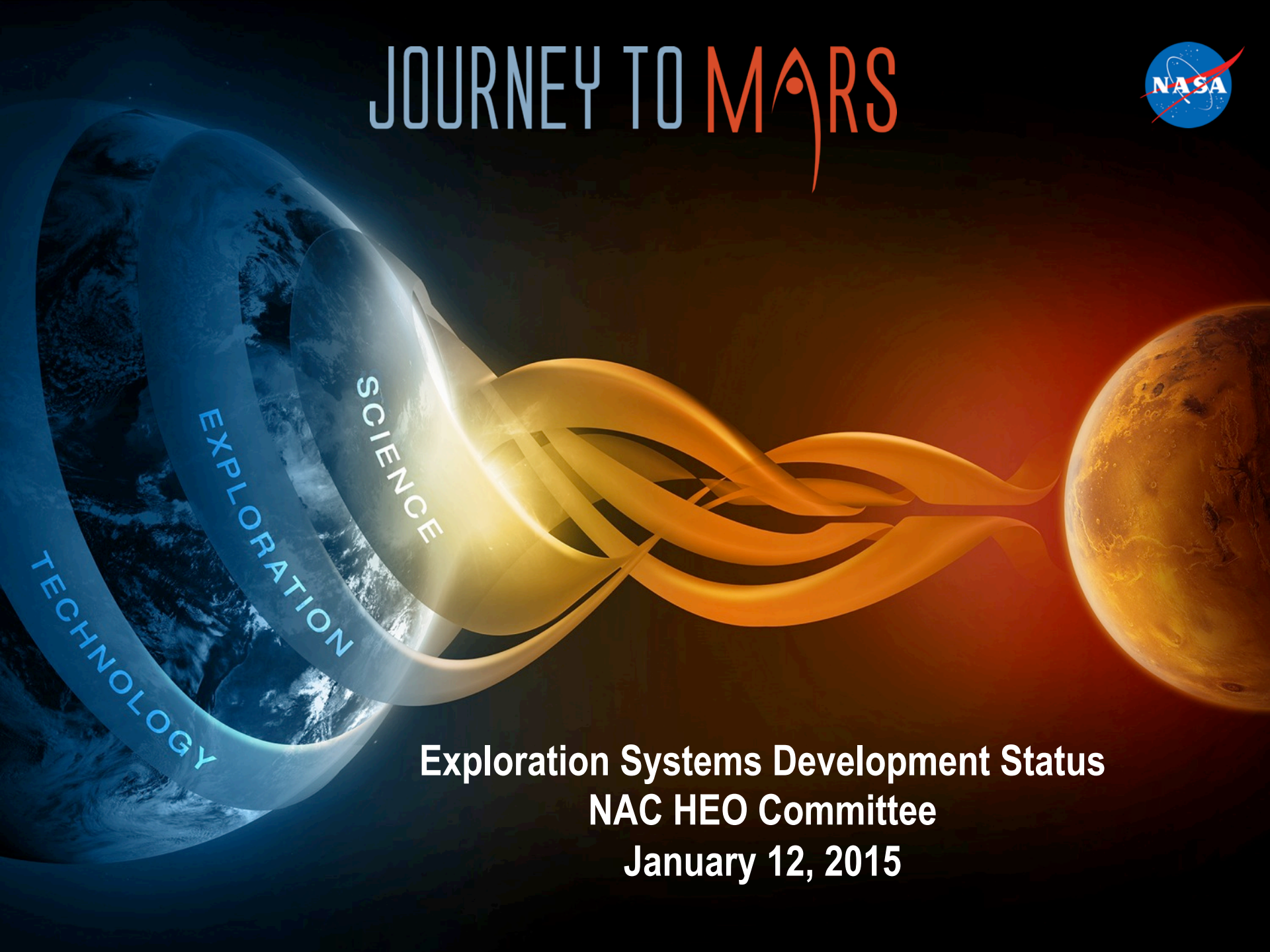
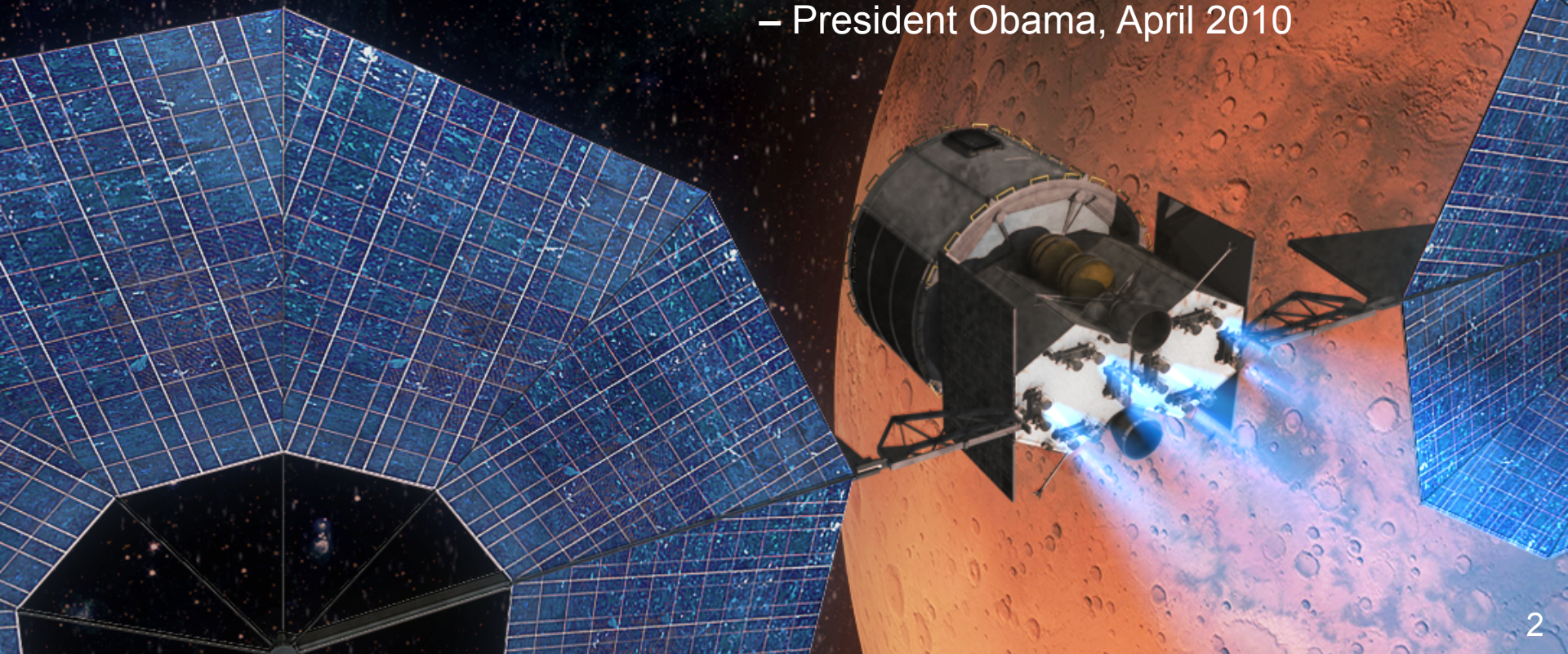

JOURNEY TO MARS
NASA
TECHNOLOGY
EXPLORATION
SCIENCE
Exploration Systems Development Status
NAC HEO Committee
January 12, 2015

Pioneering Space

"Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity's reach in space – we will strengthen America's leadership here on Earth."

– President Obama, April 2010

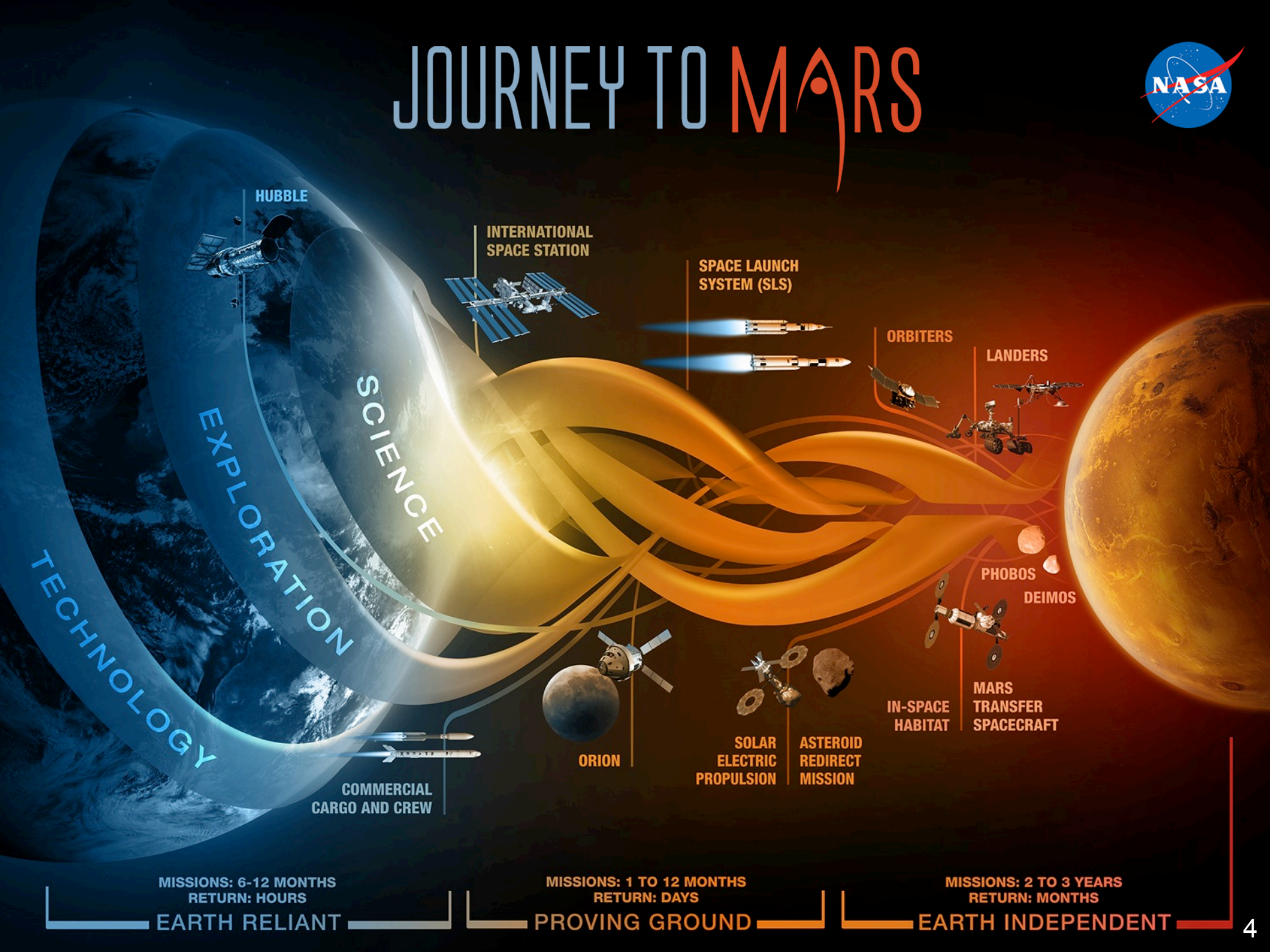


The BIG Picture

- Our emerging Exploration Strategy implements NASA's first strategic objective:
  - "Expand human presence into the solar system and to the surface of Mars" – What we call 'Pioneering Space'

- The Mission Directorates have important linkages in both goals and assets, and have begun to exercise those, e.g., Mars 2020

- The nation is investing considerable resources in NASA for this endeavor. We need to make as much progress as possible toward a program of human and robotic exploration that is sustainable over the long term.


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

SLS, Orion, and Ground Systems

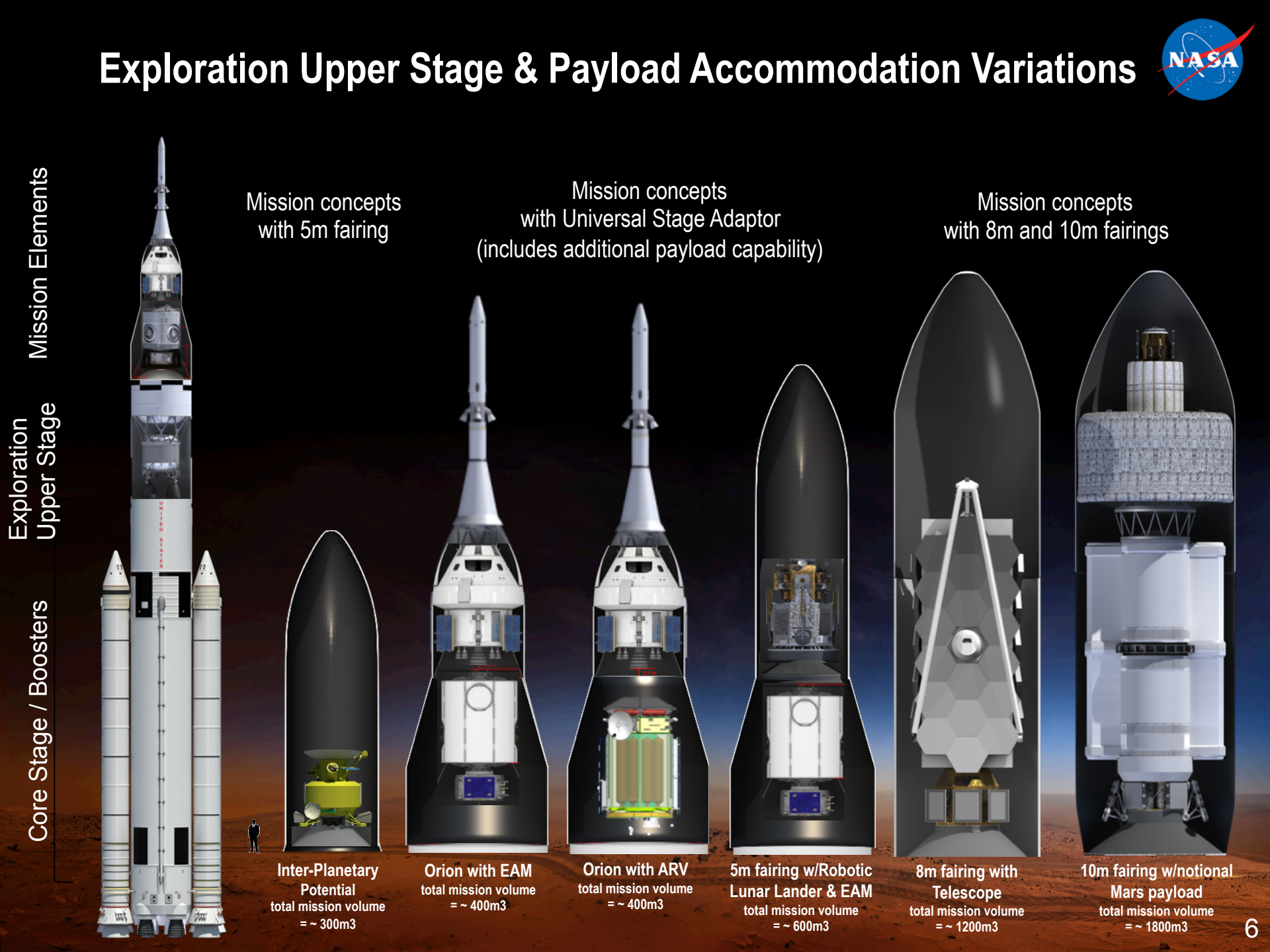
Beginning human exploration beyond LEO as soon as practicable helps secure our future in space.

Space Launch System

Orion Crew Capsule

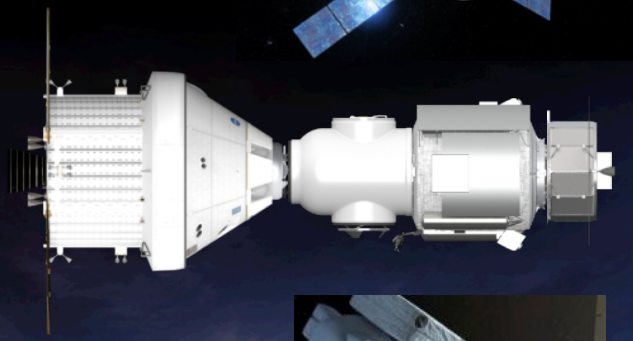
Ground Systems Development & Operations

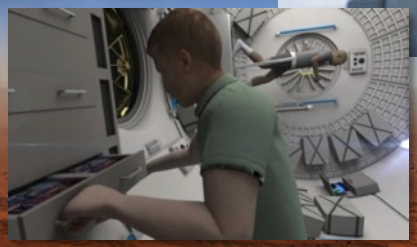
Exploration Upper Stage & Payload Accommodation Variations



Into the Proving Ground of Cis-lunar Space

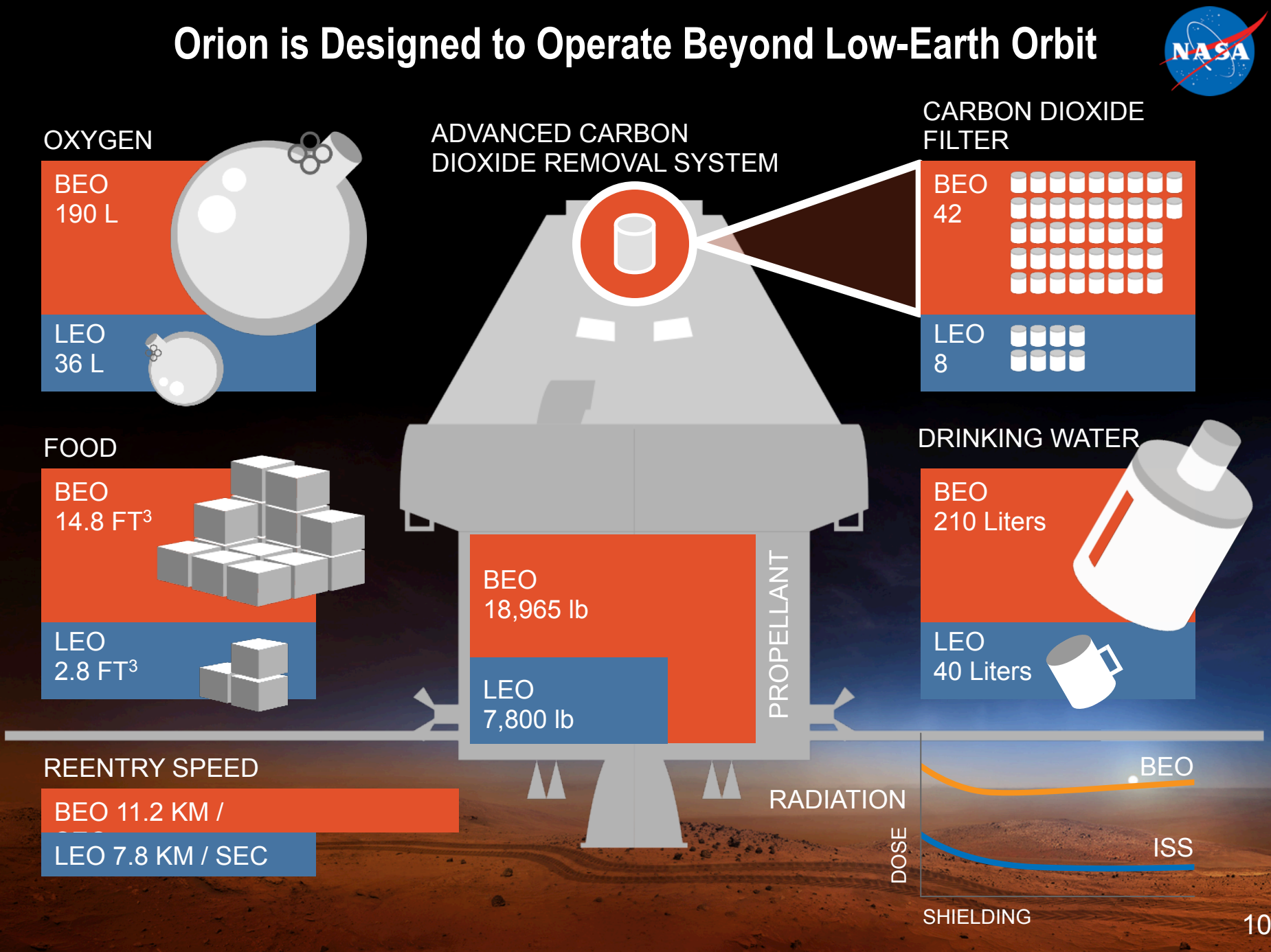
- Demonstrate SLS and Orion in deep space
  - Critical Mission Events
    - Separation Events, Key Maneuvers, Re-entry, Landing and Recovery
  - Co-manifested cargo capability with Orion, including loads, dynamics.
  - Demonstrate integrated vehicle systems in flight
    - Deep space communications, power and thermal systems, in-space maneuvering
  - Validate environments
  - Autonomous operations
- Demonstrate use of LDRO as a staging point for large cargo masses en route to Mars
- Conduct deep-space EVAs with sample handling
- Integrated human and robotic mission operations
- Evaluate crew health and performance in a deep space environment
- Demonstrate advanced Solar Electric Propulsion (SEP) systems to move large masses in interplanetary space
- Demonstration of In-Situ Resource Utilization in micro-g
- Learn to operate with reduced logistics capability
- Demonstrate long duration, deep space habitation systems
- Demonstrate structures & mechanisms
  - Low temperature and mechanisms for long duration, deep space missions
  - Inflatable structures





Orion:
Low-Earth Orbit vs. Beyond Earth Orbit

Orion is Designed to Operate Beyond Low-Earth Orbit

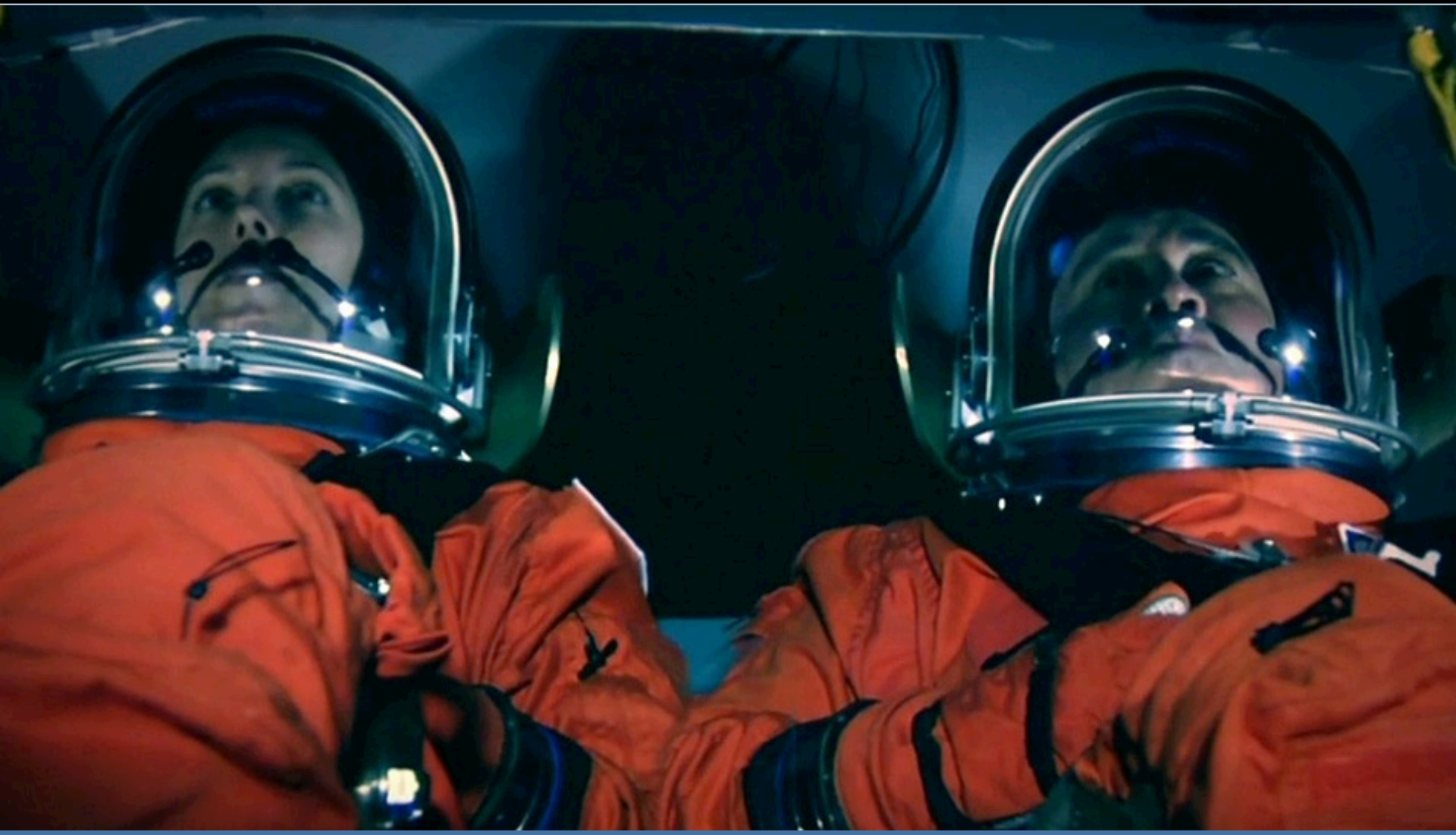


Beyond Earth Orbit Crew Safety Complexity

45 MINUTES TO EARTH

5 TO 11 DAYS TO EARTH

Beyond Earth Orbit Crew Safety Complexity

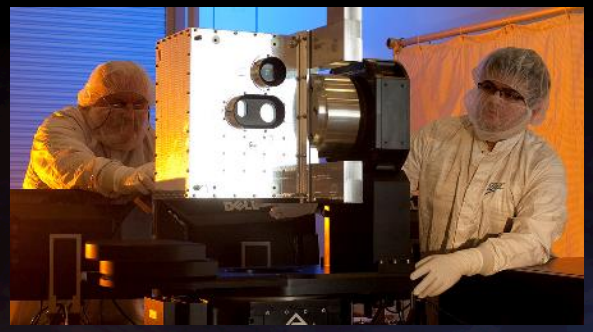


Orion can sustain crew for nearly a week in a depressed cabin

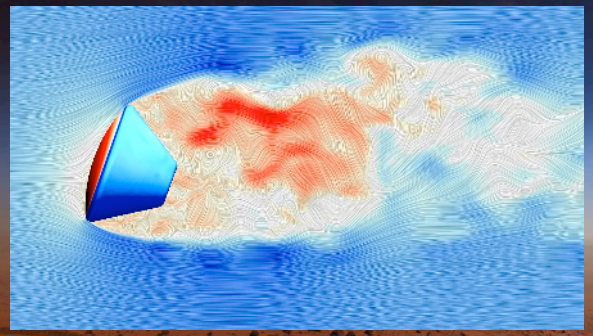
Orion Development Benefits Commercial Crew Program

Request	*Provided*
Design Data	171
Analyses / Trades	28
Models	11
Test Data	102
Operations Data	7
Interfaces	39
Other	58

Technical Design Data



Test Data and Results



Models

EFT-1 Post Flight Quick Look

Video

Summary

- Mission Success Criteria
  - ✓ Successfully launch and deliver EFT-1 into the planned orbit
  - ✓ Demonstrate critical separation events during ascent and deorbit
  - ✓ Demonstrate TPS performance during high energy return
  - ✓ Demonstrate descent, landing and recovery

  In work: Successful data recording, analysis, and delivery of flight test data to NASA in accordance with the EFT-1 Data Analysis Plan

- Flight Test Objectives
  - Current estimate is that we will meet 85 of 87 flight test objectives
  - One objective is still in work; we expect to meet it:
    - OFT1.082 Demonstrate CM propulsion system post landing processing of toxic and/or high-pressure elements
  - Initial assessment that the following objectives may not be fully met:
    - OFT1.014 Demonstrate the CMUS under operational conditions
      - 1 of 4 measures of performance not met: "All 5 CMUS bags are deployed to proper location"
    - OFT1.106 Determine the performance of the CMUS
      - 1 of 4 measures of performance partially met - "… the CMUS bags should be deployed until recovery operations require deflation" not met
  - Minor measure of performance impact noted:
    - OFT1.005 Demonstrate LAS separation during nominal ascent.
      - "Visual observation of LAS jettison to include … second approach and clearance of the Orion spacecraft and launch vehicle"
      - LAS not seen in its second approach

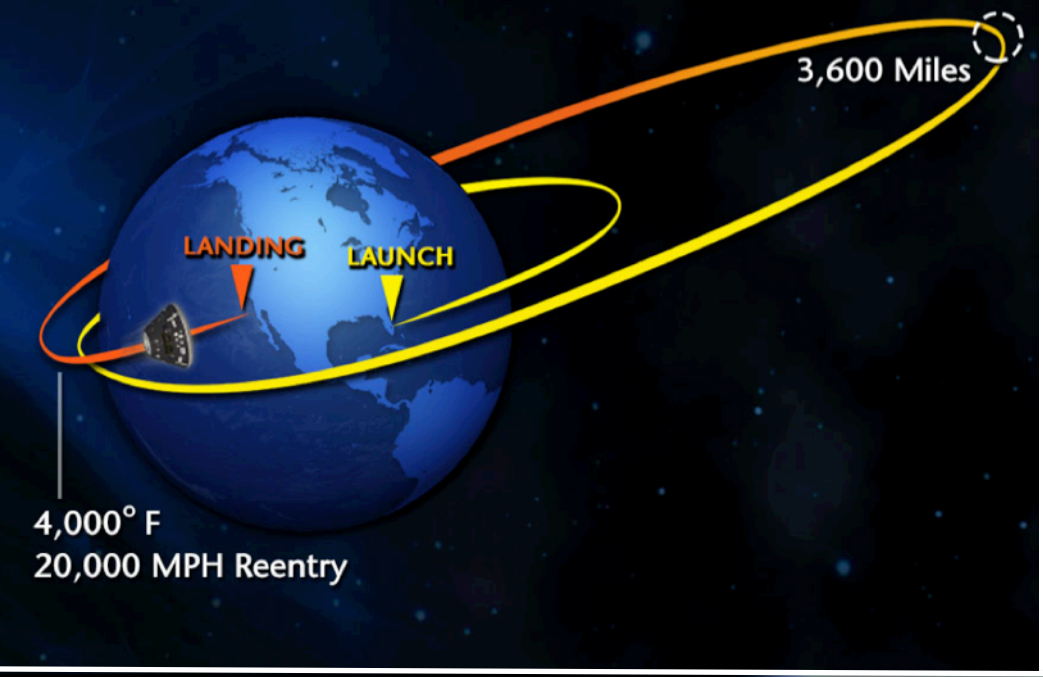
MISSION SUCCESS!

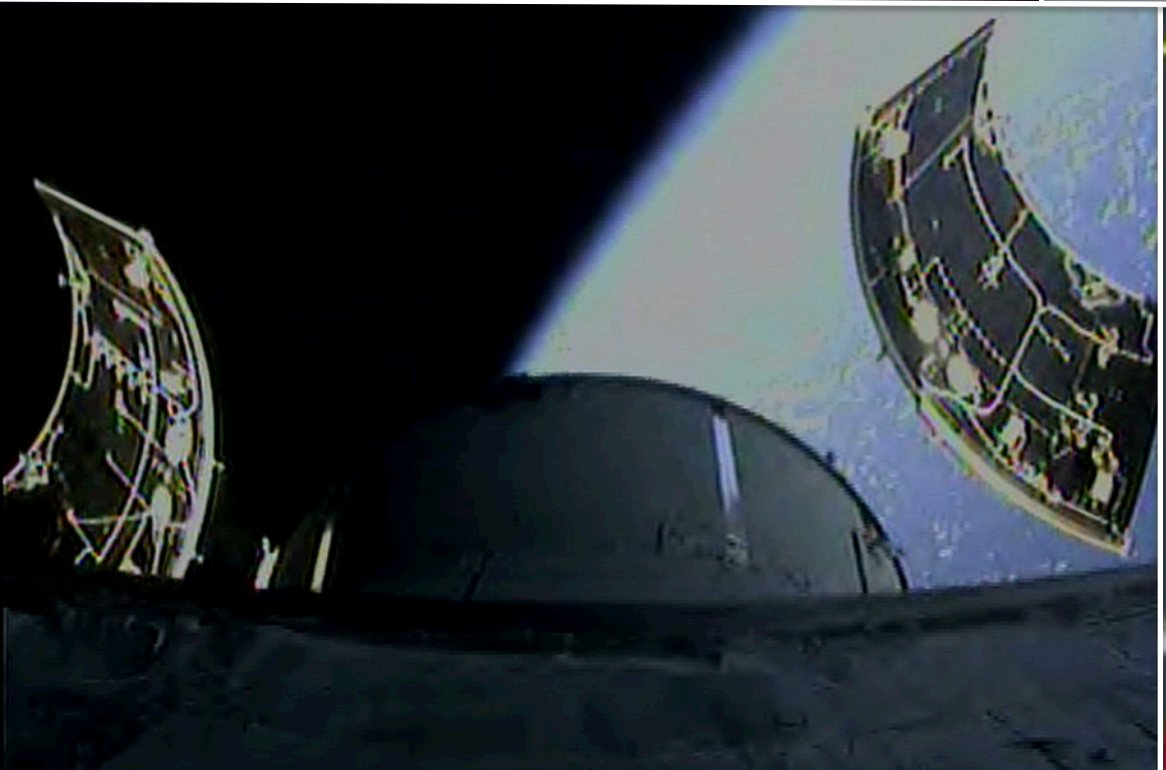
Data and Data Quality

- **Data**
  - Official data delivery to NASA is on a hard drive
- **Operational Flight Instrumentation**
  - Real time telemetry - Dropouts as expected (ZOE, reentry blackout)
  - Data stored on board is good quality
- **Developmental Flight Instrumentation**
  - Flight Data Recorder 1 had dropouts just prior to power down, FDR 2 data good
    - FDR1 and FDR2 record identical data, only FDR2 data posted for review
  - Forward bay DAU lost data for last 10 minutes prior to power down
- **Video**
  - FTCAMs – Good quality
    - FTCAM3 initially had poor quality, but improved planned shutdown/restart, no loss of FTOs
  - Forward bay cameras – Good quality from all 3 cameras
  - SM cameras – Good quality from 4 of 5
    - Umbilical camera data not available yet, being investigated by ULA
  - Peak heating resolution degraded: moved downrange to avoid cloud cover
- **Radiation Monitoring and Radar**
  - Yet to see data

Flight Performance

- Trajectory vs ULA ICD
  - Trajectory was very close to nominal (< 1 sigma)
- Environments
  - Most environmental data is still being analyzed
    - DFI (thermal, vibration, acoustic), analysis still in work
    - Radiation (RAMs and BIRDs still being analyzed)
    - No radiation upsets observed in critical hardware (VPU video FPGA resets likely SEUs)
  - Steady state acceleration was nominal
- Sequence
  - All sensors/inputs worked (redundancy maintained)
    - Including the LV discretes, no chatter
  - All events occurred based on primary triggers
    - Smart drogue release occurred (as expected)
    - Touchdown detection worked as expected
  - Both FCMs commanded all events properly
  - All PDUs delivered proper energy to all effectors (e.g. solenoids, NSIs)
  - All effectors worked
    - CMUS NSIs fired, pressure blew down, some bags did not inflate
  - Critical events executed successfully
    - SM and LAS T-0, SM panel, LAS jettison, CM/SM sep, FBC, drogue, main, cut

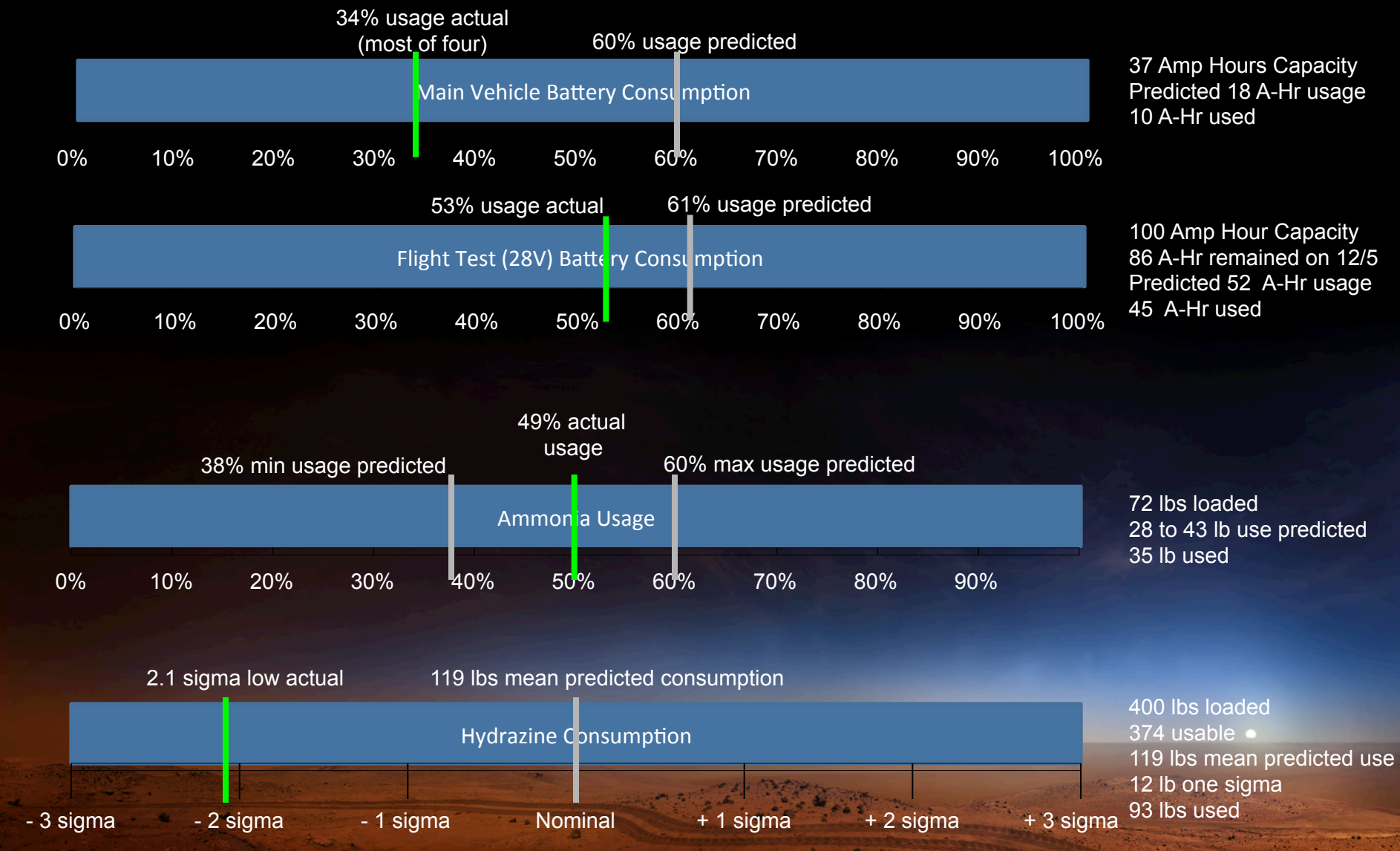

3,600 Miles
LANDING
LAUNCH
4,000° F
20,000 MPH Reentry



Flight Performance

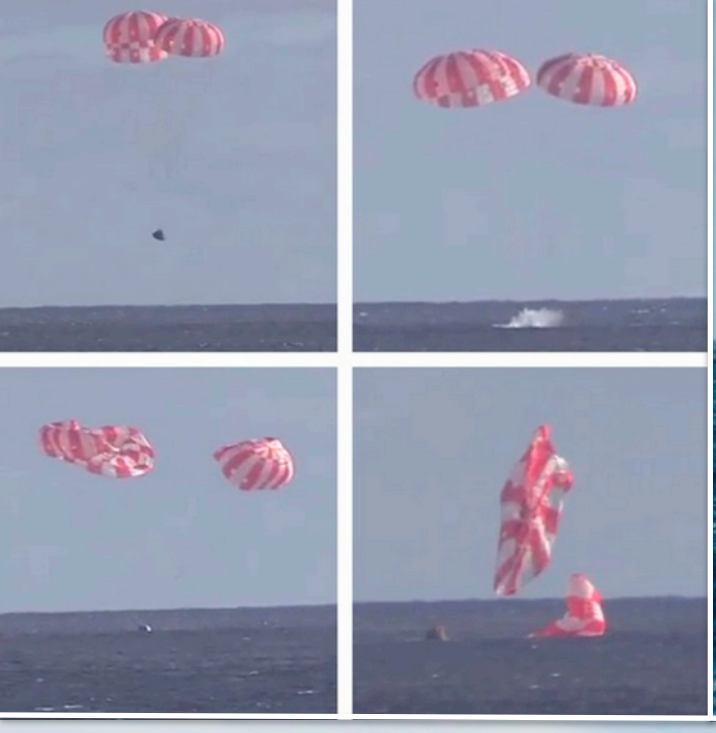
- Fault Management
  - No faults detected
- In Flight commanding
  - Nominal commands sent successfully as planned
    - CFDP file transfer (FTCAM2, 55 minutes after liftoff)
      - At the end of the file transfer, planned to command streaming FTCAM3
        - » Poor quality on FTCAM3, so MCC commanded streaming from FTCAM2
        - » This was pre-authorized, in flight rules
    - 60 minute power down extension
    - No-op sent post landing (to show that command link established in water)
  - Not planned (pre-authorized)
    - 2 minutes after CM/SM separation (onset of peak radiation)
      - Sent a command to rerun VPU radiation shutdown/restart
        - » Because VPU COP C failed to initialize correctly
      - At no time did we lose the ability to perform a stored data reset
        - » COPs are unrelated to VPU processor
  - No Cat 4 commands sent
- Integrated Test Laboratory flight followed
  - Smooth countdown, recycle, and in flight sequencing largely due to ITL rigor

Consumables



Recovery

- CM - Spacecraft looks reusable
  - Other than the expected damage due to recovery (TPS due to horse collar)
    - Very little damage to CM/SM umbilical plate
  - Three suspected MMOD impacts (two backshell, one heat shield shoulder)
    - Further inspection required at KSC
- FBC – Not recovered
  - Appears that FBC chutes stayed attached to water
  - Will confirm with radar track
- Main chutes
  - 2 of 3 main chutes recovered
- Drogues
  - 0 of 2 drogues recovered
- From power down to settled in the ship was 7.5 hours
  - Without EFT-1 unique work (e.g. photography) it could be a 4 hour operation
  - Existing RFA from PDR to relook at the operational concept for crewed missions




LPD 23

Post-Flight Plan

- Lockheed-Martin Engineering Review Board #1 held on 12/18/14
- Integrated Test Laboratory break of configuration decision: January 7
- ERB #2: Mission Overview 1/14/15
  - Pre-flight configuration summary
  - DFI & FTO
  - ATLO
  - Mission performance (Delta and Orion)
  - Overview of performance anomalies (Hardware and Software)
  - Flight Ops, Ground Ops, GSDO
  - Preliminary analysis observations
- ERB #2A: Anomaly Deep Dive, 1/28/15
  - As identified in ERB #2
- ERB #2B: Contingency Anomaly Deep Dive, TBD
- ERB #3: Post Flight Report Briefing per DRD-009 (Duszynski) 3/4/15
- ERB #2C (contingency) TBD
  - For any trailing items
  - Vehicle inspections, CPAS inspections, Photogrammetry, Disassembly

2014 Accomplishments

January
Orion – team completes Exploration Flight Test-1 Service Module
Space Launch System – avionics system sees the first light
Ground Systems – at Launch Pad 39B, space shuttle era flame deflector and Apollo-era brick walls from the flame trench were removed to make way for a new flame deflector and brick walls

February
Orion – Exploration Flight Test-1 launch prep gets boost as Delta IV rocket arrives in Florida
Space Launch System – 2-percent scale models of the SLS solid rocket boosters and core stage RS-25 engines were designed and built for Base Heating Test
Ground Systems – New roller bearings tested on Crawler-Transporter 2

March
Orion – Forward Bay Cover Jettison test successful
Space Launch System – NASA Administrator visits Marshall Space Flight Center, views SLS progress
Ground Systems – Contract awarded to modify Vehicle Assembly Building High Bay 3 at Kennedy Space Center

April
Orion – Testing designed to validate Orion's avionics systems successfully wrapped up inside the Operations and Checkout Building high bay at NASA's Kennedy Space Center in Florida
Space Launch System – NASA engineers prepare game changing Cryotank for testing
Ground Systems – Construction workers have installed the framing and some of the inner walls inside Firing Room 4 in the Launch Control Center in support of NASA's effort to transform Kennedy into a multi-user spaceport.

May
Orion – KSC, JSC launch and mission control centers simulate Orion's first flight operations
Space Launch System – A-1 Test Stand operations team examines the progress of a cold-shock test on the new A-1 structural piping system, achieving a key milestone leading to RS-25 engine testing
Ground Systems – Orion Test Vehicle undergoes EFT-1 pre-transportation simulation

June
Orion – Parachutes hit no snags in most difficult test
Space Launch System – NASA turns down the volume on rocket noise through SLS Scale Model Acoustic Testing
Ground Systems – GSDO, Corrosion Lab test coatings for aluminum ground support equipment

2014 Accomplishments

July
Orion – Orion tests set stage for mission
Space Launch System – SLS RS-25 engine installed at Stennis for testing
Ground Systems – Modifications underway in VAB for Space Launch System

August
Orion – Engineers and technicians install protective shell on Orion spacecraft
Space Launch System – NASA Engineers wrapping up Acoustic Testing for Space Launch System
Ground Systems – NASA completes second Orion Underway Recovery Test

September
Orion – Orion in final preparations for launch
Space Launch System – NASA unveils world's largest rocket welding tool for Space Launch System
Ground Systems – Third round of Underway Recovery Tests completed

October
Orion – Orion assembly complete and ready for move to the launch pad
Space Launch System – Work begins on a welding wonder, the Vertical Assembly Center, for SLS at Michoud Assembly Facility
Ground Systems – VAB crane undergoes upgrades for future launch processing

November
Orion – NASA's Orion arrives at launch pad, hoisted onto rocket ahead of its first flight
Space Launch System – SLS engine section barrel hot off the Vertical Weld Center at Michoud
Ground Systems – Ground support equipment is secured in the well deck of the USS Anchorage at Naval Base San Diego in California in preparation Orion crew module recovery

December
Orion lifts off at dawn on Friday, December 5, from Cape Canaveral Air Force Station in Florida before splashing down 4.5 hours later off the coast of Baja in the Pacific Ocean where it was met by NASA and U.S. Navy recovery teams. The spacecraft's cross-country return, a 2,700 mile road trip from Naval Base San Diego to Kennedy, sets the stage for in-depth analysis of data obtained during Orion's trip to space. It will provide engineers detailed information on how the spacecraft fared during its two-orbit flight test. The Ground Systems Development and Operations Program led the recovery, offload and transportation efforts. The Space Launch System team was there every step of the way leading outreach efforts and support, while reaching major milestones in the development of the SLS rocket.

2015 – Major Milestones

NET Jan: RS-25 engine hot fire (SLS)

March: Orion EM-1 pathfinder 1st weld

March: QM-1 Booster fire (SLS)

March: Mobile Launcher structural modification complete

April: heat shield design complete

June: Orion EM-1 pathfinder welds complete

July: SLS Critical Design Review Board

TBD 3rd Quarter: Orion EM-1 Parachute Drop Tests

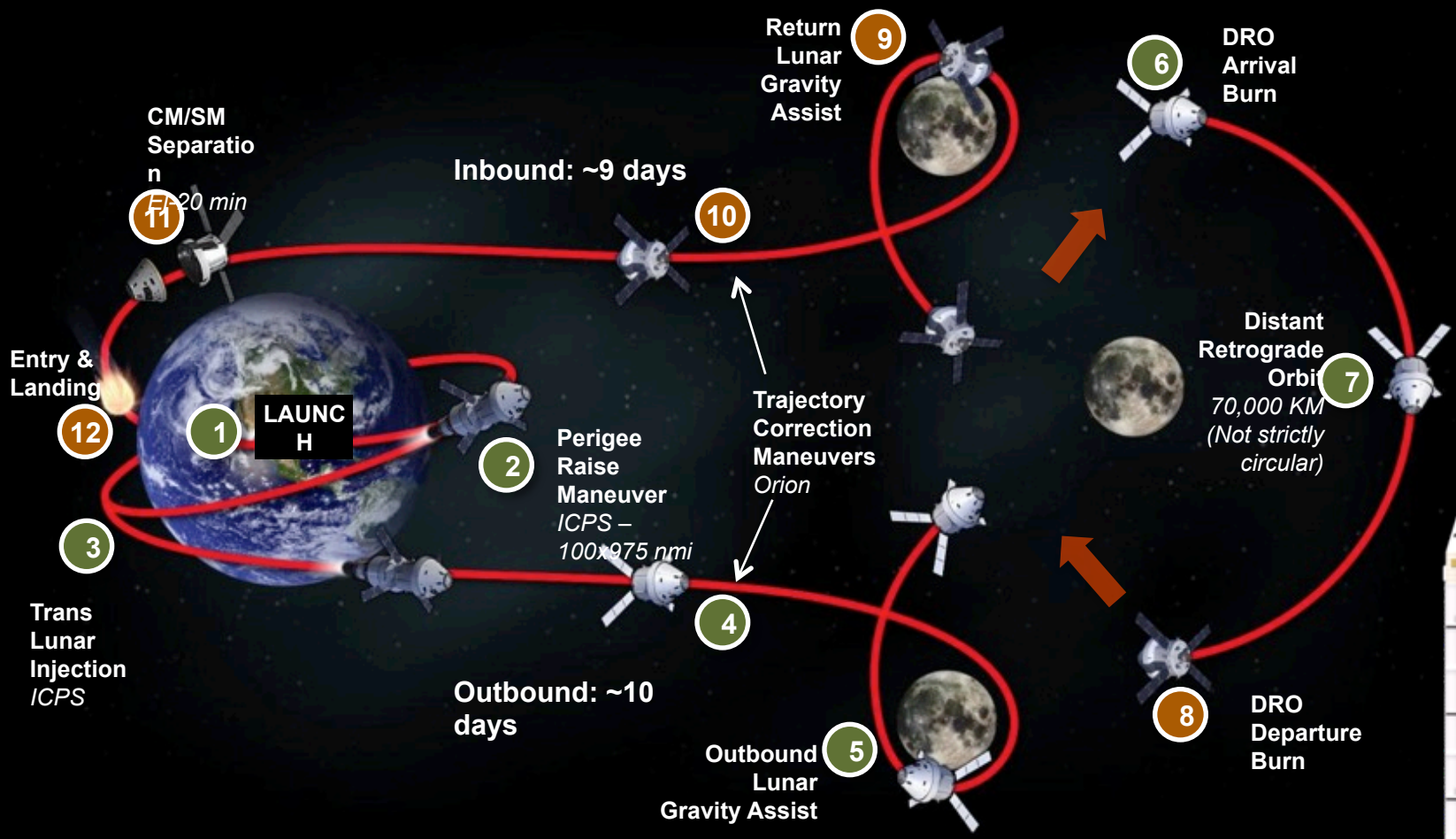
August: SLS LVSA STA Construction Complete

September: SLS LVSA /MSA/ICPS mated and on Test stand

October: SLS Lox/h2 STA's finished in VAC

November: Crawler Transporter-2 Life Extension Phase II complete

EM-1: Uncrewed Distant Retrograde Orbit 2017



Objectives:

- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight

DRM - Uncrewed MPCV

- Lunar capable heat shield
- 4 tank SM with full prop load
- EM-2 systems not included: ECLSS, Crew Systems, LAS Abort Motors (Inert)

Interim Cryogenic Propulsion Stage (ICPS) used to provide TLI burn