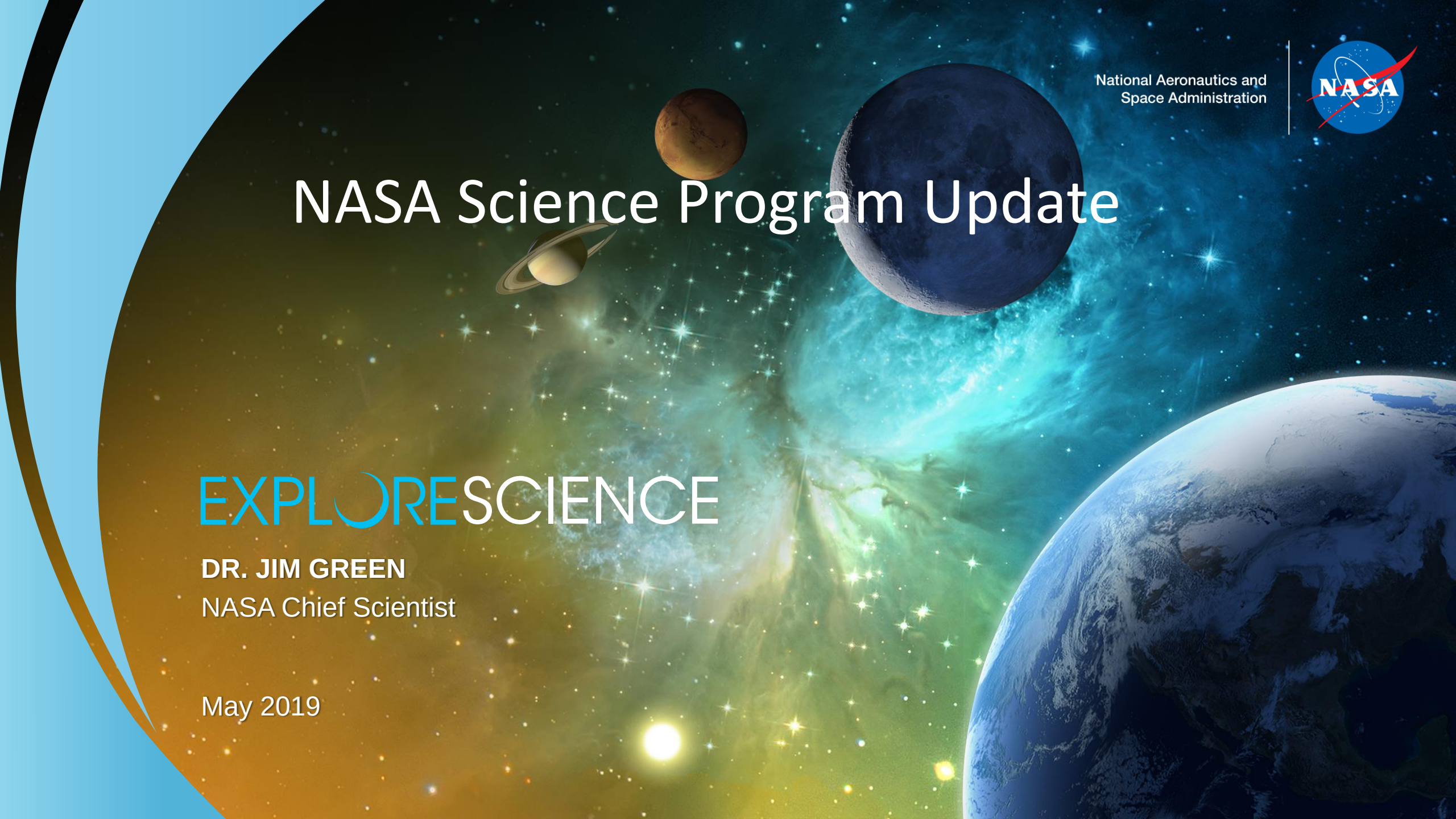
National Aeronautics and Space Administration



NASA Science Program Update

EXPLORESCIENCE

DR. JIM GREEN
NASA Chief Scientist

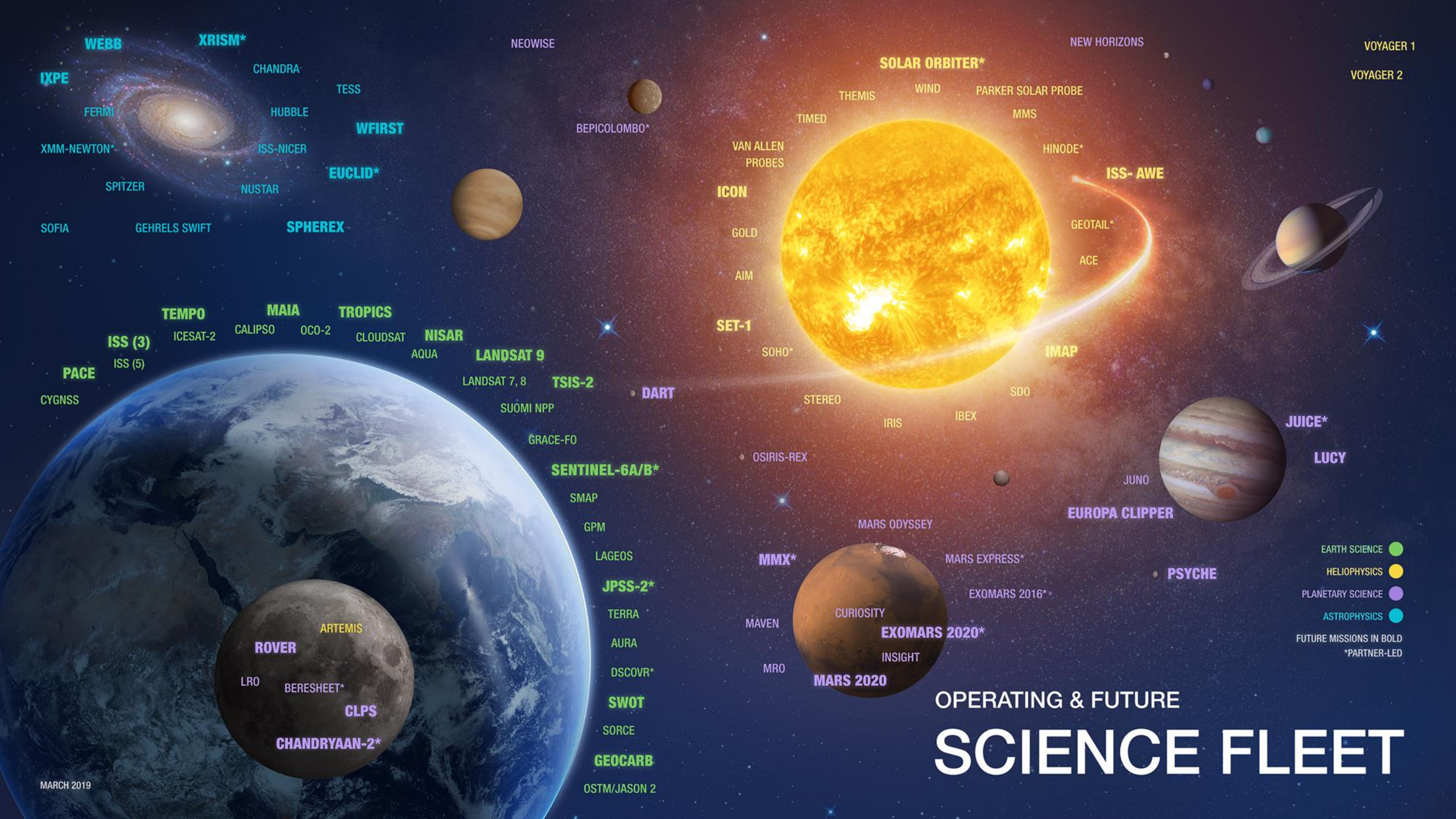
May 2019

Key Science THEMES

Protect & Improve Life on Earth

Discover Secrets of the Universe

Search for Life Elsewhere

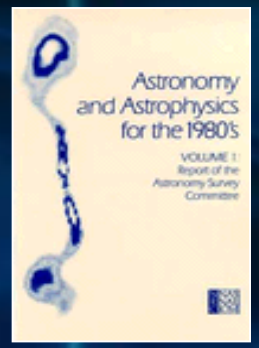


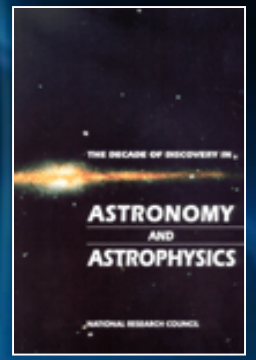
OPERATING & FUTURE

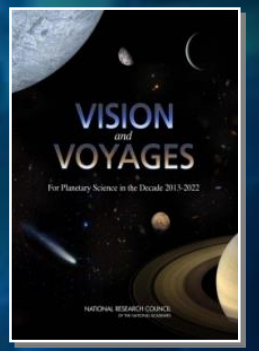
SCIENCE FLEET

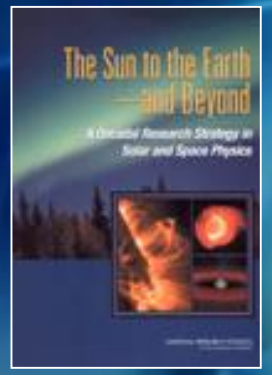
Science Decadal Surveys

- Astronomy and Astrophysics
  1963, 1973, 1982, 1991, 2001, 2010, (2020)
- Planetary Science
  2003, 2011, (2022)
- Heliophysics
  2003, 2012, (2024)
- Earth Science and Applications from Space
  2007, 2018, (2029)
- Biological and Physical Research in Space
  2011, (2022)










Spitzer
8/25/2003
Kepler
3/7/2009
10/30/2018 EOM
Formulation
Implementation
Primary Ops
Extended Ops
WFIRST
Mid 2020s
Euclid (ESA)
2022
Webb
2021
Chandra
7/23/1999
XMM-Newton (ESA)
12/10/1999
TESS
4/18/2018
NuSTAR
6/13/2012
Swift
11/20/2004
Fermi
6/11/2008
IXPE
2021
XRISM (XARM) (JAXA)
2022
SPHEREx
2023
Hubble
4/24/1990
ISS-NICER
6/3/2017
ISS-CREAM
8/14/2017
2/15/2019 EOM
GUSTO
2021
SOFIA
Full Ops 5/2014
+ Athena (early 2030s),
LISA (early 2030s)
FY19 Astrophysics Funded Missions
Revised February 21, 2019

Webb

The James Webb Space Telescope

The Webb payload (telescope + instruments, left) and spacecraft element (spacecraft + sunshield, right) in the clean room in Redondo Beach CA before spacecraft element environmental testing and observatory integration

- Science payload completed three months cryogenic testing at end of 2017
- Spacecraft and sunshield integration complete January 2018
- Spacecraft element including sunshield will complete environmental testing in Summer 2019
- Science payload and spacecraft integration planned for Fall 2019
- Launch scheduled for 2021
- Webb overrun covered using offsets from Astrophysics Probes

Wide-Field Infrared Survey Telescope

Work continues with FY19 funding

2016 – Completed Mission Concept review and began Phase A

2018 – Completed Mission Design review / System requirements Review and began Phase B

2019 – Completing Preliminary Design Reviews

2020 – Complete Confirmation Review and begin Phase C

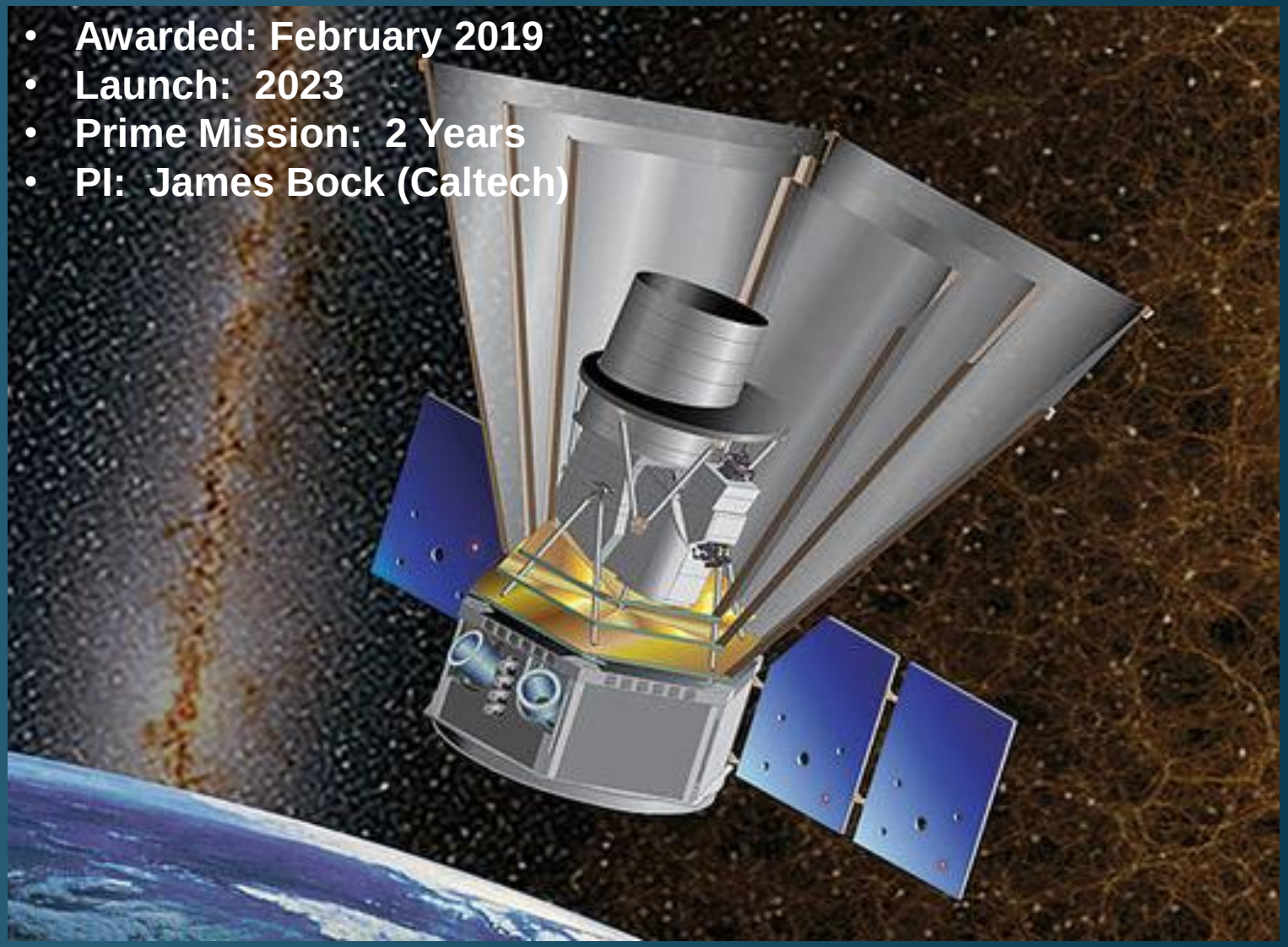
Mid-2020s -- Launch

WFIRST is 100 to 1500 times faster than Hubble for large surveys at equivalent area and depth

Science Program includes

- Dark energy and the fate of the universe through surveys measuring the expansion history of the universe and the growth of structure
- The full distribution of planets around stars through a microlensing survey
- Wide-field infrared surveys of the universe through General Observer and Archival Research programs
- Technology development for the characterization of exoplanets through a Coronagraph Technology Demonstration Instrument

Spectro-Photometer for the History of the Universe Epoch of Reionization and Ices Explorer (SPHEREx)



- Awarded: February 2019
- Launch: 2023
- Prime Mission: 2 Years
- PI: James Bock (Caltech)

Science include:

- Survey the entire sky every 6 months
- Optical and infrared survey mission (96 bands/pixel)
- Observe hundreds of millions of galaxies
  - Measure redshifts to probe the statistical distribution of inflationary ripples
  - Measure spatial fluctuations in the Extragalactic Background Light to support studies of the origin and history of galaxy formation.
- Survey Galactic Molecular Clouds for water and organic molecules (H_2O, CO, CO_2, CH_3OH)

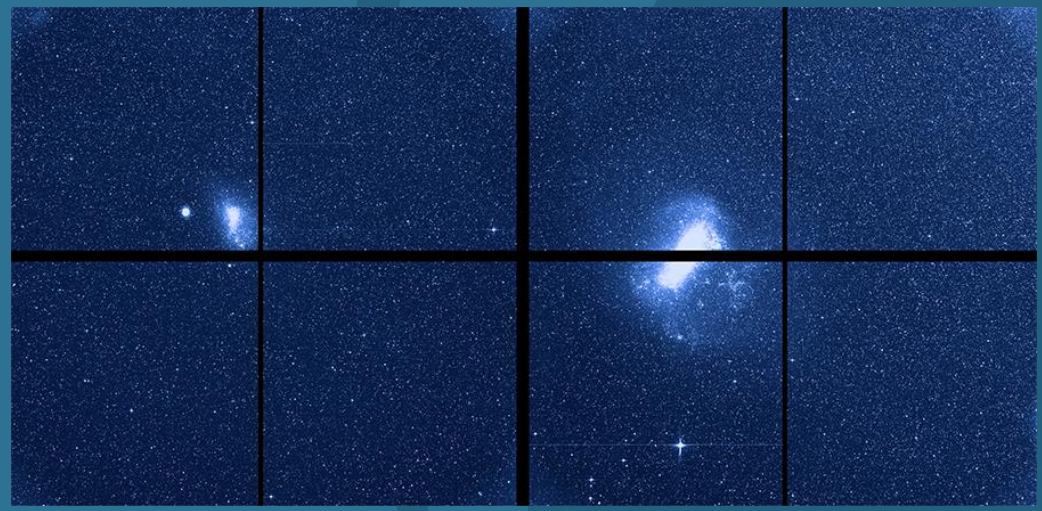
TESS

TRANSITING EXOPLANET SURVEY SATELLITE

TESS by the numbers:

- 8 confirmed planets have been published in peer-reviewed journals
- 364 ***new*** planet candidates have been identified for follow-up ground-based confirmation
- 64 ***previously known*** planets have been re-detected
- 34 TESS papers have so far been submitted to preprint servers; many of which are focused on astrophysics topics other than exoplanets

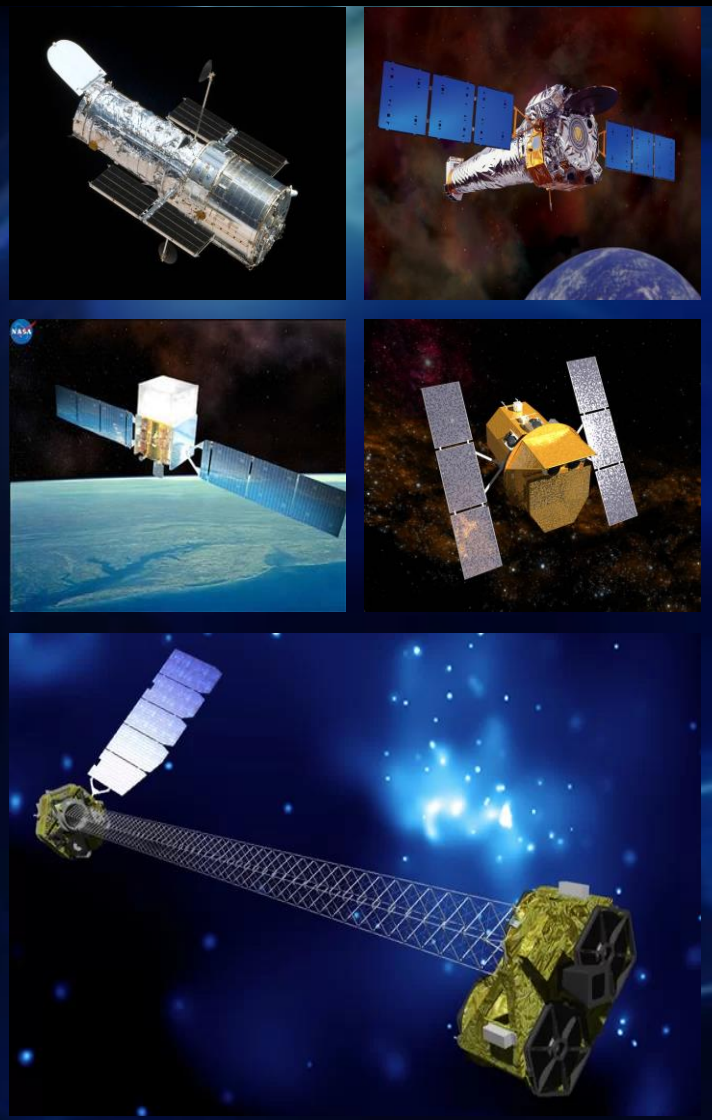
SCIENCE HIGHLIGHT



- *TESS sky survey is more than 25% complete (currently observing sector 10 out of 26)*
- *TESS data is public at MAST*
- *GI program is underway during prime mission (Cycle 1 underway, Cycle 2 proposals received)*

http://archive.stsci.edu/tess/
https://heasarc.gsfc.nasa.gov/docs/tess

Astrophysics Senior Review 2019



- Astrophysics Advisory Committee
  - Senior Review Subcommittee
    - Hubble Panel
    - Chandra Panel
    - Rest-of-Missions Panel

- **Chandra X-ray Observatory (Chandra)**
- **Fermi Gamma-ray Space Telescope (Fermi)**
- **Hubble Space Telescope (Hubble)**
- **Neutron star Interior Composition Explorer (NICER)**
- **Nuclear Spectroscopic Telescope Array (NuSTAR)**
- **Neil Gehrels Swift Observatory (Swift)**
- **Transiting Exoplanet Survey Satellite (TESS)**
- **X-ray Multi-mirror Mission-Newton (XMM-Newton)**

- **Not in Senior Review: SOFIA, Spitzer**

SOFIA

Stratospheric Observatory for Infrared Astronomy

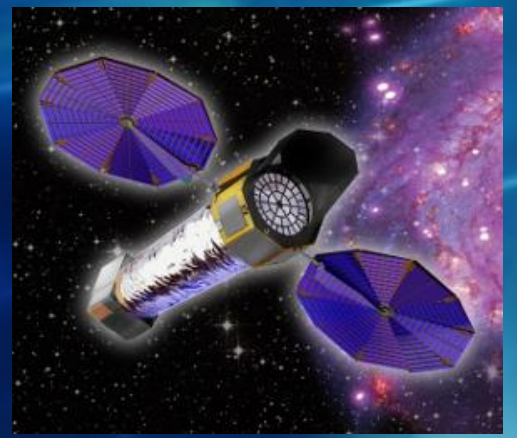
- **SOFIA's 5-year prime mission will be completed at the end of FY19**
- **At the end of a prime mission, NASA usually assesses the science performance, management of a program and proposed future science to decide on an extension of the program through a Senior Review Process, as required by the NASA Authorization Act of 2005**
- **The Explanatory Statement accompanying the FY2018 Consolidated Appropriations Act, however, forbade NASA from placing SOFIA in the 2019 Senior Review**
- **Given that the program has finished 5 years of operations, the time is appropriate to review 2 aspects of the SOFIA Project:**
  - SOFIA's maintenance and operations paradigm
  - SOFIA's science progress and science prospects
- **The reviews will not consider closeout or cancellation of SOFIA**

Decadal Survey Planning

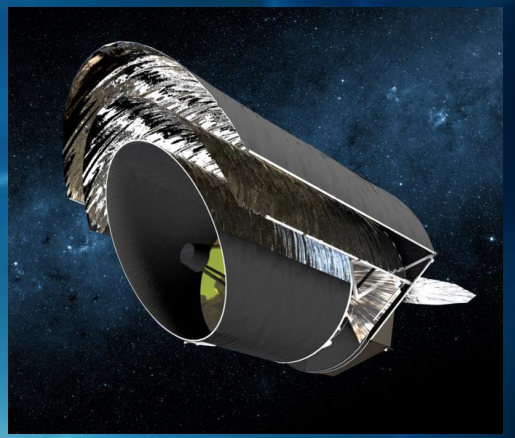
- **NASA has initiated studies for large (Flagship) and medium (Probe) size mission concepts to inform the 2020 Decadal Survey Committee in an organized and coherent way**
- Primary purpose is to provide the Decadal Survey Committee with several well-defined mission concepts to inform their deliberations

HabEx

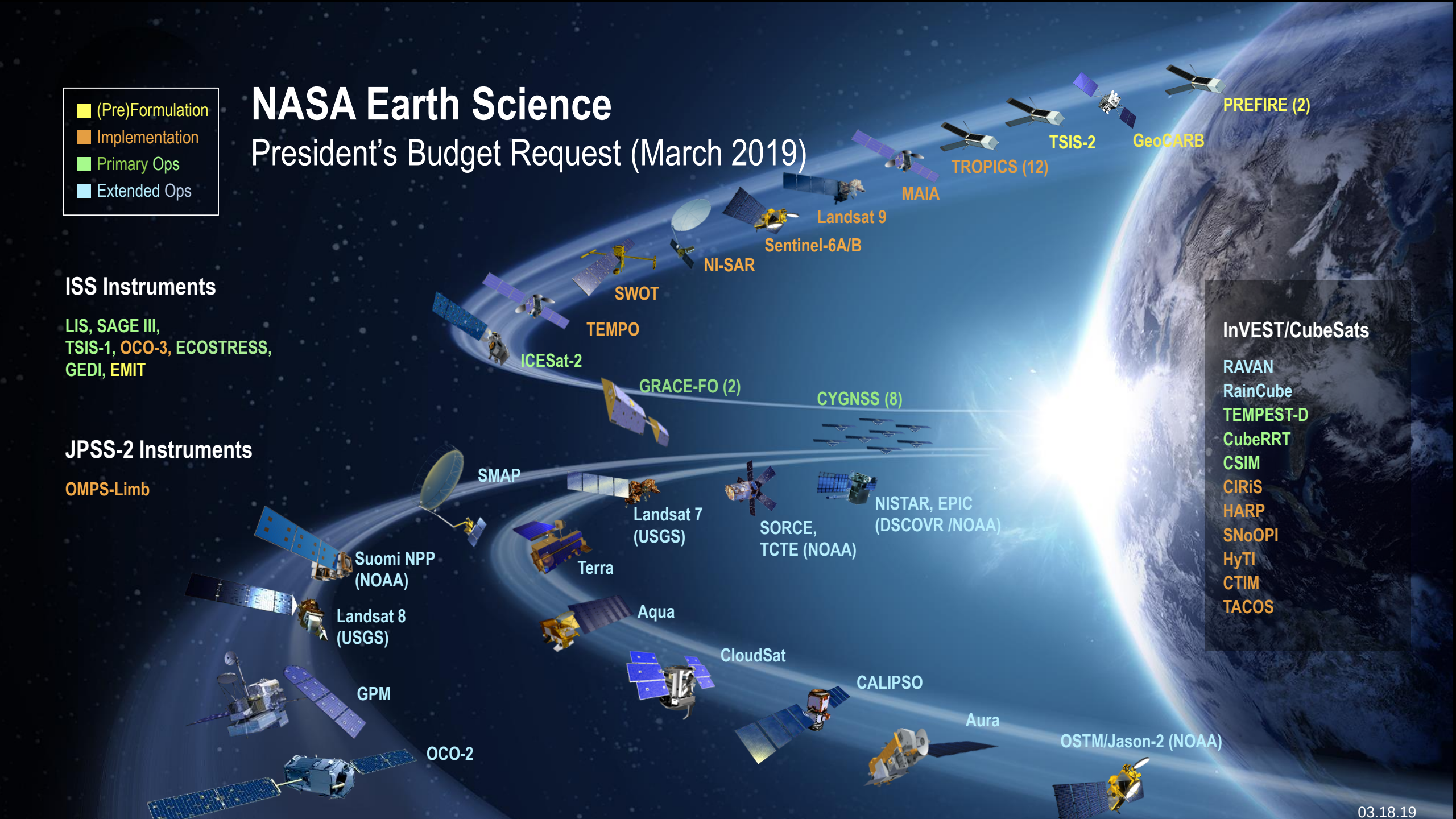
LUVOIR



Lynx



Origins


(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
President's Budget Request (March 2019)
ISS Instruments
LIS, SAGE III,
TSIS-1, OCO-3, ECOSTRESS,
GEDI, EMIT
JPSS-2 Instruments
OMPS-Limb
PREFIRE (2)
GeoCARB
TSIS-2
TROPICS (12)
MAIA
Landsat 9
Sentinel-6A/B
NI-SAR
SWOT
TEMPO
ICESat-2
GRACE-FO (2)
CYGNSS (8)
SMAP
Landsat 7
(USGS)
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(DSCOVR /NOAA)
Suomi NPP
(NOAA)
Terra
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
OCO-2
OSTM/Jason-2 (NOAA)
InVEST/CubeSats
RAVAN
RainCube
TEMPEST-D
CubeRRT
CSIM
CIRiS
HARP
SNoOPI
HyTI
CTIM
TACOS
03.18.19

NASA Earth Science

Current Operating Missions
International Collaborations

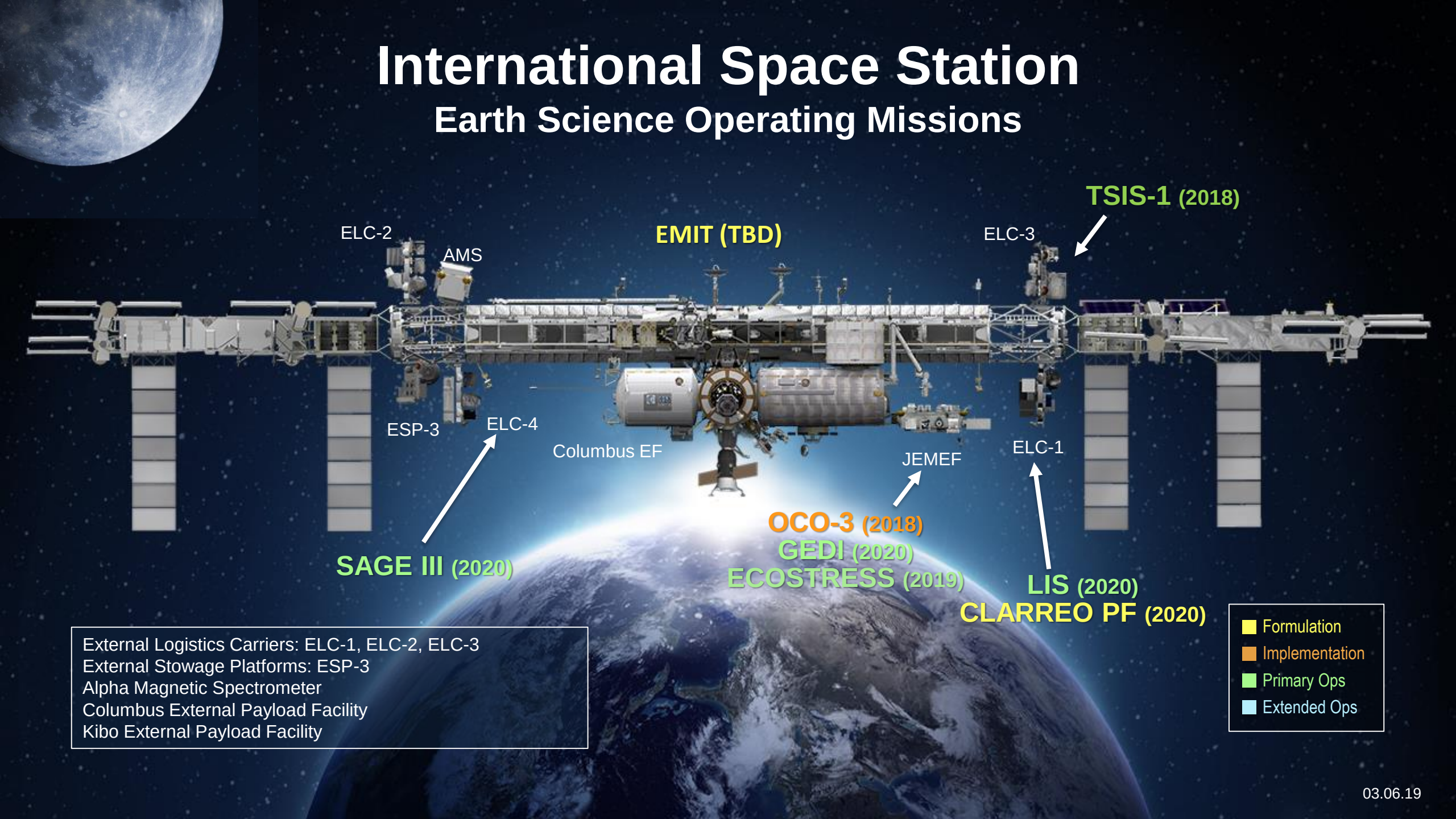
InVEST/CubeSats

- RAVAN
- RainCube
- TEMPEST-D
- CubeRRT
- CSIM

03.18.19

International Space Station

Earth Science Operating Missions



External Logistics Carriers: ELC-1, ELC-2, ELC-3
External Stowage Platforms: ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

- Formulation
- Implementation
- Primary Ops
- Extended Ops

03.06.19

Recent and Near-Term Planned ESD Launches (1 of 2)

TSIS-1: DEC 15, 2017

GRACE-FO: May 22, 2018

ECOSTRESS: June 29, 2018

TSIS-1 *The Total and Spectral Solar Irradiance Sensor (TSIS-1) is measuring the total amount of sunlight that falls on Earth, and how that light is distributed among the ultraviolet, visible and infrared wavelengths.*

GRACE-FO *Obtaining high resolution global models of Earth's gravity field, including how it varies over time*

ECOSTRESS *Providing insight into plant-water dynamics & how ecosystems change with climate via high spatiotemporal resolution thermal infrared radiometer measurements of evapotranspiration (ET)*

Recent and Near-Term Planned ESD Launches (2 of 2)

ICESat-2: Sep 15, 2018

GEDI: Dec 5, 2018

OCO-3: May 4, 2019

ICESat-2 *Quantifying polar ice-sheet contributions to sea-level change & measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change*

GEDI *Characterize the effects of changing climate and land use on ecosystem structure and dynamics, providing the first global, high-resolution observations of forest vertical structure*

OCO-3 *Investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion.*

Earth Science Division's Venture Opportunities

EVS
Sustained Sub-Orbital Investigations
(~4 years)

EVM
Complete, self-contained, small missions
(~4 years)

EVI
Full function, facility-class instruments Missions of Opportunity (MoO)
(~18 months)

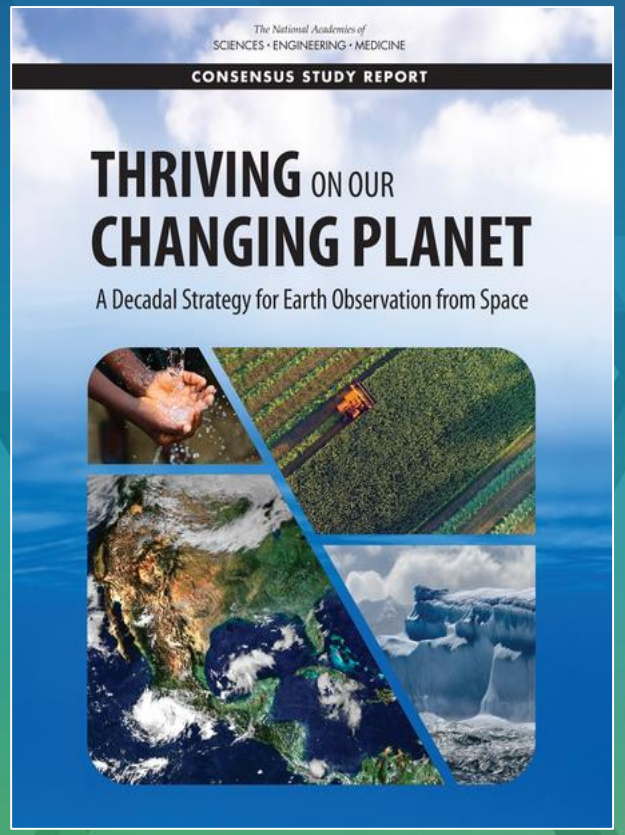
Mission	Mission Type	Release Date	Selection Date	Major Milestone
EV-1, aka EVS-1	5 Suborbital Airborne Campaigns	2009	2010	N/A
EVM-1, CYGNSS	Smallsat constellation	2011	2012	Launched Dec 2016
EVI-1, TEMPO	Geosynchronous hosted payload	2011	2012	Delivery NLT 2017
EVI-2, ECOSTRESS & GEDI	Class C & Class D ISS-hosted Instruments	2013	2014	Delivery NLT 2019
EVS-2	6 Suborbital Airborne Campaigns	2013	2014	N/A
EVI-3, MAIA & TROPICS	Class C LEO Instrument & Class D Cubesat Constellation	2015	2016	Delivery NLT 2021
EVM-2, GeoCarb	Geostationary hosted payload	2015	2016	Launch ~2021
EVI-4	Instrument Only	2016	2018	Delivery NLT 2021
EVS-3	Suborbital Airborne Campaigns	2017	2018	N/A
EVI-5	Instrument Only	2018	2019	Delivery NLT 2023
EVM-3	Full Orbital	2019	2020	Launch ~2025
EVI-6	Instrument Only	2019	2020	Delivery NLT 2024

EMIT, PREFIRE selected for EVI-4

Open solicitation - In Review

Completed solicitation

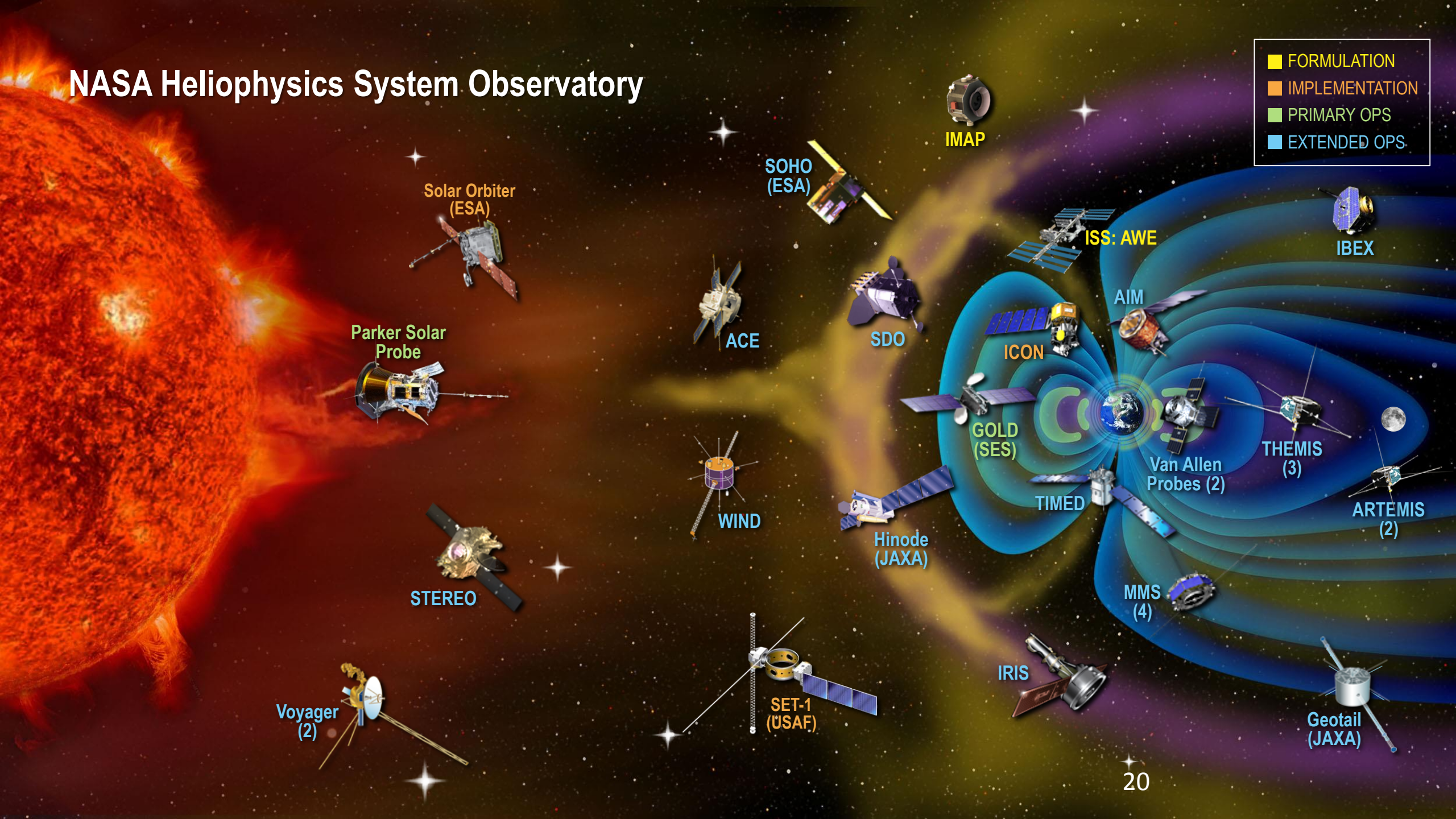
2017 Decadal Survey Snapshot



Released

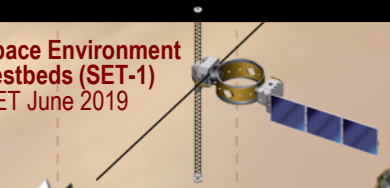
January 5, 2018

- Endorses existing balances in ESD portfolio
- Prioritizes observations rather than specific missions and allows implementation flexibility
- Encourages and notes value of international partnerships
- Recommends “Continuity Measurement” ($150M full mission cost cap) as an addition to the existing Venture-class program
- Identifies 5 mandatory observables (Aerosols; Clouds, Convection, & Precipitation; Mass Change; Surface Biology & Geology; Surface Deformation & Change)
- Introduces a new competed “Explorer” flight line at $350M cost cap
- Calls for “Incubator Program to mature specific technologies in preparation for next Decadal

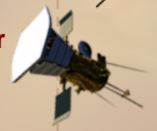

NASA Heliophysics System Observatory
FORMULATION
IMPLEMENTATION
PRIMARY OPS
EXTENDED OPS
IMAP
SOHO (ESA)
Solar Orbiter (ESA)
ISS: AWE
IBEX
ACE
SDO
AIM
ICON
Parker Solar Probe
GOLD (SES)
Van Allen Probes (2)
THEMIS (3)
WIND
TIMED
ARTEMIS (2)
Hinode (JAXA)
STEREO
MMS (4)
IRIS
SET-1 (USAF)
Voyager (2)
Geotail (JAXA)

Heliophysics Programs (2018-2030)

Living With a Star

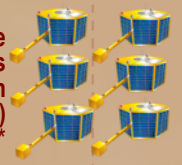


Space Environment Testbeds (SET-1)
NET June 2019



Parker Solar Probe
August 2018

Solar Orbiter Collaboration (with ESA)
February 2020

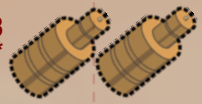


Geospace Dynamics Constellation (GDC)
NET 2029*

MO w/ GDC
NET 2029*

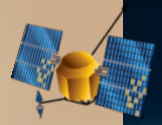
Solar Terrestrial Probes

Interstellar Mapping and Acceleration Probe (IMAP)
NET 2024*



Science MO '18
NET 2024*

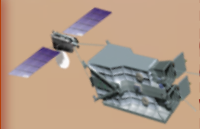
Tech Demo MO '18
NET 2024*



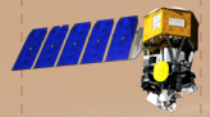
STP-6
NET 2030*

MO w/ STP-6
NET 2030*

Explorers



Global-scale Observations of the Limb and Disk (GOLD)
January 2018



Ionospheric Connection Explorer (ICON)
NET Q1 2019

SMEX '16
NET 2022*

AWE
NET Aug 2022

MIDEX '19
NET 2025*

Science MO '18
NET 2024*

SMEX '21
NET 2028*

MO '21
NET 2028*

Research Program

ELFIN-STAR, Sep 2018
MinXSS, Dec 2018
CeREs, Dec 2018

TBEx, Jun 2019
SORITE, 2019
CuPID, 2019

BITSE, Sep 2019

AZURE – Mar 2019, x2
CLASP-2 – Apr 2019
SHIELDS – Apr 2019

TOOWINDY – Jun 2019, x2
RockOn – Jun 2019

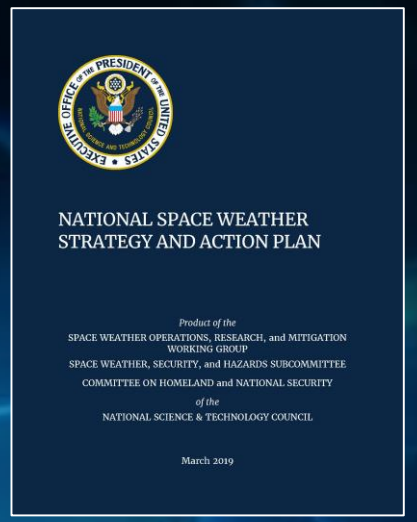
Ongoing

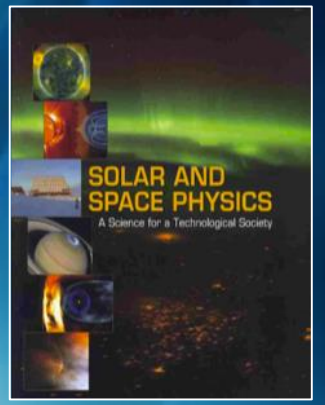
* notional

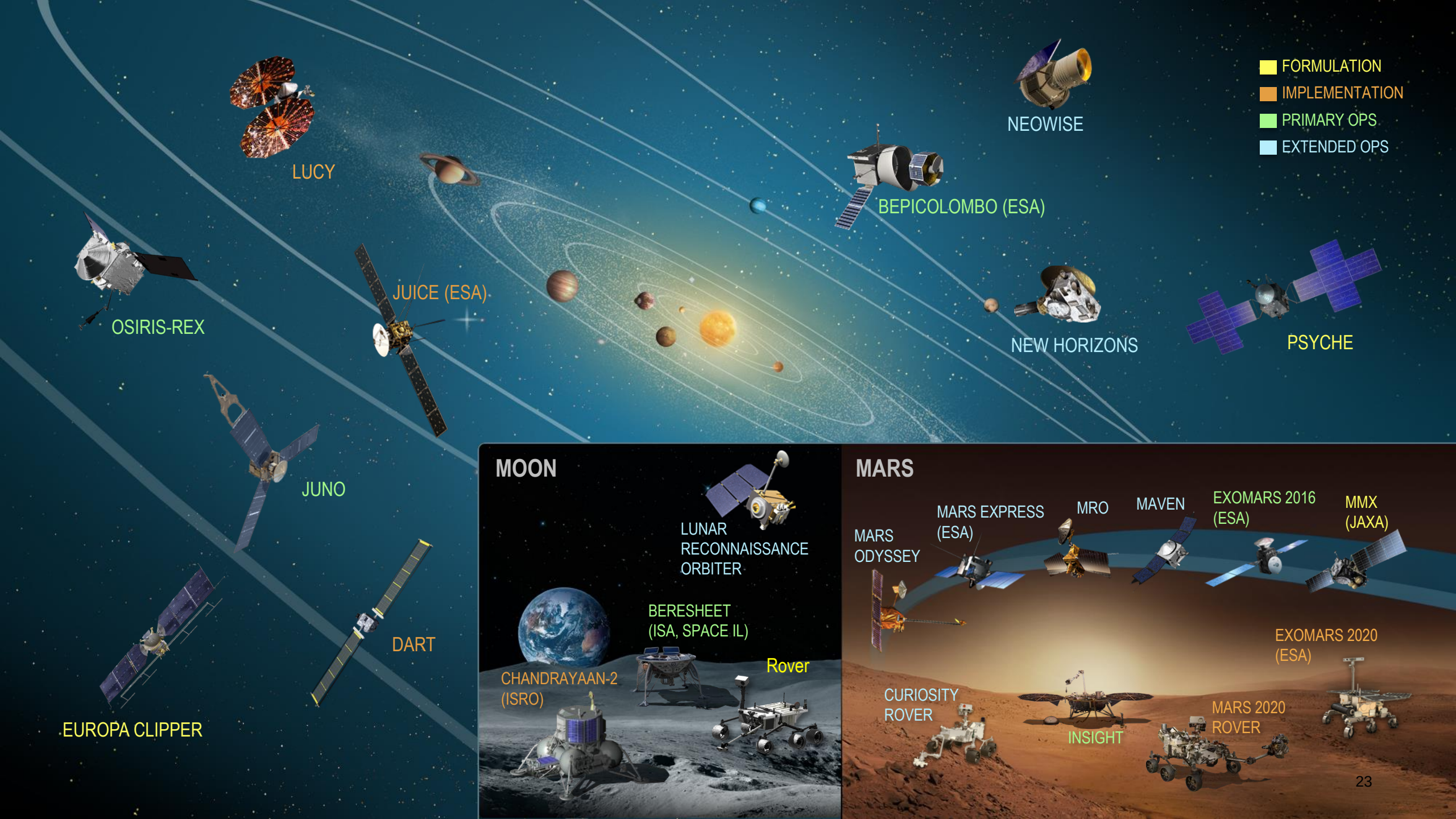
2018 2020 2022 2024 2026 2028 2030

Space Weather Science Applications Program

- **Establishes an expanded role for NASA in space weather science under single budget element**
  - Consistent with recommendation of the NRC Decadal Survey and the 2019 National Space Weather Strategy and Action Plan
- **Competes ideas and products, leverages existing agency capabilities, collaborates with other national and international agencies, and partners with user communities**
- **Main areas of the Space Weather Science Applications Program are:**
  - Collaboration – MOU with NOAA & NSF
  - Competed Elements – ROSES, SBIR
  - Directed Components – CCMC and HEC





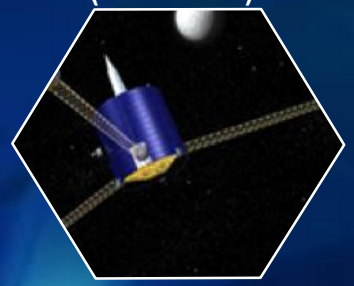

FORMULATION
IMPLEMENTATION
PRIMARY OPS
EXTENDED OPS
LUCY
NEOWISE
BEPICOLOMBO (ESA)
OSIRIS-REX
JUICE (ESA)
NEW HORIZONS
PSYCHE
JUNO
DART
EUROPA CLIPPER
MOON
LUNAR RECONNAISSANCE ORBITER
BERESHEET (ISA, SPACE IL)
Rover
CHANDRAYAAN-2 (ISRO)
MARS
MARS ODYSSEY
MARS EXPRESS (ESA)
MRO
MAVEN
EXOMARS 2016 (ESA)
MMX (JAXA)
EXOMARS 2020 (ESA)
CURIOSITY ROVER
INSIGHT
MARS 2020 ROVER

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)

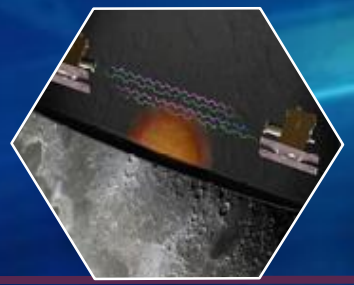
Solar wind sampling
Genesis
(2001-2004)

Comet Diversity
CONTOUR
(2002)

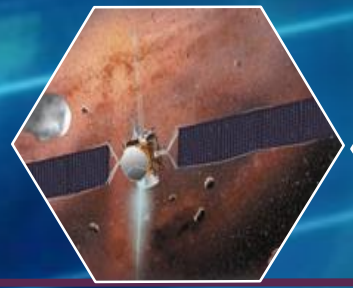
Mercury Environment
MESSENGER
(2004-2015)

Comet Internal Structure
Deep Impact
(2005-2012)

Lunar Internal Structure
GRAIL
(2011-2012)



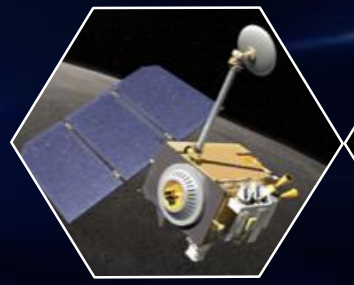
Main-belt Asteroids
Dawn
(2007-TBD)



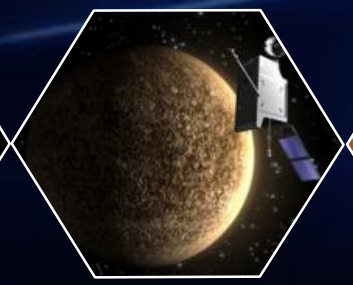
Exoplanets
Kepler
(2009-TBD)

Currently Operating

Lunar Surface
LRO
(2009-TBD)



ESA/Mercury
Surface
Strofio



Mars Interior
InSight
(2018)

Trojan Asteroids
Lucy
(2021)

Metal Asteroid
Psyche
(2022)

Martian Moons
MMX/MEGANE
(2024)

New Frontiers Program

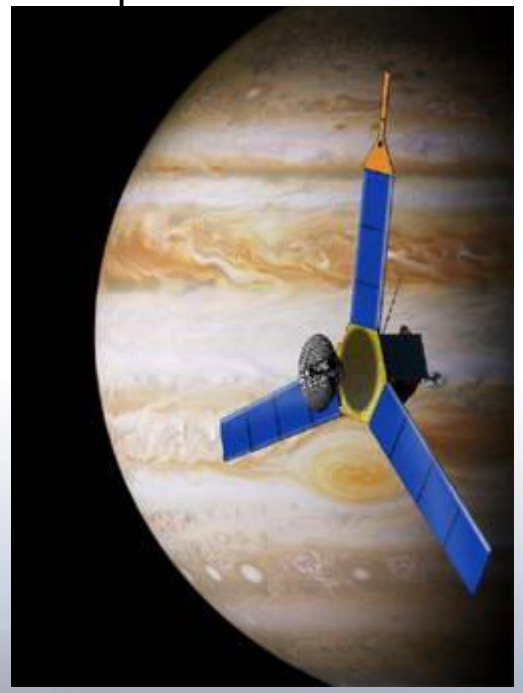
1st NF mission
New Horizons

Pluto-Kuiper Belt

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

2nd NF mission
Juno

Jupiter Polar Orbiter



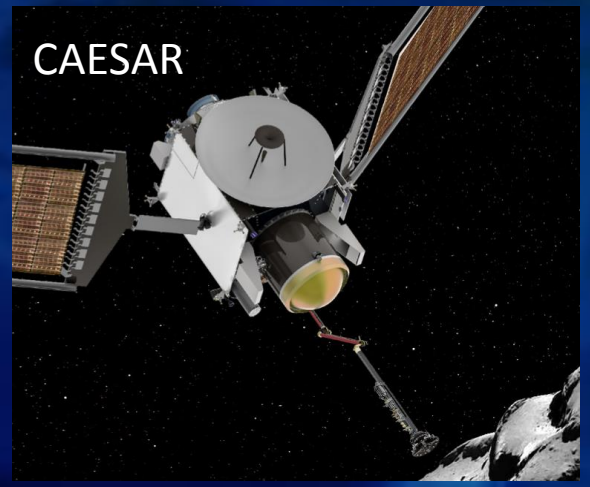
Launched August 2011
Arrived July 4, 2016
PI: Scott Bolton (SwRI-TX)

3rd NF mission
OSIRIS-REx

Asteroid Sample Return

Launched September 2016
Arrived December 2018
PI: Dante Lauretta (UA)

Upcoming Missions



Small Innovative Missions for Planetary Exploration (SIMPLEx)

- Step-1 reviews were completed before shutdown
- Step-1 selection to be scheduled NET April 12, 2019

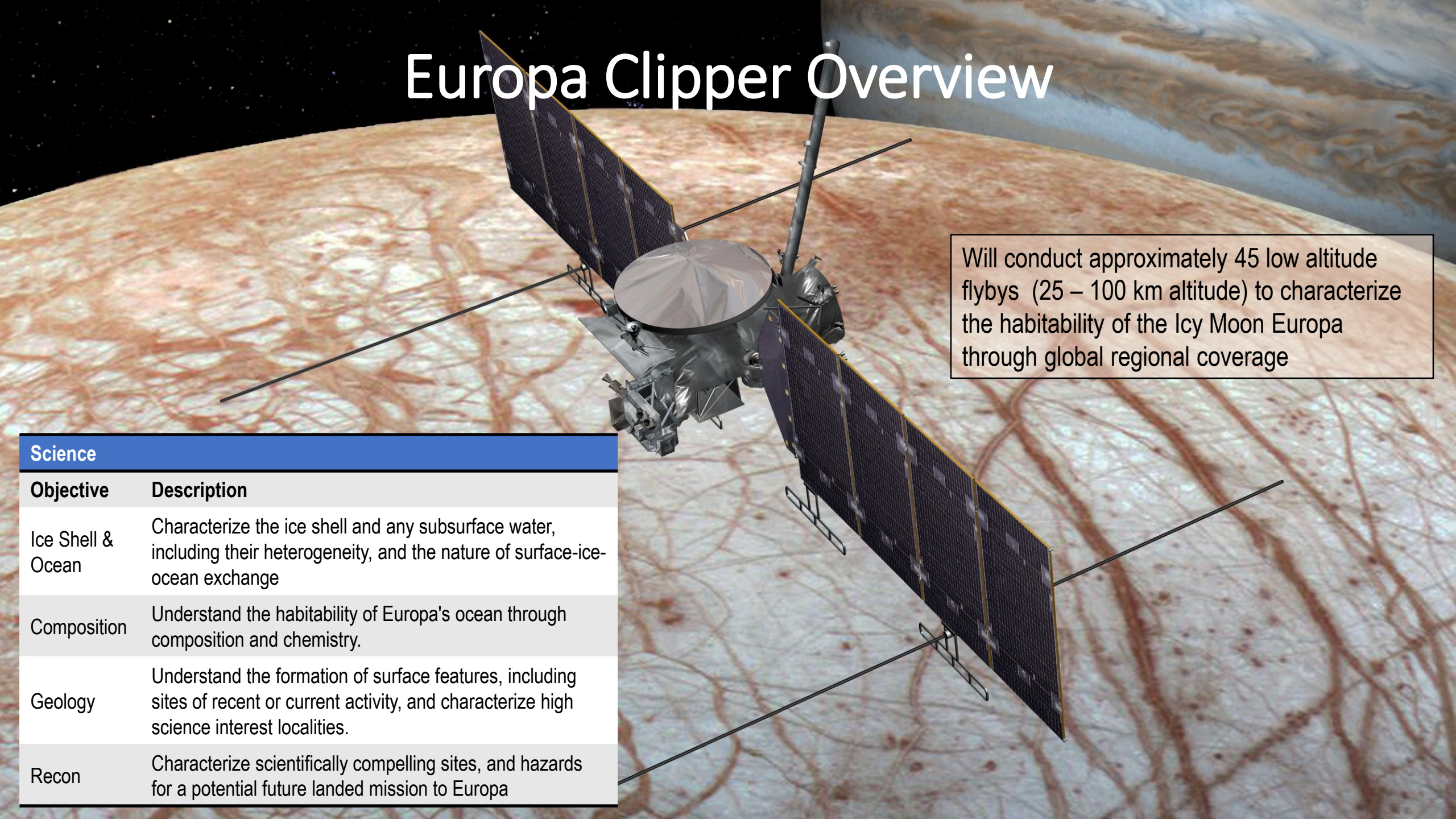
New Frontiers #4 Down-selection

- New Step-2 evaluation schedule incorporates a four-week slip in site visits
- Plenary Meetings have been rescheduled
- Down-selection announcement still expected in July 2019

Discovery 2019

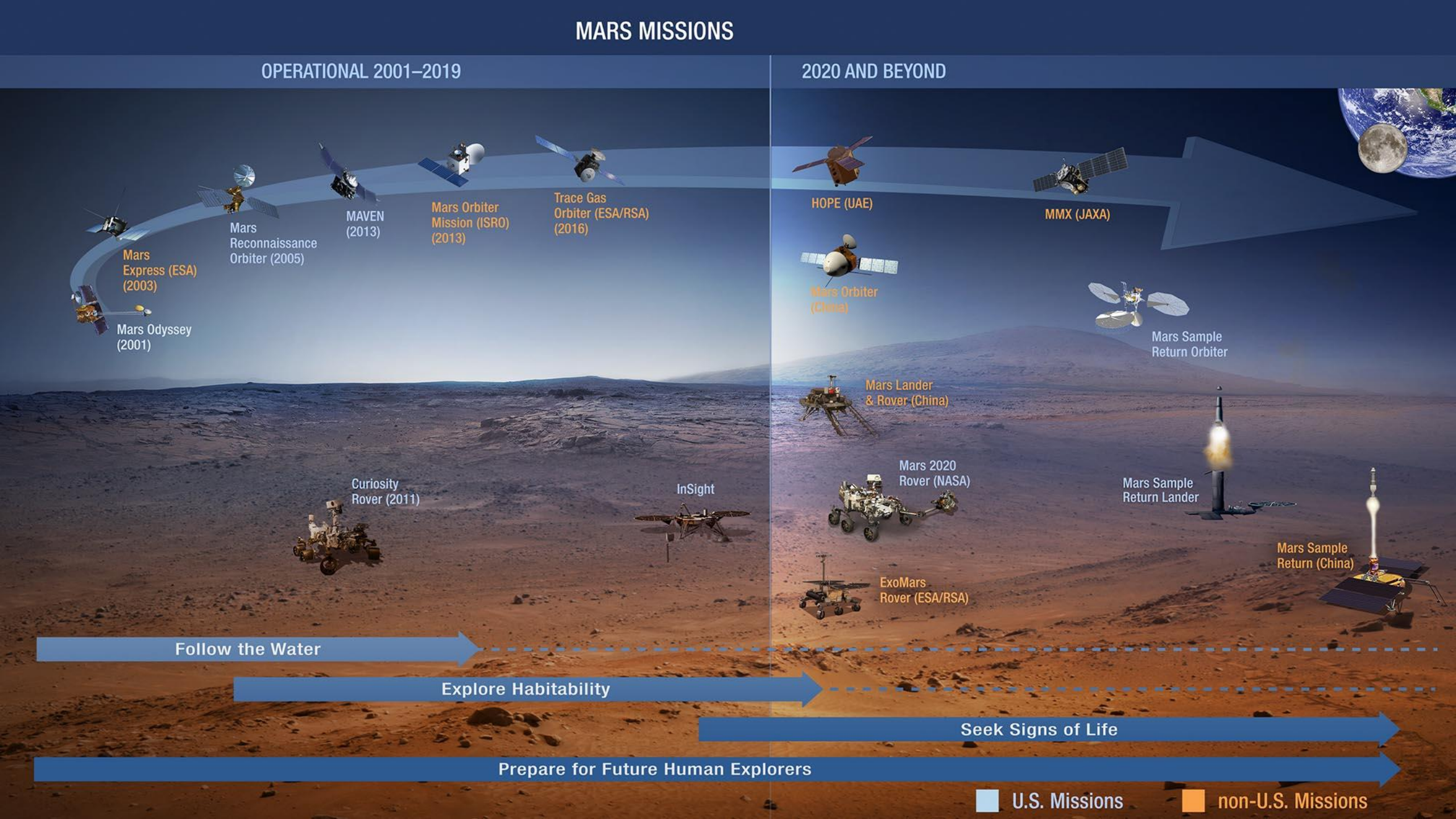
- Draft AO released before shutdown
- Comment period extended to February 11, 2019
- Final AO release expected NLT April 1, 2019
- Step-1 proposal due date rescheduled to July 1, 2019

Europa Clipper Overview



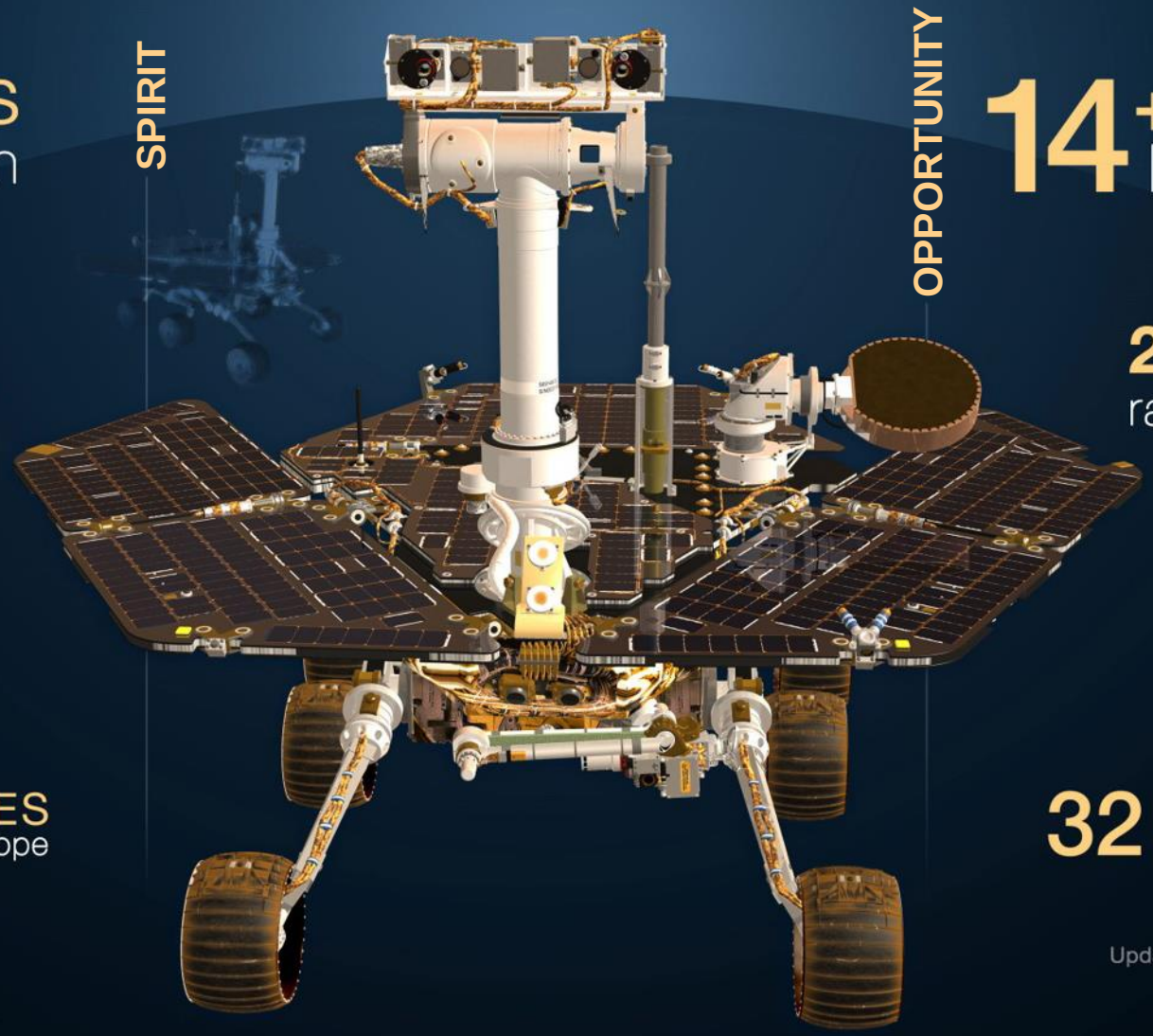
Will conduct approximately 45 low altitude flybys (25 – 100 km altitude) to characterize the habitability of the Icy Moon Europa through global regional coverage

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


MARS MISSIONS
OPERATIONAL 2001–2019
2020 AND BEYOND
Mars Express (ESA) (2003)
Mars Odyssey (2001)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
Curiosity Rover (2011)
InSight
HOPE (UAE)
MMX (JAXA)
Mars Orbiter (China)
Mars Sample Return Orbiter
Mars Lander & Rover (China)
Mars 2020 Rover (NASA)
Mars Sample Return Lander
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

SPIRIT AND OPPORTUNITY

By the Numbers



6 YEARS lifespan

124,838 raw images

4.8 MILES traveled

30 DEGREES steepest slope

14+ YEARS lifespan

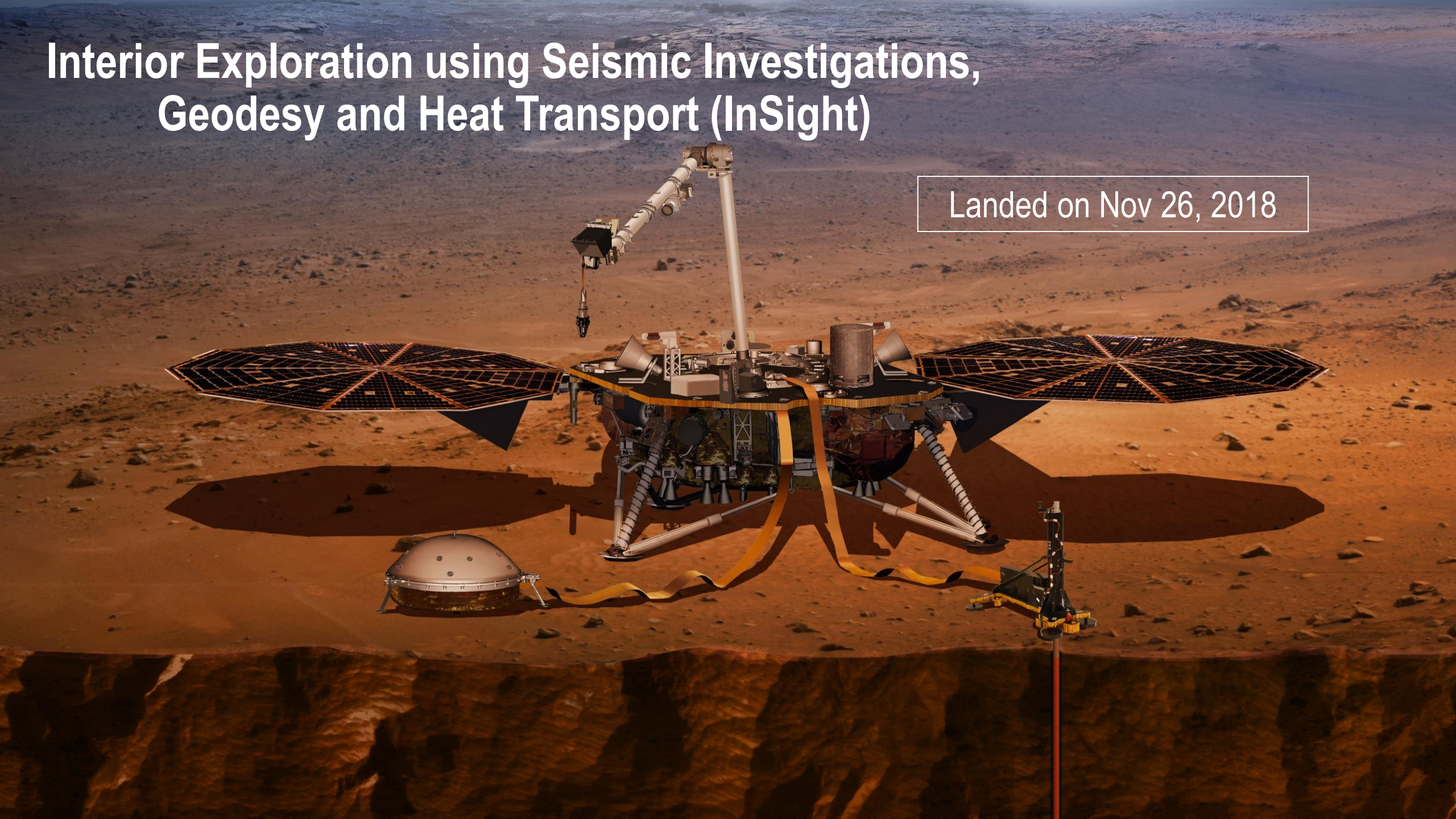
217,594 raw images

28 MILES traveled

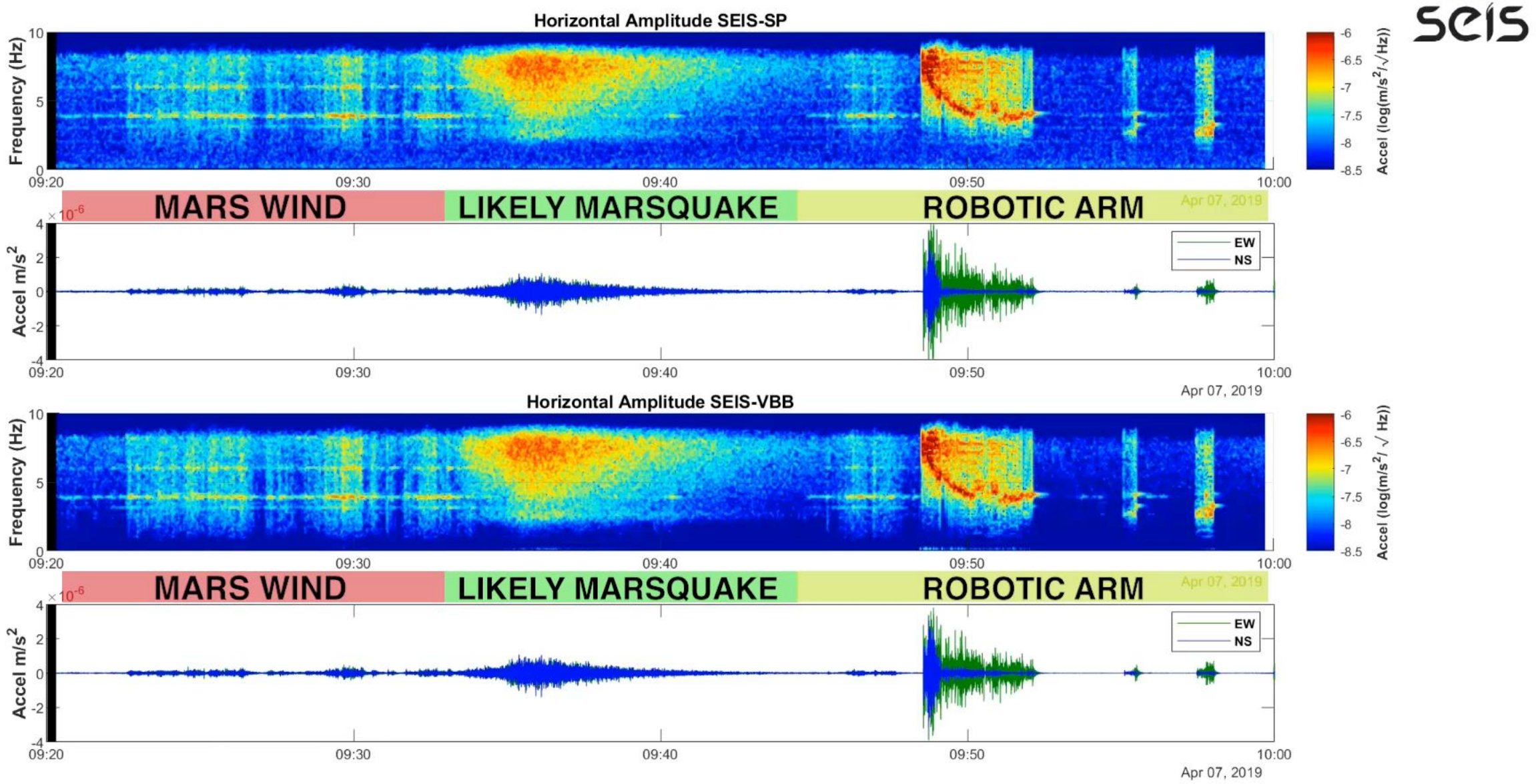
32 DEGREES steepest slope

Updated February 4, 2019

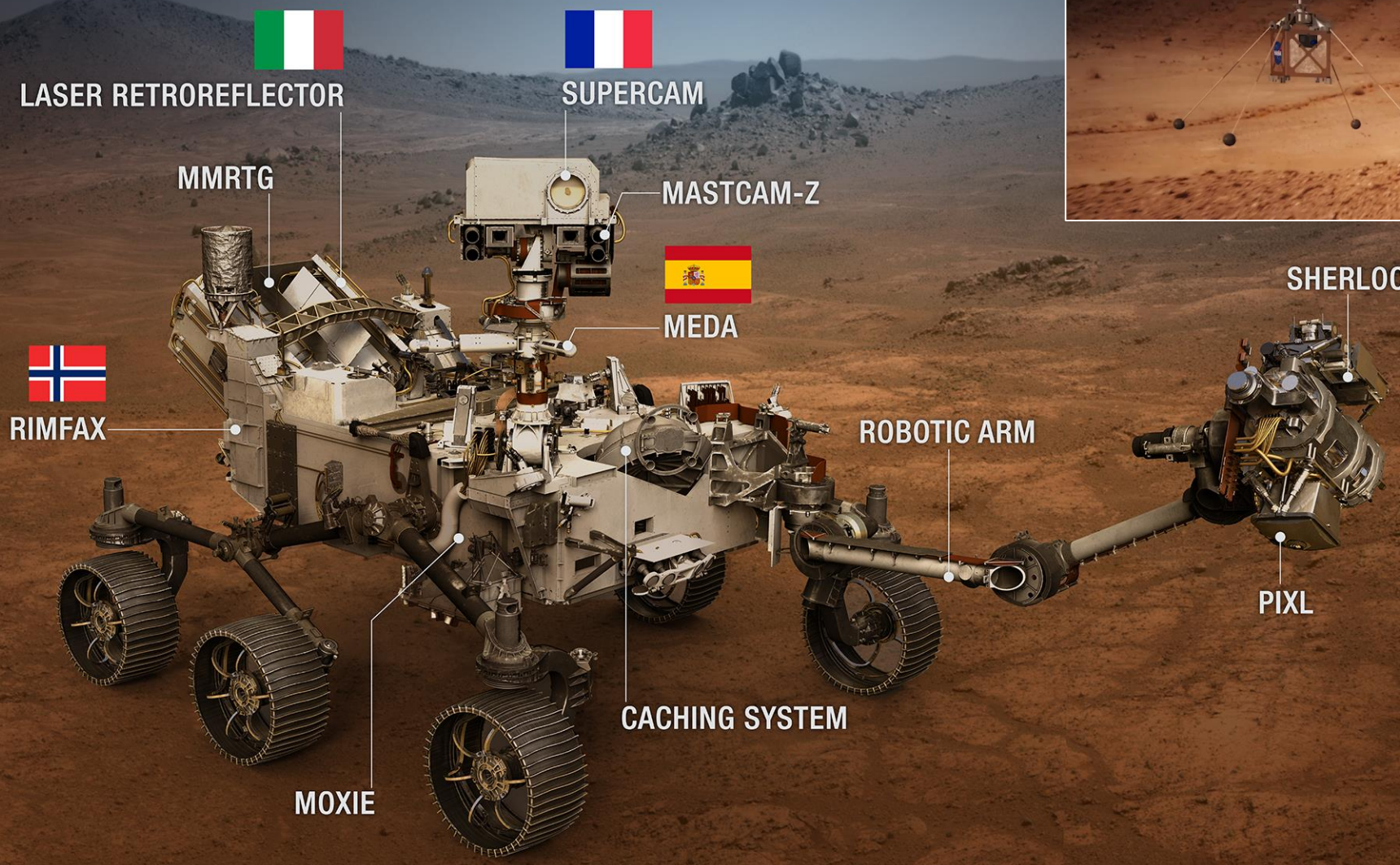
Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)

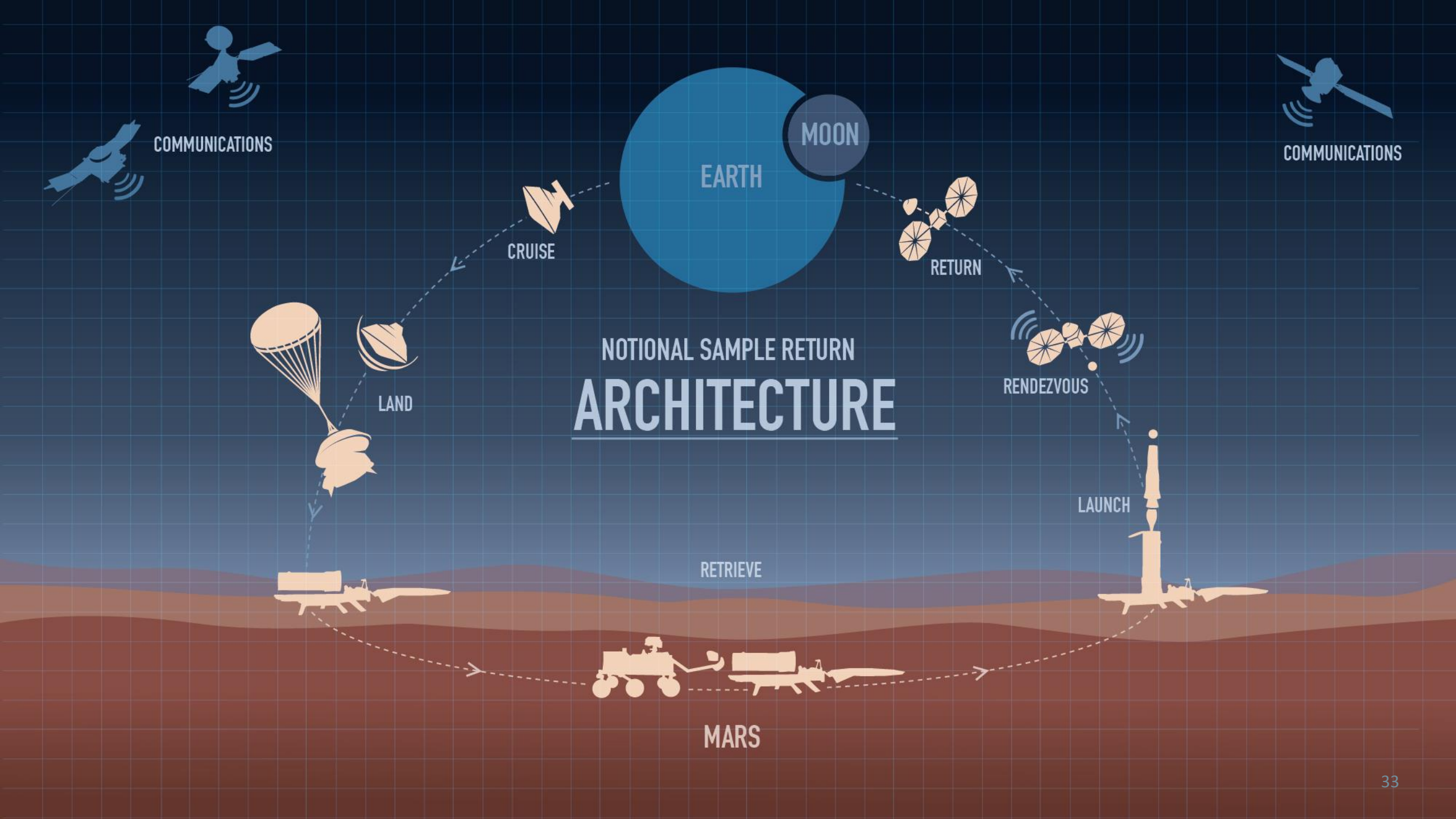


Landed on Nov 26, 2018


Horizontal Amplitude SEIS-SP
Frequency (Hz)
Accel (log(m/s²/√Hz))
MARS WIND
LIKELY MARSQUAKE
ROBOTIC ARM
Apr 07, 2019
Accel m/s²
EW
NS
Horizontal Amplitude SEIS-VBB
Frequency (Hz)
Accel (log(m/s²/ √ Hz))
MARS WIND
LIKELY MARSQUAKE
ROBOTIC ARM
Apr 07, 2019
Accel m/s²
EW
NS

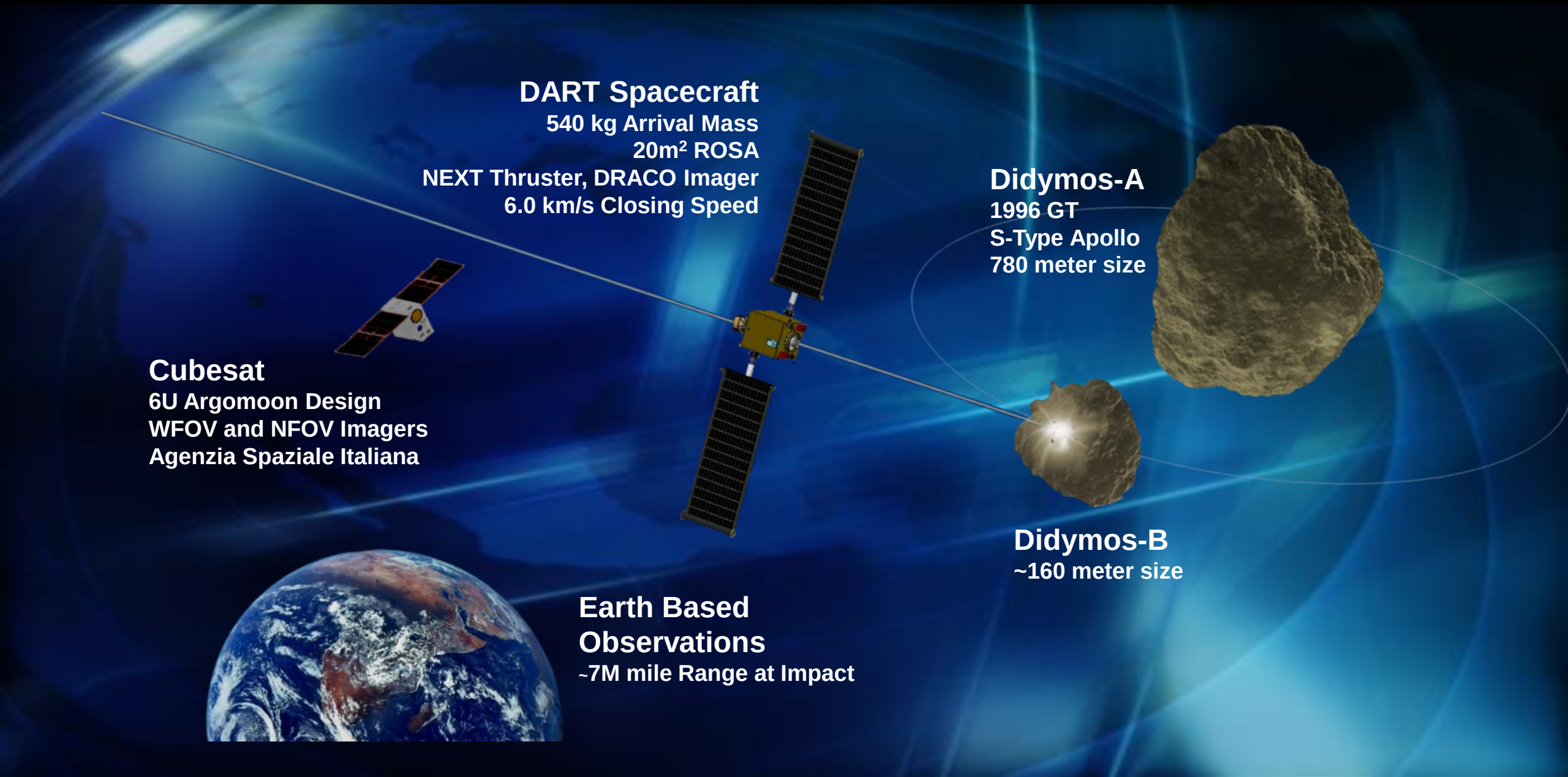
Seeking Signs of Life: Mars 2020 Rover




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


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]

Double Asteroid Redirection Test (DART)



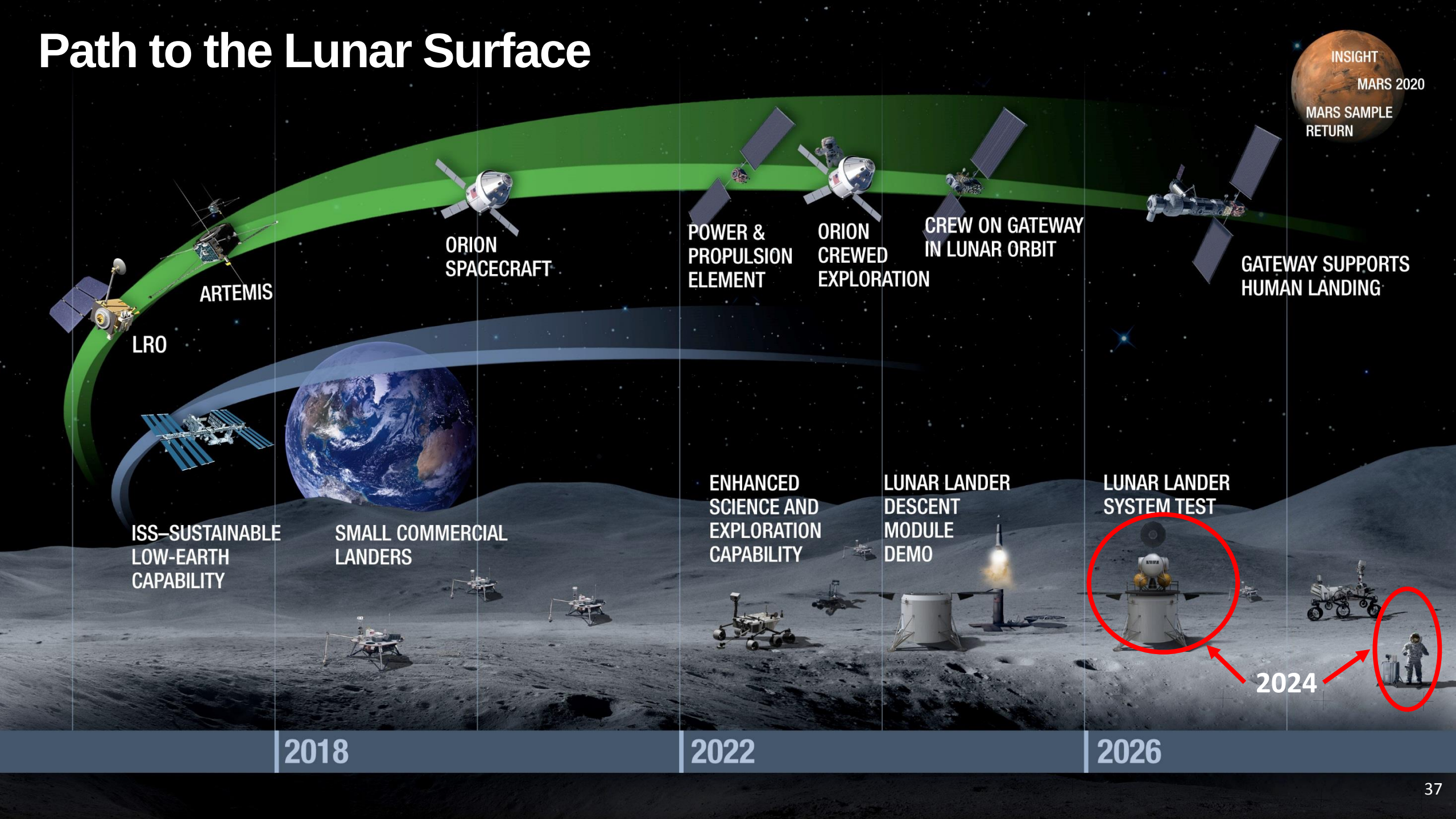
Space Policy Directive – 1

Reinvigorating America's Human Space Exploration Program

"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."

Path to the Lunar Surface




QUESTIONS?
EXPLORE
with us

GRAVITY ASSIST

Podcast

www.nasa.gov/podcasts