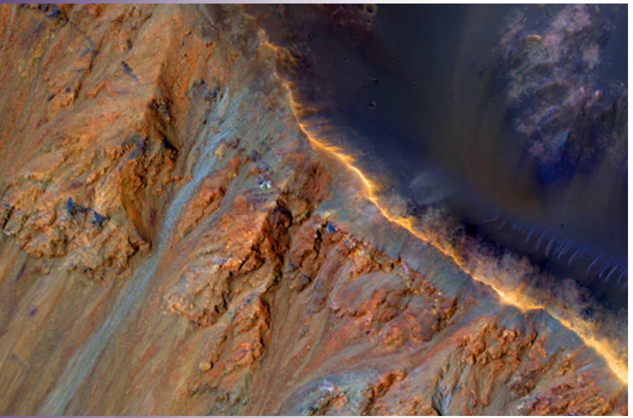
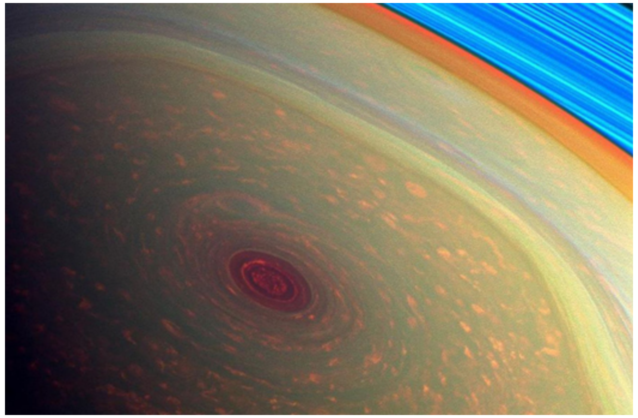
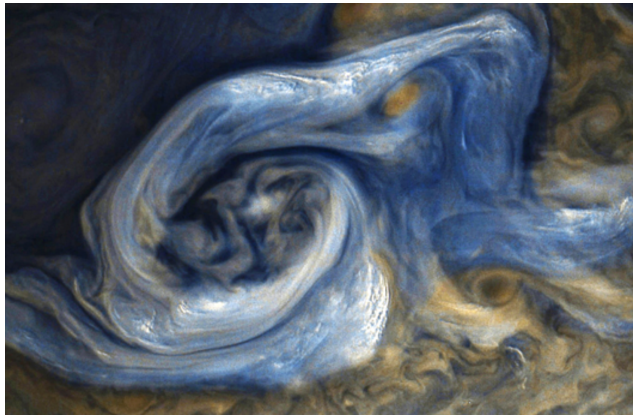
SCIENCE

National Aeronautics and Space Administration







STATUS REPORT

PLANETARY SCIENCE DIVISION

Jim Green

Division Director
Planetary Science Division
Science Mission Directorate, NASA
James.Green@nasa.gov

March 27, 2018

Planetary Science Missions: Events

2017

*Completed

January 4 – Discovery Mission selection announced

February 9-20 – OSIRIS-REx began Earth-Trojan search

April 22 – Cassini begins plane change maneuver for the “Grand Finale”

August 21 – Solar Eclipse across America

September 15 – Cassini end of mission at Saturn

September 22 – OSIRIS-REx Earth flyby

October 28 – International Observe the Moon night (1^{st} quarter)

2018

May 5 – Launch InSight mission to Mars

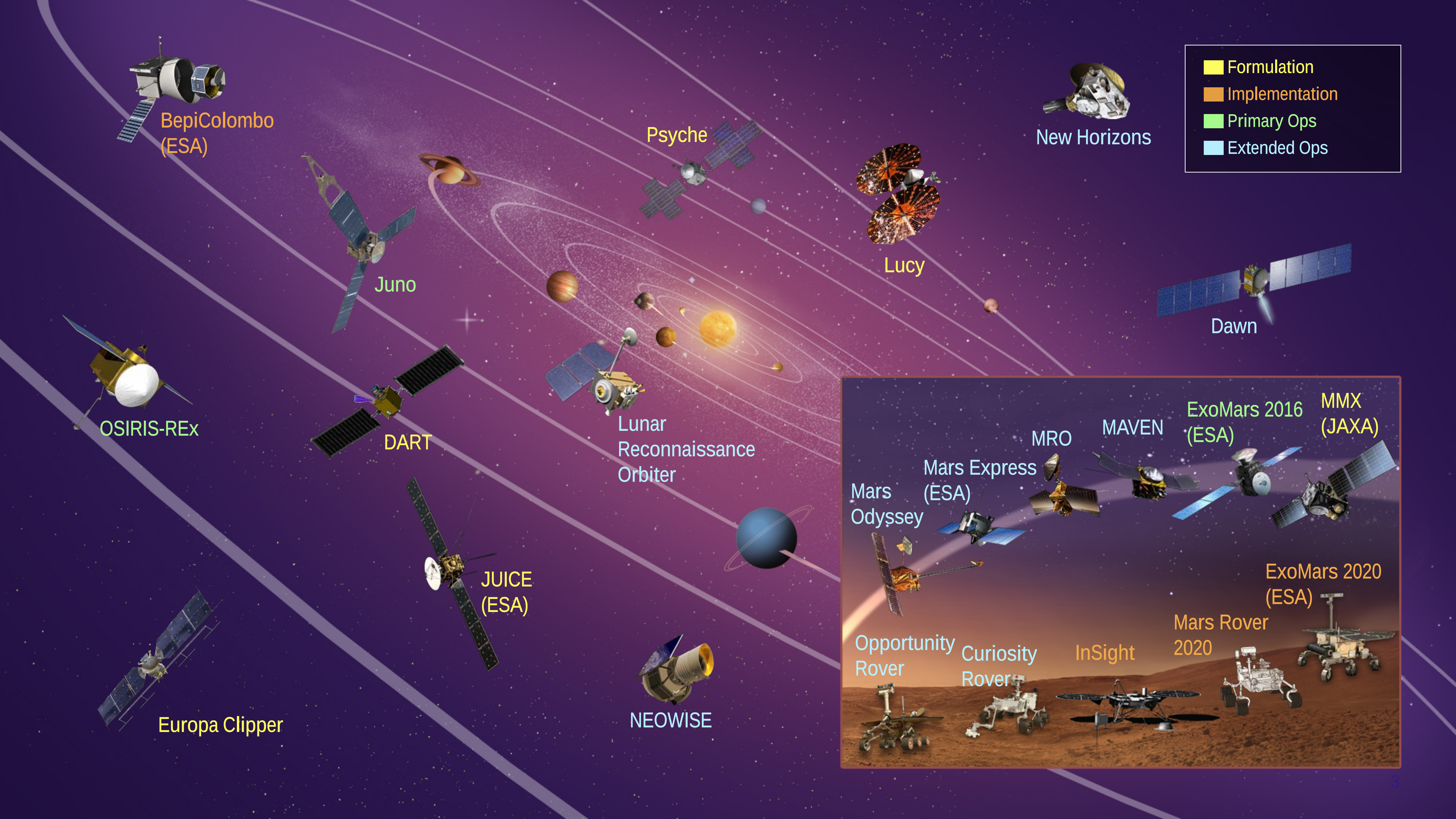
August – OSIRIS-REx begins observing Bennu

October – Launch of ESA’s Bepi Colombo to Mercury

November 26 – InSight landing on Mars

2019

January 1 – New Horizons flyby of Kuiper Belt object Ultima Thule


Formulation
Implementation
Primary Ops
Extended Ops
BepiColombo (ESA)
Psyche
New Horizons
Juno
Lucy
Dawn
OSIRIS-REx
DART
Lunar Reconnaissance Orbiter
JUICE (ESA)
Europa Clipper
NEOWISE
Mars Odyssey
Mars Express (ESA)
MRO
MAVEN
ExoMars 2016 (ESA)
MMX (JAXA)
ExoMars 2020 (ESA)
Mars Rover 2020
Opportunity Rover
Curiosity Rover
InSight

Planetary Science Budget

Planetary Science Program Content

	Actual FY 17	Enacted FY 18	Request FY 19	Notional FY 20	FY 21	FY 22	FY 23
Science	5,762.2		5,895.0	5,859.9	5,841.1	5,822.4	5,803.6
Planetary Science	1,827.5	2,227.9	2,234.7	2,199.6	2,180.8	2,162.1	2,143.3
Planetary Science Research	230.1		258.0	247.6	247.6	247.6	247.6
Planetary Defense	60.0		150.0	150.0	150.0	150.0	150.0
Lunar Discovery and Exploration	19.0		218.0	218.0	218.0	218.0	218.0
Discovery	194.6	335.8	381.2	476.6	375.0	355.6	348.5
New Frontiers	134.0	90.0	130.2	163.7	245.0	327.6	388.4
Mars Exploration	647.0	660.0	601.5	529.7	371.9	290.8	215.3
Outer Planets and Ocean Worlds	359.5		285.6	213.8	373.3	372.5	375.5
Technology	183.3		210.2	200.2	200.0	200.0	200.0

Planetary Science Budget Features

What's Changed

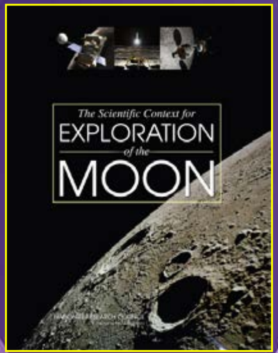
- New Lunar Discovery and Exploration Program supports public-private partnerships and innovative approaches to achieving science and human exploration goals
- New Planetary Defense Program for near-Earth object detection and mitigation includes development of DART and studies a low-cost, space-based near-Earth object detection mission
- Supports trade studies and technology development for returning Mars samples cached by Mars 2020 rover
- Europa Clipper as early as FY25; proposes to fly Clipper on a commercial launch vehicle given cost savings

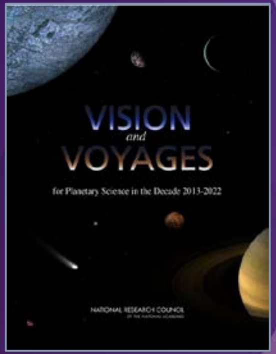
What's the Same

- Supports InSight, Psyche, Lucy, and next New Frontiers selection in FY19
- Funds all operating missions, and completes development of Mars 2020
- DoE production of radioisotope power generators and Pu-238 to fuel missions
- Healthy research program and SmallSat/CubeSat investments

Space Policy Directive-1 (December 11, 2017) amends the National Space Policy to include the following paragraph:

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will *lead the return of humans to the Moon* for long-term exploration and utilization, followed by human missions to Mars and other destinations;"

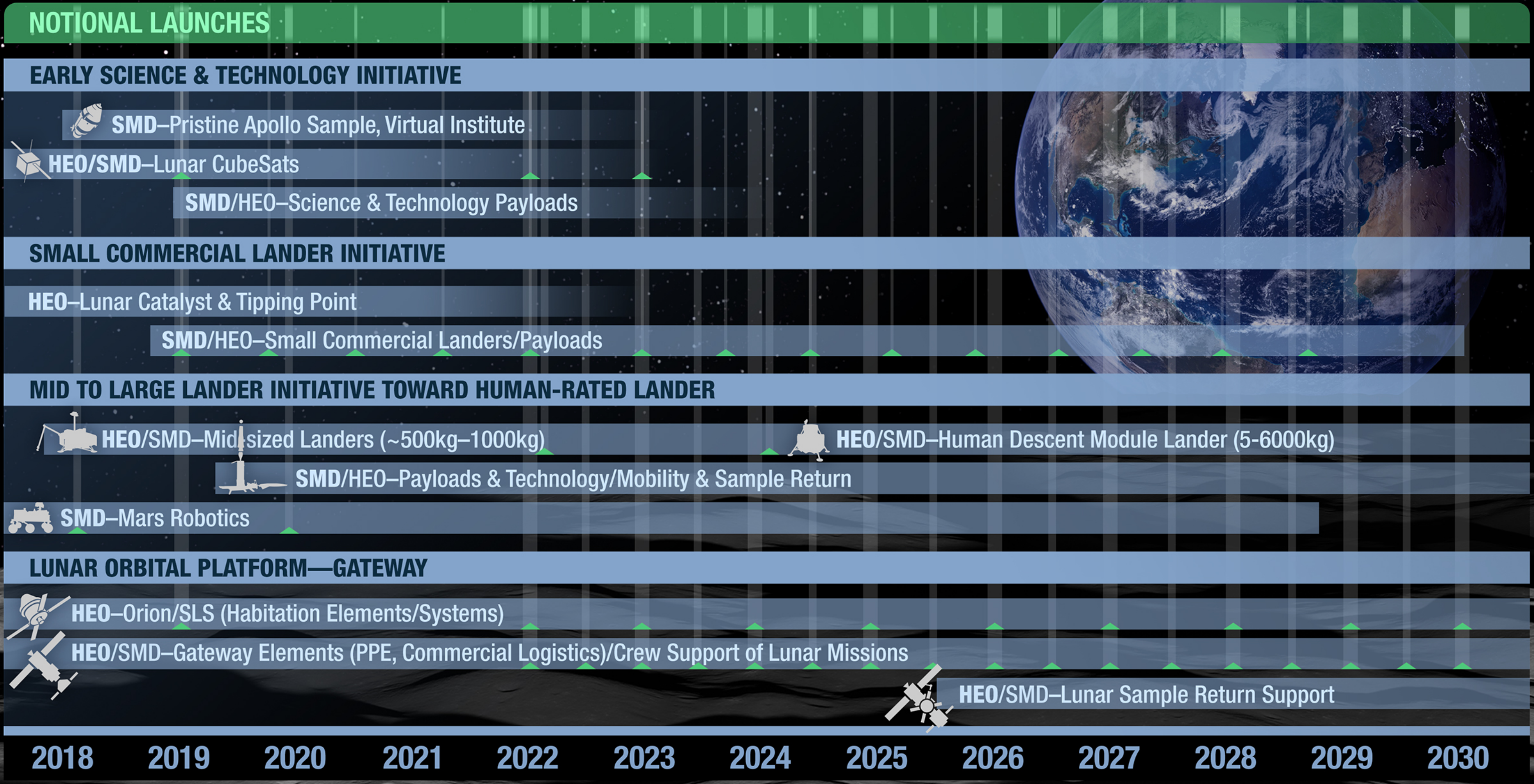




Community Input

- SCEM report (2007)
- Decadal Survey (2012)
- LEAG SATS
  - Advancing Science of the Moon (ASM-SAT)
  - Next Steps on the Moon (NEXT-SAT)
- Lunar Science for Landed Missions Workshop
  - Talks archived here: https://lunar-landing.arc.nasa.gov/
- Transformative Lunar Science Whitepaper
- New Views of the Moon II book

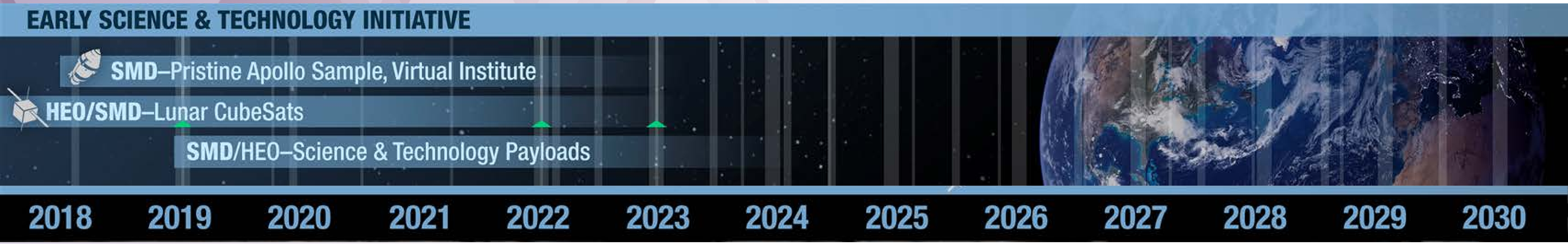
NASA Exploration Campaign



Timelines are tentative and will be developed further in FY 2019

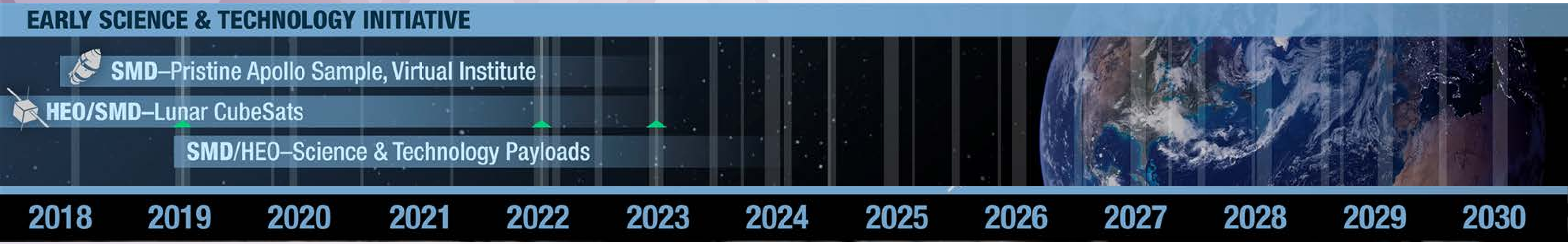
MARCH 2018

Lunar Exploration Campaign



- Research
  - SSERVI CAN3 – draft to be released soon
  - ROSES18: Enhanced Lunar Sample Analysis Campaign
    - Perhaps opening one of the sealed drive tubes
  - Developing archive system for lunar (and other) sample data, and digitizing lunar curation data
- CubeSats
  - Current: LunaH-Map, HEOMD cubesats
  - Future: SIMPLEx SALMON3-PEA– call is open to all INCLUDING Lunar proposals
- Korean Pathfinder Lunar Orbiter Participating Scientist Program
  - Launch 12/2020
- LRO continues to operate and provide excellent data for future missions

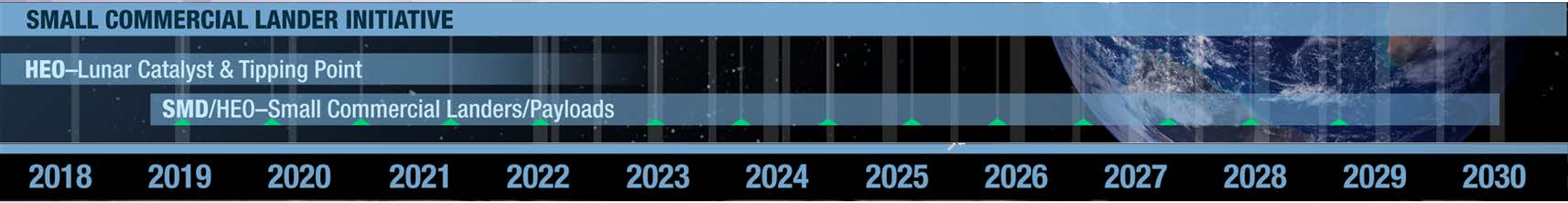
Lunar Exploration Campaign



DALI – Development and Advancement of Lunar Instrumentation

- ROSES18 call C22 (step 1 due April 3rd, step 2 due June 5th)
- Lunar instruments that support NASA's broader lunar exploration goals, including human exploration and in situ resource utilization (ISRU), as well as lunar science.
- All lunar instrument types, including rover-based and orbital, but particularly instruments for small stationary landers.
- Technologies that will reach at least TRL 6 by end of grant,
- Optimally for flight hardware builds for landers with flight opportunities as early as ~2021

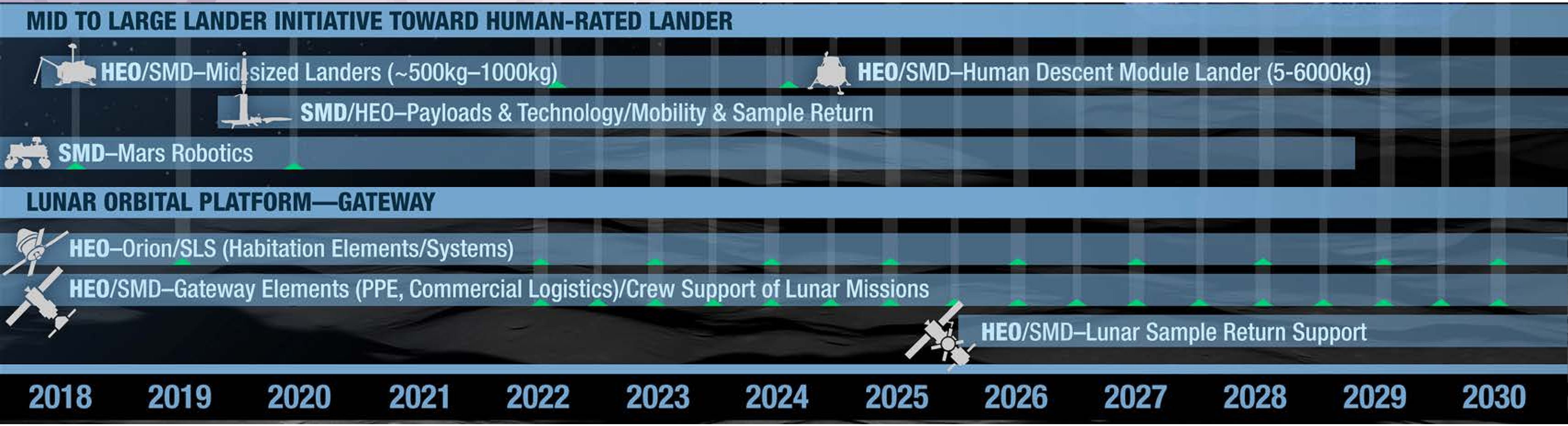
Lunar Exploration Campaign



Small Commercial Landers/Payloads

- RFP to commercial companies for hosting payloads
- GSFC to build retro-reflectors
- We will be looking for instruments to fly
  - Expect a new SALMON PEA
  - Open to Heliophysics/Astrophysics/Planetary as well as HEO/ISRU
  - Significant international participation will be permitted

Lunar Exploration Campaign

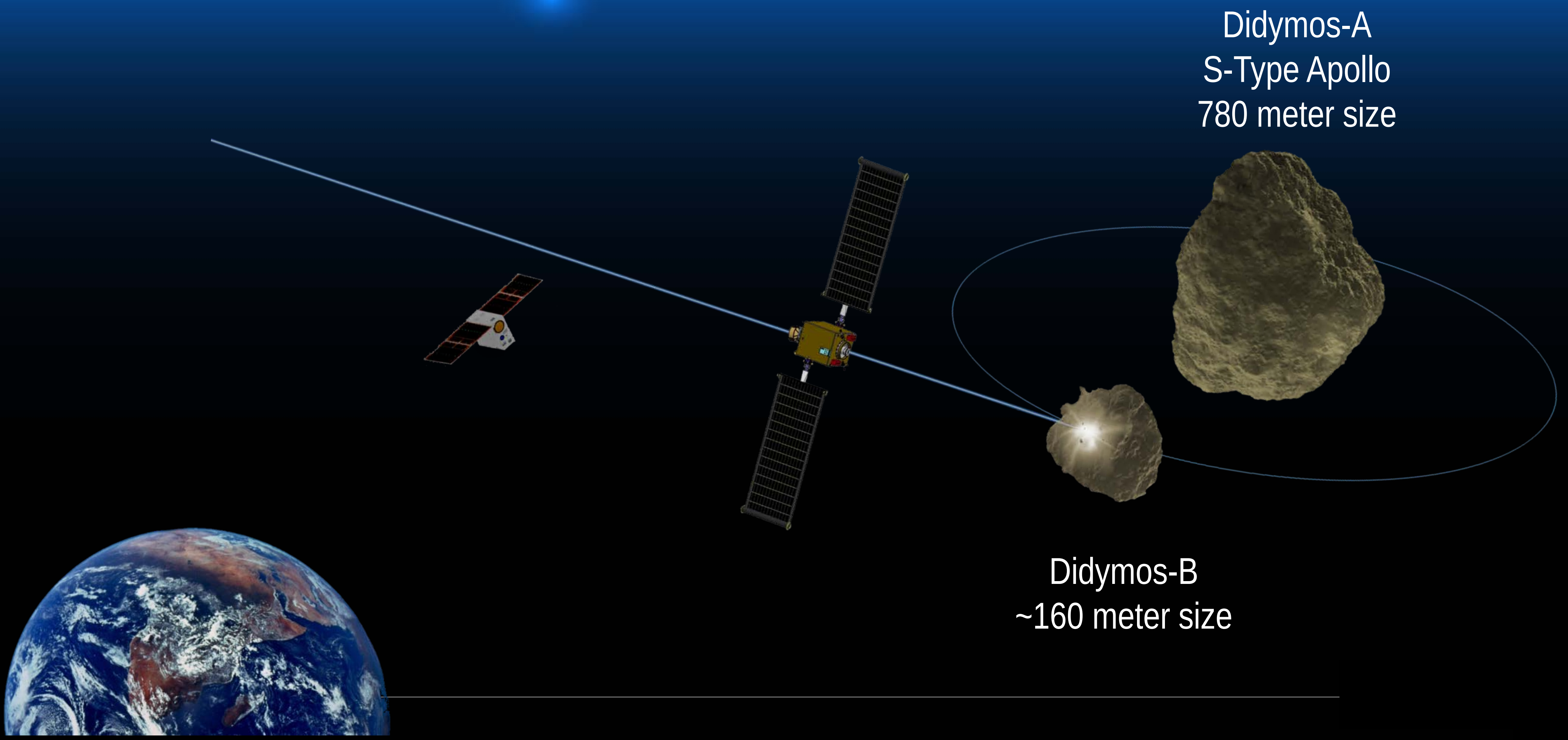


Building towards bigger, more capable, landers and sample return capabilities

IAU
Minor Planet Center
ASSESS
[CENTER FOR NEAR EARTH OBJECT STUDIES]
SEARCH, DETECT & TRACK
[GROUND-BASED & SPACE-BASED OBSERVATIONS, IAWN]
PLANETARY DEFENSE
MITIGATE
[DART, FEMA EXERCISES]
CHARACTERIZE
[NEOWISE, GOLDSTONE, ARECIBO, IRTF]
PLAN & COORDINATE
[SMPAG, PIERWG, DAMIEN IWG]

Double Asteroid Redirection Test (DART)

Mission Concept (with ASI CubeSat)



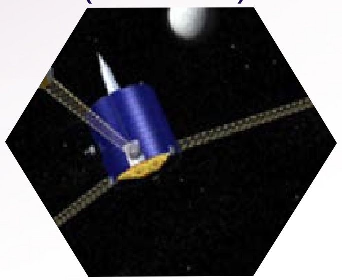
Discovery Program

Discovery Program

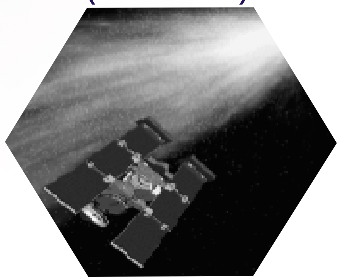
NEO characteristics
NEAR
(1996-1999)

Mars evolution
Mars Pathfinder
(1996-1997)

Lunar formation
Lunar Prospector
(1998-1999)



Nature of dust/coma
Stardust
(1999-2011)

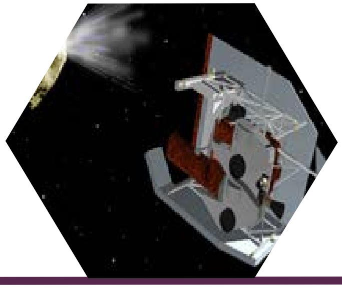


Solar wind sampling
Genesis
(2001-2004)

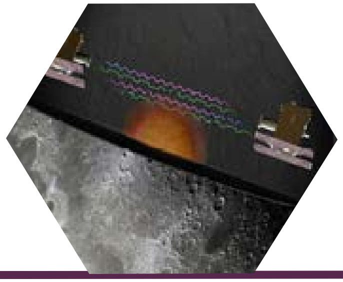
Comet Diversity
CONTOUR
(2002)

Mercury Environment
MESSENGER
(2004-2015)

Comet Internal Structure
Deep Impact
(2005-2012)



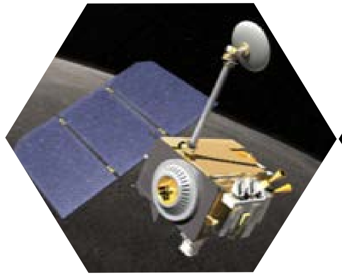
Lunar Internal Structure
GRAIL
(2011-2012)



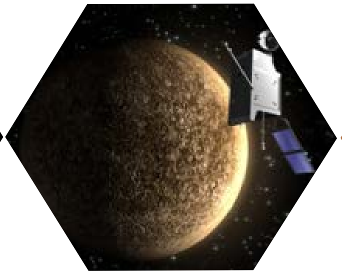
Main-belt Asteroids
Dawn
(2007-TBD)

Exoplanets
Kepler
(2009-TBD)

Lunar Surface
LRO
(2009-TBD)



ESA/Mercury
Surface
Strofio



Mars Interior
InSight
(2018)

Trojan Asteroids
Lucy
(2021)

Metal Asteroid
Psyche
(2022)

Martian Moons
MMX/MEGANE
(2024)

Discovery Long-Range Planning

- Cost Cap $495M Phase A-D (FY19) excluding LV
- ~~May not propose the use of radio-isotope power systems (RPS)~~ – UPDATED
- May include radioisotope heater units (RHUs)

Release of draft AO .... September 2018 (target)

Release of final AO .... February 2019 (target)

Pre-proposal conference .... ~3 weeks after final AO release

Proposals due .... 90 days after AO release

Selection for competitive Phase A studies ...... December 2019 (target)

Concept study reports due .... November 2020 (target)

Down-selection .... June 2021 (target)

Launch readiness date .... NLT December 31, 2026

Reconsideration In the Use of RPS for Discovery

After analysis and consultation with the Department of Energy, NASA's Planetary Science Division is pleased to announce that the ban on the use of Radio-isotope Power Systems (RPS's) by proposers responding to the upcoming Discovery 2018 AO has been removed.

Proposer's will be able to include the use of up to two (2) Multi-mission Radio-Isotope Thermal Generators (MMRTG's) to enable or significantly enhance their mission concept.

Costs to be borne by proposers for the MMRTG's, the related environmental impact assessments, and the required Nuclear Launch Approval process will be announced once determined.

New Frontiers Program

New Frontiers Program

1st NF mission
New Horizons

Pluto-Kuiper Belt

Launched January 2006
Flyby July 14, 2015
PI: Alan Stern (SwRI-CO)

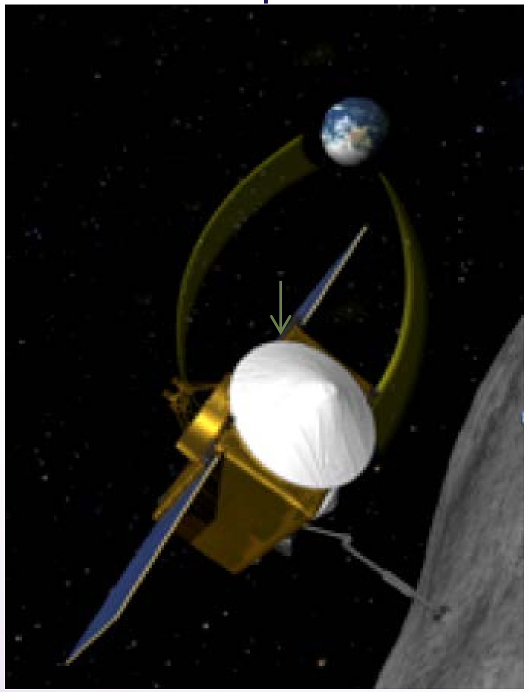
2nd NF mission
Juno

Jupiter Polar Orbiter

Launched August 2011
Arrived July 4, 2016
PI: Scott Bolton (SwRI-TX)

3rd NF mission
OSIRIS-REx

Asteroid Sample Return



Launched September 2016
PI: Dante Lauretta (UA)

New Frontiers 4 AO

Investigations (listed without priority)

- Comet Surface Sample Return
- Lunar South Pole-Aitken Basin Sample Return
- Ocean Worlds (Titan, Enceladus)
- Saturn Probe
- Trojan Tour and Rendezvous
- Venus In Situ Explorer

12 Proposals received on .... April 28, 2017

Step-1 Selections Announced (target)............. December 2017

Phase A Concept Study Reports due................. December 2018

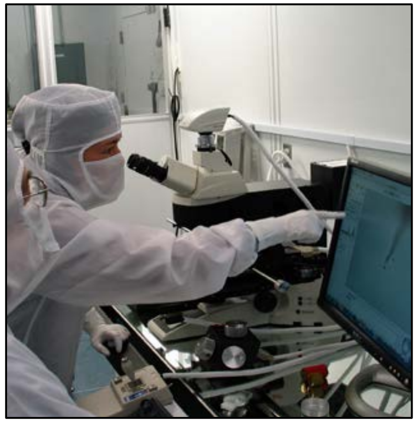
Down selection for Flight (target)..................... July 2019

Launch Readiness Date.................................... NLT December 31, 2025

Comet Astrobiology Exploration Sample Return

- Comets record presolar history, the initial stages of planet formation, and the sources of prebiotic organics and volatiles available for the origin of life.
- Target comet is 67P/Churyumov-Gerasimenko.
- Mission and Sample Acquisition System (SAS) have been designed for the known properties of 67P.
- SAS collects at least 80 g of comet nucleus sample.
- As volatiles evolve from the sample they are transferred to a separate reservoir, preventing sample alteration. Both non-volatile and volatile materials are returned to Earth for analysis.
- Sample stored at -80° to -40° C through return cruise, and below 0° C through entry, descent, landing, and recovery.

PI: Steve Sqyres, Cornell University. CAESAR will return the first sample from the nucleus of a comet. Sample analysis in worldwide laboratories will address questions about Solar System starting materials, and how they came together to form planets and give rise to life.



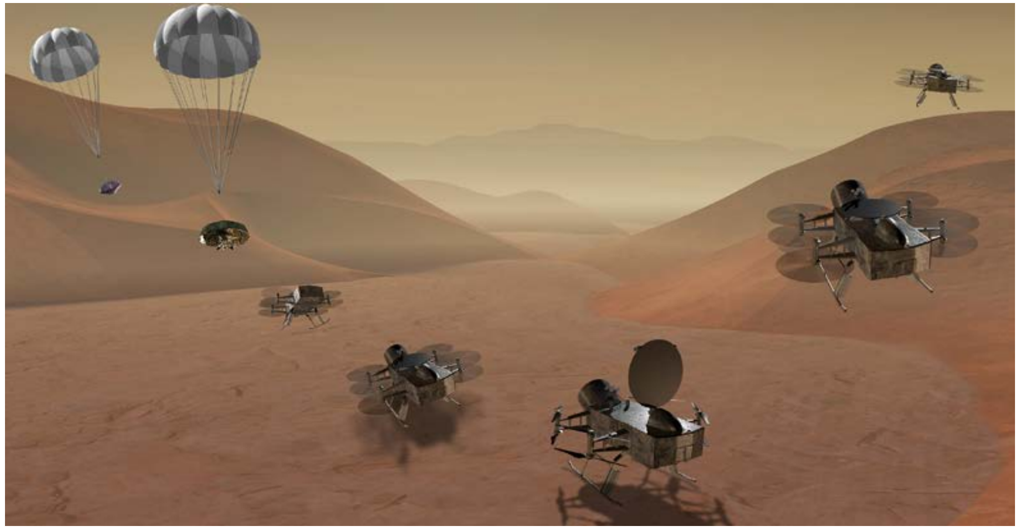
A rotorcraft to explore prebiotic chemistry and habitability on the ocean world Titan

- Flight is highly efficient on Titan, enabling Dragonfly to sample materials in a variety of settings with its science payload:
  - Mass spectrometer
  - Gamma-ray and neutron spectrometer
  - Meteorology and seismic sensors
  - Camera suite

Science Objectives:

- Analyze chemical components and processes at work that produce biologically relevant compounds
- Measure atmospheric conditions, identify methane reservoirs, and determine transport rates
- Constrain processes that mix organics with past surface liquid water reservoirs and subsurface ocean
- Search for chemical evidence of water-based or hydrocarbon-based life

Aerial mobility provides access to Titan's diverse materials at a wide range of geologic settings at dozens of sites, 10s to 100s of kilometers apart

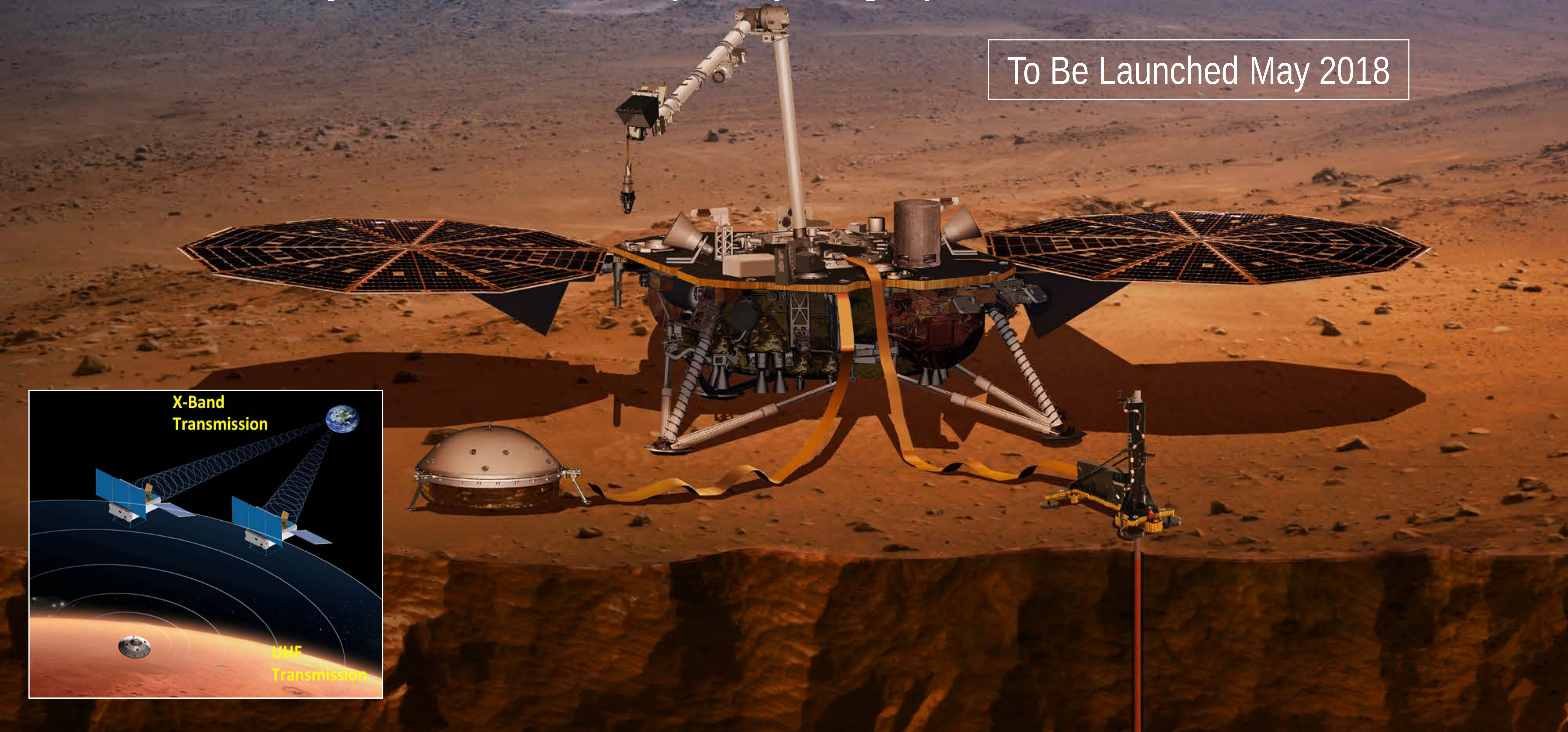


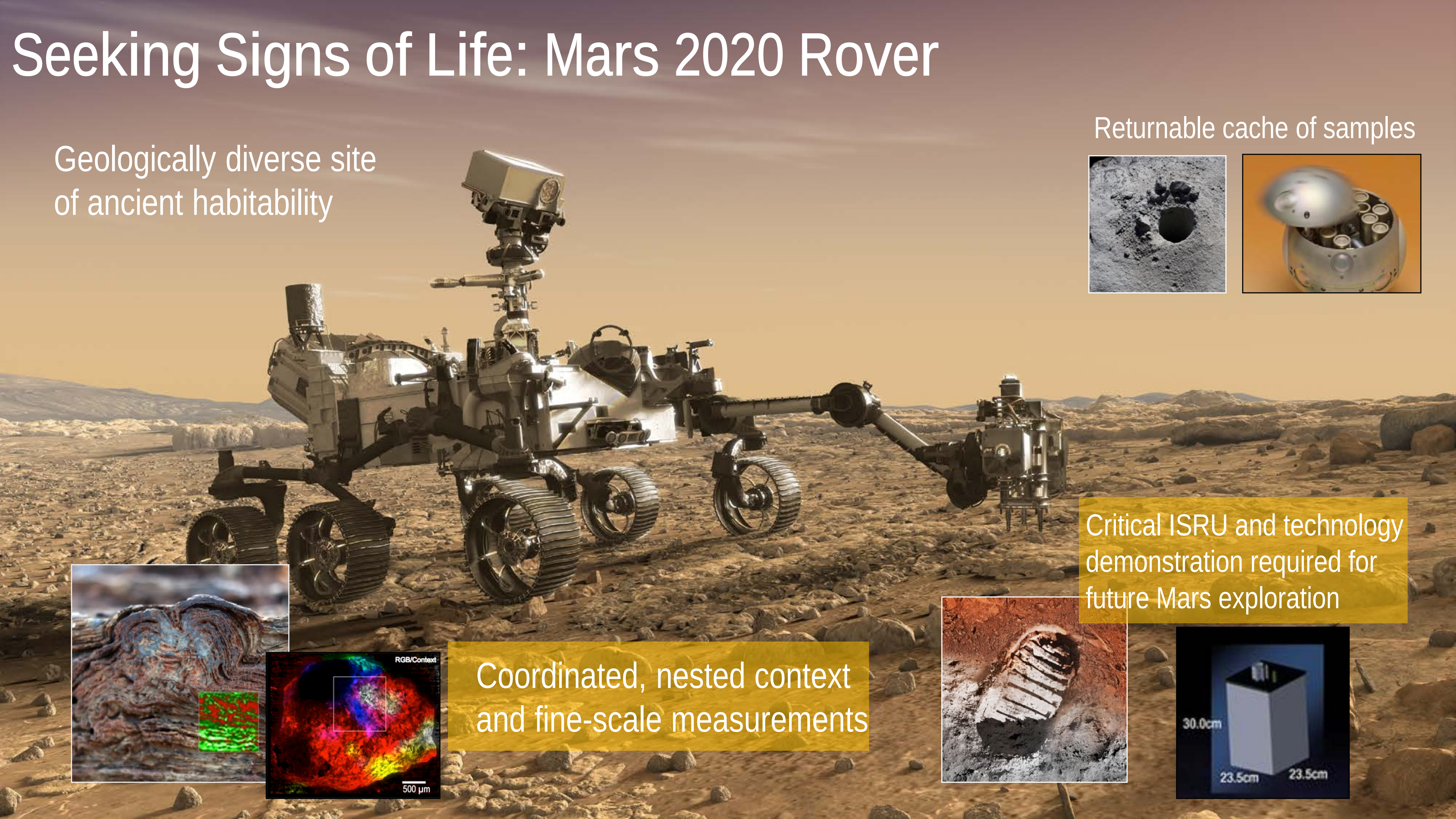
PI: Dr. Elizabeth Turtle at APL
Dragonfly would arrive at Titan in 2034 and explore for over 2 years, performing detailed chemical analyses, measuring the atmosphere and seismic activity, and imaging the surface.

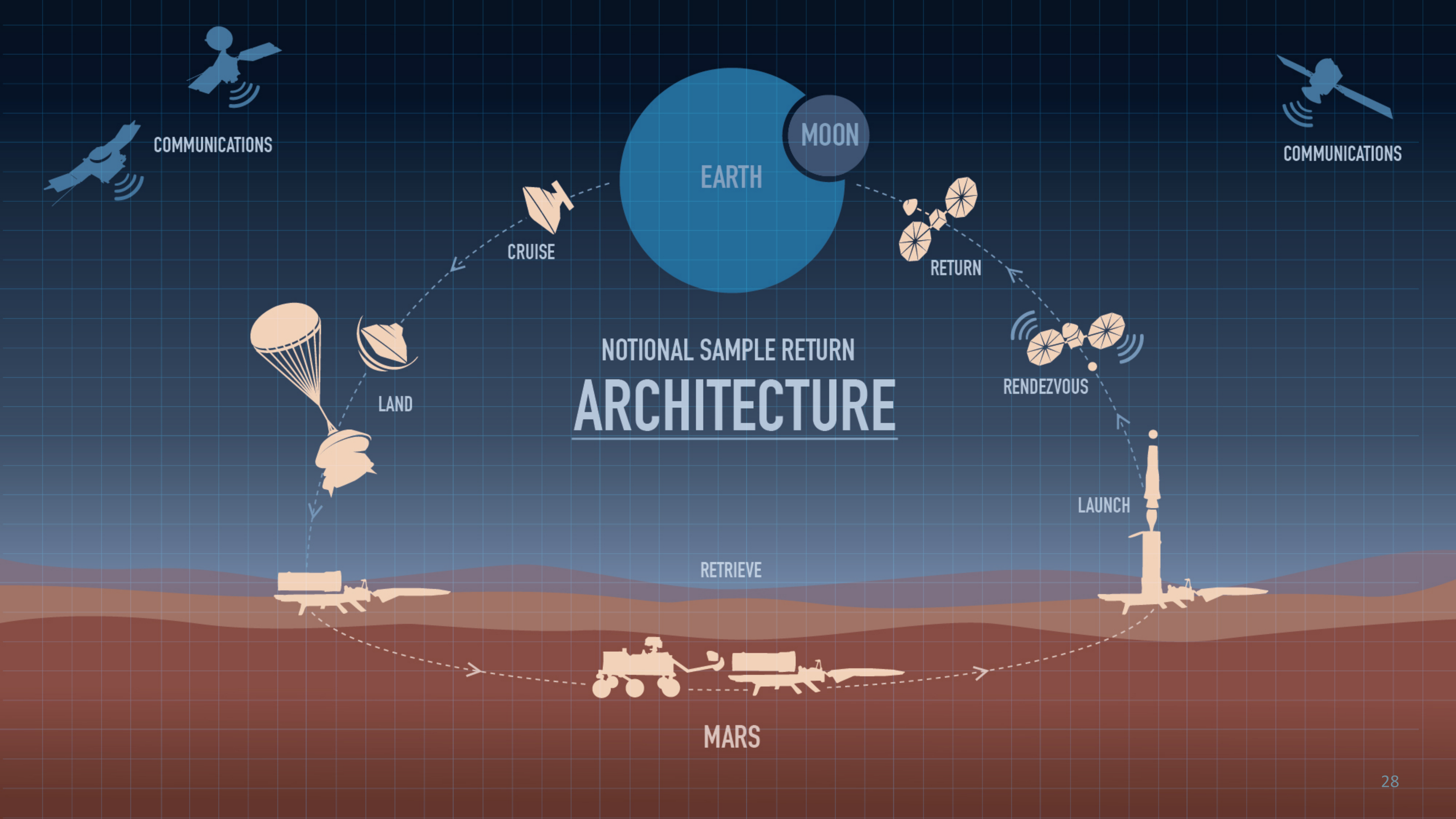
Mars

Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)

To Be Launched May 2018



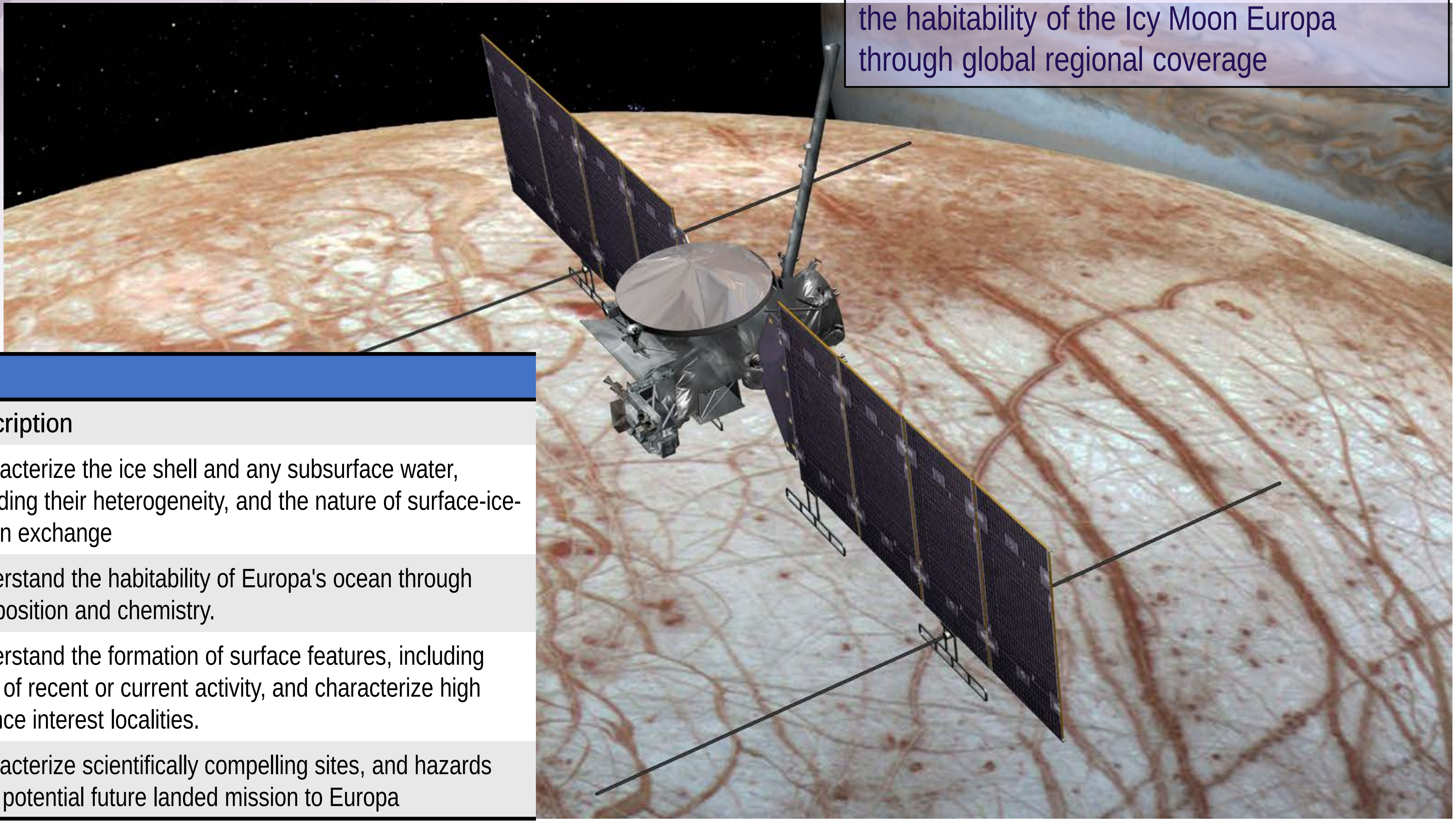

Seeking Signs of Life: Mars 2020 Rover
Geologically diverse site of ancient habitability
Returnable cache of samples
Critical ISRU and technology demonstration required for future Mars exploration
Coordinated, nested context and fine-scale measurements
RGB/Context
500 µm
30.0cm
23.5cm
23.5cm


NOTIONAL SAMPLE RETURN
ARCHITECTURE
COMMUNICATIONS
EARTH
MOON
COMMUNICATIONS
CRUISE
RETURN
LAND
RENDEZVOUS
LAUNCH
RETRIEVE
MARS

Oceans Worlds

Europa Clipper Overview

Will conduct approximately 45 low altitude flybys (25 – 100 km altitude) to characterize the habitability of the Icy Moon Europa through global regional coverage

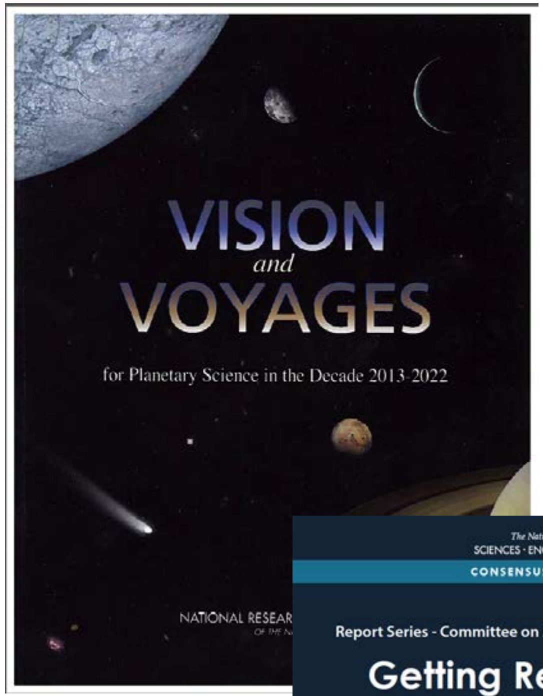


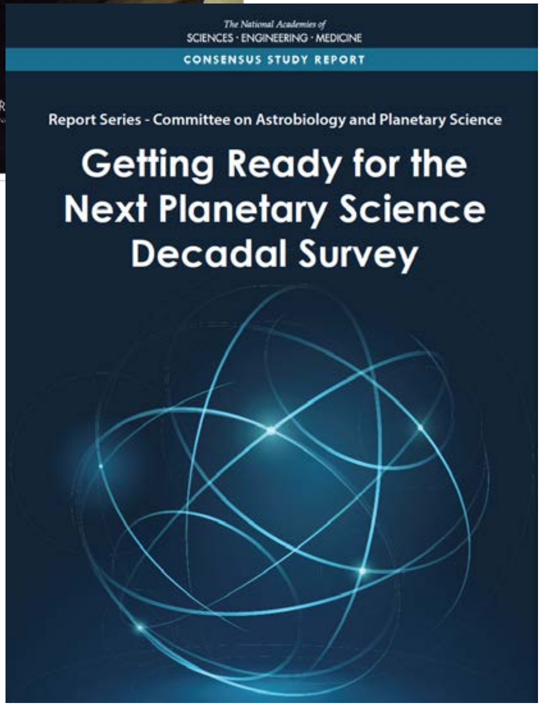
Science	
Objective	**Description**
Ice Shell & Ocean	Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange
Composition	Understand the habitability of Europa's ocean through composition and chemistry.
Geology	Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.
Recon	Characterize scientifically compelling sites, and hazards for a potential future landed mission to Europa

NASA Planetary Science Studies

Timeline of Studies

- 1st Planetary decadal: 2002-2012
- 2nd Planetary decadal: 2013-2022
- CubeSat Review: Completed June 2016
- Extended Missions Review: Completed Sept 2016
- R&A Restructuring Review: Completed June 2017
- Searching For Life : Completed Sept 2017
- Large Strategic Science Missions: Completed Aug 2017
- Midterm evaluation:
  - Tasked August 26, 2016
  - Above NAS studies will be input
  - Expect report to NASA due ~June 2018
- Sample Analysis Investment Strategy
  - Started November 2017
- 3rd Planetary Decadal: 2023-2032
  - To be tasked *before* October 2019
  - Expect report to NASA due 1st quarter 2022
- CAPS reviewed completed studies and recommended several more to be completed



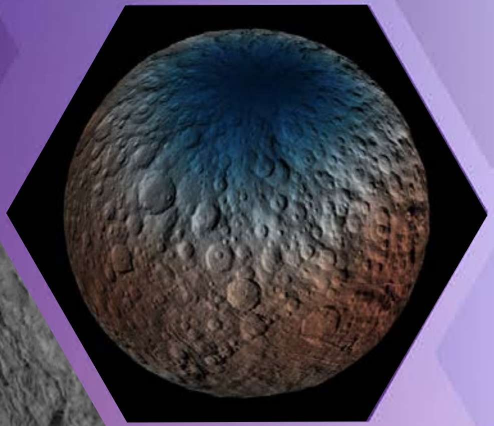


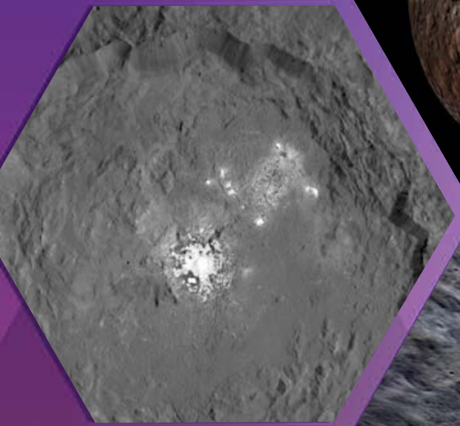
Mission Studies Completed Thus Far

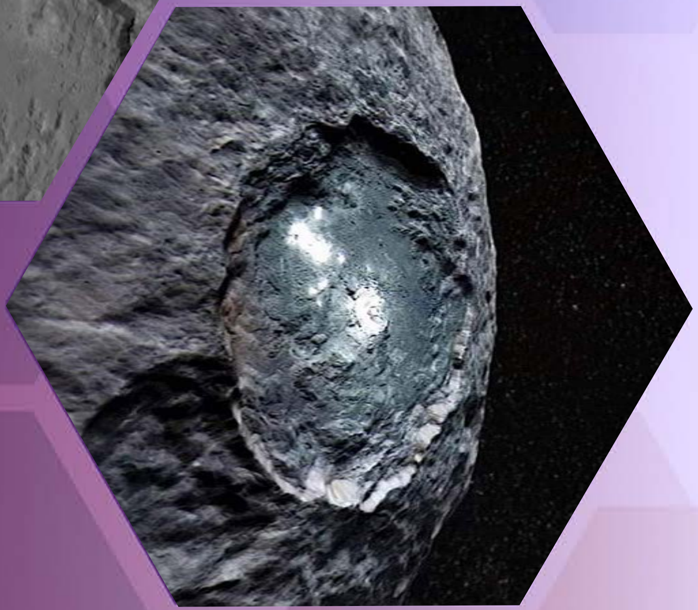
- Mars orbiter
  - 2015 MEPAG's Next Orbiter Science Analysis Group
- Uranus and Neptune (Ice Giants) system missions
  - 2017 NASA science definition team report
- Europa lander
  - 2017 NASA science definition team report
- Venus orbiter and lander (Venera-D)
  - 2017 joint U.S.-Russian science definition team report
- NEO Search and Characterization
  - 2017 NEO science definition team updated report

CAPS Priority Areas Candidates for Large or Medium Class Mission Studies (Unprioritized)

Venus exploration missions	Additional concepts beyond the Venera-D orbiter and lander
Lunar science missions	Understanding interior processes and polar volatiles (Volatiles SAT Team-2)
Mars sample-return next-step missions	Mission elements beyond Mars 2020 necessary for second and third phases of a Mars sample-return campaign
Mars medium-class missions	Multiple mobile explorers, polar explorers, & life-detection. Investigations responsive to new discoveries
Dwarf planet missions	Large- & medium-class mission concepts to Ceres, Pluto, Triton
Io science (NEW FRONTIERS FIVE)	Reexamine mission to Io
Saturn system missions	Affordable, large strategic missions that visit multiple targets
Dedicated space telescope for solar system science	Dynamic phenomena on planetary bodies







Ceres Pre-Decadal Study

- CAPS highlighted Ceres for pre-decadal study
- Dawn revealed Ceres to be an active dwarf planet; It is a solid body, but is it a relic ocean world?
- JPL to lead the Ceres study; Michael Kelley is the PSD POC
- Goals are to assess science priorities and examine trade space of mission concepts
  - Spectrum of alternatives, including New Frontiers and Large Strategic missions
  - Orbiting, landing, roving, sample return?
  - Launch dates between 2024 – 2037
  - PP to be noted, uncover technologies to be addressed
- Key dates:
  - SDT call for applications issued – team is being selected
  - Design study February – Late FY18
  - Engagement with AGs and workshops/conferences

Questions?

Acronym List

AO	Announcement of Opportunity
CDR	Critical Design Review
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
CGS	Common Ground System
CJ	Congressional Justification
CME	Coronal Mass Ejection
CNES	French Space Agency
CSA	Canadian Space Agency
DAMIEN IWG	Detecting And Mitigating the Impacts of Earthbound Near-Earth Objects Interagency Working Group
DLR	German Space Agency
DOE	Department of Energy
EDL	Entry, Descent, Landing
ESA	European Space Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GPS	Global Positioning System
HEOMD	Human Exploration and Operations Mission Directorate
IAWN	International Asteroid Warning Network
I&T	Integration and Testing
IRTF	NASA Infrared Telescope Facility
ISS	International Space Station
JAXA	Japanese Space Agency
KDP	Key Decision Point
LDEP	Lunar Discovery and Exploration Program
LRD	Launch Readiness Date
MCR	Mission Concept Review
MOO	Mission of Opportunity
NRA	NASA Research Announcement
NSF	National Science Foundation
PDCO	Planetary Defense Coordination Office
PDR	Preliminary Design Review
PI	Principal Investigator
PIERWG	Planetary Impact Emergency Response Working Group
PSD	Planetary Science Division
R&A	Research and Analysis
R&D	Research and Development
R&T	Research and Technology
RFI	Request for Information
RFP	Request for Proposals
ROSES	Research Opportunities in Space and Earth Science
SALMON	Stand Alone Mission of Opportunity
SAR	Synthetic Aperture Radar
SLS	Space Launch System
SMD	Science Mission Directorate
SMPAG	Space Missions Planning Advisory Group
SR&T	Supporting Research and Technology
STEM	Science, Technology, Engineering, and Math
STDT	Science and Technology Definition Team
STMD	Science and Technology Mission Directorate
TRL	Technology Readiness Level
USGS	U.S. Geological Survey

SCEM Concepts

1. The bombardment history of the inner solar system is uniquely revealed on the Moon
2. The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body
3. Key planetary processes are manifested in the diversity of lunar crustal rocks
4. The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history
5. Lunar volcanism provides a window into the thermal and compositional evolution of the Moon
6. The Moon is an accessible laboratory for studying the impact process on planetary scales
7. The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies
8. Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state

ASM-SAT (SCEM update)

- Progress toward each goal evaluated
  - Nearly all had at least some progress; none were “done”
  - Each section ends with summary of progress still needed
- No effort was made to reprioritize
- Identified Concepts and Goals not called out in SCEM
  - The lunar ‘water’ cycle
  - The origin of the Moon
  - Lunar tectonism and seismicity

“We are now in a much stronger position to take advantage of landed missions and identify ideal landing sites to address the SCEM goals.

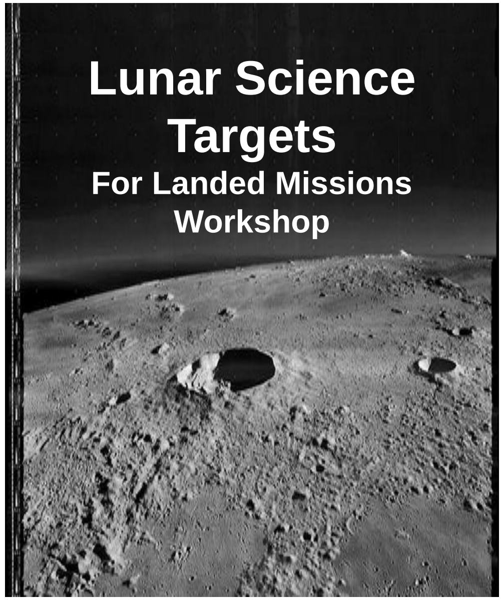
While there is still real progress to be made from orbital missions, the advancement of many of these goals requires landed missions.”

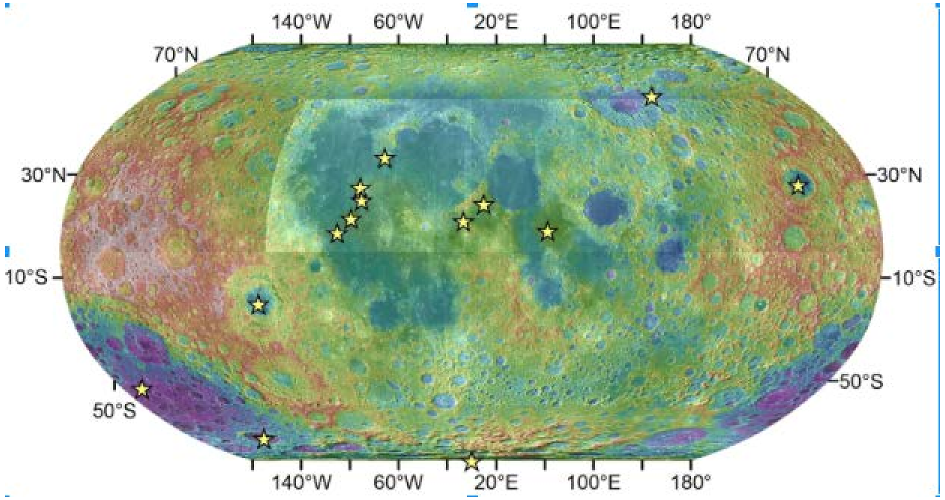
NEXT-SAT

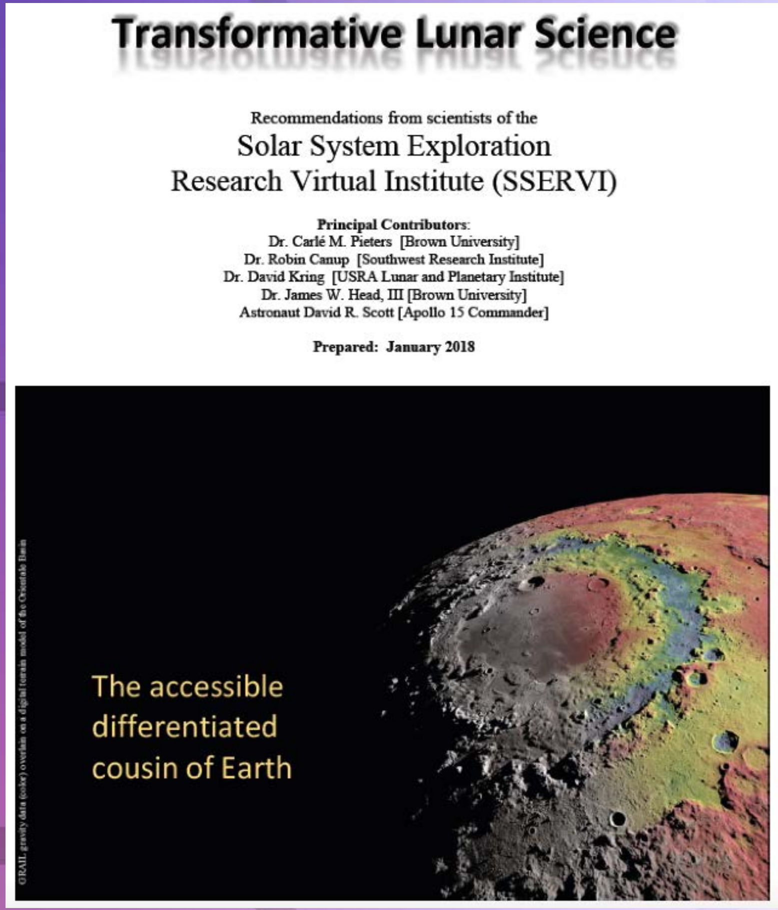
- FINDING: Lunar science presently has a well-developed slate of compelling science questions that are profoundly impactful for understanding the entire Solar System. There are numerous options for lunar missions to address these questions that would provide openings to make dramatic, paradigm-shifting advances in planetary science.
- FINDING: NEXT-SAT references the Finding 3 arising from the 2017 LEAG Commercial Advisory Board meeting. Commercial entities should be employed to the fullest practical extent to increase competition, decrease costs, and increase the flight rate.
- FINDING: There are numerous potential opportunities for commercial services, with NASA as a customer, to play a role in lunar surface exploration.
- FINDING: LRO observations of the Chang'e-3 mission activities on the surface pointed to the kinds of science and operational support that LRO data can enable and support for future missions. Future mission teams should leverage active targeting from LRO instruments to ensure that data for site selection certification is readily available, and interface with the LRO project team to enable comprehensive mission support and new science.

Lunar Science for Landed Missions

- Workshop held at Ames Jan 10-12, co-chaired by SSERVI and LEAG.
- Targets in contributed talks were evaluated for both science and human exploration interests, aligned in sessions topically:
    - Lunar volatiles
    - Lunar Magmatism and Volcanic Deposits (pyroclastics, pits and lava tubes, unusual volcanism)
    - Age dating and impact processes (Solar System chronology, basins and impact processes)
    - Lunar crust and dust
    - Geophysics and Astrophysics
    - Magnetism and Swirls
- Eight lunar commerce companies participated in 2 panel sessions; additional international session included with Japanese, European contribution
- Report in formulation; to be reviewed by community and presented to HQ 3/18







Transformative Lunar Science

Recommendations from scientists of the
Solar System Exploration
Research Virtual Institute (SSERVI)

Principal Contributors:
Dr. Carlé M. Pieters [Brown University]
Dr. Robin Canup [Southwest Research Institute]
Dr. David Kring [USRA Lunar and Planetary Institute]
Dr. James W. Head, III [Brown University]
Astronaut David R. Scott [Apollo 15 Commander]

Prepared: January 2018

Provides a response to the question "What transformative lunar science issues can be addressed in the currently evolving space science era?"

Transformative Lunar Science

SMD AA requested SSERVI produce white paper on key areas of lunar science in new era of lunar exploration delivered to SMD late January; also delivered to HEOMD

Areas addressed include:

- establish period of giant planet migration;
- provide absolute chronology for Solar System events;
- use accessible vantage from lunar far side to view universe;
- understand water cycles;
- characterize lunar interior;
- evaluate plasma interactions w/ surfaces;

New Views Of The Moon II

- NVM-2 will synthesize the recent revolution in our understanding of the Moon (NVM was published in 2006)
- To be published in Reviews in Mineralogy and Geochemistry

21 Chapters:

- Summaries of Recent Missions
- Endogenous Volatiles
- The Contribution of Lunar Meteorites
- Origin of the Moon and Earth System
- Magmatic Evolution 1: Initial Differentiation
- Magmatic Evolution 2: A New View of Post-
- Volcanic Features and Processes
- Impact History of the Moon
- Lunar Impact Chronology
- Lunar Impact Features & Processes
- Origin and Evolution of the Moon's Dynamo
- The Structure of the Lunar Interior
- Evolution of the Lunar Crust
- Lunar Tectonics
- Surface Volatiles
- Dust, Atmosphere, and Plasma
- Space Weathering
- Surface Processes (Regolith)
- Lunar Resources
- Development of the Moon & Cislunar Space
- A Framework for Lunar Surface Scientific Exploration

Benefits of Near-Term Lunar Missions

- Return Science
  - Reduce costs and risk for high priority science (Decadal Survey, SCEM, etc.)
  - Ensure the strength of the lunar science community
- Benefit Exploration
  - Volatiles may be key to future exploration architectures and characterizing volatiles entrainment in regolith is the first step
- Encourage Industry Participation
  - Expand the economic sphere to cis-lunar space
  - Foster initial R&D for resource acquisition and processing
  - Leverage investments in commercial landers
- Demonstrate Technologies
  - Precision Landing/Hazard Avoidance and Ascent
  - Improvements in power generation and storage
  - Extreme environment instruments/systems for day/night survival/operations - relevant to Icy Moons
- Advance planning for Mars and other destinations
  - Enables deep-space architectures
  - Reduces logistics chain from Earth
  - Flight qualifies critical technologies such as precision landing and ascent vehicles