Planetary Science Division Status Report

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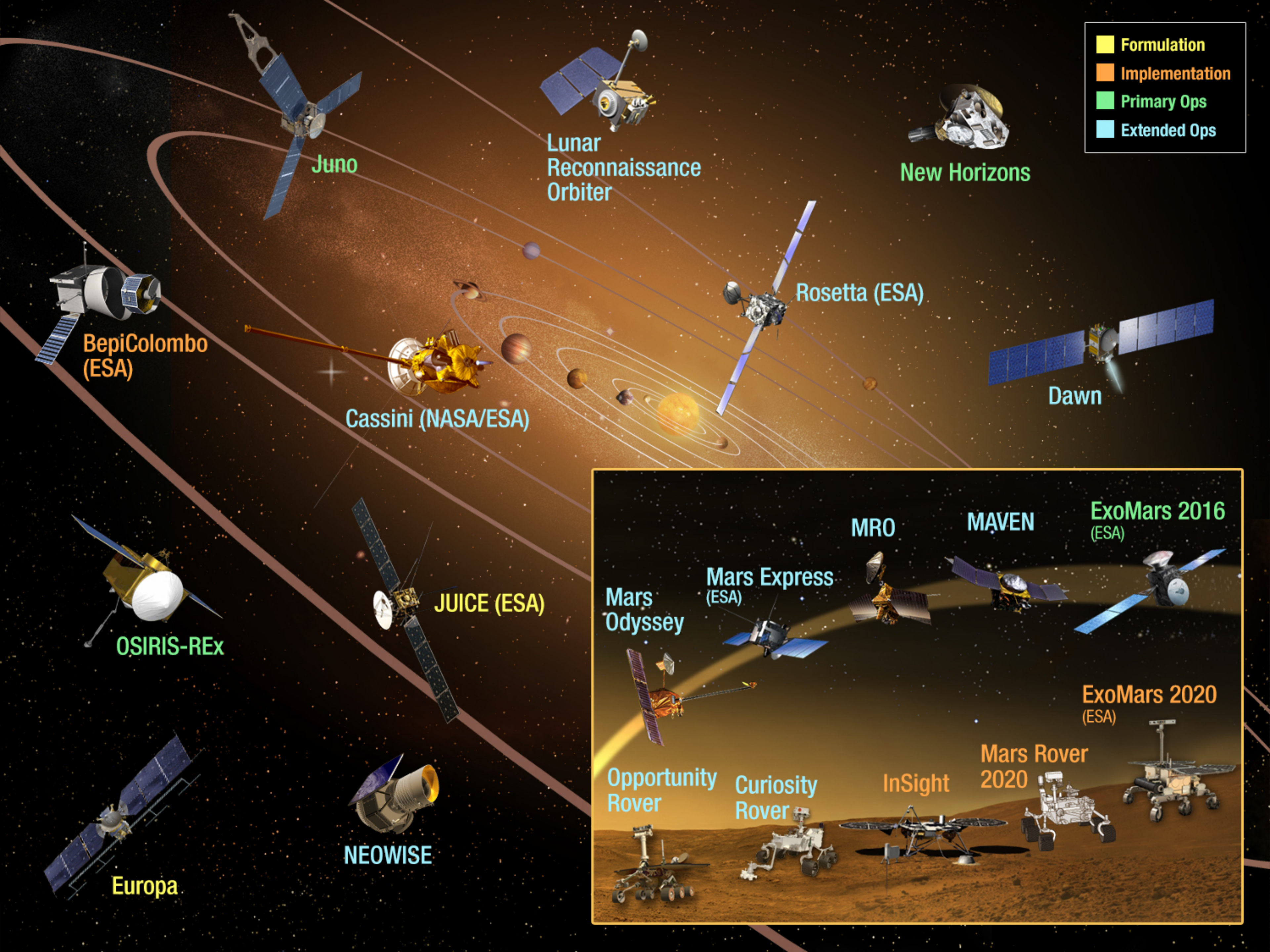
NASA, Planetary Science Division

September 14, 2016

Presentation at CAPS

Outline

- Mission Overview
- Discovery & New Frontiers Programs
- Mars Exploration Program
- Planetary Cubesats
- Research and Analysis update
- Planetary Defense Coordination Office
- NAS studies and schedule


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

Planetary Science Missions Events

2014

July – *Mars 2020* Rover instrument selection announcement *** Completed**
August 6 – 2nd Year Anniversary of *Curiosity* Landing on Mars
September 21 – *MAVEN* inserted in Mars orbit
October 19 – Comet Siding Spring encountered Mars
September – *Curiosity* arrives at Mt. Sharp
November 12 – ESA's *Rosetta* mission lands on Comet Churyumov–Gerasimenko
December 2/3 – Launch of *Hayabusa-2* to asteroid 1999 JU_3

2015

March 6 – *Dawn* inserted into orbit around dwarf planet Ceres
April 30 – *MESSENGER* spacecraft impacted Mercury
May 26 – Europa instrument Step 1 selection
July 14 – *New Horizons* flies through the Pluto system
September – Discovery 2014 Step 1 selection
December 6 – *Akatsuki* inserted into orbit around Venus

2016

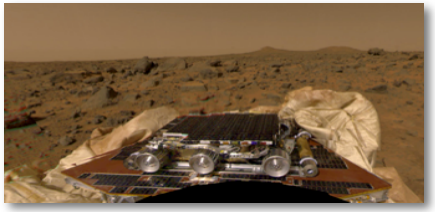
March – Launch of ESA's *ExoMars Trace Gas Orbiter*
July 4 – *Juno* inserted in Jupiter orbit
July 20 – 40th Anniversary of the Viking missions
September 8 – Launch of Asteroid mission *OSIRIS – REx* to asteroid Bennu
September 30 – Landing Rosetta on comet CG
Late 2016 – Discovery 2014 Step 2 selection

Discovery Program

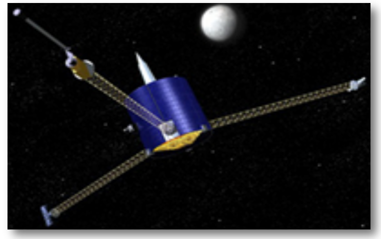
Discovery Program

Completed

Mars evolution:
Mars Pathfinder (1996-1997)

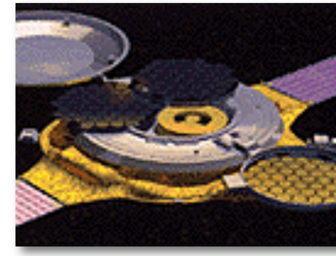


Lunar formation:
Lunar Prospector (1998-1999)



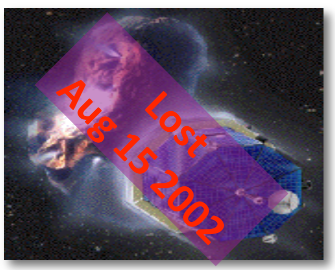
NEO characteristics:
NEAR (1996-1999)

Solar wind sampling:
Genesis (2001-2004)



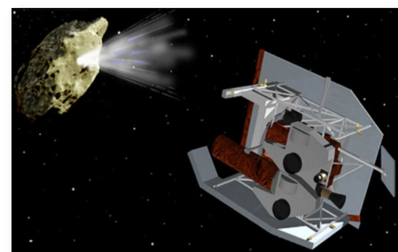
Completed

Comet diversity:
CONTOUR (2002)

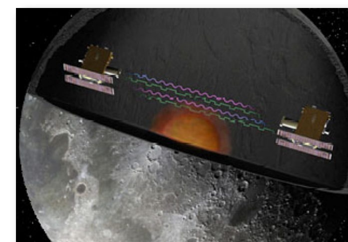


Nature of dust/coma:
Stardust (1999-2011)

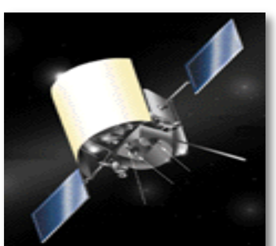
Comet internal structure:
Deep Impact (2005-2012)



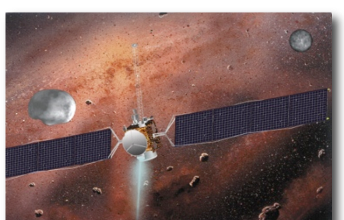
Lunar Internal Structure
GRAIL (2011-2012)



Mercury environment:
MESSENGER (2004-*2015*)



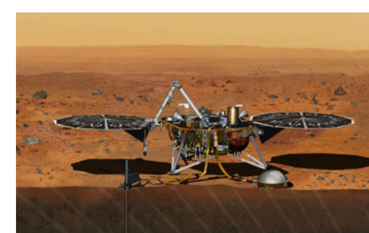
Main-belt asteroids:
Dawn (2007-*TBD*)



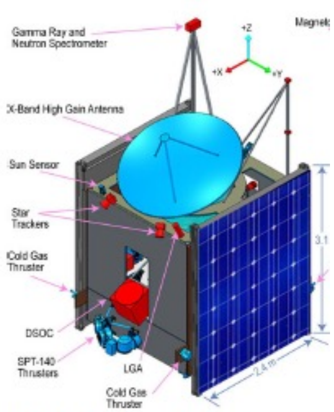
Lunar surface:
LRO (2009-*TBD*)

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

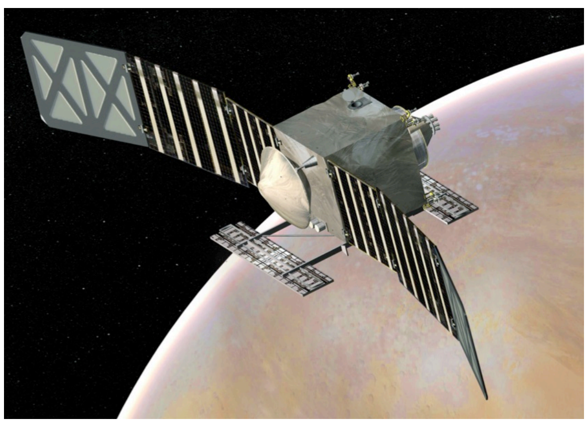
Mars Interior:
InSight (*2018*)



Discovery Selections 2014

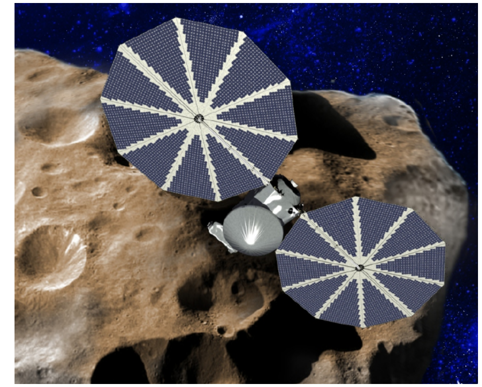


Psyche: Journey to a Metal World
PI: Linda Elkins-Tanton, ASU
Deep-Space Optical Comm (DSOC)

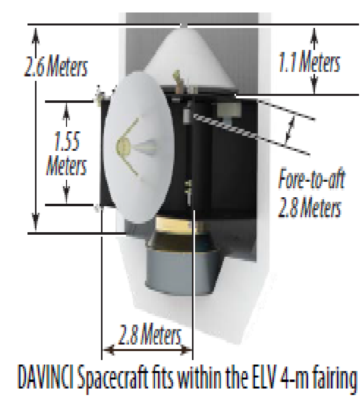


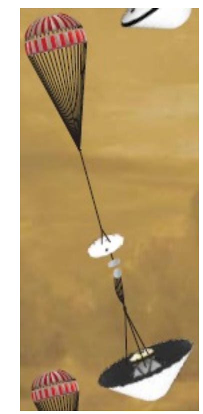
VERITAS: Venus Emissivity, Radio Science, InSAR, Topography, And Spectroscopy
PI: Suzanne Smrekar, JPL
Deep-Space Optical Comm (DSOC)

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



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





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

New Frontiers Program

New Frontiers Program

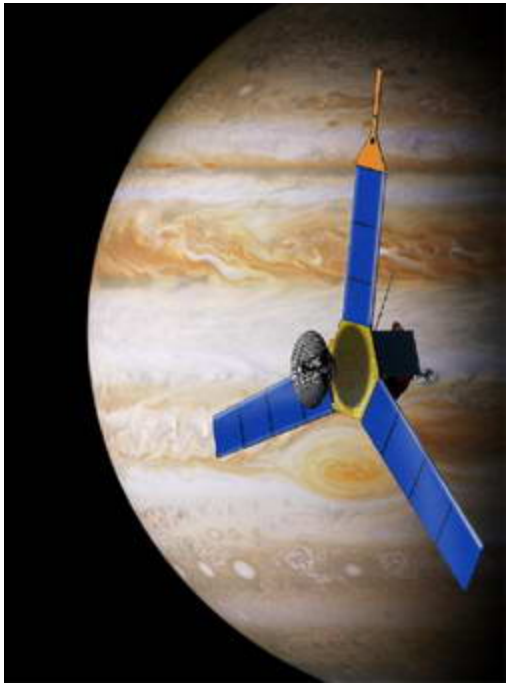
1st NF mission
<u>New Horizons:</u>

Pluto-Kuiper Belt

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

2nd NF mission
<u>Juno:</u>

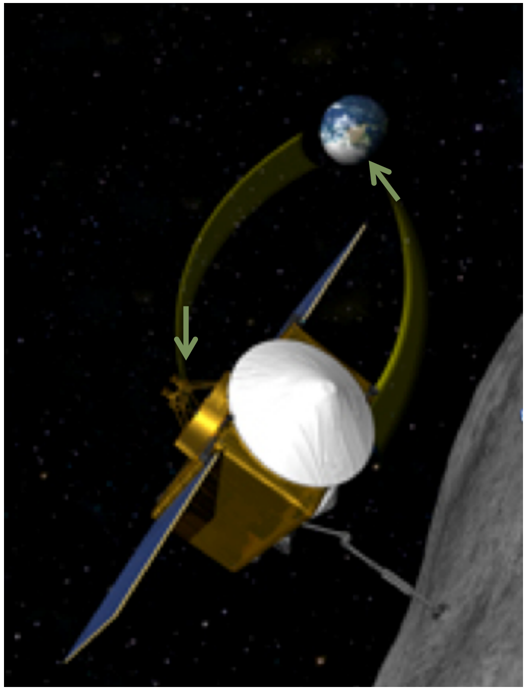
Jupiter Polar Orbiter



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

3rd NF mission
<u>OSIRIS-REx:</u>

Asteroid Sample Return

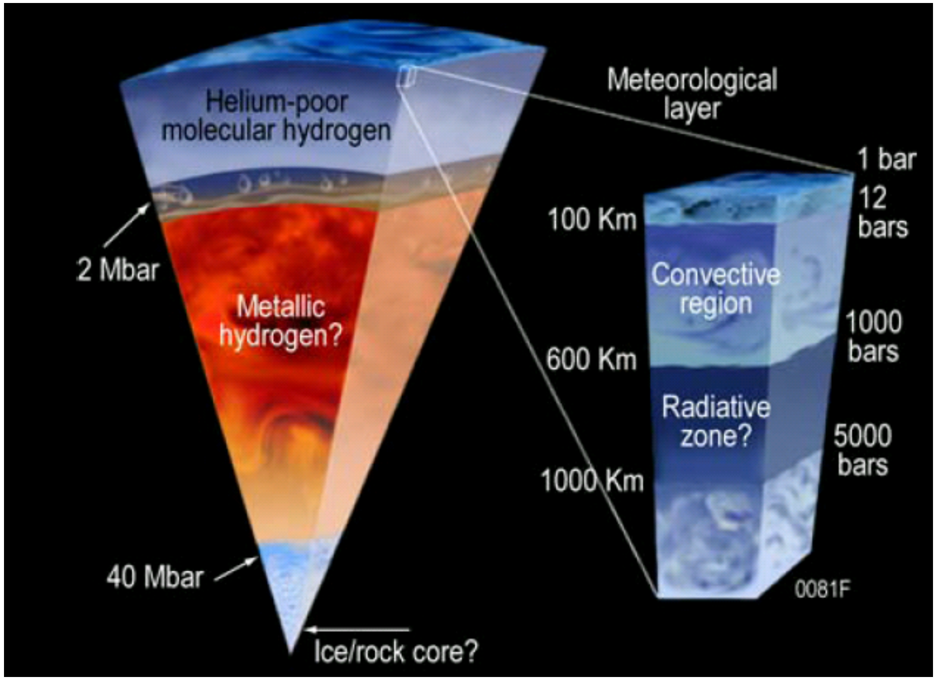


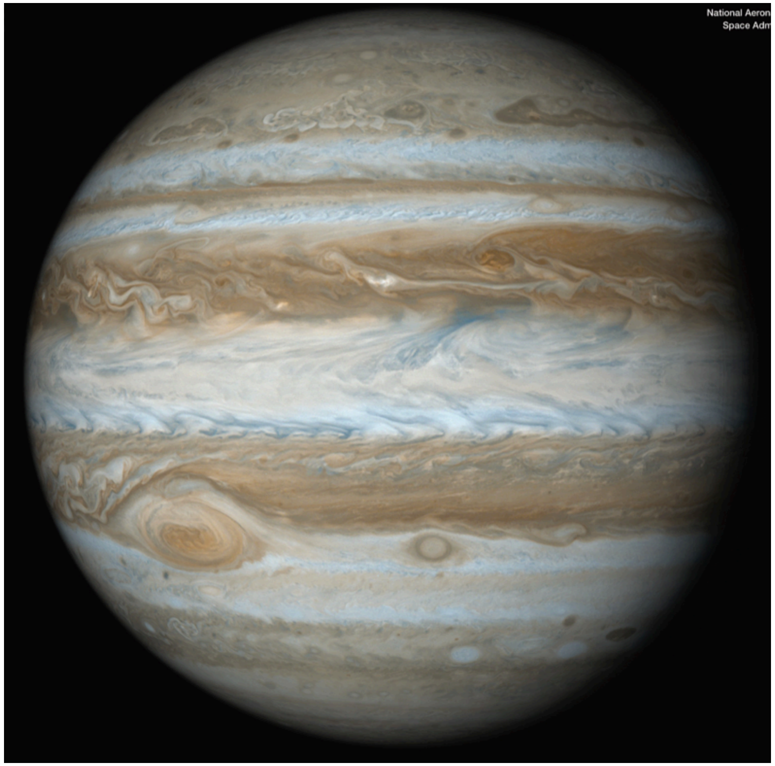
Launched Sept. 8, 2016
PI: Dante Lauretta (UA)

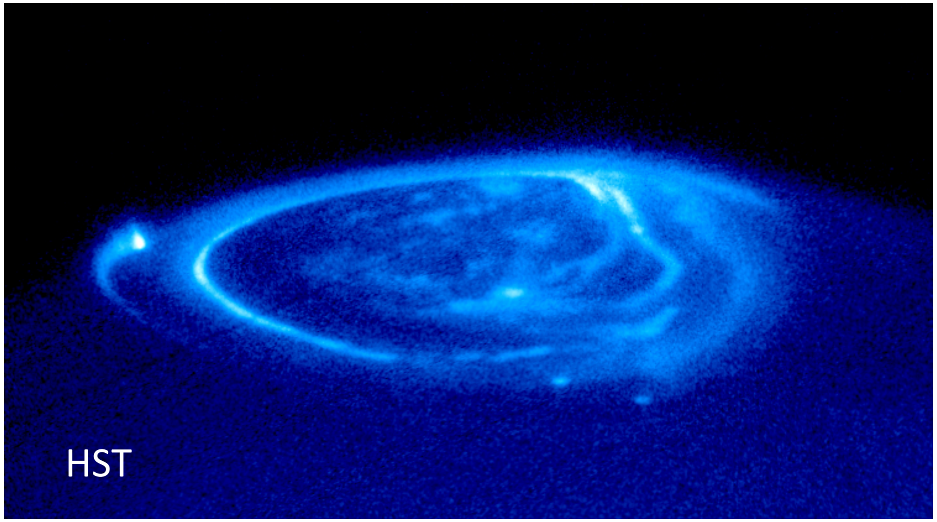
Juno: Mission to the Planet Jupiter

Science Objectives:

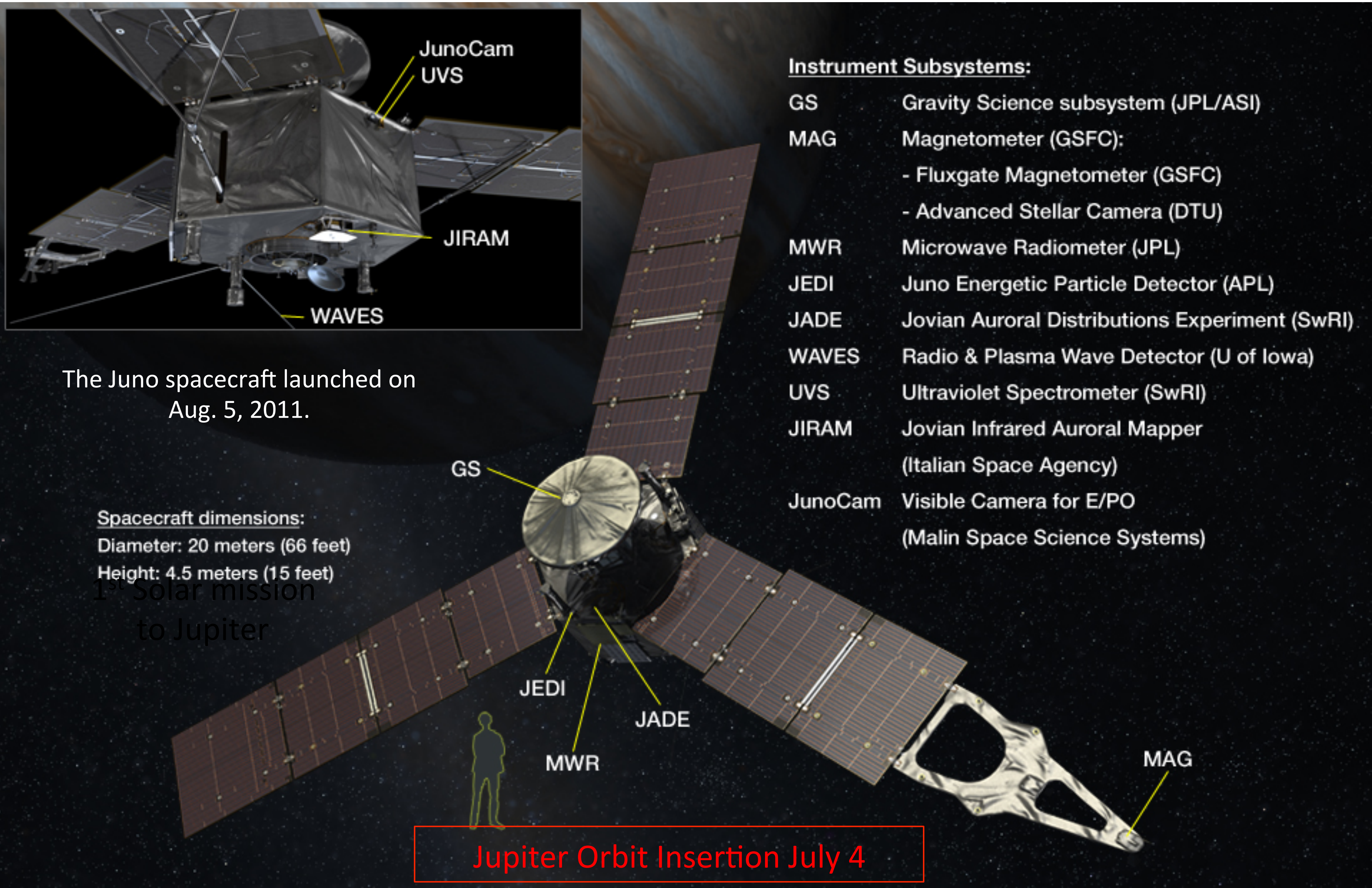
- Origin
- Interior Structure
- Atmosphere Composition & Dynamics
- Polar Magnetosphere







Juno Mission

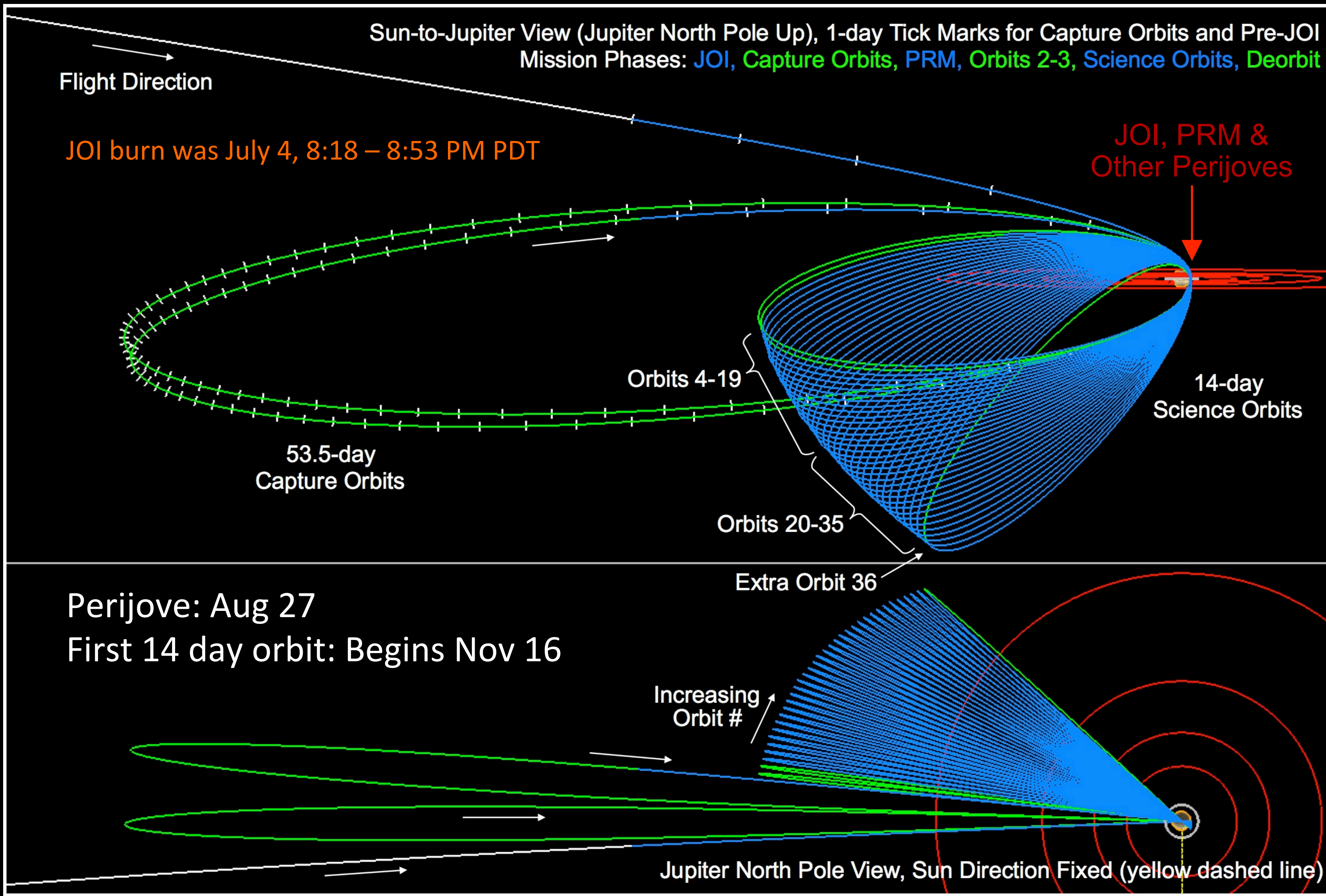


The Juno spacecraft launched on Aug. 5, 2011.

1st Solar mission to Jupiter

Jupiter Orbit Insertion July 4

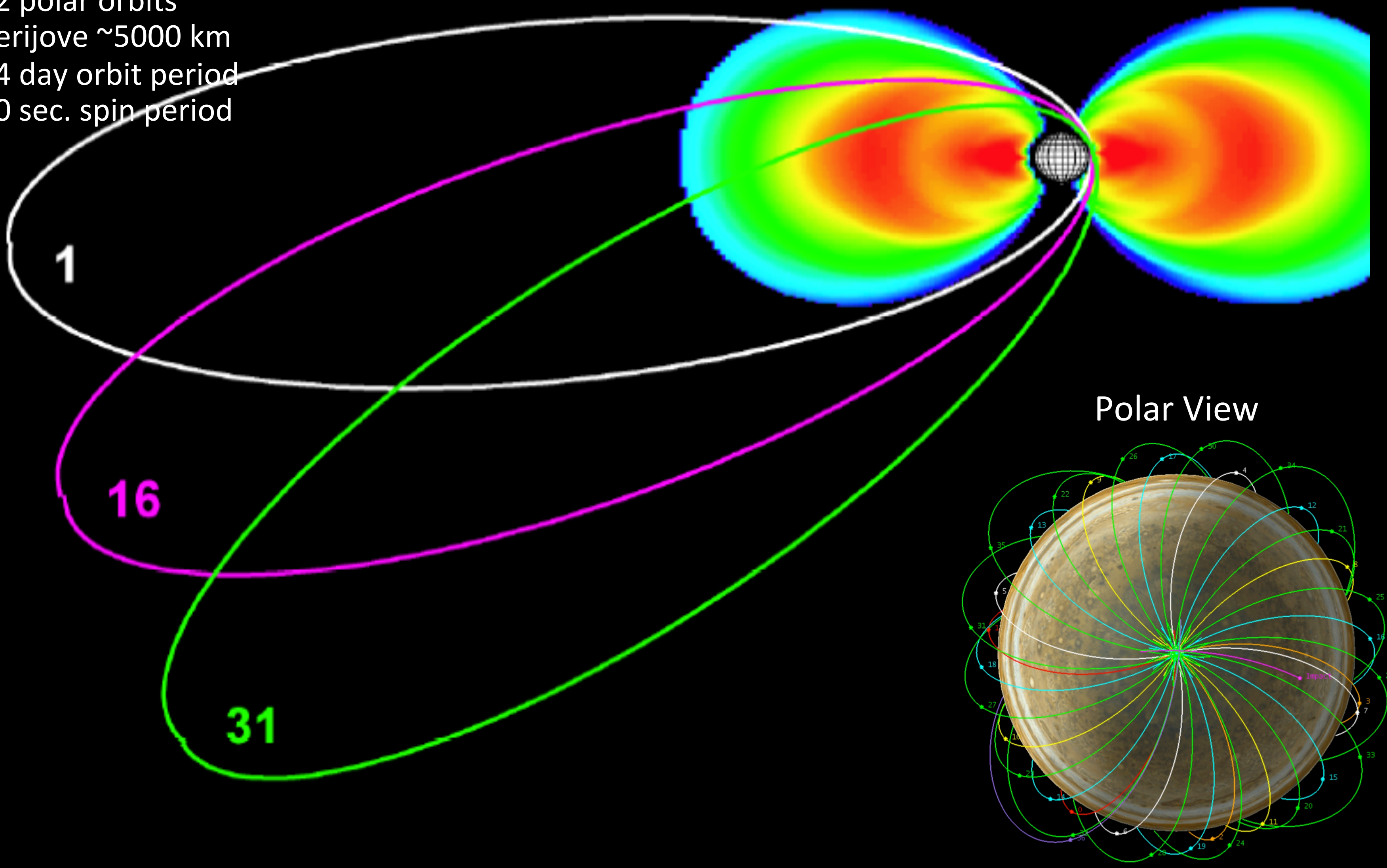
Orbital Trajectory



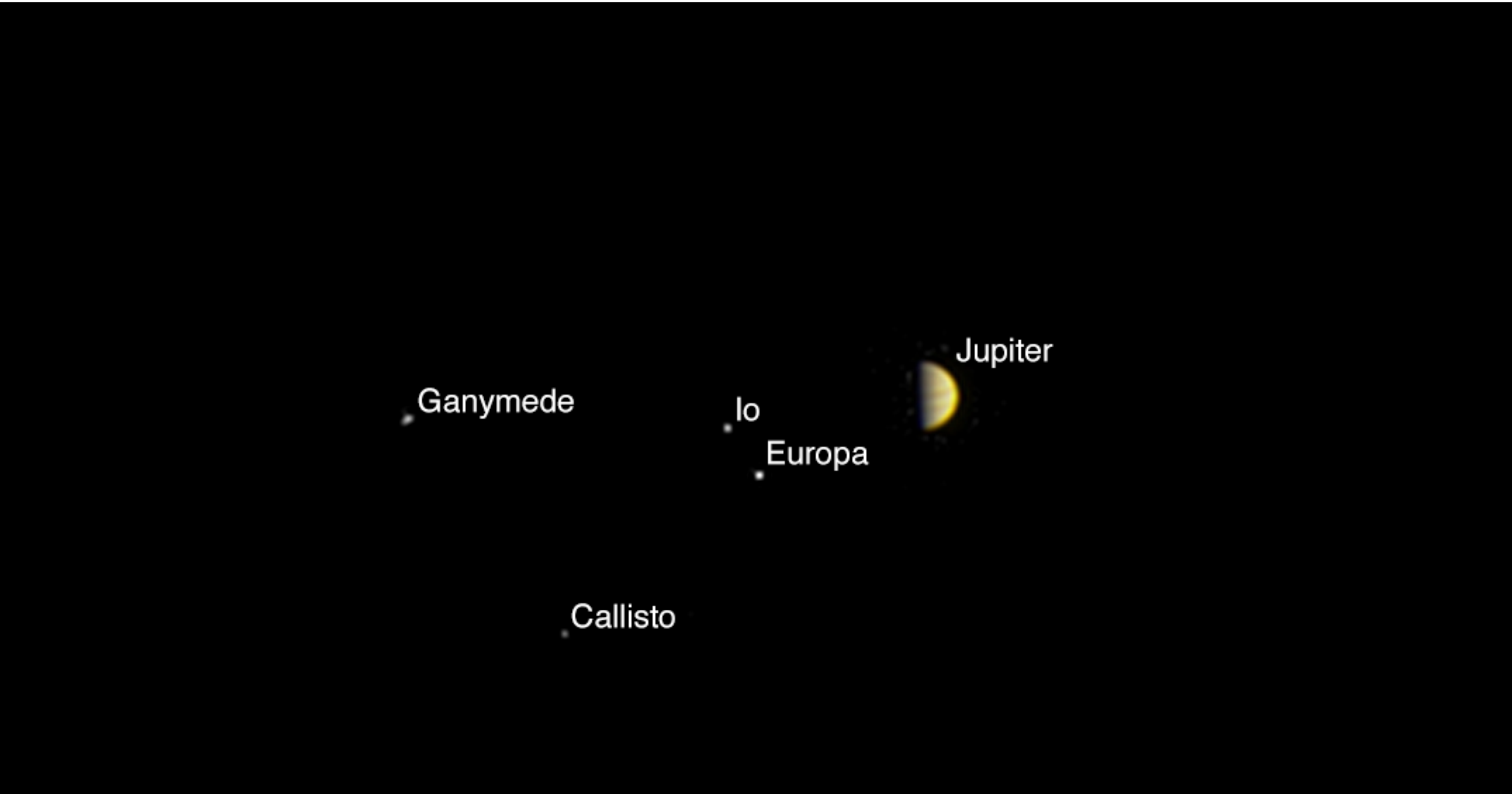
Juno's Orbit

Baseline mission:

- 32 polar orbits
- Perijove ~5000 km
- 14 day orbit period
- 30 sec. spin period



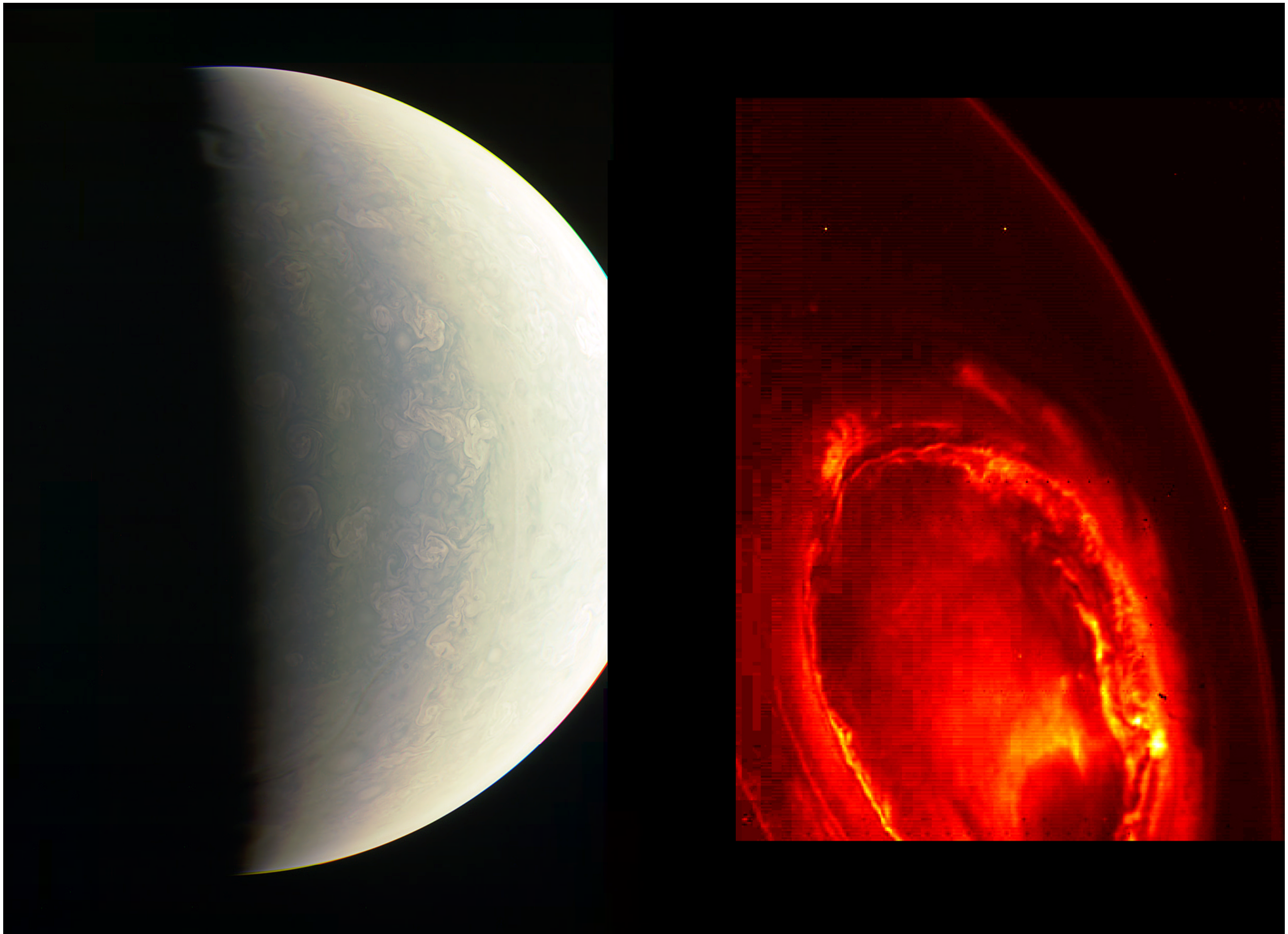
NASA's Juno Spacecraft Closing in on



JunoCam, imaged Jupiter on June 21, 2016, at a distance of
6.8 million miles (10.9 million kilometers) from the gas giant.

First Image Released After JOI

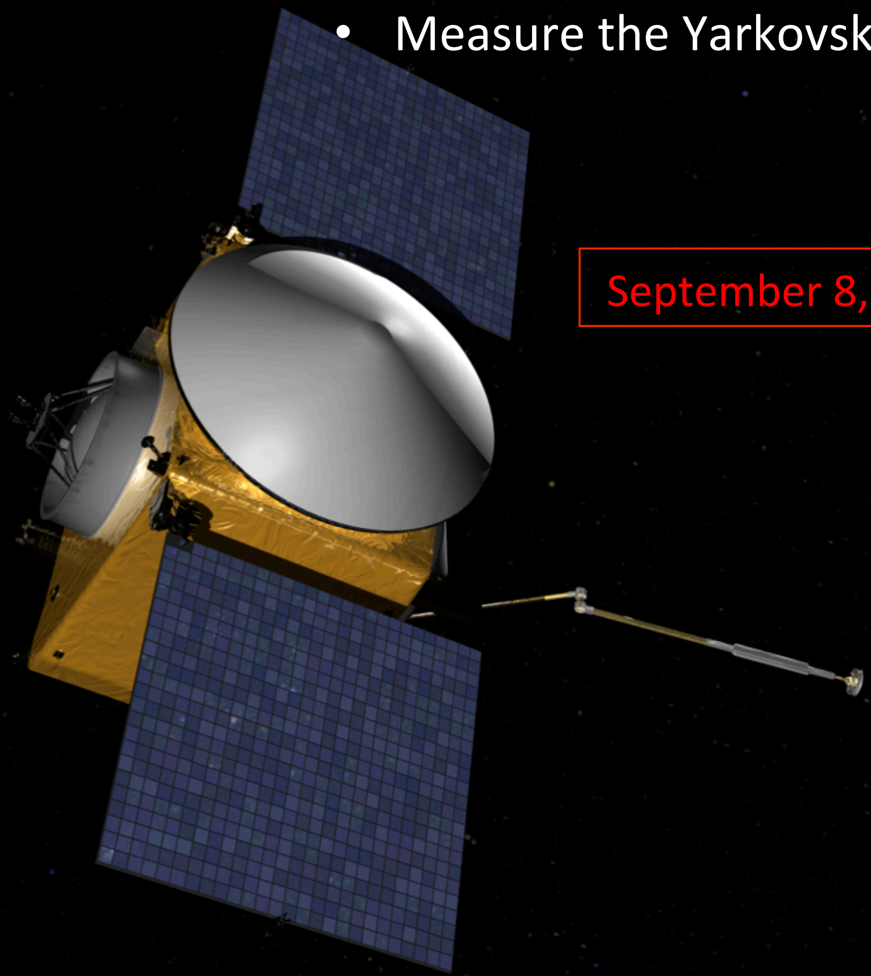
First Orbit: Sample of the Juno Data

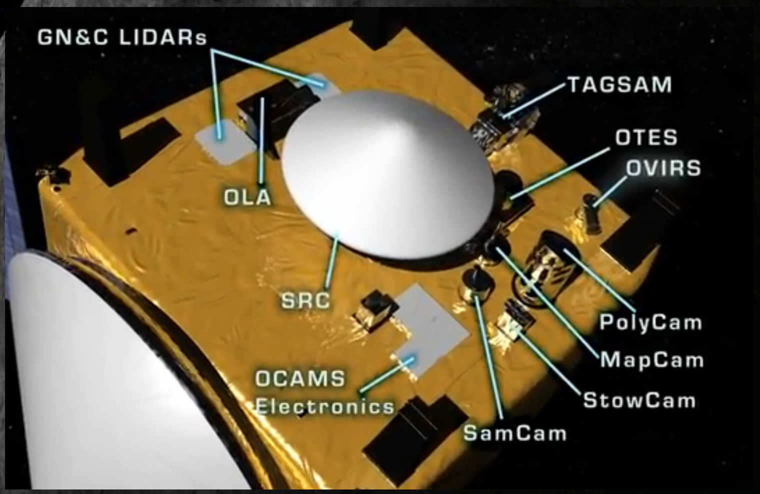


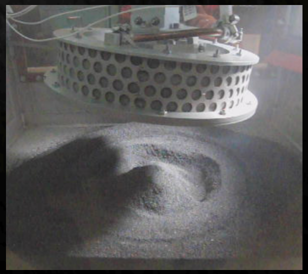
OSIRIS-REx

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

September 8, 2016







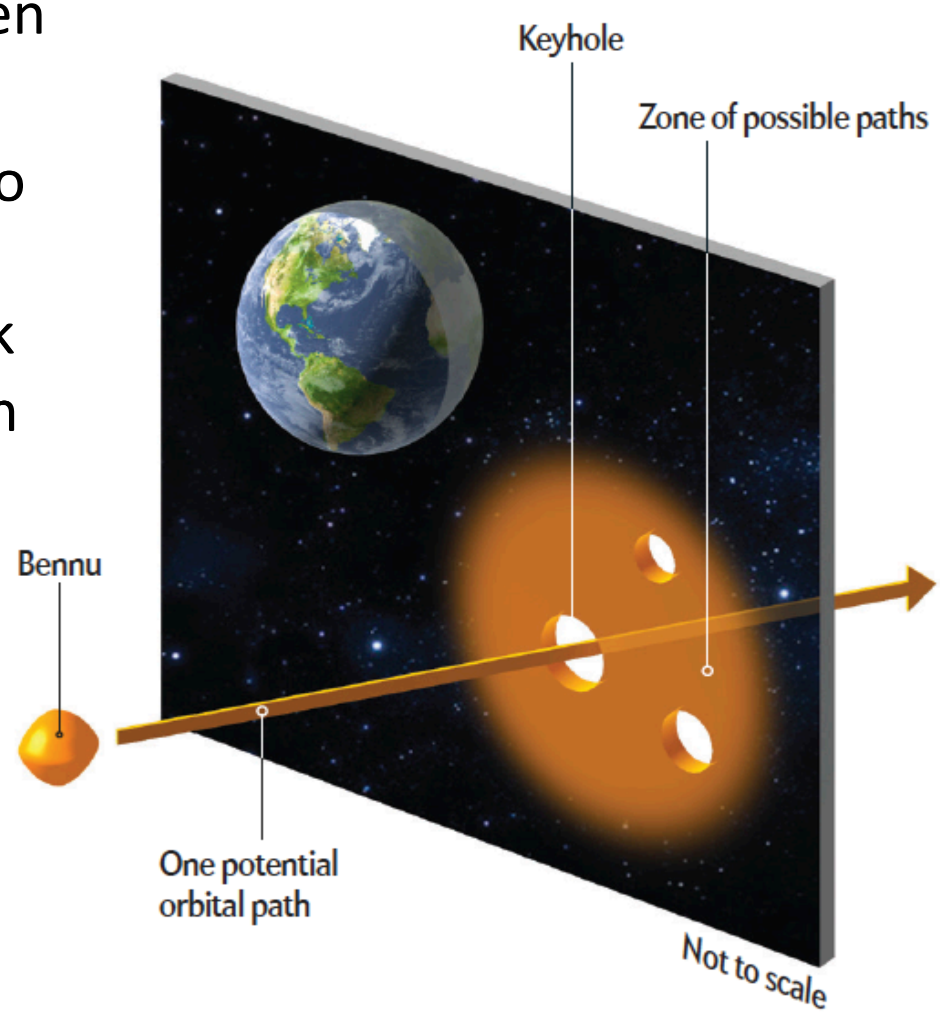
OSIRIS-REx Arrives at KSC

OSIRIS-REx Being Un-Boxed

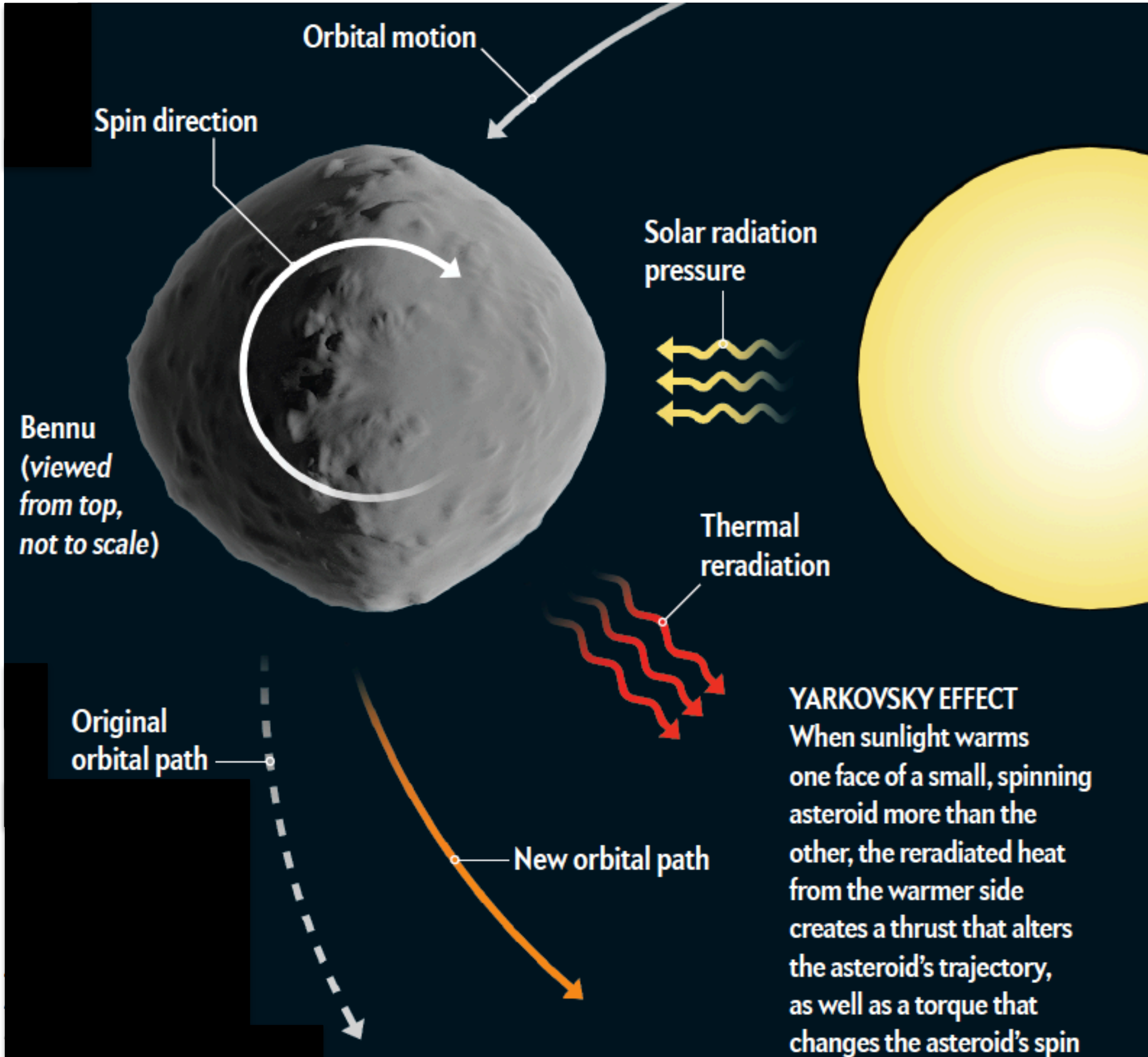
OSIRIS-REx 7:05pm Sept. 8, 2016

Bennu as a Potential Hazardous Object

- In 2135 Bennu will pass between the Earth and the Moon
- During that encounter it may go through a "keyhole" in which the Earth's gravity would tweak Bennu's trajectory and put it on a collision course with Earth
- OISIRS-REx will clarify the sources of instabilities in Bennu's orbit



Evolution in Bennu's Orbit



Next New Frontiers Program AO

- New Frontiers Program Community Announcements issued January 2016 and April 24, 2016
- Investigations are focused on the following mission themes (listed without priority):
  - Comet Surface Sample Return
  - Enceladus
  - Lunar South Pole-Aitken Basin Sample Return
  - Saturn Probe
  - Titan
  - Trojan Tour and Rendezvous
  - Venus In Situ Explorer
- Draft AO released August 8, 2016

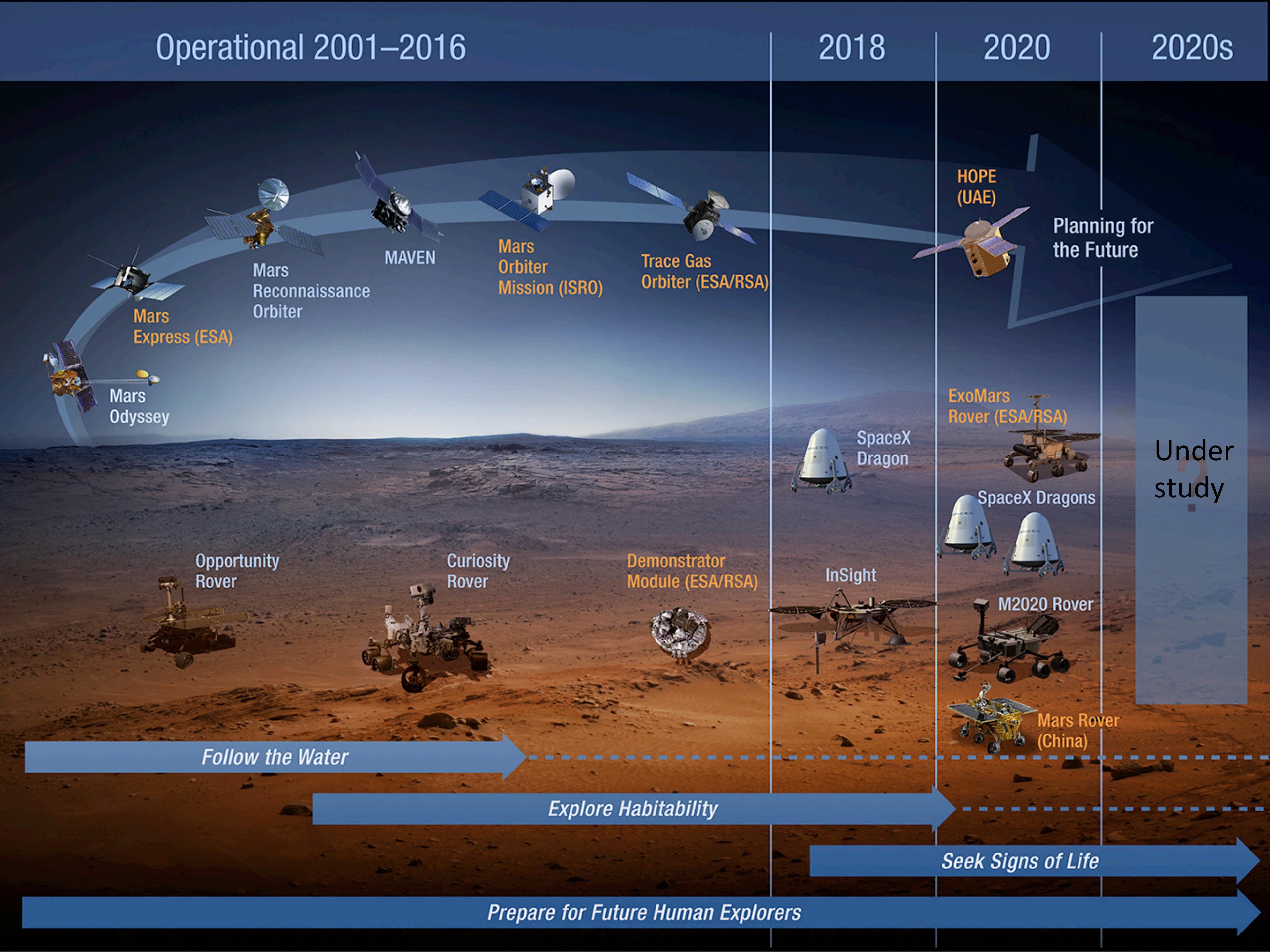
Next New Frontiers AO Time Frame

Notional Schedule:

- Release of final AO……………………… January 2017 (target)
- Preproposal conference……………..… ~3 weeks after final AO release
- Proposals due …………………………….. ~90 days after AO release
- Selection for competitive Phase A …. November 2017 (target)
- Concept study reports due…………….. October 2018 (target)
- Down-selection …………………………….. May 2019 (target)
- KDP B ………………………………………….. August 2019 (target)
- Launch readiness date ………………….. 2024

Mars Exploration Program

Overview
Science Highlights
Status, Updates
Future

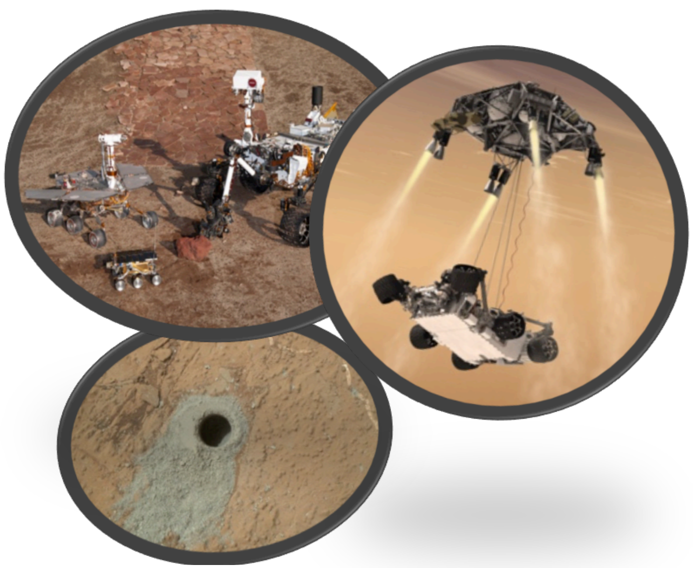


Operational 2001–2016
2018
2020
2020s
Mars Odyssey
Mars Express (ESA)
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA/RSA)
HOPE (UAE)
Planning for the Future
Under study
ExoMars Rover (ESA/RSA)
SpaceX Dragon
SpaceX Dragons
Opportunity Rover
Curiosity Rover
Demonstrator Module (ESA/RSA)
InSight
M2020 Rover
Mars Rover (China)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

Mars Exploration Program Legacy

13 covers on Science, >2000 publications in peer reviewed journals

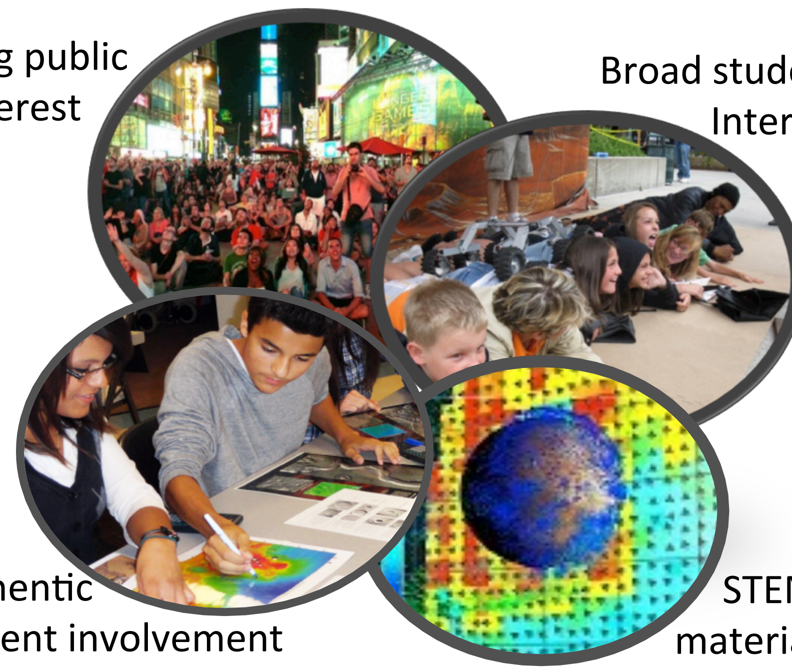
An unparalleled legacy of accomplishment at Mars



US leadership in capabilities to explore Mars

Strong public interest

Broad student Interest



Authentic student involvement

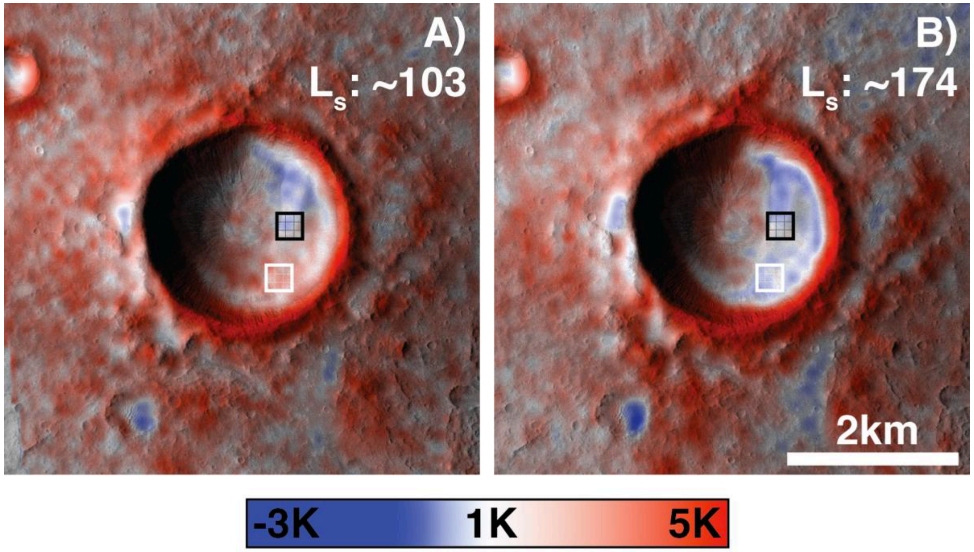
STEM material

Odyssey Science Highlight

The Water Content of Recurring Slope Lineae on Mars

C. S. Edwards and S. Piqueux, *GRL, 2016*

- Recurring Slope Lineae (RSL) have been interpreted as present-day, seasonally variable liquid water flows; orbital spectroscopy has not confirmed the presence of liquid H_2O, only hydrated salts.
- THEMIS temperature data and a numerical heat transfer model are used to constrain the amount of water associated with the RSLs
- Surface temperature differences between RSL-bearing and dry RSL-free terrains are consistent with no water associated with RSL and limit the water content of RSL to at most 0.5-3 wt%.
- High thermal inertia regolith signatures expected with crust-forming evaporitic salt deposits from cyclical briny water flows are not observed, indicating low water salinity (if any), and/or low enough volumes to prevent their formation.
- The RSL-rich surfaces experience ~100K diurnal temperature oscillations, possible freeze/thaw cycles and/or complete evaporation on timescales that challenge their habitability potential.
- The unique surface temperature measurements provided by THEMIS are consistent with a dry RSL hypothesis, or at least significantly limit the water content of Martian RSL.

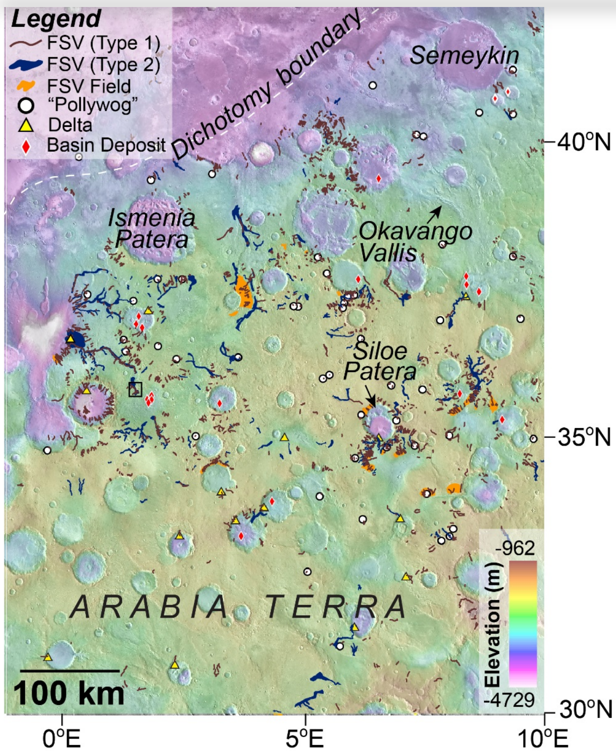


THEMIS integrated nighttime images. The white box is the location covering the most active RSL region and the black box is the chosen dry regolith reference area. These colorized ΔT images are created by subtracting the average value from the black box from entire image subset. The temperature variation observed between A & B is primarily due to the azimuthal differences between the two analysis areas and is accurately modeled as a dry regolith surface

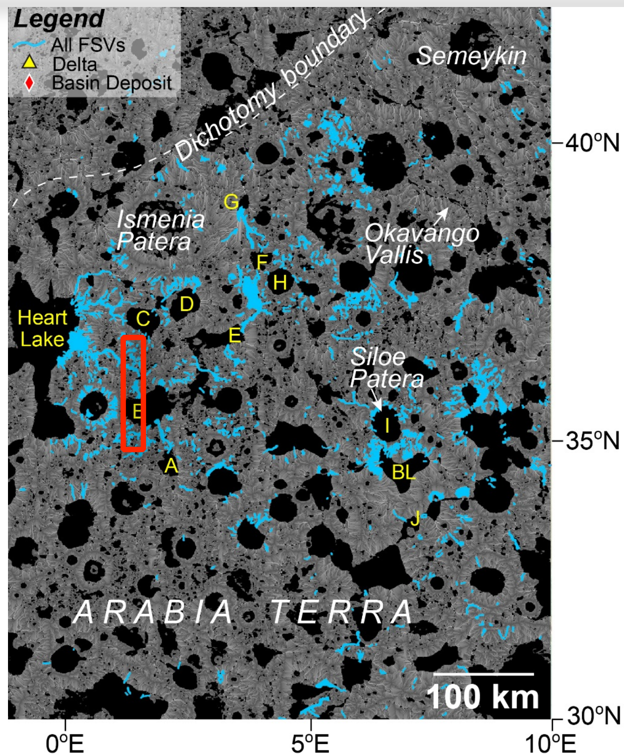
“Young” Valleys and Lakes in Northern Arabia Terra on Mars

A landscape modified by water and ice is an unambiguous marker of past climate

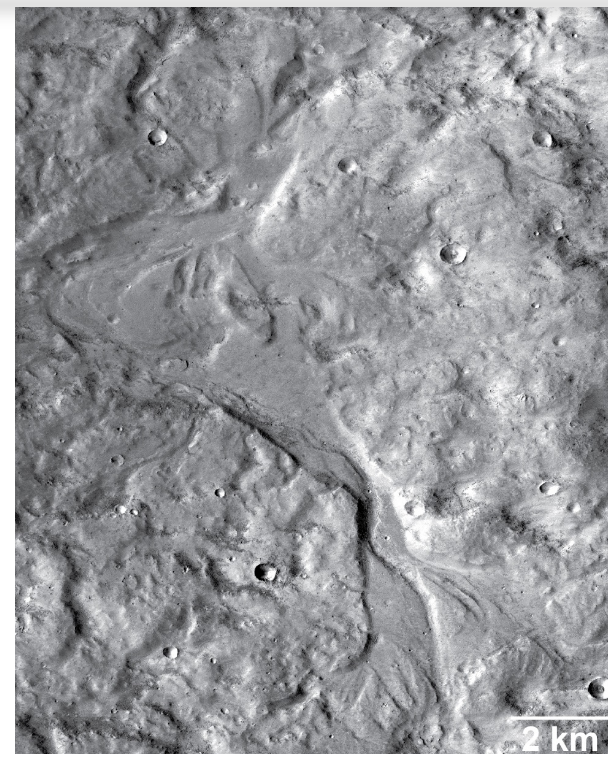
- This area located just south of the dichotomy boundary on Mars has several fresh shallow valleys (FSVs), some of which flowed into and out of large paleolakes. The extent of these systems was described using CTX data.
- Aided by HiRISE data, this drainage area is dated to be much younger (by hundreds of millions of years) than the ancient channels on early Mars.
- Modeling discovery suggests global periods of warming that allowed ice to melt and water to flow on a cold, wet Mars.



Map of study region showing high concentration of FSVs and associated landforms such as deltas. Color base is topography (see elevation scale).



Most FSVs (blue lines) stop at the edges of model-predicted paleolakes (black) and some flow into and out of paleolakes (e.g., see lake “B”).

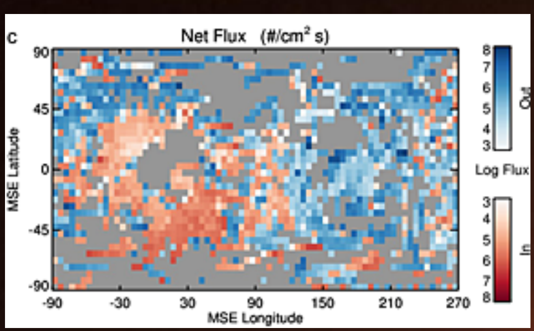


Example of FSV that formed as water spilled over the northern margin of lake “B” (red box in middle panel). Water continued to flow downhill toward “Heart Lake” (see middle panel).

HiRISE

Wilson, Sharon A., A. D. Howard, J. M. Moore and J. A. Grant (2016), A Cold-Wet Mid-Latitude Environment on Mars during the Hesperian-Amazonian Transition: Evidence from Northern Arabia Valleys and Paleolakes, JGR (#2016JE005052R).

MAVEN Science Highlights



- MAVEN launched Nov 2013; inserted into Mars orbit Sep 2014; primary mission from Nov 2014 – Nov 2015; now in extended mission.
- MAVEN spacecraft and instruments are operating nominally and are providing high-quality science data.
- MAVEN is defining the basic characteristics of the Mars upper-atmosphere / ionosphere / magnetosphere system, escape rates at the present epoch, and the processes controlling them.
- Results tell us that loss to space was a major mechanism for the changes in the Mars atmosphere and climate through time.
- First set of results released November 5, 2015:
  - 4 articles in *Science;* 44 articles in *Geophysical Research Letters*.
  - >35 subsequent papers published
- 2016 Senior Review recommended continuation for an extended mission through FY18 that also endorsed
  - Proposed new measurements modes now ongoing
  - Increased collaborations with other missions
- Continuing observations are allowing us to understand behavior through a Mars year and with variations in the solar-cycle drivers.

Why More Science?

Mars discoveries leave many mysteries

- Did Mars ever have life? Is it still there?
- Recurring Slope Lineae – What are these seasonally changing streaks?
- Methane – How much? Does it really come and go? What is the nature of the source (biological or geochemical)? How can it disappear quickly?
- The great transition from a much wetter environment to the cold, dry, acidic planet of today – How and when did that happen?
- What is the nature of accessible water/ice on Mars? Can it be used?
- Can humans live on Mars? Where are the resources? What are the hazards?

Status of MEP

Our operational assets remain healthy and productive:

- All six Mars missions did well in Senior Review and are going forward in extended missions
- Odyssey continues imaging in sunrise-sunset orbit
- MRO continues to provide reconnaissance imaging and mineralogical mapping
- Opportunity has left Marathon Valley
- Curiosity heading up Mt Sharp, soon to exit the Murray Buttes
- Mars Express continues

M2020 development on-track and proceeding well:

- Started Phase C June 27, 2016
- Heritage H/W fabrication underway; some delivered
- Sampling system development labs up and running

We are meeting our foreign commitments:

- Our two Electra payloads on TGO are on the way to Mars
- Prepared to support Oct 19 MOI and EDM landing activities
- MOMA is proceeding in development with ExoMars delay to 2020

Financially, the program is doing well:

- This fiscal year all our planned activities are funded

Near-term, the state-of-the-MEP is good

MEP Updates

- Calendar
  - Our Red Planet Sept. 20-22, 2016
  - MEPAG virtual Meeting, Oct. 6, 2016
  - AGU public lecture Dec. 11, 2016
  - Landing site Workshop Feb 8-10, 2017
- Mars Program
  - MDAP proposals: Step-1 in Aug 26; Step-2 due Oct. 28, 2016
- Mars 2020
  - RSSB, CCPPWG
- MOMA
  - 2018 delay to 2020
- MSL: tomorrow
- Future: to follow

Future Orbiter Pre-Formulation

- Conducted an RFI (July 2014) to survey for new business models for providing telecommunication relay services [NASA buys service from commercial provider]
  - 14 respondents, mostly non-responsive/non-credible, 3 with some substance, several simply expressing interest in NASA business but offered no approach
  - Credible respondents required some combination of NASA funding for launch, an early deposit, and a guaranteed subscription/lease arrangement to recoup S/C cost, recover cost of financing and ensure a reasonable ROI (essentially a deferred cost model, ie; loan)

- Reviewed recent Discovery-class orbiter analogs

- Completing (Jun-Oct 2016) multiple (5) industry studies exploring high TRL heritage system approaches
  - Specifically study low cost concepts leveraging industry capabilities, heritage designs, and strategic interests
  - Identify cost driving requirements and examine alternative approaches to further reduce cost

Conclusion

- Mars missions are accomplishing great science
- Missions/instruments in development are on-track

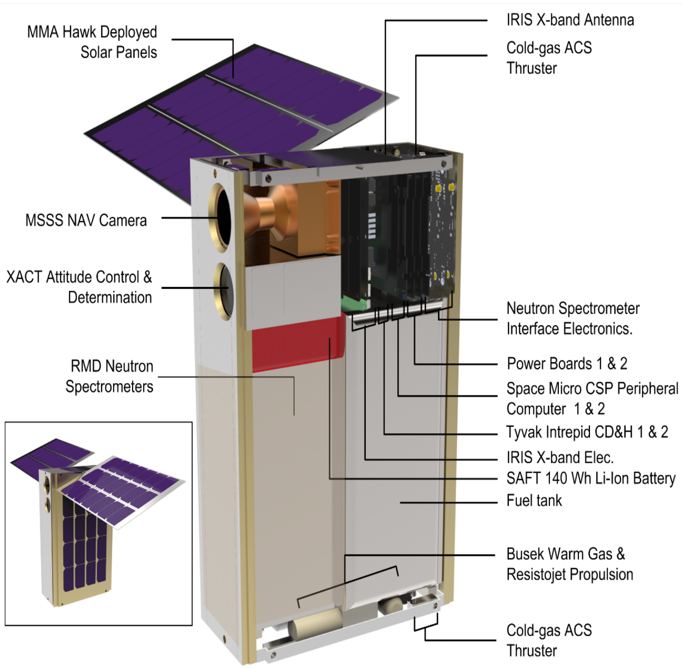
An orbiter is being studied

- Would support needed for continued surface exploration
- Would require minimal development
- Industry studies are underway (~October 2016)

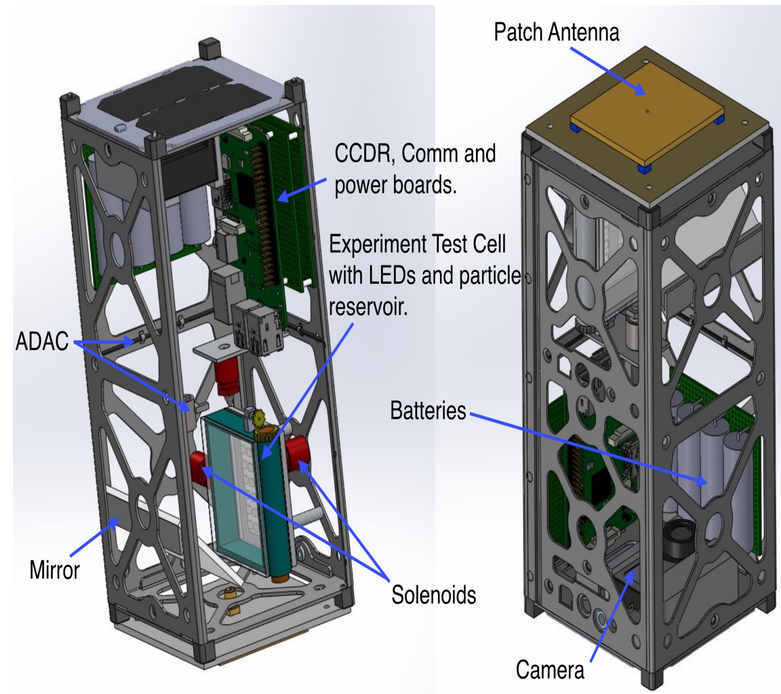
- A telecom-only solution provides marginal capability for future Mars exploration.
- Adding reconnaissance, sample rendezvous and containment capability, and remote sensing science is under study to
  - support Decadal science
  - provide valuable HEOMD SKGs, and
  - set the stage for future missions in the 2020s

SIMPLEx Cubesats Selections
Full missions (2)
and
Approved for 1 year Tech Development (3)

Small Innovative Missions for Planetary Exploration (SIMPLEx-2014) – New Awards in FY15



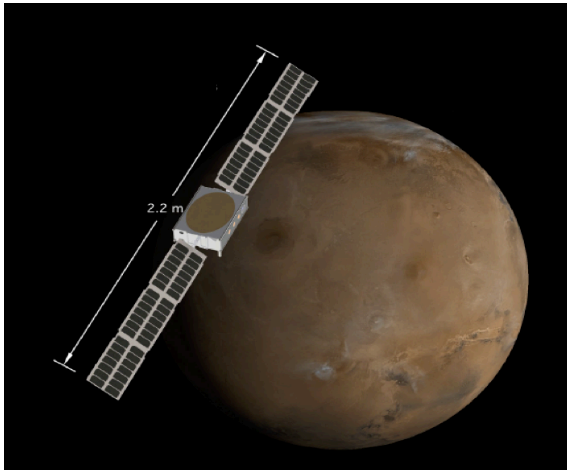
Lunar Polar Hydrogen Mapper (LunaH-Map)
PI: Craig Hardgrove
ASU School of Earth and Space Exploration



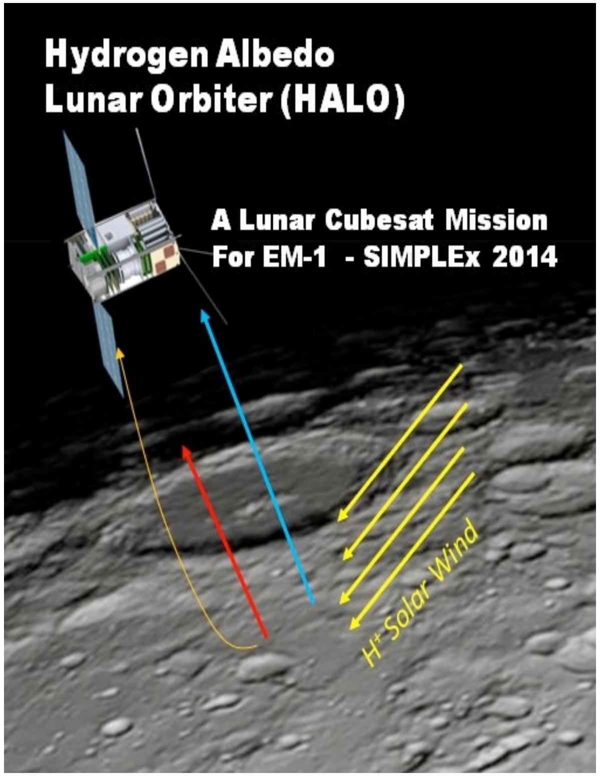
CubeSat Particle Aggregation and Collision Experiment (Q-PACE)
PI: Josh Colwel
University of Central Florida

Simplex Cubesats

Approved for Tech Development (1 year) Study ONLY



Mars Micro Orbiter
PI: Michael Malin
Malin Space Science Systems



Hydrogen Albedo Lunar Orbiter (HALO)
PI: Michael Collier,
NASA GSFC

Diminutive Asteroid Visitor using Ion Drive (DAVID)
PI: Geoffrey Landis
NASA Glenn Research Center

NAS Report: Achieving Science Goals with CubeSats: Thinking Inside the Box

Recommendation to PSD: NASA should develop and maintain a variety of CubeSat programs with cost and risk postures appropriate for each science goal and relevant science division and justified by the anticipated science return. … also important to allow CubeSats to be used for rapid responses to newly recognized needs and to realize the potential from recently developed technology.

PSD Response: 1) New R&A element supports the study of spaceflight mission concepts that can be accomplished using small spacecraft, including CubeSats. NASA's Planetary Science Program is considering including small secondary payloads on every future planetary science launch. As such, studies performed under this program element will provide valuable information to assist future AO planning and NASA's development of small spacecraft technologies relevant to deep space science investigations… 2) SIMPLEX-2 to be released soon.

Results of the 2016 Planetary Mission Senior Review (PMSR)

Senior Review Summary

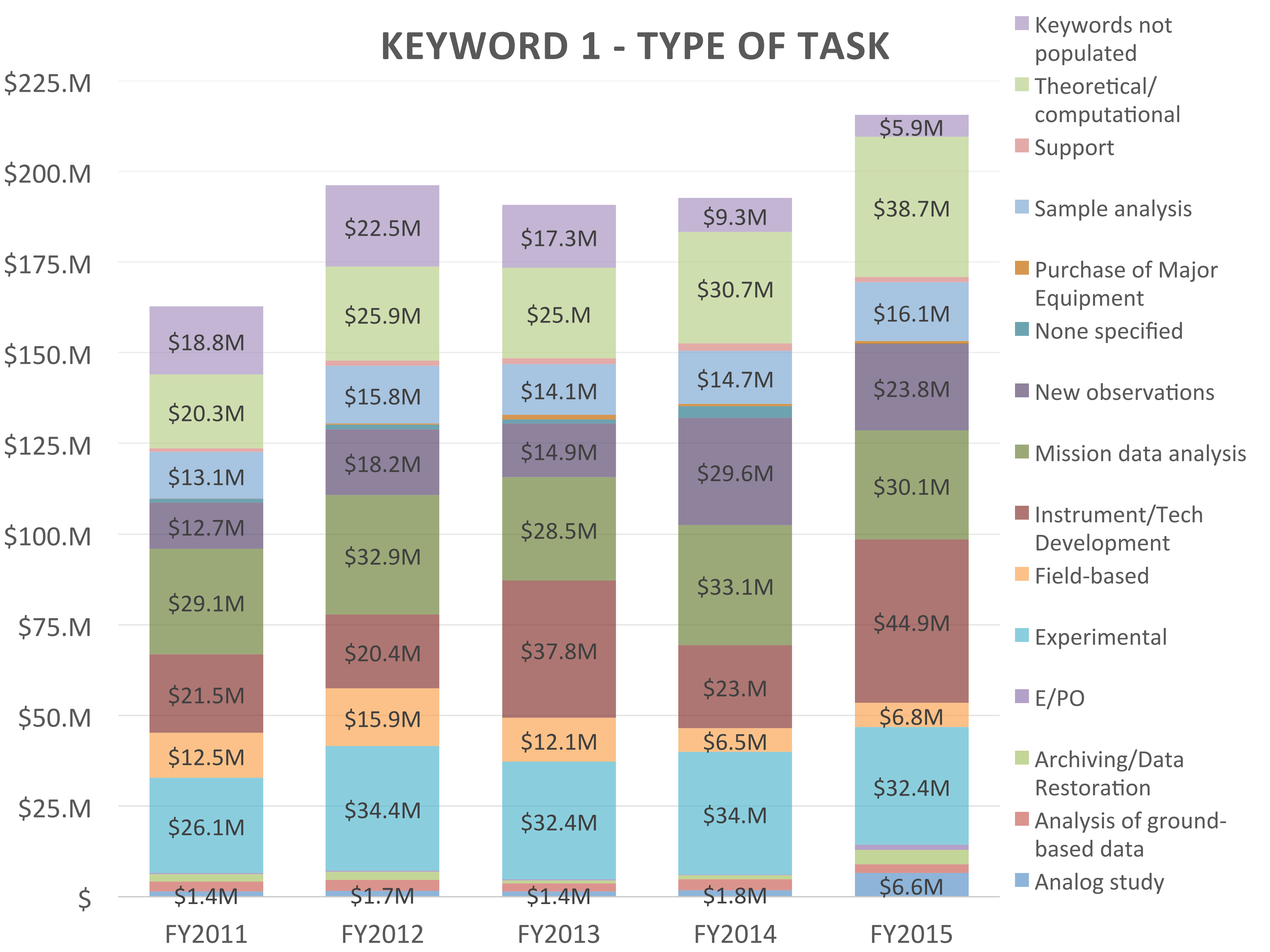
- Top Recommendation: "The Panel unanimously believes that all (missions) should be approved for extension."

MISSION	Panel Rating
Mars Reconnaissance Orbiter (MRO)	EXCELLENT
New Horizons	EXCELLENT
Lunar Reconnaissance Orbiter (LRO)	EXCELLENT/Very Good
Mars Atmosphere & Volatile EvolutioN (MAVEN)	EXCELLENT/Very Good
Opportunity/Mars Exploration Rover	EXCELLENT/Very Good
Curiosity/Mars Science Laboratory	Very Good
DAWN - Ceres	Very Good/Good
Odyssey	Very Good/Good
Mars Express (MEx)	Good
DAWN - Adeona	Good/Fair

PSD Direction to Extended Missions

- All 9 missions have been directed to plan for continued operations through FY17 and FY18.
- Kuiper Belt Extended Mission (New Horizons) is extended to 2021 with target flyby to occur in January 2019
- The Dawn mission will remain at Ceres
- Final decisions are subject to the availability of appropriated funds and the outcome of the annual budget process.

Research and Analysis Program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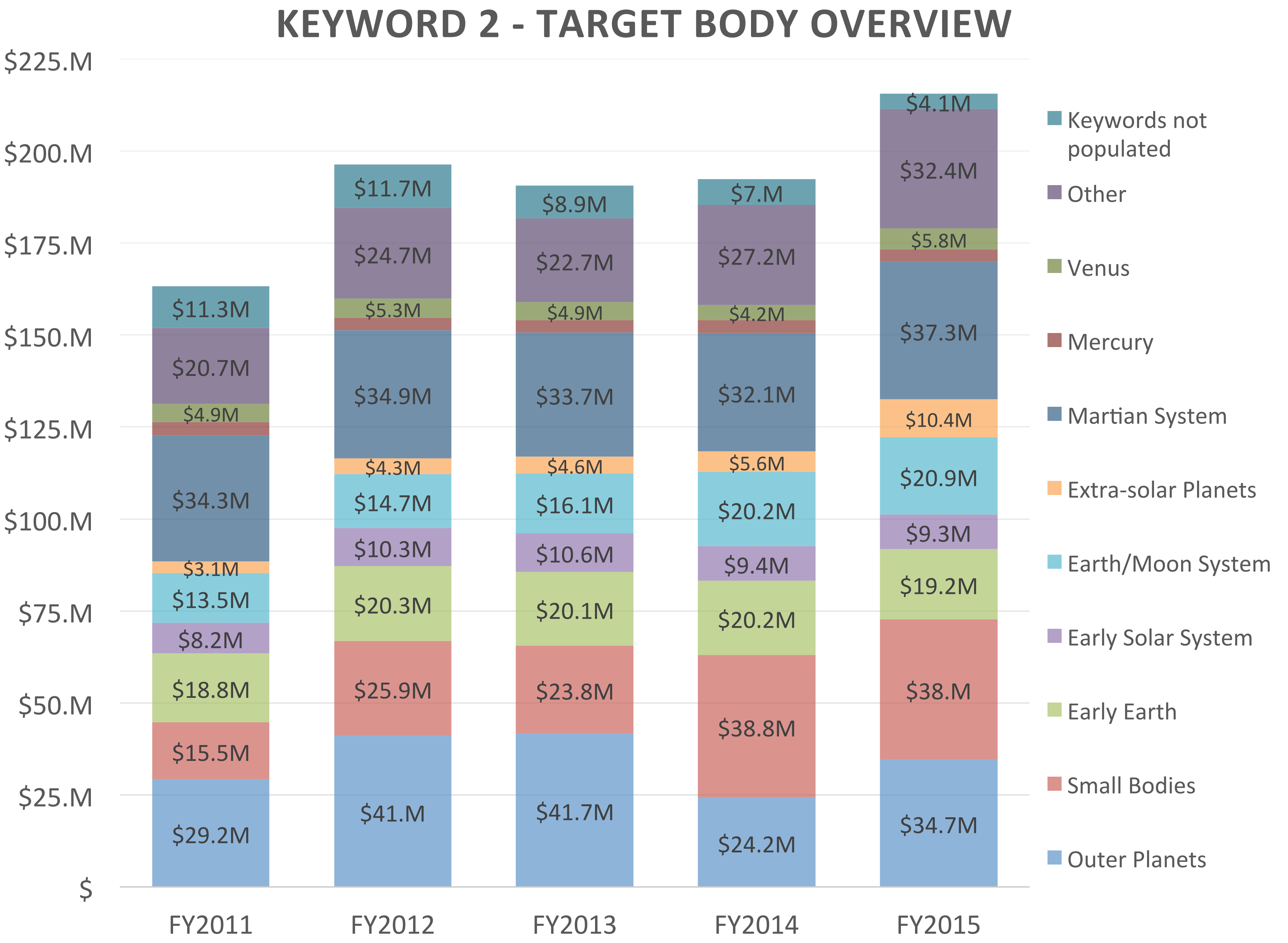
Theoretical/ computational
Support
Sample analysis
Purchase of Major Equipment
None specified
New observations
Mission data analysis
Instrument/Tech Development
Field-based
Experimental
E/PO
Archiving/Data Restoration
Analysis of ground-based data
Analog study



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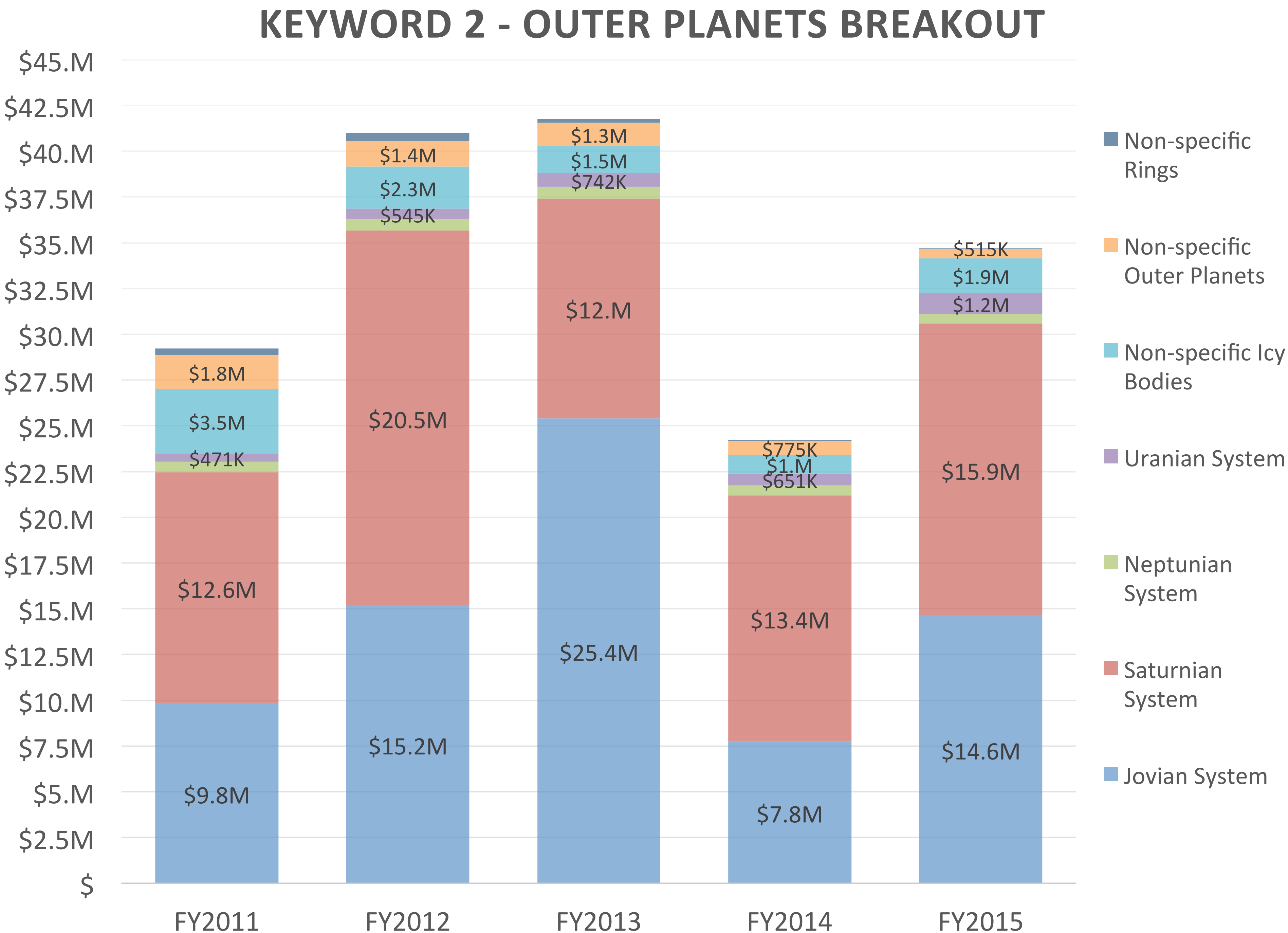
Mercury
Martian System
Extra-solar Planets
Earth/Moon System
Early Solar System
Early Earth
Small Bodies
Outer Planets



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Non-specific Icy Bodies
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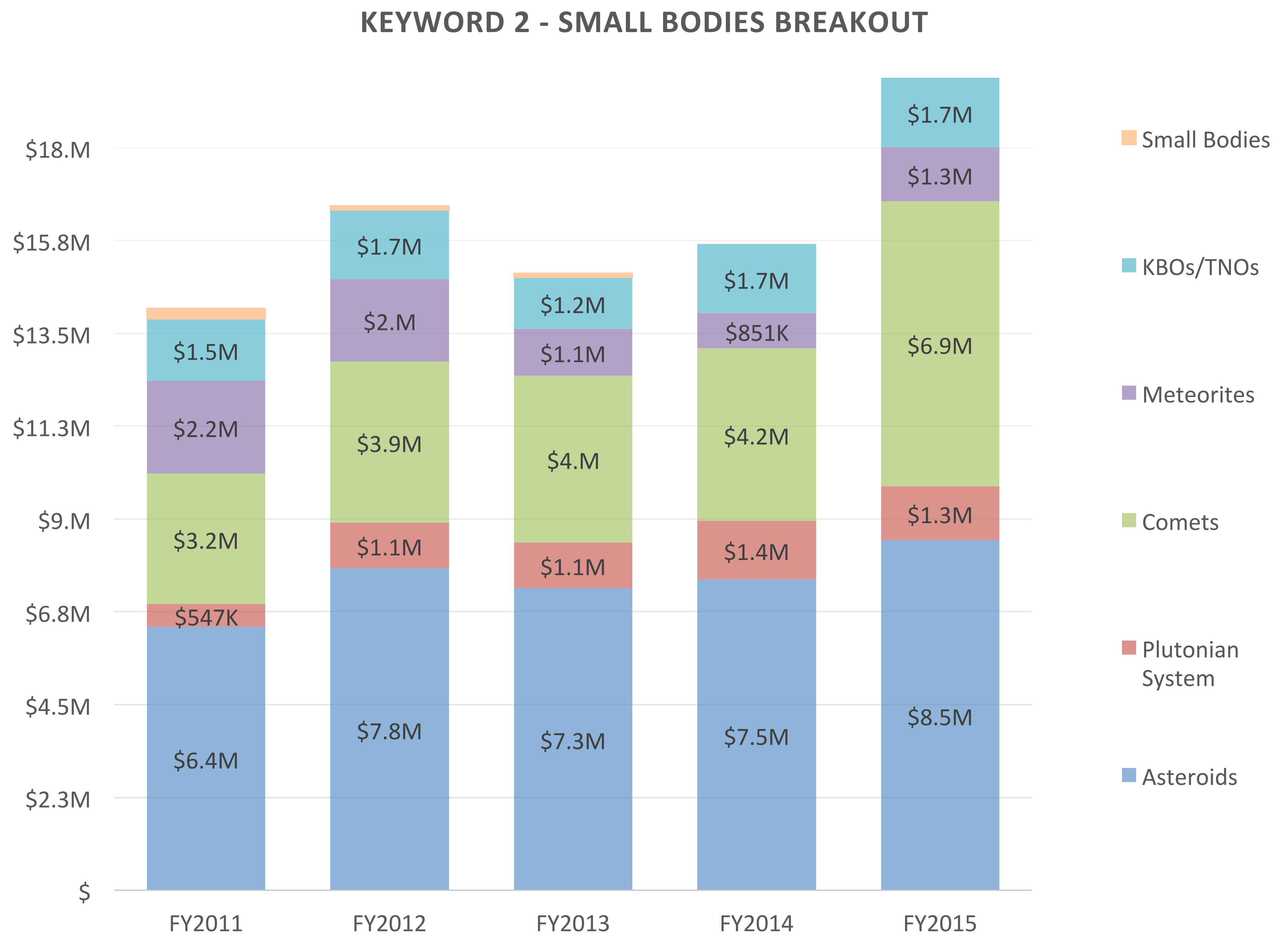
Neptunian System
Saturnian System
Jovian System



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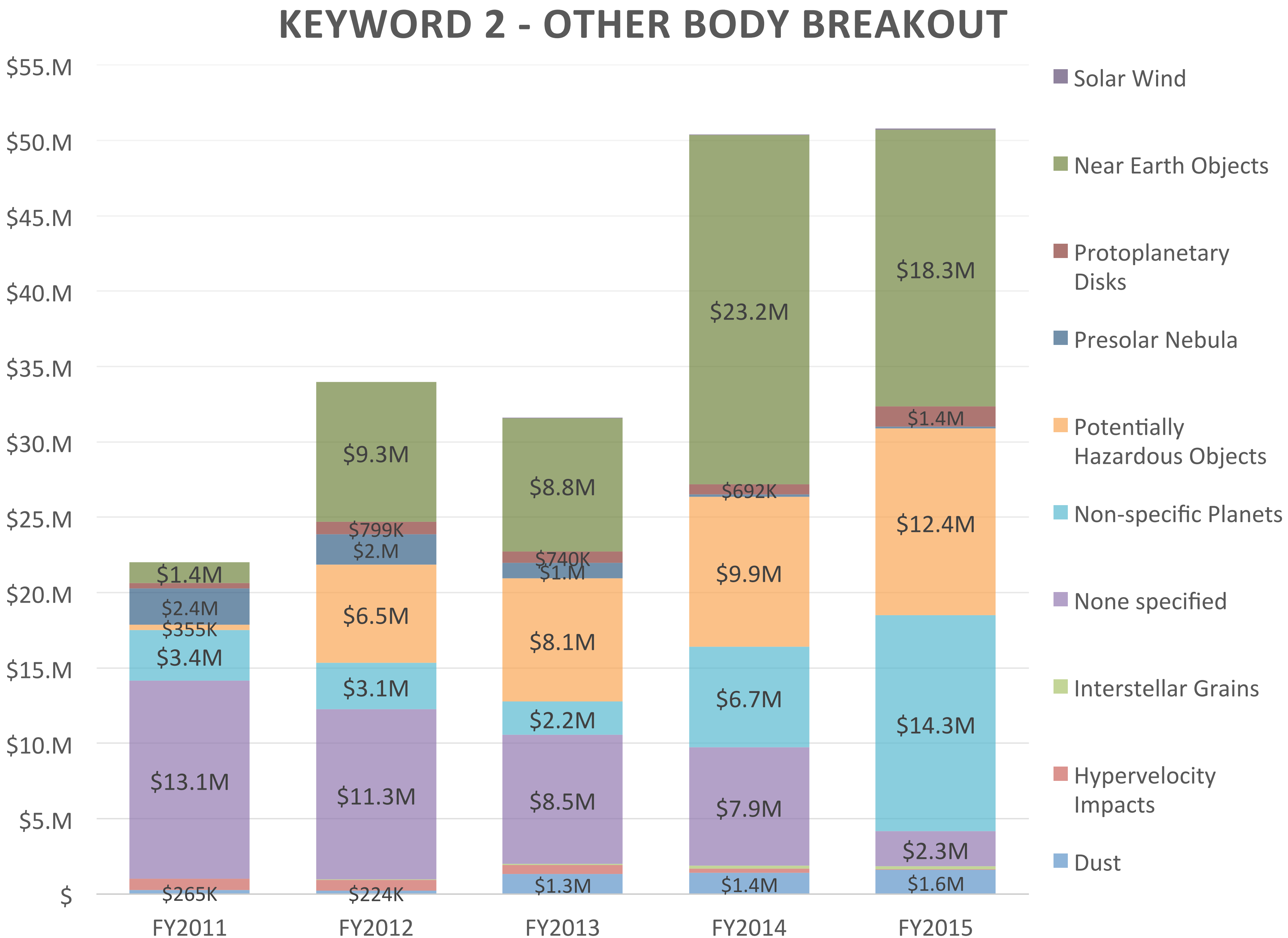
Small Bodies
KBOs/TNOs
Meteorites
Comets
Plutonian System
Asteroids



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Near Earth Objects
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Presolar Nebula
Potentially Hazardous Objects
Non-specific Planets
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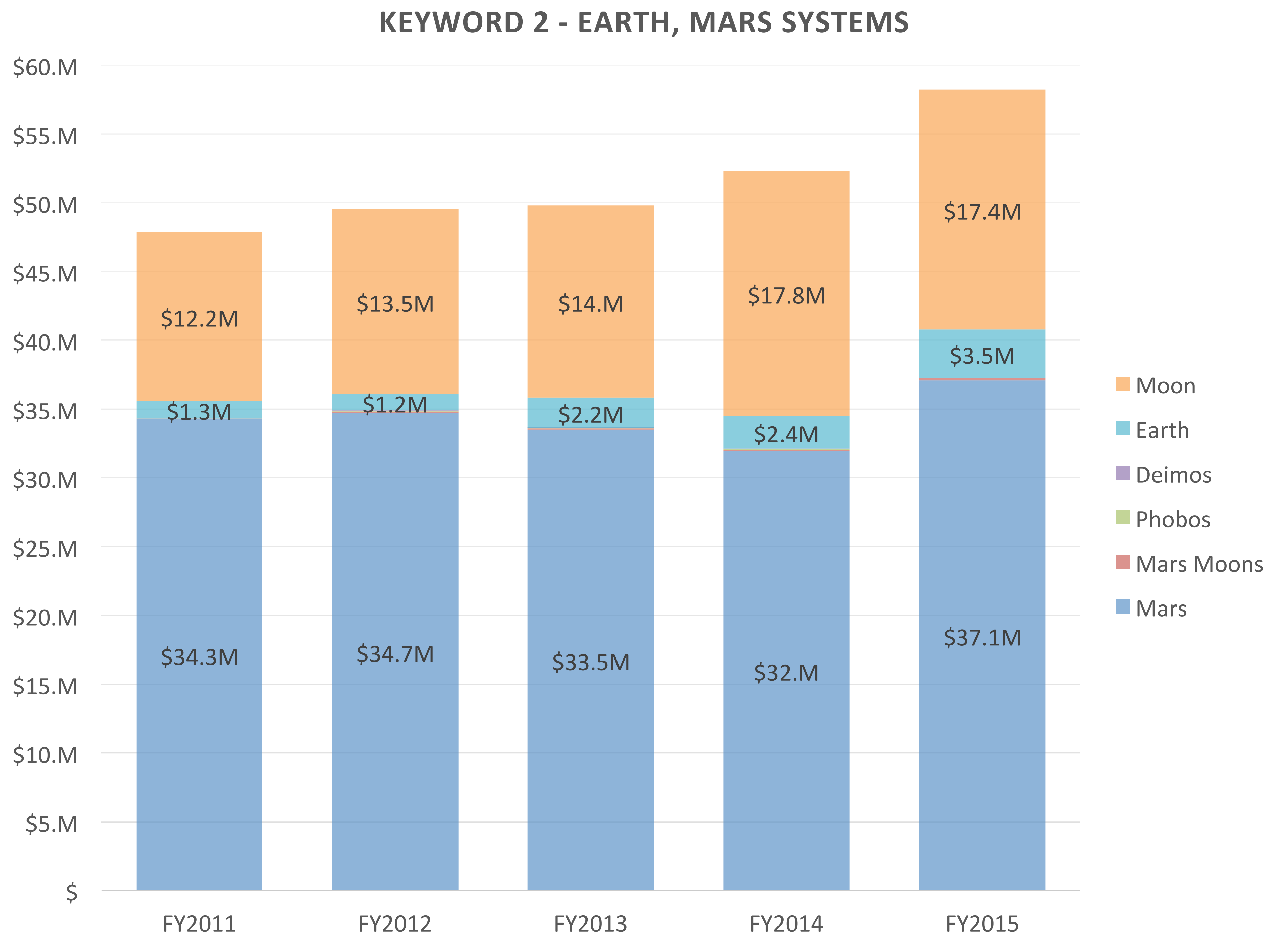
Interstellar Grains
Hypervelocity Impacts
Dust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Moon
Earth
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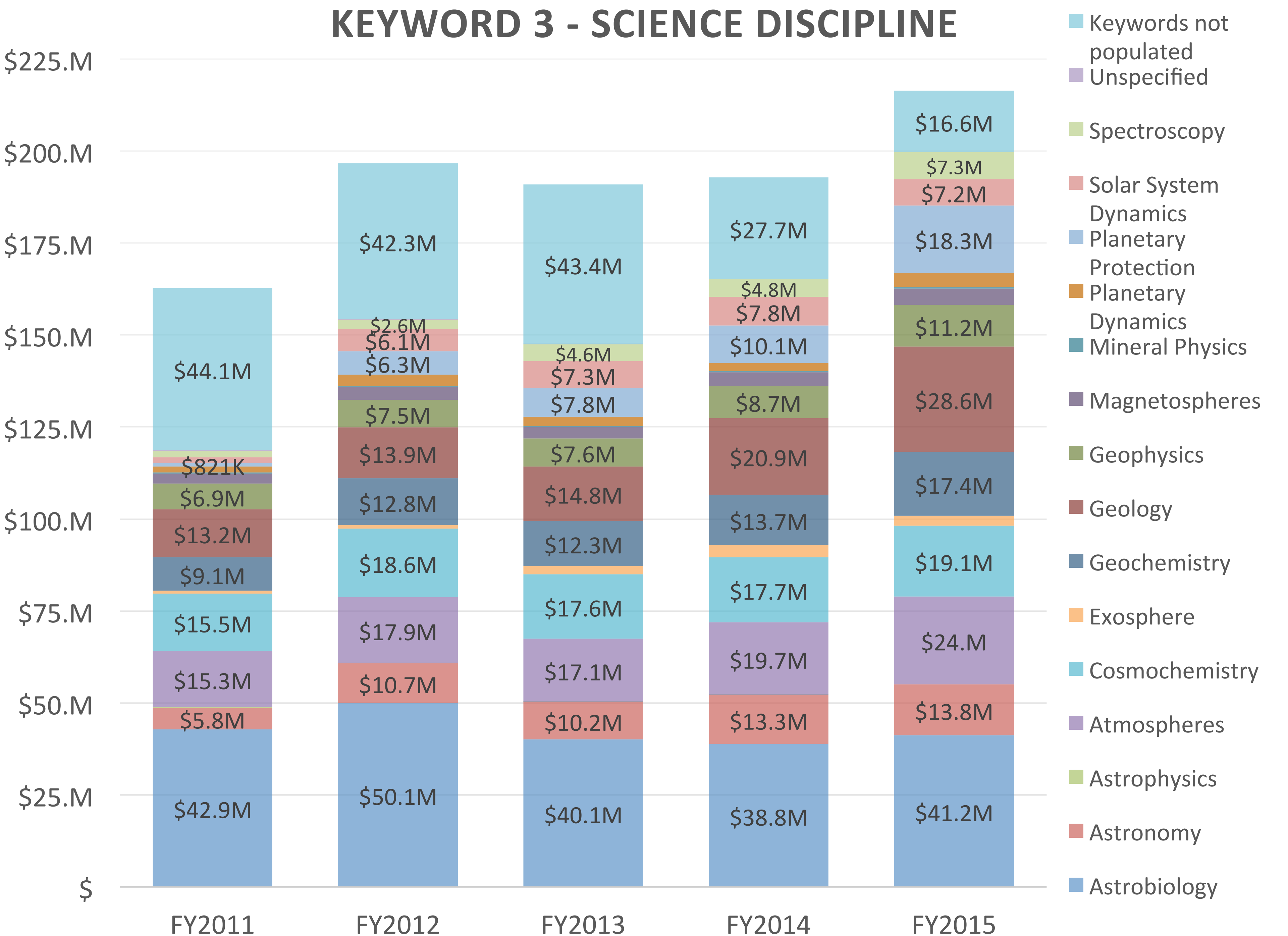

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Magnetospheres
Geophysics
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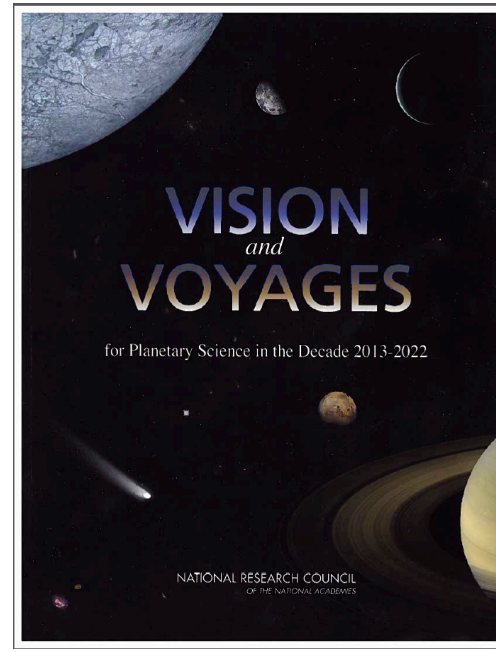
Geochemistry
Exosphere
Cosmochemistry
Atmospheres
Astrophysics
Astronomy
Astrobiology

NAS Studies for Planetary Science

Timeline of NAS Studies

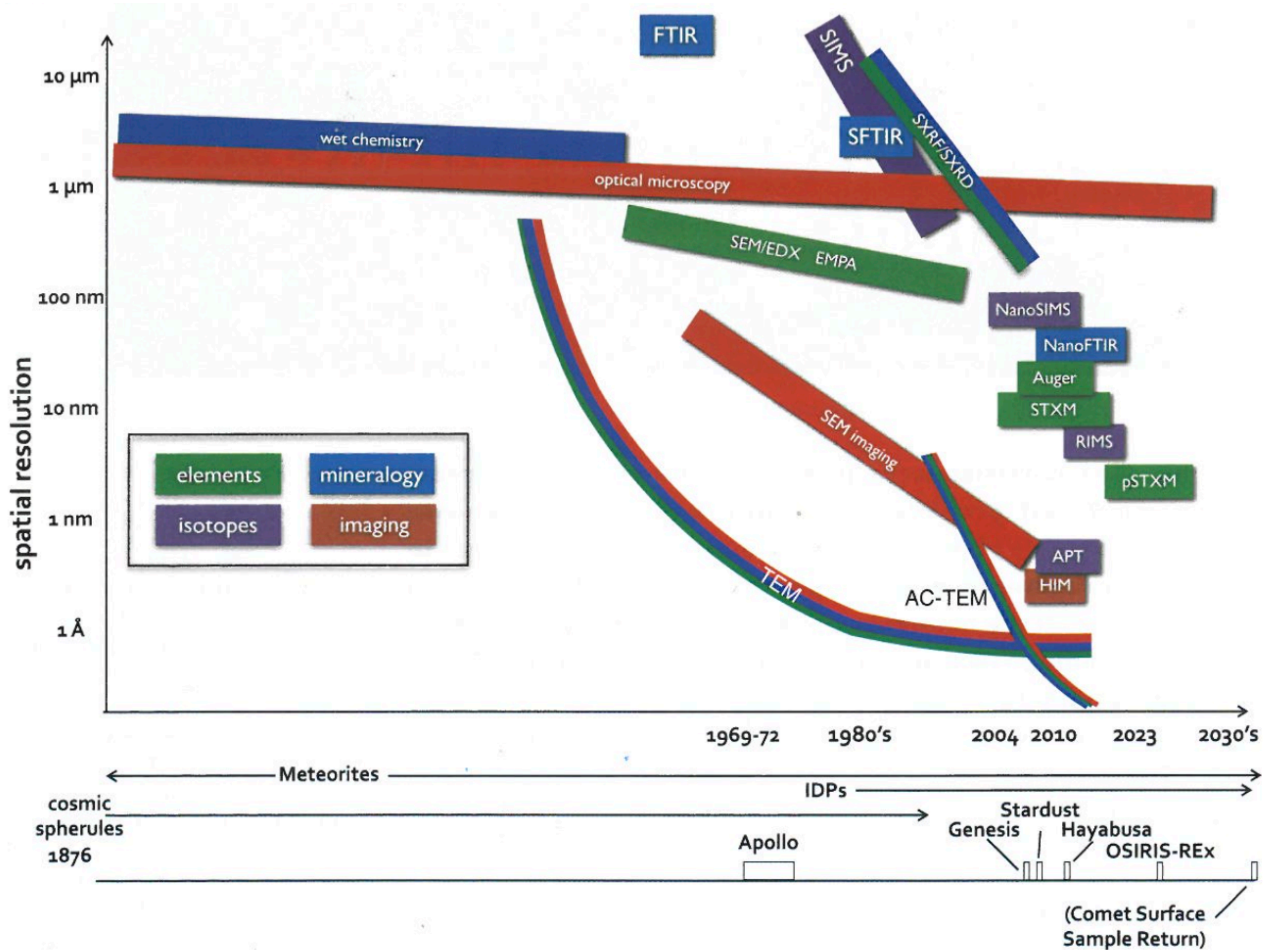


- 1st Planetary decadal: 2002-2012
- 2nd Planetary decadal: 2013-2022
- Cubesat Review: Completed June 2016
- Extended Missions Review: Completed Sept 2016
- R&A Restructuring Review:
  - Tasked August 13, 2015
  - Report due to NASA December 2016
- Large Strategic NASA Science Missions
  - Tasked December 23, 2015
  - Report due to NASA August 2017
- Midterm evaluation:
  - Tasked August 26, 2016
  - Cubesats, EX Missions, R&A Restructuring & Large Strategic Missions will be input
  - Expect report due December 2017
- New Study: Sample Analysis Future Investment Strategy (to be submitted)
- 3rd Planetary Decadal: 2023-2032
  - To be tasked *before* October 2019
  - Expect report to NASA due 1st quarter 2022

Brief Sample Management Background

- PSD has been investing in laboratory analysis instruments and techniques for several decades at a variety of institutions
- Current sample curation and archive resides at JSC contains all extraterrestrial samples for the science community
  - CAPTEM: Peer Review of sample requests for analysis
- International science community with significant sample analysis capability includes:
  - Japan, Germany, and England
- Entering an era of significant sample return missions
  - Mars: Martian Moons eXplorer, Mars Sample Return
  - Asteroids: Hayabusa 1&2, OSIRIS-REx
  - Others to follow
- Request NAS to provide recommendations for the analysis of current and future extraterrestrial samples that PSD can use to develop an investment strategy to take advantage of future sample acquisition opportunities & maximize science

Sample Analysis Instrumentation Evolution



Statement of Task

The Committee Will:

- What laboratory analytical capabilities are required to support PSD (and partner) extraterrestrial sample analysis of existing and future samples?
  - Which of these capabilities currently exist, and where are they located (including international partner facilities)?
  - What capabilities are not currently accessible that are needed?
- Assess the current structure, partnerships, community interactions, and investment strategy as to whether they meet the analytical requirements in support of current and future decadal planetary missions.
- What support structure is necessary for the science community to stay abreast of evolving techniques and to be at the forefront of sample analysis? How can NASA assure that the science community stays abreast of evolving techniques and to be at the forefront of sample analysis?

Will submit task to the NAS before October 1st

Questions?