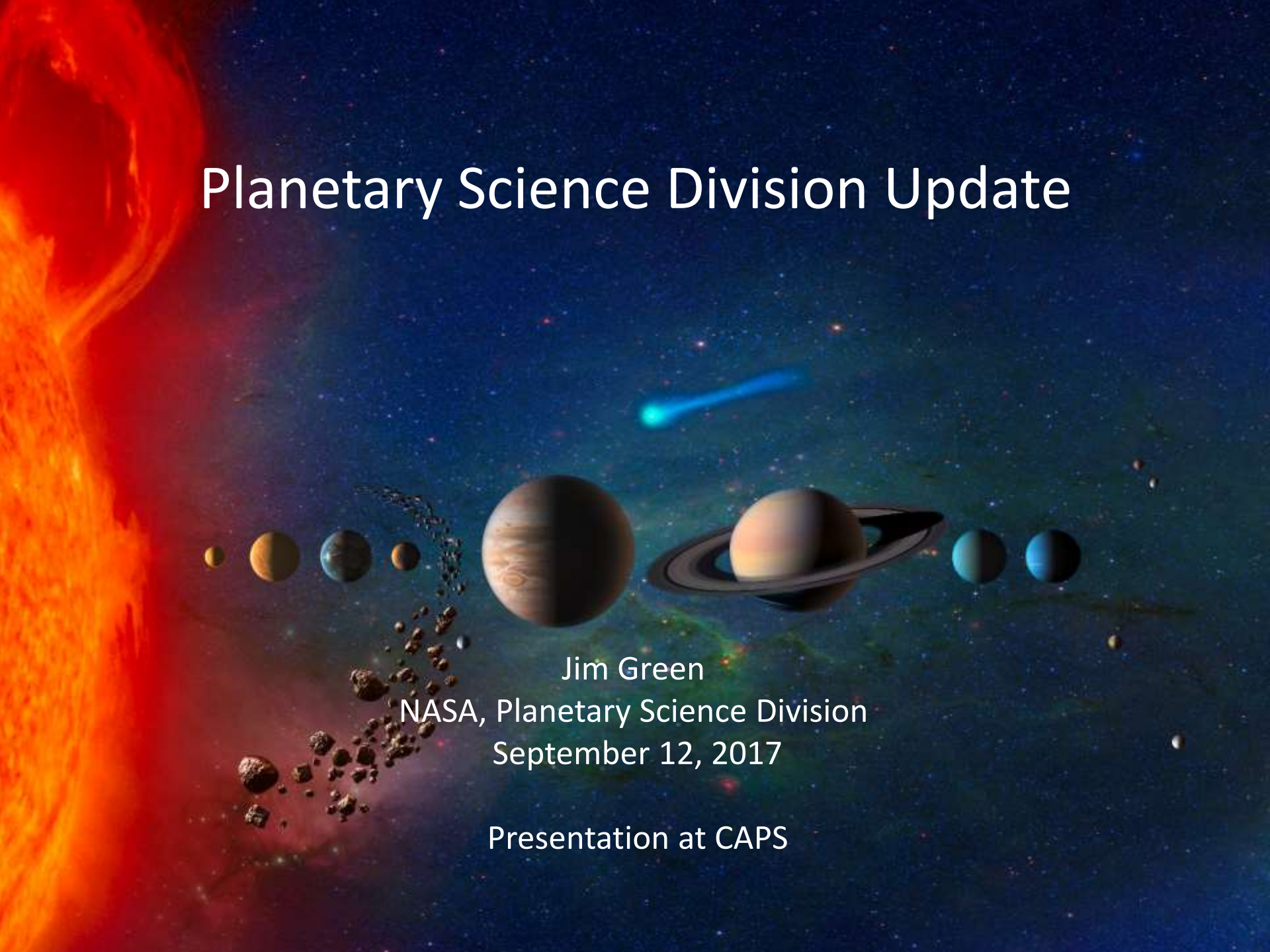
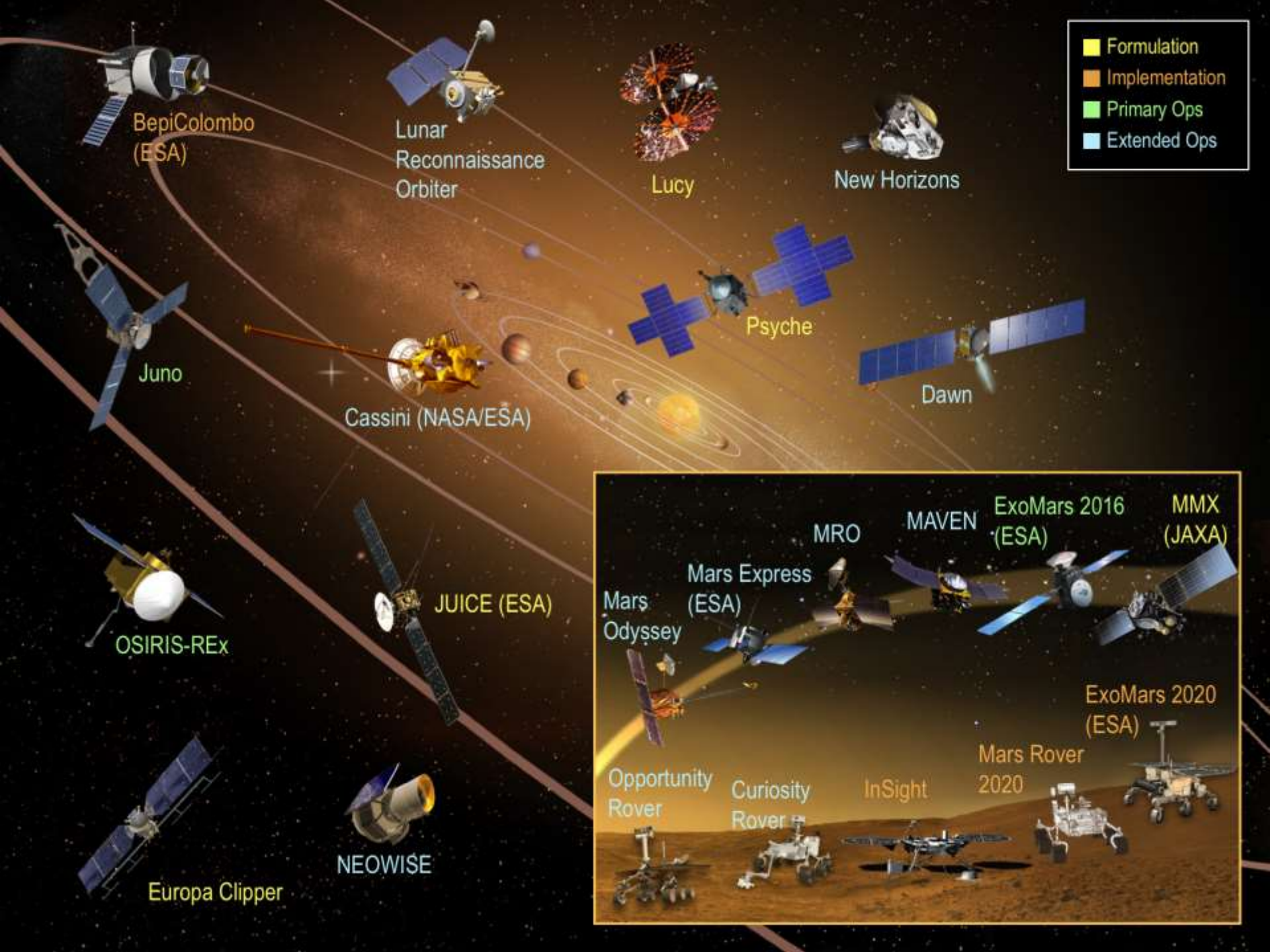
Planetary Science Division Update



Jim Green
NASA, Planetary Science Division
September 12, 2017

Presentation at CAPS


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

Planetary Science Missions Events

2016

March – Launch of ESA's *ExoMars Trace Gas Orbiter*

July 4 – *Juno* inserted in Jupiter orbit

September 8 – Launch of Asteroid mission *OSIRIS – REx* to asteroid Bennu

September 30 – Landing *Rosetta* on comet CG

October 19 – *ExoMars EDM* landing and *TGO* orbit insertion

*** Completed**

2017

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 – Total Solar Eclipse across the US

September 15 – *Cassini* end of mission at Saturn

September 22 – *OSIRIS-REx* Earth flyby

2018

May 5 - Launch *InSight* mission to Mars

August – *OSIRIS-REx* arrival at Bennu

October – Launch of ESA's *BepiColombo*

November 26 – *InSight* landing on Mars

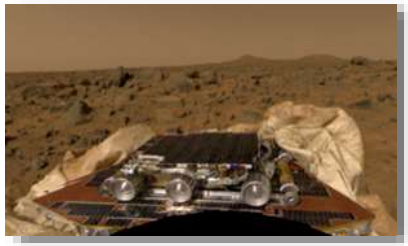
2019

January 1 – *New Horizons* flyby of Kuiper Belt object 2014MU69

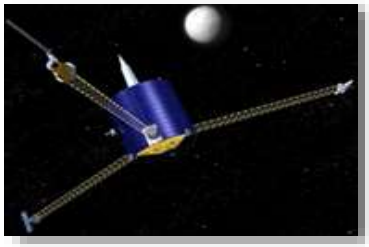
Discovery Program

NEO characteristics:
NEAR (1996-1999)

Mars evolution:
Mars Pathfinder (1996-1997)

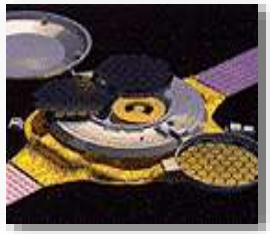


Lunar formation:
Lunar Prospector (1998-1999)



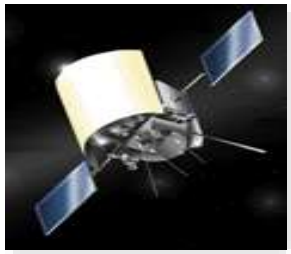
Nature of dust/coma:
Stardust (1999-2011)

Solar wind sampling:
Genesis (2001-2004)

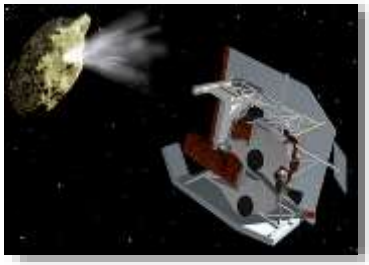


Comet diversity:
CONTOUR (2002)

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 (*2018*)

Mars Interior:
InSight (*2018*)

Trojan Asteroids:
Lucy (*2021*)

Metal Asteroids:
Psyche (*2022*)

NEW Discovery Missions

New Frontiers Program

1st NF mission
New Horizons:

Pluto-Kuiper Belt

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

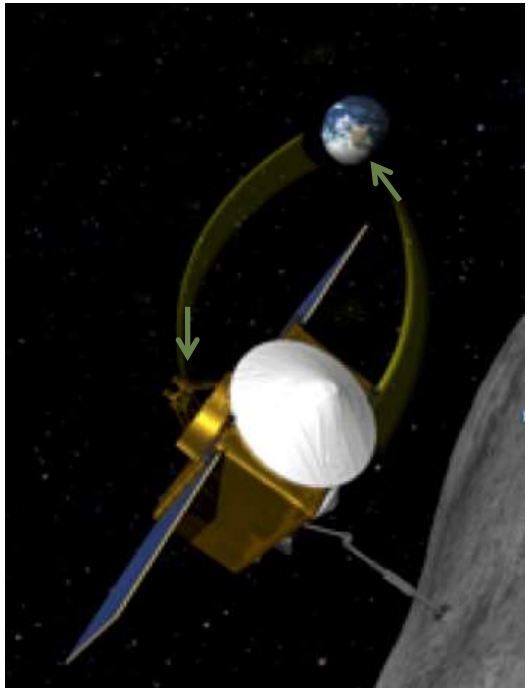
2nd NF mission
Juno:

Jupiter Polar Orbiter

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

3rd NF mission
OSIRIS-REx:

Asteroid Sample Return

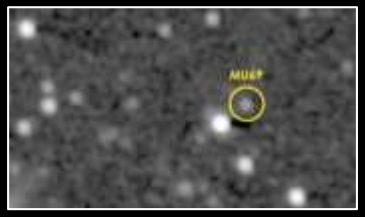


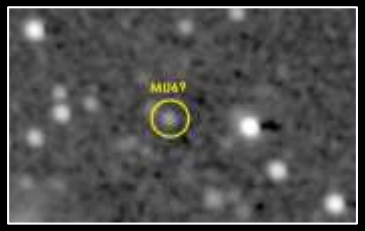
Launched Sept. 8, 2016
PI: Dante Lauretta (UA)
Gravity Assist – Sept. 22, 2017
Arrives at Bennu – Aug 2018

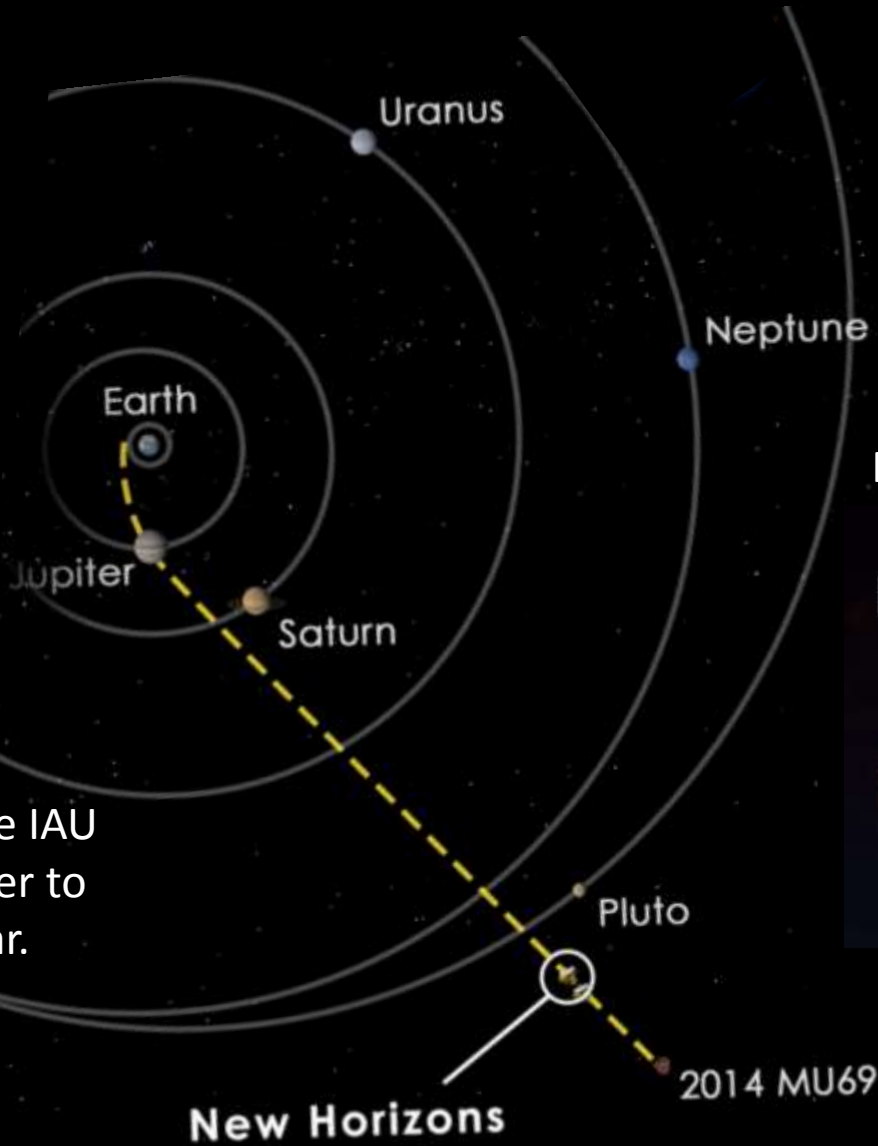
New Horizons

New Horizons

MU69 Next KBO Target



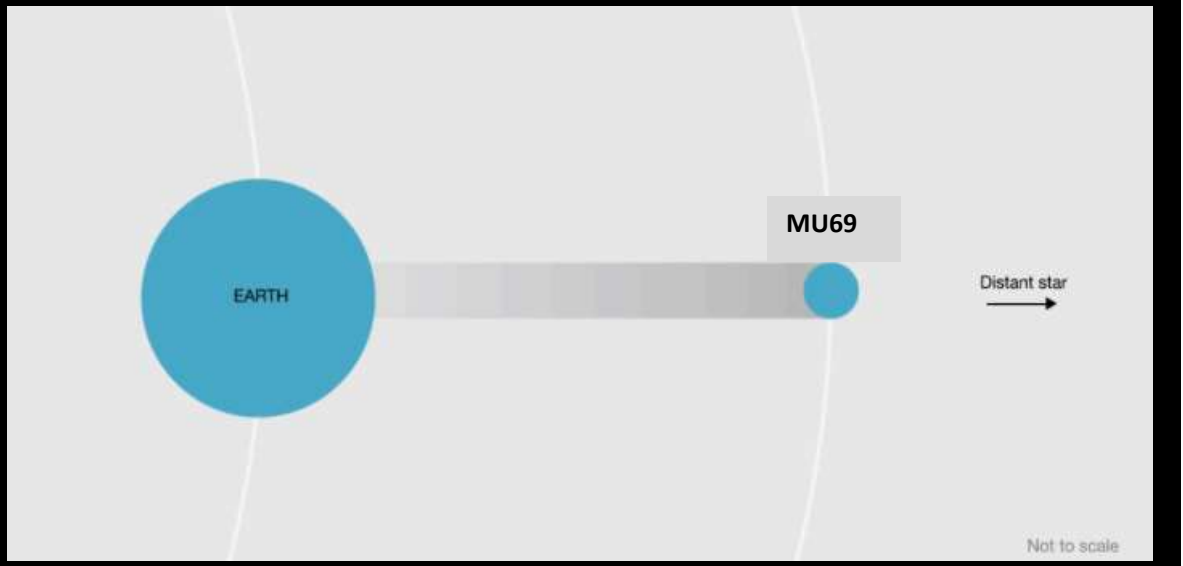




Flyby January 1, 2019

NASA, NH team, and the IAU
Will be working together to
Name MU69 this year.

Stellar Occultation of MU69



June 3, 2017

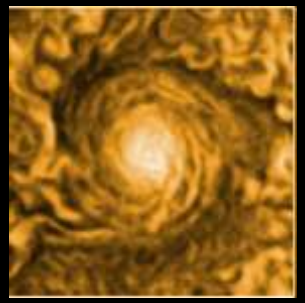
July 10, 2017

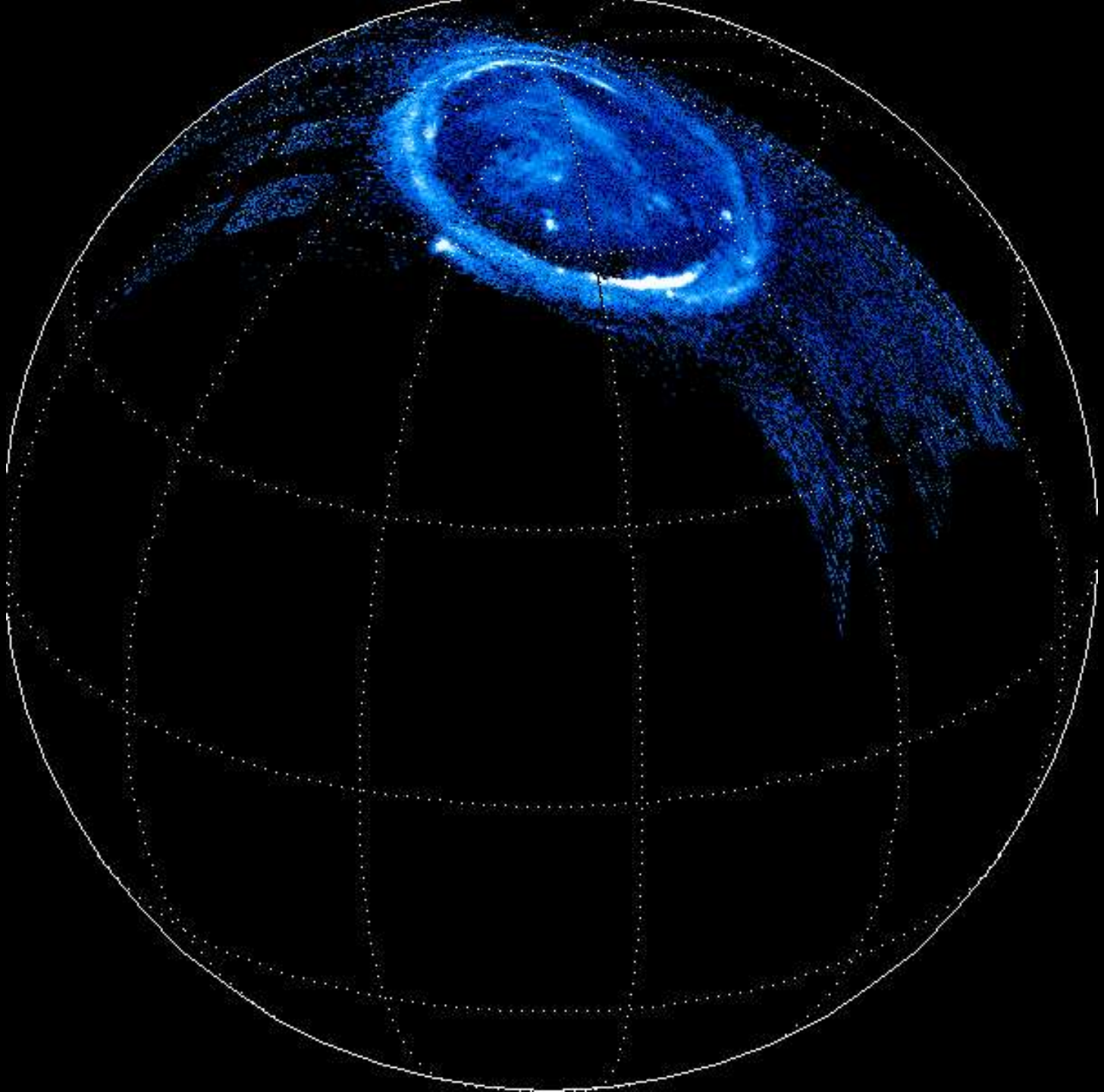
July 17, 2017


Juno

JunoCam - Primarily for outreach, but with considerable scientific contribution

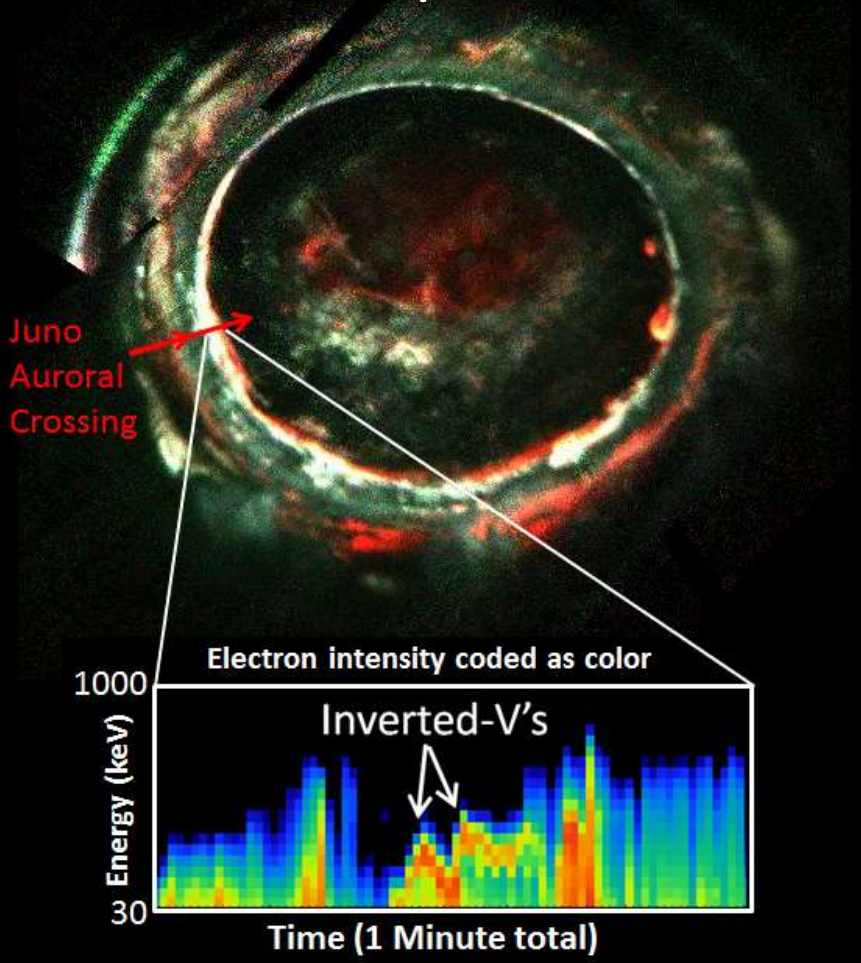
All processed results are available on the Mission Juno site





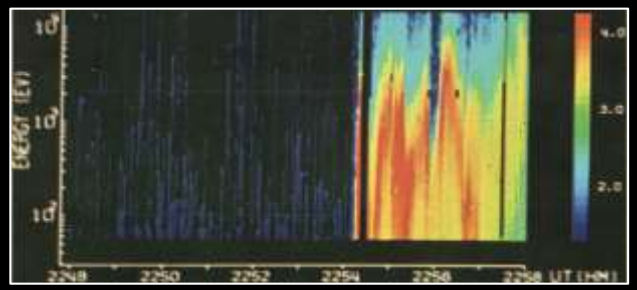
Electron Beams Power Auroras

Jupiter



Earth

Inverted V's above
Discrete Auroral arcs

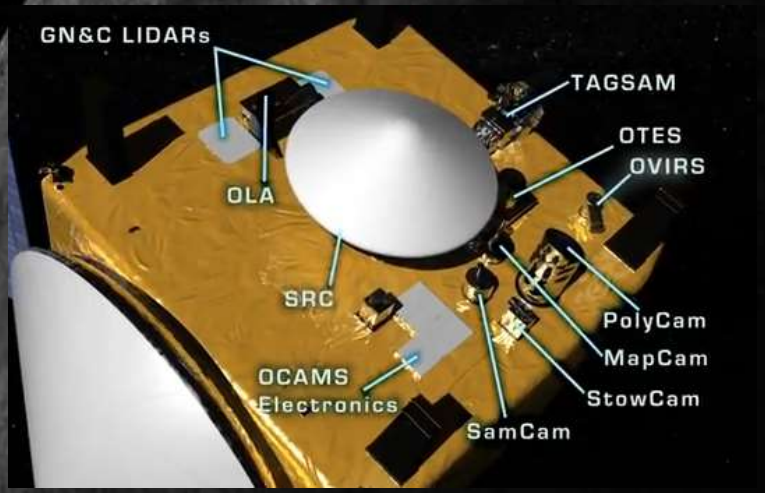


Frank et al., 1971

OSIRIS-REx

- Return and analyze a sample of Bennu's surface
- Map the asteroid & document the sample site
- Measure the Yarkovsky effect

Gravity Assist
September 22, 2016



New Frontiers 4 AO

Investigations (listed without priority):

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

Release of final AO..... December 9, 2016
Electronic Proposal Submittal Deadline..... April 28, 2017
Step-1 Selections Announced (target)..... November 2017
Phase A Concept Study Reports due..... December 2018
Down-selection for Flight (target)..... July 2019
Launch Readiness Date..... NLT Dec. 31, 2025

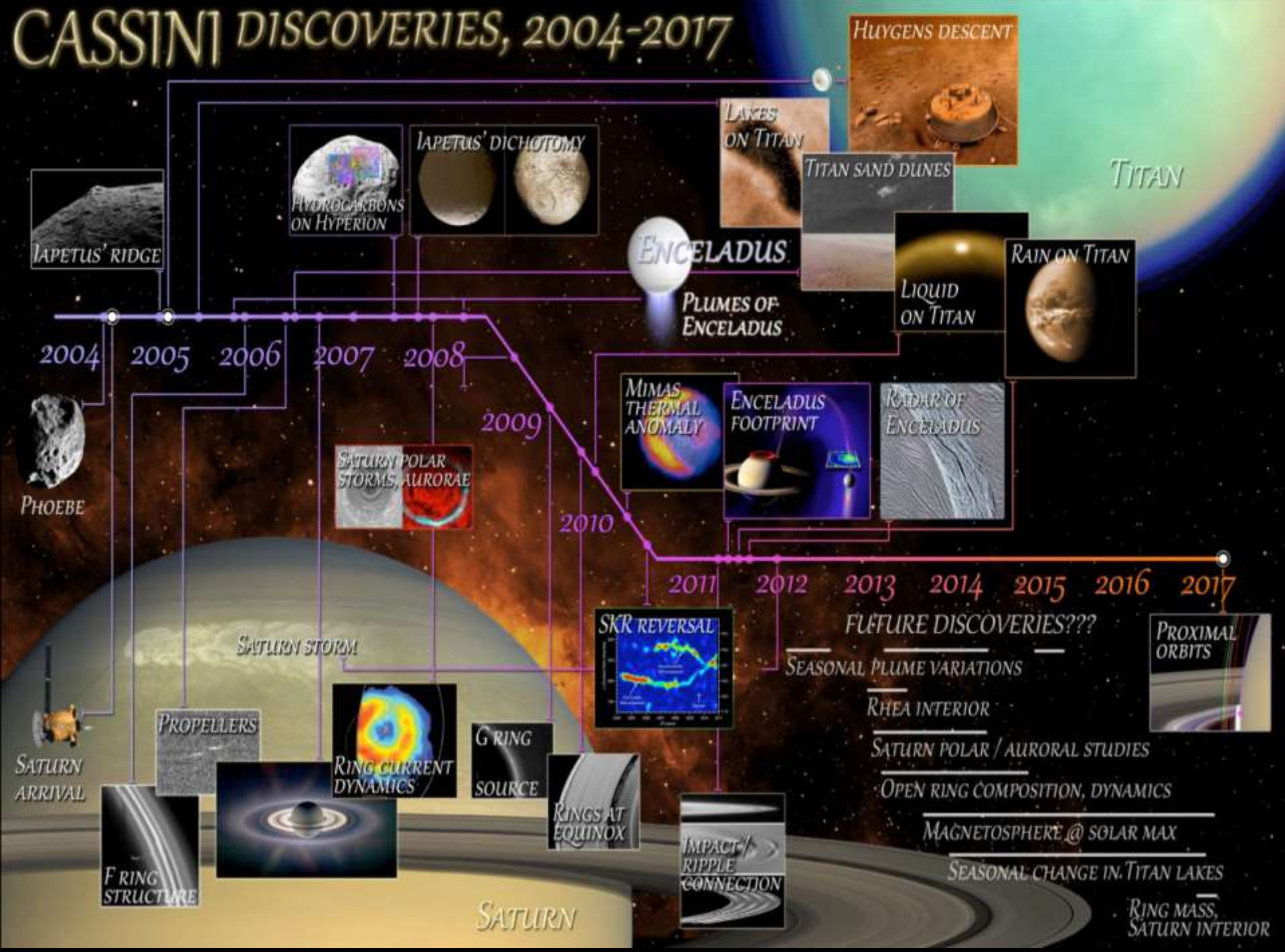
Cassini's Grand Finale

Cassini Mission Overview

Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017

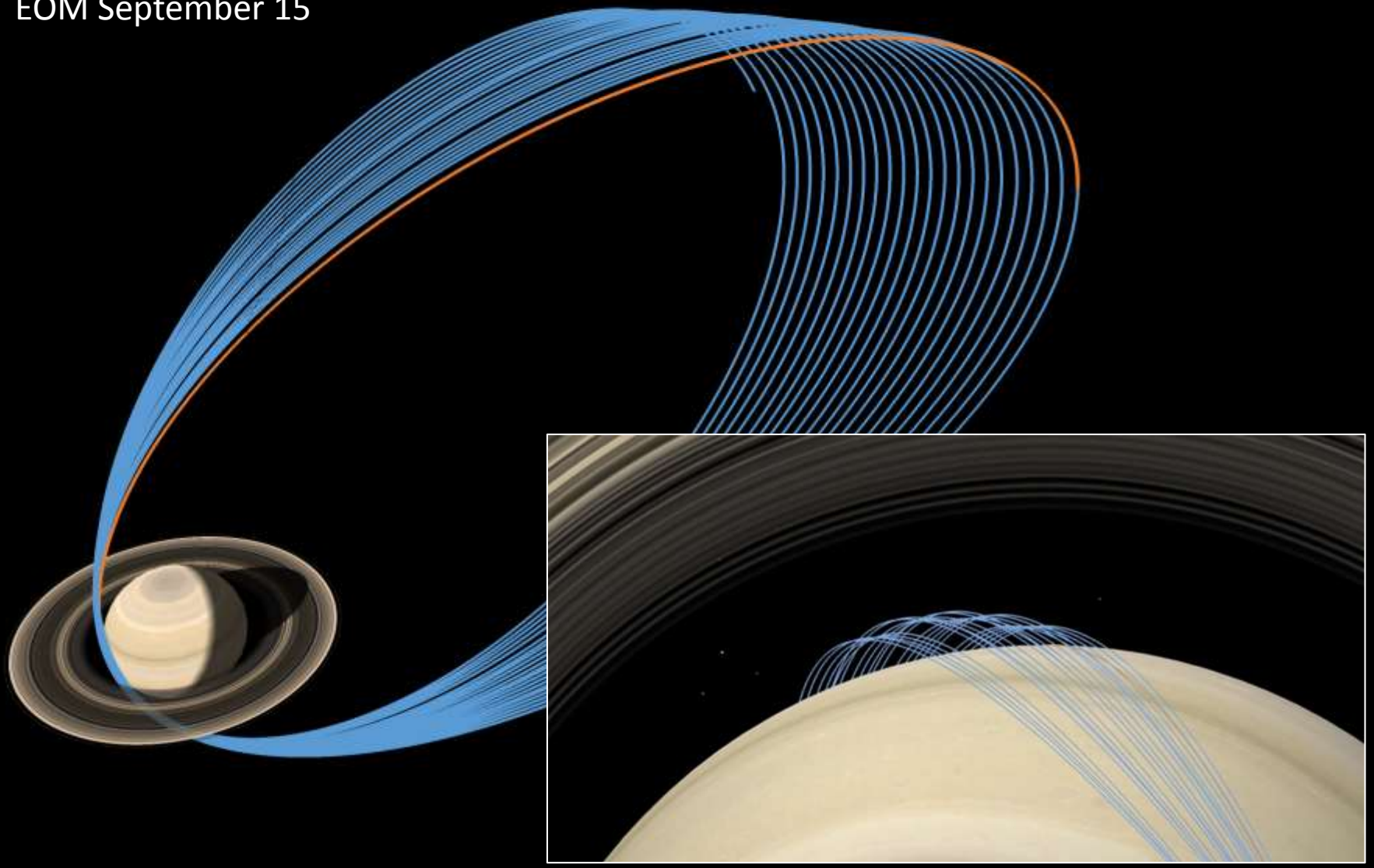
	Prime Mission				Equinox Mission		Solstice Mission						
Year of Tour	1 '04-'05	2 '05-'06	3 '06-'07	4 '07-'08	5 '08-'09	6 '09-'10	7 '10-'11	8 '11-'12	9 '12-'13	10 '13-'14	11 '14-'15	12 '15-'16	13 '16-'17
Orbits	11	15	22	27	39	21	16	19	25	12	12	20	56
Titan													
*Huygens													
Enceladus													
Other Icy Satellites (under 10,000 km)	Phoebe	Tethys, Hyperion, Dione, Telesto, Rhea		Rhea, Iapetus, Epimetheus		Mimas, Rhea, Helene, Dione, G arc	Rhea, Helene	Dione, Dione, Tethys, Methone, Telesto	Rhea		Dione, Tethys	Dione, Epimetheus, G arc	
Saturn (seen from Sun)													

CASSINI DISCOVERIES, 2004-2017



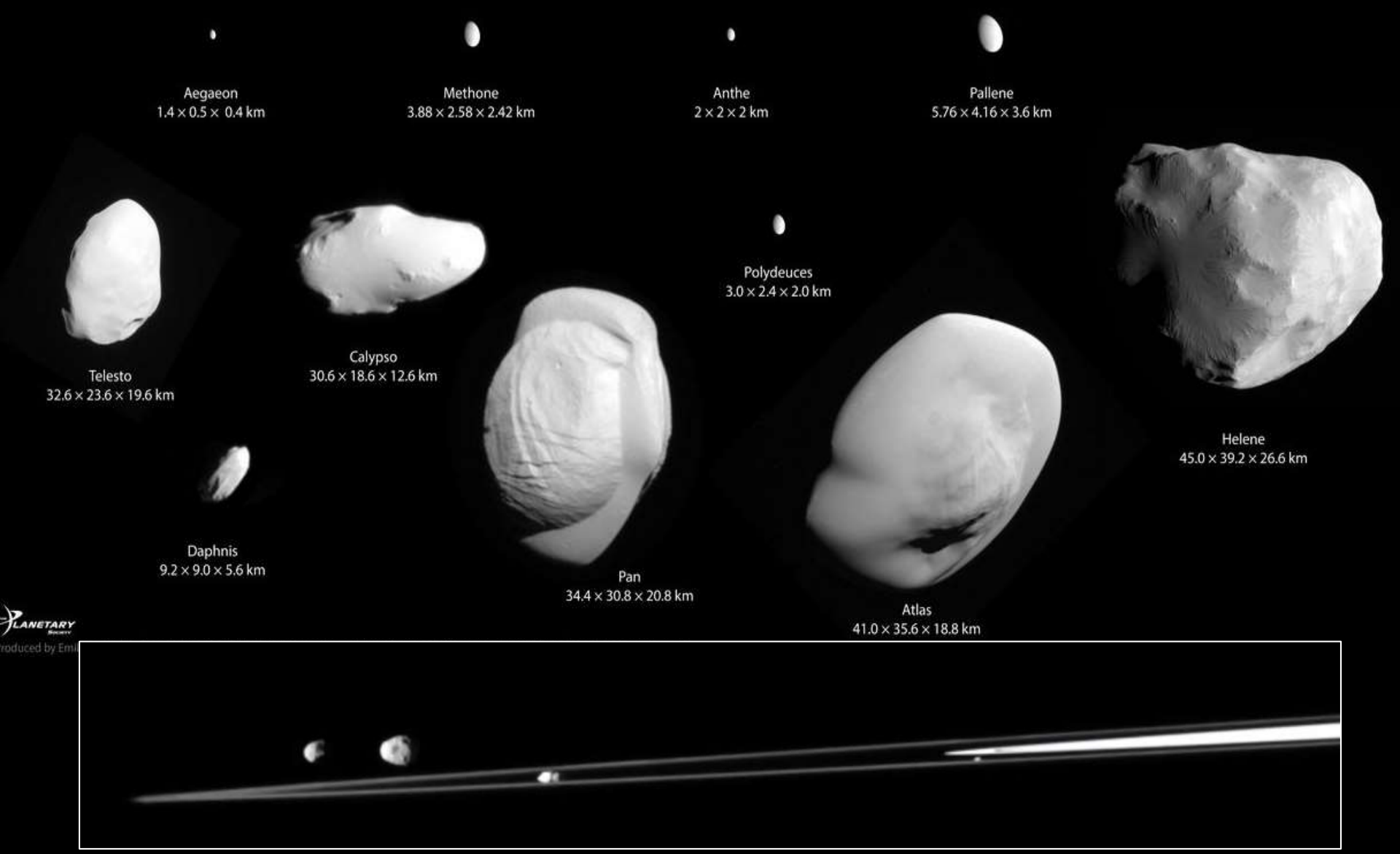
Grand Finale Orbits Have Started

EOM September 15

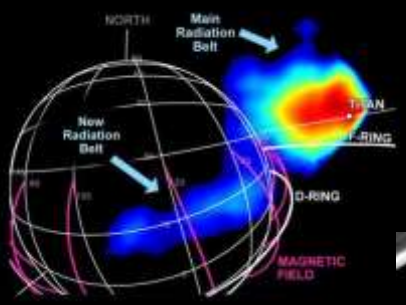


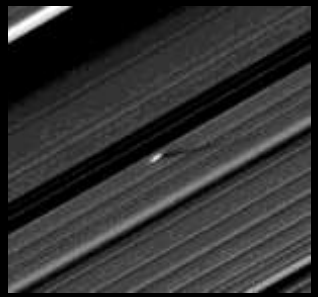
Where are the Small Moons?

High Resolution Images of the Moons



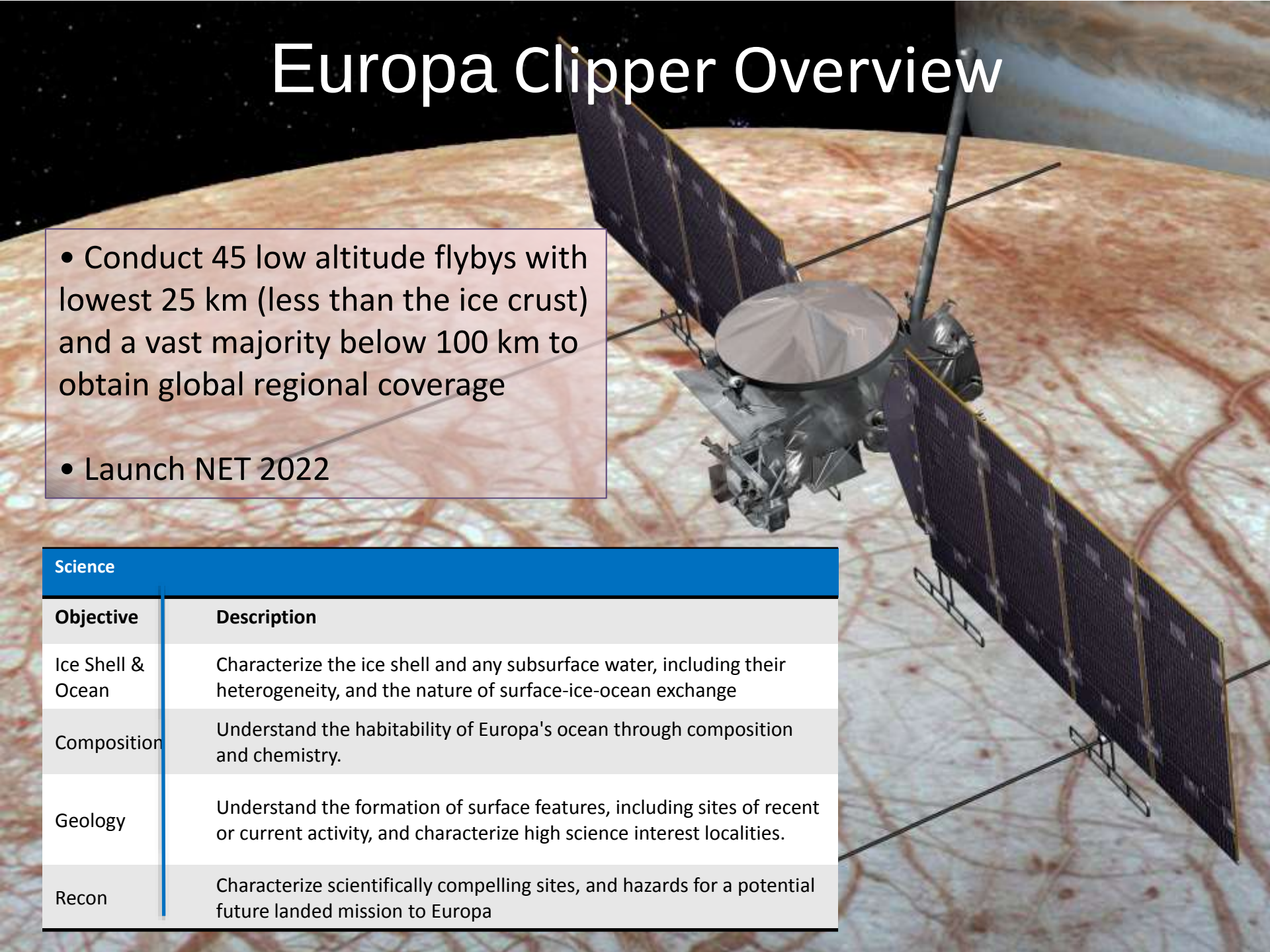
Final Orbits Science Summary





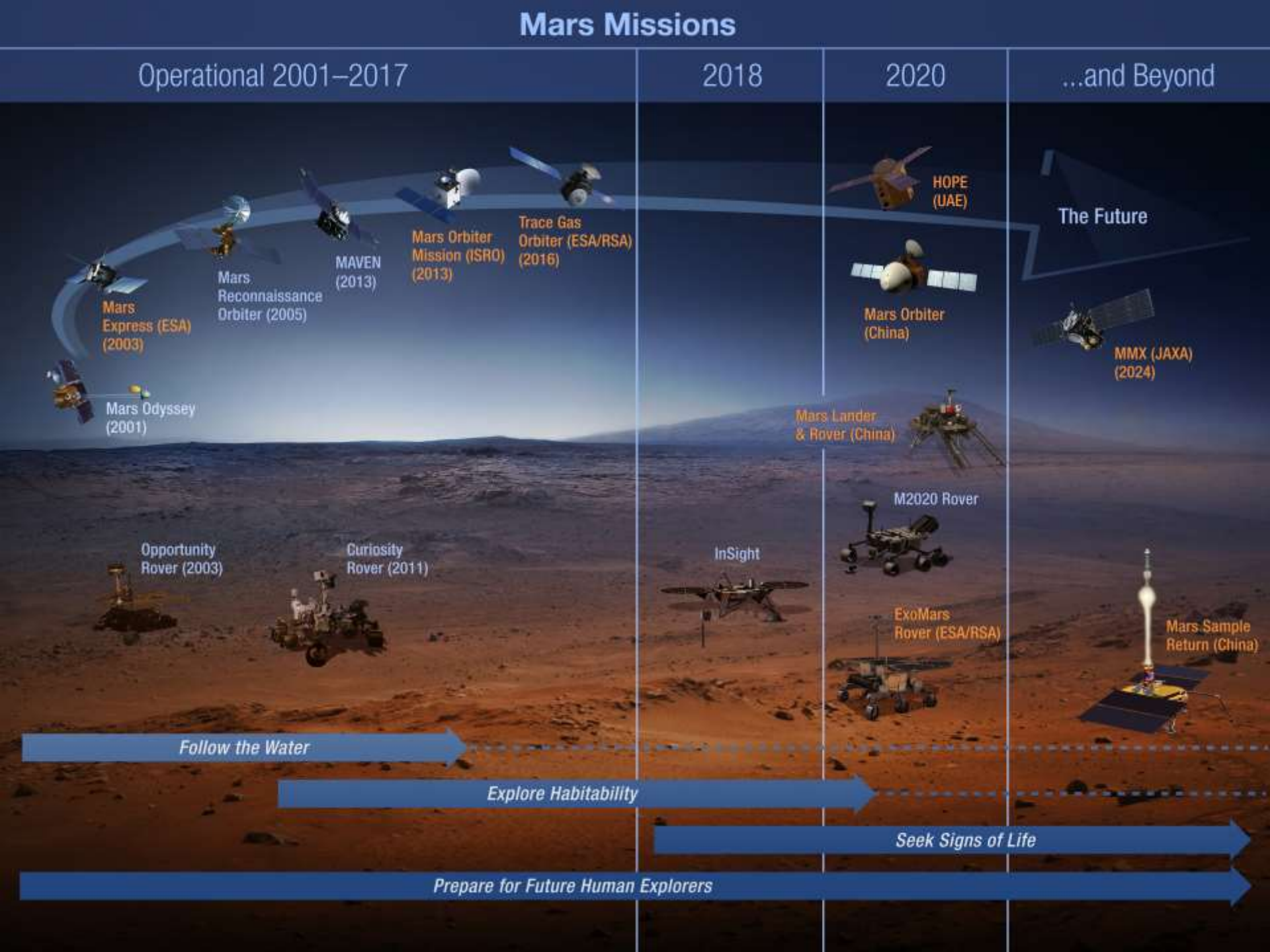
- Saturn internal structure
  - Gravitational & Magnetic Fields
- Ring mass (currently uncertain by 10x)
  - Address age of main rings
- Saturn's ionosphere, innermost radiation belts & inner D ring particles
- Highest resolution main ring observations
  - First Active Radar of the Rings
- Highest resolution Saturn polar observations and aurora
- Saturn atmospheric structure & composition
- Cassini Saturn science complements that from Juno mission to Jupiter

Europa Clipper Overview

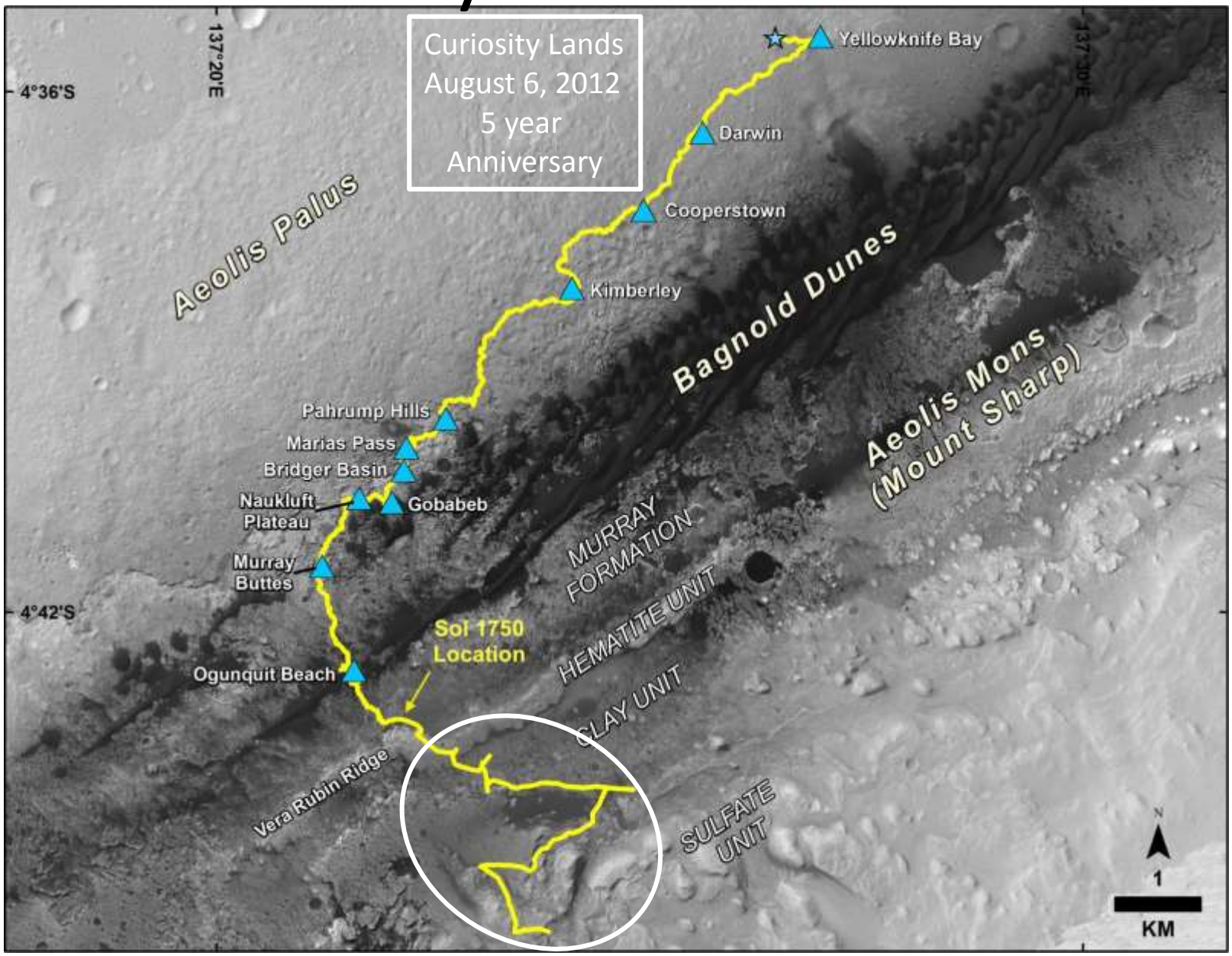


- Conduct 45 low altitude flybys with lowest 25 km (less than the ice crust) and a vast majority below 100 km to obtain global regional coverage
- Launch NET 2022

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


Mars Missions
Operational 2001–2017
2018
2020
...and Beyond
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
Mars Odyssey (2001)
HOPE (UAE)
Mars Orbiter (China)
The Future
MMX (JAXA) (2024)
Mars Lander & Rover (China)
M2020 Rover
Opportunity Rover (2003)
Curiosity Rover (2011)
InSight
ExoMars Rover (ESA/RSA)
Mars Sample Return (China)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

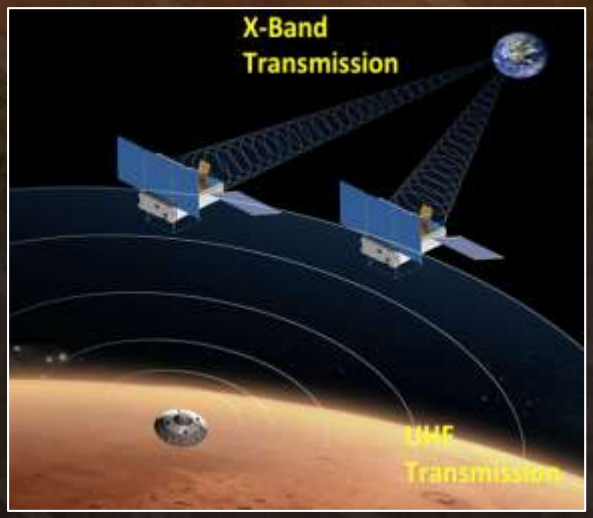
Curiosity at Gale Crater




Curiosity approaches Vera Rubin Ridge Sol 1717 June 2017
Credit: NASA/JPL/Ken Kremer/Marco Di Lorenzo

Interior Exploration using Seismic Investigations, Geodesy and Heat Transport

To Be Launched May 2018

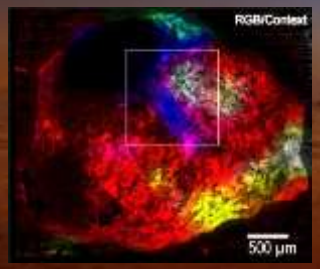


Seeking Signs of Life: Mars 2020 Rover

Conduct rigorous *in situ* science

Geologically diverse site of ancient habitability

Coordinated, nested context and fine-scale measurements



LCC: $2.4B RY

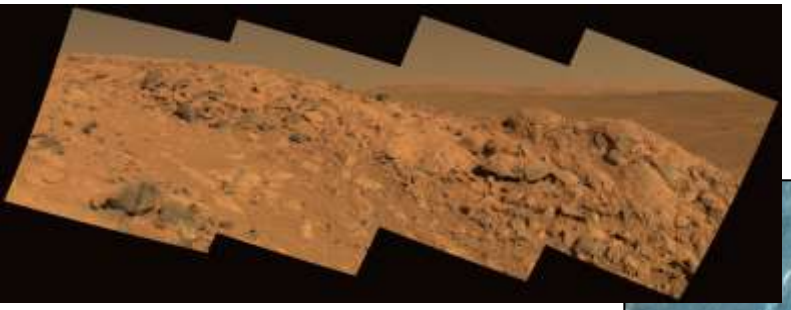
Enable the future

Returnable cache of samples

Critical ISRU and technology demonstration required for future Mars exploration

Final Mars 2020 Candidate Landing Sites

Final site selection targeted for end of 2018

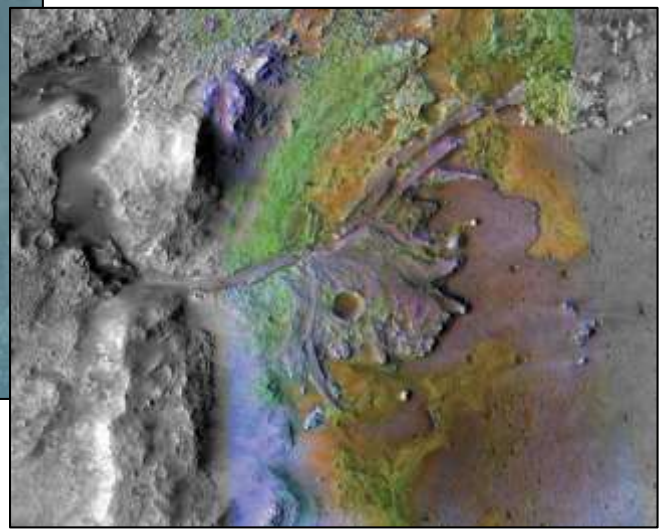


COLUMBIA HILLS

- Ancient hot springs of carbonate, sulfate, and silica-rich material
- Potential biosignatures identified
- Previously explored by **Spirit** rover

NE SYRTIS

- Extremely ancient volcanic and hydrothermal environments
- Large diversity of hydrated minerals
- Potential subsurface habitability

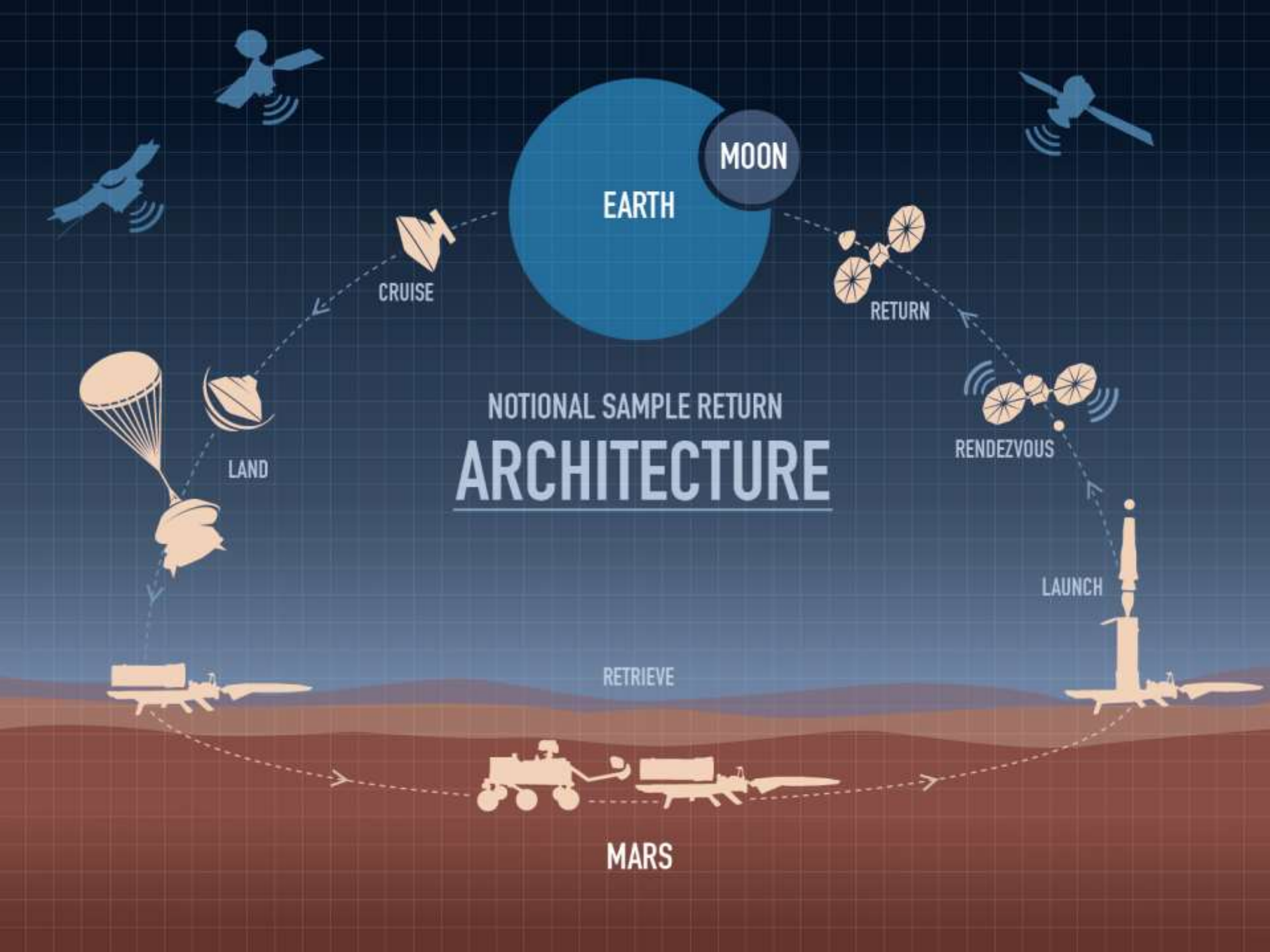


JEZERO

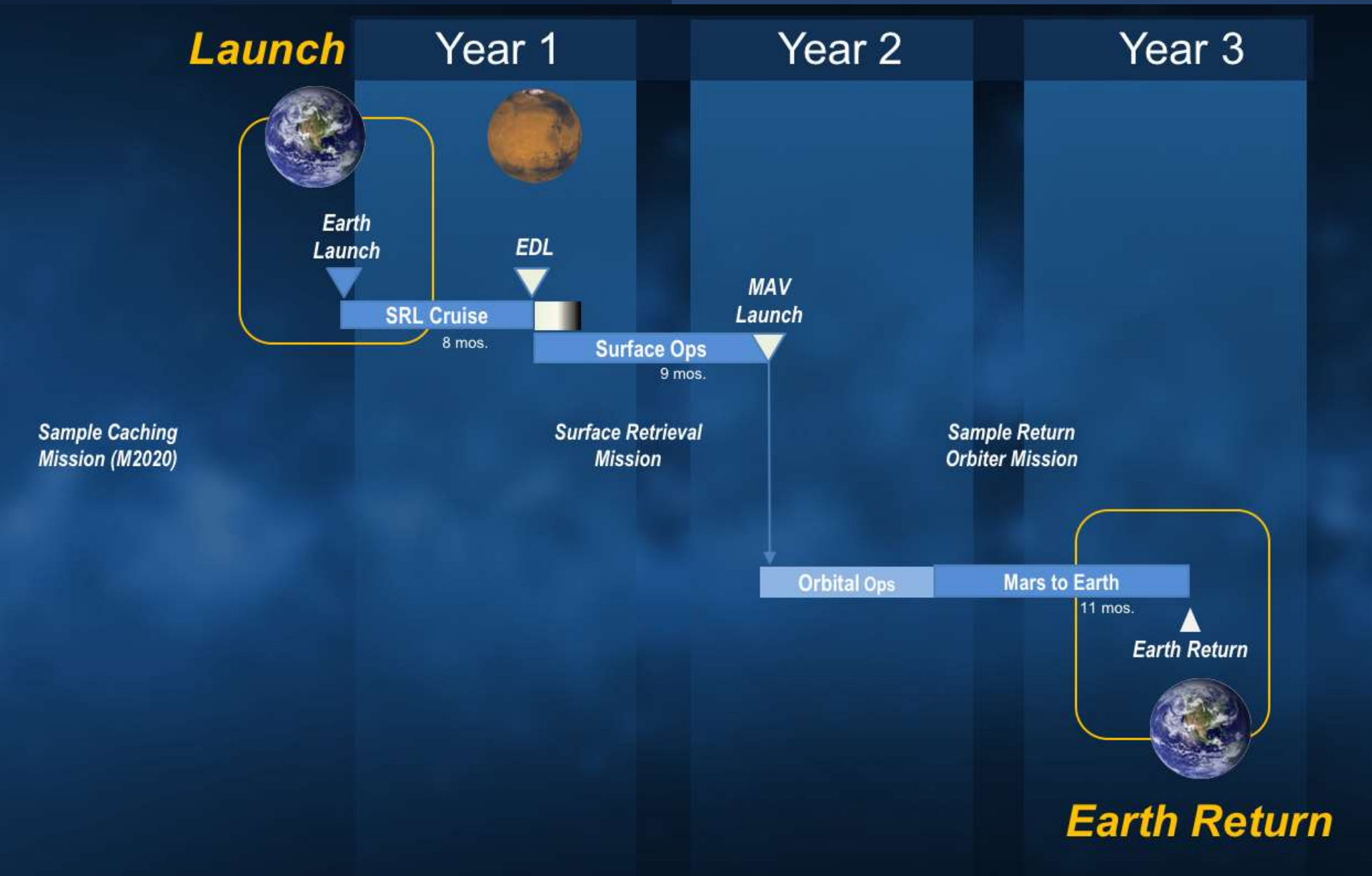
- Ancient lava and water deposition region
- Evidence for hydrous and clay minerals

MARS EXPLORATION PROGRAM

- Decadal Survey science goals
  - Determine if life ever arose on Mars
  - Understand the processes and history of climate
  - Determine the evolution of the surface and interior
- Progress report
  - Making breakthroughs in Mars science
  - Gaining knowledge in preparation of future Mars exploration
  - Current missions are healthy and performing well
  - Technology investments are addressing pivotal issues for future Mars exploration architectures
- Our future architectures should adapt to evolving Mars exploration
  - Existing program capabilities
  - Multiple international interests
  - Multiple commercial interests
- Investigating new, leaner Mars architectures to respond to global changes in Mars exploration


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

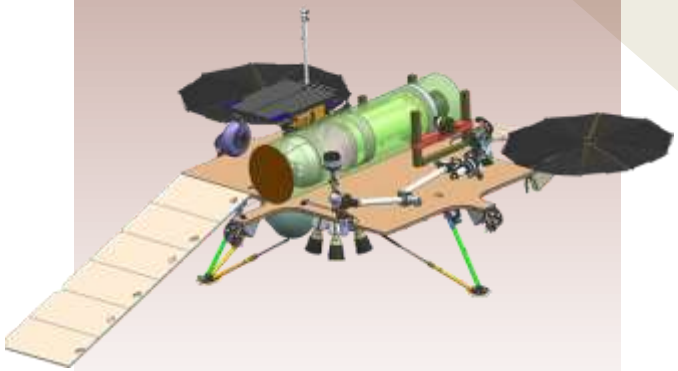
NOTIONAL MSR TIMELINE



TWO LANDER CONCEPTS

2017 Highly Integrated Concept

Propulsive Platform Lander (PPL) *Concept Packaged in MSL 4.5m Aeroshell*

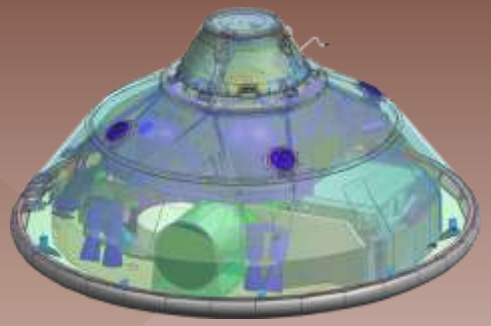


Propulsive Platform Lander
Concept Deployed

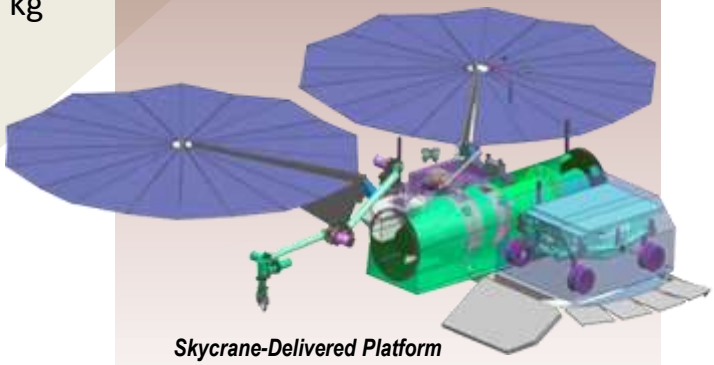
Common Attributes

- Identical cruise and entry architecture
- ~ 10 km landing ellipse
- ~ 900-1000 kg landed useful mass
- Accommodates ~ 600 kg MAV and Fetch Rover

Evolved 2011 Decadal Concept



Skycrane-Delivered Platform Concept Packaged in MSL 4.5m Aeroshell



Skycrane-Delivered Platform
Concept Deployed

Two concepts that leverage Mars program legacy system capabilities

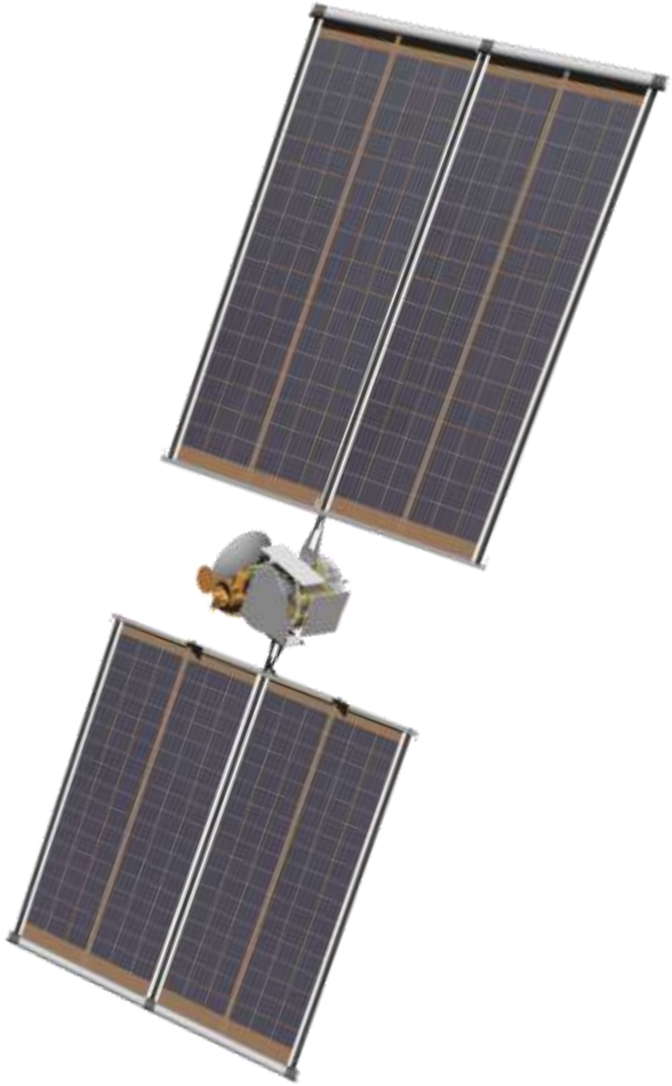
NOTIONAL SAMPLE RETURN ORBITER

Design for Orbital Rendezvous & Fast Sample Return

- Rendezvous & Capture
- Containment and Earth Planetary Protection
- Communication Relay Support for Surface Ops and Critical Events
- Return to Earth, either via
  - Direct return to Earth
  - Deliver to cis-lunar space for human-assisted returns

Implementation Options

- NASA provided
- Partner provided

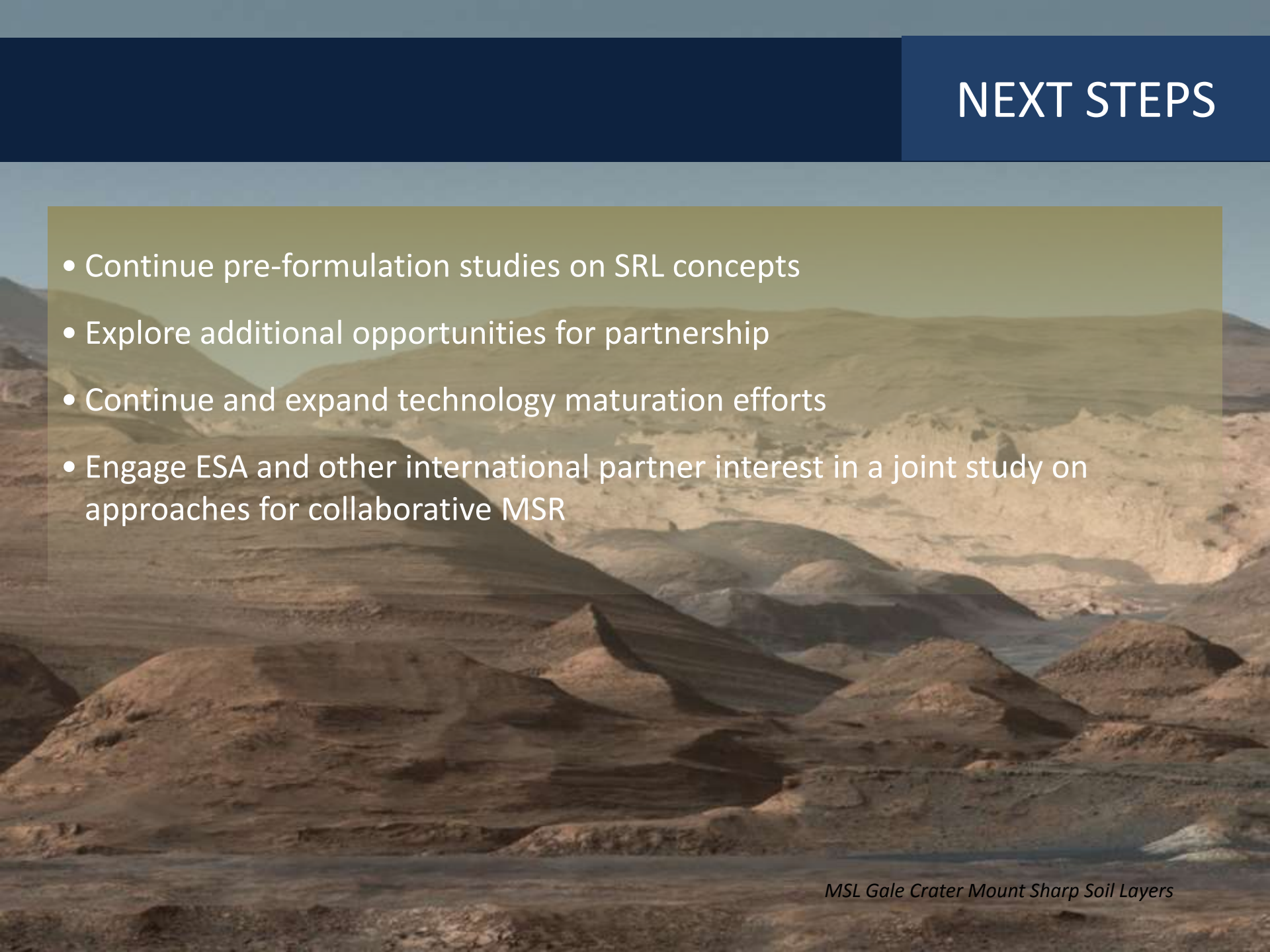


PARTNERSHIP OPPORTUNITIES

- **International**
  - Enduring scientific/technical and programmatic interests
  - Multiple space agencies headed to Mars
- **Growing commercial interest in Mars**
  - Potential to leverage commercial offerings of capability
- **Exploration benefits from MSR**
  - Feed-forward into preparation, planning and development
  - First round trip demonstration
  - Samples inform environmental uncertainties [biological, physical, toxicity]
  - Potential opportunity for early leverage of cis-lunar capabilities

NEXT STEPS

- Continue pre-formulation studies on SRL concepts
- Explore additional opportunities for partnership
- Continue and expand technology maturation efforts
- Engage ESA and other international partner interest in a joint study on approaches for collaborative MSR



MSL Gale Crater Mount Sharp Soil Layers

Mission Studies Completed

- 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

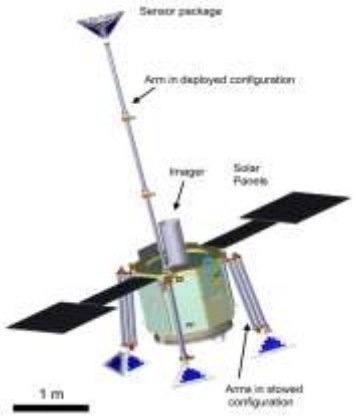
CAPS Priority Areas Candidates for Large or Medium Class Mission Studies (Unprioritized)

Venus exploration missions	Additional concepts beyond the Venera-D orbiter and lander
Lunar science missions	Understanding interior processes and polar volatiles
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

Planetary Science Deep Space Small Satellite Studies

- Concept studies to scope science capability and cost of small secondary missions
- 19 awards ($6 M investment over one year)
- Report out at LPSC in March 2018

Christophe Sotin (JPL)
Cupid's Arrow spacecraft concept



Jeff Plescia (Purdue)
APEX spacecraft concept

Venus

Valeria Cottini, CUVE - Cubesat UV Experiment
Attila Komjathy, Seismicity Investigation on Venus Using Airglow Measurements
Tibor Kremic, Seismic and Atmospheric Exploration of Venus (SAEVe)
Christophe Sotin, Cupid's Arrow

Moon

David Draper, Innovative Strategies for Lunar Surface Exploration
Charles Hibbitts, Lunar Water Assessment, Transportation, and Resource Mission
Noah Petro, Mini Lunar Volatiles (MiLUV) Mission
Suzanne Romaine, CubeSat X-ray Telescope (CubeX)
Timothy Stubbs, Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)

Small Bodies

Benton Clark, CAESAR: CubeSat Asteroid Encounters for Science and Reconnaissance
Tilak Hewagama, Primitive Object Volatile Explorer (PrOVE)
Jeffrey Plescia, APEX: Asteroid Probe Experiment

Mars

Anthony Colaprete, Aeolus - to study the thermal and wind environment of Mars
Michael Collier, PRISM: Phobos Regolith Ion Sample Mission
Robert Lillis, Mars Ion and Sputtering Escape Network (MISEN)
David Minton, Chariot to the Moons of Mars
Luca Montabone, Mars Aerosol Tracker (MAT)

Icy Bodies and Outer Planets

Kunio Sayanagi, SNAP: Small Next-generation Atmospheric Probe
Robert Ebert, JUpiter MagnetosPheric boundary ExploreR (JUMPER)

Questions?