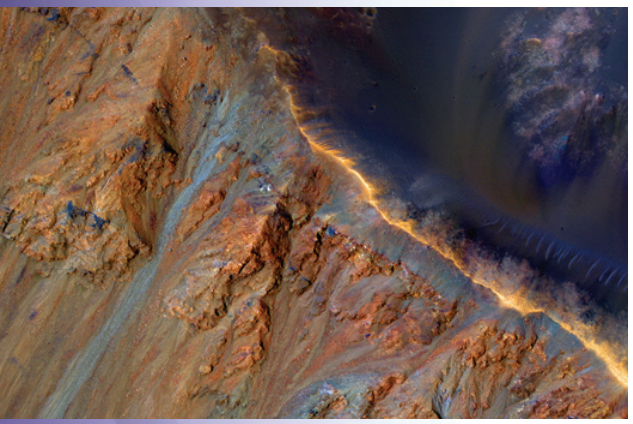
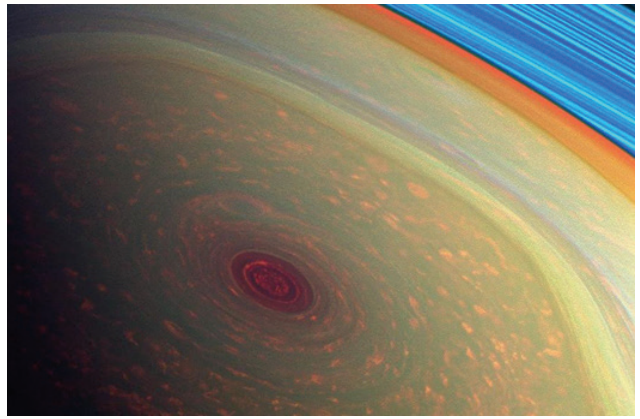
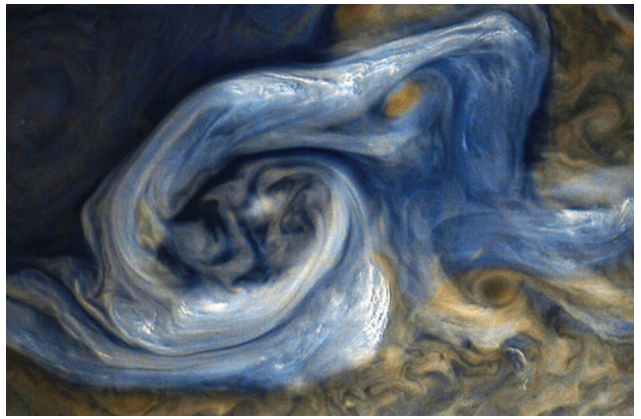
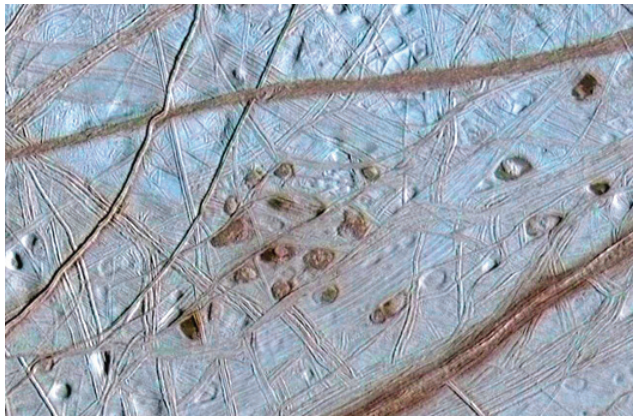
SCIENCE

National Aeronautics and Space Administration

Planetary Science Division

Mary Voytek
Senior Scientist Astrobiology
Planetary Science Division
March 6, 2018

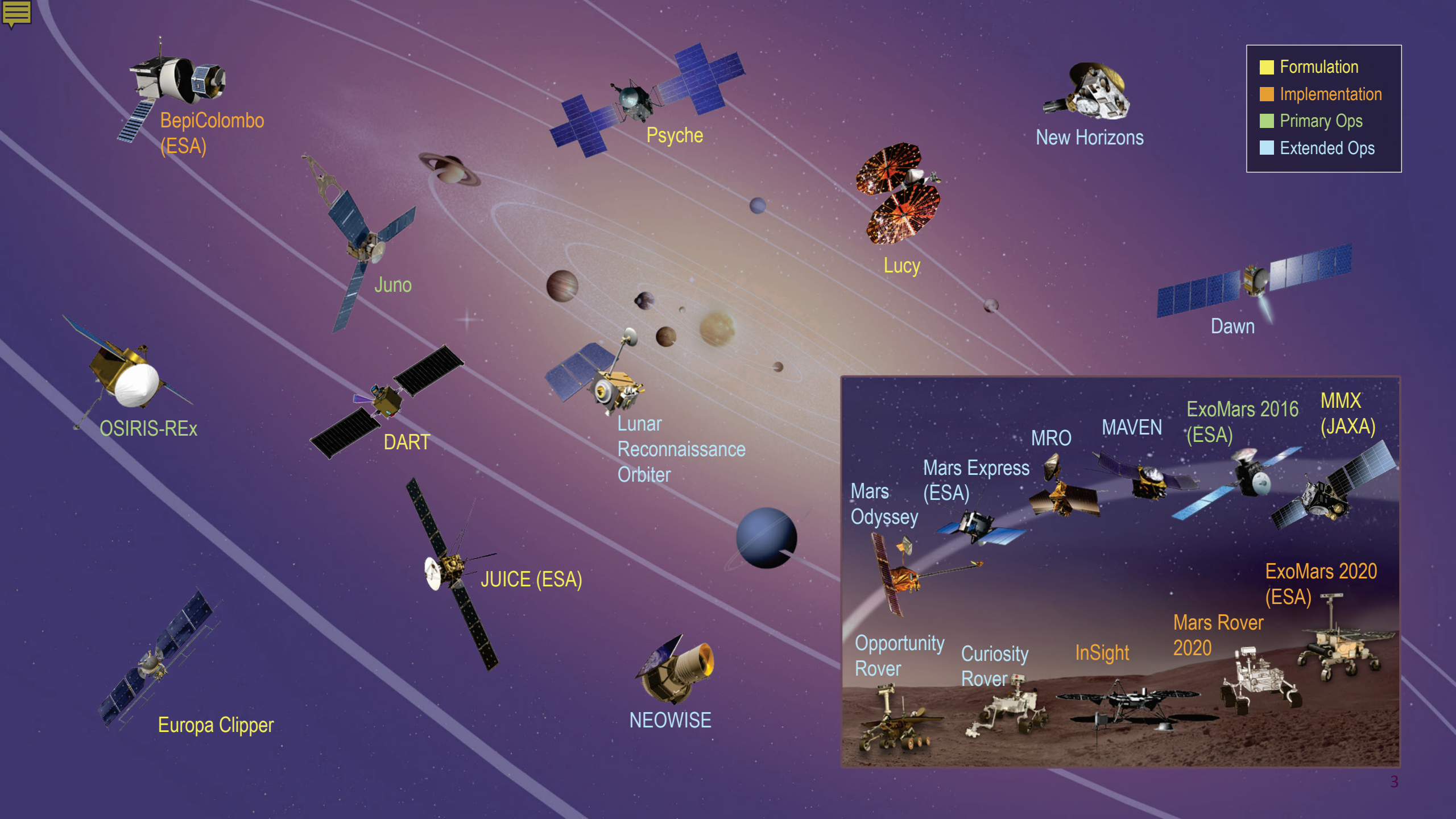
Planetary Science Overview

Strategic Objective

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

Major Activities

- Initiates a new Lunar science and exploration program
- Manage both Principal Investigator-class and strategic missions to numerous objects within our Solar System
- Enhanced efforts to detect, track, and characterize NEOs of all sizes under a new planetary defense program
- Engage international & commercial partners on PSD missions, including development of instruments and support services
- Advance the highest quality Planetary Science Research and Technology Program


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)
Opportunity Rover
Curiosity Rover
InSight
Mars Rover 2020

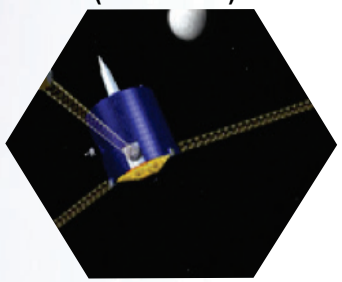
Discovery Program

Discovery Program

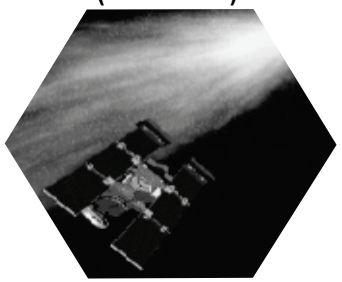
NEO characteristics
NEAR
(1996-1999)

Mars evolution
Mars Pathfinder
(1996-1997)

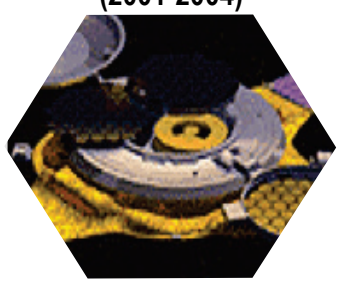
Lunar formation
Lunar Prospector
(1998-1999)



Nature of dust/coma
Stardust
(1999-2011)

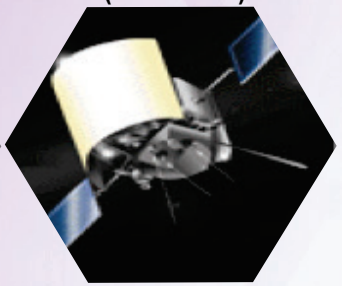


Solar wind sampling
Genesis
(2001-2004)

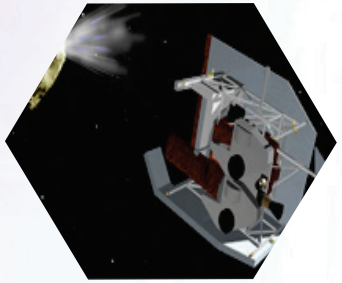


Comet Diversity
CONTOUR
(2002)

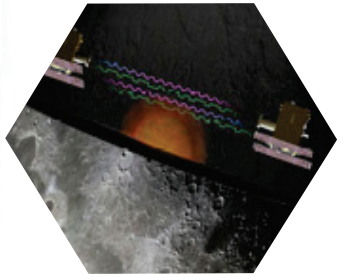
Mercury Environment
MESSENGER
(2004-*2015*)



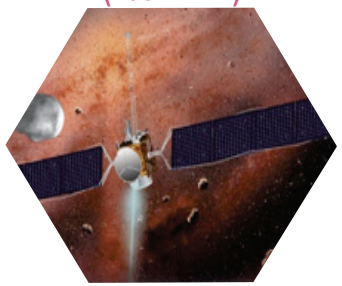
Comet Internal Structure
Deep Impact
(2005-2012)



Lunar Internal Structure
GRAIL
(2011-2012)

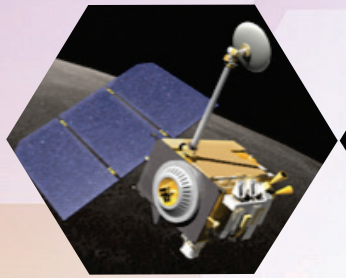


Main-belt Asteroids
Dawn
(2007-*TBD*)

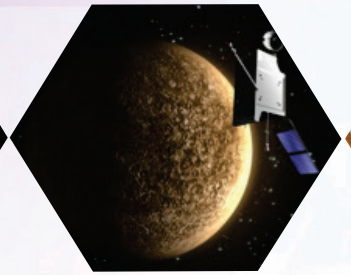


Exoplanets
Kepler
(2009-TBD)

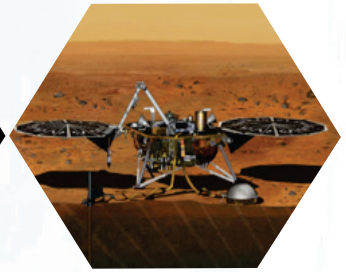
Lunar Surface
LRO
(2009-*TBD*)



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

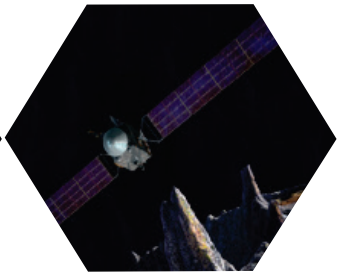


Mars Interior
InSight
(*2018*)

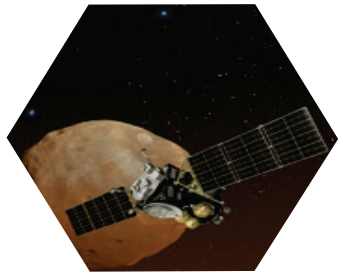


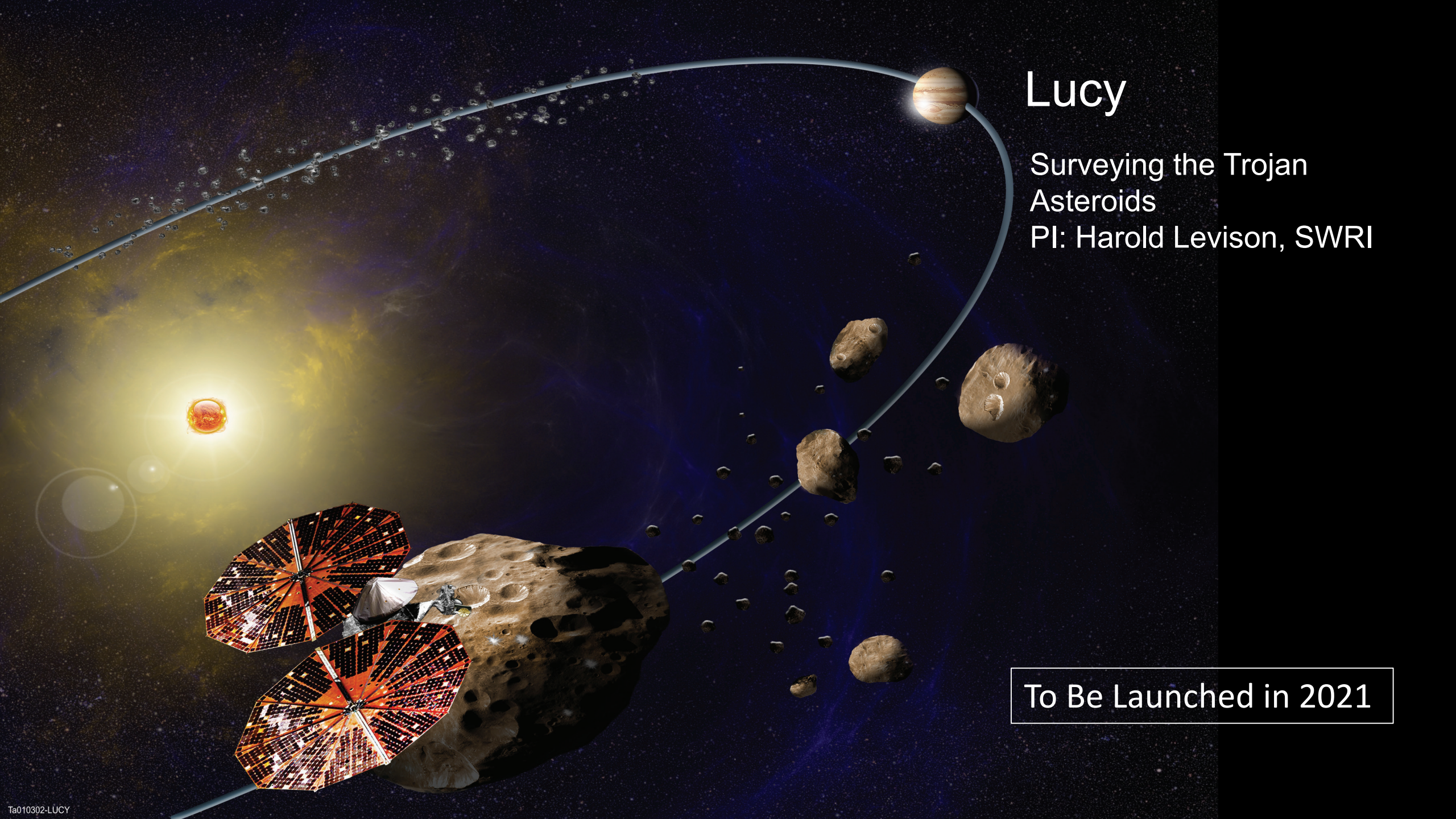
Trojan Asteroids
Lucy
(*2021*)

Metal Asteroids
Psyche
(*2022*)



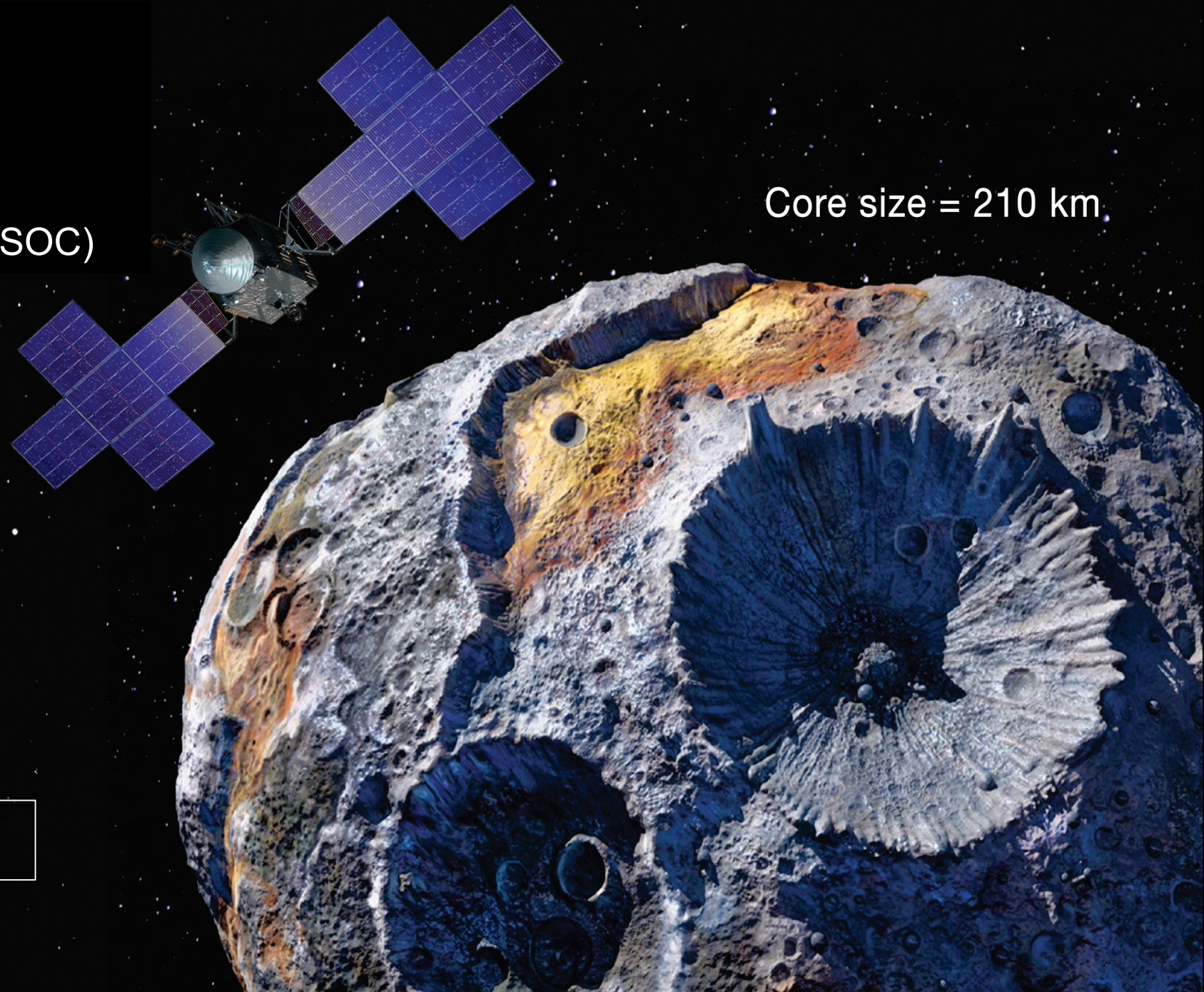
Martian Moons
MMX/MEGANE
(*2024*)




Lucy
Surveying the Trojan Asteroids
PI: Harold Levison, SWRI
To Be Launched in 2021
Ta010302-LUCY

Psyche

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



To Be Launched in 2022

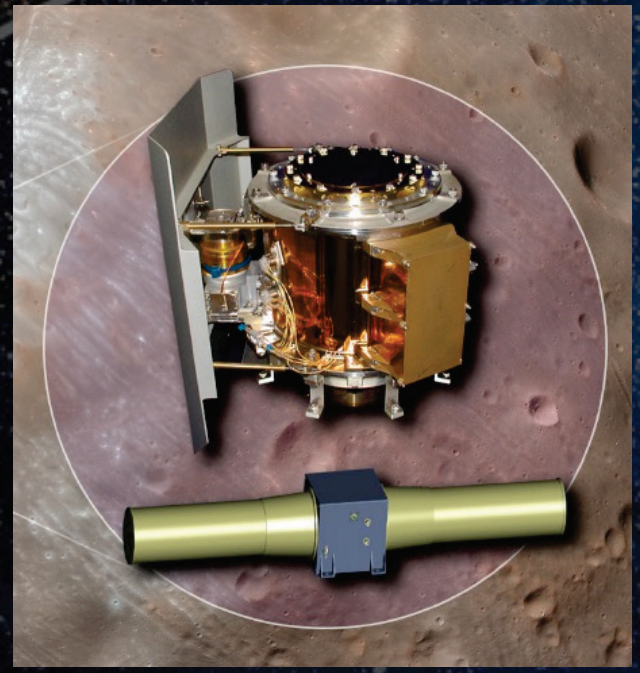
JAXA Martian Moons eXploration (MMX) Mission

Neutron & Gamma-Ray Spectrograph

- Solicited by NASA through the SALMON-3 AO
- Selection Announced Nov 16, 2017
  - MEGANE (“eyeglasses”)
  - David Lawrence (JHU APL), PI

To Be Launched in 2024

- Cryocooled high-purity Germanium γ-ray detector (MESSENGER GRS heritage)
- ^{3}He proportional counter neutron detector (Lunar Prospector heritage)



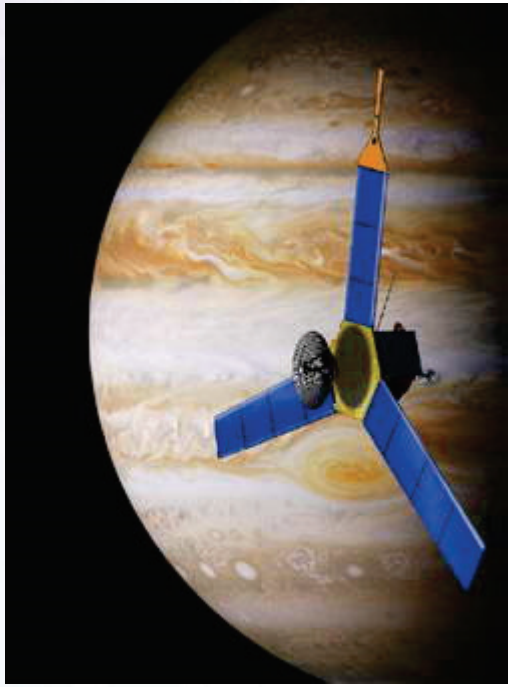
New Frontiers Program

New Frontiers Program

1st NF mission
New Horizons
Pluto-Kuiper Belt

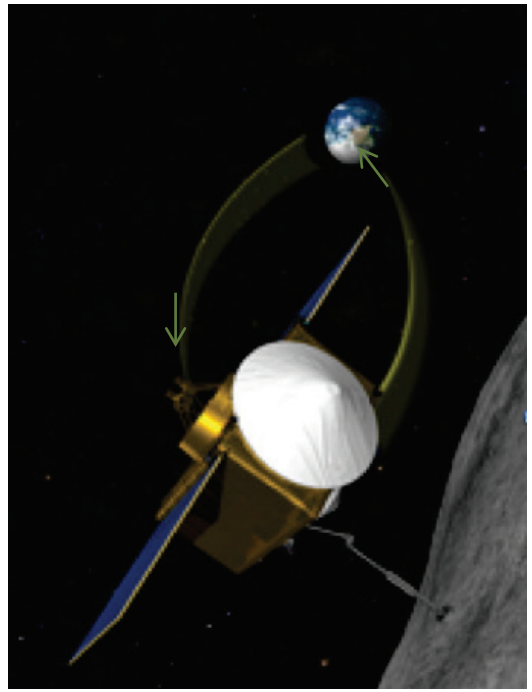
Launched January 2006
Flyby July 14, 2015
PI: Alan Stern (SwRI-CO)

2nd NF mission
Juno
Jupiter Polar Orbiter



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

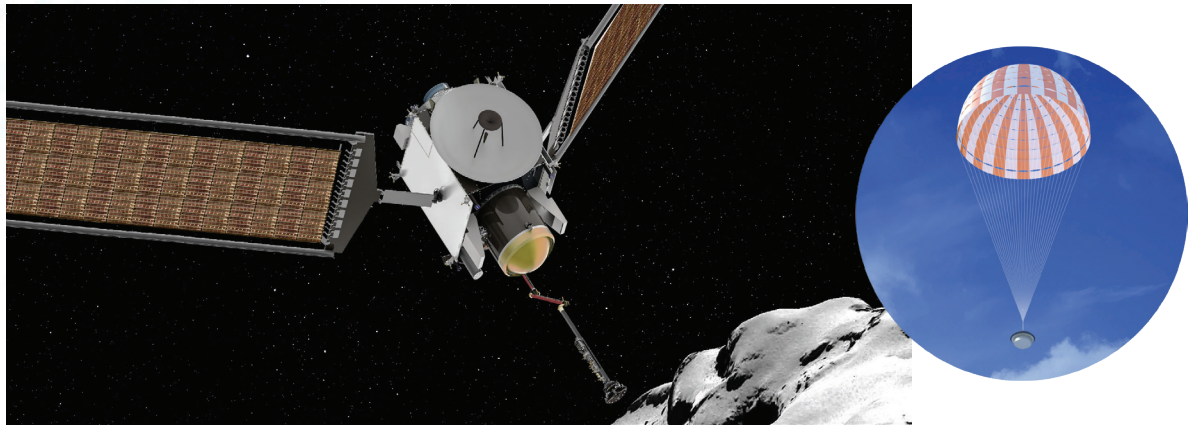
3rd NF mission
OSIRIS-REx
Asteroid Sample Return



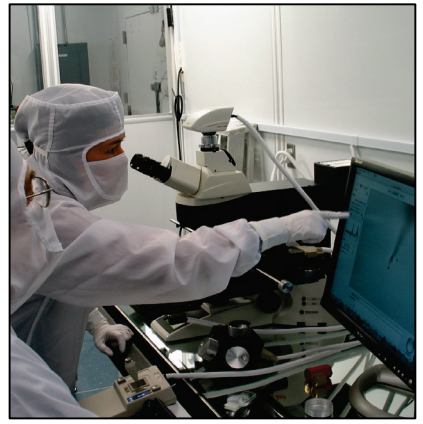
Launched September 2016
PI: Dante Lauretta (UA)

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.



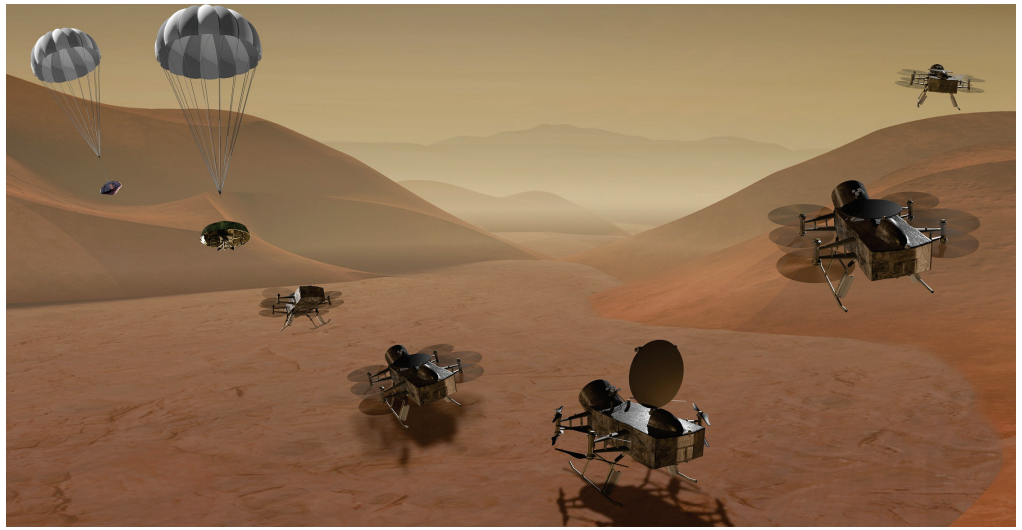
A rotorcraft to explore prebiotic chemistry and habitability on the ocean world Titan

- 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

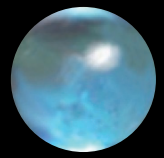
Aerial mobility provides access to Titan's diverse materials at a wide range of geologic settings at *dozens* of sites, *10s to 100s of kilometers apart*

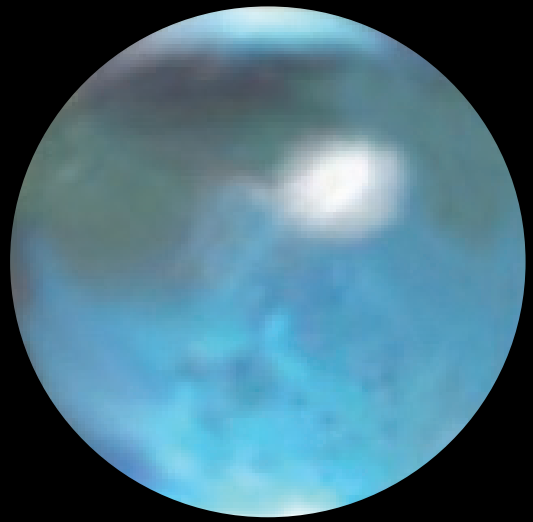


PI: Dr. Elizabeth Turtle at APL
Dragonfly would arrive at Titan in 2034 and explore for over 2 years, performing detailed chemical analyses, measuring the atmosphere and seismic activity, and imaging the surface.

Ocean Worlds

Exploration of Ocean Worlds





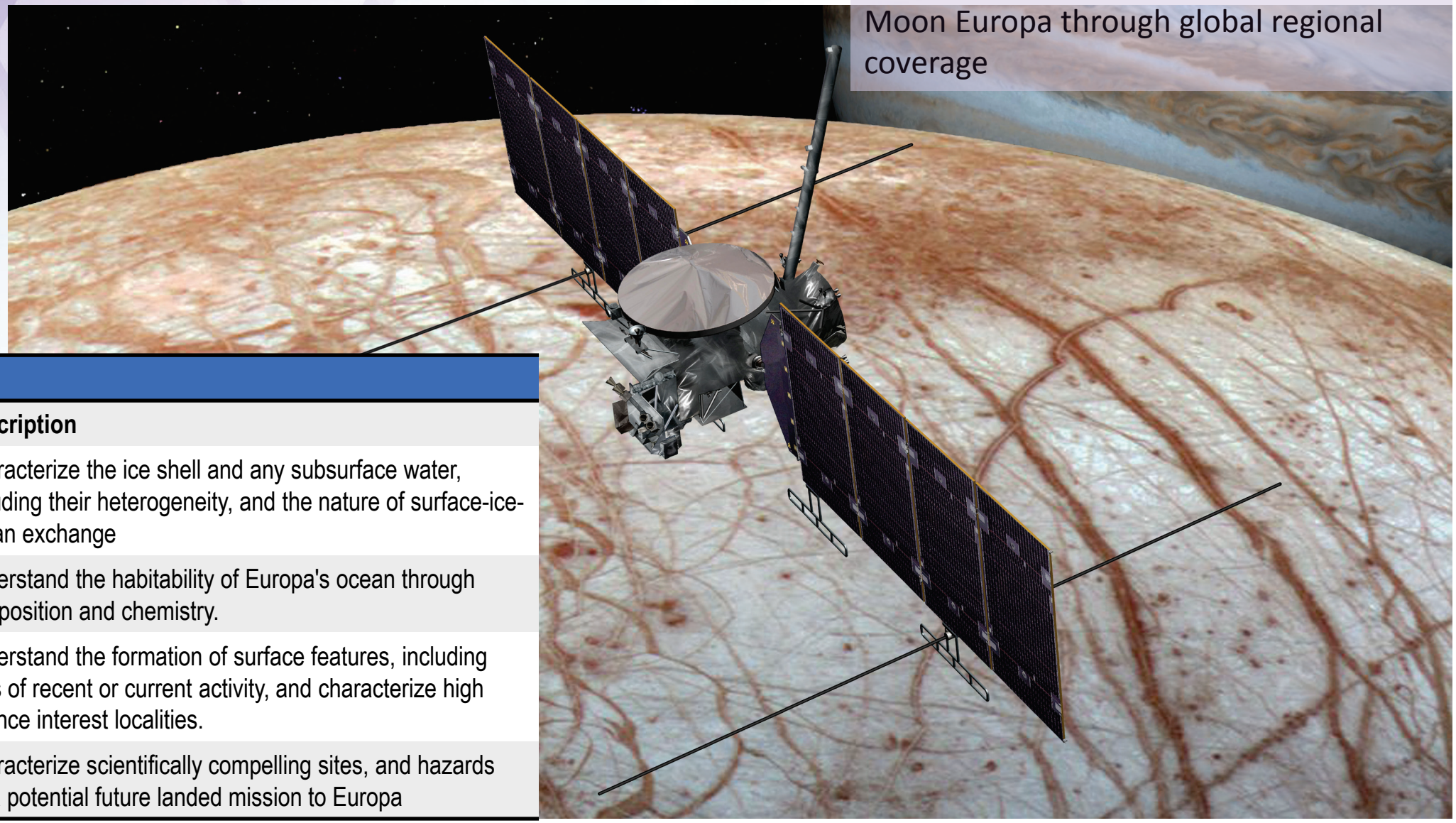
Earth

Ice-covered moons

Ocean 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

Research and Analysis-Planetary Science

Goals of the Reorganization in Response to Stakeholder Needs

- To make the structure of the R&A program explainable to those outside of NASA.
- To make it easy for those outside of NASA to compute the amount of money spent on grants.
- To reduce the time between proposal submission and award announcement.
- To encourage interdisciplinary research.
- To enable PSD strategic decision making.
- To be more flexible in responding to changing research priorities.
- To reduce overlaps between program elements.

Planetary Science Overview

Strategic Objective

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

New Core Research Programs

- The five new core research programs are aligned with PSD's guiding principles.

How did the Sun's family of planets, satellites, and minor bodies form and evolve?	Emerging Worlds
How do the chemical and physical processes active in our solar system operate, interact and evolve?	Solar System Workings
What are the characteristics of the solar system that lead to habitable environments?	Habitable Worlds
How did life originate and evolve here on Earth and can that guide our search for life elsewhere?	Exobiology
What are characteristics of planetary objects and environments that pose threats to, or offer potential resources for, humans as we expand our presence into the solar system?	Solar System Observations (NEOO & PAST)

How did we get here?

Where are we going?

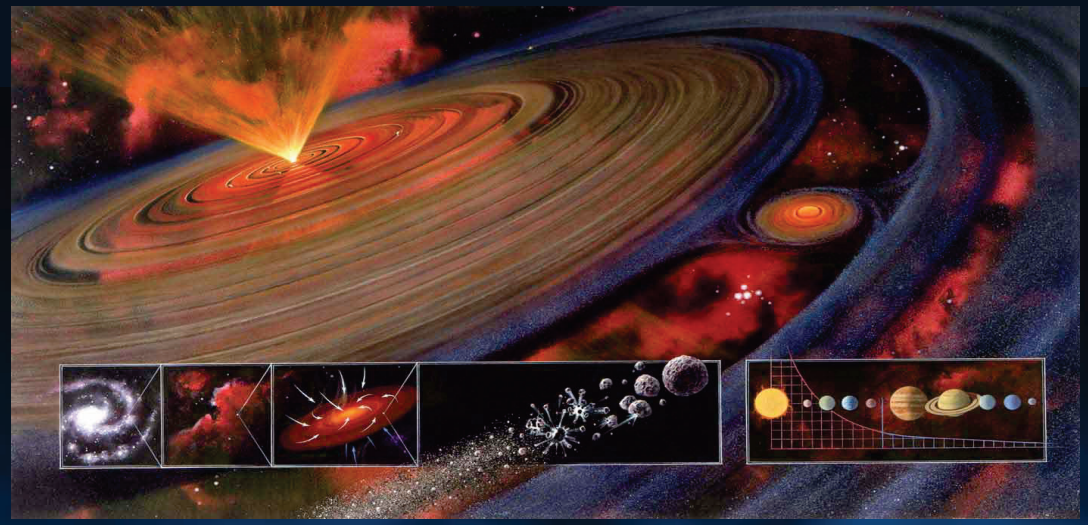
Are we alone? *or,*
Is there anybody else out there?

Knowledge of Space Environments

Knowledge of Earth Organisms

Astrobiology Unites Disciplines to Study Life in the Universe

Origins and distribution of habitable planets

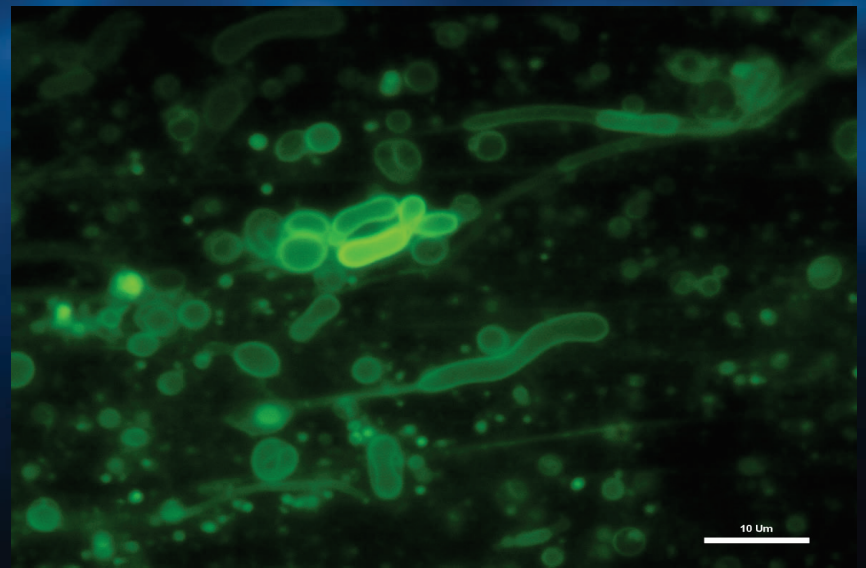


Chemistry of prebiotic environments

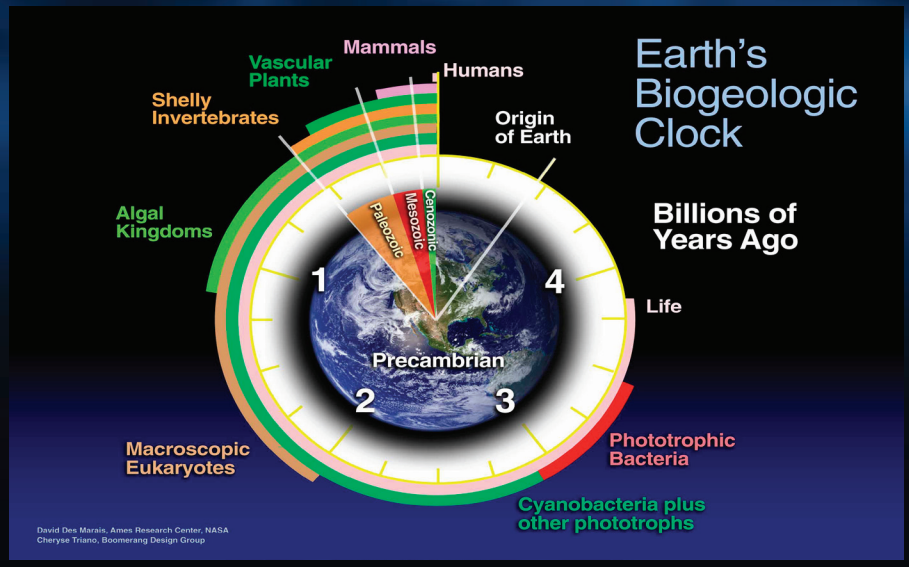
Prebiotic evolution and origins of life

Evolution of biospheres and their biosignatures

Origins, Evolution & Distribution of Life



Attributes of living systems



Astrobiology Science Strategy

(Released Fall 2015)

- Community based & semi-decadal
- Broad participation in creation:
  - 77 Contributors
  - 744 members of *astrobiologyfuture.org*
  - 12 reviewers who made invaluable contributions.
- Goal was to create an “inspirational and aspirational” document.

Six Major Research Areas Covered in the Strategy

1. Identifying abiotic sources of organic compounds
2. Synthesis and function of macromolecules in the origin of life
3. Early life and increasing complexity
4. Co-evolution of life and the physical environment
5. Identifying, exploring, and characterizing environments for habitability and biosignatures*
6. Constructing habitable worlds*

* (Overlaps with Astrophysics Division)

NASA Authorization Act of 2017

The SMD-related portion of this bill includes several additional reporting requirements:

Sec. 508 requires NASA to task the National Academies to develop a science strategy for the study and exploration of extrasolar planets; this strategy is due 18 months after enactment (~September 2018).

Sec. 510 requires a report on how NASA plans to expand public-private partnerships in astrobiology; this report is due 180 days after enactment (~September 2017)

Sec. 509 requires NASA to task with the National Academies to develop a science strategy for astrobiology; this strategy is due 18 months after enactment (~September 2018).

Charge to NRC

In preparation for the upcoming decadal surveys in astronomy and astrophysics and planetary science, the National Academy of Sciences will appoint an ad hoc committee to carry out a study of the state of the science of astrobiology as it relates to the search for life in the solar system and extrasolar planetary systems.

Such a study shall—

- assess and build on the current Astrobiology Science Strategy 2015;
- outline key scientific and technology challenges in astrobiology particularly as they pertain to the search for life in the Solar System and extrasolar planetary systems;
- should accommodate the overlap with the Exoplanet Exploration study in the area of assessing habitability and search for signs of life;
- identify the most promising research goals in the field of life detection in which progress is likely in the next 20 years;
- consider the role of and how to expand partnerships in furthering the to study life's origin, evolution, distribution, and future in the universe;
- indicate the extent to which U.S. and international missions and telescopes in operation or in development address the key research goals; and
- make recommendations on the above as appropriate.

Additional Foundational Activities and Documents

- Exoplanet Biosignatures Workshop July 2016- Joint NExSS-ExEP effort
- Agnostic Biosignatures: Recognizing life as we don't know it. HQ hosted, September 7-9, 2016
- Biosignatures of Extant Life on Ocean Worlds Workshop. GSFC hosted, September 12-14, 2016
- Searching for Life Across Space and Time: A Workshop NRC hosted, December 5-6, 2016 Irvine, CA
- Europa Lander Study 2016 Report
- Ocean Worlds Exploration Roadmap OPAG coordinated Input for Mid-Term Decadal (Delivery Date 2018)
- NExSS

What is the NExSS Experiment?

A 3 year experiment to:

•use the model of a research coordination network dedicated to the study of planetary habitability and the search for life on exoplanets.

• begin a NASA cross-division initiative that brings astrophysicists, planetary scientists, Earth scientists, and heliophysicists together to yield a “systems science” approach to the effort.

History

- Originally proposed as a Grand Challenge in 2010
- Leveraged selections from *existing* FY15 ROSES NRAs and CANs
- 17 PIs selected from NAI, XRP, APT, ADAP, Living With a Star proposal calls were invited to become part of the pilot project
- No new research funds as a result of joining NExSS
- NExSS teams are responsible for organizing community-wide activities that reach well beyond NExSS team members

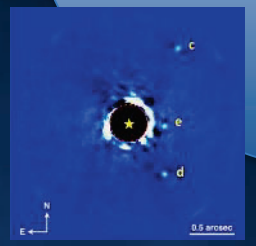
Strategic Objectives

- To further our joint strategic objective to explore exoplanets as potentially habitable and inhabited worlds outside our solar system.
- To establish common goals across divisions in SMD including Planetary Science (PSD), Heliophysics (HPD), Earth Science (ESD) and Astrophysics (APD).
- To leverage existing Programs in SMD to advance the field of Exoplanet Research, specifically research in comparative planetology, biosignature and habitat detection, and planet characterization.
- To establish a mechanism to break down the barriers between divisions, disciplines, and stove piped research activities.

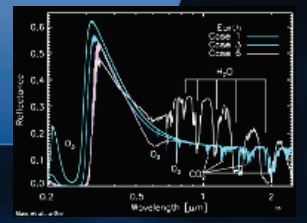
Nexus for Exoplanet Systems Science,NExSS

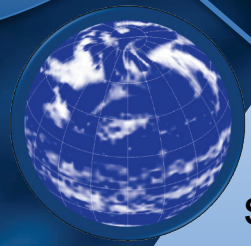
NASA's cross-divisional studies of Search for Life Elsewhere

Astrophysics
Exoplanet detection
Star characterization
Mission Data Analysis
Hubble, Kepler, TESS, JWST, WFIRST, Etc.



PSD Astrobiology
Comparative planetology
Planetary atmospheres
Exoplanet detection of Biosignatures
Habitability

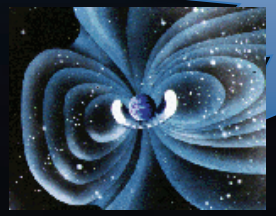




Earth Sciences
How planet systems works

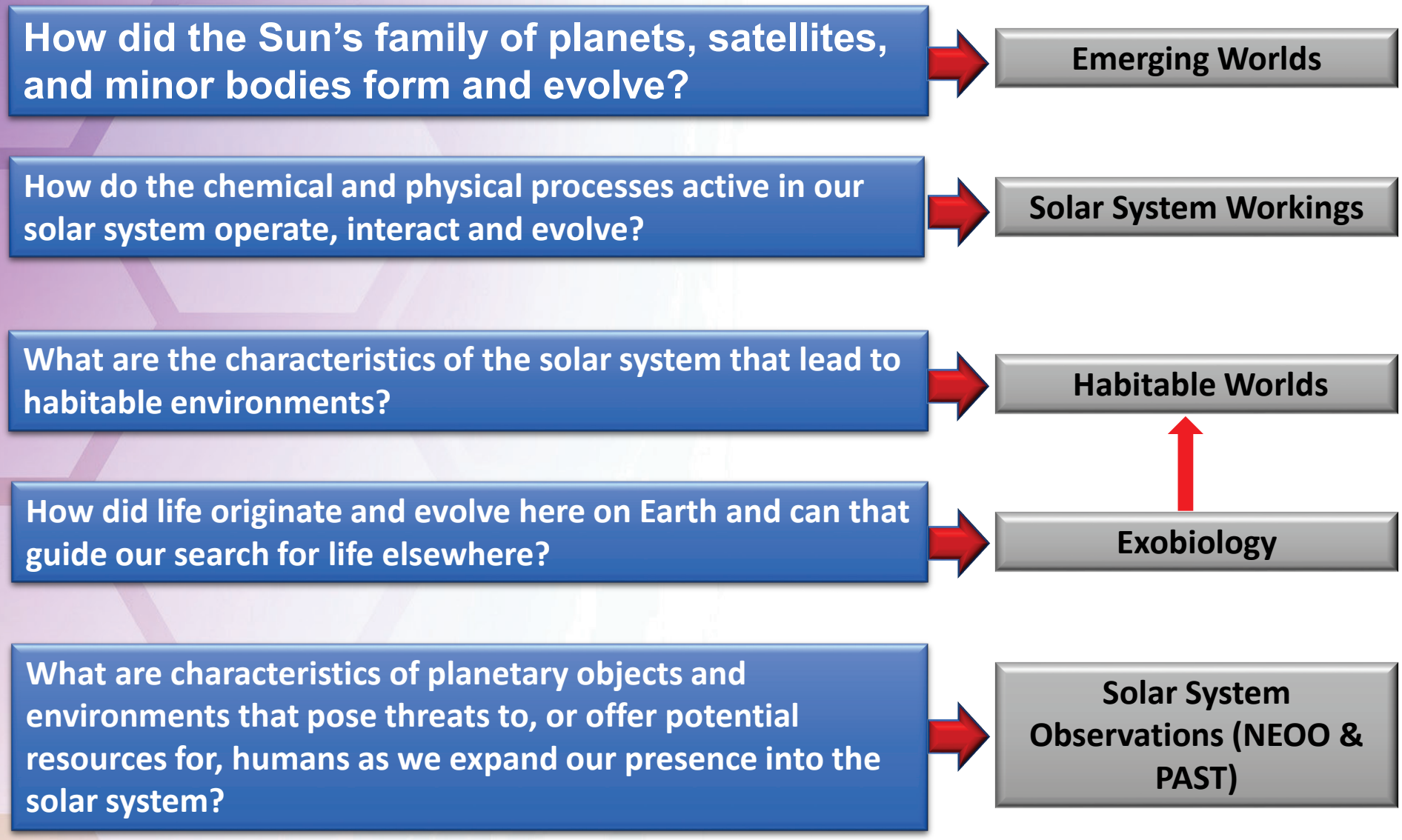
PSD Exoplanet Research Program (XRP)
Exoplanet characterization
Protoplanetary Disks
Planet formation
Comparative planetology

Heliophysics
Star characterization
Detection of planetary magnetospheres
Stellar winds



Core Research Programs

The five core research programs are aligned with PSD's guiding principles.



Habitable Worlds

Characteristics and distribution of habitable environments in the Solar System and beyond

- Target bodies for this program element include, but are not limited to:
  - Mars
  - Icy Worlds
  - Exoplan ets

Programmatic Impacts

E.4 HABITABLE WORLDS

The goal of the Habitable Worlds program is to use knowledge of the history of the Earth and the life upon it as a guide for determining the processes and conditions that create and maintain habitable environments and to search for ancient and contemporary habitable environments and explore the possibility of extant life beyond the Earth.

2017 NASA's Habitable Worlds Program includes elements of the Astrobiology Program, the Mars Exploration Program, the Outer Planets Program (all in the Planetary Science Division) and Exoplanet research in the Astrophysics Division. A common goal of these programs is to identify the characteristics and the distribution of potentially habitable environments in the Solar System and beyond.

Programmatic Impacts

E.4 HABITABLE WORLDS

2018 The Habitable Worlds element will be administered primarily by the Planetary Science Division…..

The Astrophysics Division will consider supporting investigations that are focused upon the characterization of potentially habitable exoplanets and their atmospheres in order to:

- inform targeting and/or operational choices for current NASA missions, or
- provide targeting, operational, and/or formulation data for future Astrophysics observatories.

The Heliophysics Division will consider supporting investigations that are focused on space weather signatures that may be indicative of impacts to planetary habitability.

2.6 Nexus of Exoplanet System Science

Although Habitable Worlds solicits proposals aimed at habitability of any planet, including those within the solar system, PIs of proposals selected for funding from this program element that cover a research topic related to the habitability of, or search for life on, exoplanets specifically are eligible to be part of the Nexus of Exoplanet System Science (NExSS). Relevance to NExSS is not an evaluation criterion for proposals to this program element. Eligibility for participation in NExSS does not indicate that additional funding will be provided; NExSS is a research coordination network that brings together scientists from many disciplines that study planets beyond our Solar System. For more information see https://nexss.info/.

Exoplanets

Cross-division program between Planetary Science and Astrophysics

Topics covered by this program element include, but are not limited to:

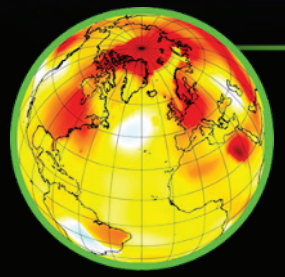
Astrophysics

- Investigations to detect exoplanets
- Characterization that aids in the detection of new exoplanets

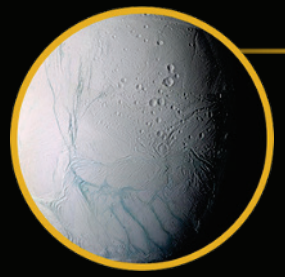
Planetary Sciences

- Explain observations of exoplanets
- Understand the chemical and physical processes occurring on exoplanets
- Improve understanding to the origins of exoplanetary systems

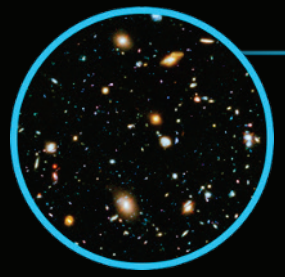
Key NASA/SMD Crosscutting Science Themes



Safeguarding and Improving Life on Earth



Searching for Life Elsewhere



Expanding our Knowledge

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