Robotic Missions as Precursors to Human Missions

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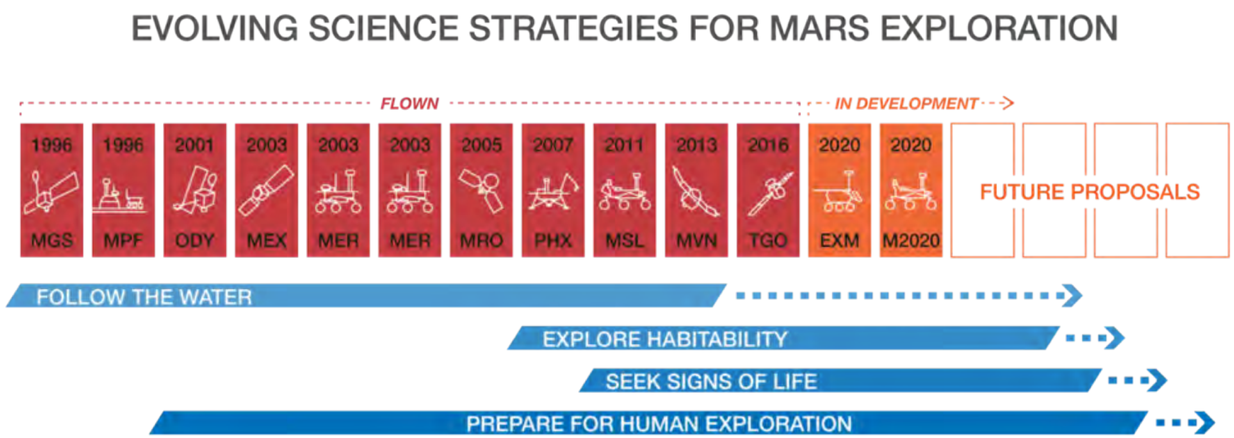
Tuesday 8 October 2019

A History of Robotic Preparation - Mars



- Mars Global Surveyor
- Mars Pathfinder
- Mars Odyssey
- Mars Express
- Mars Exploration Rover
- Mars Reconnaissance Orbiter
- Phoenix Mars Lander
- Mars Science Laboratory
- MAVEN: Mars Atmosphere and Volatile EvolutioN
- Trace Gas Orbiter
- ExoMars: Exobiology on Mars
- Mars 2020

https://mars.nasa.gov/resources/5406/evolving-science-strategies-for-mars-exploration/

A History of [Robotic] Preparation - Moon

spacecraft/programme name	nationality	launch year	mission description
Luna 2	USSR	1959	first lunar impact
Luna 3	USSR	1959	flyby: first farside images
Ranger probes (3/7)	USA	1962–1965	impact probes: near surface imagery
Luna 9	USSR	1966	soft lander: first surface images
Luna 10	USSR	1966	first lunar orbiter
Surveyor landers (5/7)	USA	1966–1968	soft landers: surface properties
Lunar Orbiters (5/5)	USA	1966–1967	orbiters: orbital photography
Apollo 8, 10	USA	1968	human lunar orbiters: orbital photography
Apollo 11, 12, 14–17	USA	1969–1972	human landings: surface and interior properties; sample return; orbital remote sensing
Lunokhod 1, 2 (Luna 17, 21)	USSR	1970, 1973	robotic rovers: surface properties
Luna 16, 20, 24	USSR	1970, 1972, 1976	robotic sample return
Hiten (MUSES-A)	Japan	1990	lunar orbiter: dust detection
Clementine	USA	1994	orbital remote sensing
Lunar Prospector	USA	1998	orbital remote sensing
SMART-1	Europe	2003	orbital remote sensing
Kaguya	Japan	2007	orbital remote sensing
Chang'e-1	China	2007	orbital remote sensing
Chandrayaan-1	India	2008	orbital remote sensing
Lunar Reconnaissance Orbiter	USA	2009	orbital remote sensing
Lunar Crater Observation and Sensing Satellite (LCROSS)	USA	2009	impact probe; polar volatile detection
Chang'e-2	China	2010	orbital remote sensing
Gravity Recovery and Interior Laboratory (GRAIL)	USA	2011	orbital gravity mapping
Lunar Atmosphere and Dust Environment Explorer (LADEE)	USA	2013	orbital exosphere and dust studies
Chang'e-3	China	2013	soft lander with rover: surface properties

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4128274/table/RSTA20130315TB1/?report=objectonly

Side Note: “Metric Moon”

Metric Moon

+ Play Audio | + Download Audio | + Join mailing list

January 8, 2007: If you think in pounds and miles instead of kilograms and kilometers, you're in the minority. Only the United States, Liberia, and Burma still primarily use English units -- the rest of the world is metric. And now the Moon will be metric too.

https://science.nasa.gov/science-news/science-at-nasa/2007/08jan_metricmoon

Four Science Goals

Robots as Precursors to Humans

MARS Reconnaissance Orbiter

Mission News Multimedia Participate All M

Mission › Science **Goals** Objectives

Goal 4: Prepare for human exploration

With eagle-eye vision, the Mars Reconnaissance Orbiter will home in on rocks the size of 3-4 feet. With this capability, mission planners will identify the most promising locales for scientific study and know, too, which are safe and which might be hazardous to future landers carrying humans.

[MORE ON GOAL 4 FOR THE ENTIRE MARS EXPLORATION PROGRAM]

https://mars.nasa.gov/mro/mission/science/goals/

Primary Themes for Human Preparation

- Water and Water Ice
- Landing Sites
- Entry, Descent, and Landing (EDL) Techniques
- Radiation
- Weather
- Soil/In-Situ Resources
- Atmosphere

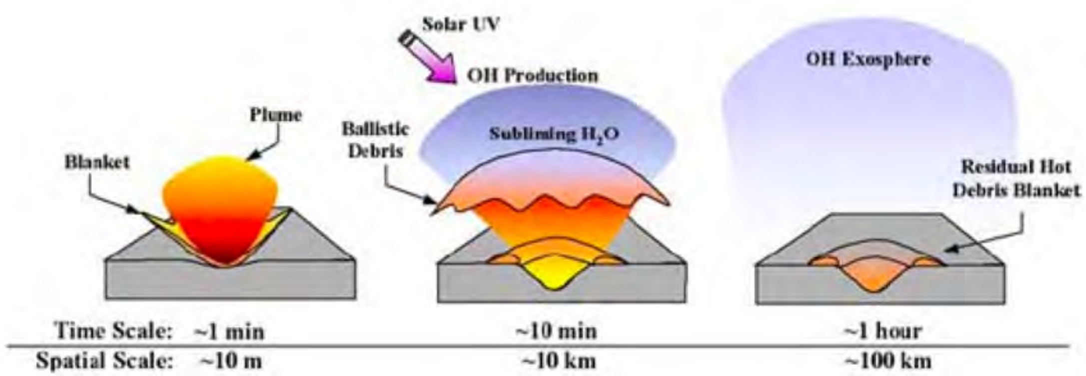
https://mars.nasa.gov/programmissions/science/goal4/

Searching for Water and Water Ice

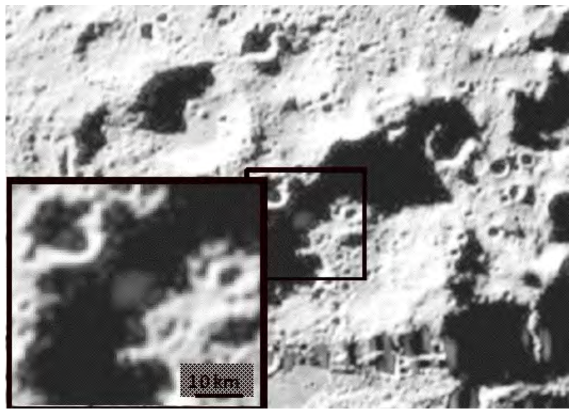
- Lunar Reconnaissance Orbiter (LRO) found evidence that up to 10% of the material inside the Shackleton Crater near the South Pole of the moon could be patchy ice, using the Mini-RF radar instrument.
- Mars Exploration Rovers Spirit and Opportunity each found evidence for past wet conditions that possibly could have supported microbial life.
- Mars Science Laboratory Curiosity found rounded pebbles likely formed by a flowing river and evidence of rivers and lakes in Gale Crater.

https://www.nasa.gov/mission_pages/LRO/news/shackleton-ice.html
https://mars.nasa.gov/mars-exploration/missions/mars-exploration-rovers/
https://mars.nasa.gov/msl/mission/science/results/

Searching for Water: LCROSS (2009)



The life cycle of a lunar impact. The LCROSS instruments are designed to collect data on the evolving impact environment.

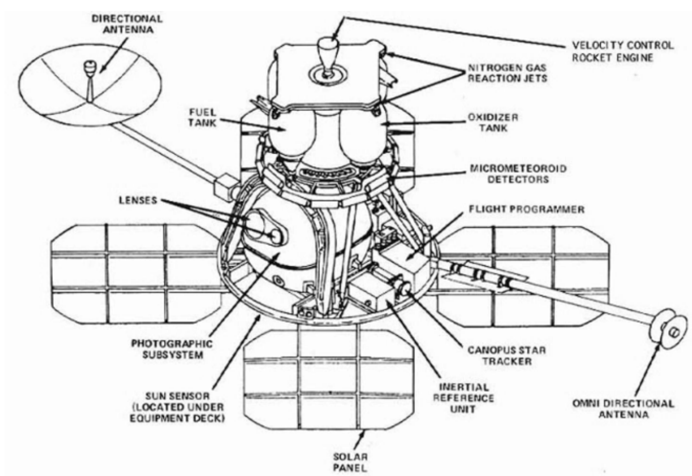


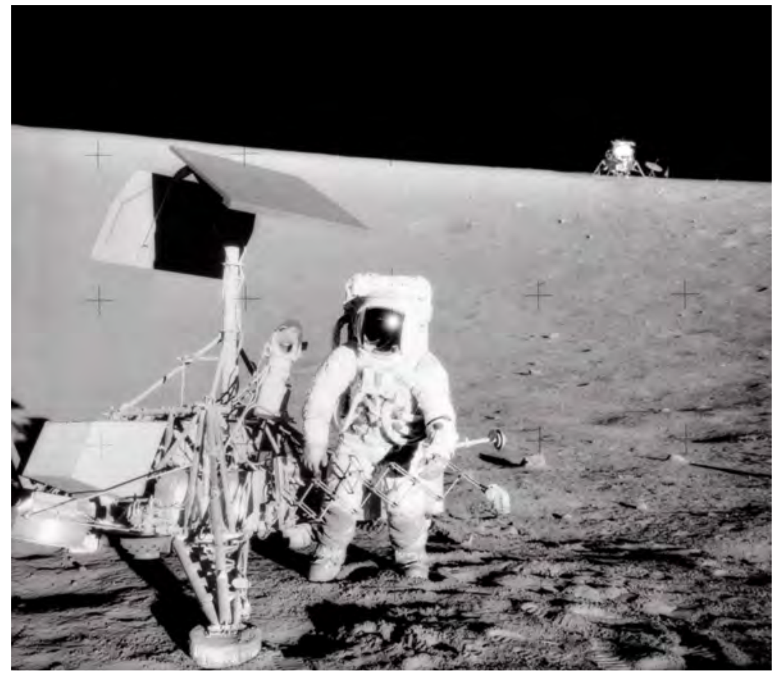
The visible camera image showing the ejecta plume at about 20 seconds after impact.

https://www.nasa.gov/mission_pages/LCROSS/searchforwater/LCROSS_impact.html
https://www.nasa.gov/mission_pages/LCROSS/main/prelim_water_results.html

Exploring Possible Landing Sites: Moon

- Ranger (1961-1965)
- Surveyor (1966-1968)
- Lunar Orbiter (1966-1967)

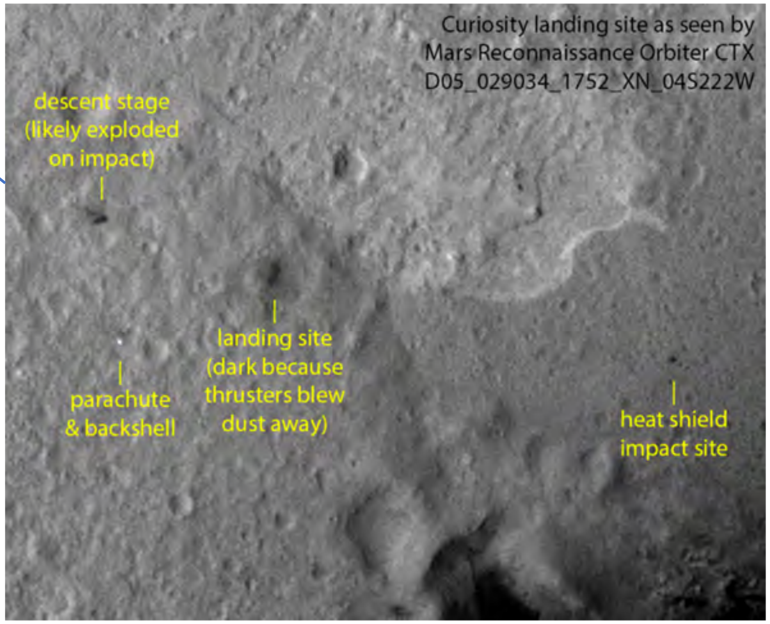




https://airandspace.si.edu/exhibitions/apollo-to-the-moon/online/early-steps/robots-on-moon.cfm

Exploring Possible Landing Sites: Moon & Mars

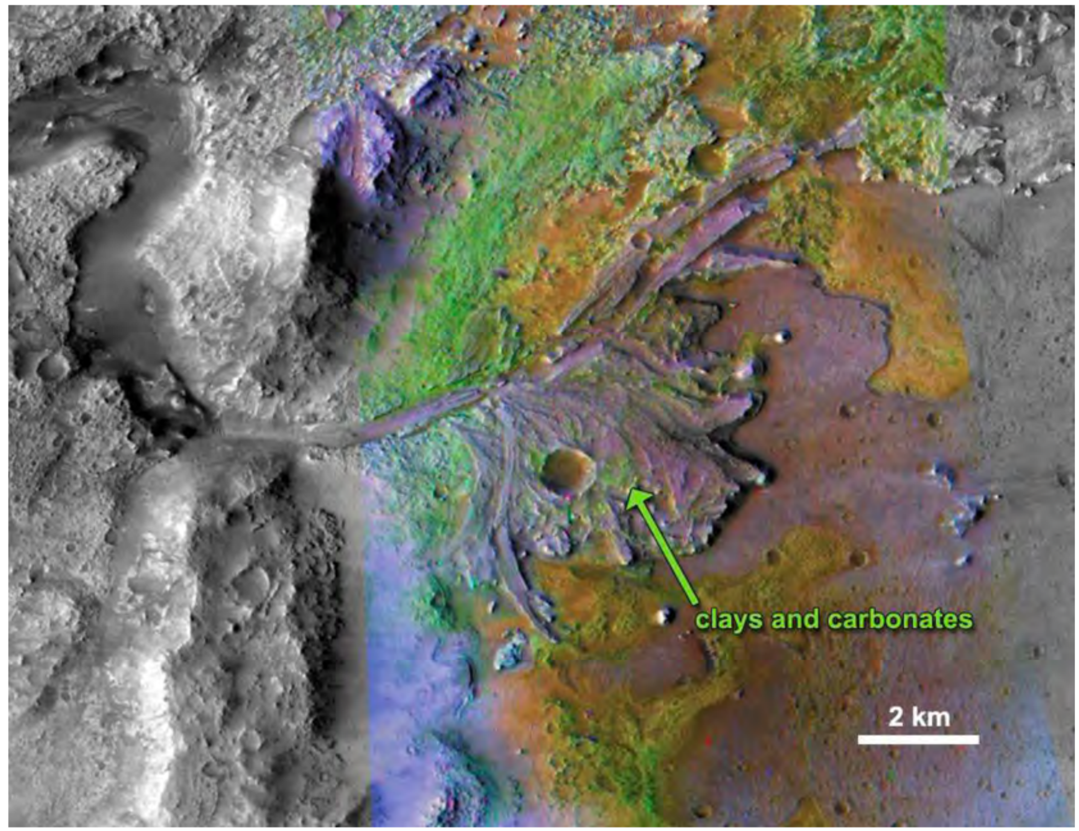
- LRO providing highly accurate 3D maps
- MRO imaging past and future landing sites



https://lunar.gsfc.nasa.gov/science.html
http://www.planetary.org/multimedia/space-images/mars/ctx-curiosity.html

Exploring Possible Landing Sites: Mars

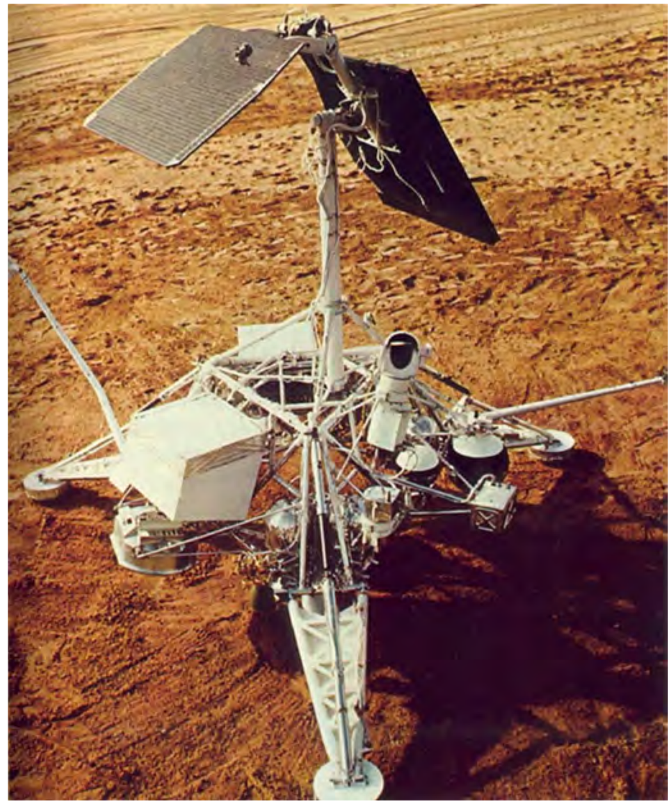
- Mars 2020 rover landing site chosen using MRO imagery: Jezero Crater



https://mars.nasa.gov/news/8387/nasa-announces-landing-site-for-mars-2020-rover/

Honing Entry, Descent, and Landing Techniques: Surveyor

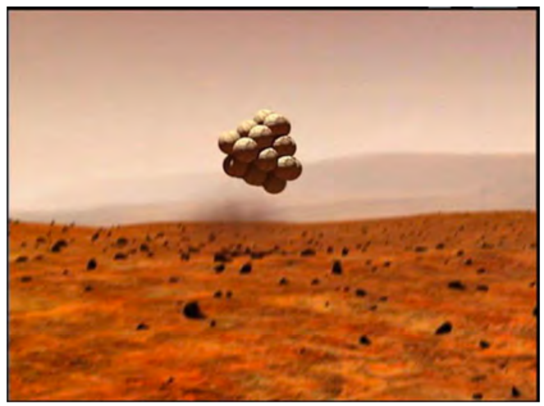
- First soft landing on the moon

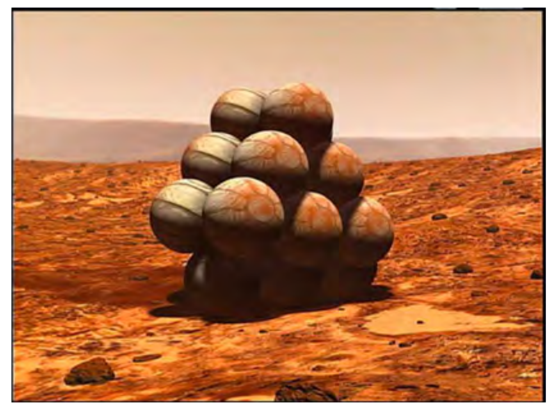


https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-045A

Honing Entry, Descent, and Landing Techniques: MER/Spirit and Opportunity

- Airbags





https://mars.nasa.gov/mer/spotlight/rocknroll01.html

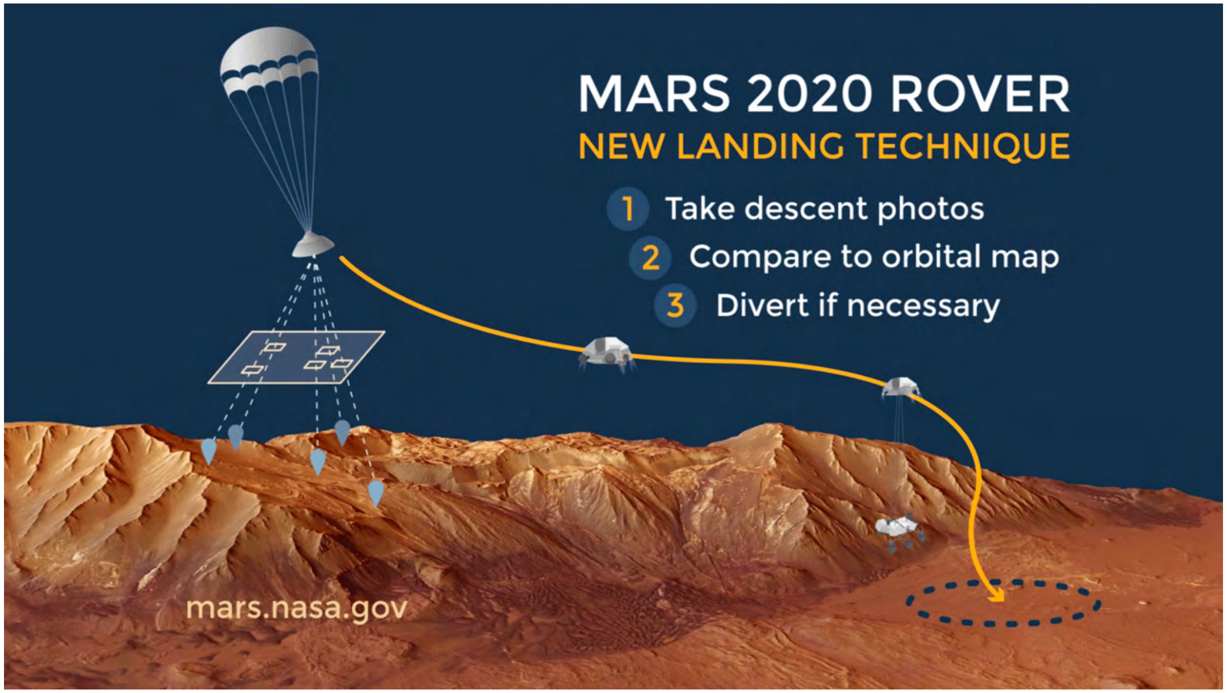
https://mars.nasa.gov/resources/20314/mars-exploration-rover-mission-animation/

Honing Entry, Descent, and Landing Techniques: MSL/Curiosity

- Skycrane

https://www.nasa.gov/mission_pages/msl/multimedia/gallery/pia14839.html
https://www.youtube.com/watch?v=P4boyXQuUIw 1:50 – 3:20
https://science.nasa.gov/science-news/science-at-nasa/2012/30jul_skycrane

Honing Entry, Descent, and Landing Techniques: Mars 2020



https://mars.nasa.gov/resources/7911/entry-descent-and-landing-system/

https://www.nasa.gov/sites/default/files/atoms/files/skg-sat-theme-3-sept-2016.pdf

SKG (Strategic Knowledge Gap) Example

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
Theme 1-D-Polar Resources 1: Extent of Cold Traps.	DIVINER maps show temperature distributions, model stability and evolution of spin axis, mapping of old topographic lows.	Enabling	RETIRED	Exploration Science	LRO Observations have satisfied objective	Continued Diviner observations in 3rd extended mission will improve spatial coverage of polar regions by increasing SNR

Strategic Knowledge Gap	Narrative (modified from LEAG 2012 GAP SAT report)	Enabling or Enhancing	Status	Exploration Science or Technology	Messurements or Mission needed to retire SKG	Notes 2016 Assessment
III-A-2 Technologies for transporting lunar resources	Load, excavate, transport, process, and dispose of regolith; enables ISRU, surface trafficability, and ejecta plume mitigation.	Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.	**OPEN**	Technology	Missions to the lunar surface, at both polar and non-polar locations, testing the transportation of lunar resources, are required to retire this gap.	University competition at KSC involving regolith manipulation. Demonstrations at Hawaii (PISCES) NASA ISRU types: Sanders, Mueller, Sacksteder, Linne Open University 3-D printing with lunar regolith (Mahesh Anand)

https://www.nasa.gov/sites/default/files/atoms/files/skg-sat-theme-1-sept-2016.pdf

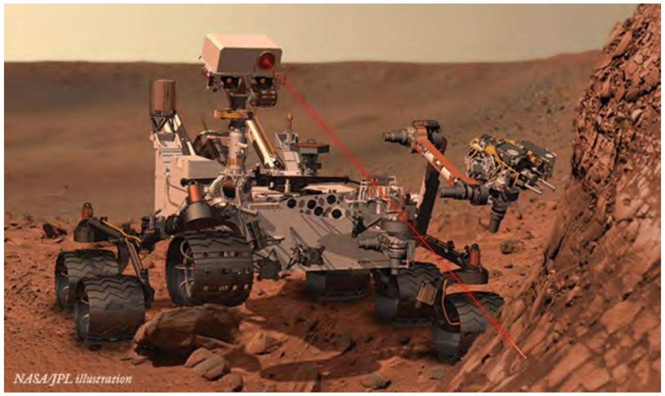
Soil Composition (Goals)

- In situ measurement of organics/composition in a pristine environment
- Allows for in-situ resource utilization
- ‘Ground truth’ to orbital measurements. 10m scale laterally over 1-5km baselines, depths 0-3m.
- Gas analyzers (heat the soil, measure the composition), spectrometers
- Search for bulk hydrogen within 1m of surface
- Volatile inventory
- Geological context
- Geotechnical and physical properties of the site

http://phoenix.lpl.arizona.edu/science05.php

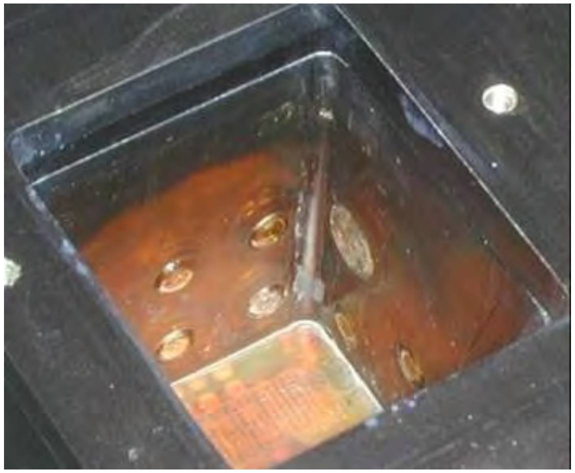
http://www.planetary.org/explore/space-topics/space-missions/change-4.html

Soil Composition Examples



Curiosity

- Chang'e 4 Rover (2019, moon) (spectroscopy + dosimetry)
- Viking CGMS (1976, mars)
- Gas Chromatography/mass spectrometry to analyze composition of soils
- Viking Labelled release; release nutrient solution onto soil, measure if any Co2 comes out, evidence of microbes
- Phoenix (2008,mars) TEGA (oven that bakes out soil samples, measure gas composition)
- Phoenix Wet Chemistry Lab (flood sample with water, measure what leaches out)
- Optical/AMU microscopes
- Thermal/Electrical conductivity probe to sense for water, soil properties



https://www.nasa.gov/sites/default/files/atoms/files/skg-sat-theme-3-sept-2016.pdf

ISRU In Situ Resource Utilization (Goals)

- Idea is to reduce resources needed to go to mars, by being able to acquire it in situ. Industry, etc.
- Heat up and dispose of leftover lunar regolith after processing
- Process soil at high temperature to test metal extraction techniques
- Do this in situ on the moon.
- Excavation, create trenches, roads, berms, etc.
- Test surface trafficability, in situ measurements at different locations, poles, etc.
- Test for transporting, processing, and sorting of lunar resources (crushing, grinding, etc)

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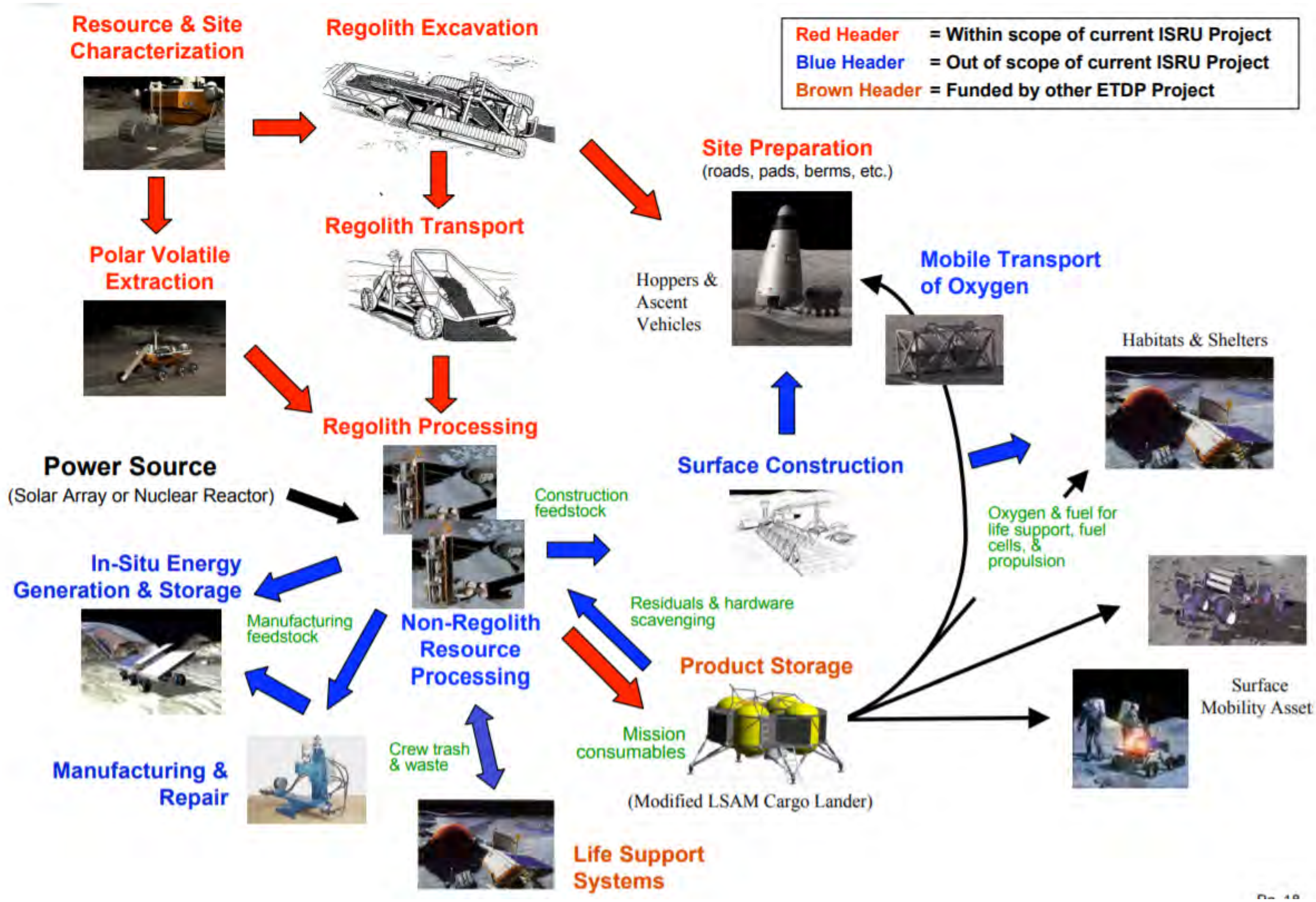

Resource & Site Characterization
Regolith Excavation
Red Header = Within scope of current ISRU Project
Blue Header = Out of scope of current ISRU Project
Brown Header = Funded by other ETDP Project
Polar Volatile Extraction
Regolith Transport
Site Preparation
(roads, pads, berms, etc.)
Hoppers & Ascent Vehicles
Mobile Transport of Oxygen
Habitats & Shelters
Regolith Processing
Power Source
(Solar Array or Nuclear Reactor)
Surface Construction
Construction feedstock
Oxygen & fuel for life support, fuel cells, & propulsion
In-Situ Energy Generation & Storage
Manufacturing feedstock
Non-Regolith Resource Processing
Residuals & hardware scavenging
Product Storage
Surface Mobility Asset
Manufacturing & Repair
Crew trash & waste
Mission consumables
(Modified LSAM Cargo Lander)
Life Support Systems

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https://www.nasa.gov/sites/default/files/atoms/files/skg-sat-theme-2-sept-2016.pdf

Dust (Goals)

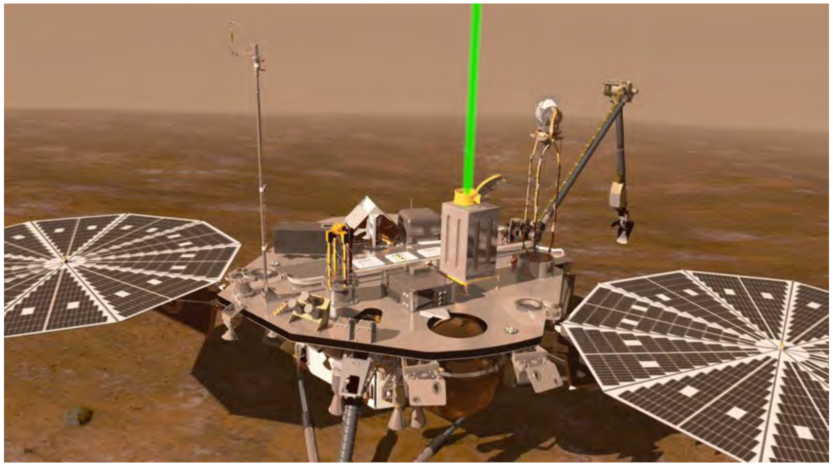
- Biological effects of lunar dust
- Obtain particle size distribution, dust shape/morphology, clump sizes/adhesion strength, grain reactivity in different conditions
- Biohazards in Martian environment? Is the dust toxic?
- Measure electrostatic charge of dust, sticks to equipment
- Lunar/Martian dust remediation for hardware
- Analysis of effect of dust on joints/bearings, etc.

Dust Examples

https://mars.nasa.gov/mer/mission/instruments/magnet-array/

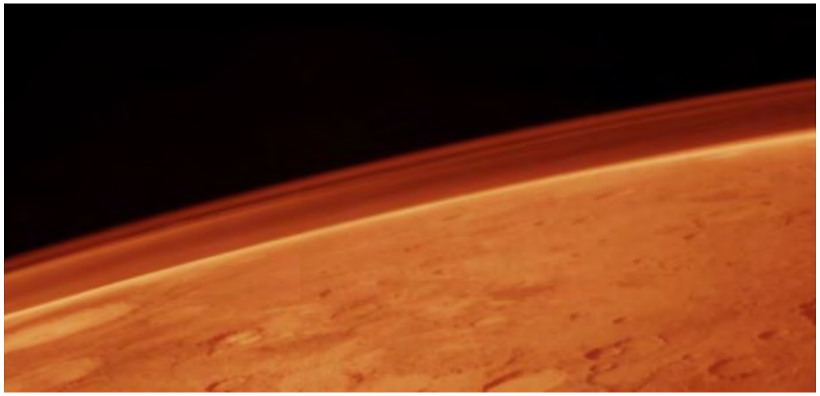
https://nssdc.gsfc.nasa.gov/planetary/marspath_results.html

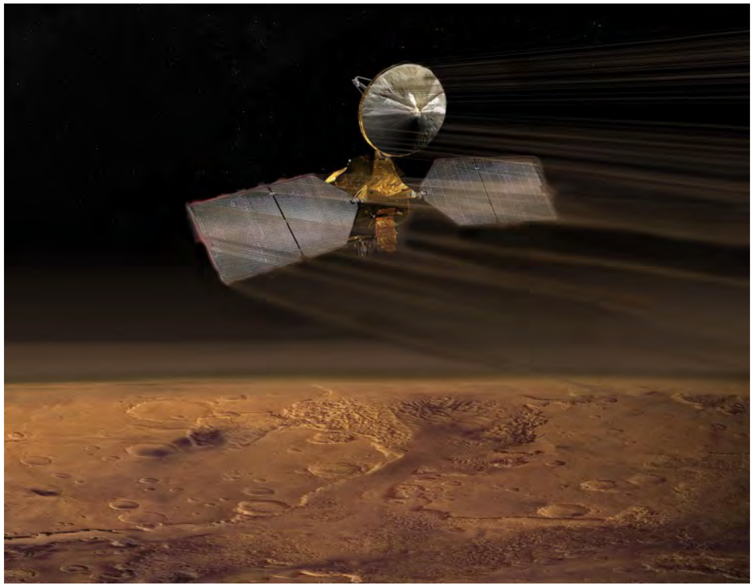
- Materials Adherence Experiment on Pathfinder (1997, mars) (glass slide measuring solar panel dust accumulation)
- Magnet Array on Spirit/Opportunity (2004, mars) (Measuring + imaging magnetic/non magnetic dust)
- Phoenix (2008, mars) Weather Lab (dust in air from LIDAR measurements)



https://mepag.jpl.nasa.gov/reports/P-SAG_final_report_06-30-12_main_v26.pdf

Weather (Goals)





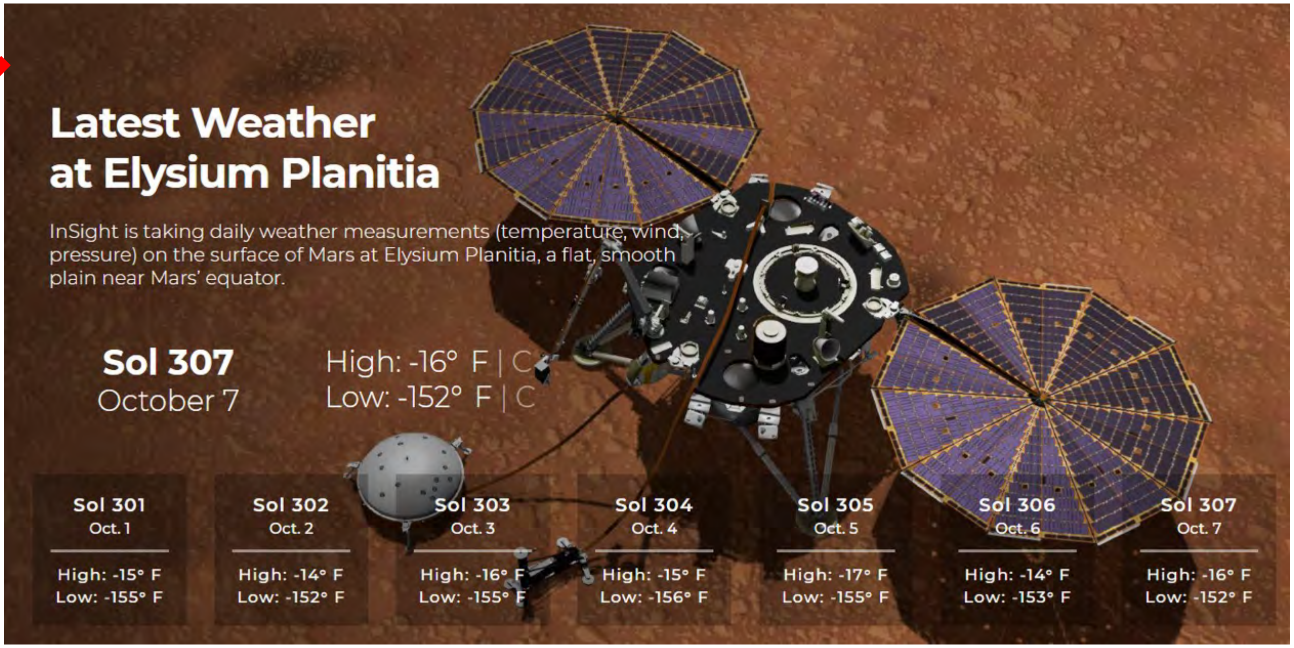
- THEME: We have orbiter measurements or theoretical calculations, measure in situ as well, to check ('ground-proof').
- Need global atmospheric models of mars, insufficient data
- Orbital particulate environment, might impact delivery of cargo/crew to mars
- Lower atmosphere, EDL, risk to ascent vehicles, ground systems, human explorers.
- Need to better understand the upper atmosphere, for better aerobraking, aerocapture, etc for human scale missions.
- Tied to dust, as dust affects weather/temperature

https://mars.nasa.gov/mars2020/mission/instruments/meda/

Weather Examples

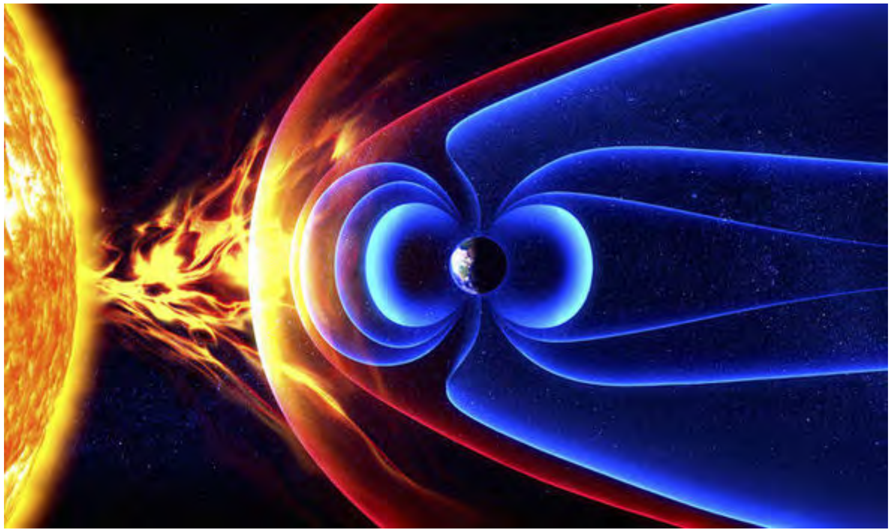
MAVEN!!!

- Phoenix Weather Lab (2008, mars) (wind speed, pressure, temperature)
- REMS instrument on Curiosity (2012, mars)
- TWINS instrument on InSight (2018, mars)
- MEDA on MARS 2020 rover
- All are similar weather stations, at different locations on Mars.



Radiation (Goals)

- Radiation sensors to provide information to feed into models/experiments on Earth
- Early warning system from landed ion detector stations
- Understand any secondary radiation effects on the lunar/martian surface
- Landed mission to measure radiation shielding of different depths of lunar regolith. Shielding studies in general
- Studies of cells, viruses, etc on moon/martian surface. See how immunity is affected
- Set up a spacecraft 'sentinel' in the EUV/optical to watch the sun for CME's or SEPs that might affect other missions/astronauts on mars/moon
- Micrometeorite protection testing



Radiation Examples

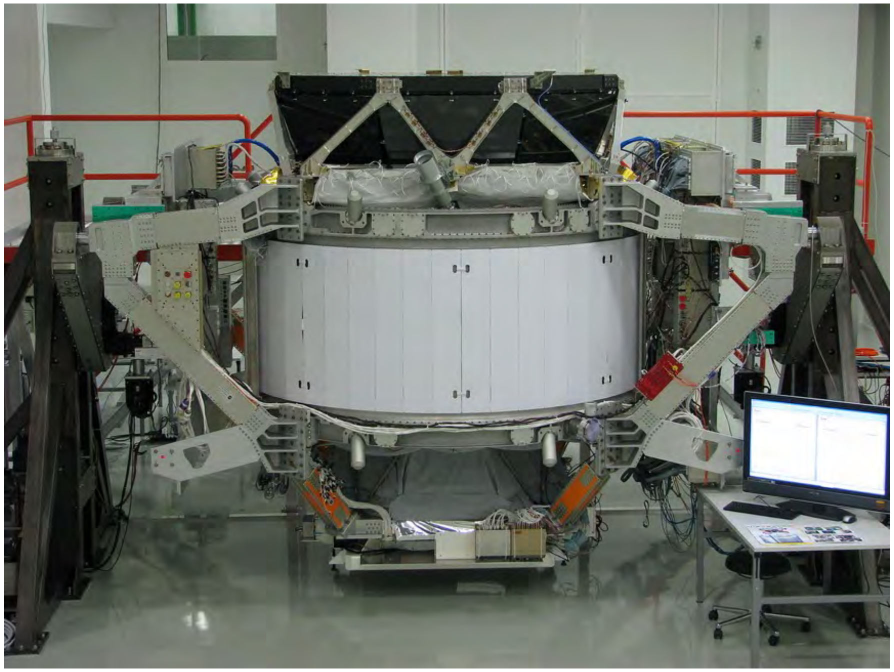
https://mars.nasa.gov/msl/spacecraft/instruments/rad/

https://ams02.space/

http://crater.sr.unh.edu/

https://exploration.esa.int/web/mars/-/48523-trace-gas-orbiter-instruments

- AMS-02 (present, ISS) measures rad. Environment on ISS
- Chang'e 4 Rover (2019, moon) in situ dosimetry
- CRaTER instrument on LRO (2009, moon), "human tissue equivalent" plastic
- MARIE (2001, mars) measured radiation environment on-orbit
- FREND on TGO (2016, mars) is similar
- RAD Instrument Curiosity (2012, mars)
- SHERLOC MARS 2020 testing spacesuit fragments



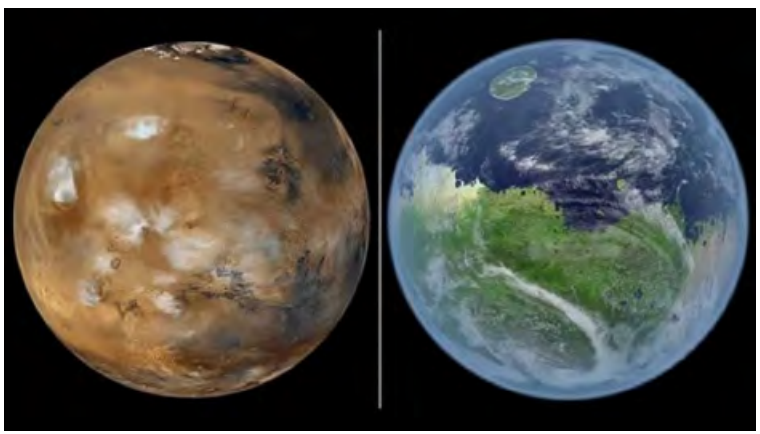
Sweet, sweet oxygen (Goals)

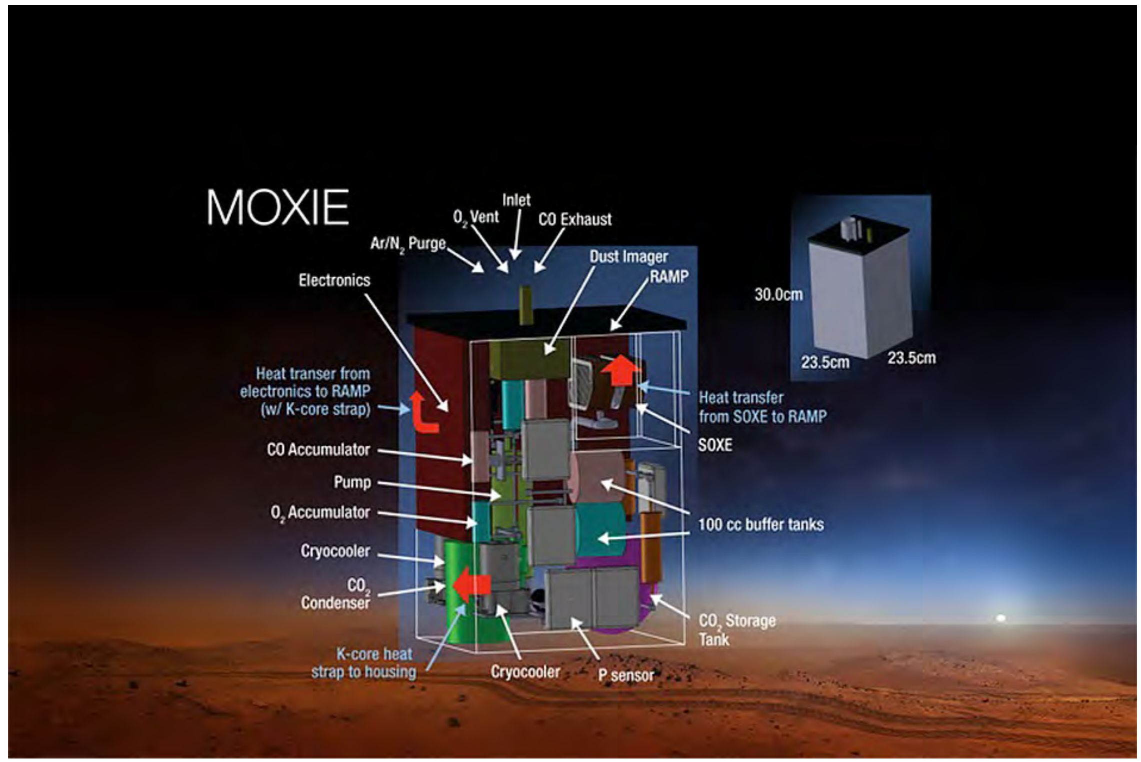
- Actually produce H and O2 from melted ice or icy regolith on the moon or mars

https://mars.nasa.gov/mars2020/mission/instruments/moxie/

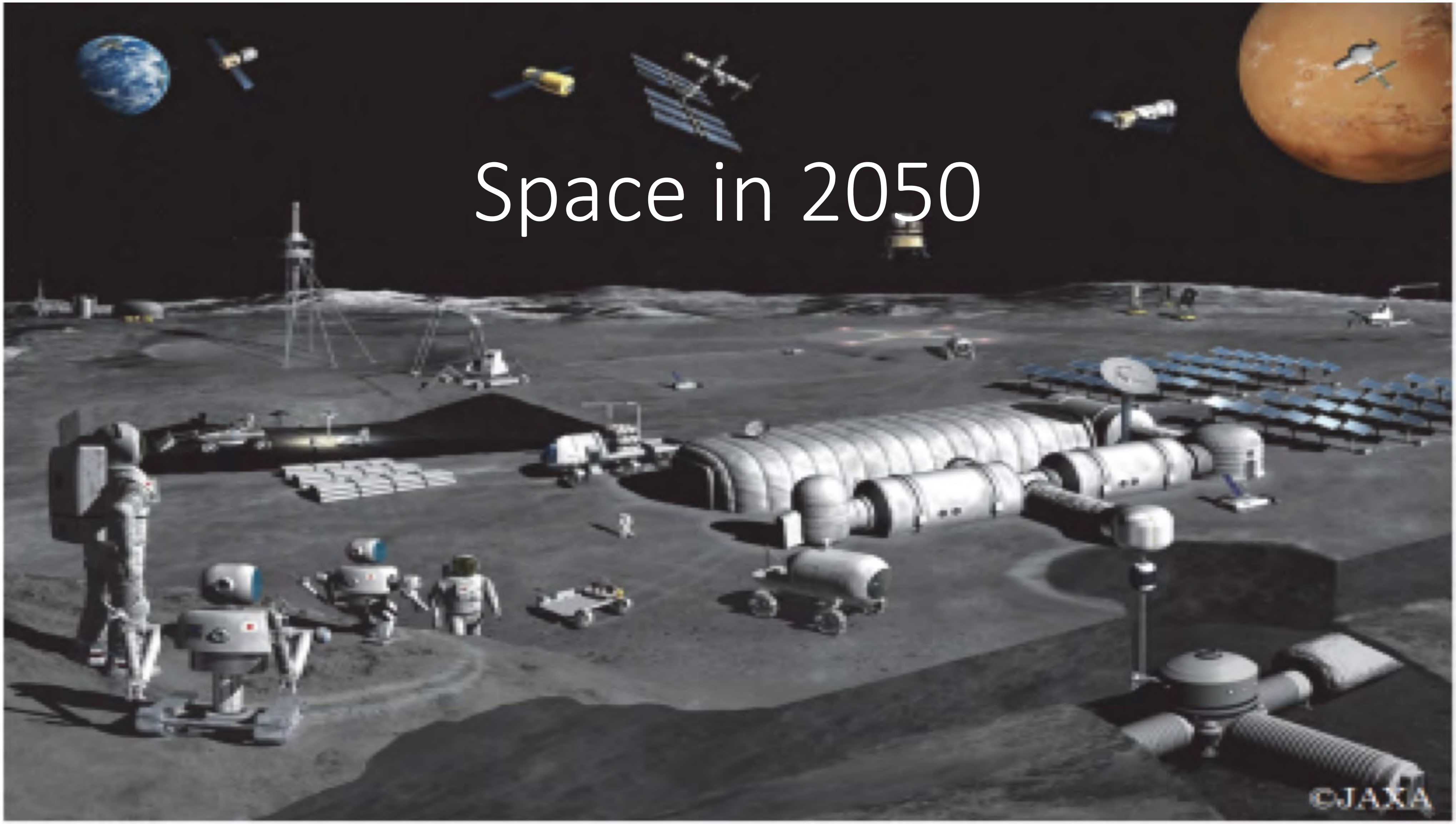
Oxygen Examples (Goals)

- MOXIE instrument on MARS 2020 rover
- 10 grams per hour over 2 hours





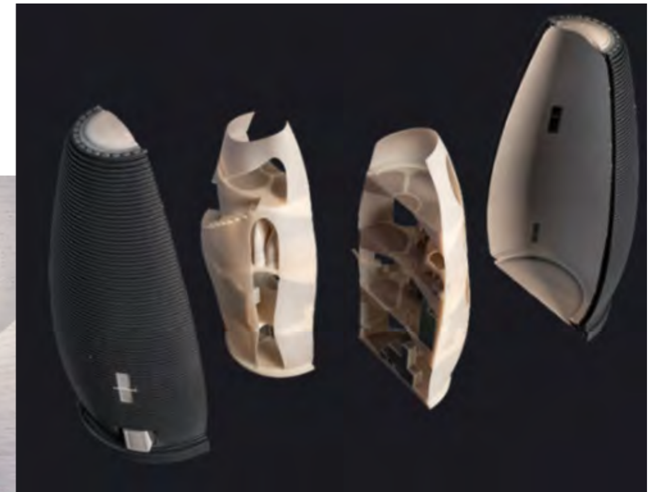
Space in 2050



Nasa 3D-Printed Habitat Challenge

- Partnering with industry to develop ways to use in situ resources
  - Ex: innovative mixture of basalt fiber extracted from Martian rock and renewable bioplastic (polylactic acid, or PLA) processed from plants grown on Mars
  - Recyclable materials

Priorities of Habitat Construction

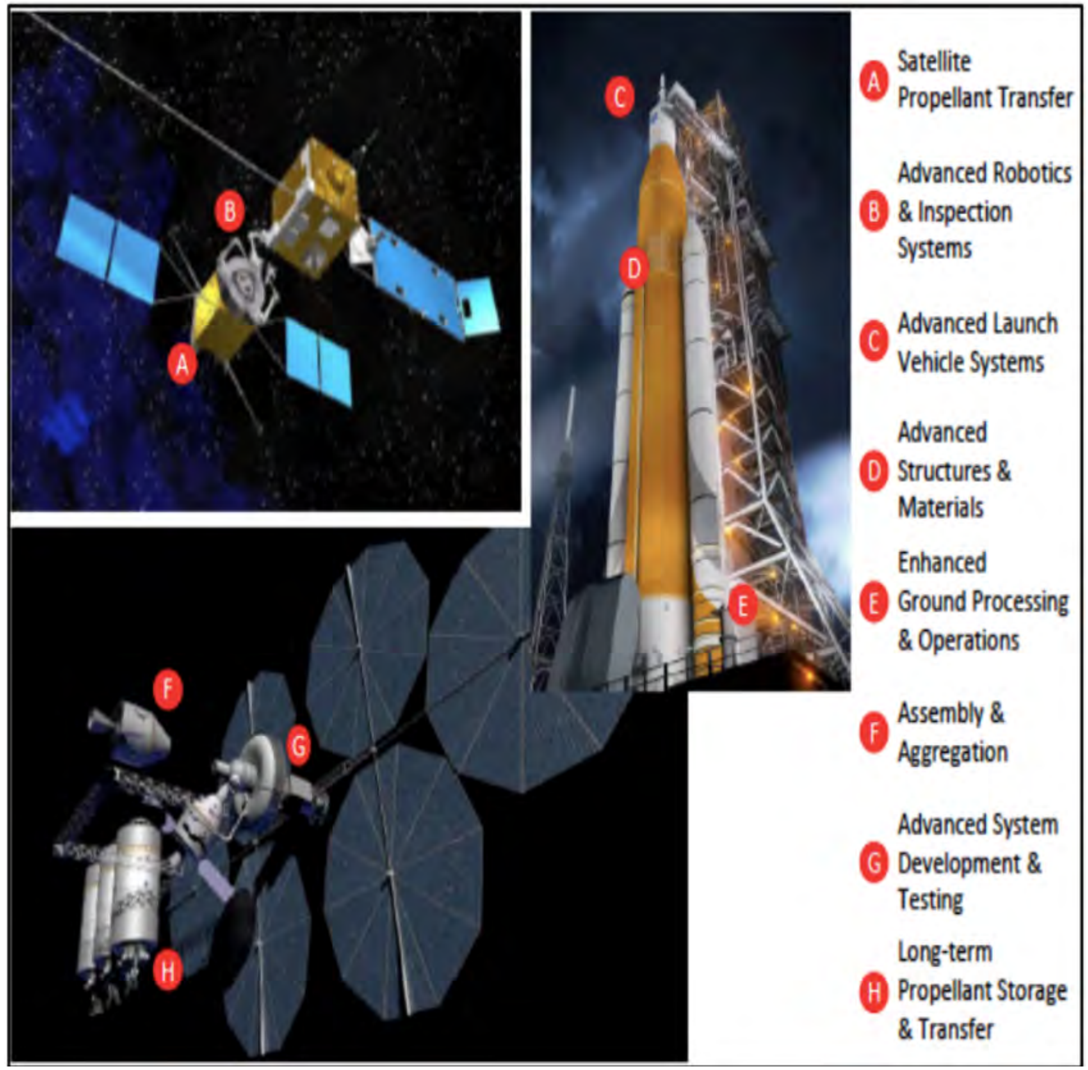


- Shape optimizes usable floor area for both surface area and volume
- Internal atmospheric pressure and thermal stresses
  - Rapid temperature and pressure swings means structure must be able to expand/contract
  - Dual shell deals with these as well as radiaton
- Crew Health
  - Multiple public and private spaces
  - Windows on each floor and large waterfilled skylight
  - Recreation and exercise areas
- Functional:
  - Dry and wet labs
  - Kitchen
  - Eva Prep area

Local Space Infrastructure

Local Space Infrastructure

- **Expand utilization of Near-Earth Space**
  - Provide Safe & Affordable Routine Access to Space
  - Enable Extension, Reuse, and Repair of Near-Earth Assets
  - Expand Near-Earth Infrastructure & Services to Support HSF
  - Facilitate Econo-Space Development & Commercial Opportunities
  - Establish Outposts, Permanent Bases & Colonies

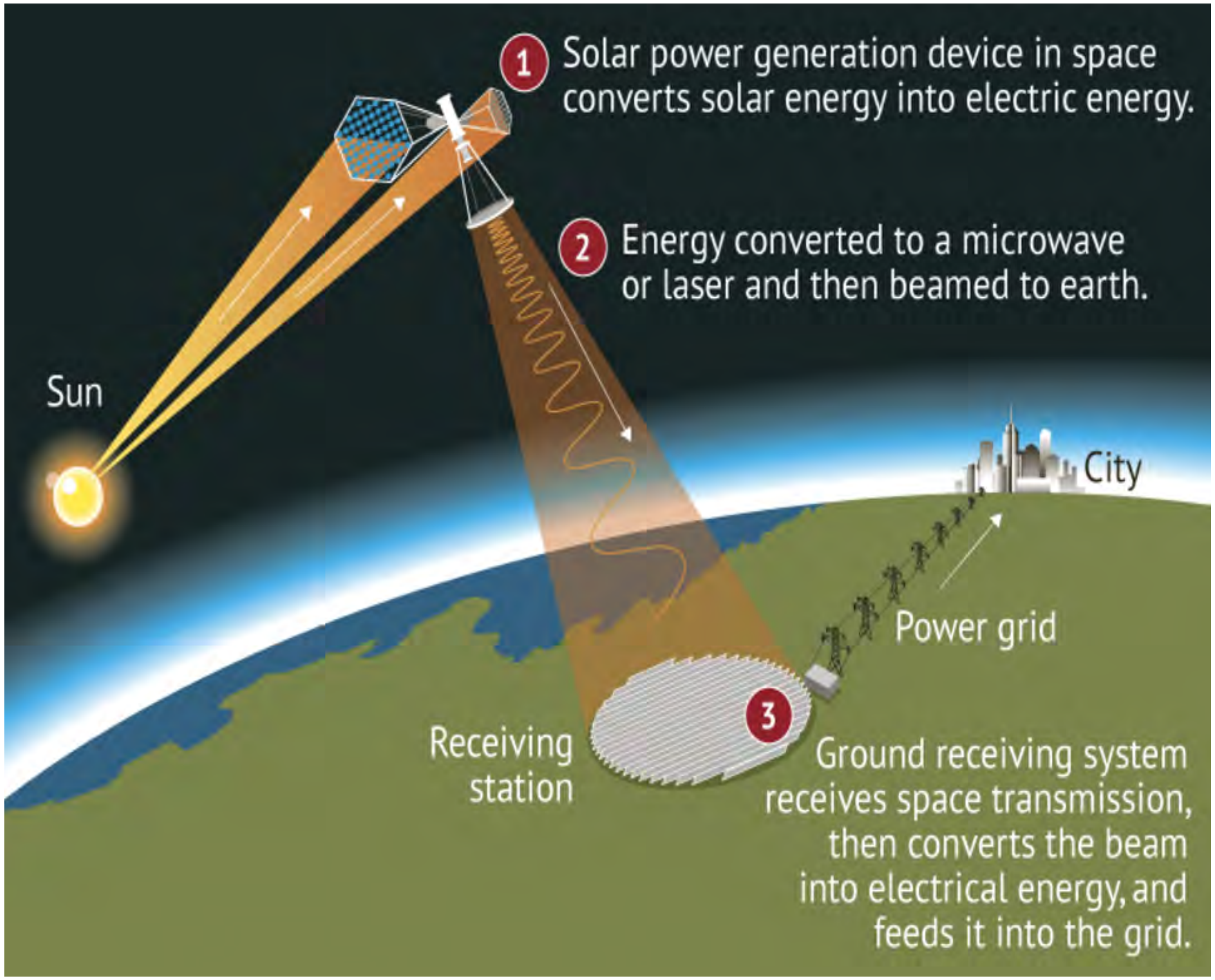


The Space Elevator

- Make transport of goods to GEO much cheaper
  - From $10,000 per pound to $100-400
- Lift Port
  - The anchor/port on earth would use large ships to allow for course adjustments
- Ribbon/Cable
  - The current technology gap—any cable we built to withstand gravity and centripetal forces would be way too large to be practical
  - Carbon nanotubes give hope the material is within reach 2 options:
    - Long carbon nanotubes would be braided into a structure resembling a rope. As of 2013, the longest nanotubes is only 550mm (.5m) long
    - Shorter nanotubes could be placed in a polymer matrix. Current polymers do not bind well to carbon nanotubes, which results in the matrix being pulled away from the nanotubes when placed under tension
- Lifter
  - Robotic Lifter would pull the ribbon through treads to ascend upwards
- Counterweight
  - 62,000 miles (100k km) high
  - Moves in orbit to keep ribbon taught
  - Manmade or asteroid?

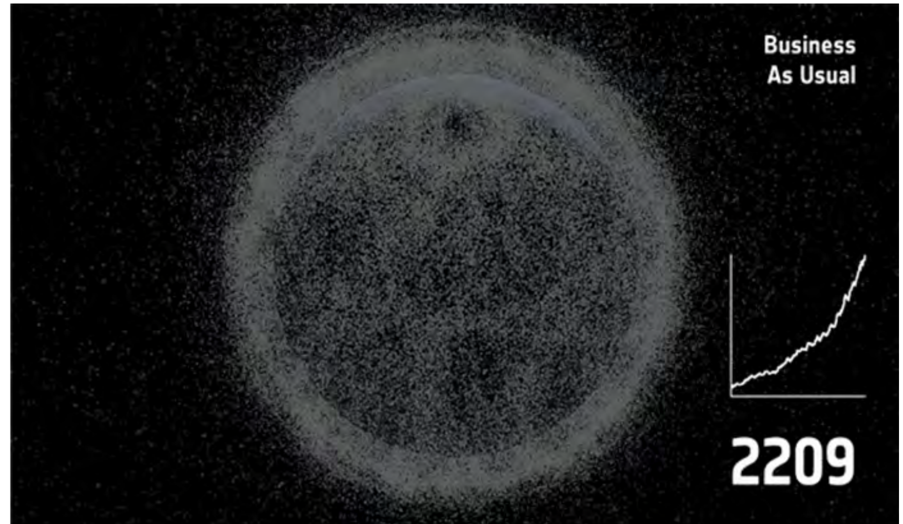
Space Solar Power Station

- Test Case Launches by 2025 by China
  - Is successful, megawatt facilities by 2030s, gigawatt by 2050+
  - Planned to orbit at 36,000km
  - Avoids atmospheric interference as well as day-night oscillations
- Challenges:
  - Energy transfer
    - Current plan is to beam energy down to a facility on earth as Microwaves or Lasers
  - Maintenance
  - Weight of the power station
    - Robots and 3d printing?
    - Space elevator?
  - Ecological impact of electricity transfer
  - Radio frequency interference



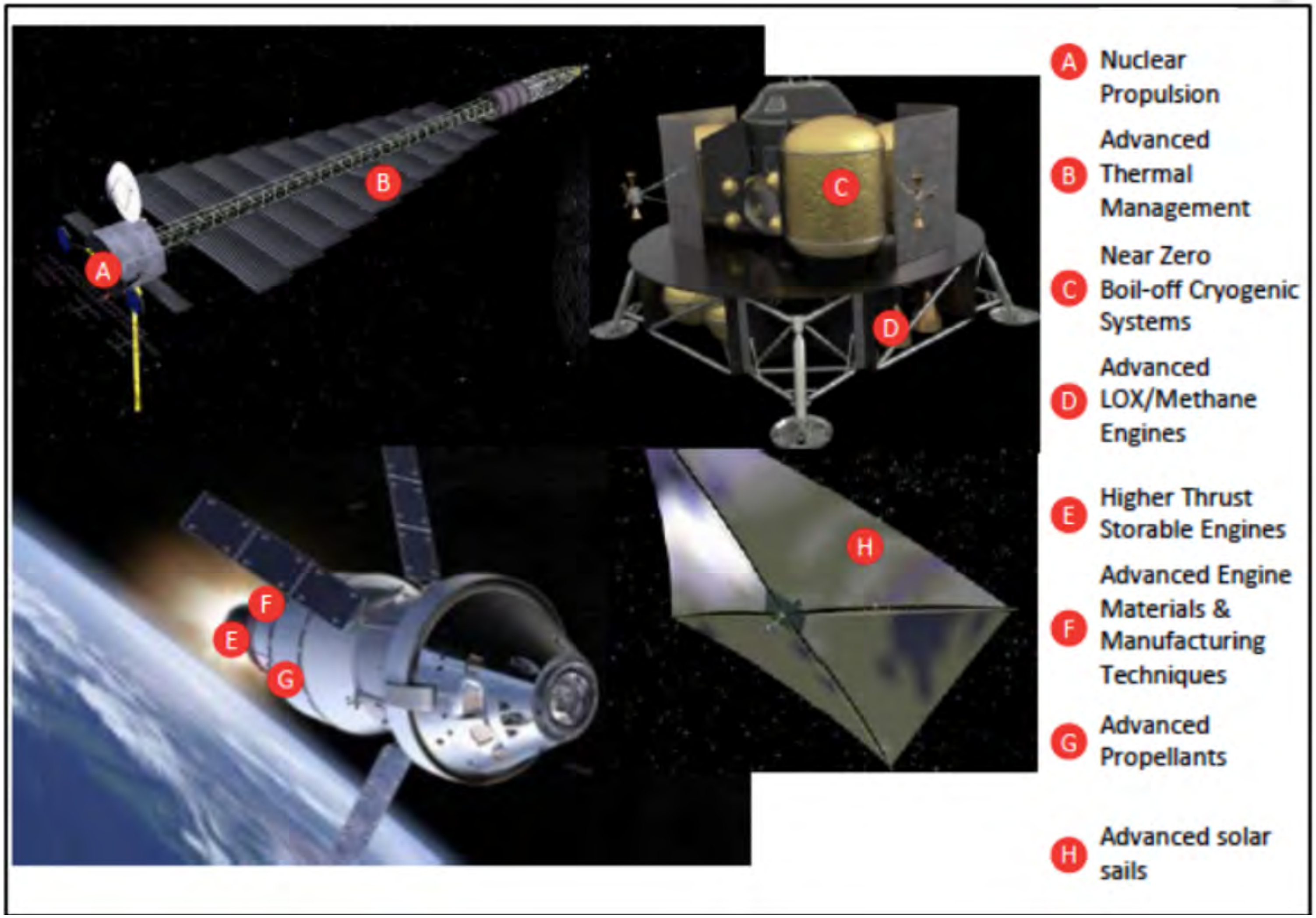
Debris Removal Systems and Safe Space

- Currently around 6 metric tons or 22,000 objects to be removed
- First testing began in 2018 with the RemoveDebris craft released from the ISS
  - Experiments include:
    - Net and pen sized harpoon to recover experimental space junk (cubesat)
    - A drag sail intended to enable much faster deorbiting procedures for defunct aircraft
      - From 100weeks to 10weeks
- Laser Orbital Debris Removal (LODR)
  - shoots plasma jets from ground on the objects to slow them down
  - Low cost and feasible, but range and angle of operation is limited
- Satellite based robotic arms
  - Very versatile but difficult from an engineering perspective
- CleanSpace One
  - Spacecraft that rendezvous and deorbit junk



Exploring Further Afield

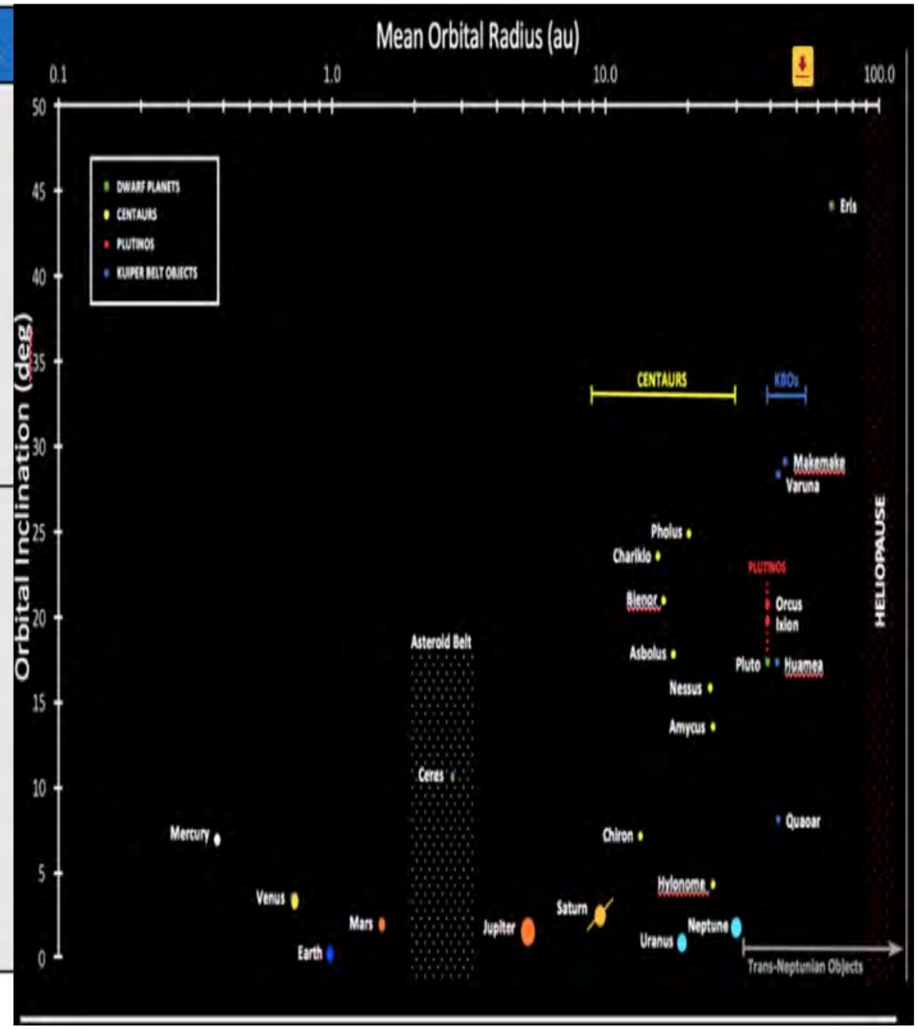
- **Develop efficient and safe transportation through space**
  - Provide Cost-Efficient, Reliable Propulsion for Long Duration Missions
  - Increase Effectiveness & Applicability of Current Propulsion Options
  - Enable Faster, More Efficient Deep Space Missions
  - Provide Efficient & Safe In-Space Habitation



Exploring Further Afield - Distances

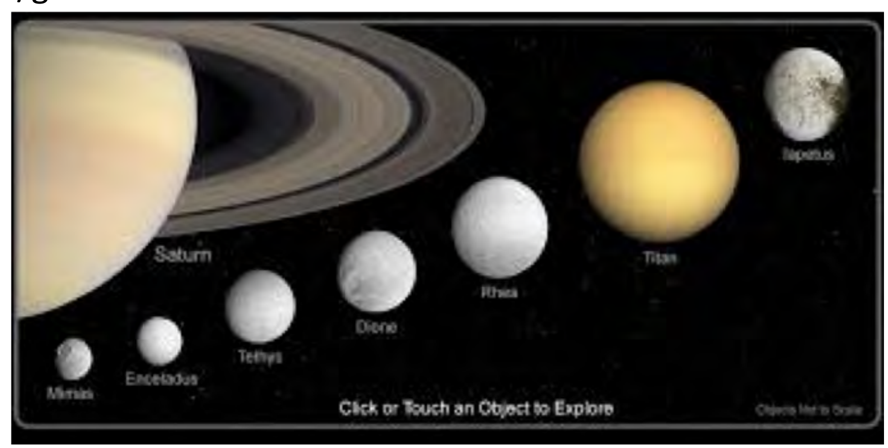
Mission Data	Jupiter	Saturn	Uranus	Neptune
Heliocentric Distance (AU)	5.20	9.50	19.2	30.1
Round Trip Flight Duration (yrs)	4.0	4.0	4.0	4.0
Flyout Time (yrs)	2.0	2.0	2.0	2.0
Flyout Thrust Time (yrs)	1.0	1.2	1.1	1.3
Flyout Payload MF* (%)	20	20	20	20
Propulsion System Power (MW)	100	100	200	200
Thrust Efficiency (%)	80	80	80	80
C_3 (km^2/s^2)	0	0	0	0
Mission Δv (km/s)	27.9	59.2	122.1	205.1
Mission Specific Energy (GJ/kg)	0.365	1.45	8.54	18.3
Thrust (N)	8734	4382	3619	2468
Isp (ksec)	1.87	3.72	9.02	13.22
Launch Mass (Mkg)	19.3	5.9	1.9	1.0
Launch Propellant MF (%)	93	93	93	93
Earth Return Payload MF (%)	2	2	2	2
$\alpha_{propulsion}$ (kg/kW)	3.47	1.05	0.163	0.090
$\phi_{propulsion}$ (kW/kg)	0.288	0.952	6.13	11.1

* Includes habitat, structures, propulsion system, and flyback propellant



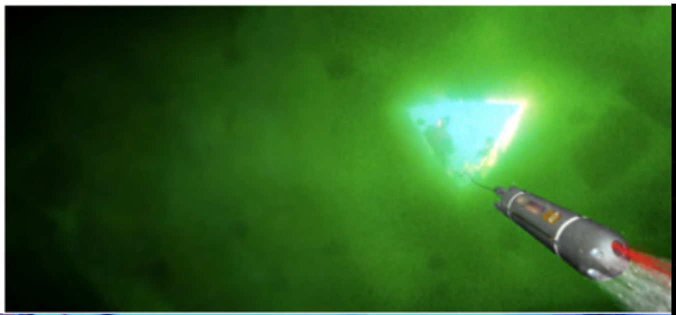
Exploring Further Afield – Small Body Targets

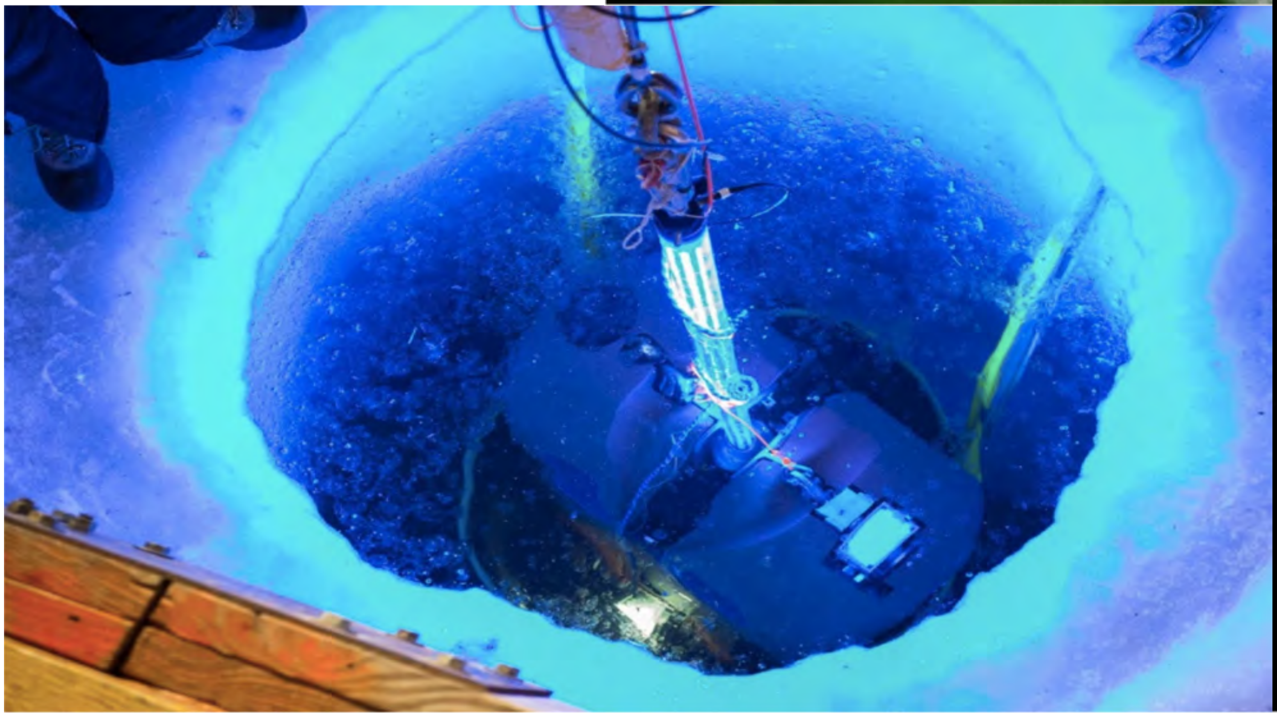
- Small body targets are any small body in Non Earth Orbit (NEO) such as Phobos and Deimos near Mars
- SB community behind Lunar and Martian, very significant SKGs in 4 categories:
  - Human mission target idenfication
    - Round trip limitations due to radiation
    - NEO sizes, albedos, rotation states
  - Understand how to work on/interact with each specific SB surface
    - Biohazards/hazards to equipment and mitigation
  - Understand the SB environment and its potential risk/benefit to crew, systems, and operational assets
    - Is there a particulate environment? Effects from solar flares on plasma and electrostatic environment?
    - The SB surface generating radiation or the local structural stability
  - Understanding SB resource potential
    - What? Where? How do we extract it? How do we refine/store/get it back?

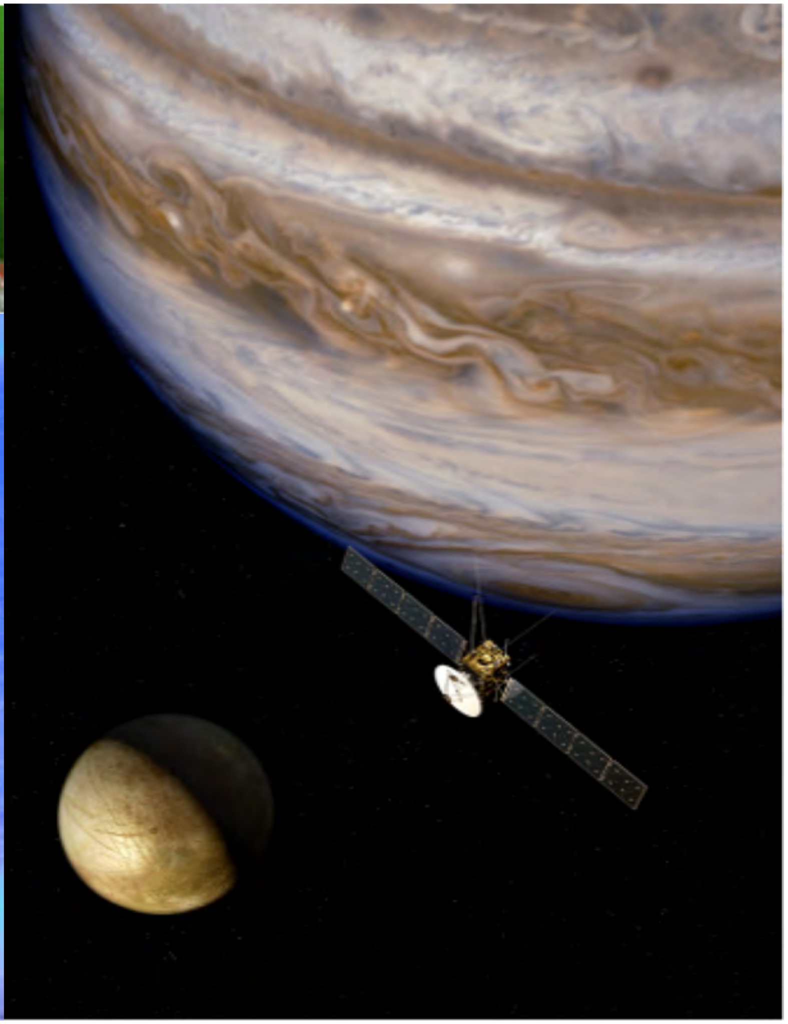


Exploring Further Afield – Jupiter and its Moons

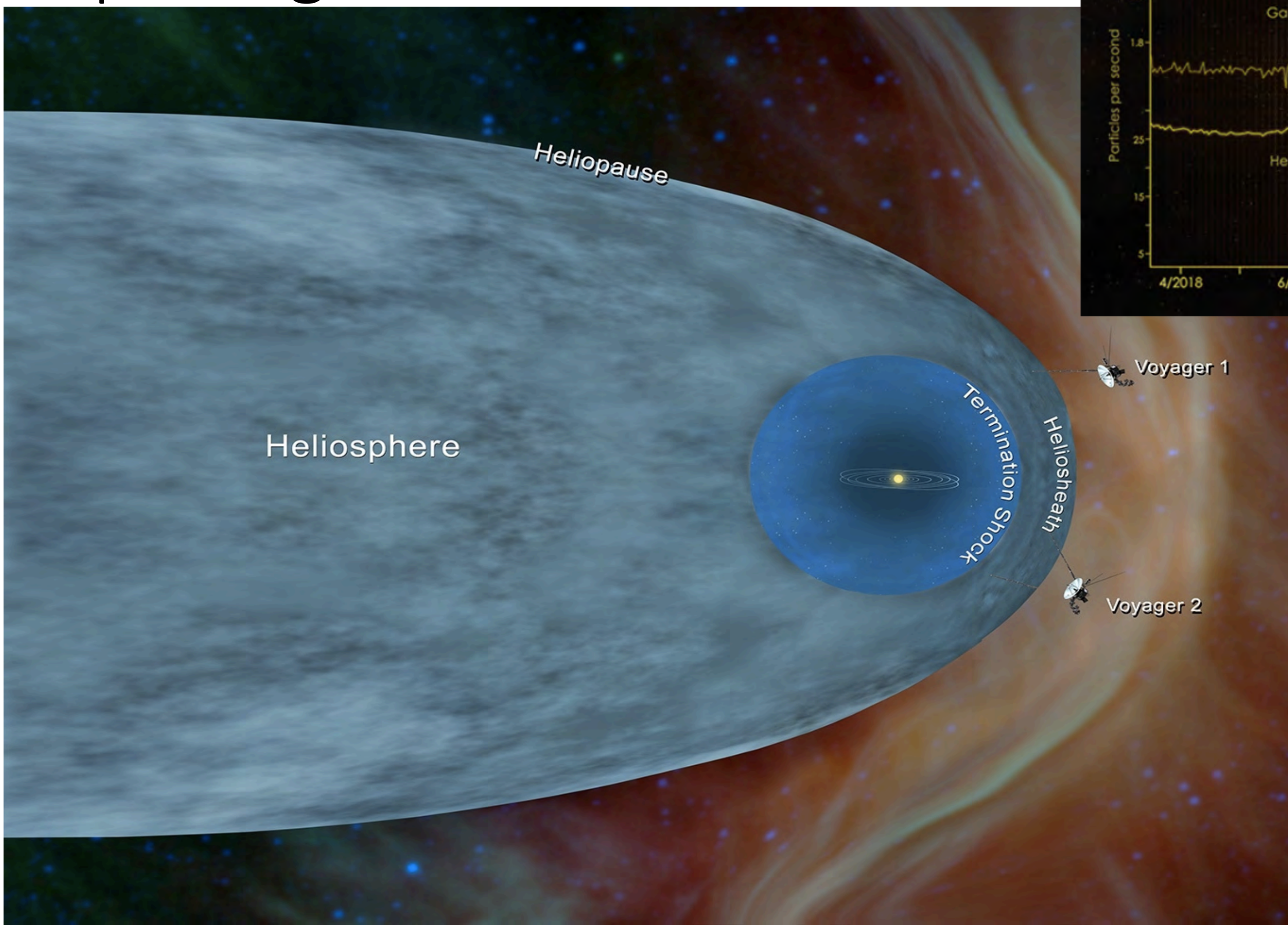
- Measure Ice thickness
- Test drilling tech
- Design small/light submersible
- Hone remote guidance tech

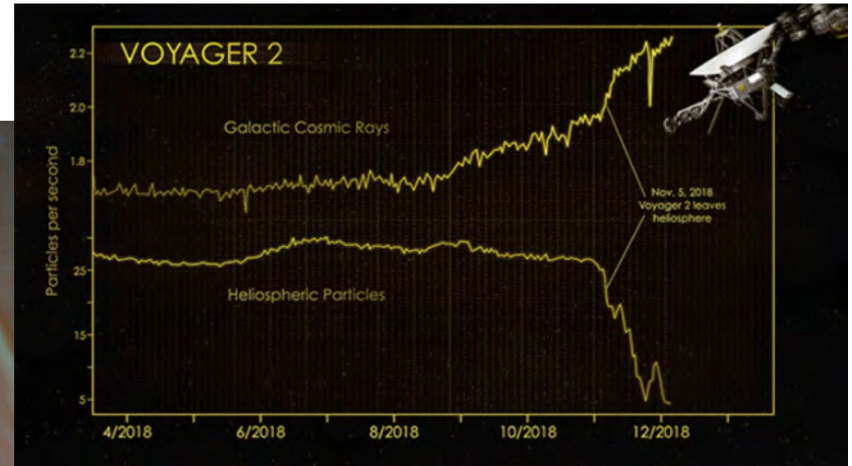


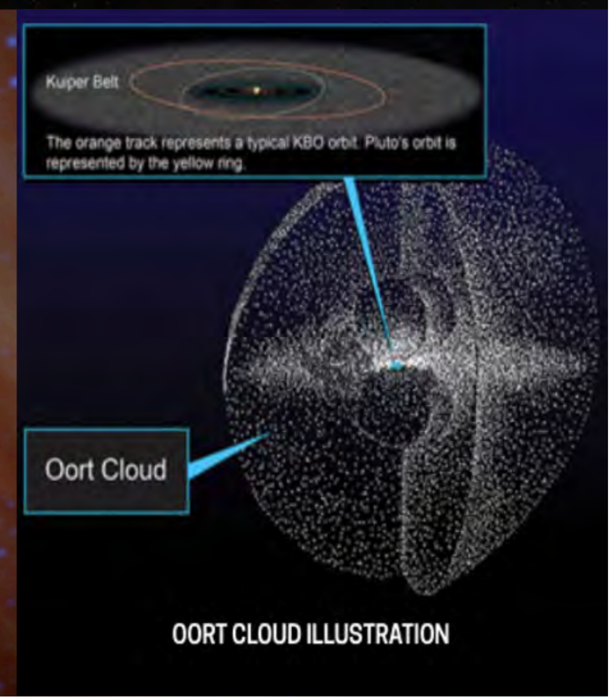




Exploring Even Further Afield







Thanks: Questions?