Phase Lead SE Role at GSFC

GSFC Systems Engineering Seminar

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What is a phase lead?

- A phase lead is the single Systems Engineering bellybutton that the project assigns to coordinate the successful execution of a mission phase from design to verification
- Organizationally serves as a sub-discipline of the systems engineering team
- Core responsibilities include:
  - Concept of operations development and documentation
  - Management and tracking of phase-specific risks
  - Planning and execution of phase-specific V&V
  - Support through operations

History of phase lead role

- First formally defined in Jet Propulsion Laboratory's (JPL) Mars Exploration Rovers (MER) project
- Utility of Phase Lead role on MER was adopted outside the Mars program
- Past GSFC projects with phase leads
  - First adopted on MAVEN with Mars orbit insertion phase
  - OSIRIS-Rex – science, touch-and-go (TAG), and earth return phases
  - Lucy – encounter, launch+cruise
  - JWST – deployment and commissioning phase
- Current GSFC projects in development with phase leads:
  - Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging (DAVINCI)
  - Capture, Containment, and Return System (CCRS)
  - On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)

Similarities and differences from the traditional SE role

Item description	Phase lead SE	Traditional SE
Technical focus / scope	• Specific portion of the mission objectives relevant to phase • Detailed technical knowledge in phase-specific area (i.e. AEDL) may be needed	• Responsible for the execution of the entire mission objectives • Broad technical knowledge and understanding of the SE discipline
Place and interactions within organizational structure	• Usually resides within project SE team similar to a discipline SE • Interacts closely with a subset of the implementing subsystem teams that execute the phase functions	• Usually resides within project SE team as S/C, payload, or instrument SE • Interacts broadly with all implementing subsystem teams required to complete mission
Characteristics / skills	Both require strong leadership, communication, and coordination skills	
SE experience	Must have experience enough to understand and engage in all the various SE subdisciplines (ie. system architecting, requirements, trade studies, risks, design development, V&V, system performance analyses)	

Why is it important?

- Ensures focus on mission and/or time-critical activities throughout the life cycle
  - Requirements, ops concept, design, V&V, risk management
  - Operations implementation – timeline & sequence of events, ground processes/schedules, key decisions, training
- Continuity of knowledge from development through operations implementation

What types of projects would benefit?

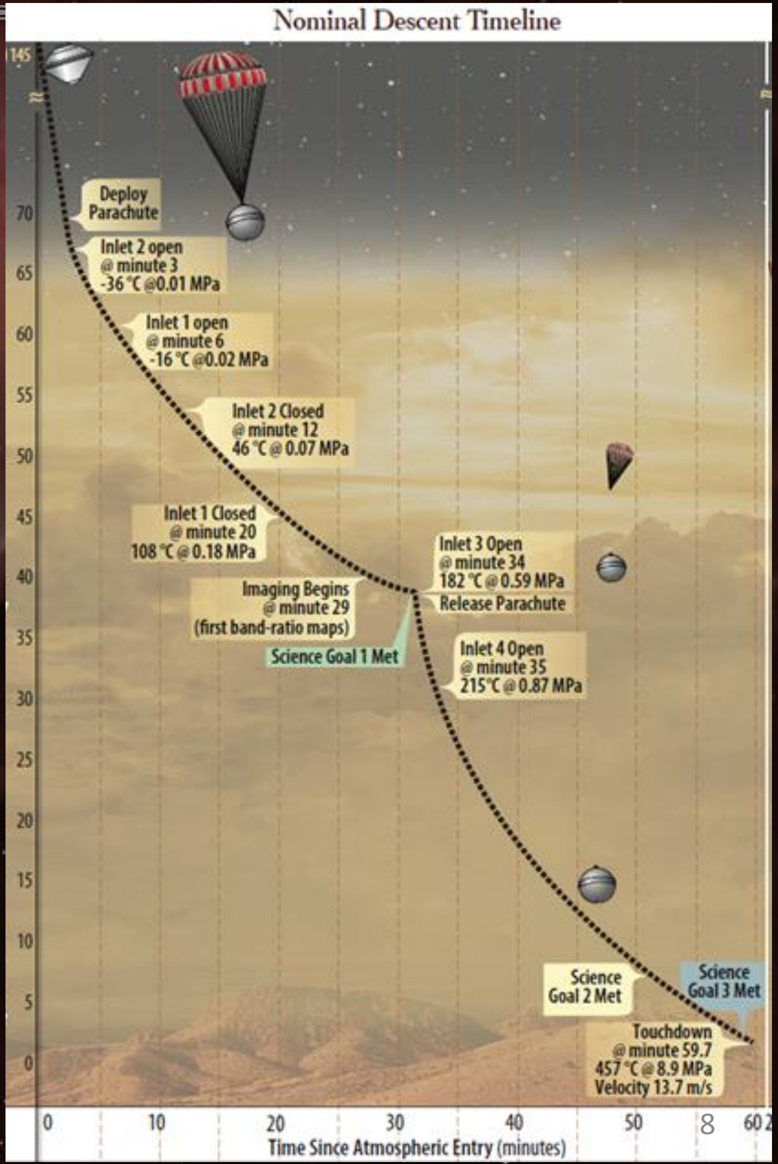
- Unique and changing ConOps with multiple critical events
- ConOps that focus on a functional sequence of activities
- Thus far, these characteristics primarily serve planetary missions
  - Earth science and astrophysics traditionally just have launch and commissioning phases, followed by science observations

Project Examples

- DAVINCI
- CCRS
- OSIRIS-Rex

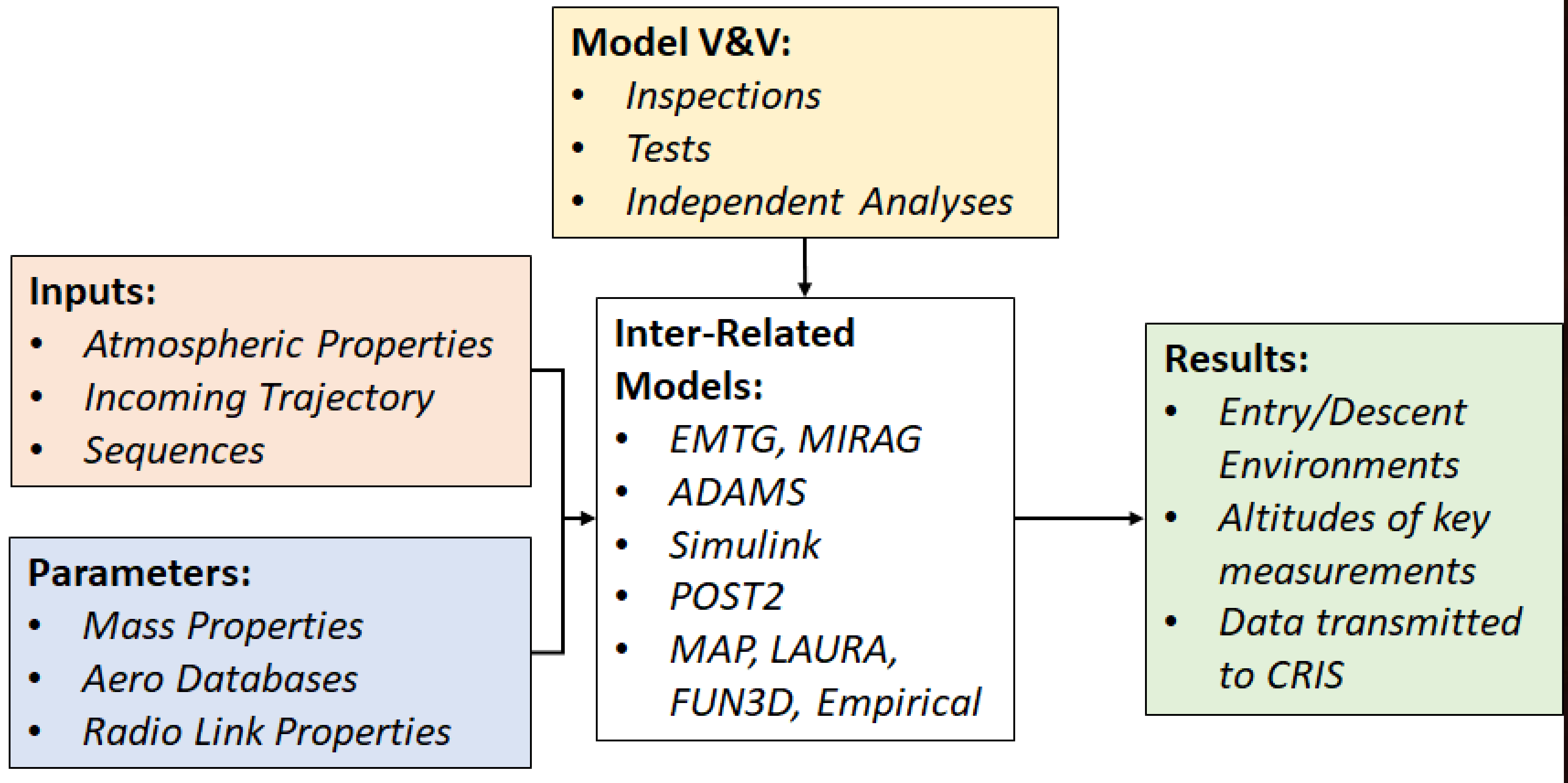
DAVINCI: In-Situ Phase

- The heart of DAVINCI is a 1-hour, single-shot descent through the Venus atmosphere
- No requirement to survive landing
- 7 of the 8 DAVINCI science goals can only be met during the In-Situ campaign
- Coordinated activities between 12 of the 15 project elements
- Primary In-Situ Phase challenges are:
  - Survive entry and descent
  - Get all of the right measurements at the right altitudes
  - Uplink all of the right data before landing



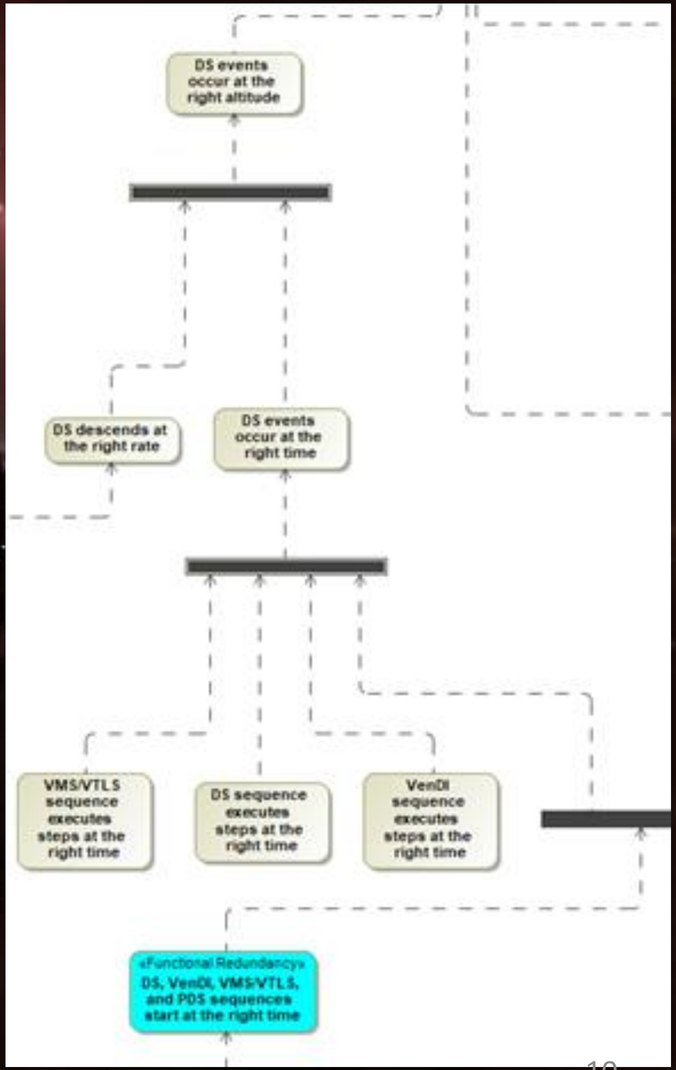
DAVINCI: In-Situ Integrated Modeling

- Series of inter-related models used to simulate the descent phase
- All inputs and parameters include error bars or variance. The POST2 model incorporates those into a Monte Carlo simulation.
- Quantified requirements are checked on each run and report out results two ways:
  - 1% or 99% worst case
  - % of cases that meet the requirement

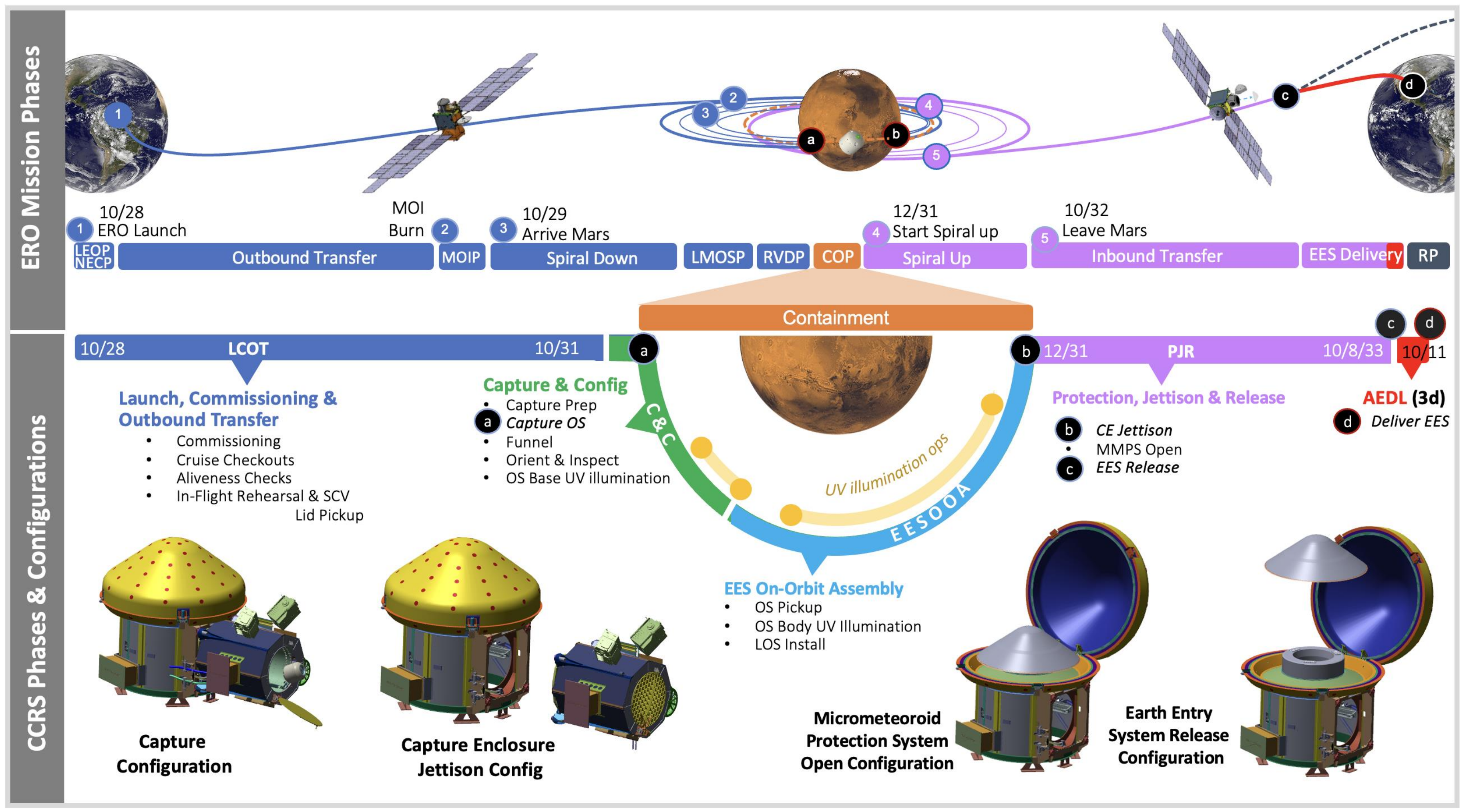


DAVINCI: In-Situ Requirement Validation

- Built an In-Situ phase success tree down to the level of “element does a thing”
  - Provides a framework for decomposing and framing a successful descent.
  - Mapped L1, L2, and L3 requirements to those nodes on the success tree to ensure that all necessary functions are adequately described by requirements.
  - Will be used to structure validation tests going forward
- Significant amount of design and verification relies on the descent model, so we need to validate that as well.
  - Every sub-model and input gets checked against test results or independent analysis before launch
  - No end-to-end model V&V available



CCRS: Capture & Configuration (C&C) Phase



- CCRS key objective is to capture Martian regolith samples from Mars orbit & safely return it to Earth
- Established 5 phases requiring
  - Unique ConOps
  - Single person to support focused discussions across external interfaces
  - Complex dynamic analyses for V&V
- C&C phase
  - Key capture function
  - Configure sample for secondary containment

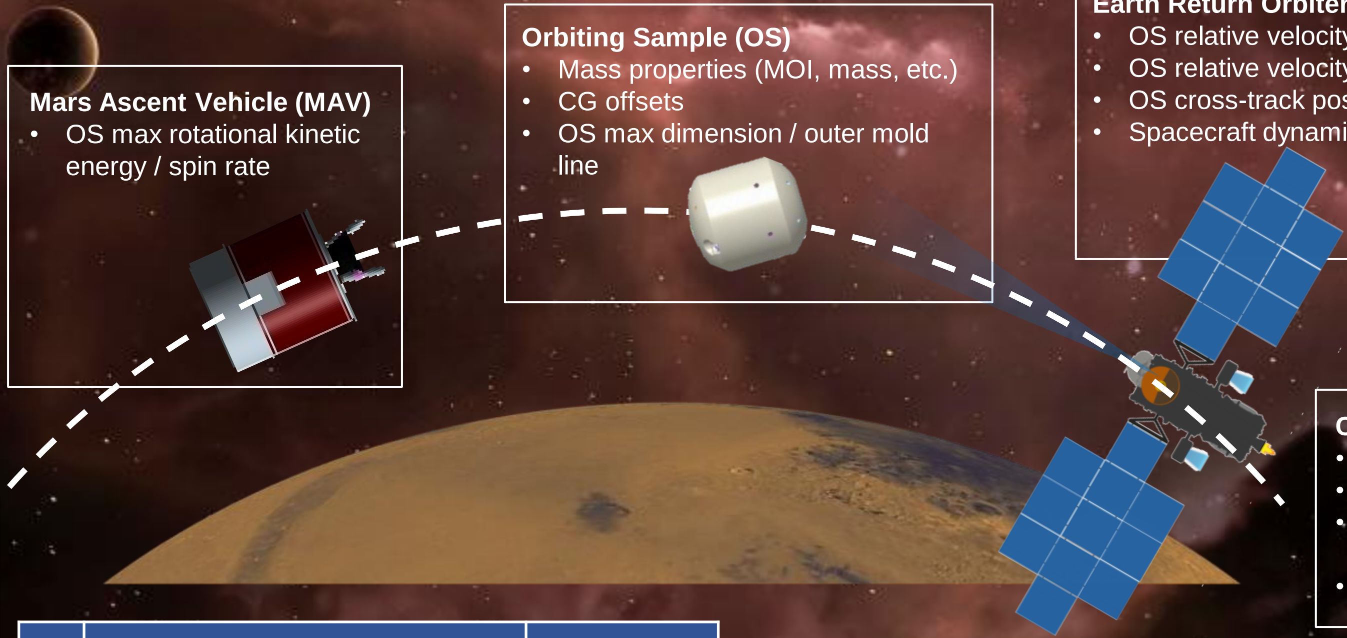
Note: As part of the [illegible] the recent MSR Independent Review Board's report and in light of the current budget environment, the MSR Program is undergoing a consideration of changes in its mission architecture. This presentation is based upon the previous baseline MSR architecture in which CCRS [illegible] return the OS to Earth within five years of landing on Mars to retrieve samples collected by the [illegible] rover. The CCRS project has indefinitely stopped work after successfully [illegible] pending results of re-architecting effort

CCRS: Dynamic Simulations for V&V of C&C Phase

Mars Ascent Vehicle (MAV)
- OS max rotational kinetic energy / spin rate

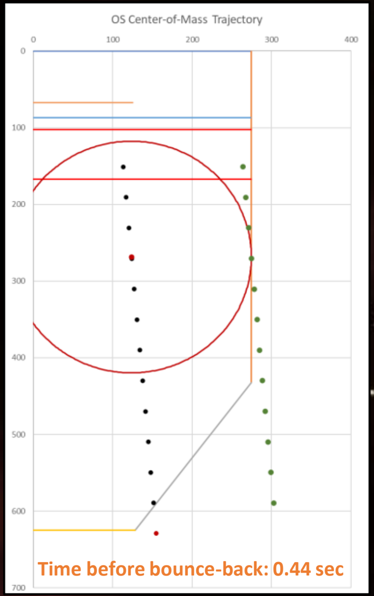
Orbiting Sample (OS)
- Mass properties (MOI, mass, etc.)
- CG offsets
- OS max dimension / outer mold line

Earth Return Orbiter (ERO)
- OS relative velocity magnitude
- OS relative velocity vector
- OS cross-track position
- Spacecraft dynamics / attitude control



CCRS
- Capture geometry
- Sensor plane locations
- Mechanism plane where physical capture of OS occurs
- Capture cone alignment

Monte Carlo approach reduces conservatism in highly-constrained system → Phase lead responsible for working requirements across external interfaces to determine appropriate distributions to the analysis



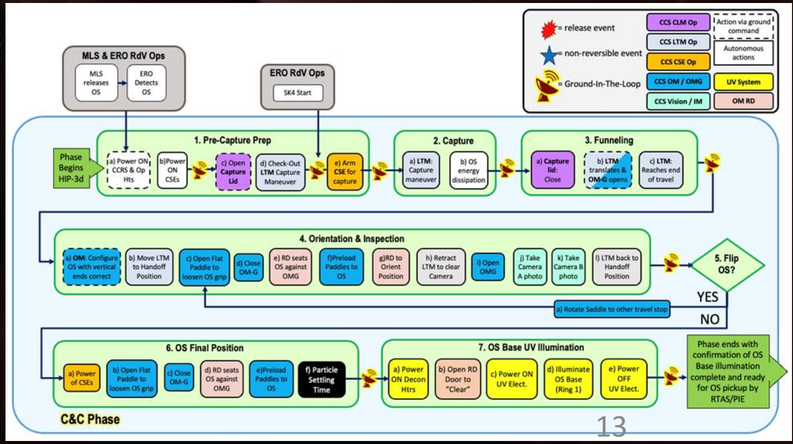
#	Capture-before-bounce-back Input Parameter	Value [Requirement*]
1	OS Velocity (cm/s)	4*
2	OS Cross Track (cm)	≤10*
3	OS Trajectory Angle (deg)	≤5*
4	OS Max Dimension (mm)	332
5	OS CG Offset (mm)	±10 X_{OS}; ±5 radial*
6	OS Max Rotational Kinetic Energy (J)	0.53*
7	OS MOI Ixx, Iyy/Izz (kg-m^2)	0.079, 0.091*
8	S/C dynamics (deg/sec)	±0.025*
9	OS Initial Orientation, 3 Euler angles (deg)	[0 360]
	Time Before Bounce-back (sec)	0.44

→

#	Capture-before-bounce-back Input Parameter	Value [Requirement*]	Input Distribution for Monte Carlo Budget Derivation
1	OS Velocity (cm/s)	4*	Fixed
2	OS Cross Track (cm)	≤10*	Gaussian distribution with 3 sigma at requirement values
3	OS Trajectory Angle (deg)	≤5*	Uniform distribution +/- 5 deg
4	OS Max Dimension (mm)	332	Assumes CG at centroid
5	OS CG Offset (mm)	±10 X_{OS}; ±5 radial*	Uniform CG, Uniform Offset
6	OS Max Rotational Kinetic Energy (J)	0.53*	Triangular distribution from 0-0.53J
7	OS MOI Ixx, Iyy/Izz (kg-m^2)	0.079, 0.091*	Fixed for 11.5kg OS
8	S/C dynamics (deg/sec)	±0.025*	Fixed rotation about spacecraft CG
9	OS Initial Orientation, 3 Euler angles (deg)	[0 360]	Uniform

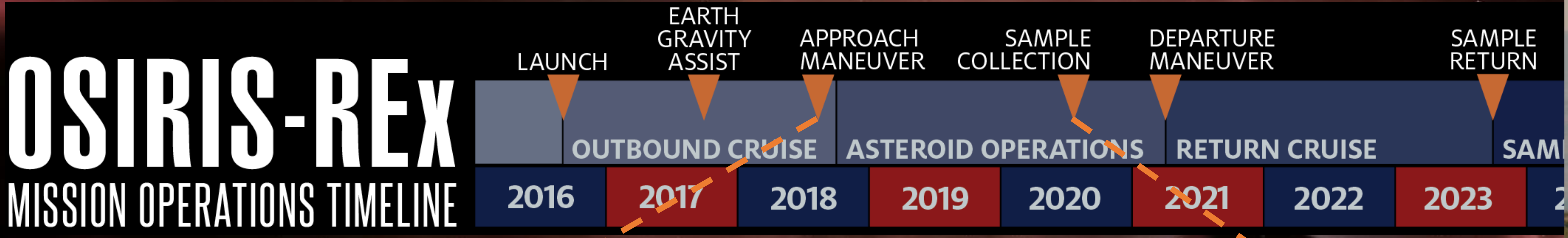
CCRS: C&C Phase Lead Role

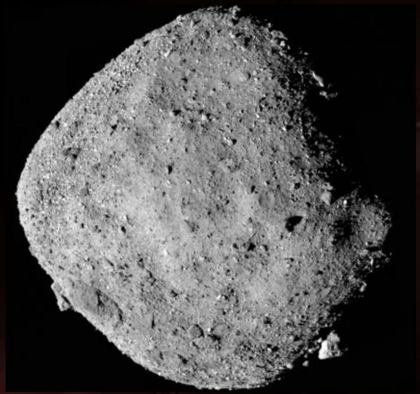
- The phase lead was important for identifying a single bellybutton to own the key capture and configuration functions of the mission
  - Fulfilled a missing human interface to other MSR program missions
- During SRR thru PDR timeframe, focused on defining all the input parameters needed to assess capture performance and deliverables included:
  - Success trees
  - Requirements development
  - V&V plans
  - ConOps documents (snake chart, phase timeline, etc)

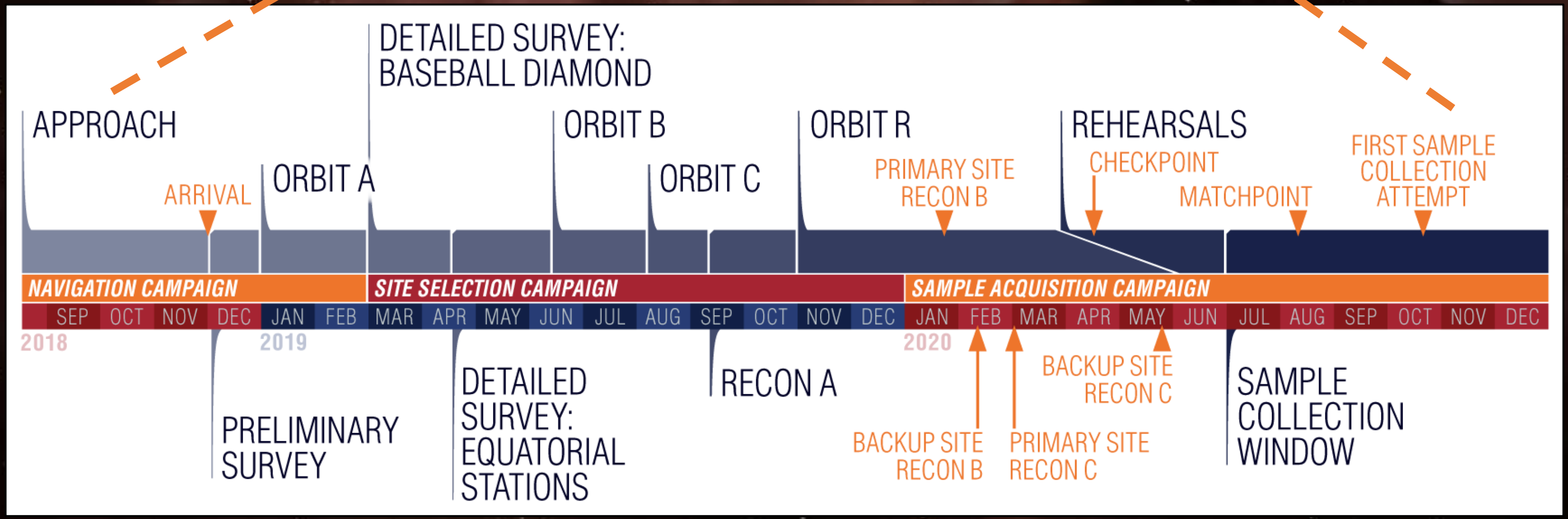


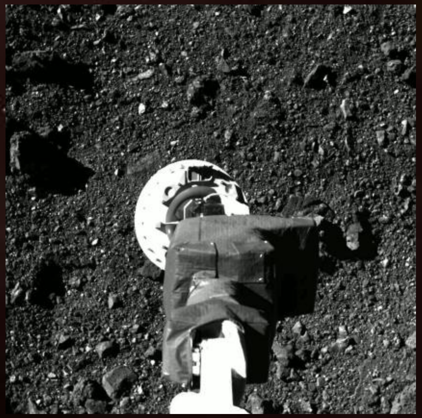
OSIRIS-REx Overview

- Primary technical objective: collect and return to Earth at least 60 grams of pristine regolith sample from asteroid Bennu





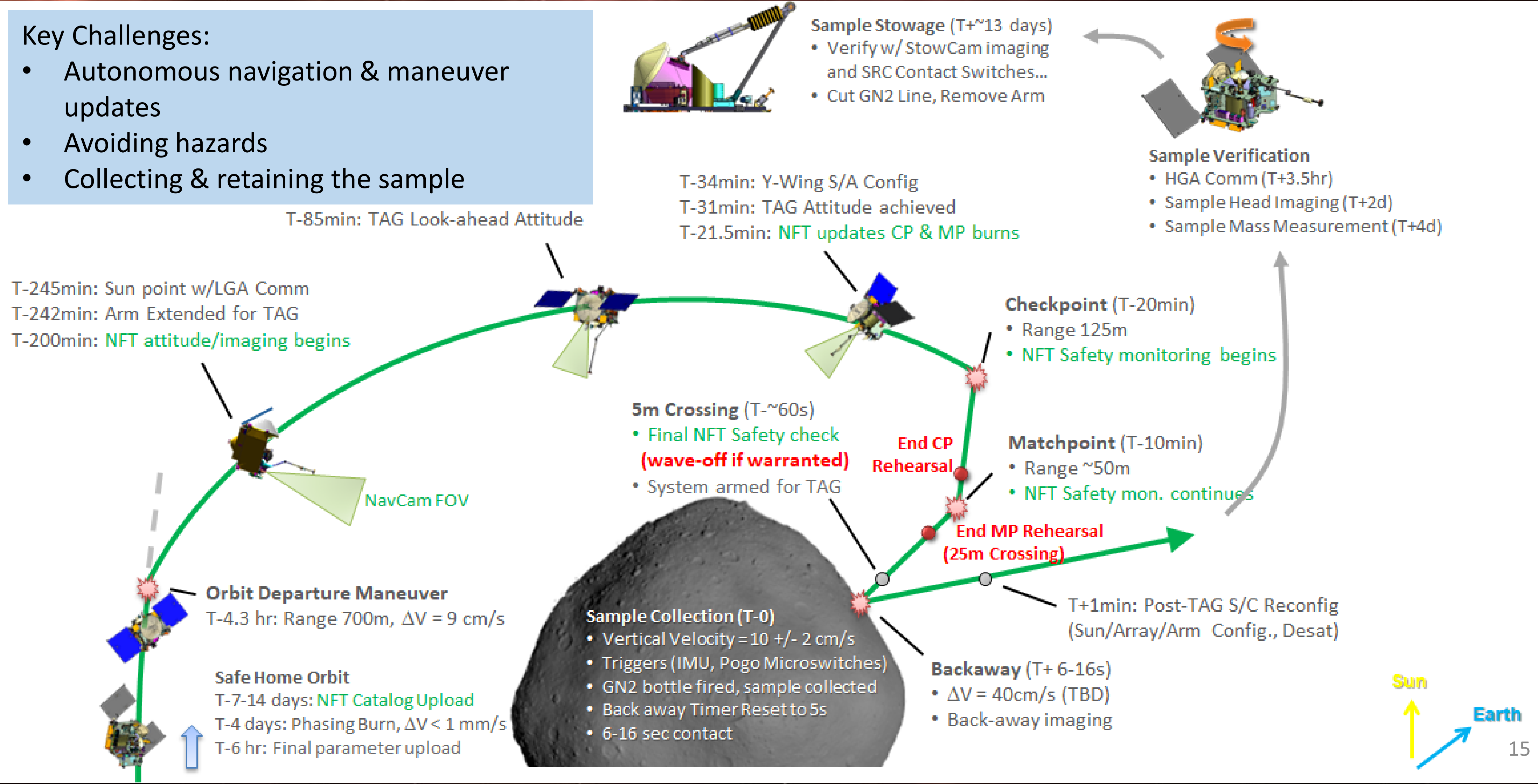




OSIRIS-REx: Touch-and-Go (TAG) Phase (1 of 2)

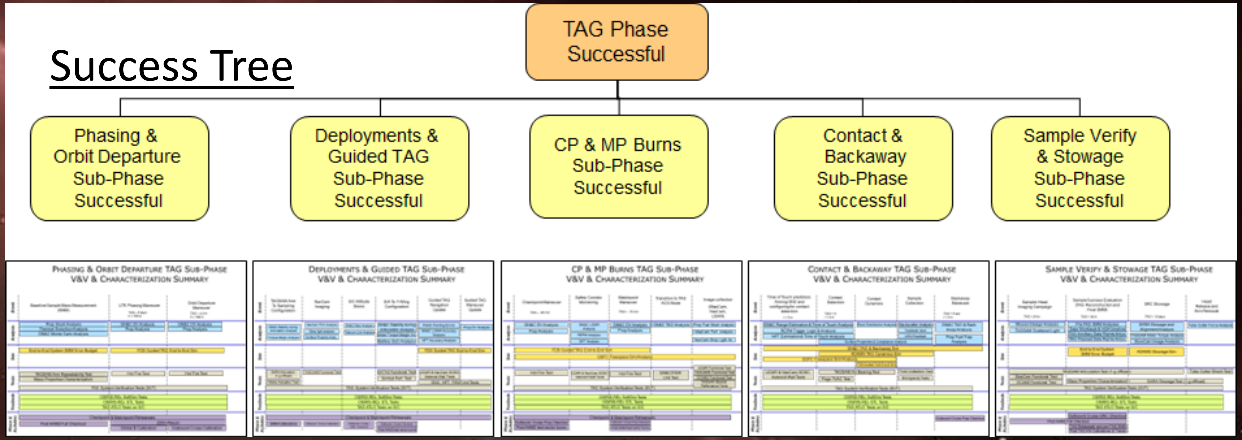
Key Challenges:

- Autonomous navigation & maneuver updates
- Avoiding hazards
- Collecting & retaining the sample



OSIRIS-REx: Touch-and-Go (TAG) Phase (2 of 2)

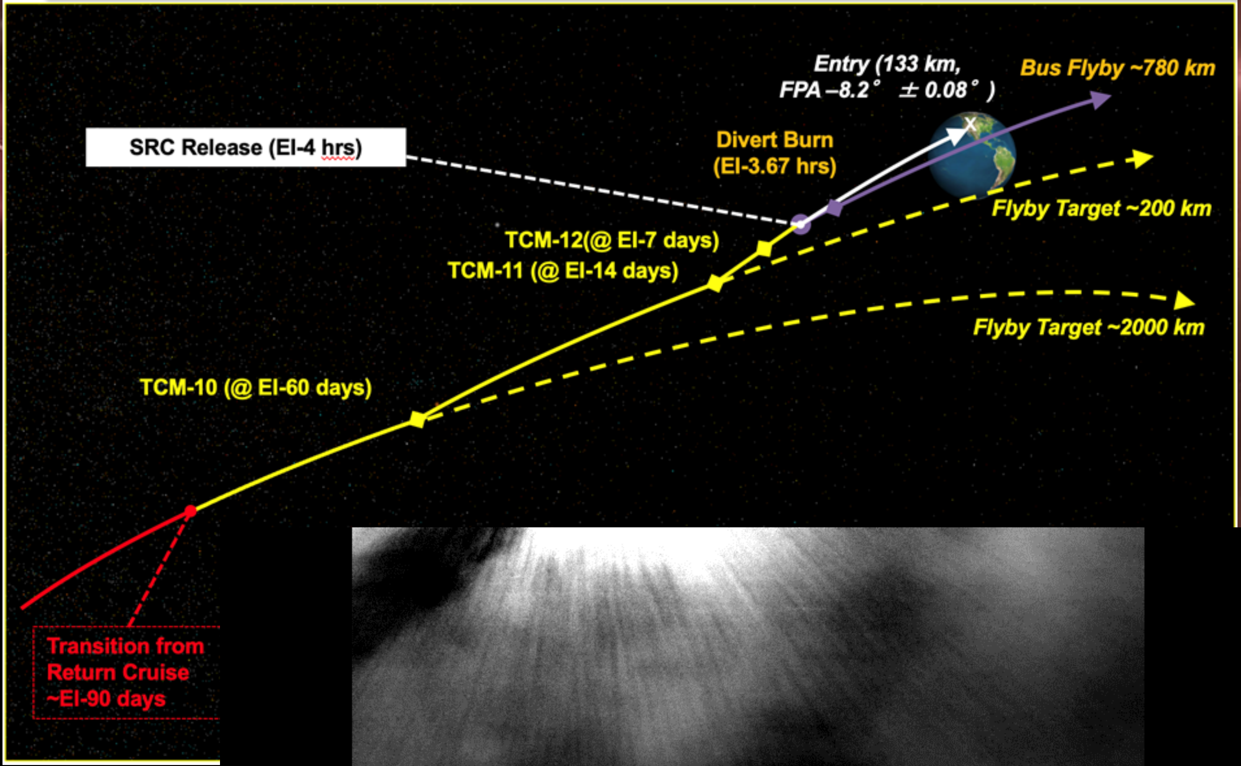
- TAG Phase Leads for both NASA and prime (Lockheed-Martin), for both development and operations
  - Key focus in development was the TAG Success Tree and corresponding Verification & Validation Matrix, used to ensure all activities required for a successful TAG were fully V&V'd
  - Key focus in operations was the TAG Readiness Checklist, used to ensure all preparations were completed and products ready to support the final rehearsal and sample collection



Readiness Checklist

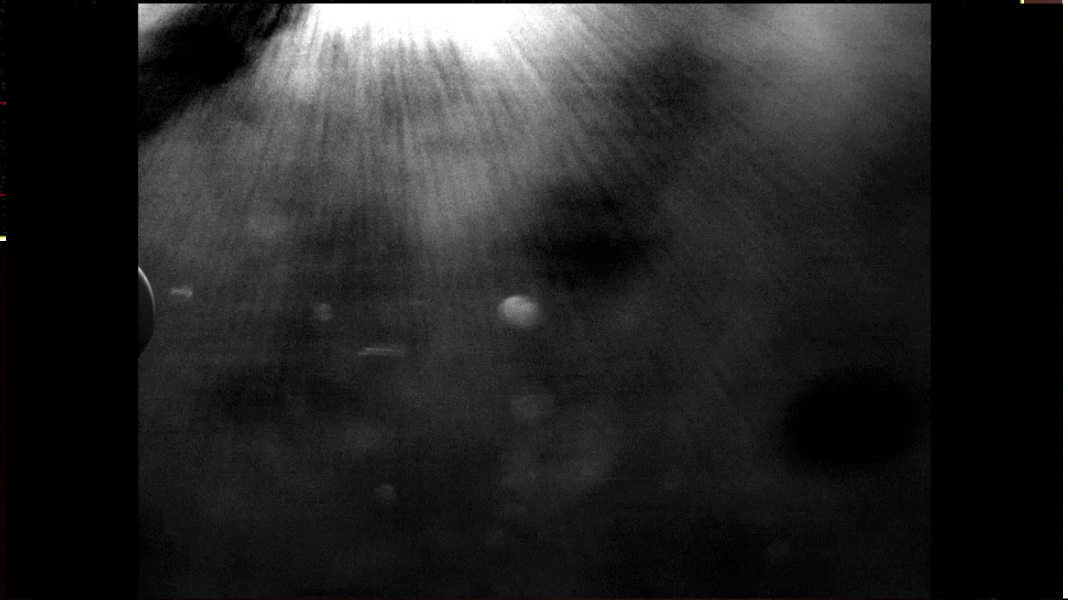
	27-Jan-2020 (MMR)	18-Feb-2020 (CP MPB)	20-Mar-2020 (MMR)	14-Apr-2020 (CP Rehearsal)	05-May-2020 (TRR)	11-AUG-2020 (MP Rehearsal)	20-Oct-2020 (TAG)
TAG Phase Plan	Reference trajectory delivered	CP Phase Plan TCR in review	CP Phase Plan TCR approved	MP Phase Plan TCR opened	MP Phase Plan TCR in review	MP Phase Plan TCR approved	TAG Phase Plan TCR approved
NFT Products	Nightingale features identified	Nightingale features delivered	Nightingale features delivered	Nightingale features uploaded	Nightingale features delivered	Nightingale features uploaded	Nightingale features uploaded
Hazard Map	On schedule; DEM specs settled	On schedule; 1st cut final map	On schedule; parameters finalized	On schedule; parameters finalized	Patch in test; map finalized	Patch uploaded; map uploaded	Patch uploaded; map uploaded
TAG Sequence	CP Rehearsal testing started	Nominal CP testing complete	All required CP testing complete	All required CP sequences uploaded	Nominal MP testing complete	All required MP testing complete	All required TAG testing complete
Contingencies	Plans worked for OPIE 5	Plans reviewed at OPIE 5	Plans finalized for CP	Plans finalized for CP	Plans finalized for MP	Plans finalized for MP	Plans finalized for TAG
TAG Rehearsals	CP set for 4/14; MP set for 6/23	CP set for 4/14; MP set for 6/23	CP set for 4/14; MP set for 6/23	CP set for 4/14; MP set for 6/23	CP complete; MP set for 8/11	CP complete; MP set for 8/11	CP complete; MP complete

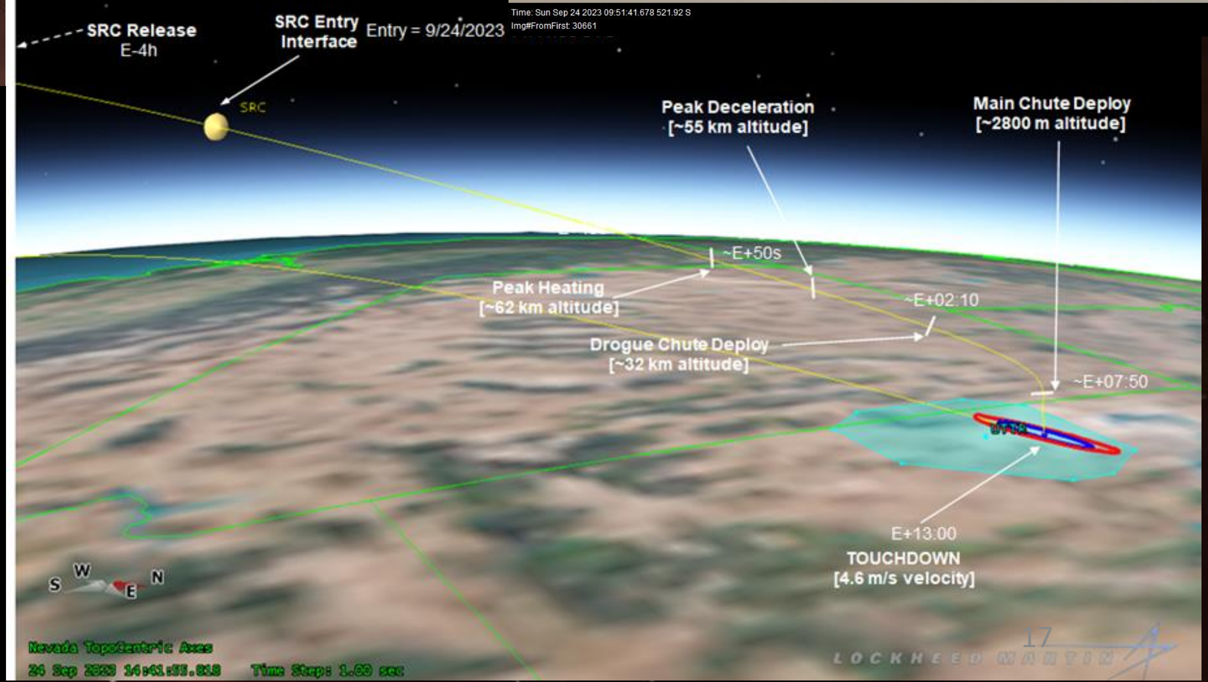
OSIRIS-REx: Entry, Descent, & Landing (EDL) Phase (1 of 2)



Key challenges:

- Precisely targeting the return capsule to Entry Interface for landing within UTTR target area
- Surviving peak heating and structural loads
- Parachute deployment





OSIRIS-REx: Entry, Descent, & Landing (EDL) Phase (2 of 2)

- Sample Return Capsule (SRC) development approach:
  - SRC's design was heritage from successful Stardust mission
  - Much of the design was "build to print" from Stardust, save for the sampling hardware
  - SRC developed and managed as a spacecraft "structural" subsystem
  - SRC release and EDL sequence essentially the same as Stardust
  - LM SRC Lead Engineer during development retired shortly after launch; no dedicated NASA Phase Lead
- NASA MSE during return operations (yours truly) was not involved in EDL phase development pre-launch; little continuity
- Value of Phase Lead SEs for EDL – with continuity between development and operations – evident
  - SRC structural and thermal margins relative to requirements was not quantified, which complicated development of SRC release criteria
  - Incorrect SRC release performance assumptions used by Flight Dynamics and EDL teams
  - The need to update the SRC release attitude following the change in asteroid departure date was a "surprise" a couple months prior to Earth return
  - Timing of drogue chute deployment during descent was very late because of miswiring of the SRC harness and failure to identify this error in test

Wrap Up

- A dedicated Phase Lead SE for time-critical and complex sequenced operations provides high value in both development and operations to ensure mission success
  - Provides a system-level "champion" for that phase throughout the life cycle
- DAVINCI's reliance on a tightly integrated entry, descent, and science profile within a hostile environment necessitates a Phase Lead SE to orchestrate the modeling, analysis, and V&V to ensure successful execution in flight
- Similarly, the complex sequence of steps to capture and configure the Mars "Orbiting Sample" for CCRS relied on a Phase Lead SE to define the process and all input parameters for assessing capture performance
- OSIRIS-REx provided evidence of the impact when Phase SE leadership is present (TAG) and when it's not (EDL) from formulation through landing

THANK YOU!