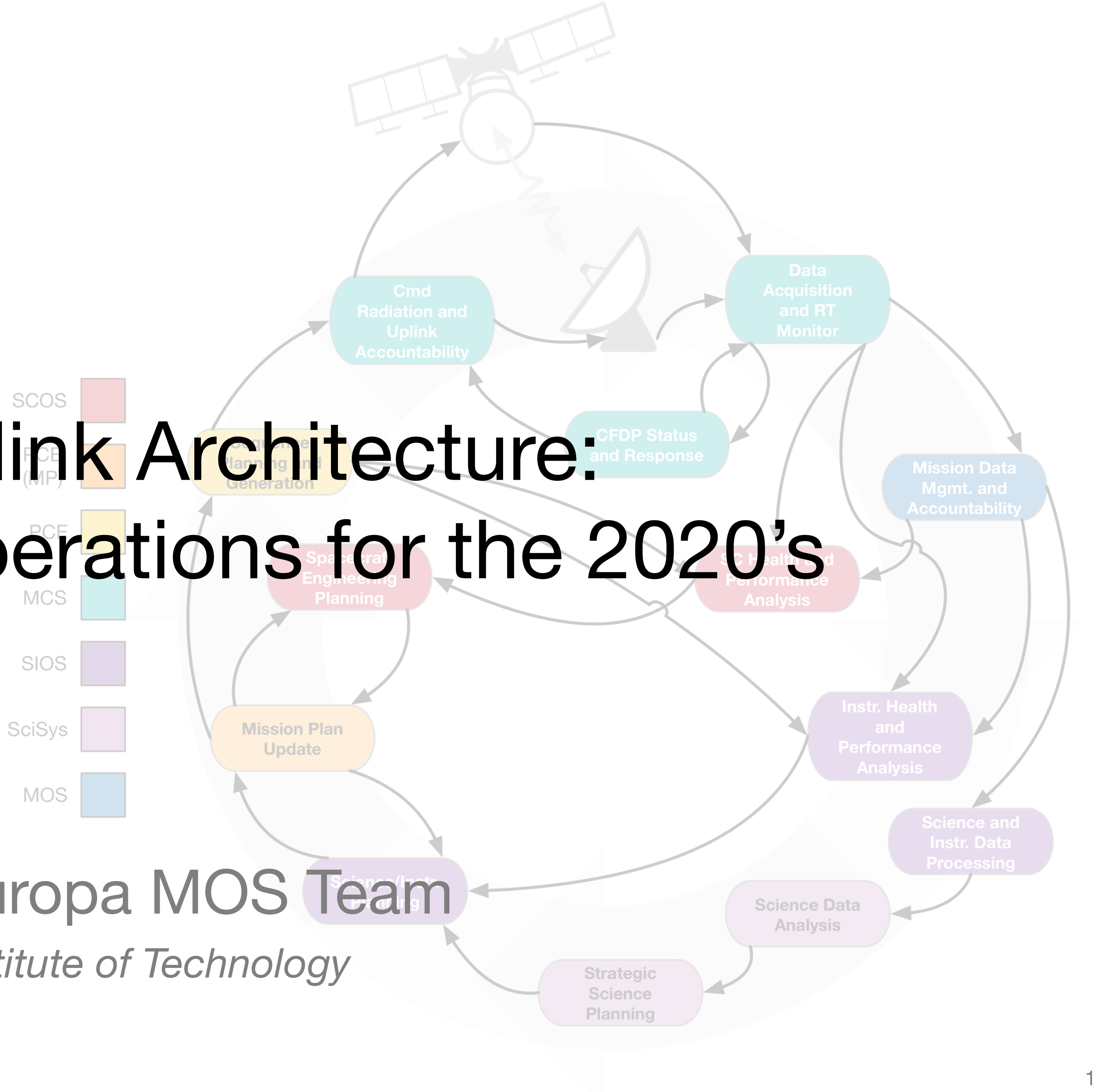
Europa Uplink Architecture: More Efficient Operations for the 2020's



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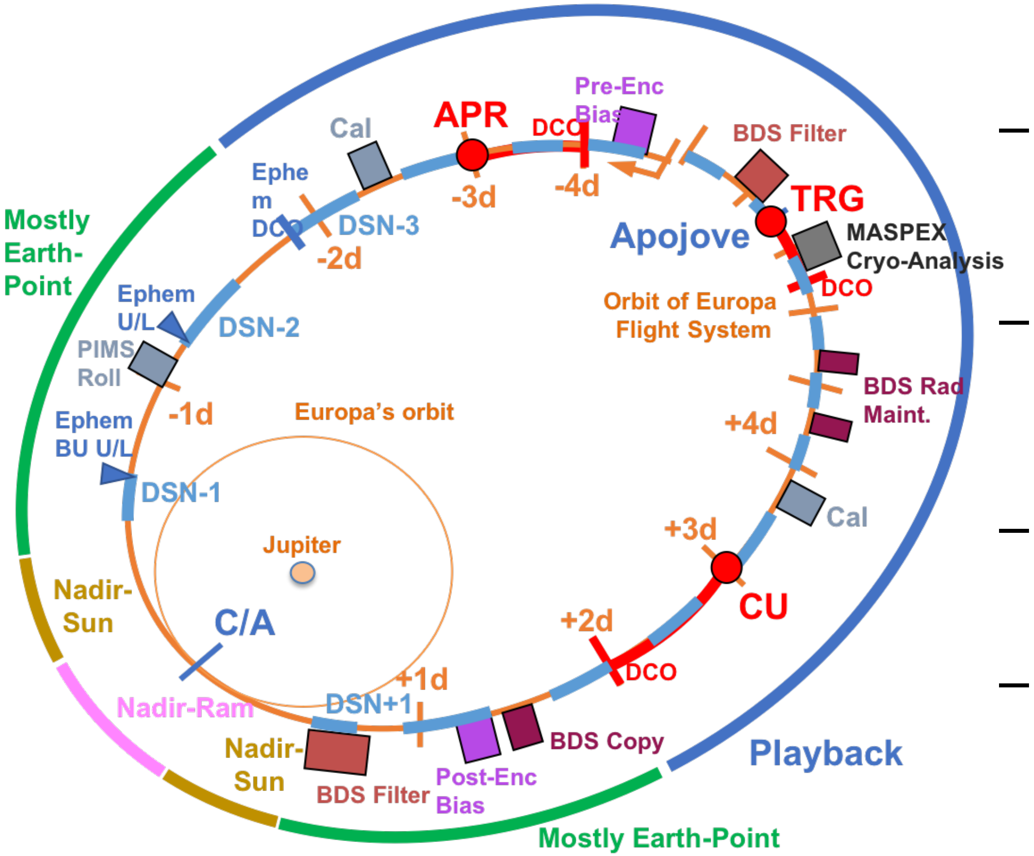
MOS Overview & Architecture Topics

1. Drivers on Clipper Uplink
2. Architectural Principles and Responses
3. Architectural Responses
4. MOS and Uplink Design
5. Key Challenges
6. Lessons / Summary

Driving Attributes of the EC Mission

Rapid cadence of targeted science flybys dipping in and out of radiation environment



- One Europa flyby per 14.2 days for most of Tour
  - Repeatable pattern centered around closest approach, gathering ***collaborative nadir-focused science***
- Three maneuvers per encounter, spaced apart by ~4-6 days
  - Flyby ephemeris is updated every orbit following approach maneuver on a short timeline – including non-interactive instrument updates
- Maintain a relatively small Flight Ops team size (compared to other flagships)
- Science is highly strategic; planned observations are commonly interrelated.
  - Achieving Science objectives requires coordinated plan
  - Less emphasis on response to new information
  - Primary method for control of Clipper will be sequences

Driving Attributes of the EC Mission (2/2)

9 science instruments - Each with varying flight system interfaces, unique control approaches for commanding, unique (but collaborative) operations concepts

- Distributed instrument operations architecture
  - Science & instrument operations from multiple U.S. institutions
- Diverse control methods for instruments
  - S/C commands
  - Internal instrument high-level commands (“macros”)
  - Reference files / tables with command parameters in instrument memory
  - Tables that control macros execution timing (essentially, sequences)
- The need to create data product accountability and prioritization capabilities to account for unique onboard data storage design

MOS Architectural Principles

- Enable a “Right-Sized,” Efficient Ops Team
- “Close the Loop” - Explicitly design in assessment of whether a plan met its intent at all levels
- Automate workflow/tasks where possible and benefit is clear
- Plan for Change – Create an iterative system that enables and expects re-planning as we learn more
- Information Availability - Ensure people have the information and situational awareness they need to do their jobs
- MOS as an Ecosystem - We are developing a system, not a collection of disconnected tools & processes

Key MOS Architecture Responses

- Adopt a planning cadence that balances responsiveness and workload
  - Trade Result: <4 weeks for production of a 4-week (2-encounter) sequence
- Tools and process support an iterative approach to planning and sequencing, based on current mission planning simulation capability
  - Single set of planning tools from integrated science planning through sequencing and production of uplink products
  - Common modeling interfaces to enable single, authoritative models for key resources and constraints
- Develop from a user-centric POV
  - Utilize scenarios, simulations, and human-centered design techniques to flesh out needs as early as possible
  - Identify performance needs, range of use cases and interfaces, and ensure we close the loop

MOS Composition and External Interfaces

Europa Clipper Flight System

DSN and other Flight/Ground Comm. Networks

Mission Operations System

Planning, Coordination, and Execution Operations

- Mission planning & Coordination
- Sequence planning, generation, validation, review & approval
- Command generation, validation, review & approval
- Ground station scheduling

Spacecraft Operations

- Plan Spacecraft activities
- Maintain flight system health
- Monitor & predict FS state/perf.
- Generate & validate S/C sequence inputs & commands
- Resolve S/C anomalies

Navigation Operations

- Plan/design trajectory
- Monitor/determine orbit
- Plan and Design maneuvers
- Analyze maneuver performance
- Provide Trajectory and Ephemeris products

Mission Control Operations

- Interface w/DSN
- Send CMD files
- Monitor/receive TLM
- Monitor DSN ops
- Manage & distribute downlink data received by DSN

Science & Instrument Operations

- Science planning coordination
- Instrument activity planning
- Maintain Instrument health
- Monitor and predict Instrument state/perf.
- Generate & validate inst. sequences & commands
- Resolve instrument anomalies
- Perform low-level instrument/science data processing, management, & distribution

Ground Data System (GDS) Operations

Deploy, Monitor, and Sustain Operations Facilities, Hardware, Software, Networks, Data Storage, Security, Infrastructure, and overall system performance.

Launch Services

PDS Planetary Data System

Science System

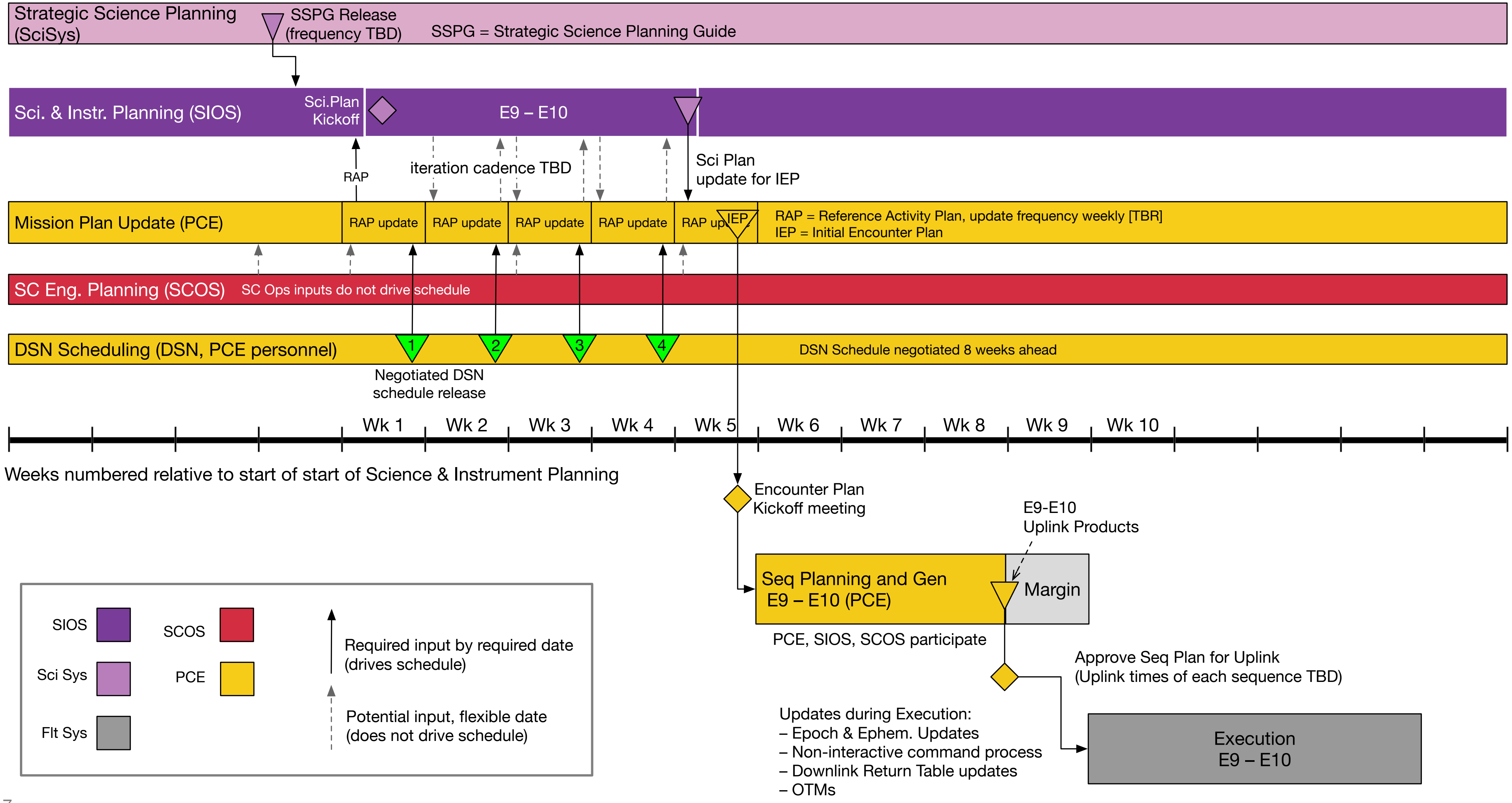
Uplink Design Approach

- Leverage current, robust Mission Planning capability
  - Build plans incrementally, starting now, leveraging current software-enabled capability
  - Maintain a Reference Activity Plan (RAP)
    - Information object containing (at least) all planned Spacecraft and Payload Instrument activities
    - Scope is all of Tour going forward (likely will have a Cruise RAP as well)
- The plan is always verified at the end of an iteration
  - A verified plan that meets all the constraints we impose
  - Non-final plans may not always meet our intent (but final one does)
- Individual teams/subsystem personnel are responsible for all planning inputs for their subsystem(instrument)
  - SE's (Science, SC, PCE) are responsible for the overall Plan
- Planning is done at the activity level (command expansion is done using Activity Dictionary) as opposed to command level

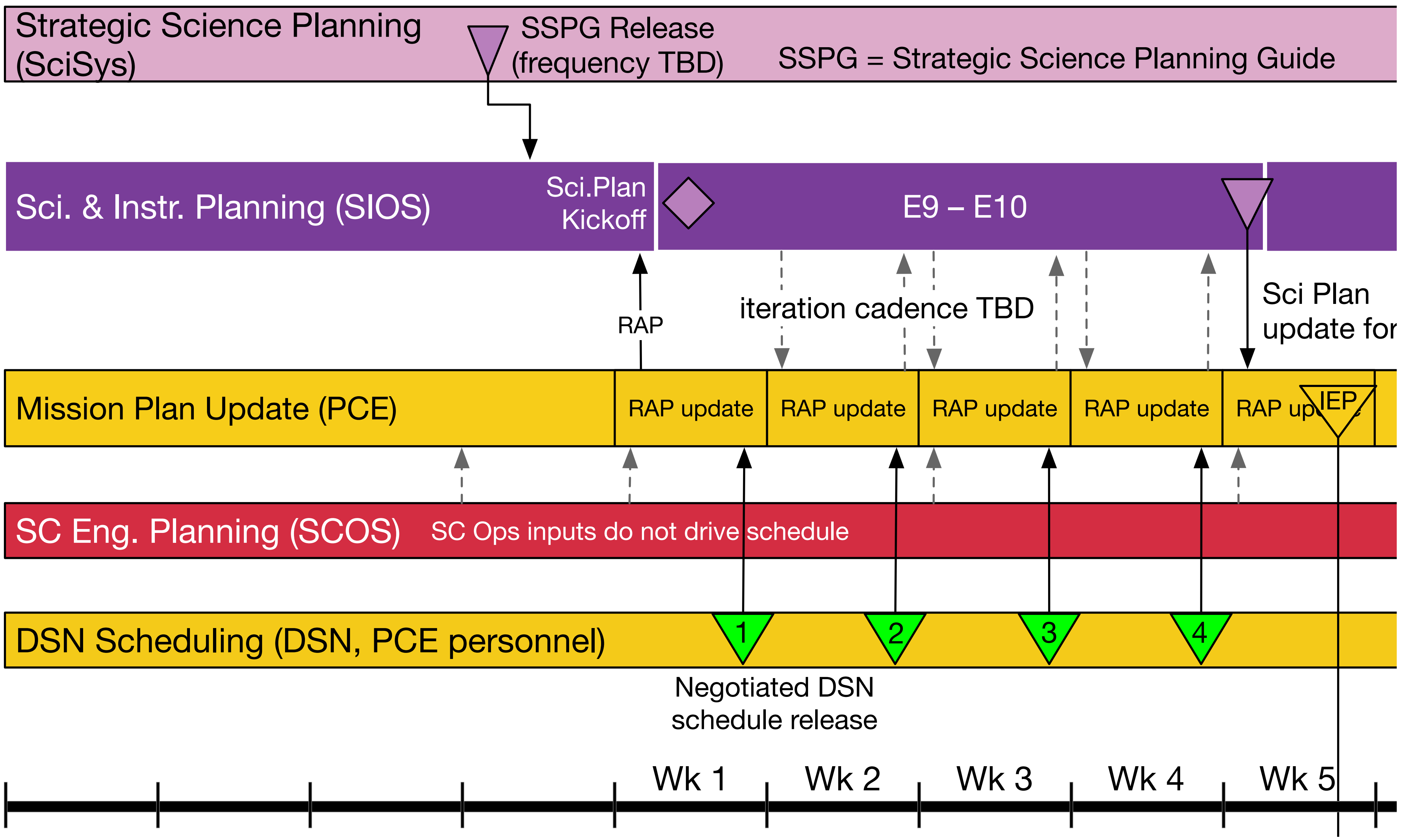
Activities

- What is an Activity?
  - A collection of mutually related behaviors, typically associated with some intent (source: *Europa Glossary*)
  - A basic unit of planning within MOS software
  - A ground-only construct (not uplinked to Flt System)
- What are the components of an Activity Definition?
  1. Constraints on execution (geometric, relationships to other activities, etc.)
  2. Commands used to implement the activity onboard the Flight System
  3. Command arguments (constant or variable)
- Activity Dictionary contains the set of all Activity Definitions
- Constraints on an Activity are used to schedule instantiations of that activity
  - Currently executing a prototype in Clipper Mission Planning simulations

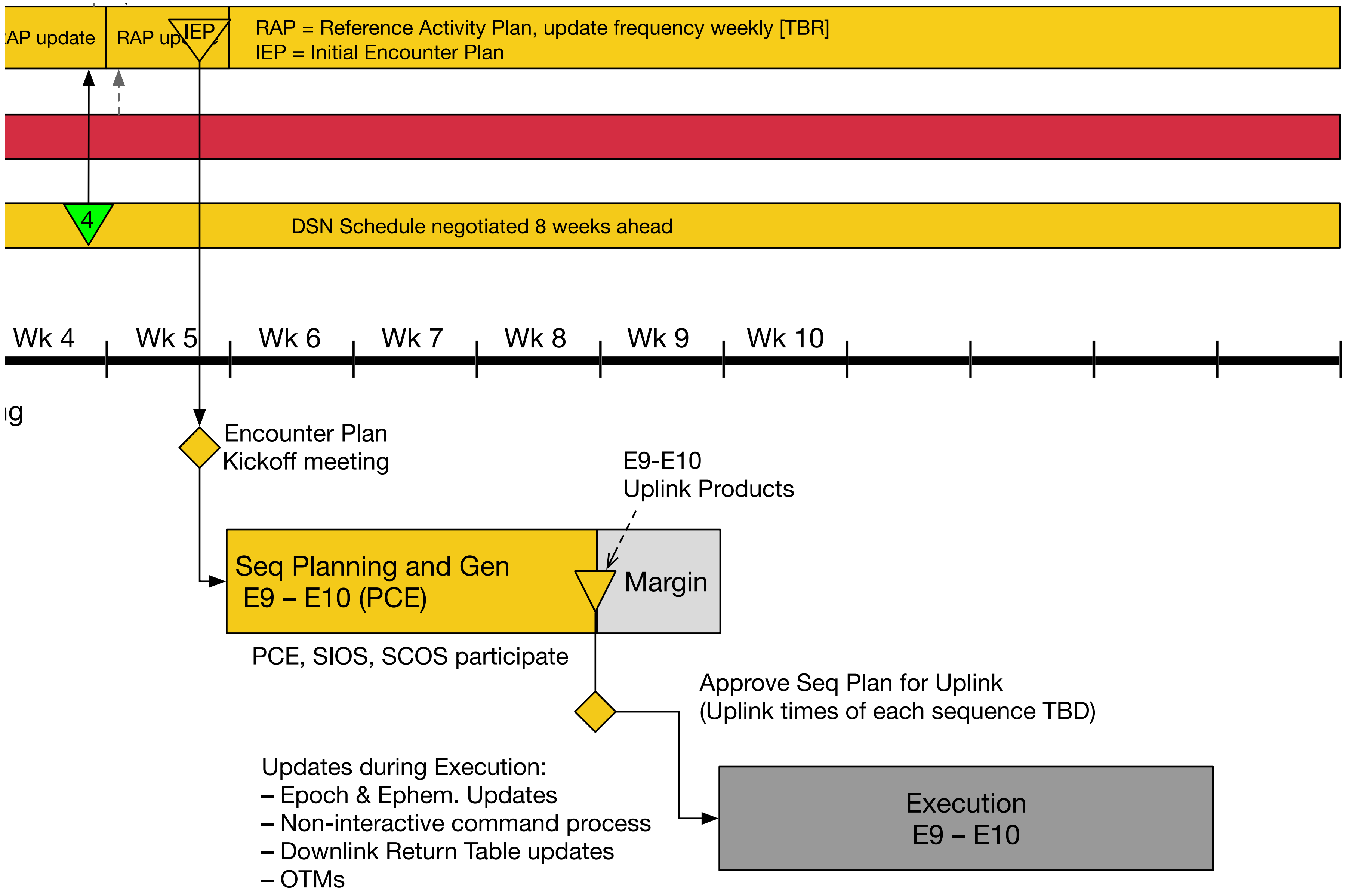
Uplink Process (Tour)



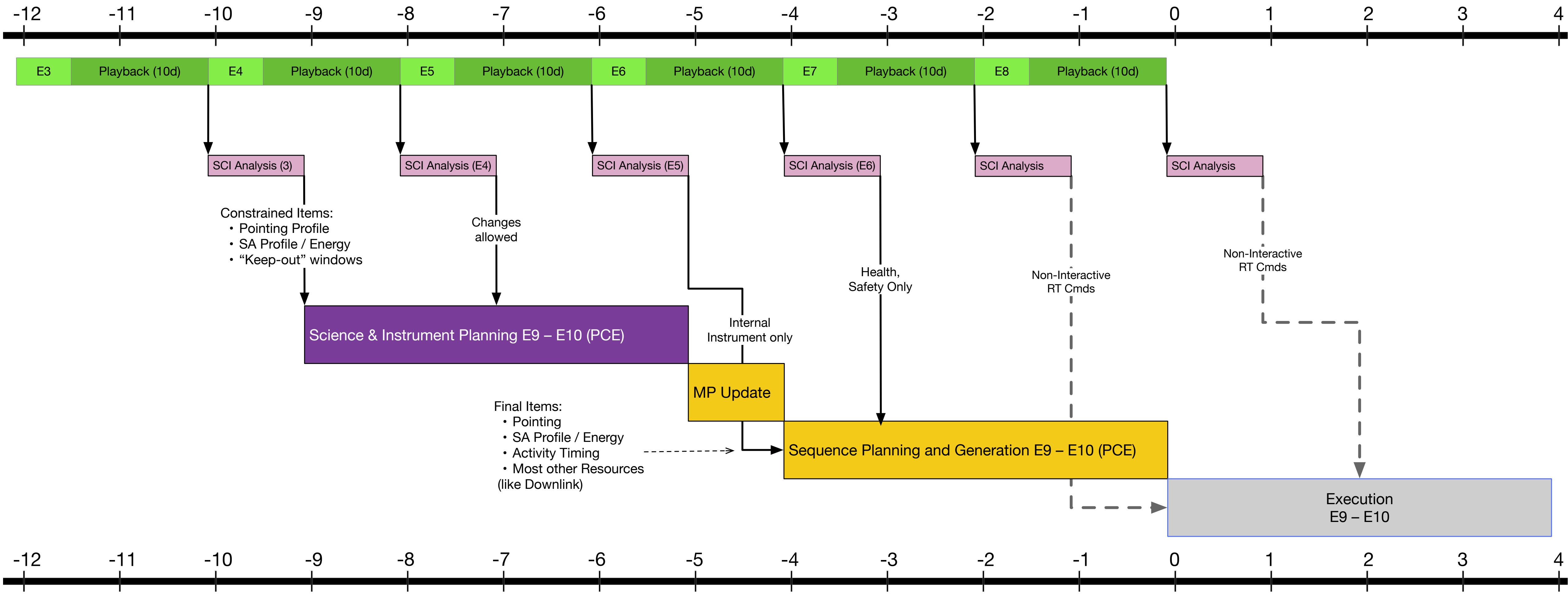
Uplink Process (Tour)



Uplink Process (Tour)



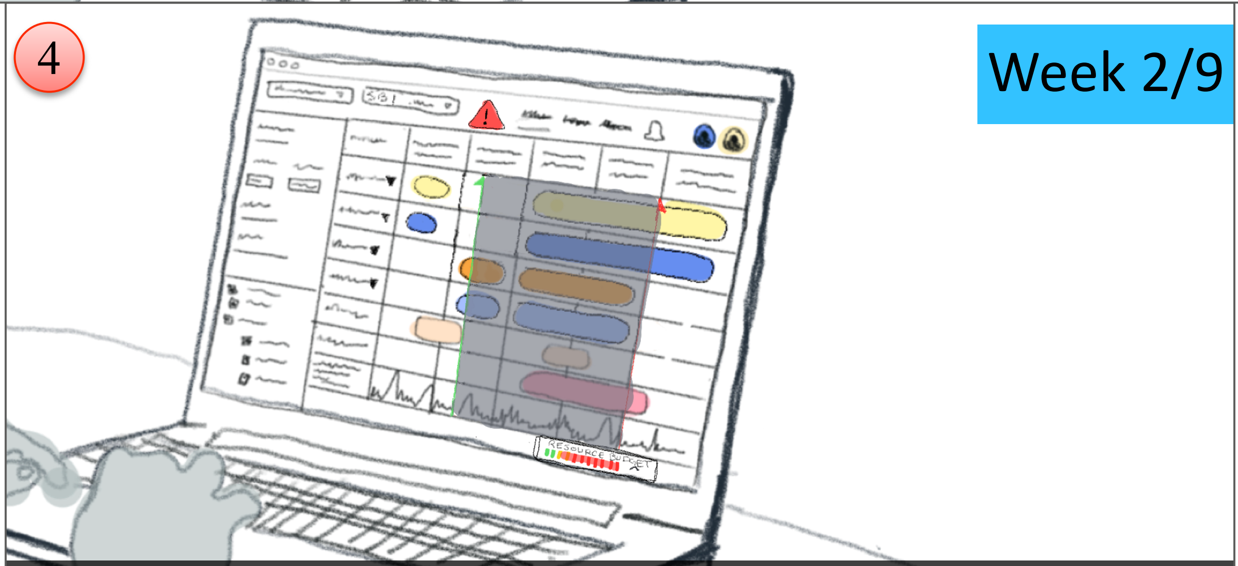
Feed Forward Opportunities - Sequenced



Juan, a member of another investigation reaches out to Shelley to see if she might be interested in doing a collaborative observation.

The collaboration would require a change to the plan so Shelley uses the collaborative-sandbox portion of her planning tool to determine the impact of such a change.

Shelley and Juan work together in the collaborative sandbox to figure out how they could adjust their activities to support simultaneous observation.



The planning tool shows Shelley how much resources her proposed activities would require. Using this feature, she edits the activity sequence for the planned encounter that stays within her resource allotment.

Common Model Interface

- Common framework to enable single-source authoritative models to be used across planning (uplink) and analysis (downlink)
  - Intended to enable single set of software for integrated planning and sequence development
  - Facilitates automation of sequencing
- Key modeled quantities include:
  - Power, attitude (pointing), solar array configuration/mode
  - Data production/volume (both ENG and SCI),
  - Downlink rate and volume, science data product accounting

Key Challenges

- Modeling onboard resources and constraints
  - Integrated modeling of shared resources and constraints
  - Processes for reporting, tracking, and resolution of constraint violations during planning
  - Model update and CM process (for SC / Instrument models)
- Integration of diverse Instrument control methods
- Activity-based planning
  - Automated scheduling of activities
  - Define Activity Dictionary (AD) Content
  - Integrating DL accountability and prioritization identifiers into Uplink Planning activities
  - Fully automated expansion of activities to commands (edits only at the activity level)
  - Socialization and buy-in by all key stakeholders
- Performance supporting interactive usage by distributed, multiple users

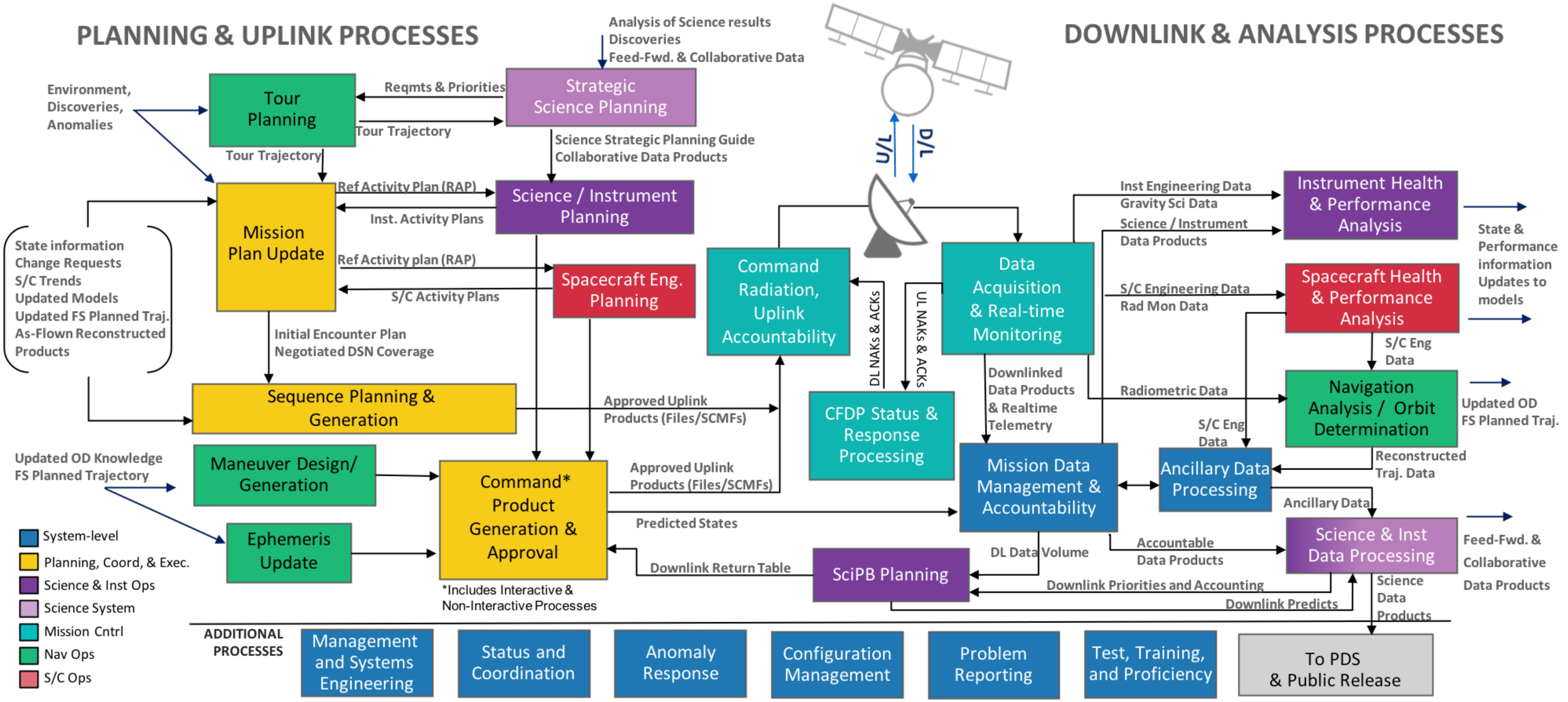
Key Lessons and Summary

- Operations would benefit significantly from
  - Standard interface/abstraction layer to onboard sequencing capabilities (e.g., VML functionality)
  - Standardization of payload control methods and interfaces
    - Diverse methods between various Clipper instruments are likely to entail costs to planning/sequencing design, implementation, and flight operations
- Key improvements planned for Clipper
  - Authoritative models for key onboard resources and constraints
  - Activity-based planning with software-assisted scheduling
    - Minimize editing/review at individual command level
    - Decrease time spent in negotiation over conflicts

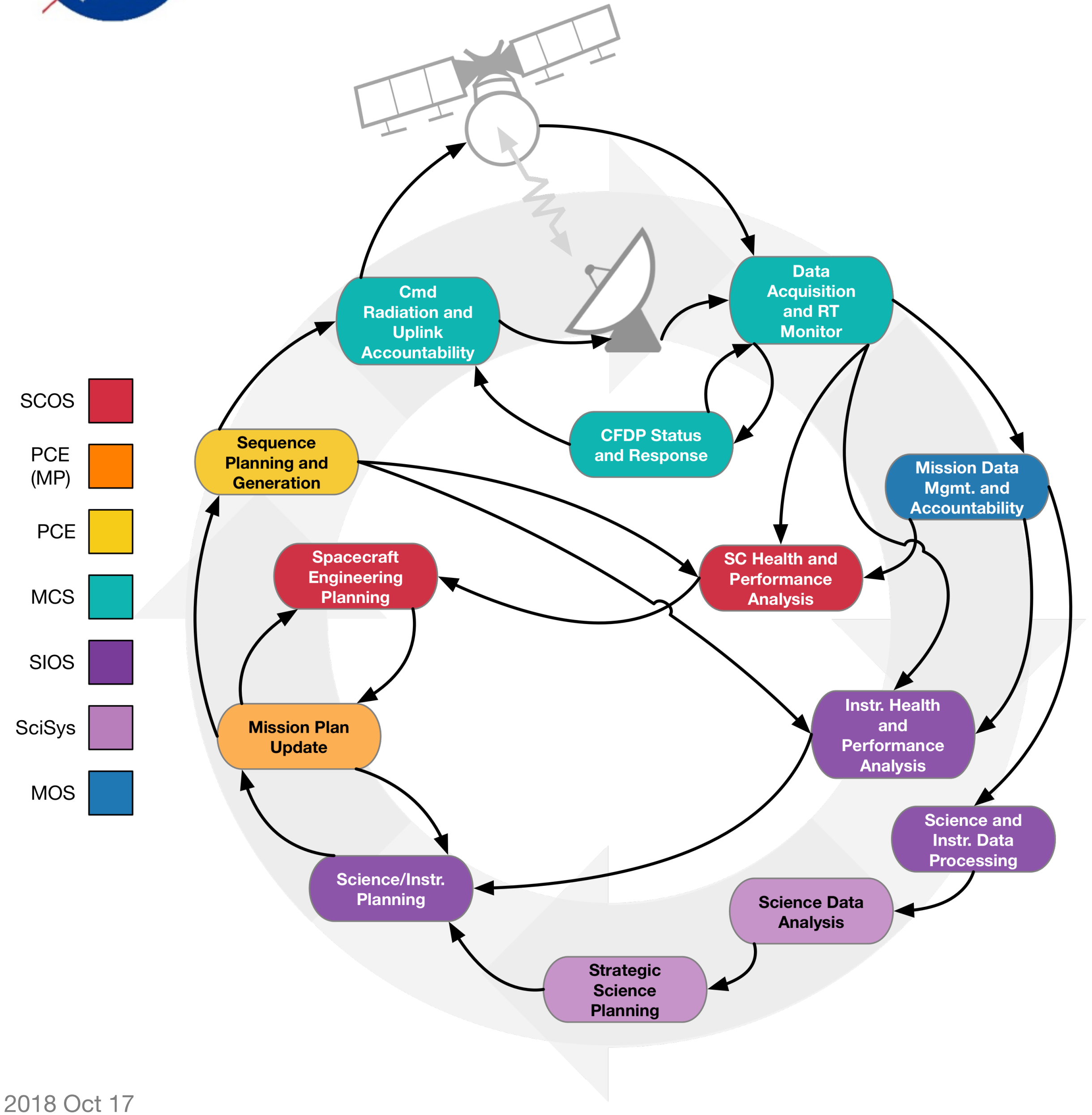
Backup

SCOS
PCE (MP)
PCE
MCS
SIOS
SciSys
MOS
Cmd Radiation and Uplink Accountability
Data Acquisition and RT Monitor
CFDP Status and Response
Sequence Planning and Generation
Mission Data Mgmt. and Accountability
Spacecraft Engineering Planning
SC Health and Performance Analysis
Mission Plan Update
Instr. Health and Performance Analysis
Science and Instr. Data Processing
Science/Instr. Planning
Science Data Analysis
Strategic Science Planning

MOS Ops Processes Overview



Uplink Process - Interfaces



- MOS processes use subsystem capabilities to execute the L3 Uplink Process
- Sequences are primary mode of control throughout flight operations
  - Possible exception: initial checkout and deployment activities
- Focus here is identification of MOS-internal interfaces

Benefits of Maintaining a Full-Tour RAP

- Project has shown the extent to which the current Clipper mission design and flight system configuration can meet science observation requirements.
  - APGEN modeling and simulation together with MP's VERITaS software
- During orbital operations, comparing as-flown coverage to these same measurement requirements will be a powerful way to assess the status of mission success criteria at any time.
- This assessment could then inform updates to science priorities, inter-team negotiations, and modifications to the remainder (not-yet-executed portion) of the Tour RAP.
- Full-tour RAP allows MOS to work strategic planning problems early and record solutions for them via the RAP.