NASA Briefing: Planetary Science & Astrobiology

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Irvine, CA

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Senior Scientist Astrobiology
NASA Headquarters

Astrobiology lies at the heart of the NASA Vision

To improve life here,

To extend life there,

To find life beyond,

- *Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration;*
- *Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter's moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources;*
- *Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars;*

NASA Transition Authorization Act of 2017 added the search for life to NASA's list of objectives

NASA ... "shall be conducted so as to contribute materially to one or more of the following objectives:"

(1) The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space.
(2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles.
(3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space.
(4) The establishment of long-range studies … for peaceful and scientific purposes.
(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology…
(6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency.
(7) Cooperation by the United States with other nations and groups of nations …
(8) The most effective utilization of the scientific and engineering resources of the United States …
(9) The preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes.
(10) The search for life's origin, evolution, distribution and future in the Universe.

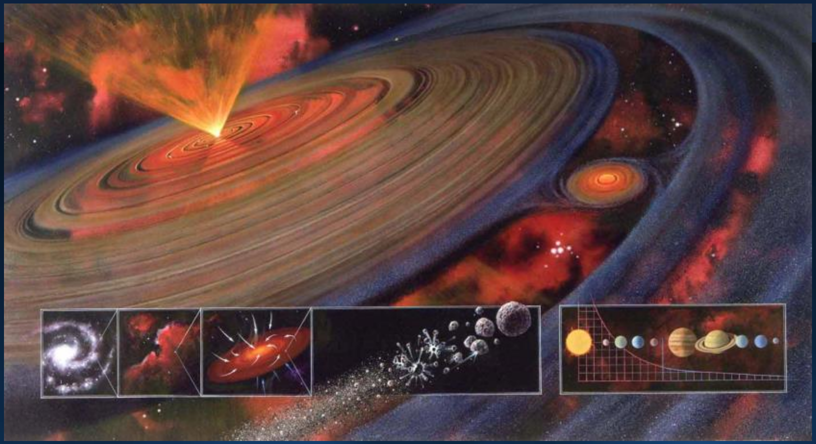

How did we get here?
Where are we going?
Are we alone? *or,*
Is there anybody else out there?
Knowledge of Space Environments
Knowledge of Earth Organisms

Astrobiology Program Funding Priorities

- Identified by Gaps in Investment Portfolio
- Identified through Topical Workshops/Studies
  - National Academies
  - NASA
- Science Needs in Support of Ongoing and Future Missions
  - MSL/Curiosity
  - OSIRIS-REx
  - ExoMars
  - MARS 2020
  - Europa Clipper
- Partnerships with Other Agencies
  - NSF- Center for Chemical Evolution
  - NSF- Ideas Lab
- National Science Priorities
  - Microbiome Initiative
  - Ocean Worlds

Astrobiology Unites Disciplines to Study Life in the Universe

Origins and distribution of habitable planets

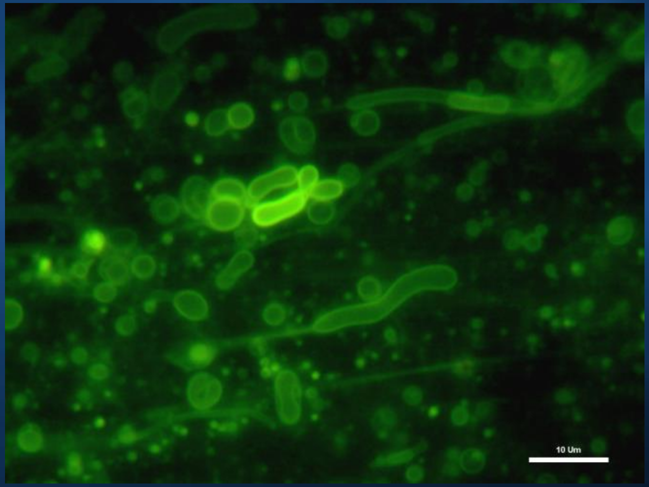


Chemistry of prebiotic environments

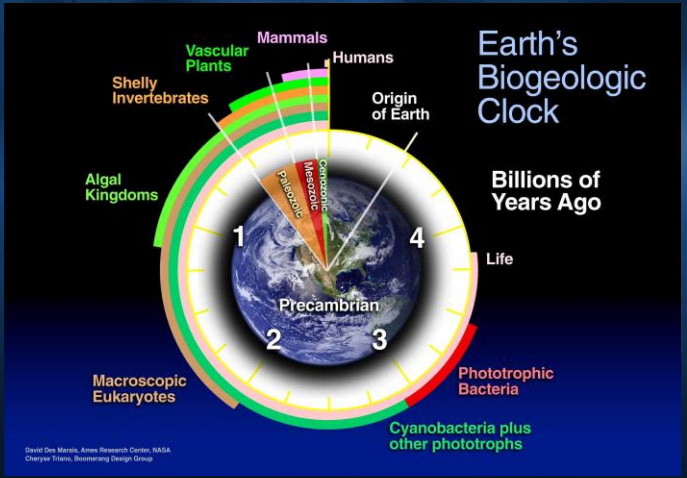
Prebiotic evolution and origins of life

Origins, Evolution & Distribution of Life

Evolution of biospheres and their biosignatures



Attributes of living systems



Astrobiology Science Strategy

(Released Fall 2015)

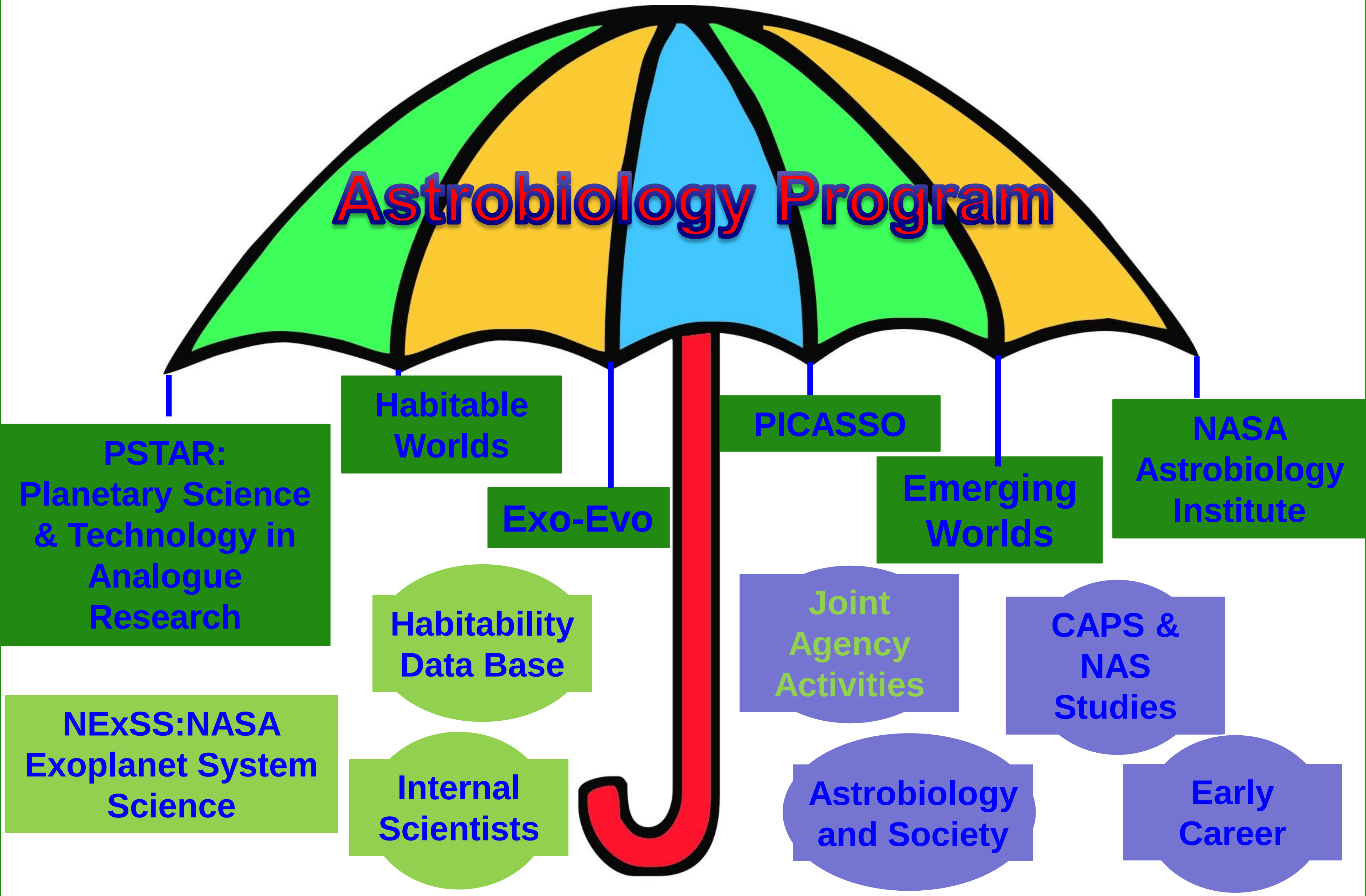
- Community based & semi-decadal
- Broad participation in creation:
  - 77 Contributors
  - 744 members of *astrobiologyfuture.org*
  - 12 reviewers who made invaluable contributions.
- Goal was to create an "inspirational and aspirational" document.
- A PDF version is available on the Web. (Limited Printed Copies)
  - Will be "wiki-fied" to make it a living document.

Six Major Research Areas Covered in the Strategy

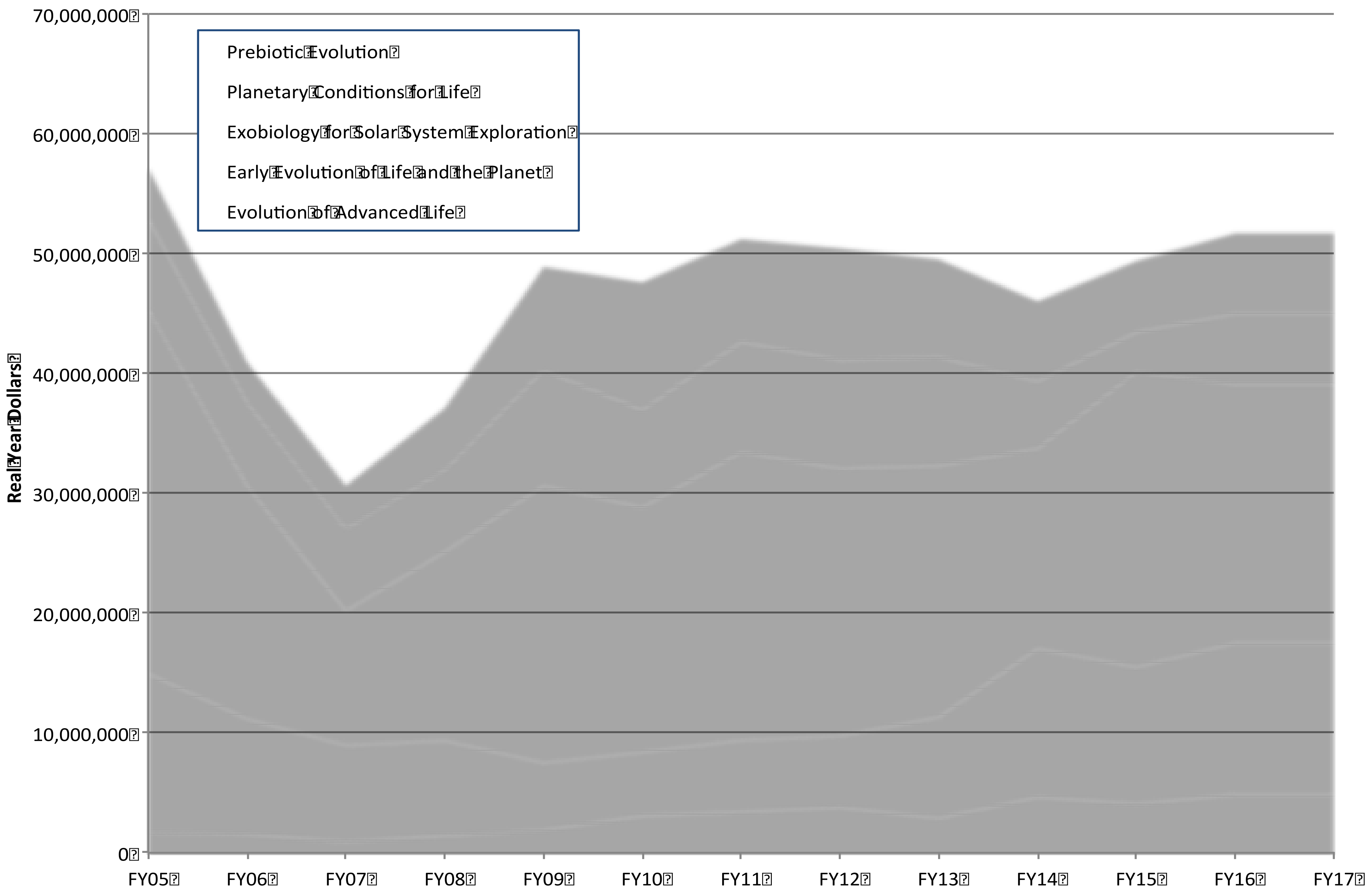
1. Identifying abiotic sources of organic compounds
2. Synthesis and function of macromolecules in the origin of life
3. Early life and increasing complexity
4. Co-evolution of life and the physical environment
5. Identifying, exploring, and characterizing environments for habitability and biosignatures*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

* (Overlaps with Astrophysics Division)

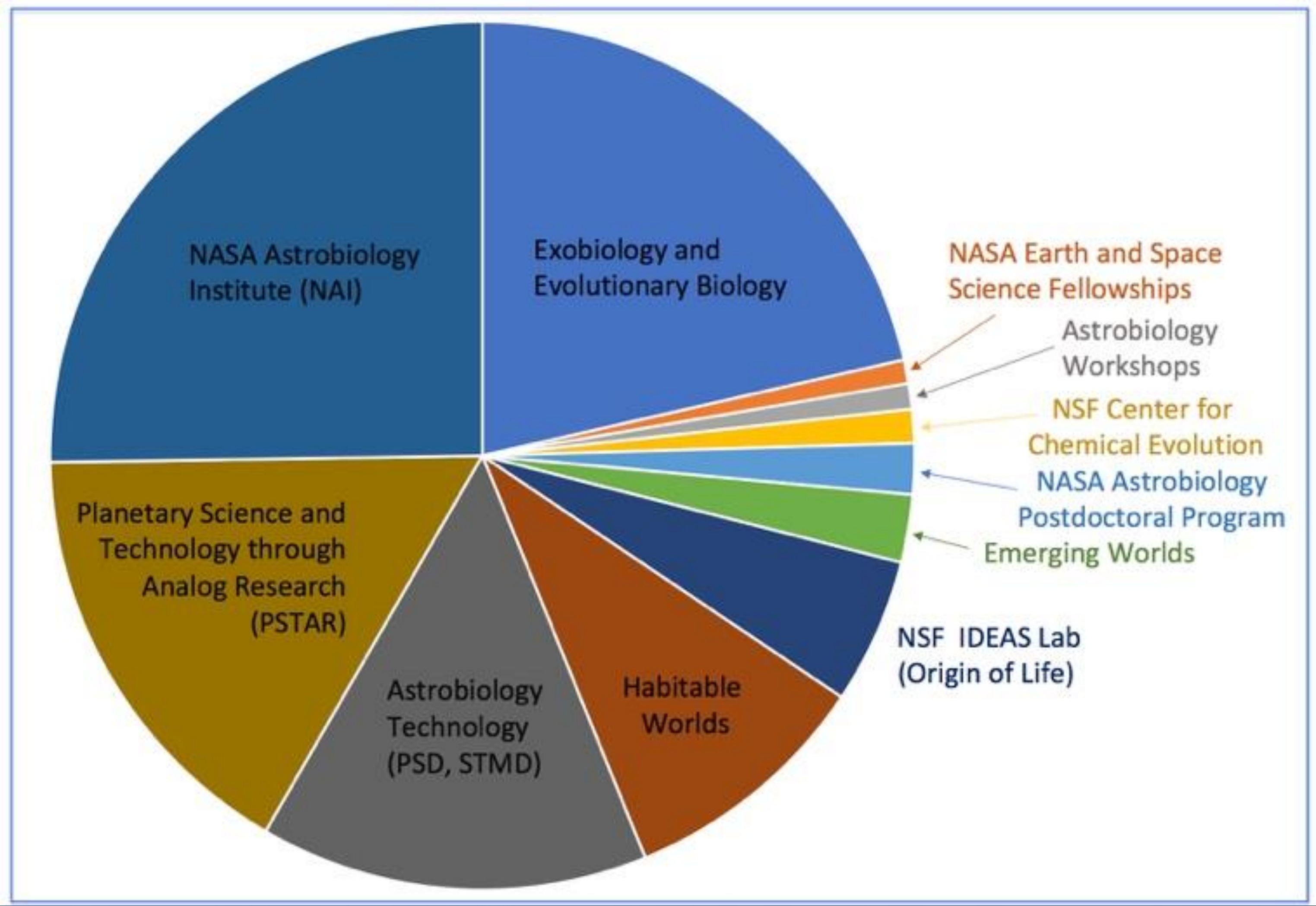
Astrobiology in NASA Science Mission Directorate



Astrobiology Research Portfolio



Astrobiology Support



Typical annual allocations of astrobiology funds support basic research, technology, and development for off-world exploration.

What is the Ideas Lab?

Inputs: Grand Challenge Topic, Creative People, Money

↓

Creative Environment: "Ideas Lab"

↓

Outputs: Potentially Transformative, Novel, Adventurous, Innovative, Interdisciplinary Ideas

"Wow Factor"

NSF-NASA Joint Ideas Lab

Working Title: “The Origin of Translation”

Timeline

Call by June 2016- 130 apps

Participant Selections Sept 2016 -29

In Person “Ideas Lab” Sept 2016

Final Proposals Due Dec 17, 2016

Selections (5) March, 2017

Origins of Life Ideas Lab Selections

NASA-funded:

1. Becoming Biotic: Recapitulating Ancient Cofactor-Mediated Metabolic Pathways on the Early Earth, PI: Laurie Barge (JPL).
2. The emergence of evolvable surface-associated interacting molecular ensembles: A chemical ecosystem selection approach, PI: David Baum (U Wisconsin)
3. Understanding Translation through Experimental Evolution, PI: Michael Travisano (U Minnesota)

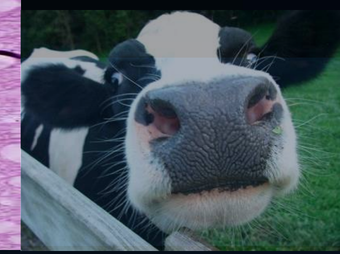
NSF-funded:

1. Life Out of Water - Possibility of Evolution in Non-Aqueous Environments, PI: Loren Williams (GA Tech)
2. Biochemical, Genetic, Metabolic and Isotopic Constraints on an Ancient Thiobiosphere, PI: Boswell Wing (U Colorado, Boulder)

Life detection has always been a goal of NASA Planetary Science

…and recently interest has been increasing.





Defining Life

- Life is chemistry with a history (and memory).

- NASA: Life is a self-sustaining chemical system capable of Darwinian evolution.

- Definition → General theory of living systems

E.g. Terran life:

- Uses water as a solvent
- Is built from cells, exploits a metabolism that focuses on the C=O carbonyl group
- Is a thermodynamically dissipative structure exploiting chemical energy gradients
- and Exploits a two-biopolymer architecture that uses nucleic acids to perform most genetic functions and proteins to perform most catalytic functions.

- How do you develop a definition that can help you detect life?

LIFE DETECTION LADDER

Ladder Rung	Feature	Measurement	Instrument	Target	Likelihood	Specific to Earth Life vs. Generic Life	Ambiguity of Feature	Ambiguity of Interpretation	False Positive	False Negative	Detectability
Life (metabolism, growth, reproduction)											
Darwinian Evolution											
Growth and Reproduction											
Metabolism											
Suspicious biomaterials [not necessarily biogenic]											
Functional Molecules											
Potential Building Blocks											
General indicators											
Habitability											
Environmental conditions											

Ladder Rung	Feature	Measurement	Instrument	Target	Likelihood	Specific to Earth Life vs. Generic Life	Ambiguity of Feature	Ambiguity of Interpretation	False Positive	False Negative	Detectability
Suspicious biomaterials [not necessarily biogenic]											
Functional Molecules	DNA	material produced by ET life	spectrographic, immunoassay, PCR, hi-prec MS	plume, rock, or physical sample	low	Earth	None	Negligible	high (contamination)	high (technology limited, only terran)	hard (linked to specificity of instrument)
	RNA	material produced by ET life	spectrographic, immunoassay, PCR, hi-prec MS	plume, rock, or physical sample	low	Earth	None	Negligible	low (RNA reactive, contamination possibility low)	high (technology limited, only terran) highly reactive	hard to measure on earth
	pigments	material produced by ET life	Spectrometer	plume, rock, or physical sample	low/ med	Earth (can you abstract?)	How to define if it is not the ones we know?	very low	low	high (limitation of what we are looking for)	easy (fluorescence)
	structural preferences in organic molecules [non random and enhancing function]	evidence of non random chemistries (such as specific biochemical pathways)	LCMS	plume, rock, or physical sample	low/ med	Earth	to detect?				discernable]

CONTEXT MATTERS!

Life Detection Ladder on ABP Website

ASTROBIOLOGY at NASA
LIFE IN THE UNIVERSE

About Astrobiology ˅ | Research ˅ | Missions ˅ | News ˅

HOME → LIFE DETECTION

- Astrobiology @ NASA
- Astrobiology Strategy
- Publications
- Life Detection
- Research Locations

Life Detection Ladder

The direct detection of extant life has not been attempted by NASA since the Viking Missions in the late 1970s. NASA's Ladder of Life Detection was generated to stimulate and support discussions among scientists and engineers about how one would detect extant life beyond Earth but within our Solar System (particularly on Europa and the other "Ocean Worlds"). In creating the Ladder, we started with the NASA definition of life, "Life is a self sustaining chemical system capable of Darwinian evolution" and considered the specific features of the one life we know —Terran life.

Contribute!

Table: Life Detection Ladder

Ladder Rung	Feature	Measurement	Instrument	Target	Likelihood	Specific to Earth Life vs. Potential for Generic Life	Ambiguity of Feature	Ambiguity of Interpretation	False Positive	False Negative	Detectability
Life (metabolism, growth, reproduction)											
Darwinian Evolution	changes in heritable traits in response to selective pressures	not possible			no	~	~		~		~
Growth and Reproduction	concurrent life stages or identifiable reproductive form [growth and reproduction]	cell(like?) structures in multiple stages	microscope				What is a cell? What			high (don't	
Metabolism	isotopes	isotopes indicative of active metabolism	irMS								
	co-located reductant and oxidant (e.g. persistant H_2 +/- CH_4 v. O_2, nitrate, Fe^{3+}, CO_2) [Inferred Persistence]	chemical concentrations of substrates and products involved in redox reactions	spectroscopy	remote detection	med/high	Generic	mixed reactions, large inventory of chemistries	low-med	low-med	med-high	hard (linked to specificity of instrument)
Suspicious biomaterials [not necessarily biogenic]											

What features are you working with? Want to modify or add a rung? Download a blank spreadsheet and fill it out with your data. Then email it to: arc-nai@mail.nasa.gov/

Life Detection and Civil Servant Internal Funding

Sellers Exoplanet Environments Collaboration (SEEC)

AMES- Center for Life Detection Studies

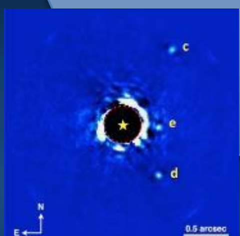
Foundational Activities and Documents

- Exoplanet Biosignatures Workshop July 2016- Joint NExSS-NAI-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
- NExSS

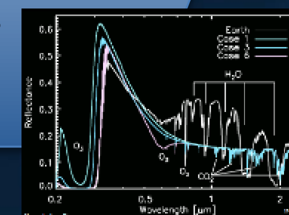
Nexus for Exoplanet Systems Science,NExSS

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

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

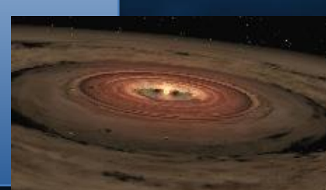


PSD Astrobiology
Comparative planetology
Planetary atmospheres
Exoplanet detection of
Biosignatures
Habitability

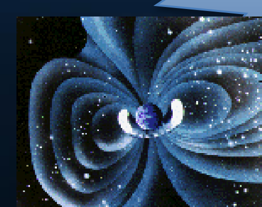


Earth Sciences
How planet systems works

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



Heliophysics
Star characterization
Detection of planetary magnetospheres
Stellar winds



Planetary Science Missions Events

* 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
September 22 – *OSIRIS-REx* Earth flyby

2018

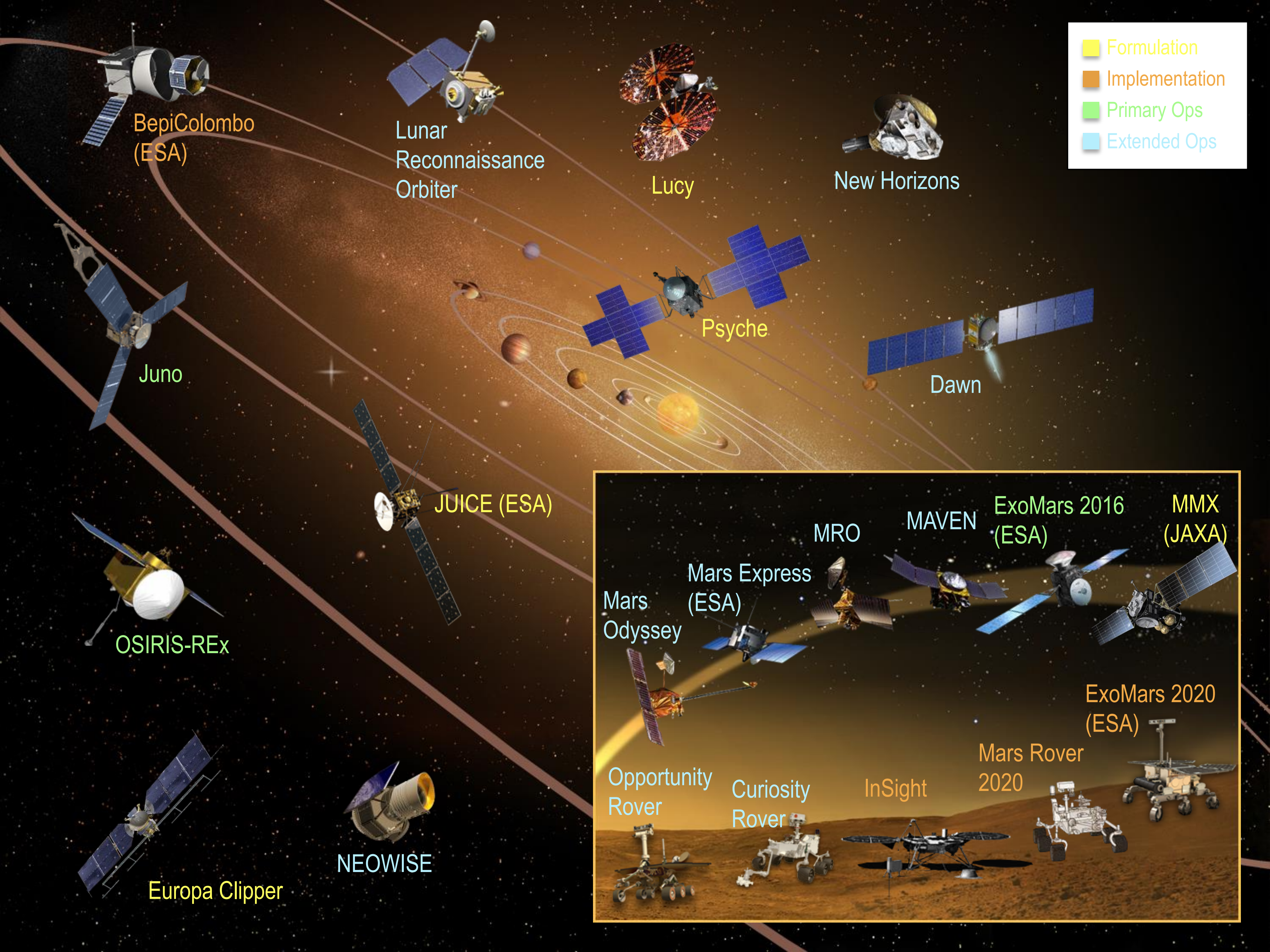
May 5 - Launch *InSight* mission to Mars
June 21-July 5– *Hayabusa 2* arrives at Ryugu
August – *OSIRIS-REx* arrival at Bennu
October – Launch of ESA's *BepiColombo*
November 26 – *InSight* landing on Mars

2019

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

2020

July – Launch of *Mars2020* mission to Mars
July – Launch of ESA *ExoMars* mission to Mars
July – *OSIRIS-Rex* retrieves a sample from Bennu
December 7 - *Hayabusa 2* reentry operation on 16:54 UTC in Australia
December – Landing of *Mars2020* rover on Mars

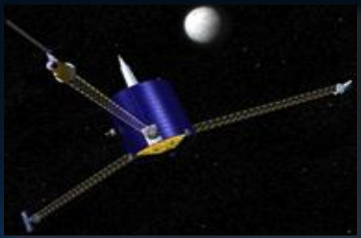

Formulation
Implementation
Primary Ops
Extended Ops
BepiColombo (ESA)
Lunar Reconnaissance Orbiter
Lucy
New Horizons
Juno
Psyche
Dawn
JUICE (ESA)
OSIRIS-REx
Europa Clipper
NEOWISE
MRO
MAVEN
ExoMars 2016 (ESA)
MMX (JAXA)
Mars Express (ESA)
Mars Odyssey
ExoMars 2020 (ESA)
Mars Rover 2020
Opportunity Rover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

Discovery Program

NEO characteristics:
NEAR (1996-1999)

Mars evolution:
Mars Pathfinder (1996-1997)

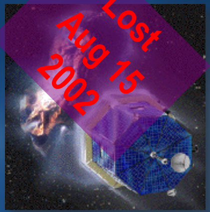
Lunar formation:
Lunar Prospector (1998-1999)



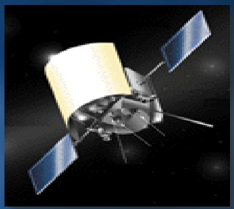
Nature of dust/coma:
Stardust (1999-2011)

Solar wind sampling:
Genesis (2001-2004)

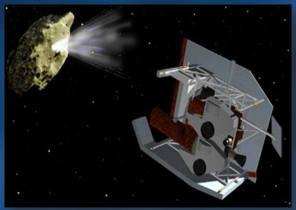
Comet Diversity:
CONTOUR
(2002)



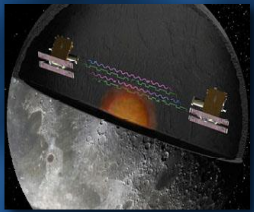
Mercury Environment:
MESSENGER
(2004-*2015*)



Comet Internal Structure:
Deep Impact
(2005-2012)



Lunar Internal Structure
GRAIL
(2011-2012)

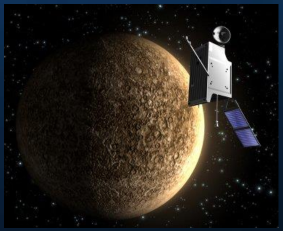


Main-belt Asteroids:
Dawn (2007-*TBD*)

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*)

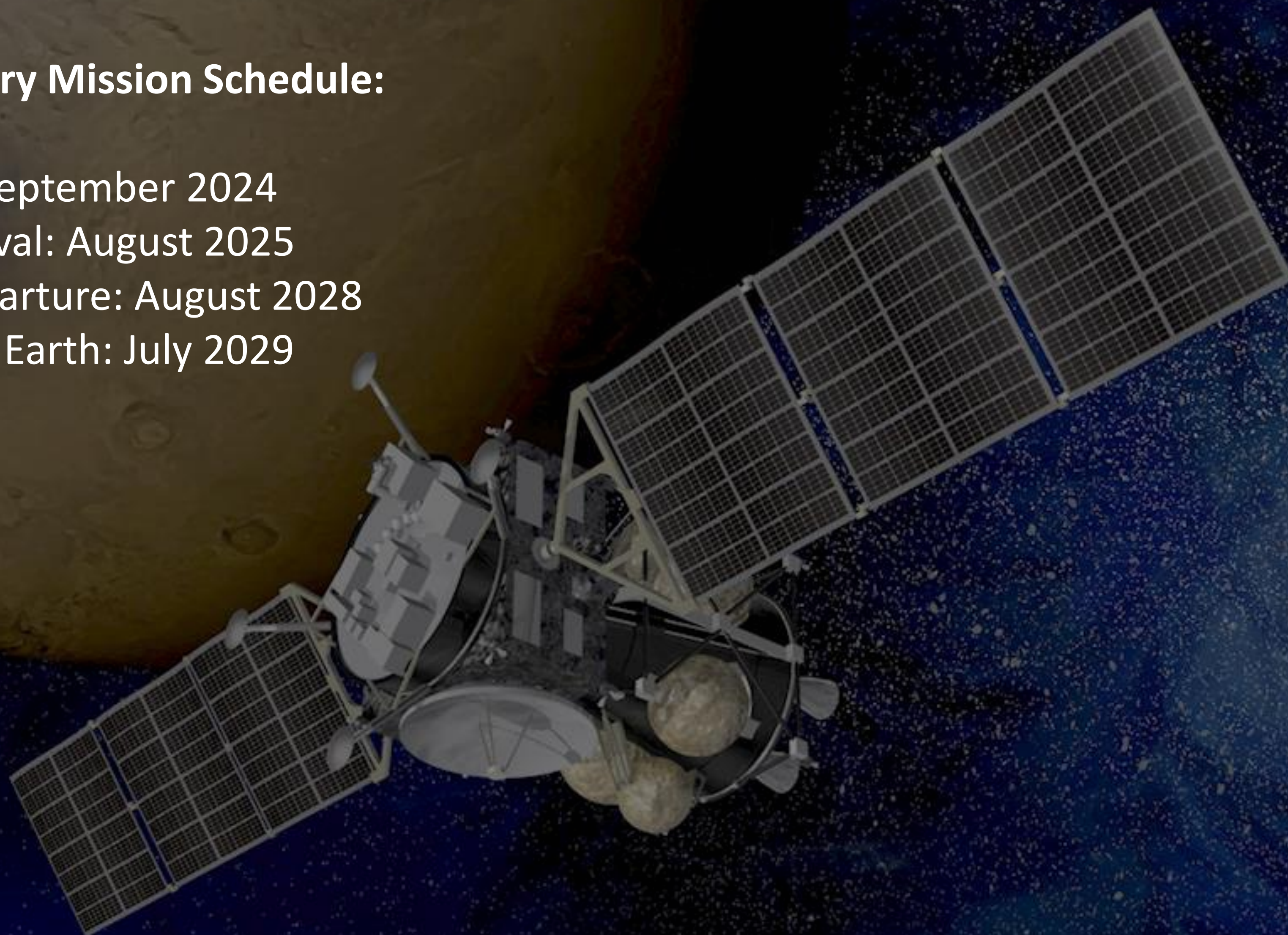
Martian Moons:
MMX/MEGANE (*2024*)

JAXA Martian Moons eXploration (MMX) Mission

1. To reveal the origin of Phobos and Deimos
2. Understand processes in the circum-Martian environment

Preliminary Mission Schedule:

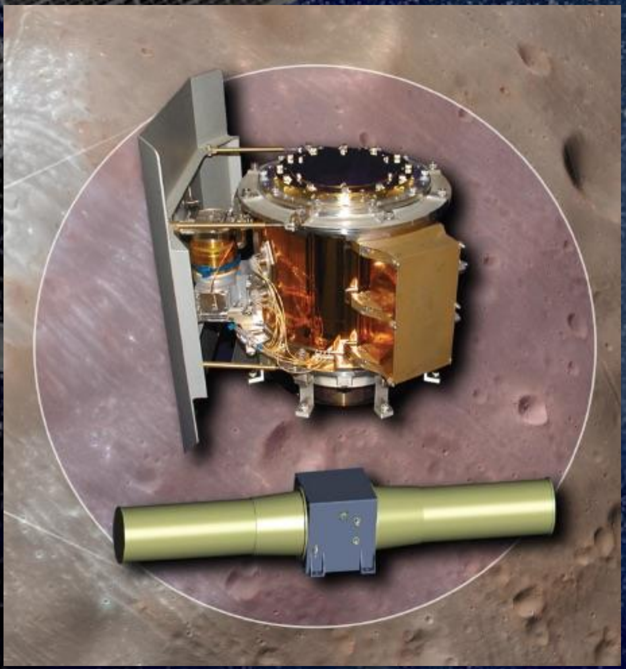
Launch: September 2024
Mars Arrival: August 2025
Mars Departure: August 2028
Return to Earth: July 2029



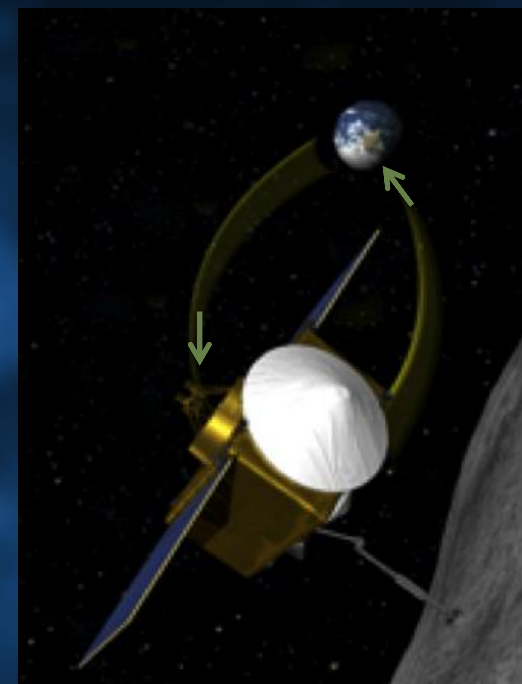
JAXA Martian Moons eXploration (MMX) Mission
Neutron & Gamma-Ray Spectrograph

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

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

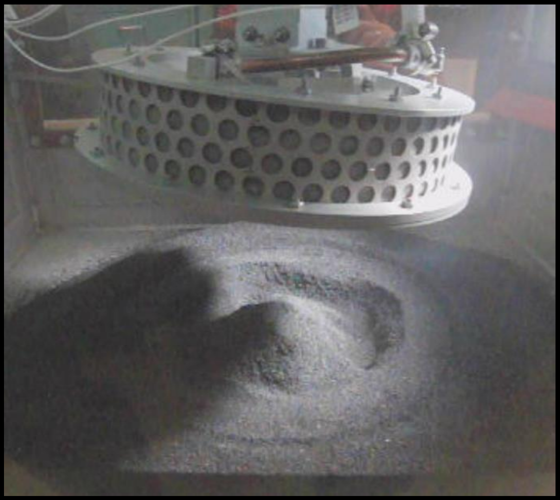


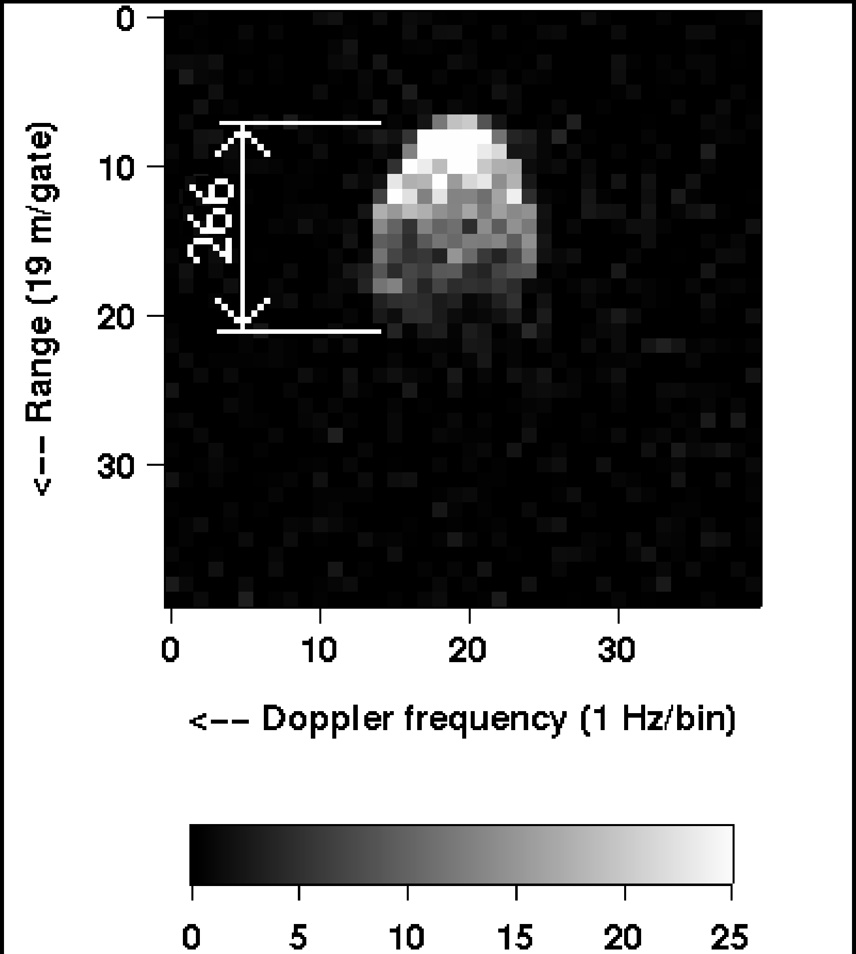
New Frontiers Program

1st NF mission	2nd NF mission	3rd NF mission
<u>New Horizons:</u>	<u>Juno:</u>	<u>OSIRIS-REx:</u>
Pluto-Kuiper Belt	Jupiter Polar Orbiter	Asteroid Sample Return
		
Launched January 2006 Flyby July 14, 2015 PI: Alan Stern (SwRI-CO)	Launched August 2011 Arrived July 4, 2016 PI: Scott Bolton (SwRI-TX)	Launched September 2016 PI: Dante Lauretta (UA)

Origins-**S**pectral **I**nterpretation-**R**esource **I**dentification-**S**ecurity-**R**egolith **Ex**plorer

- **O**rigins
  - Return and analyze a sample of pristine carbonaceous asteroid regolith
- **S**pectral **I**nterpretation
  - Provide ground truth for telescopic data of the entire asteroid population
- **R**esource **I**dentification
  - Map the chemistry and mineralogy of a primitive carbonaceous asteroid
- **S**ecurity
  - Measure the Yarkovsky effect on a potentially hazardous asteroid
- **R**egolith **Ex**plorer
  - Document the regolith at the sampling site at scales down to the sub-cm





Why Bennu?

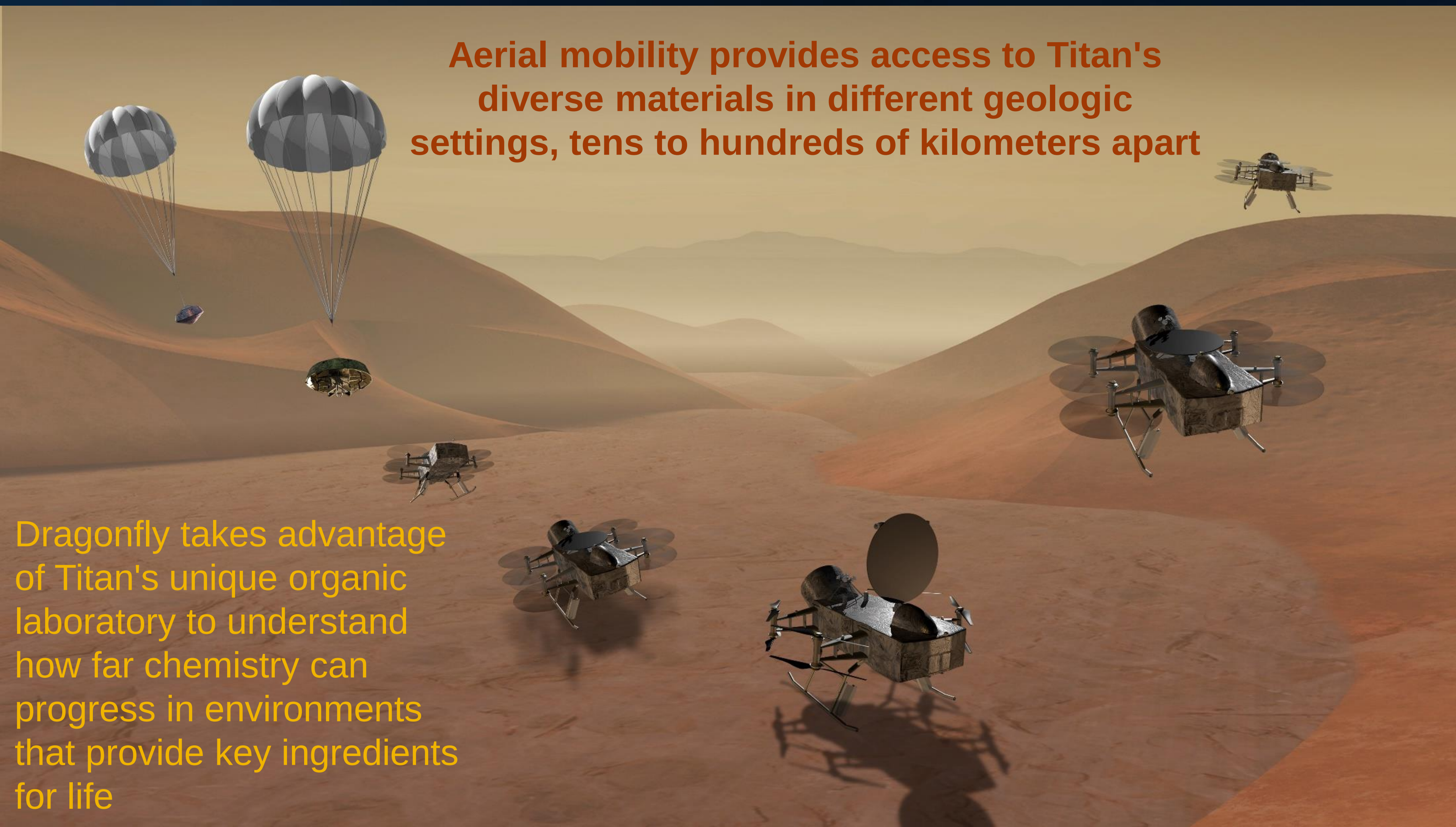
- Composition
  - -Primitive, volatile-rich
- Proximity
  - -Aphelion 1.356 AU
  - -Perihelion 0.897 AU
  - -every 6 y within 0.002 AU
- Size -492 m diameter

Mission Overview:

- Launched in September 2016
- Encounter asteroid Bennu in August 2018
- Study Bennu for up to 505 days
- Obtain at least 60 g of pristine regolith/surface material
- Return sample to Earth in September 2023
- Deliver samples to JSC curation facility

Dragonfly

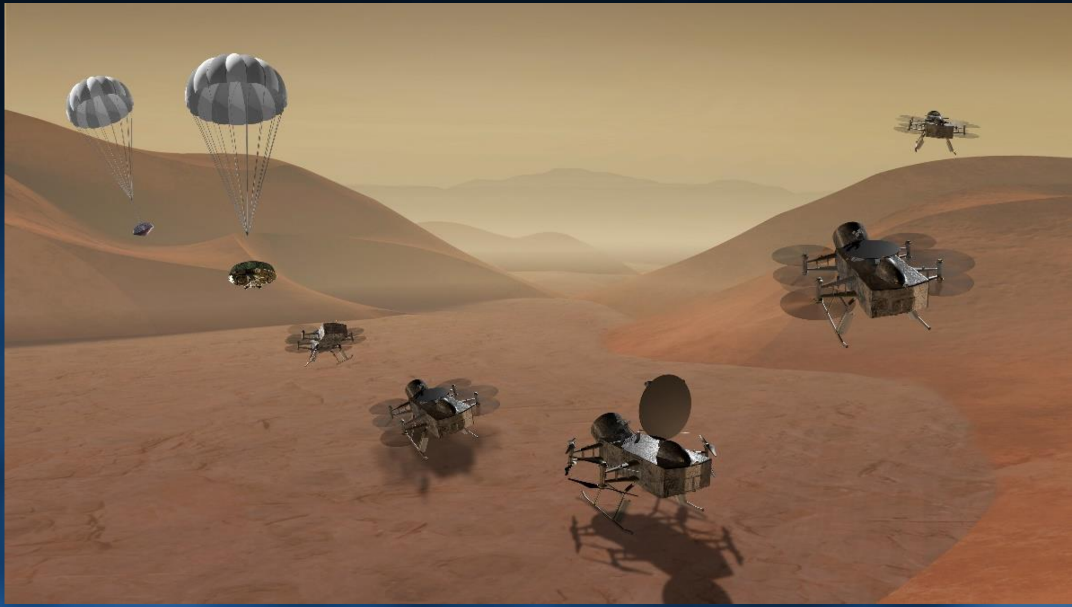
Dragonfly is a dual-quadcopter rotorcraft lander to explore prebiotic chemistry and habitability at dozens of sites on Saturn's moon Titan



Dragonfly

Dragonfly is a dual-quadcopter rotorcraft lander to explore prebiotic chemistry and habitability at dozens of sites on Saturn's moon Titan

- PI: Dr. Elizabeth Turtle, JHUAPL
- APL manages the project
- Dragonfly arrives in 2034 and explores Titan for over 2 years, performing chemical analyses of the surface and atmosphere and measuring meteorology and seismic activity
- Flight is highly efficient on Titan, enabling Dragonfly to investigate materials in a variety of geologic settings with its science payload:
  - ➢ Mass spectrometer
  - ➢ Gamma ray and neutron spectrometer
  - ➢ Meteorology and seismic sensors
  - ➢ Camera suite



<u>Science Objectives</u>

- 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

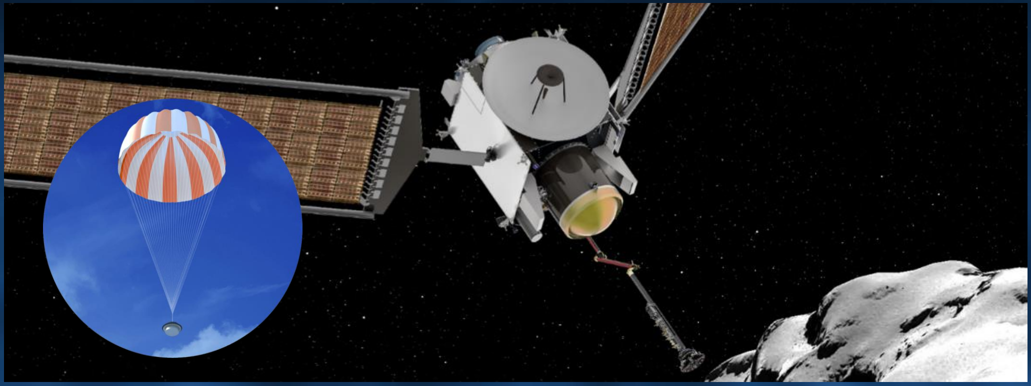
Comet Astrobiology Exploration Sample Return (CAESAR)

CAESAR will collect and return to Earth the first sample from the surface of a comet nucleus. Analysis of the sample in worldwide laboratories will help answer questions regarding the nature of Solar System starting materials, and how these primitive components came together to form planets and give rise to life.

Comet Astrobiology Exploration Sample Return (CAESAR)

- **CAESAR will collect and return to Earth the first sample from the surface of a comet nucleus. Laboratory analysis will help answer questions regarding the nature of Solar System starting materials, and how they came together to form planets and give rise to life.**

- Dr. Steve Squyres (Cornell Univ.) serves as PI with GSFC providing project management.
- Mission provides up to ~4.5 years of operations at comet 67P/Churyumov-Gerasimenko, culminating in sampling.
- Payload consists of sample acquisition and containment systems, and a suite of cameras.



Science Objectives

- Acquire and return material from the surface of a well-characterized comet nucleus, and determine its geologic and geomorphic context
- Protect the sample from contamination/alteration
- Analyze returned volatile and non-volatile material to determine origin and history of the comet and Solar System starting materials
- Determine the changes that occur on a comet nucleus as a result of multiple perihelion passages

PSD CubeSats/SmallSats

Planetary Science Deep Space SmallSat Studies: Awards

Venus **Concept Title**

CUVE - CubeSat UV Experiment
Seismicity Investigation on Venus Using Airglow Measurements
Seismic and Atmospheric Exploration of Venus (SAEVe)
Cupid's Arrow

Moon

Innovative Strategies for Lunar Surface Exploration
Lunar Water Assessment, Transportation, and Resource Mission
Mini Lunar Volatiles (MiLUV) Mission
CubeSat X-ray Telescope (CubeX) (also applicable to NEOs and Phobos/Deimos)
Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)

Small Bodies

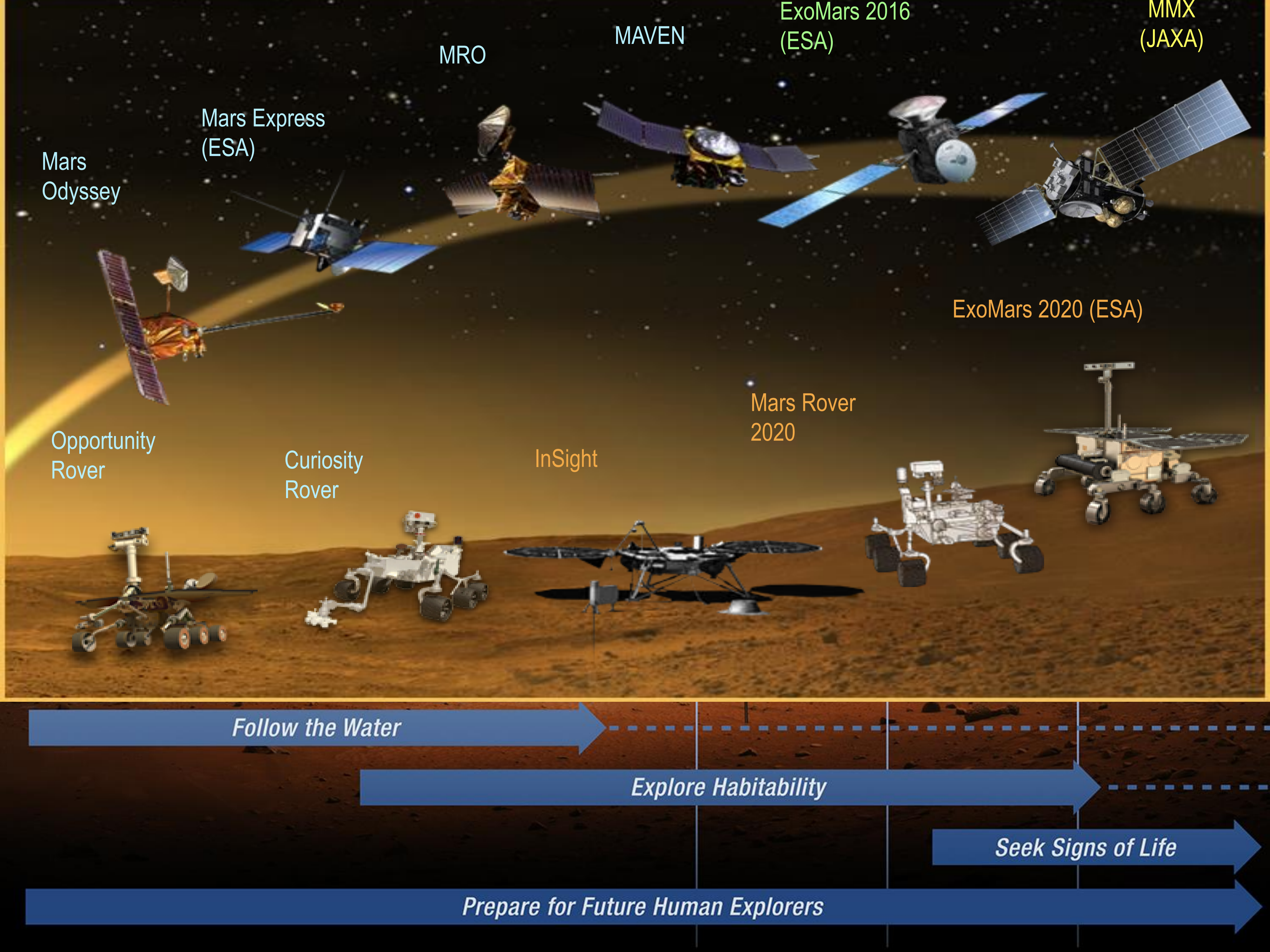
CAESAR: CubeSat Asteroid Encounters for Science & Reconnaissance
Primitive Object Volatile Explorer (PrOVE)
APEX: Asteroid Probe Experiment

Mars

PRISM: Phobos Regolith Ion Sample Mission
Chariot to the Moons of Mars
Aeolus - to study the thermal and wind environment of Mars
Mars Ion and Sputtering Escape Network (MISEN)
Mars Aerosol Tracker (MAT)

Icy Bodies and Outer Planets

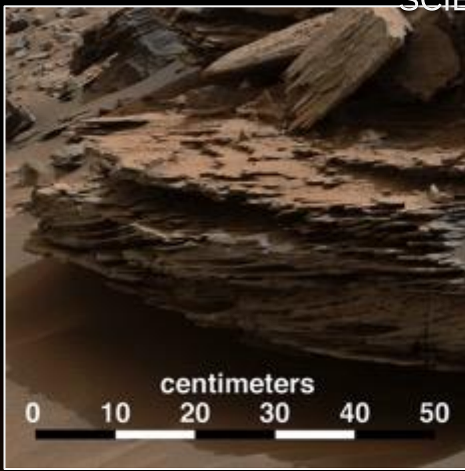
SNAP: Small Next-generation Atmospheric Probe

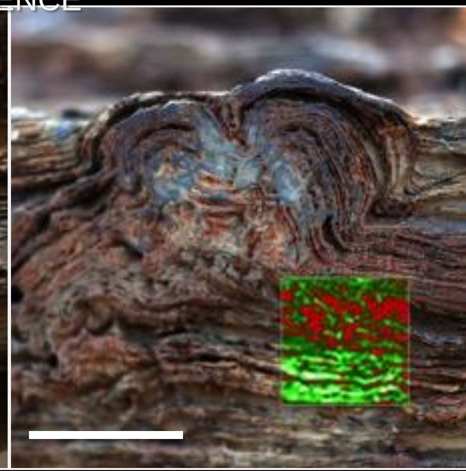

Mars Odyssey
Mars Express (ESA)
MRO
MAVEN
ExoMars 2016 (ESA)
MMX (JAXA)
ExoMars 2020 (ESA)
Opportunity Rover
Curiosity Rover
InSight
Mars Rover 2020
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

Mars 2020 Seeking Signs of Ancient Life

CONDUCT RIGOROUS *IN SITU* SCIENCE

ENABLE THE FUTURE





GEOLOGIC EXPLORATION

- Explore an ancient environment on Mars
- Understand processes of formation and alteration

HABITABILITY AND BIOSIGNATURES

- Assess habitability of ancient environment
- Seek evidence of past life
- Select sampling locations with high biosignature preservation potential

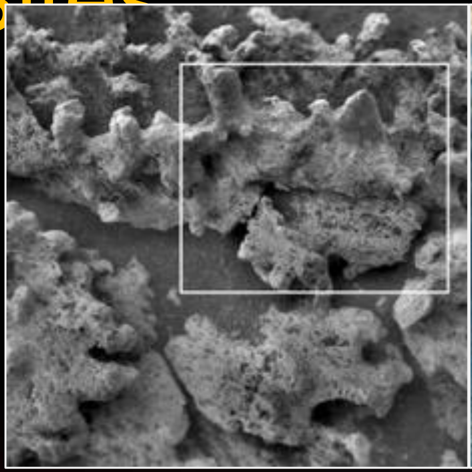
PREPARE A RETURNABLE CACHE

- Capability to collect ~40 samples and blanks, 20 in prime mission
- Include geologic diversity
- Deposit samples on the surface for possible return

PREPARE FOR HUMAN EXPLORATION

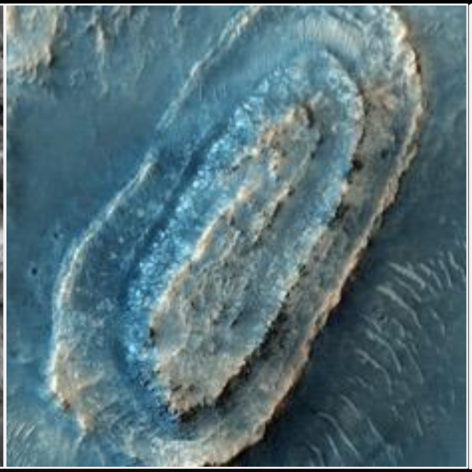
- Measure temperature, humidity, wind, and dust environment
- Demonstrate In Situ Resource Utilization by converting atmospheric CO_2 to O_2

Mars 2020 Candidate Landing Sites



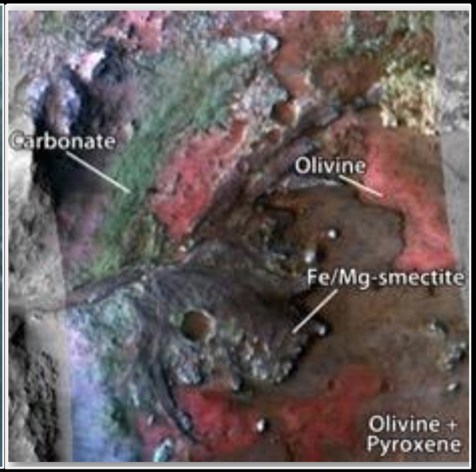
COLUMBIA HILLS

- Carbonate, sulfate, and silica-rich outcrops of possible hydrothermal origin and Hesperian lava flow
- Potential biosignatures identified
- Previously explored by MER



NE SYRTIS

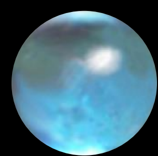
- Extremely ancient igneous, hydrothermal, and sedimentary environments
- High mineralogic diversity with phyllosilicates, sulfates, carbonates, olivine
- Serpentinization and subsurface habitability?



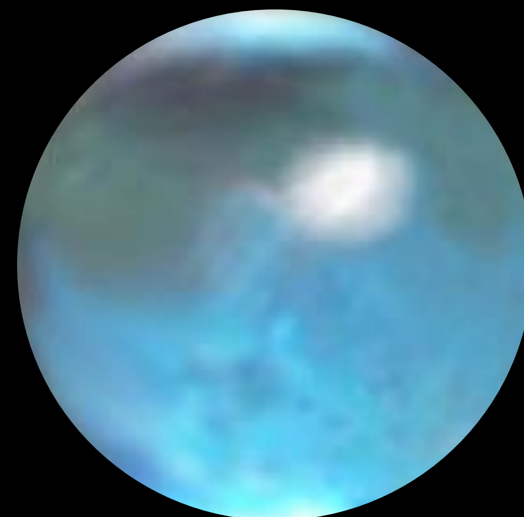
JEZERO

- Deltaic/lacustrine deposition with Hesperian lava flow and hydrous alteration
- Evidence for hydrous minerals from CRISM, *including carbonates*

Exploration of Ocean Worlds



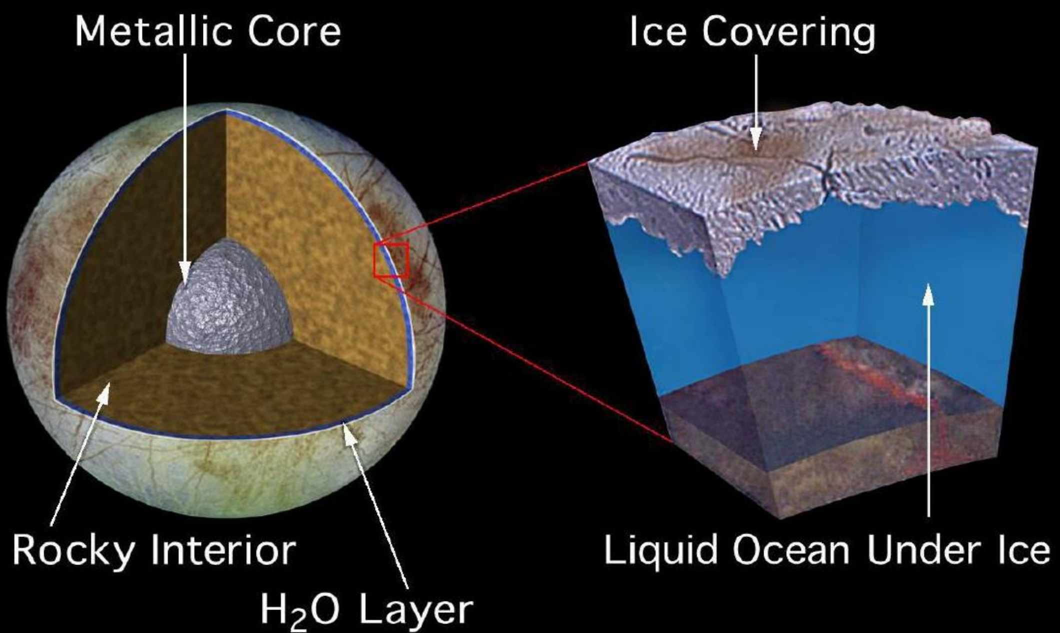
Earth

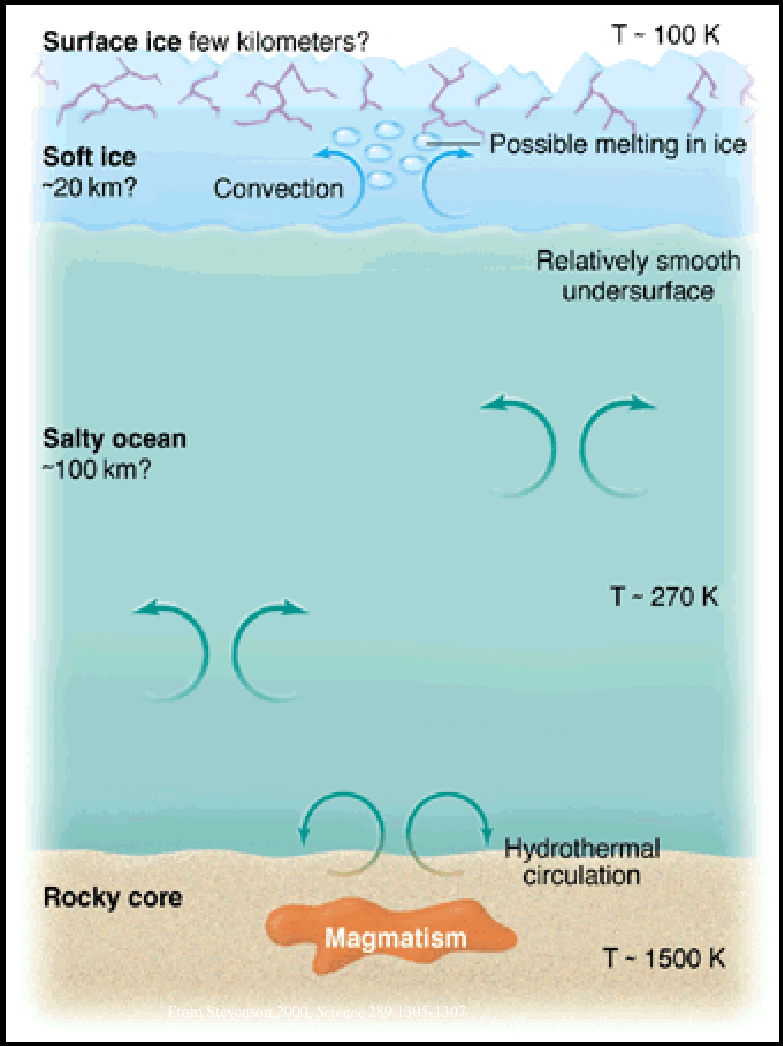


Ice-covered moons

Ocean Worlds

Europa—Focus of Future Astrobiological Study





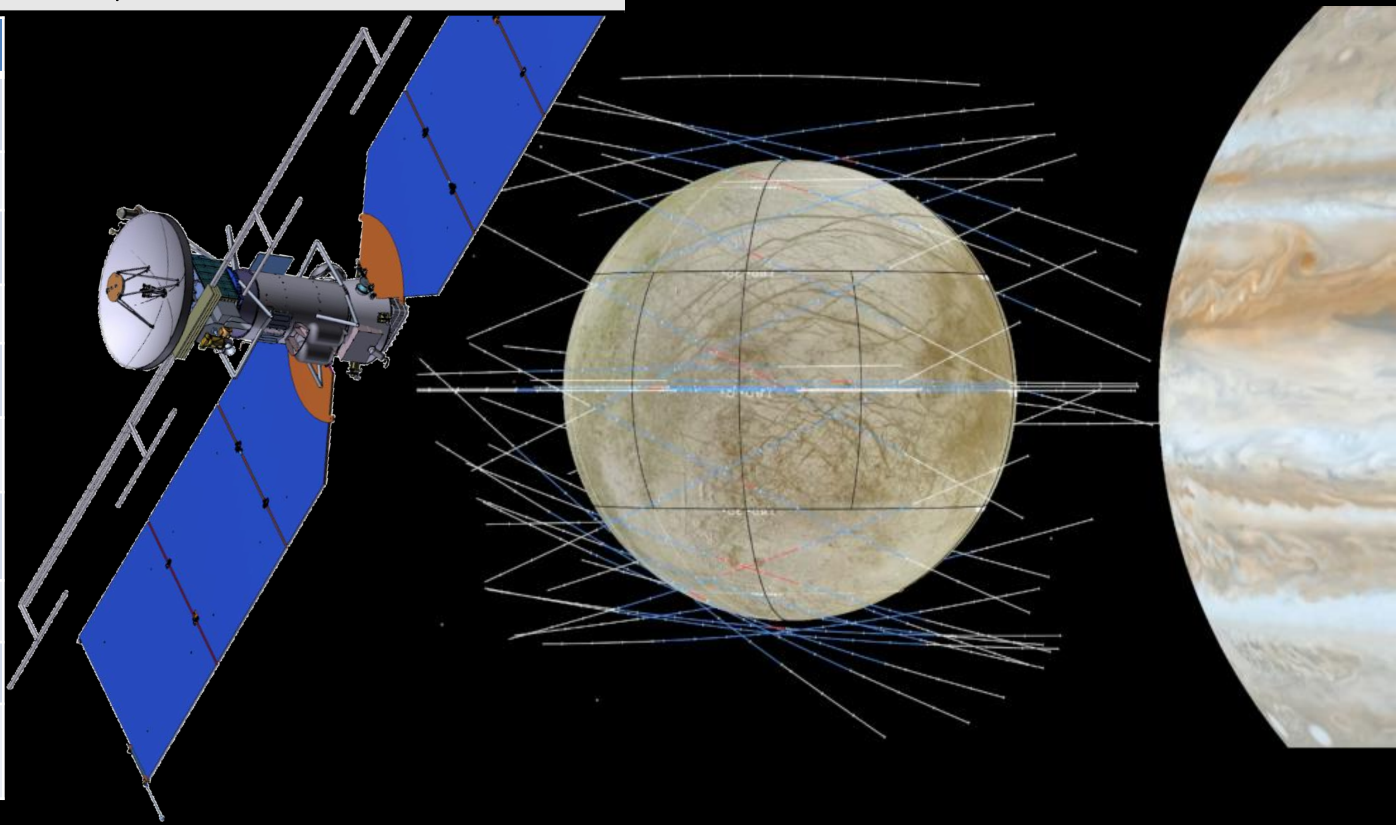
Hydrothermal Vents?

Europa Flyby 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

Mission Opportunity (example opportunity)	
Launch Opens	June 6, 2022
Jupiter Arrival	March 5, 2025 (using SLS)
Science Tour	45 Europa Flybys
Primary Mission End	December 6, 2028

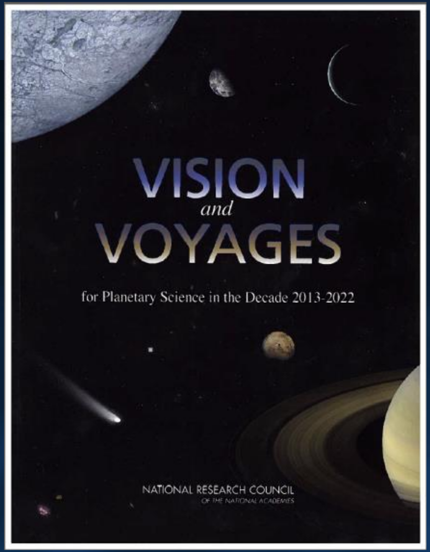
Model Payload	
	Instrument Type
1	Ice Penetrating Radar
2	Shortwave Infrared Spectrometer
3	Topographical Imager
4	Neutral Mass Spectrometer
5	Reconnaissance Camera
6	Thermal Imager
7	Magnetometer
8	Langmuir Probe
9	Gravity Science

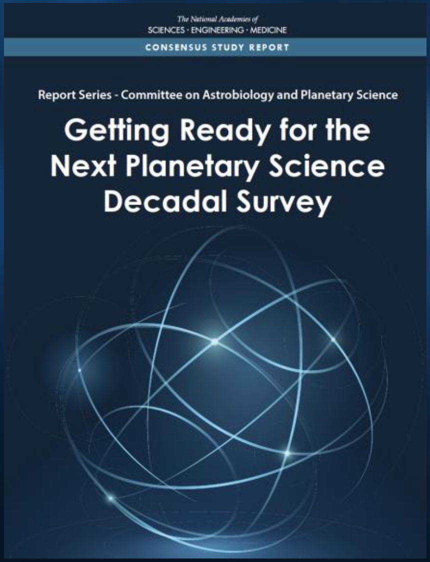


National Academy of Science
Studies for NASA's Planetary Science

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 ~March 2018
- NEW: 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



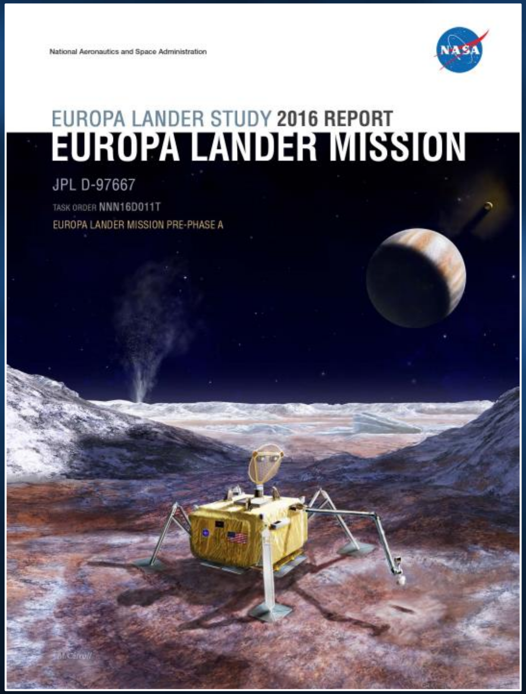


Mission Studies Completed Thus Far

- 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

Europa Lander SDT

- Science Definition Team (SDT) delivered its report with 3 prioritized goals:
    1. Search for Evidence of Life
    2. Assess habitability
    3. Characterize surface and subsurface
- Applying lessons learned from Viking landers
- Used extreme, limited nutrient Earth environments as analogs
- Approach: Multiple line of evidence are needed to detect life
- Presented a decision framework for life detection to assess how results should be interpreted



Ceres Pre-Decadal Study

- Dawn revealed Ceres to be an active dwarf planet; It is a solid body, but is it a relic ocean world?
- CAPS highlighted Ceres for pre-decadal study
- PSD has directed 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 NF and Flagship
  - Orbiting, landing, roving, sample return?
  - Launch dates between 2024 – 2037
  - PP to be noted, but technologies to be addressed later
- Key dates
  - SDT call for applications issued via NSPIRES in Dec.; responses (36) are being evaluated
  - FACA process required for participants
  - Design study January/February – Late FY18
  - Engagement with AGs and workshops/conferences

Public/ Private Partnerships in Astrobiology

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

- International
- Federal
- Universities
- Commercial
- Non-Profit

Questions???