Strategic Missions in Planetary Science

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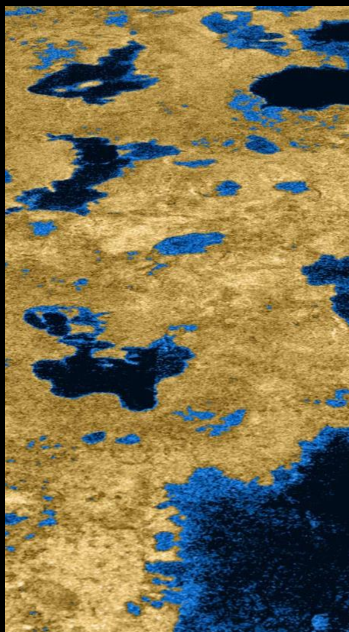
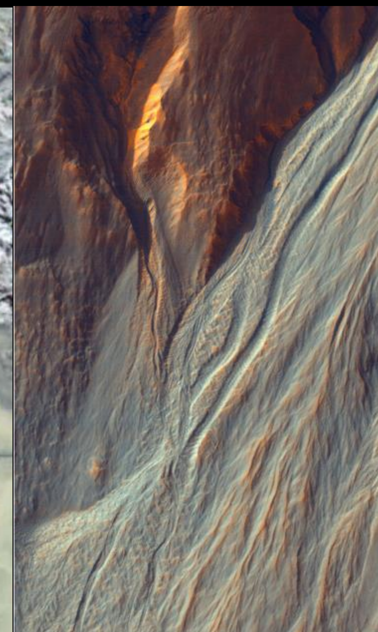
Outline

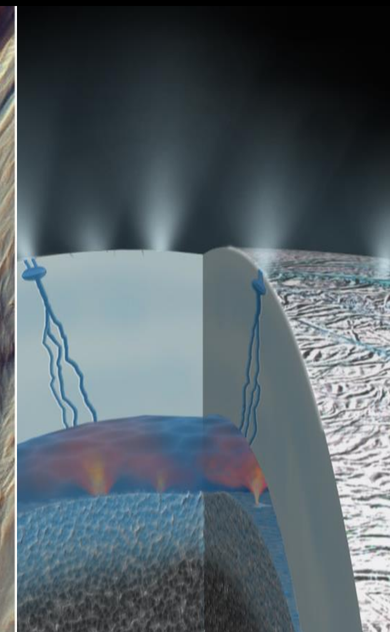
- What Makes a “Strategic Mission”
  - Balance within the Planetary Decadal
- Current Strategic Missions
- Future Strategic Missions

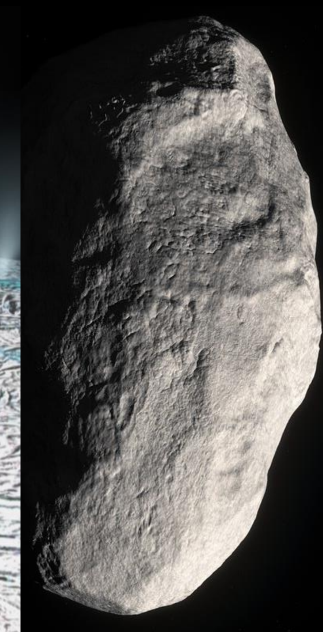
Planetary Science

Ascertain the content, origin, and evolution of the Solar System and the potential for life elsewhere!









Objective 1.5.1
Demonstrate progress in advancing the understanding of how the chemical and physical processes in the Solar System operate, interact and evolve

Objective 1.5.2
Demonstrate progress in exploring and observing the objects in the Solar System to understand how they formed and evolve

Objective 1.5.3
Demonstrate progress in exploring and finding locations where life could have existed or could exist today

Objective 1.5.4
Demonstrate progress in improving understanding of the origin and evolution of life on Earth to guide the search for life elsewhere

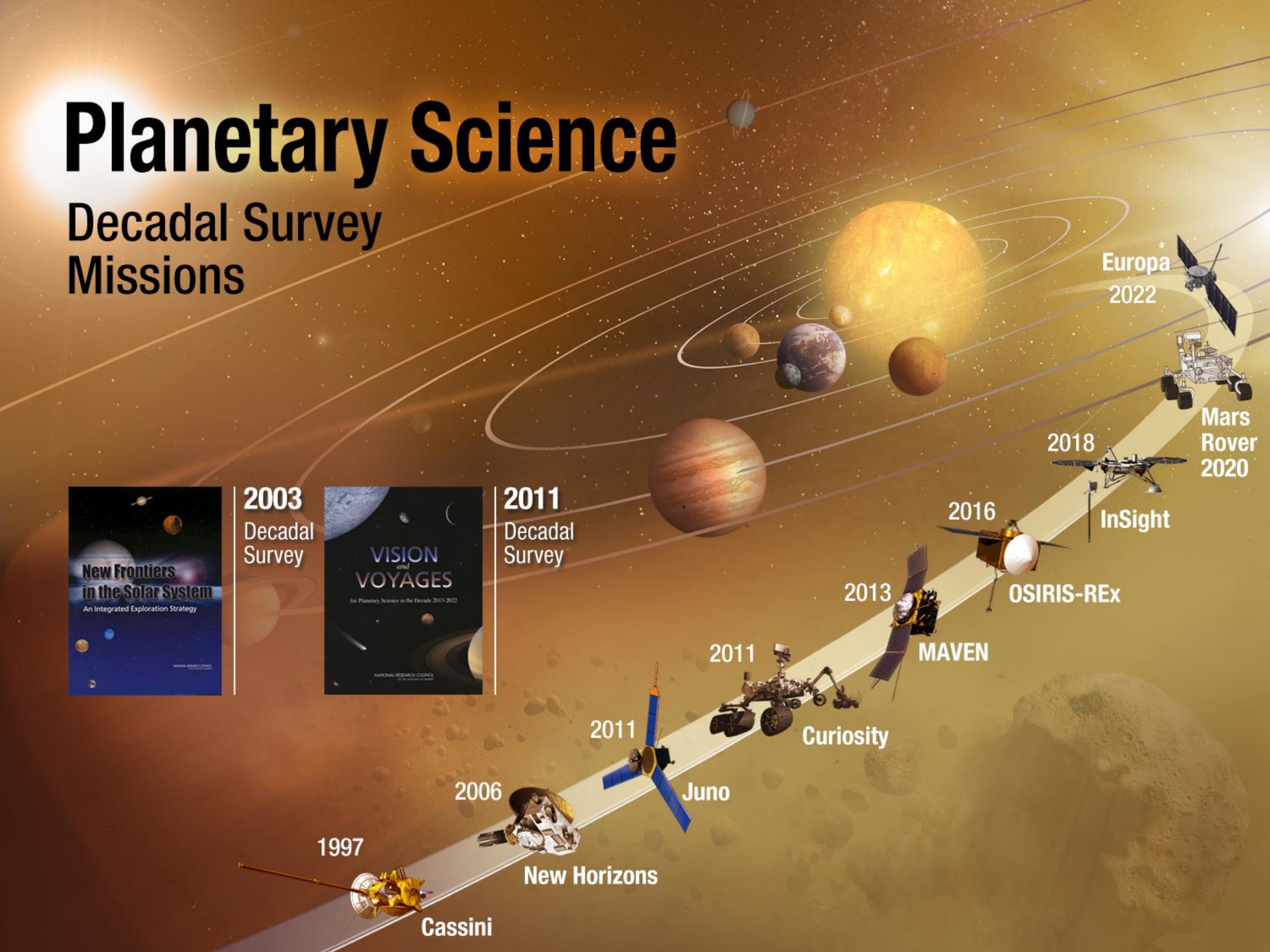
Objective 1.5.5
Demonstrate progress in identifying and characterizing objects in the Solar System that pose threats to Earth or offer resources for human exploration

Over-Arching Principles

- Sustained progress requires particular attention to a balanced science portfolio including basic research, modeling programs, technology development, missions, mission data analysis, and data and information systems.
- Planetary missions are accomplished in two broad classes:
  - Principal Investigator Missions
  - Strategic Missions

- An NRC report, *An Enabling Foundation for NASA's Earth and Space Science Missions* (NRC, 2010), highlighted the importance of mission-enabling programs in meeting NASA's science goals.
  - Planetary's investment in this area is in the Research & Analysis program

- At NASA, space missions represent the largest area of investment.



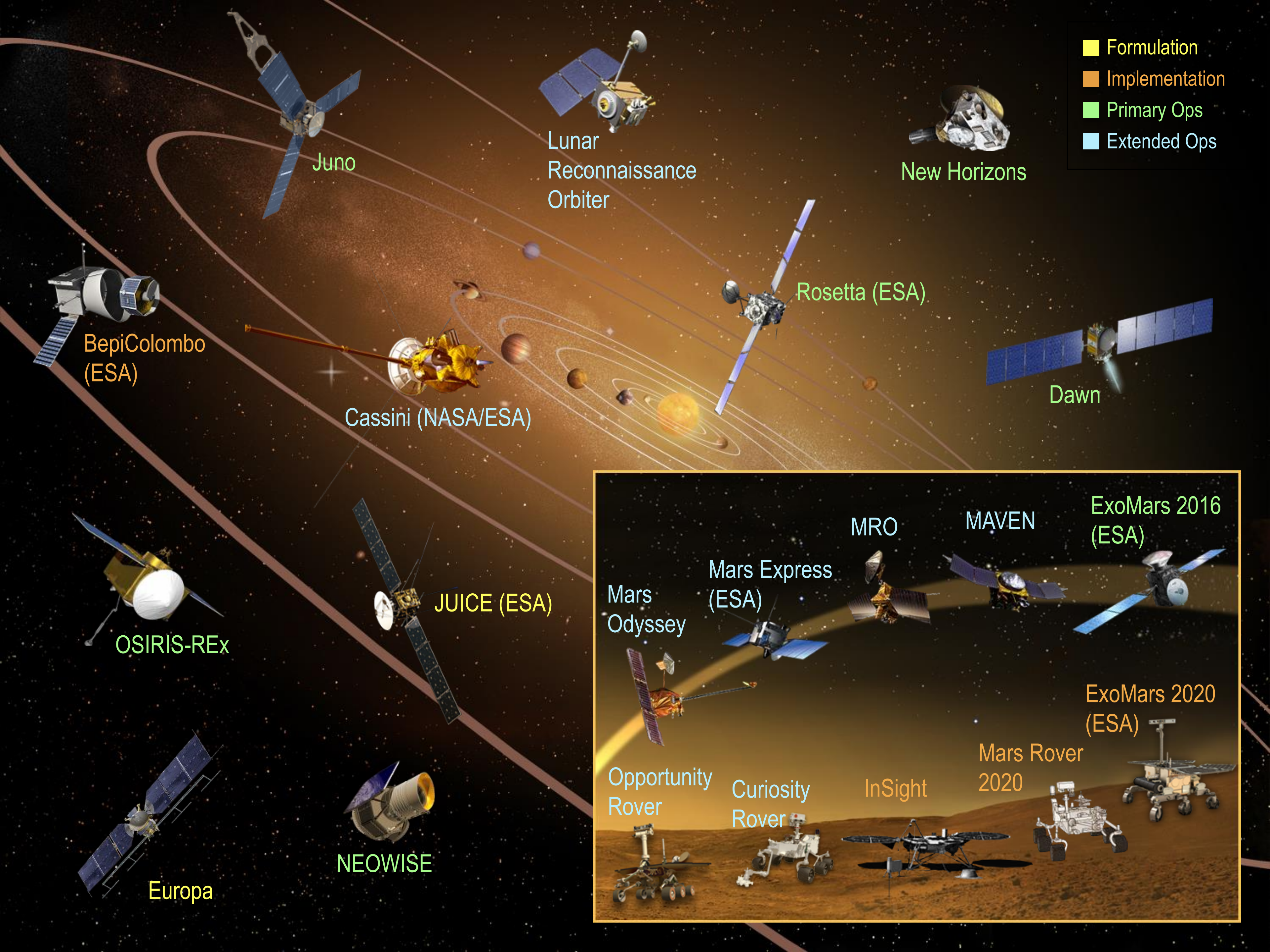
Planetary Science
Decadal Survey Missions
2003 Decadal Survey
New Frontiers in the Solar System
An Integrated Exploration Strategy
2011 Decadal Survey
VISION and VOYAGES
for Planetary Science in the Decade 2013-2022
1997
Cassini
2006
New Horizons
2011
Juno
2011
Curiosity
2013
MAVEN
2016
OSIRIS-REx
2018
InSight
Mars Rover 2020
Europa
2022

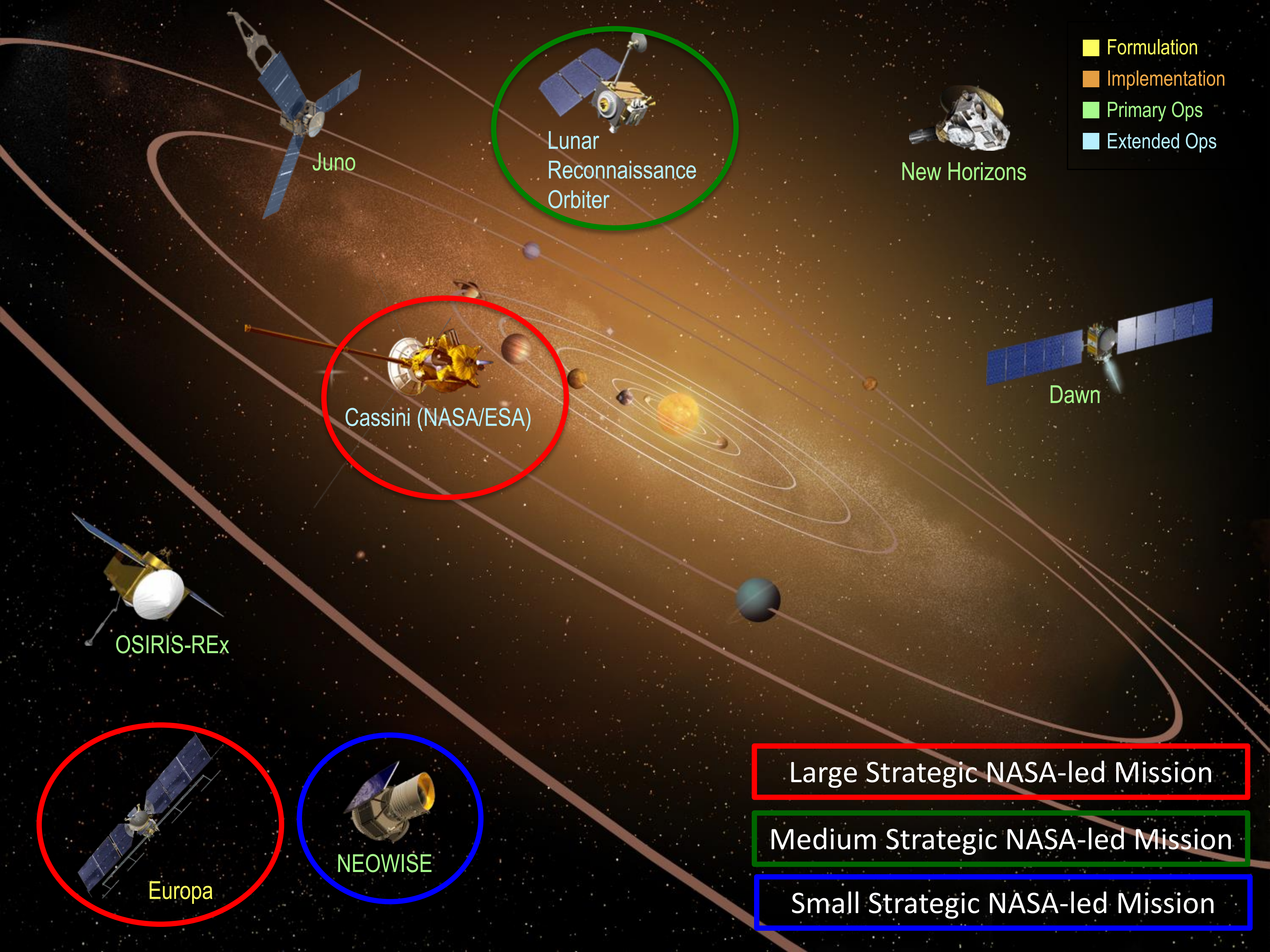
Mission Size Categories

How does each division define mission size categories?

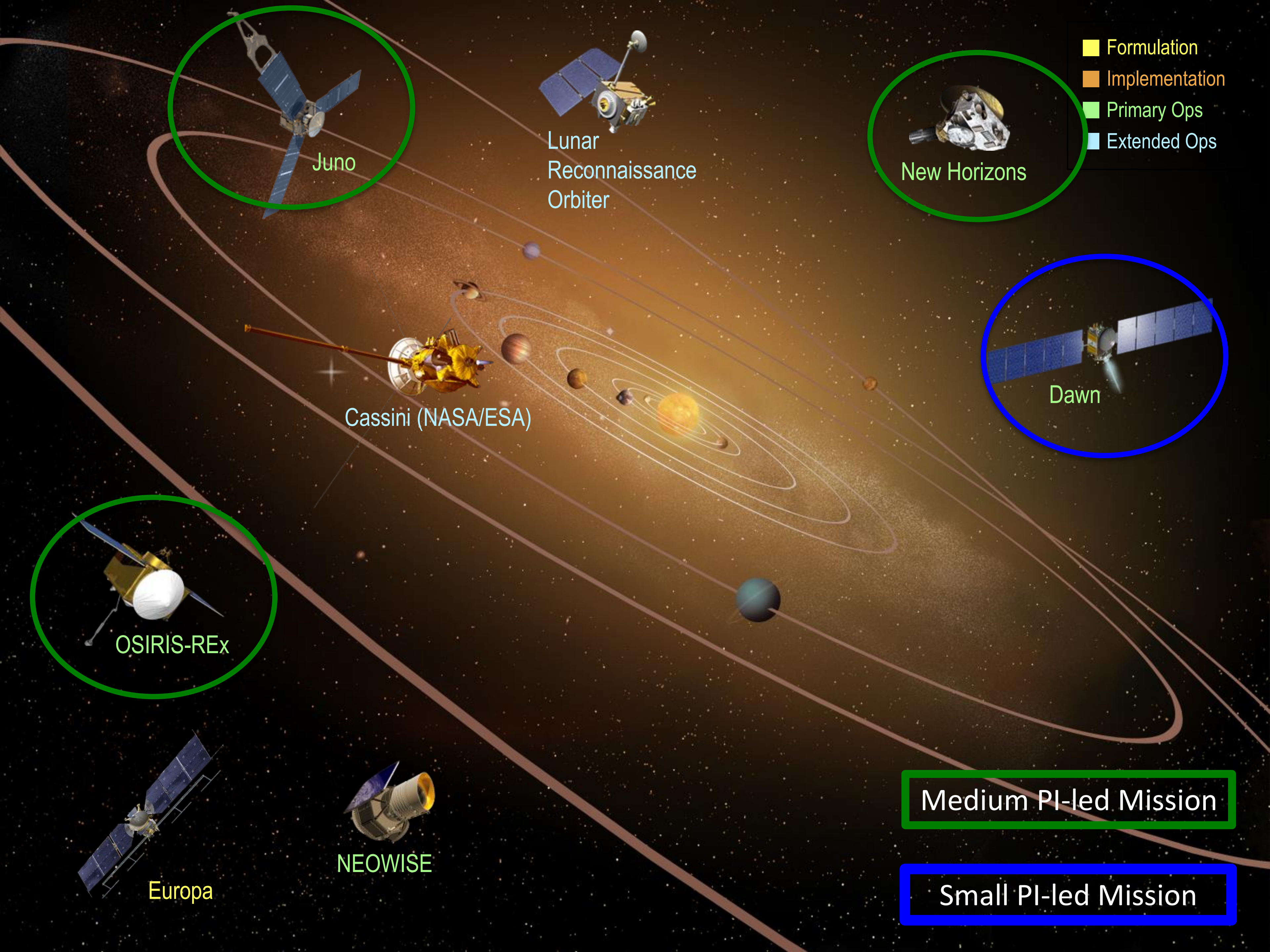
(For instance, what qualifies as small, medium, and large per division?)

- Discovery (Small) and New Frontiers (medium) PI missions
- All large missions are strategic:
  - Recommended by the Decadal Survey
  - Total LCC in excess of $2B
  - Assigned for execution at a NASA Center or JPL
- Contribution to non-NASA Missions are accomplish via:
  - Agency to Agency bilateral agreements
  - Instruments through Salmon AO to be delivered to a foreign partner


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



Formulation
Implementation
Primary Ops
Extended Ops
Juno
Lunar Reconnaissance Orbiter
New Horizons
Cassini (NASA/ESA)
Dawn
OSIRIS-REx
Europa
NEOWISE
Large Strategic NASA-led Mission
Medium Strategic NASA-led Mission
Small Strategic NASA-led Mission



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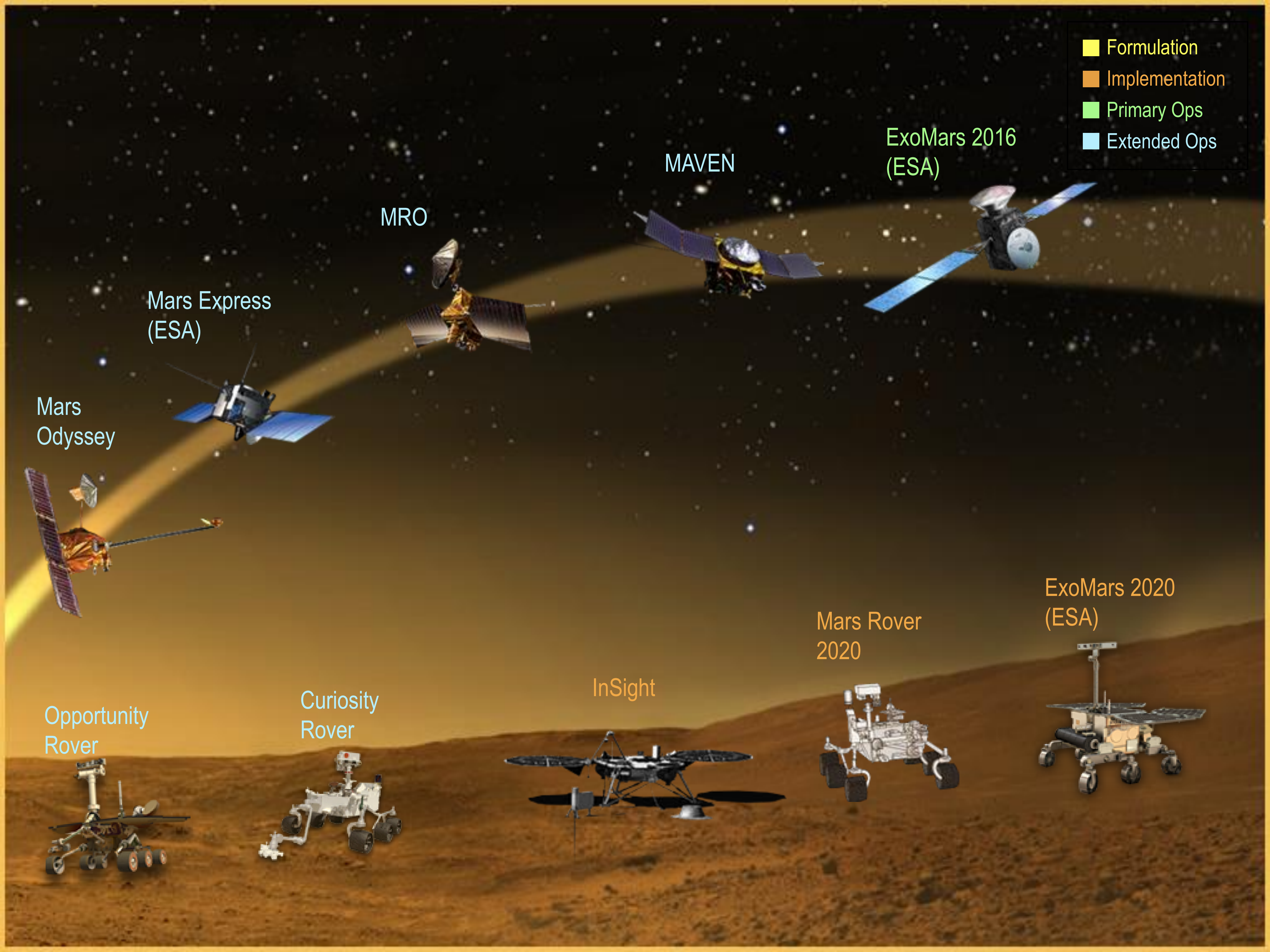
Medium PI-led Mission
Small PI-led Mission


Formulation
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Mars Odyssey
Mars Express (ESA)
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MAVEN
ExoMars 2016 (ESA)
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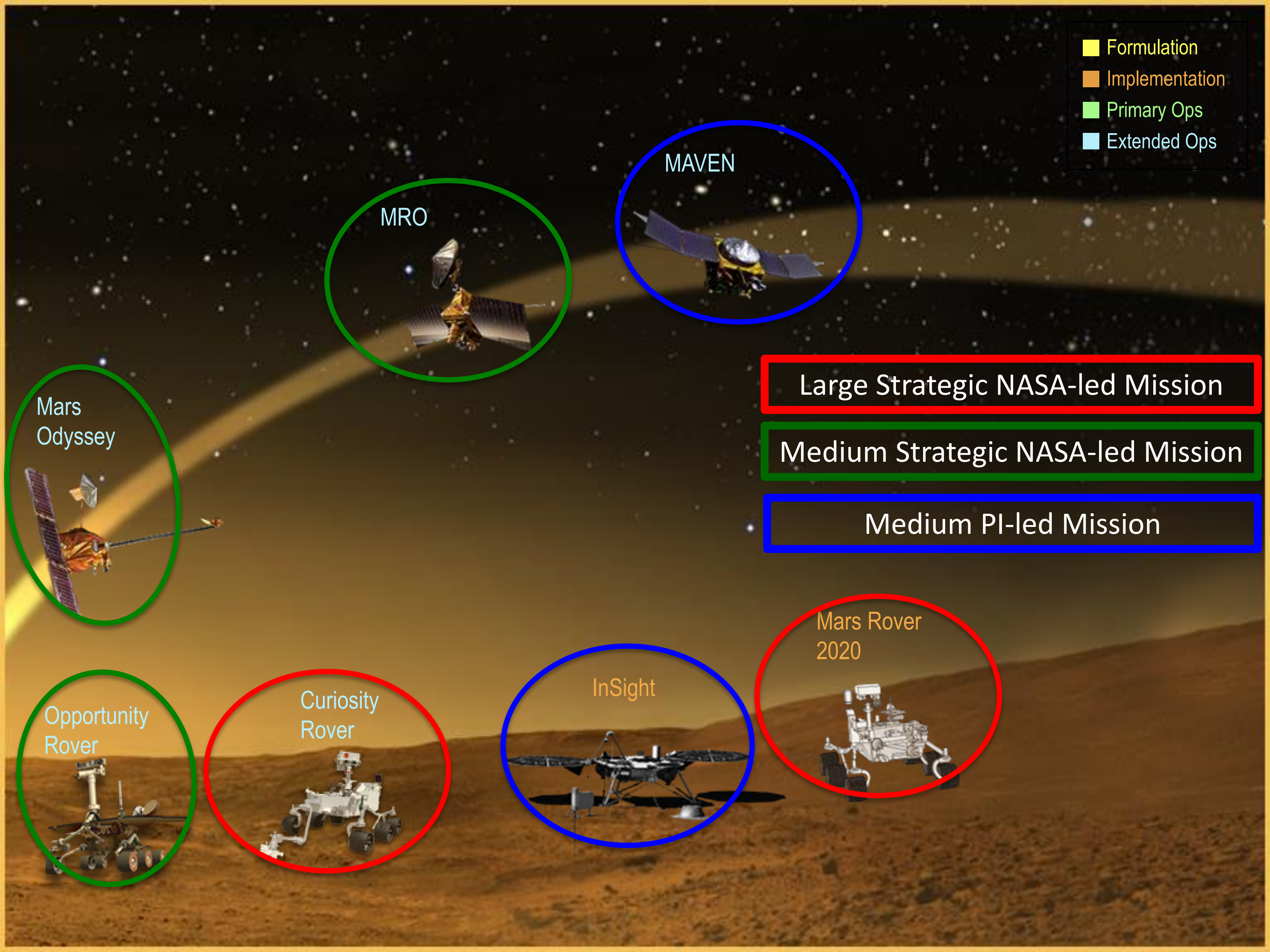
Curiosity Rover
InSight
Mars Rover 2020
ExoMars 2020 (ESA)


Formulation
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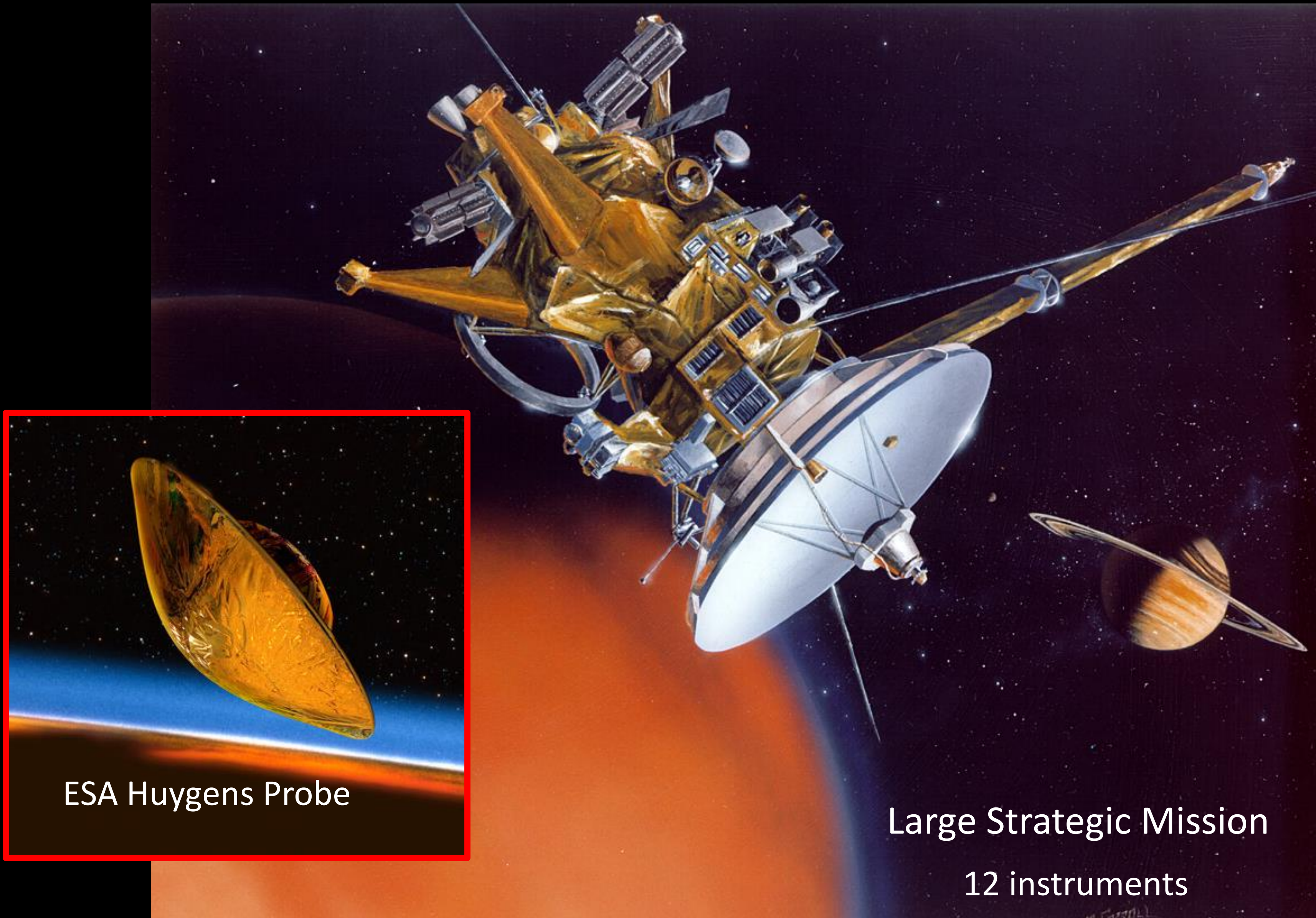
Curiosity Rover
Opportunity Rover

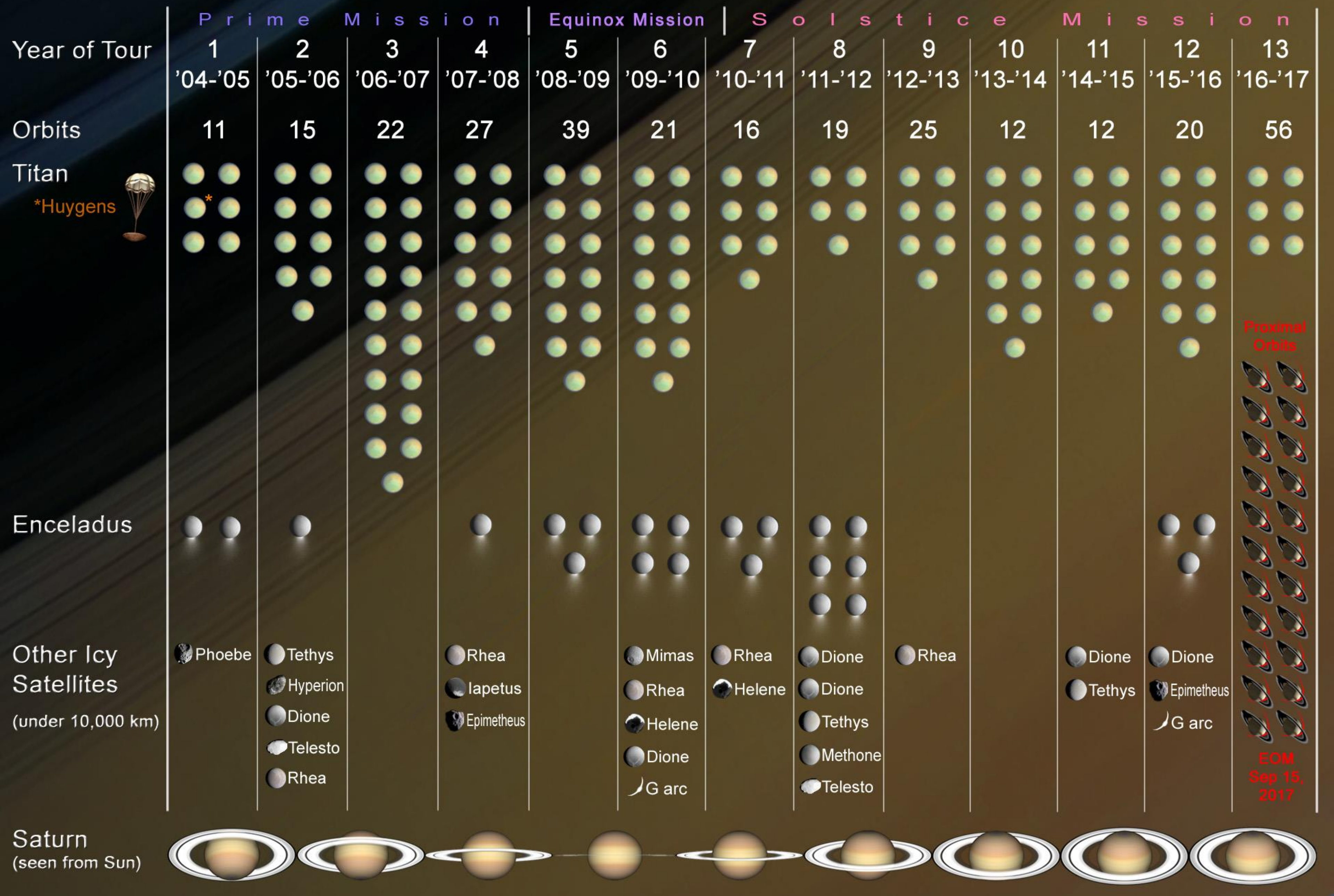
Strategic Mission in Planetary Science
Cassini

Cassini Mission To Saturn

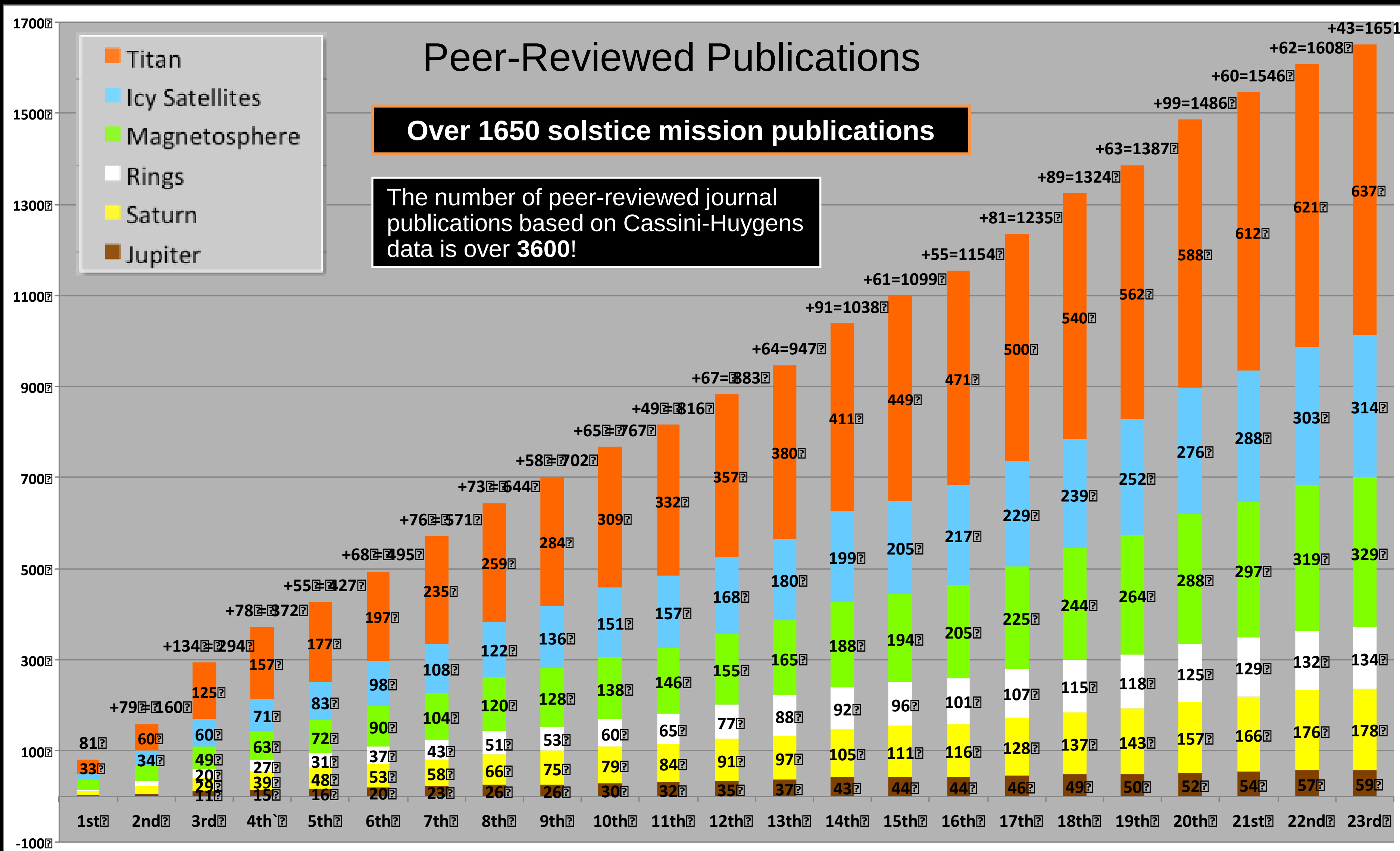


Cassini Mission Overview

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



Cassini Publications



Cassini Solstice Mission Quarters

Recent Enceladus Discoveries (1/2)

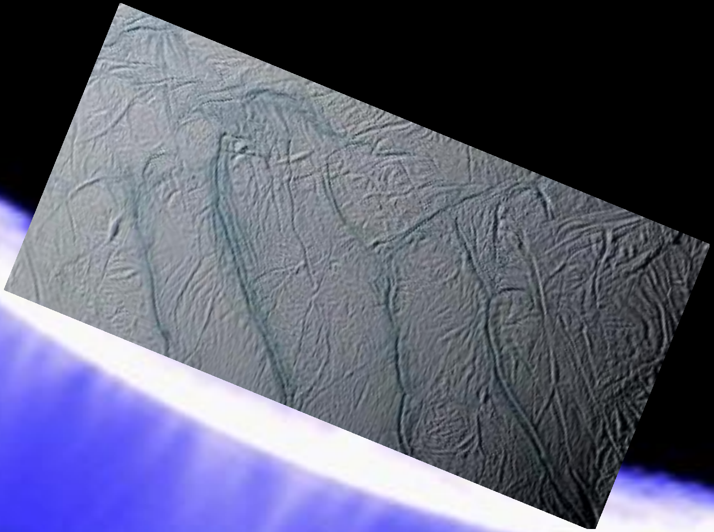
Year paper Accepted	Summary of Discovery
2009	The plume of Enceladus feeds the E ring of Saturn
2010	The plumes of Enceladus vary over time
2010	Enceladus maybe the ultimate source of oxygen for the upper atmospheres of Titan and Saturn
2010	Heat output of Enceladus is greater than thought possible
2011	Dusty plasma, previously theorized, discovered near Enceladus
2011	Grains from Enceladus plume are from a subsurface ocean or sea
2011	Saturn & Enceladus share electrical circuit: Auroral footprint of Enceladus on Saturn"
2011	Saturn and Enceladus share an electrical circuit: Observing auroral hiss, electron beams and standing Alfvén wave currents near Enceladus
2012	Enceladus Plume is a new Kind of Plasma Laboratory
2012	Enceladus is theorized to have hydrothermal activity
2012	Many craters on Enceladus are unusually shallow, suggesting high heat fluxes
2013	Enceladus' subsurface ocean may be long-lived; Ice rheology and tidal heating
2013	Enceladus' subsurface ocean may be long-lived: Shape of Enceladus due to an irregular core: Implications for gravity, libration, and survival of its subsurface ocean"
2013	Intensity of Enceladus jets depends on proximity to Saturn
2013	Plume activity and tidal stresses on Enceladus are correlated
2013	Enceladus fissures are ~9 m wide

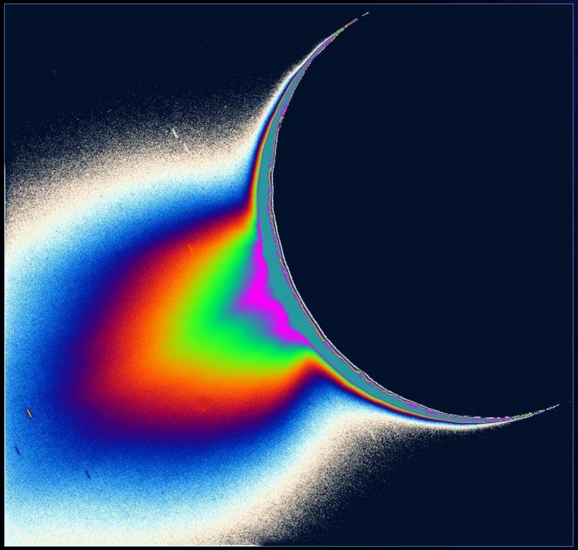
Recent Enceladus Discoveries (2/2)

Year paper Accepted	Summary of Discovery
2014	Enceladus is differentiated and has a regional subsurface ocean (global ocean not ruled out)
2014	Jet activity & tidal stresses correlate spatially along the active tiger stripe fractures in the South Polar Terrain
2015	Enceladus has a fragmented, unconsolidated core that may produce sufficient heat to keep the global subsurface ocean from freezing over long timescales
2015	The pH of the ocean is basic (11-12)
2015	Plume structure may be curtain-like
2015	Detection of a global ocean
2015	Ongoing hydrothermal activity
2015	Hydrothermal vents: Evidence for a methane source in Enceladus' ocean
2015	Heating on Enceladus is not caused by obliquity tides, but probably eccentricity tides
2015	Enceladus' core is irregularly shaped, possibly due to low-velocity impacts by impactors in the 10 km size range (supports hydrothermal activity)
2015	Confirmation of a global ocean
2015	Liquid water on Enceladus could be only 2 km below the surface

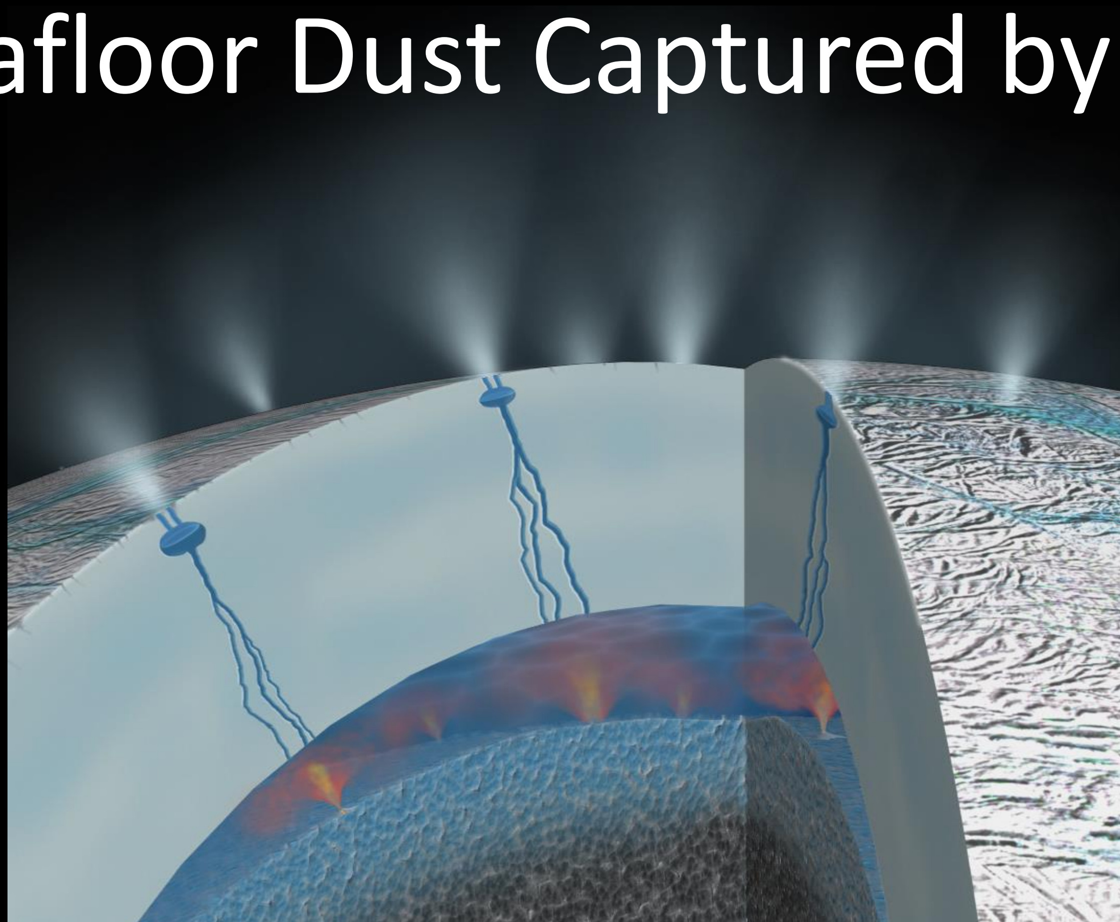
19 NASA Press Releases

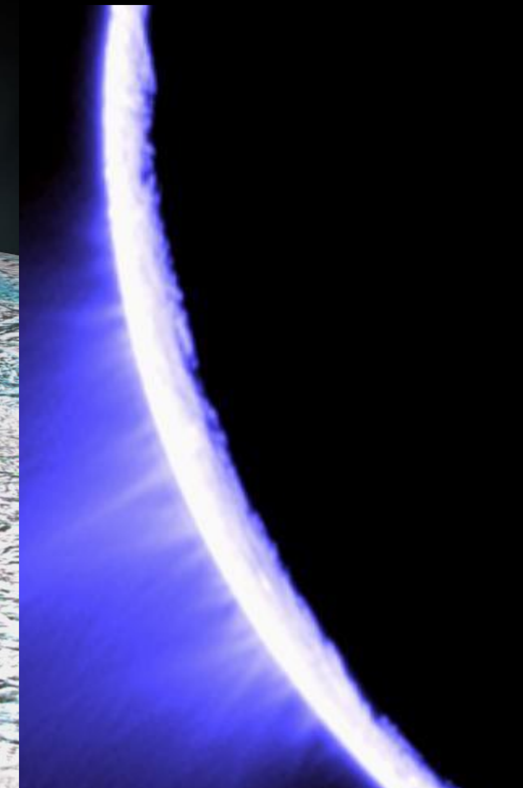
Saturn’s Moon Enceladus





Seafloor Dust Captured by Cassini





Silica nanoparticles captured by Cassini provides first evidence for ongoing seafloor hydrothermal activity.

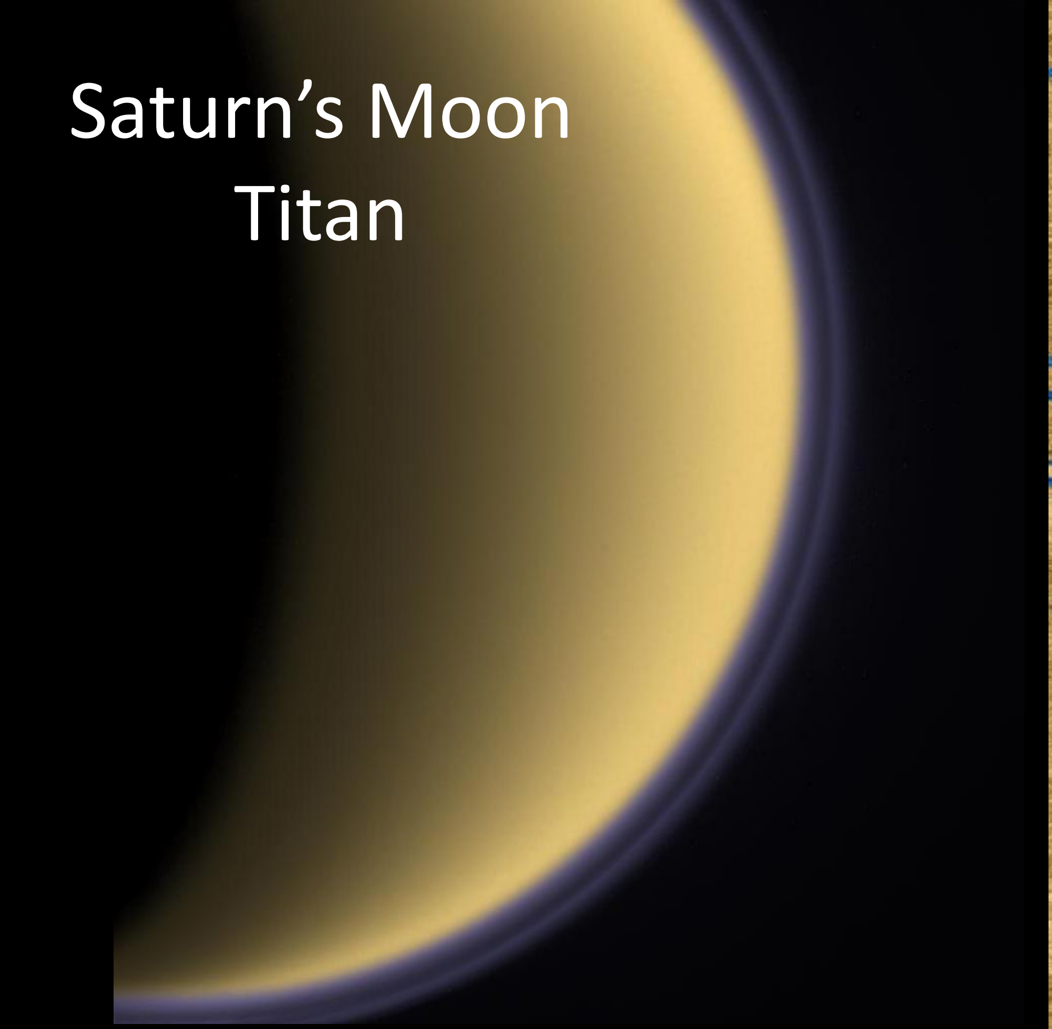
Hydrothermal activity occurs when seawater infiltrates and reacts with a rocky core, emerging as a heated, mineral-laden liquid.

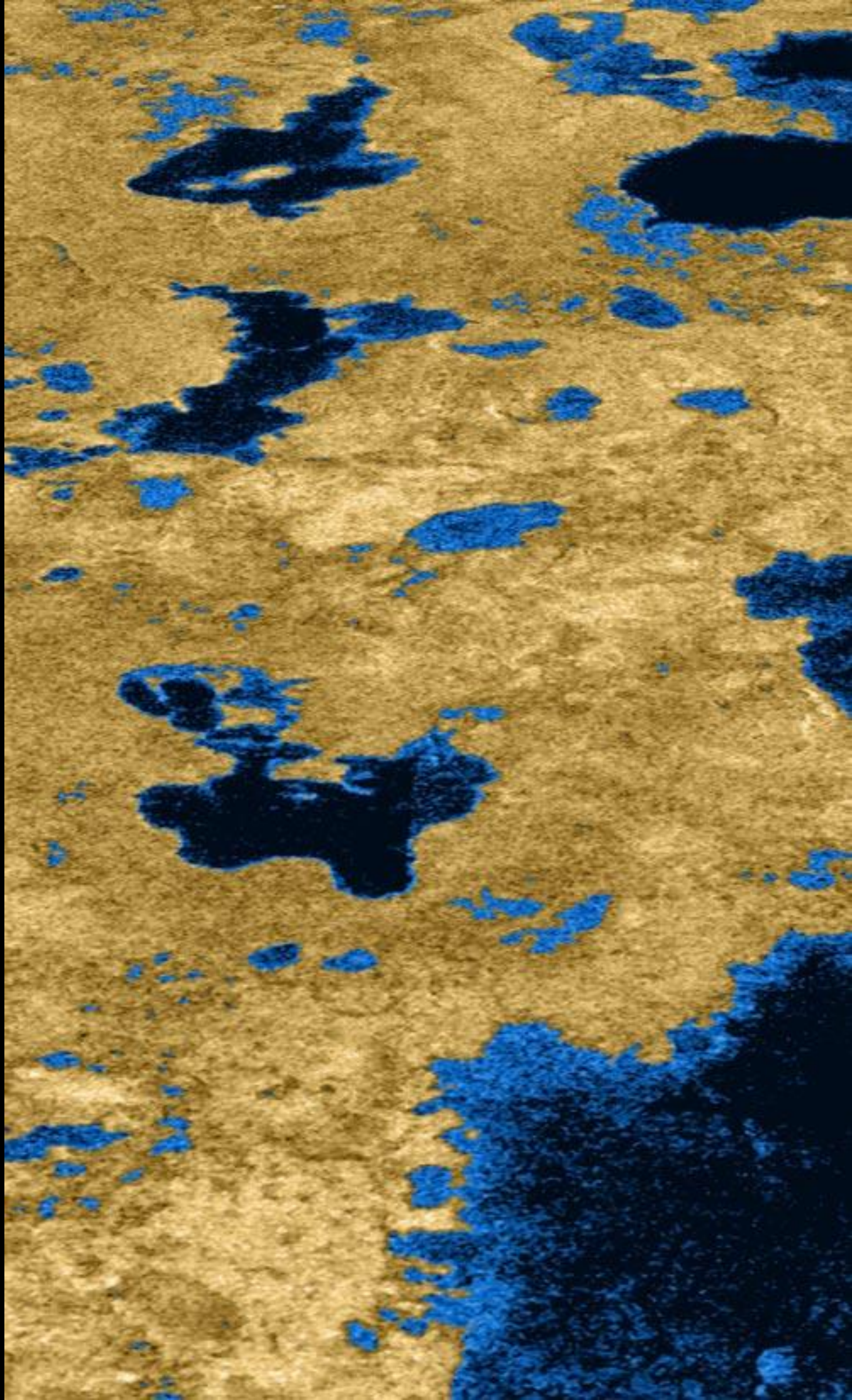
Recent Titan Discoveries

Year paper Accepted	Summary of Discovery
2010	Changing shoreline of northern seas
2011	Titan south polar vortex
2011	Methane rain storm
2012	Global subsurface ocean
2012	Seasonal change in atmosphere circulation
2012	Tropical lakes
2013	Definitive detection of a plastic ingredient
2013	Confirmation of complex hydrocarbons in Titan's upper atmosphere
2013	Large Abundances of Polycyclic Aromatic Hydrocarbons in Titan's Upper Atmosphere
2013	Titan’s ionospheric density linked to solar activity
2014	First determination of depth of a Titanian sea
2014	Titan's "Magic Islands": initial discovery
2014	Titan's ocean as salty as Dead Sea
2014	Methane Ice Cloud in Titan’s Stratosphere
2014	Titan Observed Outside of Saturnian Magnetosphere
2015	Titan dissolves to form small lake basins
2016	"Magic Islands" ongoing observations

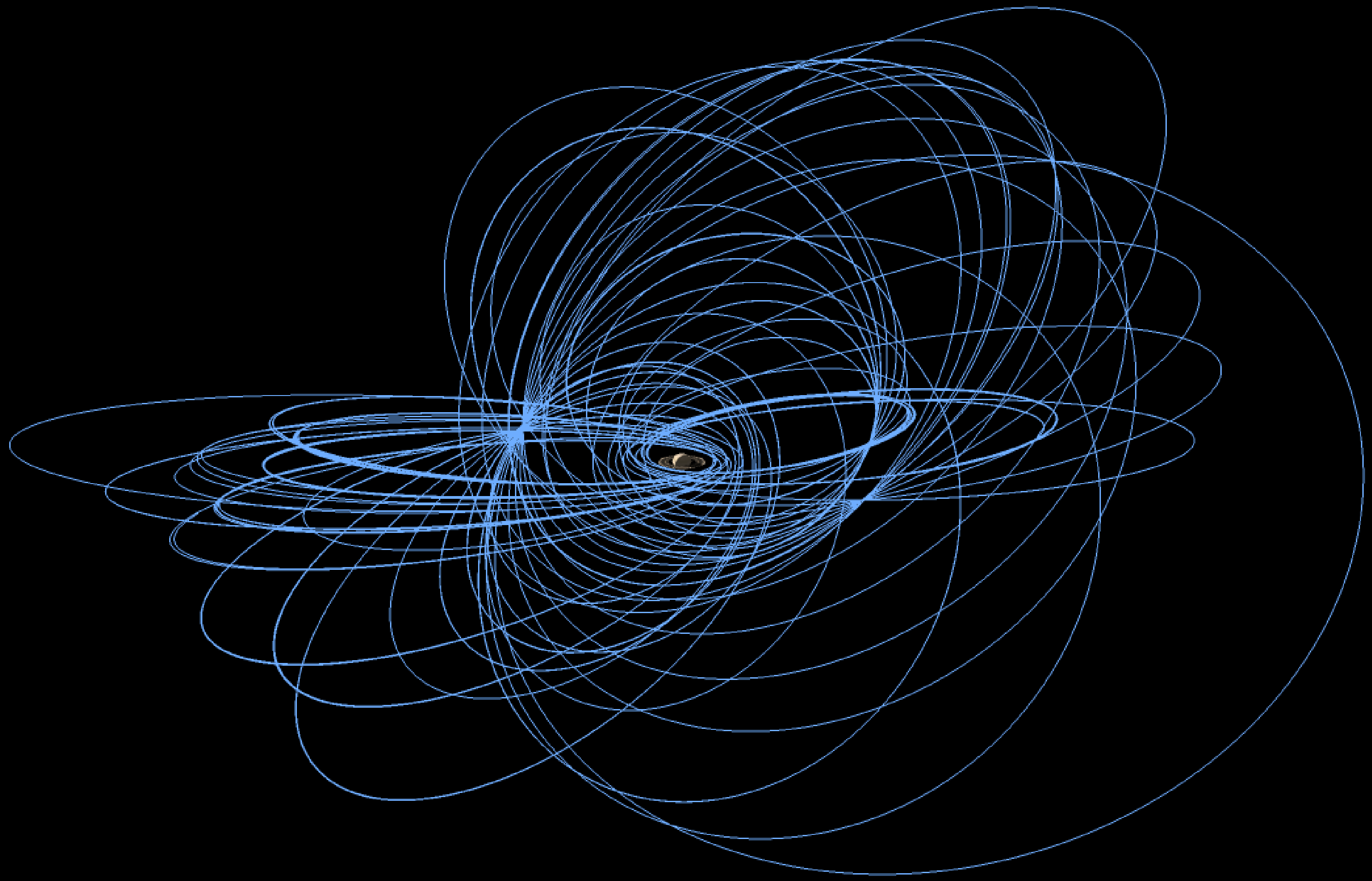
22 NASA Press Releases

Saturn’s Moon Titan

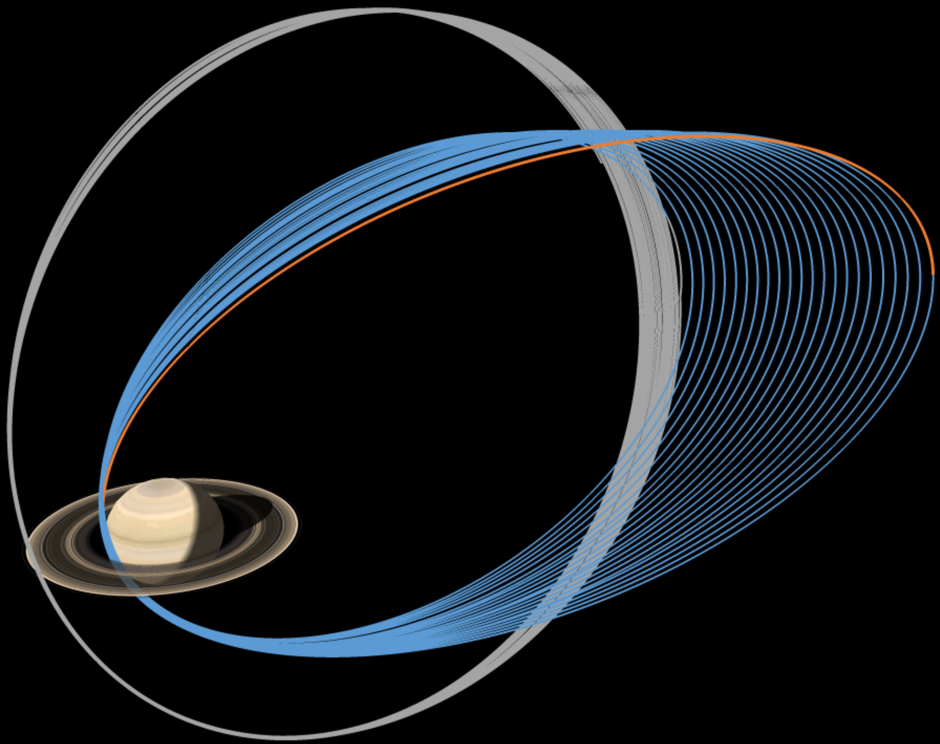




Mission Trajectories

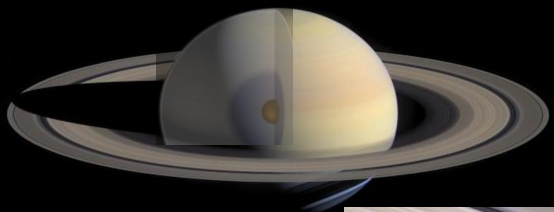


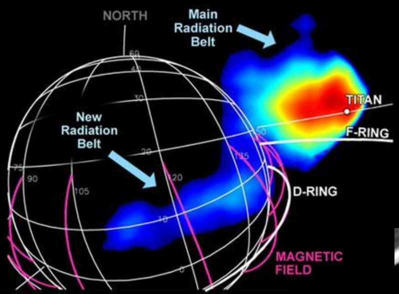
Key Orbital Characteristics of Final Orbits

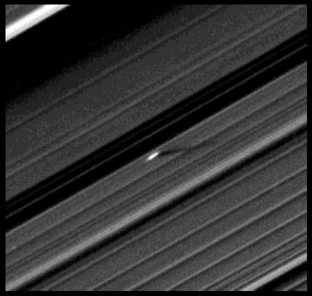


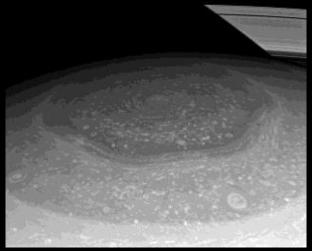
- 42 short-period orbits
  - Nov. 2016 to Sept. 2017
- 20 F ring orbits
  - Periapses just outside Saturn's F ring
  - Sets up Cassini for final jump to orbits inside D ring
- 22 Grand Finale orbits
  - Periapses in 2,400 km "clear" zone

Final Orbits Science Summary



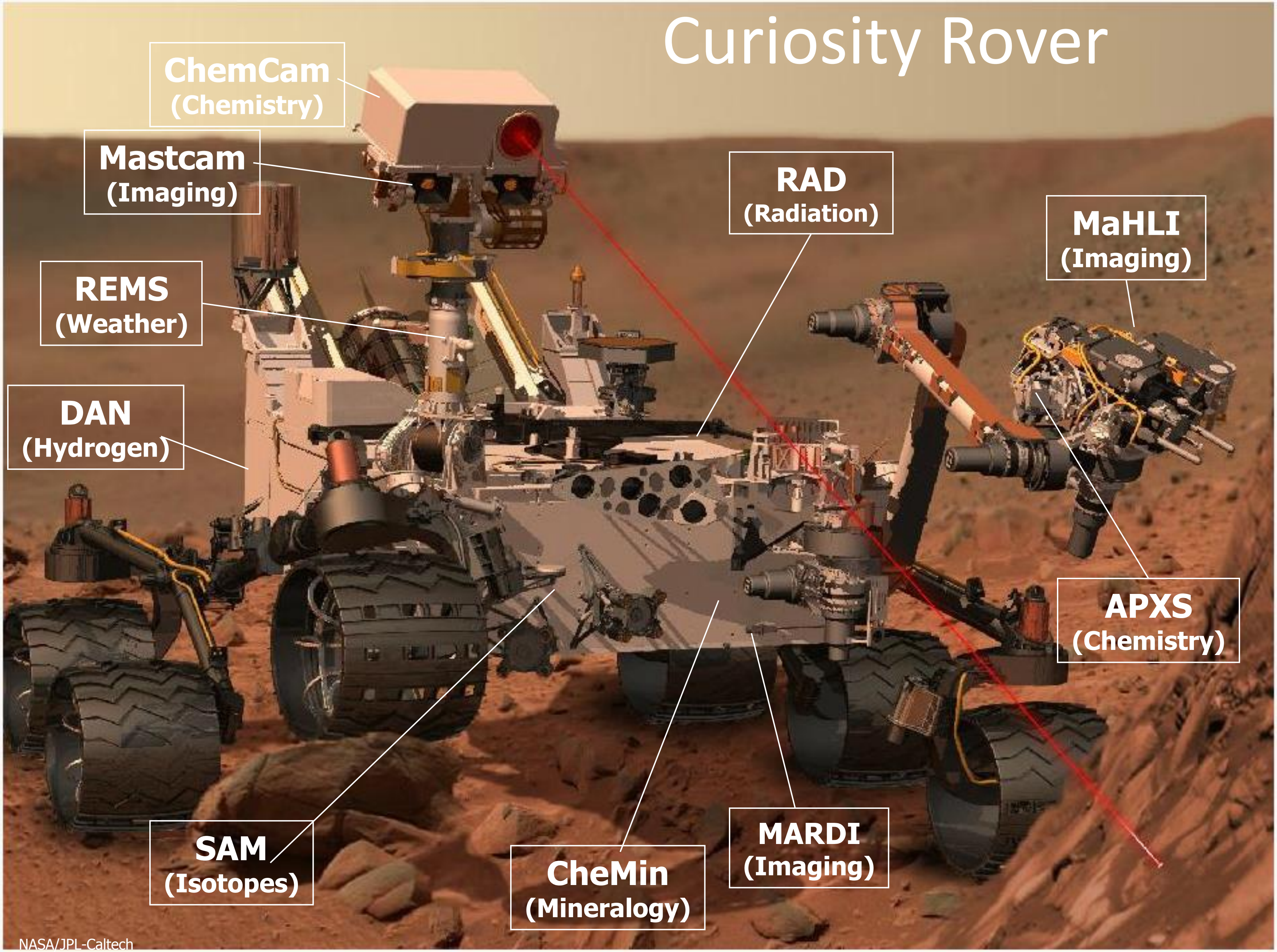




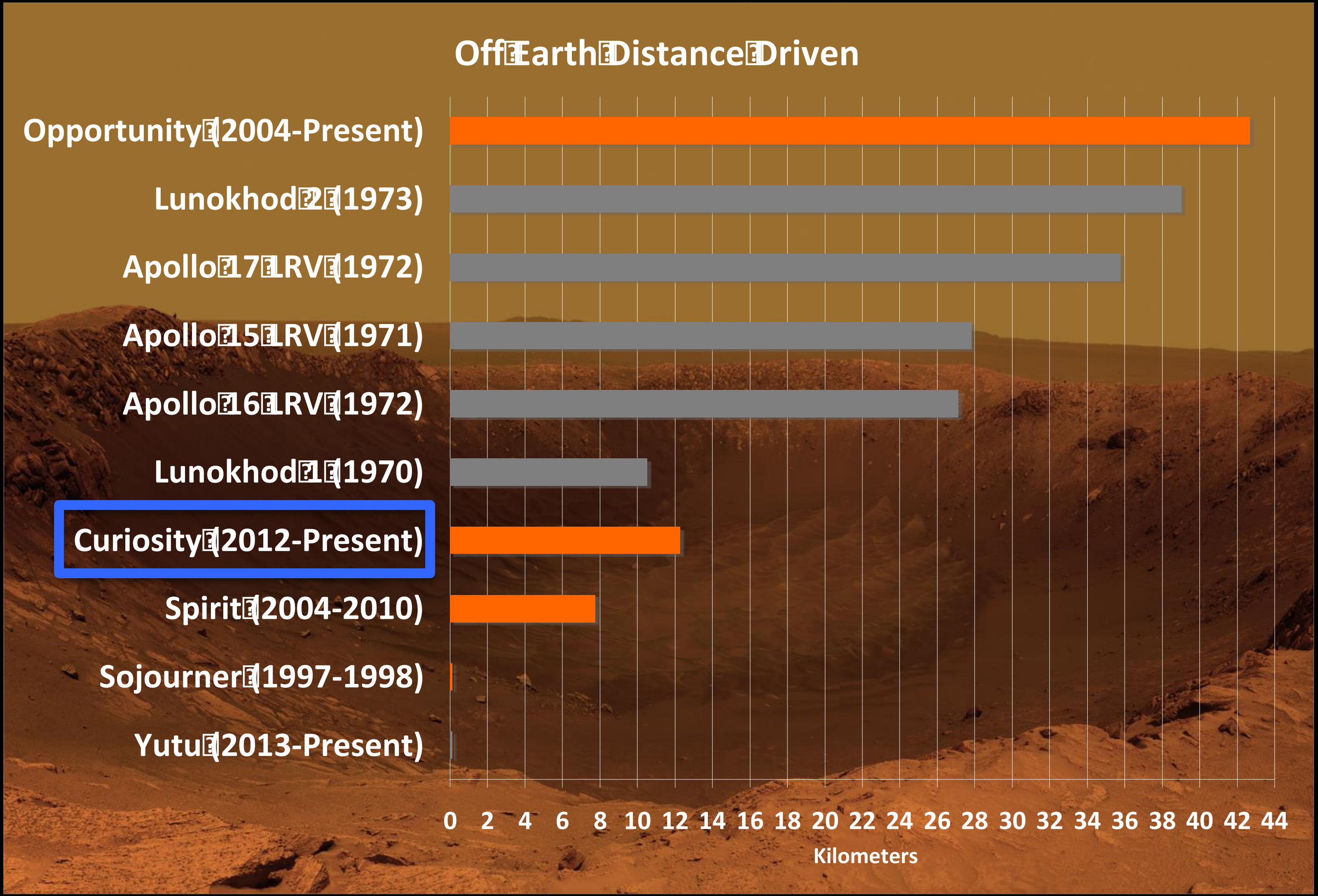


- Saturn internal structure
  - Gravitational & Magnetic Fields
- Ring mass
  - Address age of main rings
- Saturn's ionosphere, innermost radiation belts & inner D ring particles
- Highest resolution main ring observations
  - First Active Radar of the Rings
- Highest resolution Saturn polar observations and aurora
- Saturn atmosphere composition

Strategic Mission Mars
Curiosity


Curiosity Rover
ChemCam (Chemistry)
Mastcam (Imaging)
REMS (Weather)
DAN (Hydrogen)
RAD (Radiation)
MaHLI (Imaging)
APXS (Chemistry)
SAM (Isotopes)
CheMin (Mineralogy)
MARDI (Imaging)
NASA/JPL-Caltech

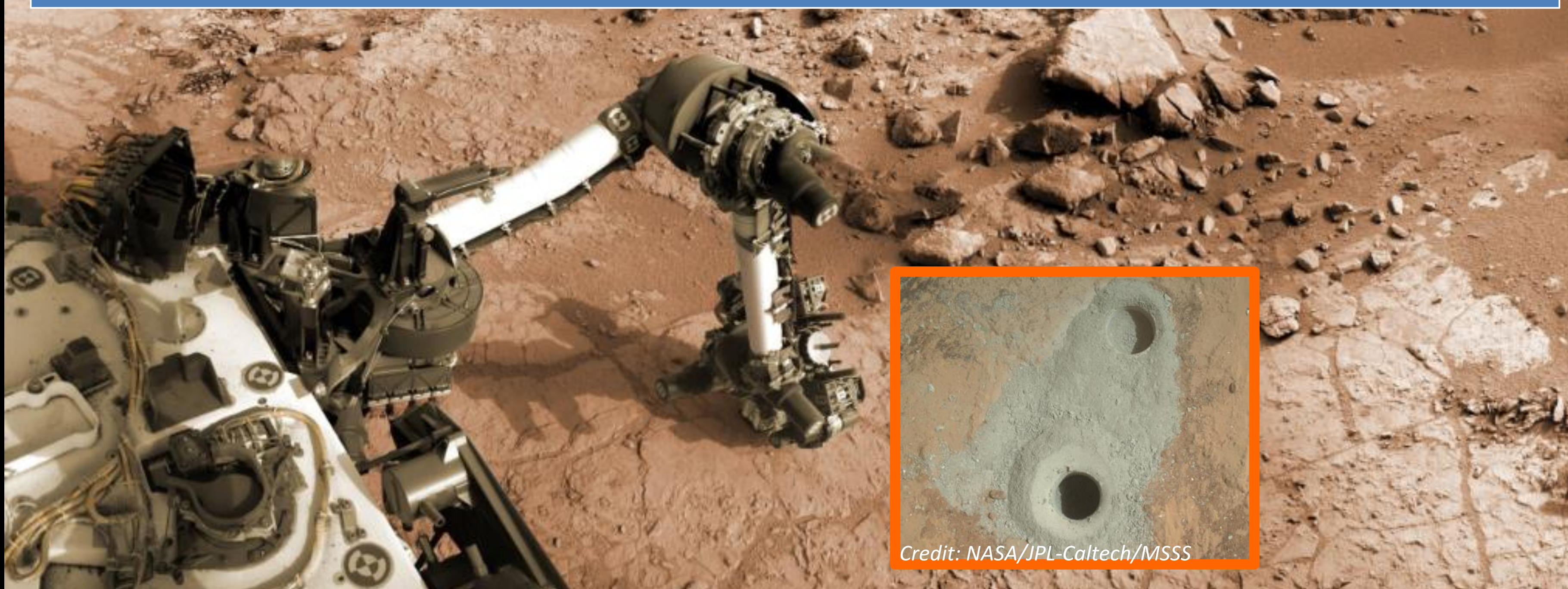
Off-Earth Odometry Records



January 2016

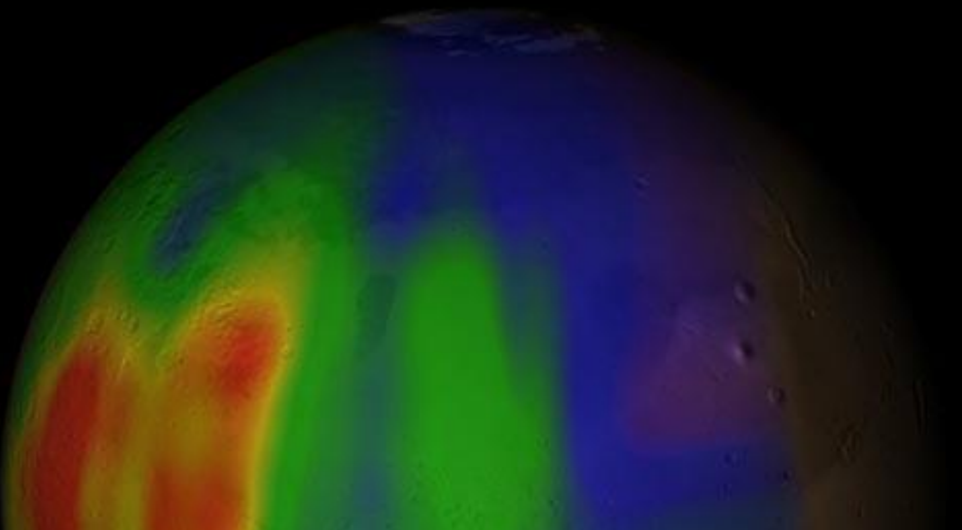
An Ancient Habitable Environment

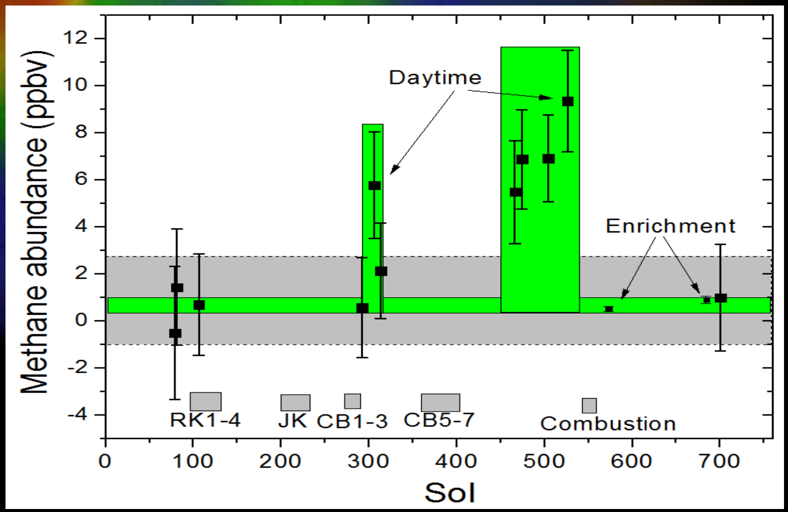
Mineralogy indicates sustained interaction with liquid water also providing a source of energy for primitive biology.
Key chemical ingredients for life are present:
carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

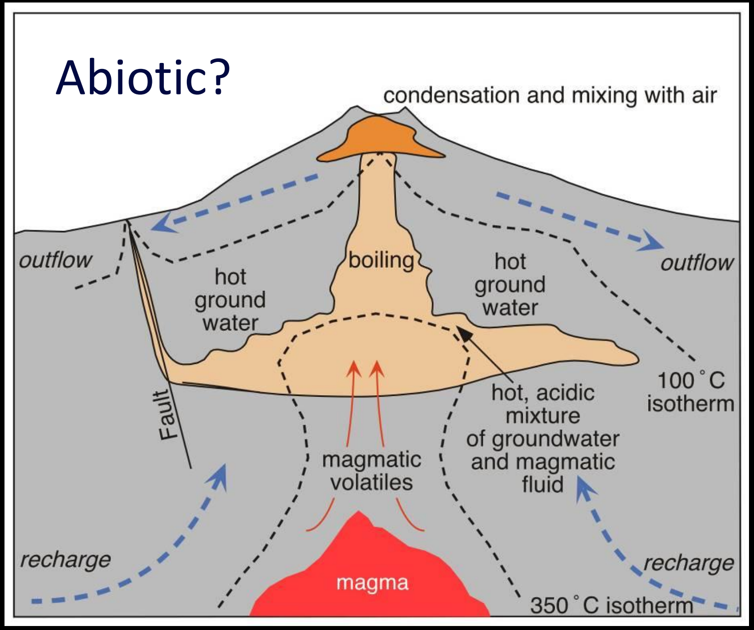


Credit: NASA/JPL-Caltech/MSSS

Methane Found on Mars!
Source Indicates an Active Planet

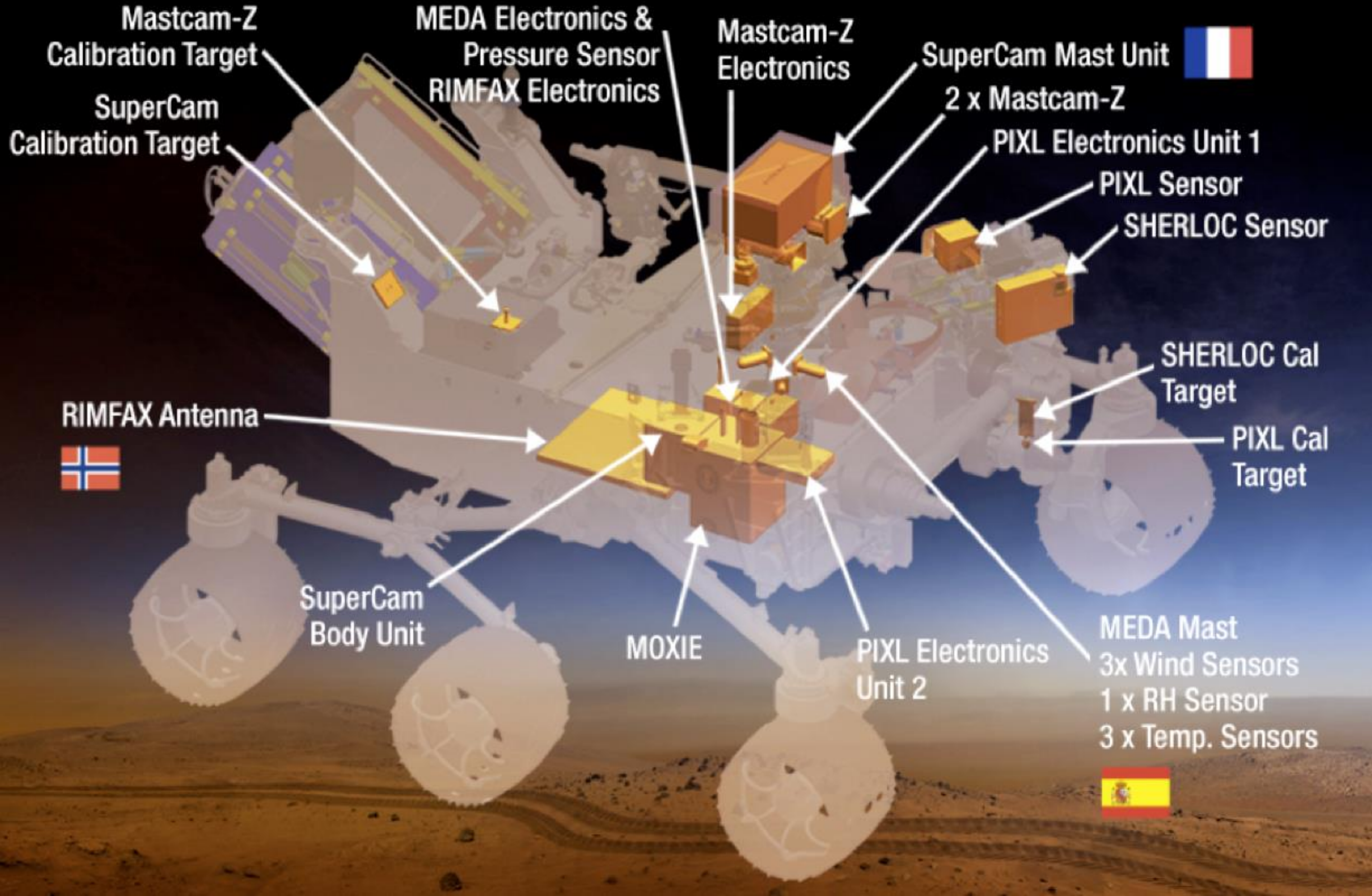






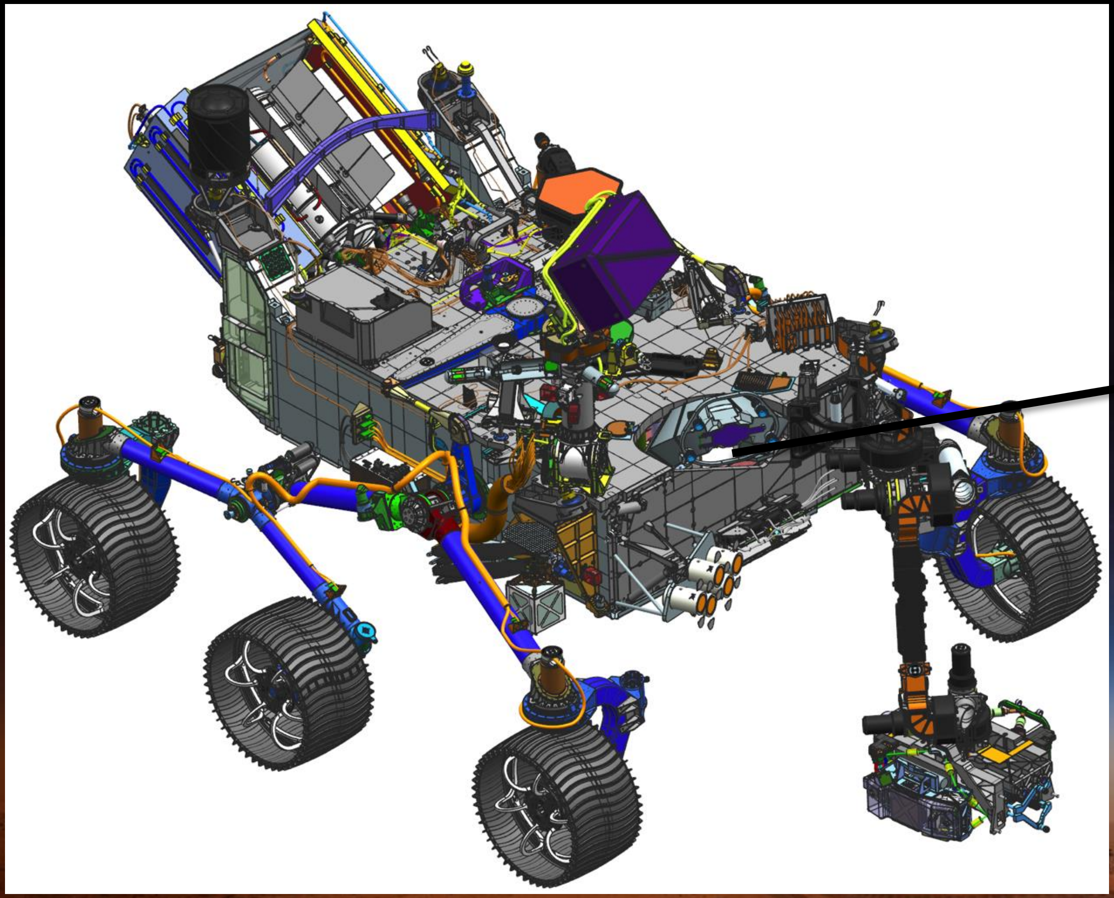
Mars 2020

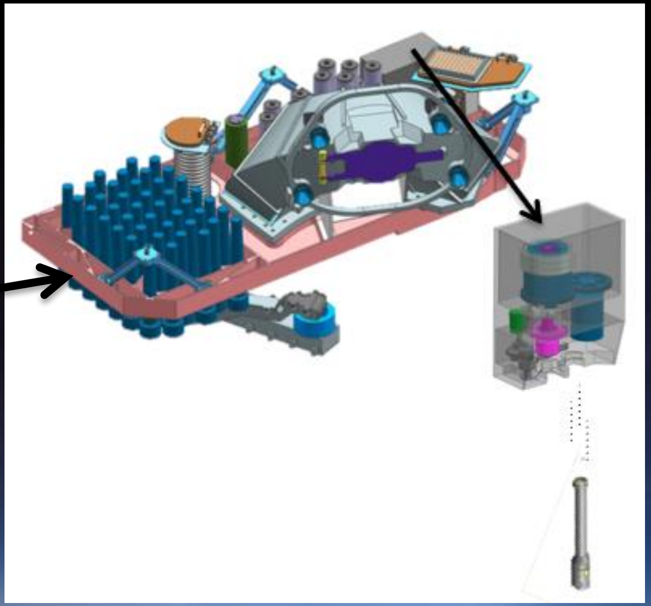
Seeking signs of life: Mars 2020 Rover



Mars 2020 Mission: Sampling and Caching

Mars 2020 Sampling and Caching System (SCS) is responsible for acquiring and sealing samples of Mars for possible return to Earth

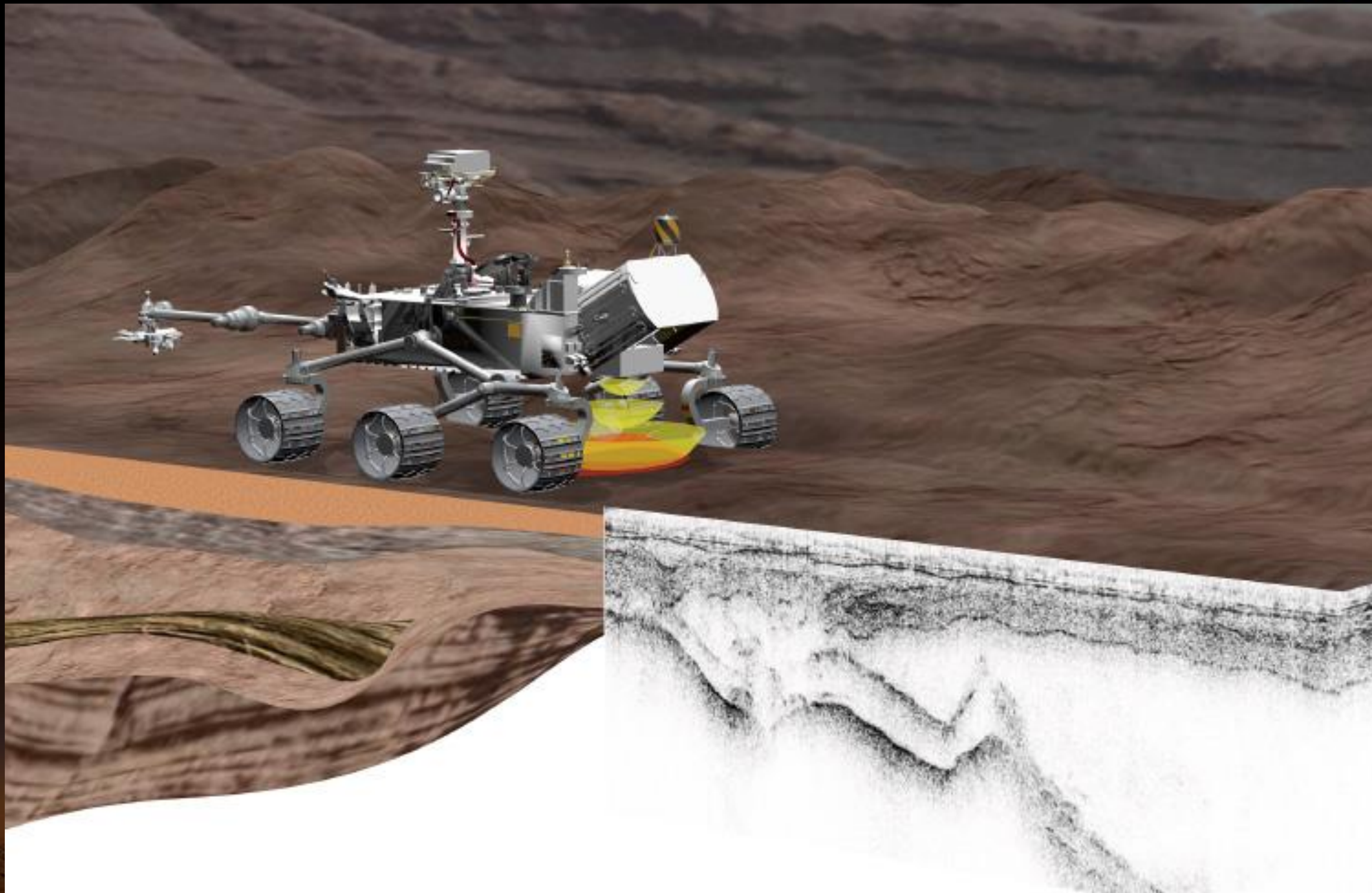




Mars Oxygen ISRU Experiment

#JOURNEYTOMARS

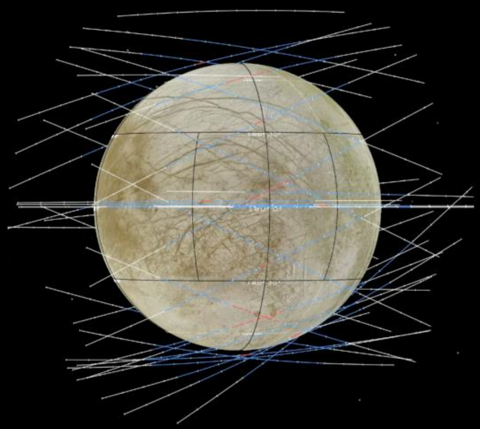
Radar Imager for Mars' Subsurface Experiment



#JOURNEYTOMARS

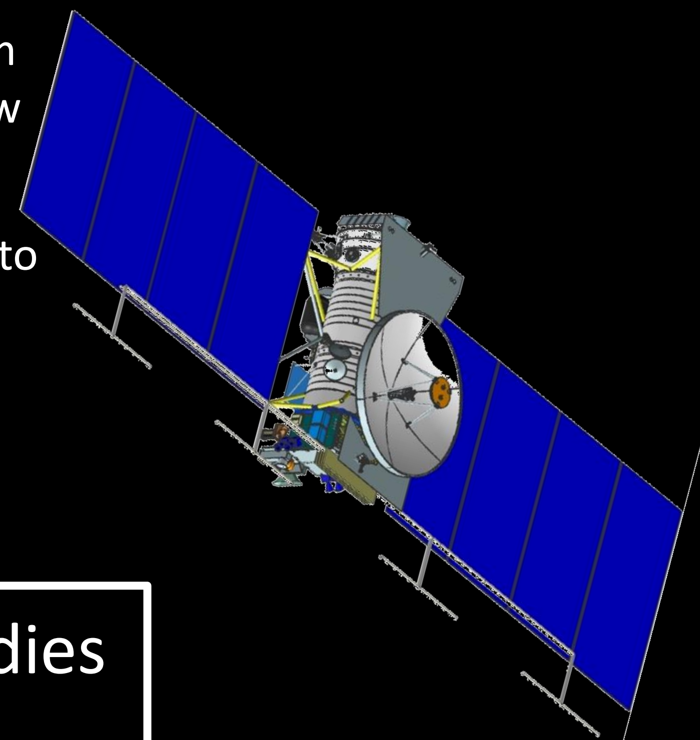
Europa Mission

Europa Multi-Flyby Mission Concept Overview



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

- 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
- Traded enormous amounts of fuel used to get into Europa orbit for shielding (lower total dose)
- Simpler operations strategy
- No need for real time down link



Lander Concept Studies Are Continuing

Discovery and New Frontiers

- Address high-priority science objectives in solar system exploration
- Opportunities for the science community to propose full investigations
- Fixed-price cost cap full and open competition missions
- Principal Investigator-led project

- Established in 1992
- **$425M cap** per mission excluding launch vehicle (FY10)
- Open science competition for all solar system objects, except for the Earth and Sun

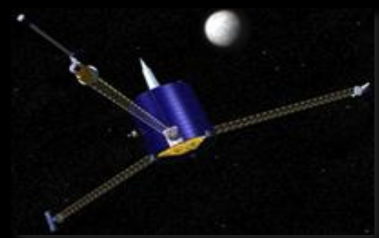
- Established in 2003
- **$1000M** cap per mission excluding launch vehicle (FY10)
- Addresses high-priority investigations identified by the National Academy of Sciences

Discovery Program

Completed

Mars evolution:
Mars Pathfinder (1996-1997)

Lunar formation:
Lunar Prospector (1998-1999)



NEO characteristics:
NEAR (1996-1999)

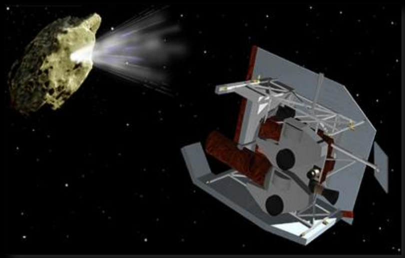
Solar wind sampling:
Genesis (2001-2004)

Completed

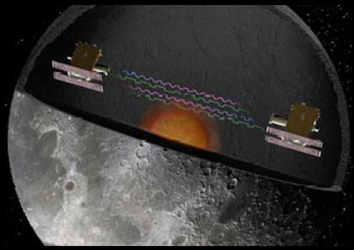
Comet diversity:
CONTOUR (2002)

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

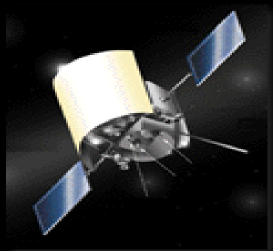
Comet internal structure:
Deep Impact (2005-2012)



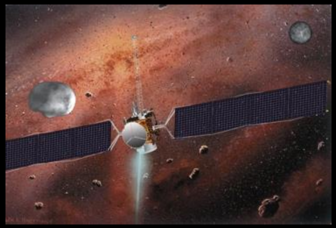
Lunar Internal Structure
GRAIL (2011-2012)



Mercury environment:
MESSENGER (2004-*2015*)



Main-belt asteroids:
Dawn (2007-*TBD*)



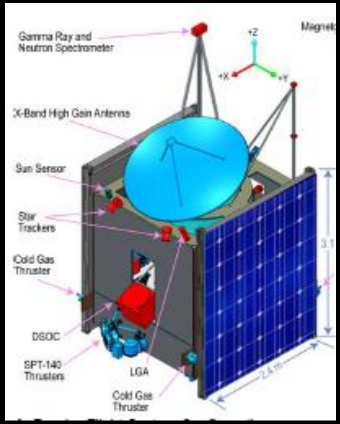
Lunar surface:
LRO (2009-*TBD*)

ESA/Mercury Surface:
Strofio (*2017-TBD*)

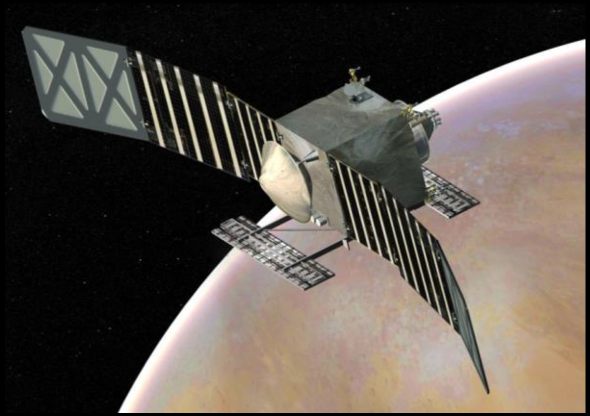
Mars Interior:
InSight (*2018*)

Discovery Selections 2014

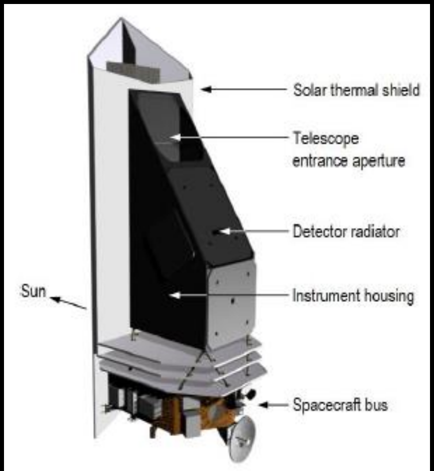
Targeted Technology
For testing only.



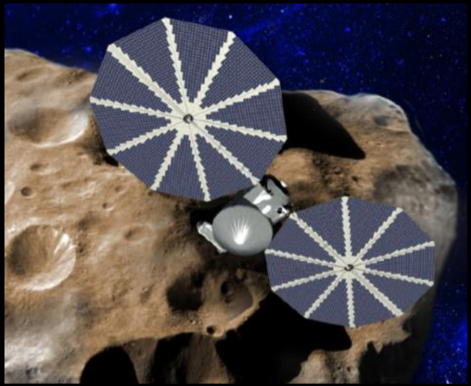
Psyche: Journey to a Metal World
PI: Linda Elkins-Tanton, ASU
Deep-Space Optical Comm (DSOC)



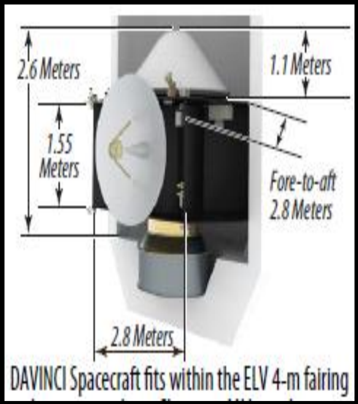
VERITAS: Venus Emissivity, Radio Science, InSAR, Topography, And Spectroscopy
PI: Suzanne Smrekar, JPL
Deep-Space Optical Comm (DSOC)



NEOCam:
Near-Earth Object Camera
PI: Amy Mainzer, JPL
Deep-Space Optical Comm (DSOC)



Lucy: Surveying the Diversity of Trojan Asteroids
PI: Harold Levison, Southwest Research Institute (SwRI)



DAVINCI: Deep Atmosphere Venus Investigations of Noble gases, Chemistry, and Imaging
PI: Lori Glaze, GSFC

New Frontiers Program

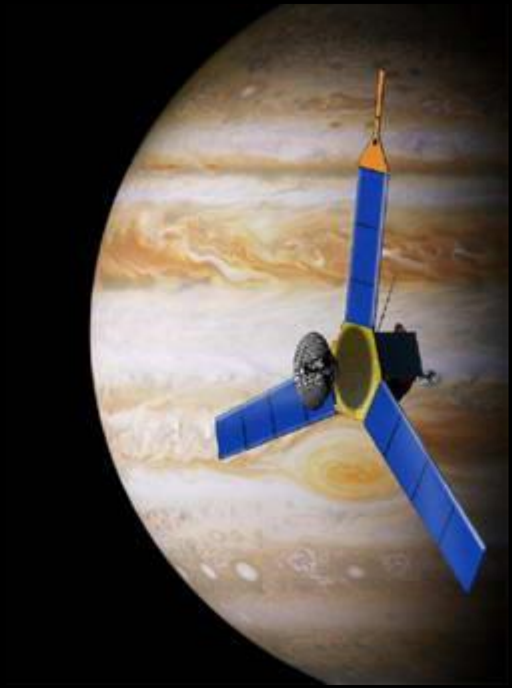
1st NF mission
New Horizons:

Pluto-Kuiper Belt

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

2nd NF mission
Juno:

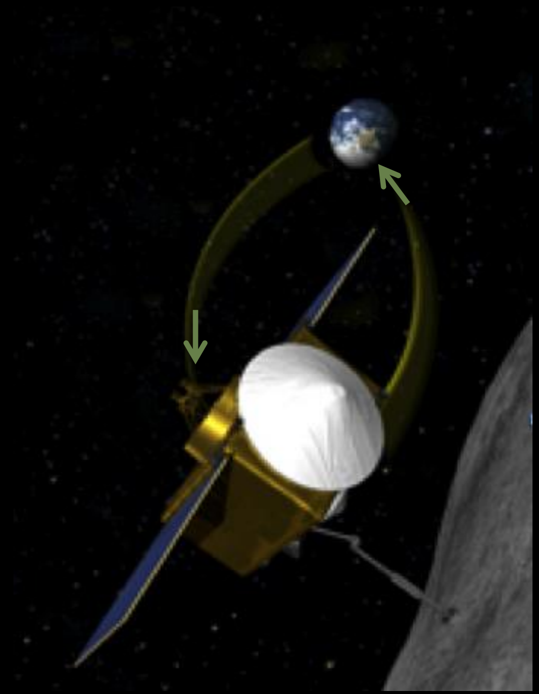
Jupiter Polar Orbiter



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)

Science Only Flagship or Strategic Mission

Is there science that can only be done with a flagship or strategic mission?

- What merits do you see for flagship missions besides science return?
- What disadvantages do you see for flagship missions besides cost?

Some Decadal Survey science priorities require large missions. The following examples are from the 2013 Decadal Survey:

1. Begin NASA/ESA Mars Sample Return campaign: *Descoped Mars Astrobiology Explorer-Cacher (MAX-C)* –> *Mars 2020 Mission*
2. Detailed investigation of a probable ocean in the outer solar system: *Descoped Jupiter Europa Orbiter (JEO)* –> *Europa Multi-flyby Mission*
3. First in-depth exploration of an Ice Giant planet: *Uranus Orbiter and Probe* –> *Under Study*
4. Either *Enceladus Orbiter* or *Venus Climate Mission* (no relative priorities assigned) –> NF-4 Opportunity and Joint RSA/NASA Venus study

Science Only Flagship or Strategic Mission

Is there science that can only be done with a flagship or strategic mission?

- What disadvantages do you see for flagship missions besides cost?

- Large missions have pros and cons
  + *Large missions accomplish science that cannot otherwise be done*
  + *Large, general purpose observatories can be used by the general observer community in ways that were not envisioned by the designers nor captured in the science requirements*
  + *Large missions drive development of new capabilities that can be infused later into smaller missions without further technical development*
  – *Large mission costs must be carefully managed to preserve programmatic balance*
  – *Sometimes large missions are too big to fail – but some have been canceled*

Capability and Leadership

- What concerns do you have about how long flagship missions take for development and the difficulty for young researchers or even potential future PIs to gain experience?
  - Planetary takes the approach of soliciting a Participating Scientist Program for both PI and Strategic missions. This is designed to train the next generation on various aspects of mission operations in a science framework. With Discovery and New Frontiers there are a number of opportunities for scientists to obtain experience.
- What is the value of flagship missions for science base concerns? Talent pools, corporate knowledge, continuity of capabilities etc., and the impact on the future health of this support base?
  - Without an ongoing program of missions that use these capabilities, the capabilities will be lost.
- What is the role of international partnerships in strategic and flagship missions? How is this different for other classes of missions?
  - Strategic missions have various degrees of international participation.
  - PIs missions have limited or have no international partners.

Technology Program Evolution

How does each division do technology development?

- Do you have a separate technology development line?

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Mars Instrument Development Project	X	X								
Planetary Instrument Definition and Development	X	X	X	X	X					
Astrobiology Science and Technology Instrument Development, including Concept Studies for Small Payloads and Satellites	X	X		X	X					
Maturation of Instruments for Solar System Exploration (Mid TRL)						X		X		X
Planetary Inst Concepts for Advancement of Solar System Obs (Low TRL)							X	X	X	X
Instrument Concepts for Europa Exploration							X			
Small, Innovative Missions for Planetary Exploration										X
New Frontiers Homesteader									X	
Concepts for Ocean worlds Life Detection Technology (COLDTech)										X

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Astrobiology Science and Technology for Exploring Planets	X			X	X					
Moon and Mars Analogue Mission Activities (with HEO)	X	X		X	X	X				
Planetary Science and Technology Through Analog Research								X	X	X

- Instrument field testing also supported

Technology Development

- Do you primarily use flagship missions for technology development?
  - Not primarily. Targeted instrument calls and mid-TRL technology calls are funded by the R&A program to help both strategic and PI missions.
- Can you afford the risk of including new technologies on flagship missions?
  - Yes, but it must be appropriately funded and managed (ex: sample acquisition system on M2020)
- Can you do technology development with smaller size missions?
  - Typically, PI Mission proposals with technology development (low TRLs) are not selectable.
- Do you treat new technology differently on flagship missions vs. small missions (by, for example, incentivizing missions to use new technologies)?
  - PI Mission may use targeted technologies for testing purposes (ex: Discovery Step 2 testing DSOC).

Cost Control for Large Missions

- How do cost overruns on flagship class missions affect the other mission classes in your portfolio?
  - Lessons Learned:
    - Mature technology early
    - Properly scope the effort (descope early, reassess requirements)
    - Budget adequate reserves year-by-year
    - Understand the budget impact of carrying risks and delays into the future
  - Program balance can be maintained (no impact to other mission classes) by extending development period without increasing annual budget. Impact is delay to next strategic mission start.

Cost Control for Large Missions

- How do you address cost overruns on flagship missions vs. how you address cost overruns on smaller class missions?
  - Strategic missions are too important scientifically to cancel depending on when they overrun. Overruns must be handled through descopes and replanning (cost and schedule readjustments).
  - PI missions are cost capped, and they should be terminated if they overrun significantly before confirmation. The ability to stay within the cost cap is a feature of the mission class and also a factor in the selection.

Image by john doe