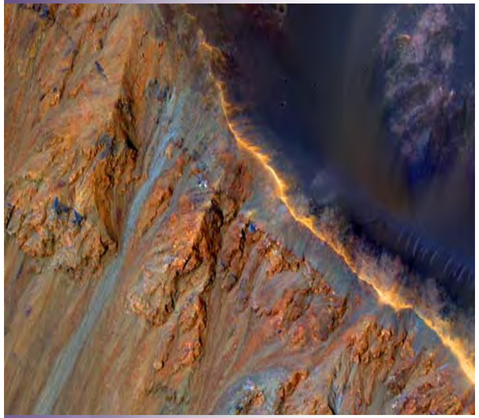
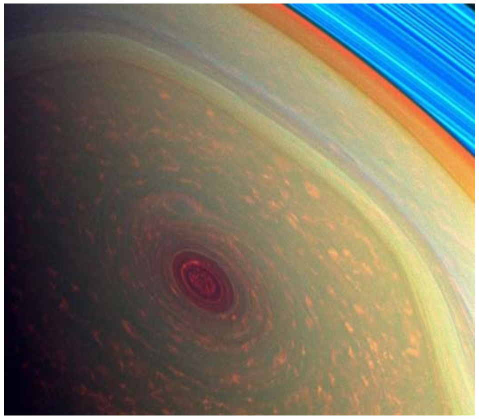
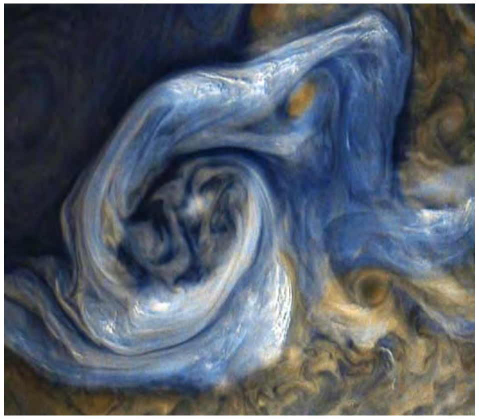
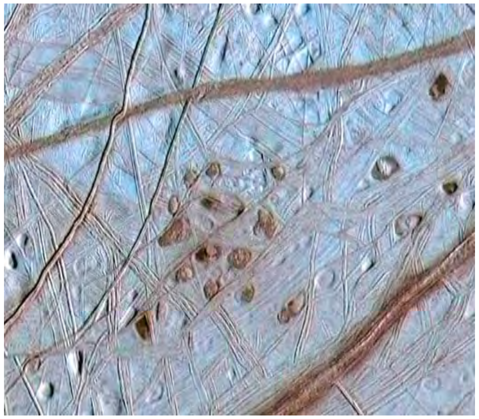
SCIENCE

National Aeronautics and Space Administration

NASA’s PLANETARY PROGRAMS AND TECHNOLOGY

15th International Planetary Probe Workshop

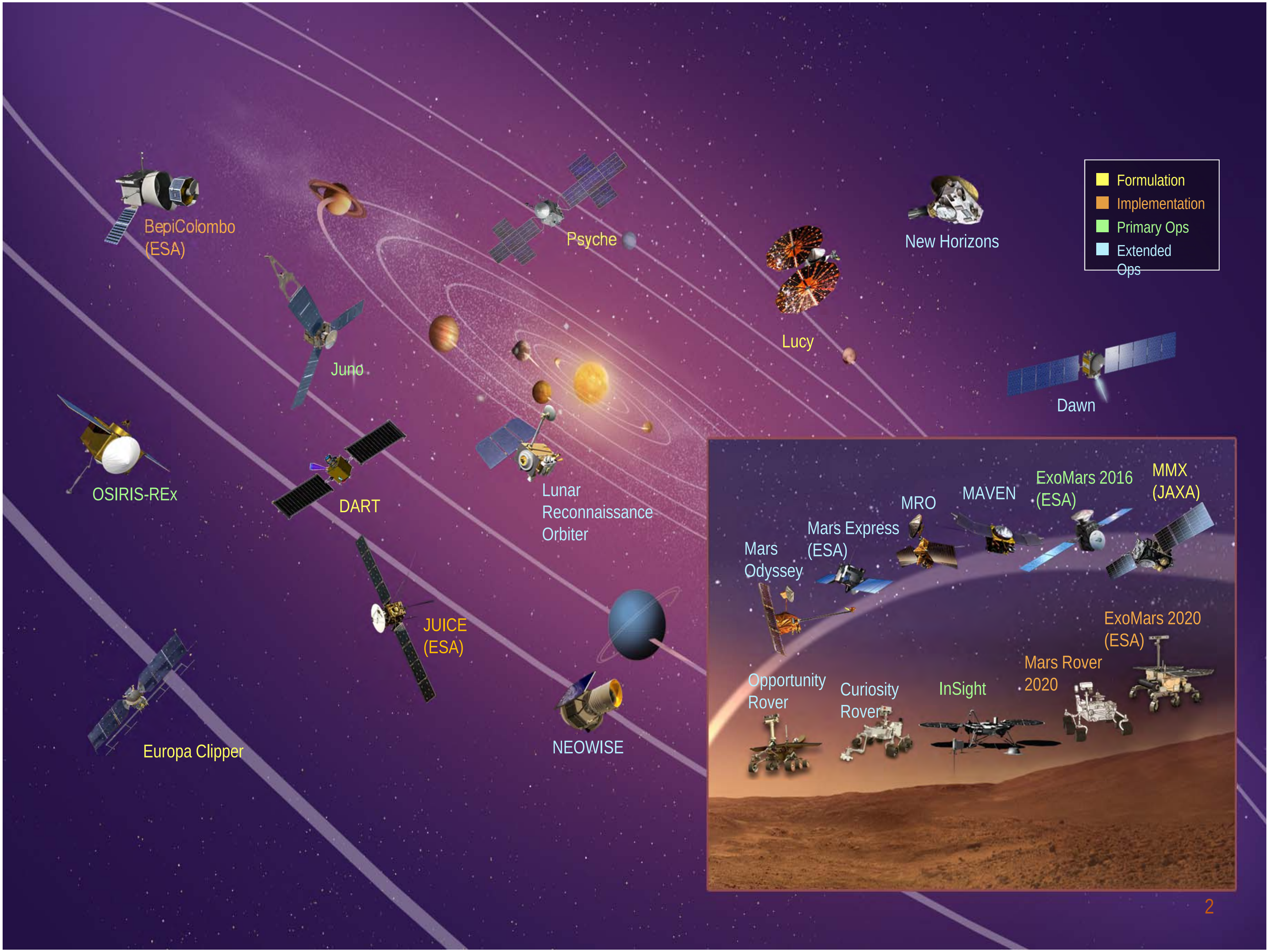
David Schurr

Deputy Director

Planetary Science Division

Science Mission Directorate, NASA

June 11, 2018

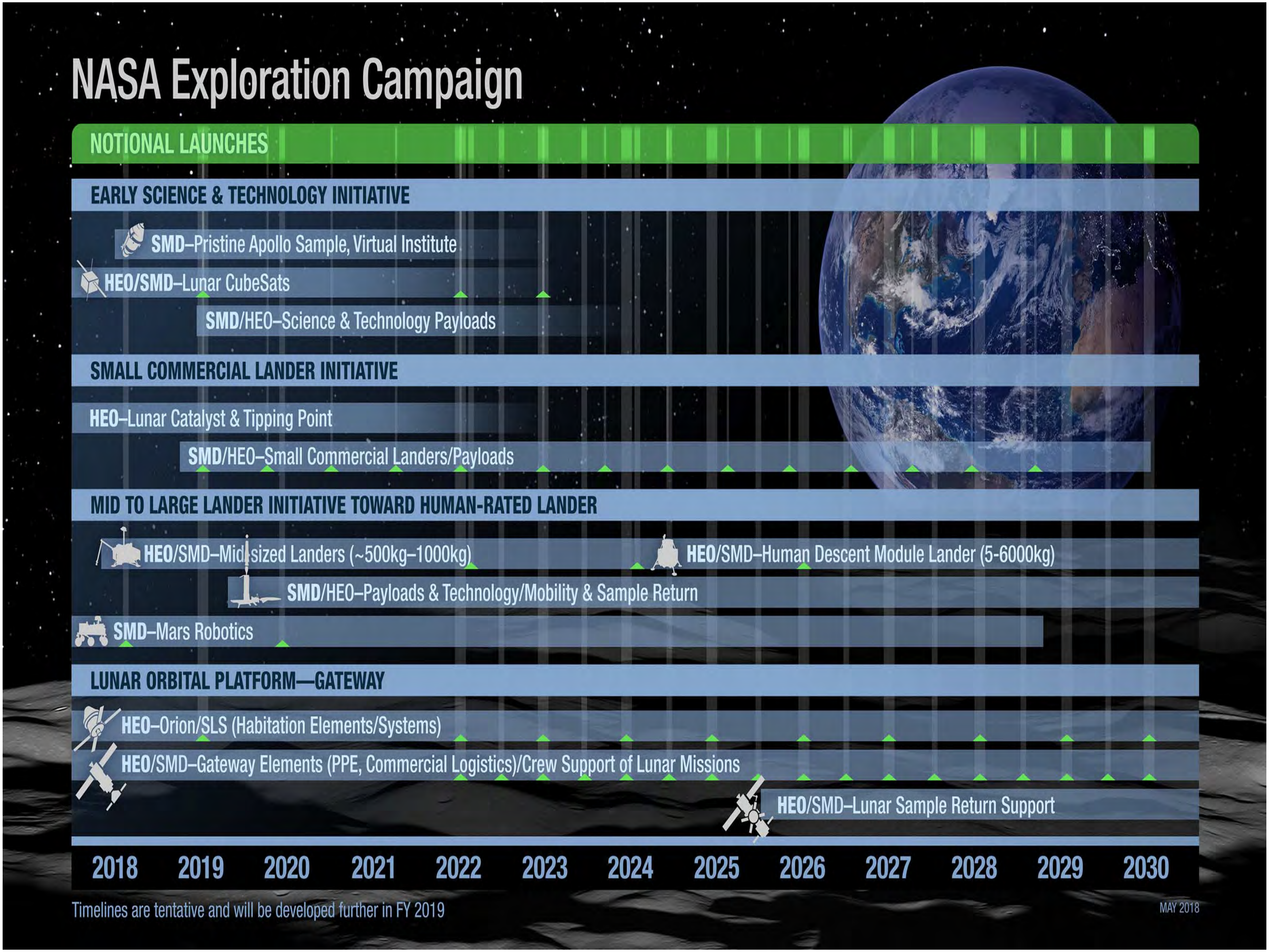


Formulation
Implementation
Primary Ops
Extended Ops
BepiColombo (ESA)
Psyche
New Horizons
Lucy
Juno
Dawn
OSIRIS-REx
DART
Lunar Reconnaissance Orbiter
JUICE (ESA)
Europa Clipper
NEOWISE
MRO
MAVEN
ExoMars 2016 (ESA)
MMX (JAXA)
Mars Express (ESA)
Mars Odyssey
ExoMars 2020 (ESA)
Mars Rover 2020
Opportunity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

NASA Exploration Campaign

NASA Exploration Campaign

“Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations;” – SPD-1


NASA Exploration Campaign
NOTIONAL LAUNCHES
EARLY SCIENCE & TECHNOLOGY INITIATIVE
SMD–Pristine Apollo Sample, Virtual Institute
HEO/SMD–Lunar CubeSats
SMD/HEO–Science & Technology Payloads
SMALL COMMERCIAL LANDER INITIATIVE
HEO–Lunar Catalyst & Tipping Point
SMD/HEO–Small Commercial Landers/Payloads
MID TO LARGE LANDER INITIATIVE TOWARD HUMAN-RATED LANDER
HEO/SMD–Mid-sized Landers (~500kg–1000kg)
HEO/SMD–Human Descent Module Lander (5-6000kg)
SMD/HEO–Payloads & Technology/Mobility & Sample Return
SMD–Mars Robotics
LUNAR ORBITAL PLATFORM—GATEWAY
HEO–Orion/SLS (Habitation Elements/Systems)
HEO/SMD–Gateway Elements (PPE, Commercial Logistics)/Crew Support of Lunar Missions
HEO/SMD–Lunar Sample Return Support
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Timelines are tentative and will be developed further in FY 2019
MAY 2018

Commercial Lunar Payload Services (CLPS)

- Draft RFP (SMD/HEOMD/STMD developed) for CLPS posted April 27
- Competition open to U.S. commercial providers of space transportation services, consistent with National Space Transportation Policy and Commercial Space Act
- Multi-vendor catalog, 10-year IDIQ contract, managed through task order competition for specific payload missions
- First vendor selection by Dec 31; future on-ramps as more capabilities are developed
- Structured for NASA as the marginal buyer of a commercial service
- Statement of work permits addition of more complex services as vendor capabilities grow such as providing surface mobility or sample return
- Based upon prior HEOMD investments through the Lunar CATALYST public-private partnerships with industry, we expect multiple vendors to bid

Payloads for Small Commercial Landers

- Retro-reflectors
- Initiating new Announcement of Opportunity under the Stand Alone Missions of Opportunity Notice (SALMON) to procure instruments that could be ready to fly on first lander missions
  - Existing engineering models or spares,
  - Student-built hardware,
  - Off the shelf hardware
- Will assess existing in-house developments
  - Resource Prospector instruments
  - Technology under development

Long-Lived Instruments, Landers and Rovers

- Initial landers delivered through the Commercial Lunar Payload Services (CLPS) are expected to last one lunar day (14 Earth days)
- NASA is planning investments to enable operations and mobility for long-lived instruments, stationary landers and small rovers
  - Power supplies, electronics, and mechanisms to survive and/or operate across the extreme temperatures of lunar day and night, despite lunar dust
  - Mobility systems or surface utility stations to enable small, long-lived rovers compatible with delivery to the lunar surface under CLPS capabilities
  - Radioisotopes for heat or power
  - An initial Long Duration Lunar Surface Operations workshop is planned for Fall 2018 co-sponsored by HEOMD, SMD, and STMD

Planetary Defense


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

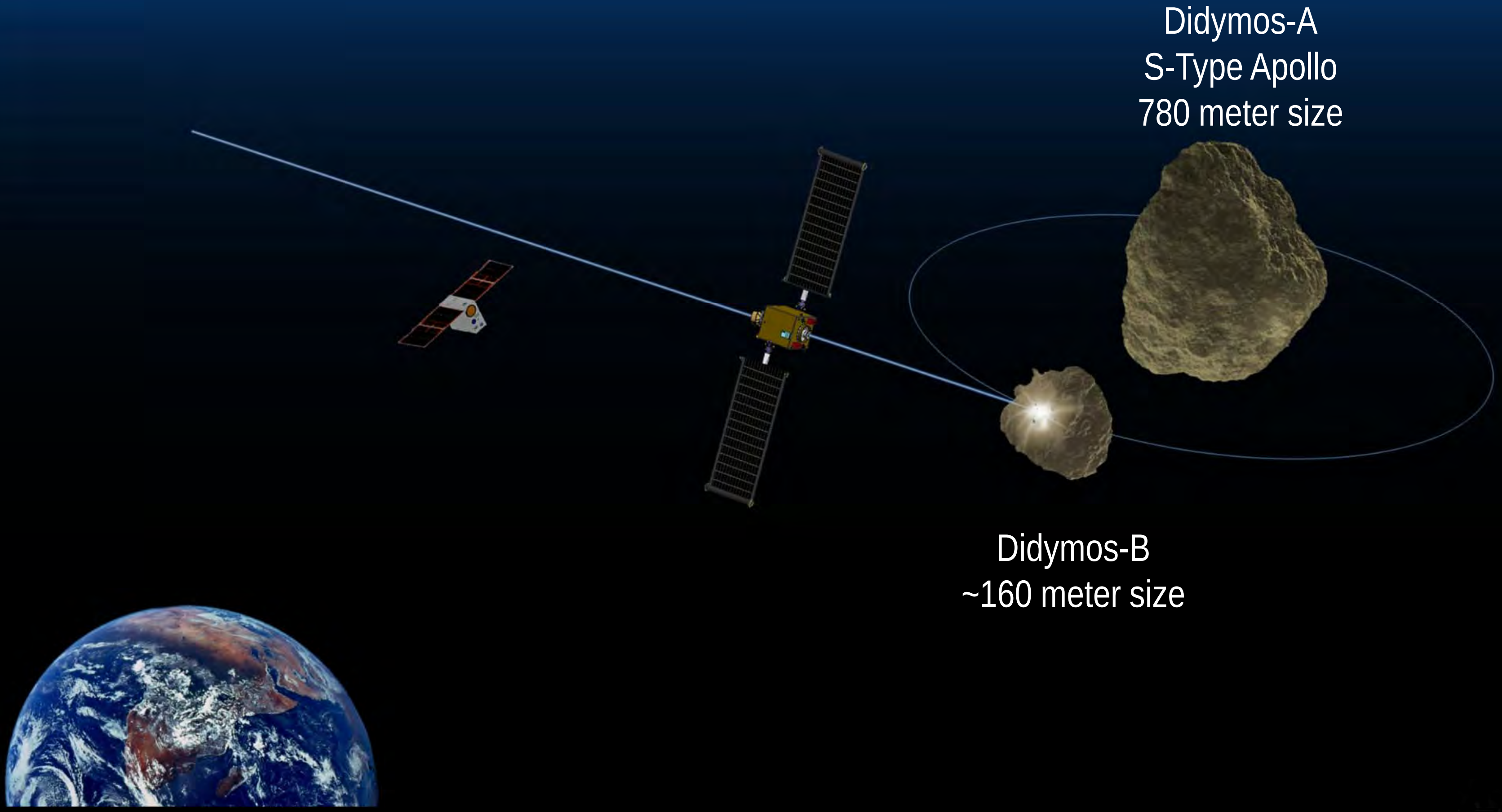
Planetary Defense Status

- Over 18,000 near-Earth objects (NEOs) discovered and confirmed to date
  - Over 8,000 NEOs greater than 140 meters in size
  - Over 1,900 NEOs are Potentially Hazardous Asteroids
- DART: Double Asteroid Redirection Test
  - Demonstration of kinetic impactor mitigation technique
  - Target - Moon of 65803 Didymos
  - Launch period opens June 2021, impact October 2022

- 2017 NEO Science Definition Team reassessed NEO search and characterization given current technology and understanding of the NEO population. Of the estimated 25,000 NEOs 140 meters or larger in size (that can cause regional damage), 1/3 have been found. Space-based assets will be needed to complete the catalog.

Double Asteroid Redirection Test (DART)

Mission Concept (with ASI CubeSat)



Small Innovative Missions For Planetary Exploration (SIMPLEx)

SIMPLEx Spacecraft Type and Launch Opportunities

- SIMPLEx is soliciting small complete science missions based on small spacecraft (SmallSats) flying as secondary payloads
  - ESPA-class (180 kg) or smaller
    - Allowable configurations include CubeSats up to 12U, and ESPA-class
    - ESPA-Grande sized spacecraft allowed for some opportunities (still limited to 180 kg)
  - Total mission cost capped at $55M
  - NASA expects awards to span the full range of cost

- Proposed missions are limited to the launch opportunities listed in Appendix A of the PEA. Currently listed are:
  - SMD missions (Lucy, Psyche, and IMAP),
  - Commercial Lunar opportunities,
  - LEO/GTO opportunities, and
  - Exploration Mission “x” (EM-2 or beyond)

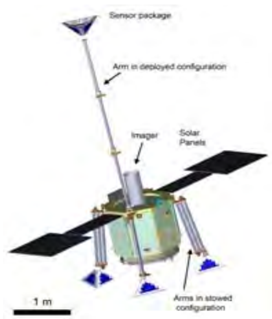
- Proposals due Jul 24 for first round of evaluation and selections/Cutoff for Lucy and Psyche opportunities

SmallSat Technology

PSDS3: Planetary Science Deep Space Small Satellite Studies

- 19 awards ($6 M investment over one year)
- Concept studies to scope science capability and cost of small secondary missions

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

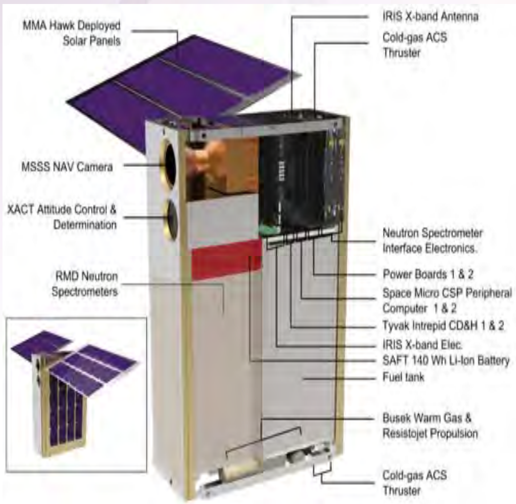
Mars

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)

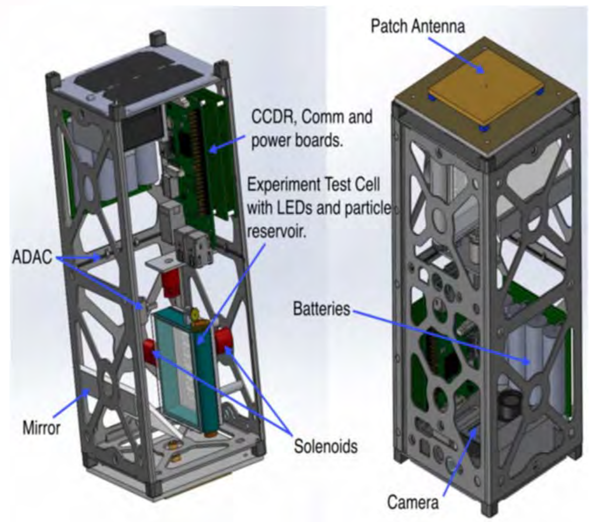
Icy Bodies and Outer Planets

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

Small Innovative Missions for Planetary Exploration (SIMPLEx-2014)



Lunar Polar Hydrogen Mapper
(LunaH-Map)
PI: Craig Hardgrove
ASU School of Earth and Space Exploration



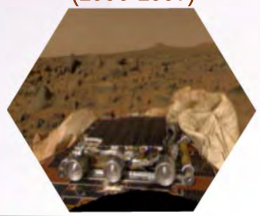
CubeSat Particle Aggregation and Collision Experiment
(Q-PACE)
PI: Josh Colwel
University of Central Florida

Discovery Program

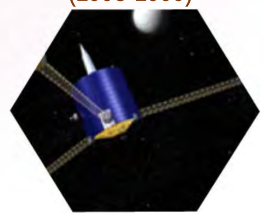
Discovery Program

NEO characteristics
NEAR
(1996-1999)

Mars evolution
Mars Pathfinder
(1996-1997)



Lunar formation
Lunar Prospector
(1998-1999)



Nature of dust/coma
Stardust
(1999-2011)

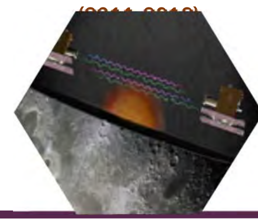
Solar wind sampling
Genesis
(2001-2004)

Comet Diversity
CONTOUR
(2002)

Mercury Environment
MESSENGER
(2004-2015)

Comet Internal Structure
Deep Impact
(2005-2012)

Lunar Internal
Structure
GRAIL



Main-belt Asteroids
Dawn
(2007-TBD)

Exoplanets
Kepler
(2009-TBD)

Lunar Surface
LRO
(2009-TBD)

Mercury Surface
BepiColombo/Strofio
(2018-TBD)

Mars Interior
InSight
(2018)

Trojan Asteroids
Lucy
(2021)

Metal Asteroid
Psyche
(2022)

Martian Moons
MMX/MEGANE
(2024)

Discovery Long-Range Planning

- Cost Cap $495M Phase A-D (FY19) excluding LV
- May propose the use of radio-isotope power systems (RPS) and radioisotope heater units (RHUs)

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

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

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

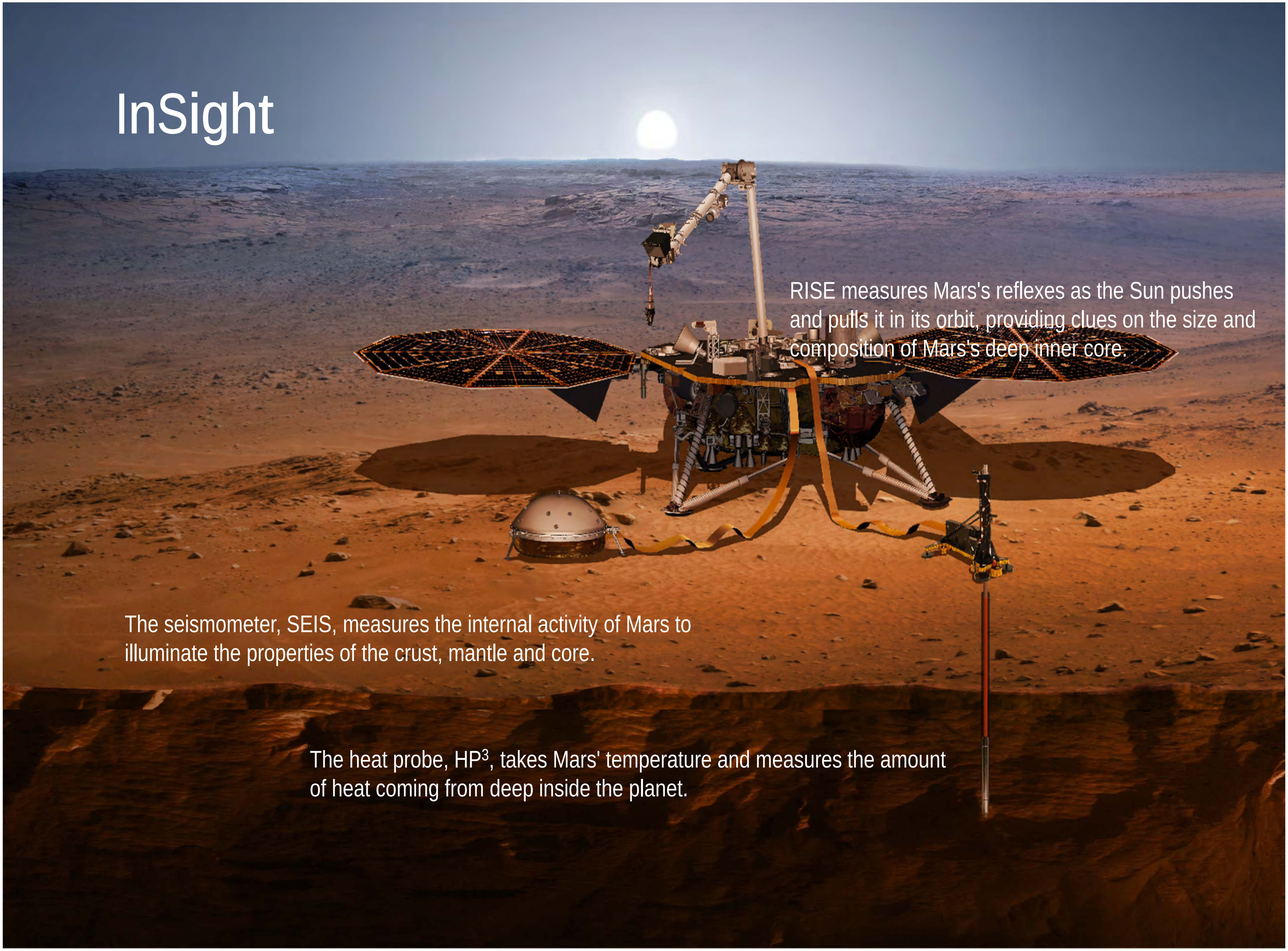
Proposals due .... 90 days after AO release

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

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

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

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


InSight
RISE measures Mars's reflexes as the Sun pushes and pulls it in its orbit, providing clues on the size and composition of Mars's deep inner core.
The seismometer, SEIS, measures the internal activity of Mars to illuminate the properties of the crust, mantle and core.
The heat probe, HP3, takes Mars' temperature and measures the amount of heat coming from deep inside the planet.


NEW Discovery Missions
Psyche
Journey to a Metal World
Launch in 2022
Lucy
Launch in 2021
Surveying the Trojan Asteroids

JAXA: Martian Moons eXploration (MMX) mission

- Phobos sample return, Deimos multi-flyby
- Launch 2024, Return sample in 2029 or 2030
- NASA providing MEGANE - a neutron & gamma-ray spectrometer
  Proposals for NGRS instrument solicited through

New Frontiers Program

New Frontiers Program

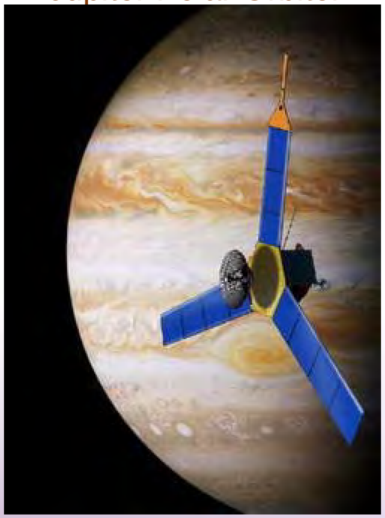
1st NF mission
New Horizons

Pluto-Kuiper Belt

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

2nd NF mission
Juno

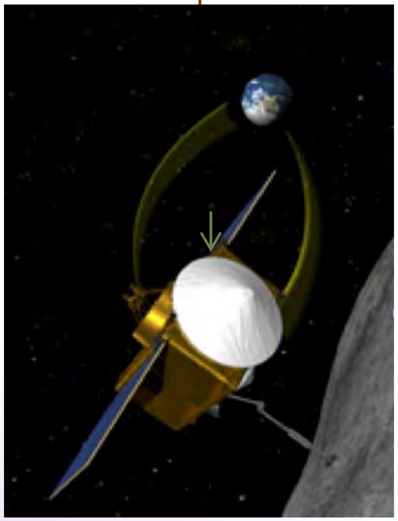
Jupiter Polar Orbiter



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

3rd NF mission
OSIRIS-REx

Asteroid Sample Return



Launched September 2016
PI: Dante Lauretta (UA)

New Frontiers 4 AO

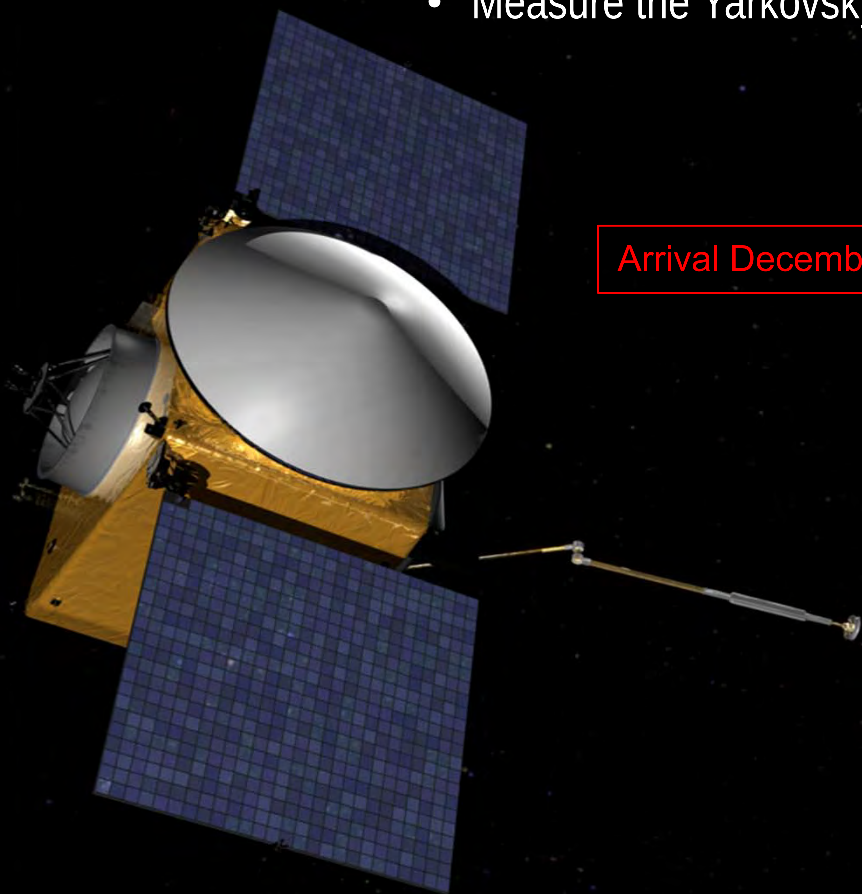
- Two missions selected for Phase A study
  - Dragonfly – helicopter based investigation of Titan
  - CAESAR – Comet Churyumov-Gerasimenko sample return

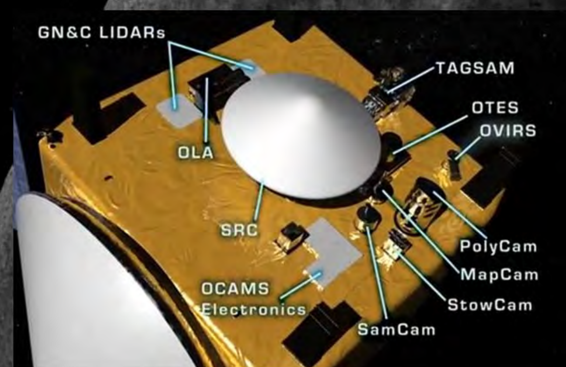
- Phase A Concept Study Reports due.................. December 2018
- Down selection for Flight (target)........................ July 2019
- Launch Readiness Date..............................NLT December 31, 2025

OSIRIS-REx

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

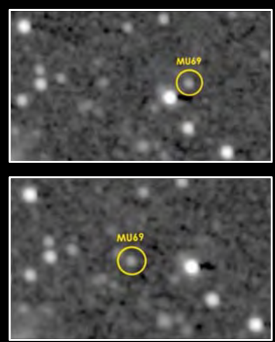
Arrival December 2018





New Horizons

MU69 Next KBO Target

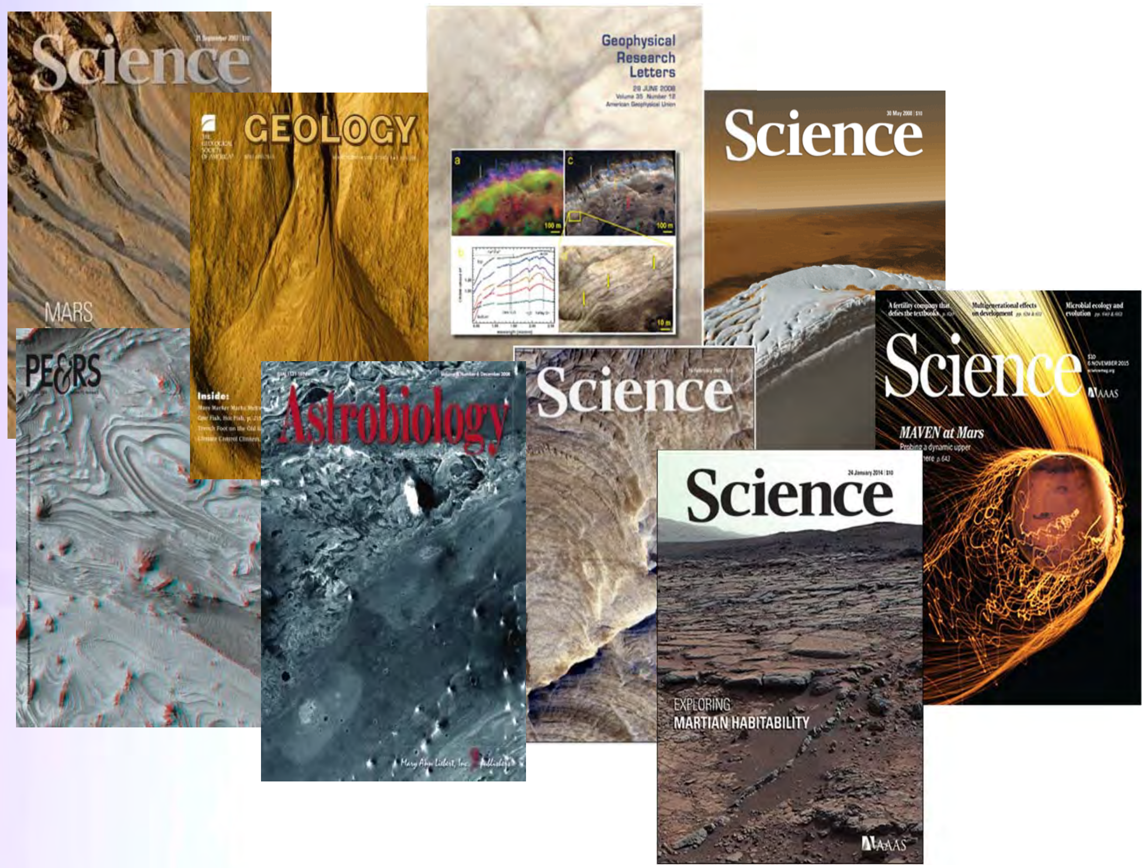


Flyby January 1, 2019

Mars Exploration Program

Mars Science Highlights

- Orbiters and rovers confirmed ancient habitable environment
- Orbiters estimated that Mars has lost over 70% of its atmosphere to interactions with solar wind
- Rovers found evidence of past fresh water, nitrates, organic molecules
- Both revealed complex and evolving planet



6

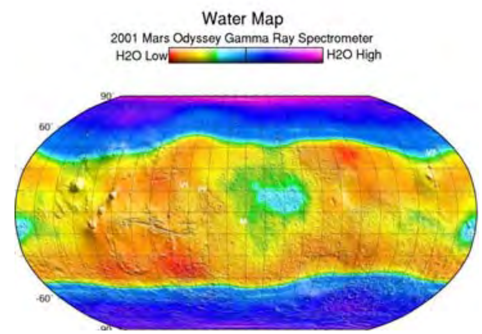
Preparing for Future Human Exploration

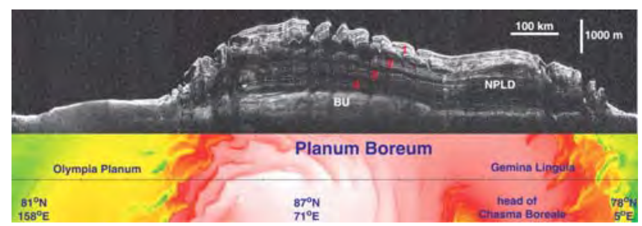
Mars orbiters and landers have:

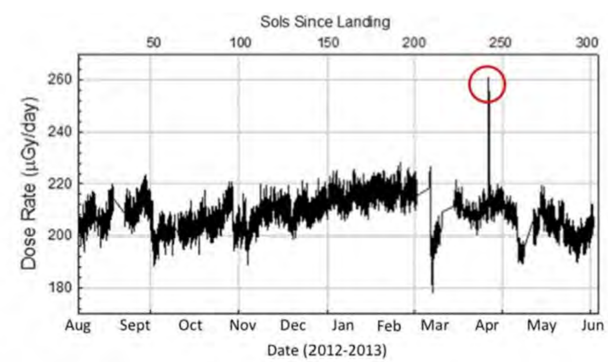
- Found massive ice reserves near poles and mid-latitude remnant glaciers, detected thousands of areas rich in hydrated minerals

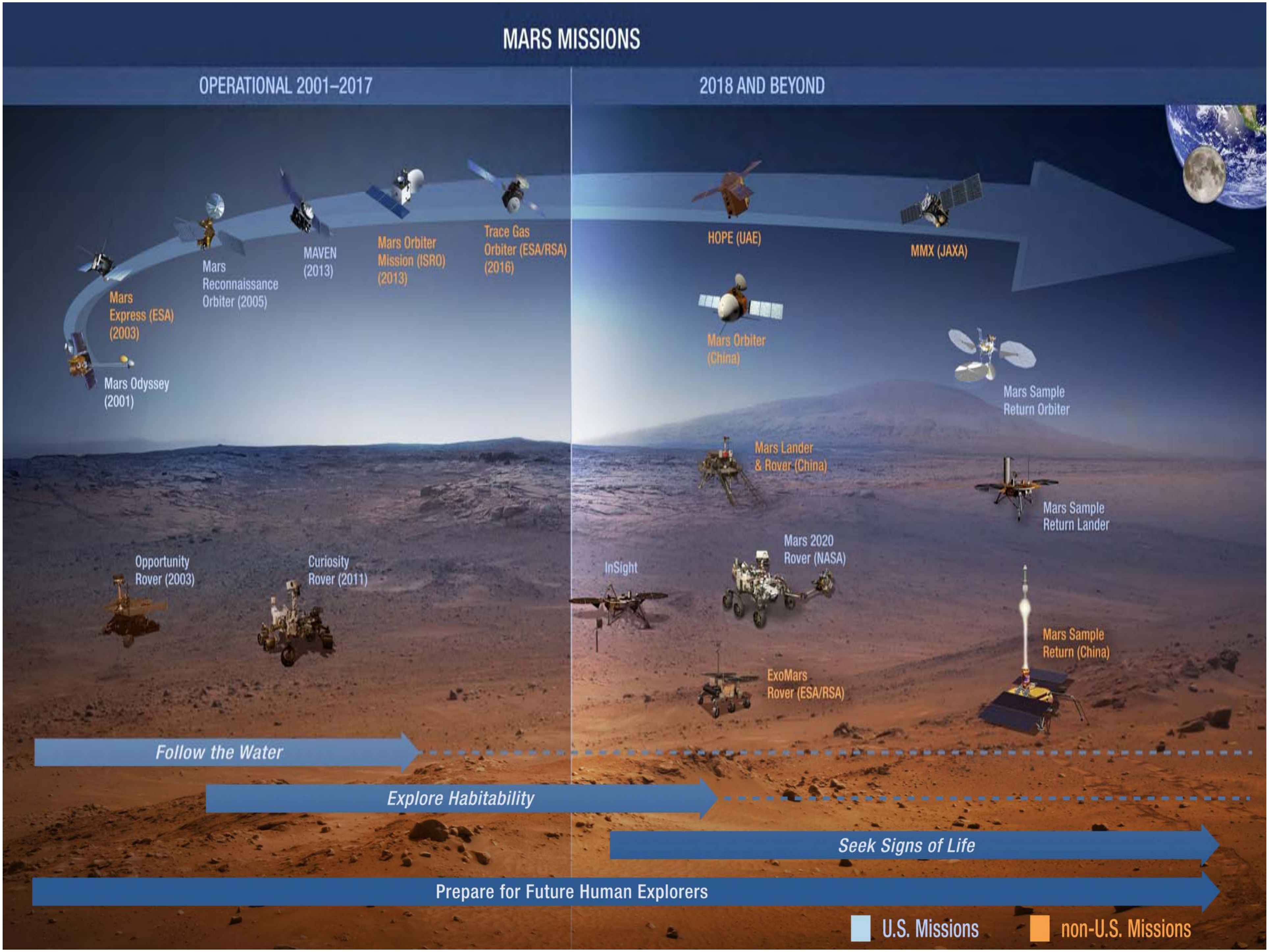
- Recorded temperature, atmospheric pressure, dust, water vapor, wind, and solar visible and UV flux

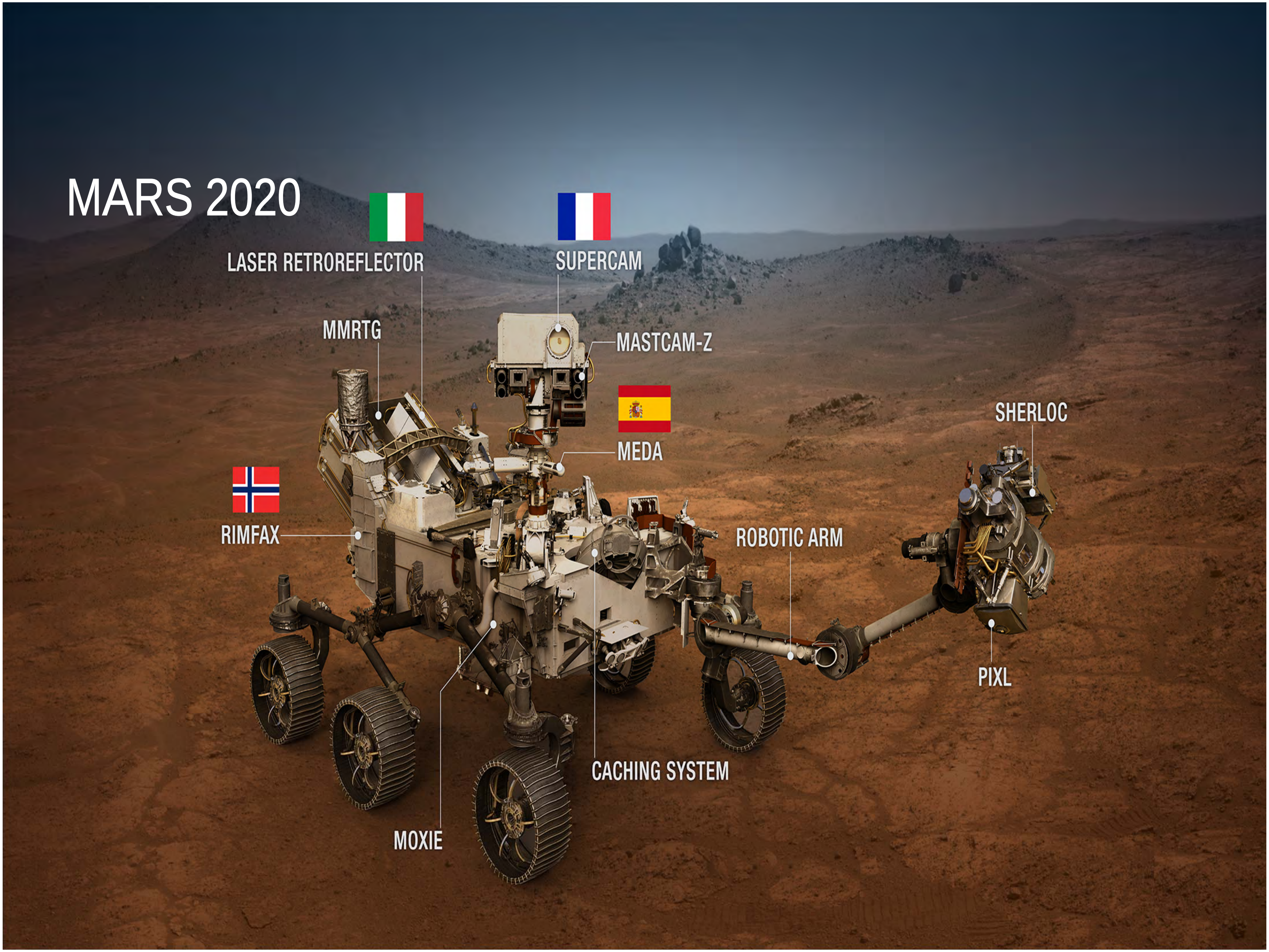
- Measured high-energy radiation doses received during cruise and at the Martian surface, variations with solar cycles and space weather





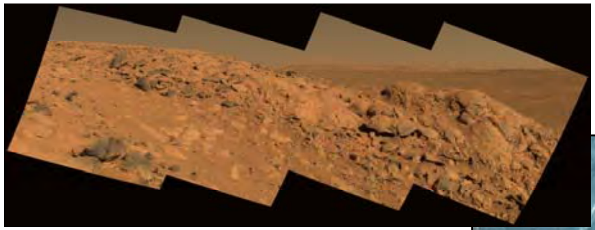



MARS MISSIONS
OPERATIONAL 2001–2017
2018 AND BEYOND
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
HOPE (UAE)
MMX (JAXA)
Mars Orbiter (China)
Mars Sample Return Orbiter
Mars Lander & Rover (China)
Mars Sample Return Lander
Opportunity Rover (2003)
Curiosity Rover (2011)
InSight
Mars 2020 Rover (NASA)
Mars Sample Return (China)
ExoMars Rover (ESA/RSA)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
U.S. Missions
non-U.S. Missions


MARS 2020
LASER RETROREFLECTOR
SUPERCAM
MMRTG
MASTCAM-Z
MEDA
SHERLOC
RIMFAX
ROBOTIC ARM
PIXL
CACHING SYSTEM
MOXIE

Final Mars 2020 Candidate Landing Sites

Final site selection targeted for end of 2018

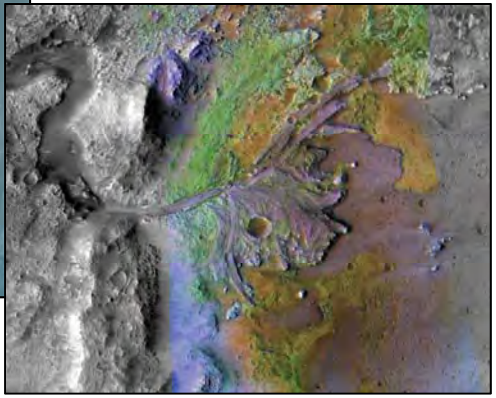


COLUMBIA HILLS

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

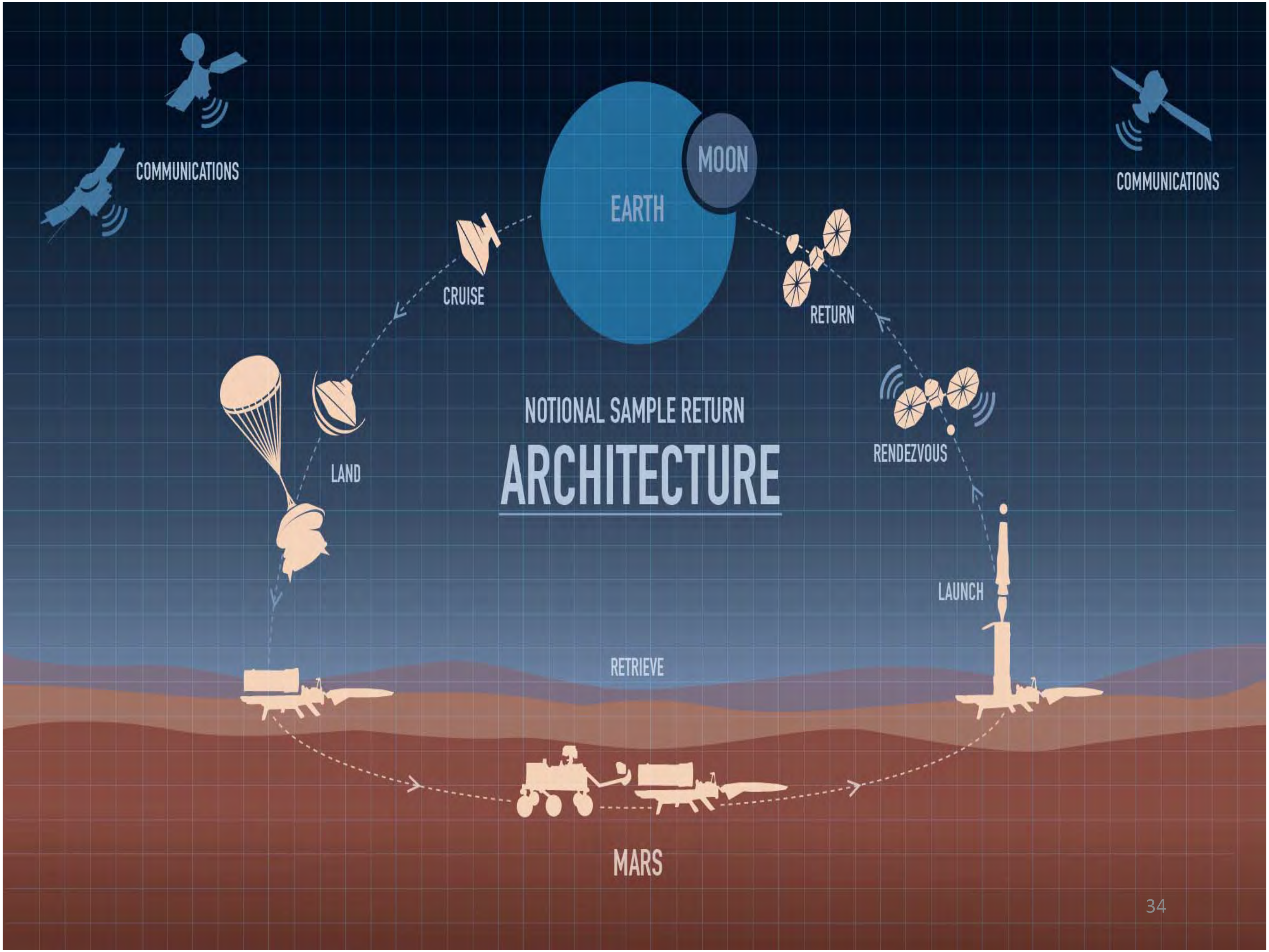
NE SYRTIS

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

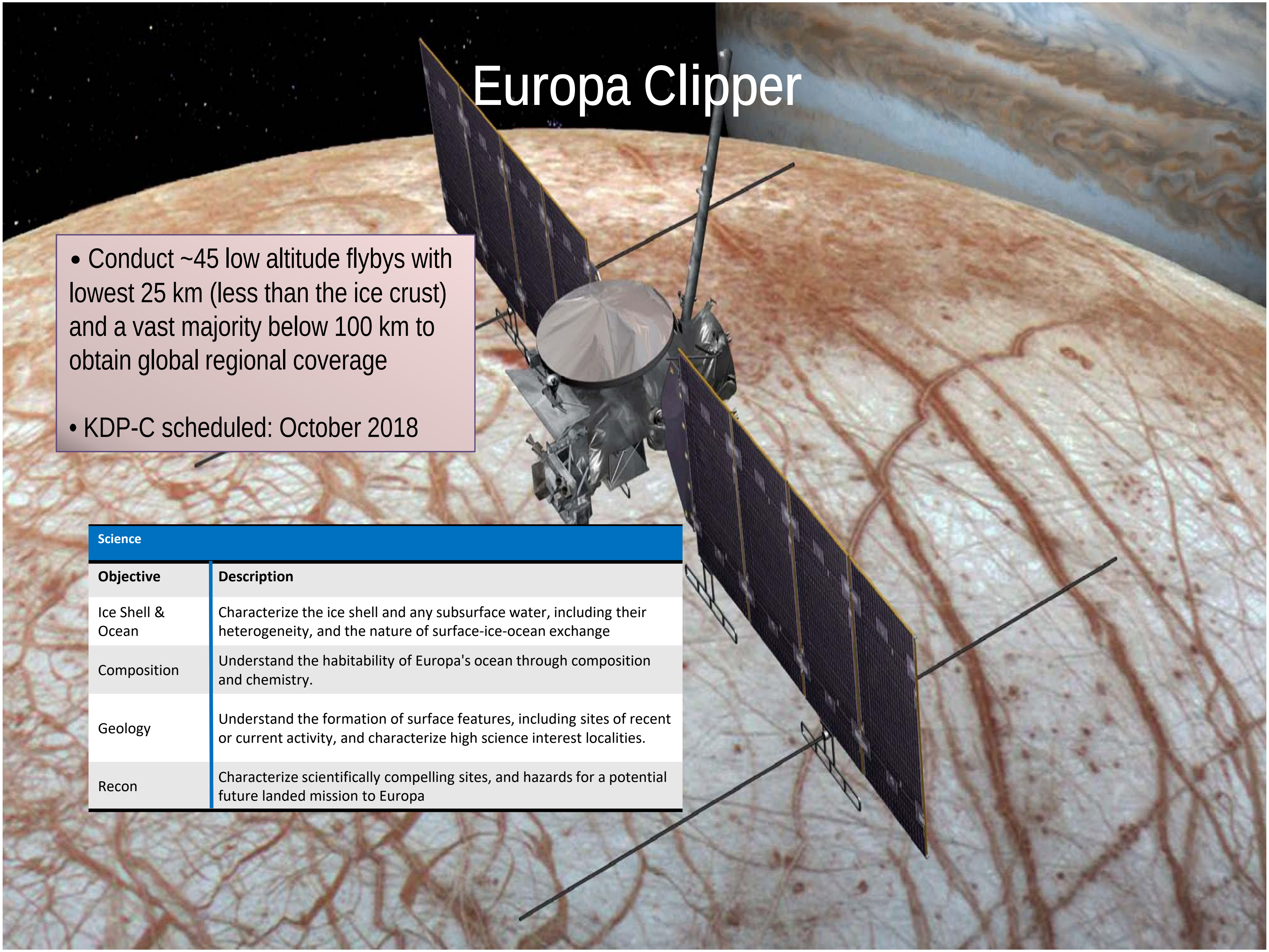


JEZERO

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


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

Outer Planets and Ocean Worlds



Europa Clipper

- 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

- KDP-C scheduled: October 2018

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

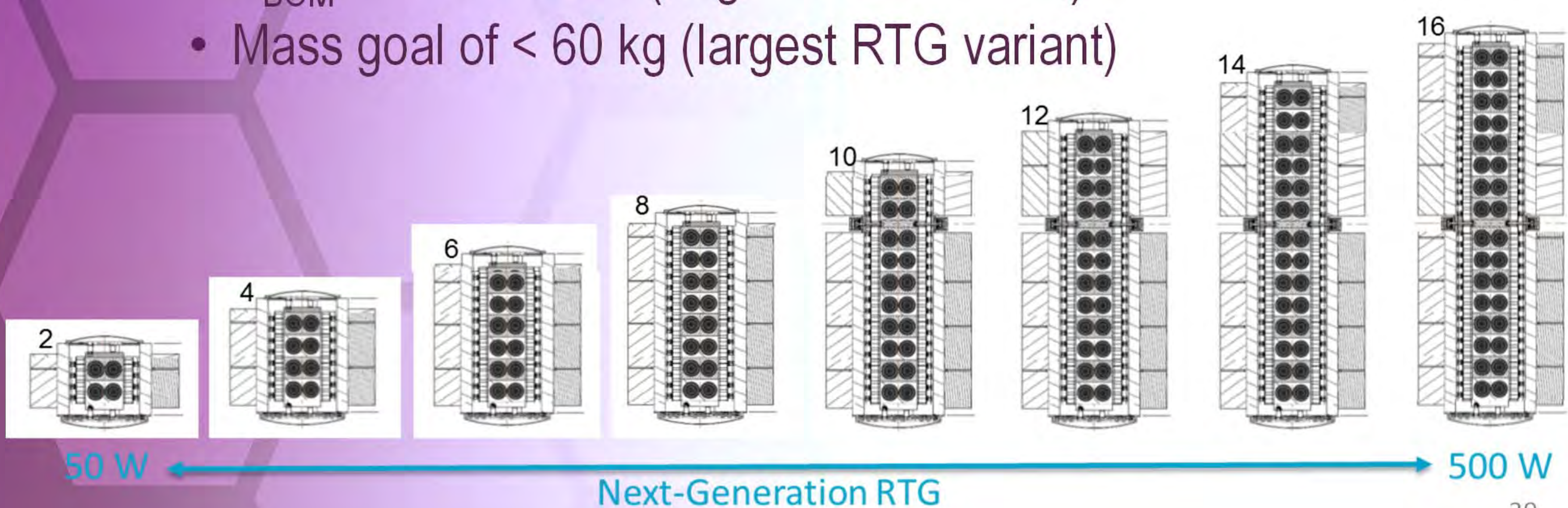
Planetary Science Technology

Planetary Science Technology Investments

- New RPS Capabilities (eMMRTG, NExtGen, DRPS)
- NEXT-C
- Common Atmospheric Probe Study
- Mars Sample Return Earth Entry Vehicle
- Mars Helicopter
- Venus environment
  - HotTech
  - LLISE
  - GEER
- ColdTech/Icy Satellites
  - Tunnelbot Study
  - SESAME

Next-Gen RTG: Driving Requirement

- Final Report of Next-Gen RTG Study team:
  - https://rps.nasa.gov/galleries/reports/
- Level I requirement:
  - The RPS Program shall develop and qualify a new vacuum-rated RPS by 2028.
- Modular
- 16 GPHSs (largest RTG variant)
- P_{BOM} = 400-500 W_e (largest RTG variant)
- Mass goal of < 60 kg (largest RTG variant)



Scientific Exploration Subsurface Access Mechanism for Europa

- The SESAME program is a new opportunity to formulate probe concepts and develop technologies for deep subsurface access on icy ocean worlds
- The objective is to create a system that can penetrate many kilometers of ice to reach subsurface liquid water bodies
- Realistic architectures capable of eventually being flown on a mission are desired (i.e., limited mass, limited power)
- Proposals will be due 3 months after the NRA is released, with selected efforts receiving ~$2M each

Recent Technology Investments to Support Missions

Technology investments to support future missions:

- NEXT, DSOC, HEEET to support Discovery & New Frontiers AO
- Homesteader to prepare instruments for New Frontiers AO
- ICEE to prepare for Europa Clipper Instrument AO
- ICEE2 to prepare for Europa Lander Instrument AO
- HOTTech for high-temperature environments like Venus or Mercury
- PICASSO and MatISSE general instrument maturation
- DALI lunar instrument maturation

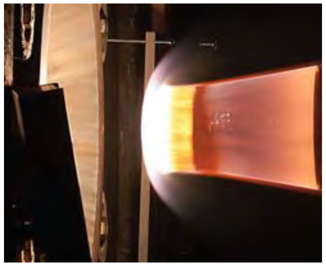
Agency Technology Investments that support Planetary missions

Spacecraft Technology

- Heat Shield for Extreme Entry Environment Technology
- Extreme Environment Solar Power
- Deep Space Engine
- Bulk Metallic Glass Gears
- High Performance Spaceflight Computing
- SPLICE/TRN
- Entry System Modeling

Instruments

- Mars Science Laboratory EDL Instrument II



Heat shield material testing (HEEET)
Potential mass savings for missions to Venus, Mars, and the outer planets

Bulk metallic glass gear testing.
Amorphous metal doesn't get brittle in the cold,
requires no lubricant.

Deep Space Engine
Lower mass, smaller volume,
lower cost for landers and orbiters

QUESTIONS ?