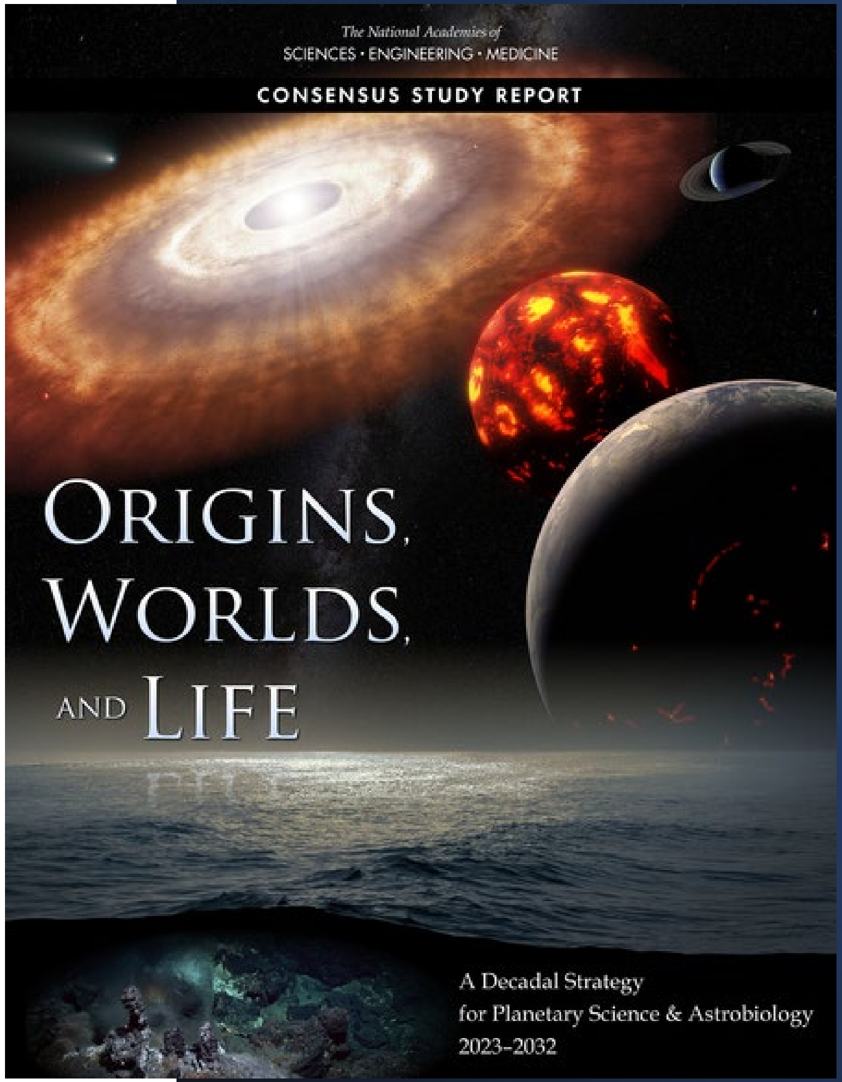
"A program of scientific exploration can be constructed this decade whereby science enables human exploration and human exploration enables science."

- From "Origins, Worlds, and Life" A Decadal Strategy for Planetary Science and Astrobiology 2023-2032



Workshop Objectives

- Explore leveraging Artemis era infrastructure to conduct unique science experiments from the Moon
- Advance synergistic approaches between human and science exploration while addressing key engineering challenges and risks

Workshop Deliverable:
A report containing…

- Unique science case studies from the Moon
- Synergistic approaches for human/robotic science exploration
  - Trade Analysis: Robotic vs human deployment of science facilities
  - Integrated human/robotic approaches such as assembly and servicing by astronauts following robotic delivery
- Lunar science exploration engineering challenges and approaches for risk mitigation
- Proposed Artemis mission requirements for sustainability of science exploration

Shaping the future of scientific human and robotic exploration

National Aeronautics and
Space Administration

EXPLORE
SCIENCE

NASA Lunar Discovery and Exploration Program (LDEP) and Near-term Artemis Science

NASA Engineering & Safety Center (NESC)
Unique Science from the Moon in the Artemis Era Workshop
June 7, 2022

Dr. Joel Kearns
Deputy Associate Administrator for Exploration (DAAX)
Science Mission Directorate, NASA

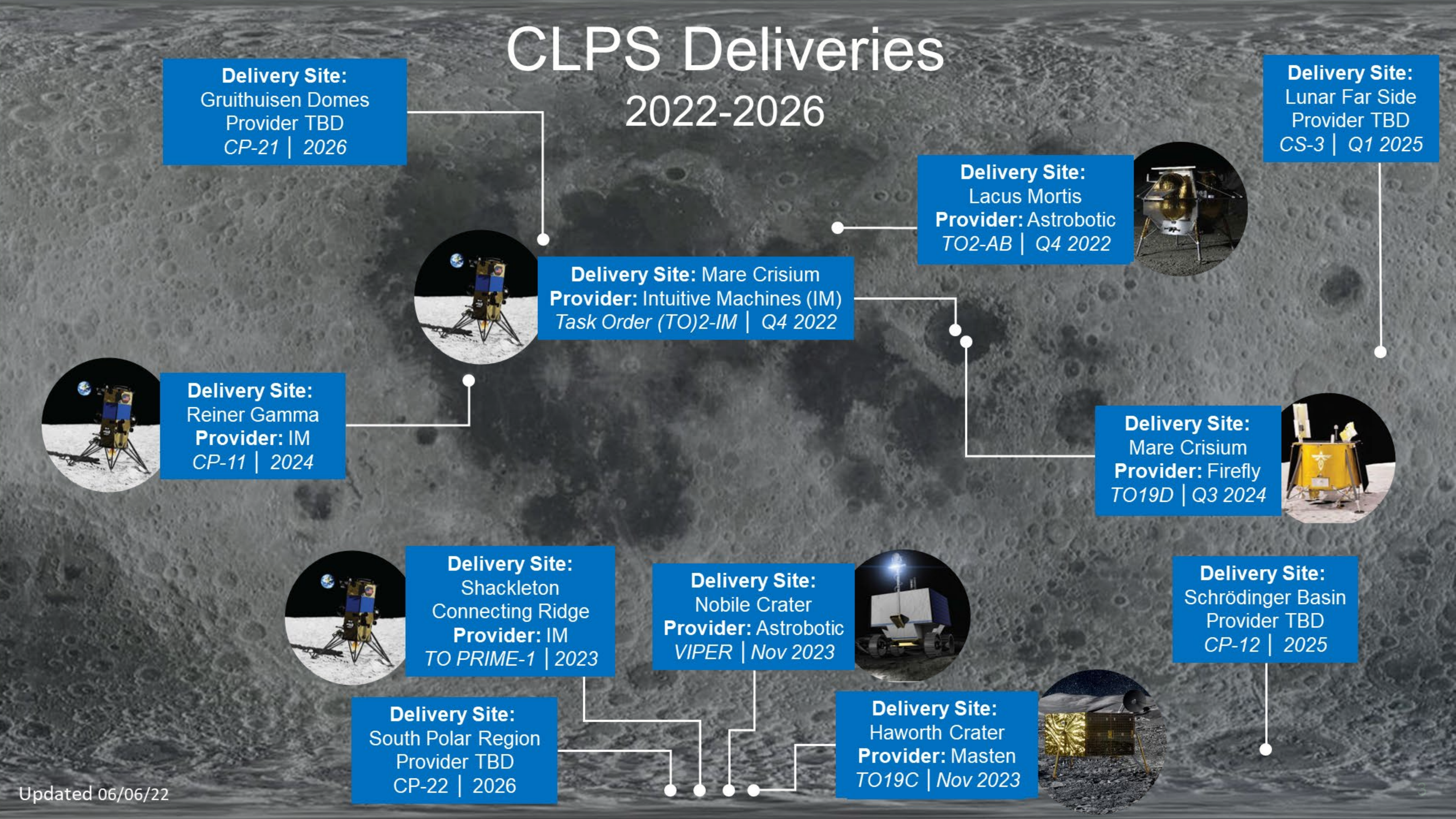
Lunar Discovery and Exploration Program

The Lunar Discovery and Exploration Program (LDEP):

- Develops lunar surface science instruments that address Decadal and other community document science priorities
  - NASA-internal payloads, Community-developed payloads, PRISM, DALI
- Uses commercial companies to deliver payloads to the Moon (CLPS)
- Develops mobility systems to expand and enhance science investigations on the lunar surface
- Leverages international partnerships for additional opportunities (e.g., instruments, rovers)
- Defines, integrates and leads Artemis science efforts across SMD, other NASA mission directorates, and with other US and international agencies

> …Infusing decadal-level science goals into both the Lunar Discovery and Exploration Program in general, and into the Artemis program in particular, is viewed by the committee as an essential priority for the next decade.

- Origins, Worlds, and Life:
A Decadal Strategy for Planetary Science and Astrobiology 2023-2032

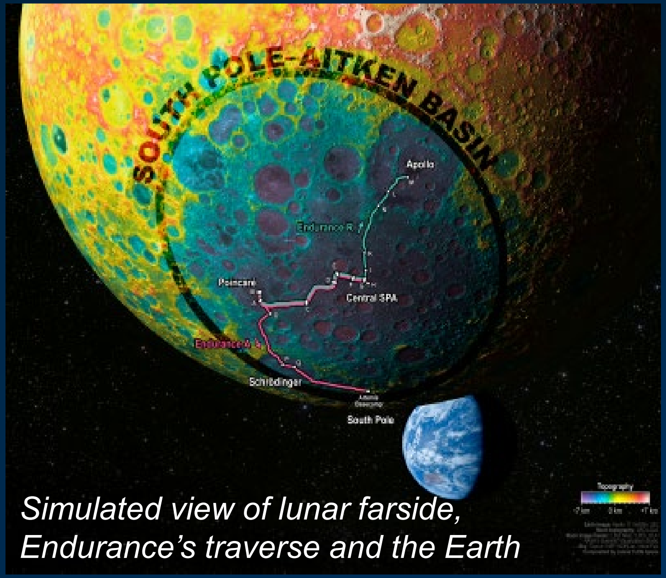

CLPS Deliveries
2022-2026
Delivery Site: Gruithuisen Domes
Provider TBD
CP-21 | 2026
Delivery Site: Lunar Far Side
Provider TBD
CS-3 | Q1 2025
Delivery Site: Lacus Mortis
Provider: Astrobotic
TO2-AB | Q4 2022
Delivery Site: Mare Crisium
Provider: Intuitive Machines (IM)
Task Order (TO)2-IM | Q4 2022
Delivery Site: Reiner Gamma
Provider: IM
CP-11 | 2024
Delivery Site: Mare Crisium
Provider: Firefly
TO19D | Q3 2024
Delivery Site: Shackleton Connecting Ridge
Provider: IM
TO PRIME-1 | 2023
Delivery Site: Nobile Crater
Provider: Astrobotic
VIPER | Nov 2023
Delivery Site: Schrödinger Basin
Provider TBD
CP-12 | 2025
Delivery Site: South Polar Region
Provider TBD
CP-22 | 2026
Delivery Site: Haworth Crater
Provider: Masten
TO19C | Nov 2023
Updated 06/06/22

How the Lunar Science Themes Map to Key Science Questions (As Defined in the Planetary Science Decadal Survey)

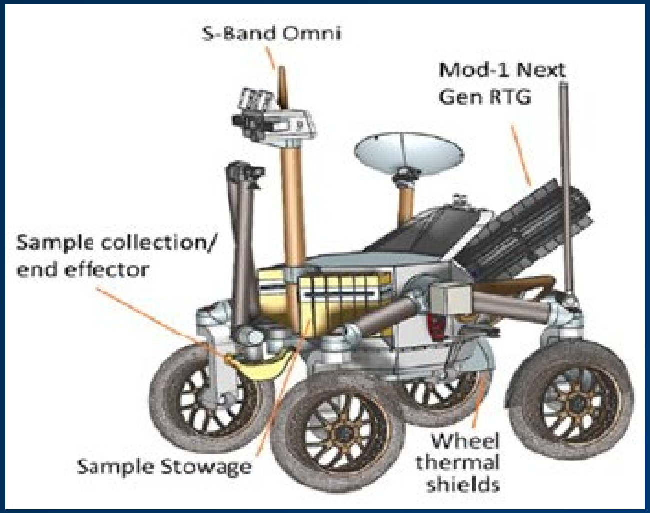
2023 Planetary Science and Astrobiology Decadal	2023 Planetary Science and Astrobiology Decadal Questions
Lunar Science Theme 1: Solar System origin and early history	**Q3.** Origin of Earth and inner solar system bodies. How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer solar system materials incorporated?
	Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
Lunar Science Theme 2: Geologic processes of early Earth preserved on the Moon	**Q4.** Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
Lunar Science Theme 3: Volatile origin and delivery processes	**Q5.** Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?

Planetary Science Decadal Survey Endurance A: South Pole-Aitken Sampling Campaign

- One of the top lunar priorities of the Planetary Decadal is Endurance A, a long-duration rover capable of traversing ~2000km and returning ~100kg of samples taken at strategic sites throughout the South Pole-Aitken basin to investigate several lunar science objectives:
  - Solar System Chronology: Anchors the earliest impact history of the Solar System, tests the giant planet instability, impact cataclysm, and late heavy bombardment hypotheses, and anchors the “middle ages” of solar system chronology
  - Planetary Evolution: Tests the lunar magma ocean hypothesis, characterizes the thermochemical evolution of terrestrial planets, and explores the geologic diversity of a giant impact basin from floor to rim



Simulated view of lunar farside, Endurance’s traverse and the Earth



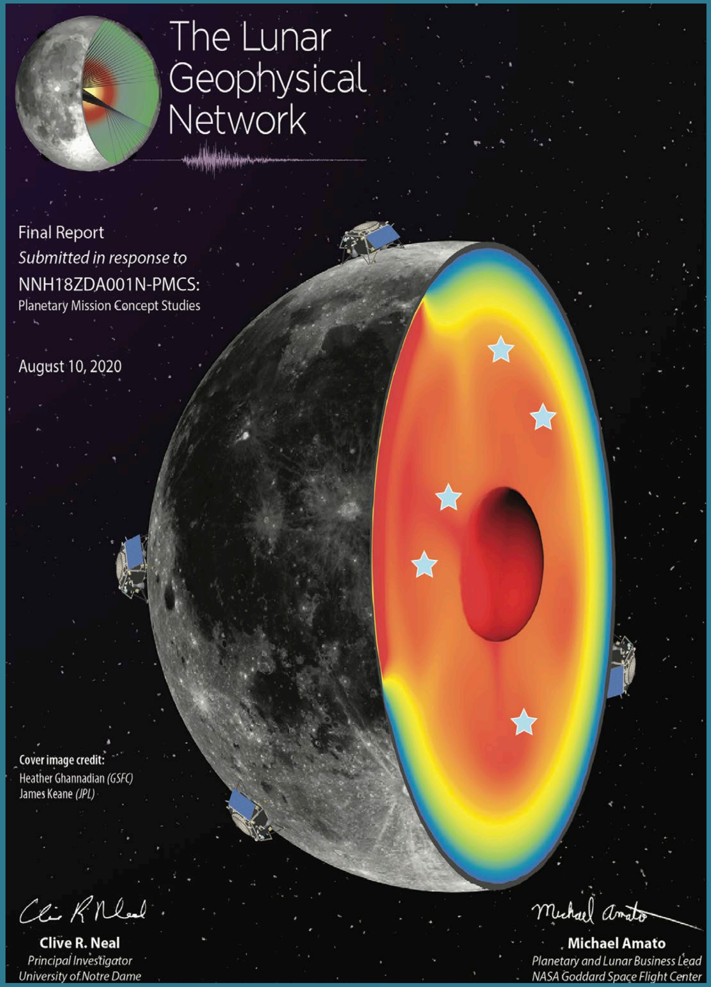
***Recommendation*: Endurance-A should be implemented as a strategic medium-class mission as the highest priority of the Lunar Discovery and Exploration Program. Endurance-A would utilize CLPS to deliver the rover to the Moon, a long-range traverse to collect a substantial mass of high-value samples, and astronauts to return them to Earth.** *– Origins, Worlds, and Life (Planetary Decadal), 22-17*

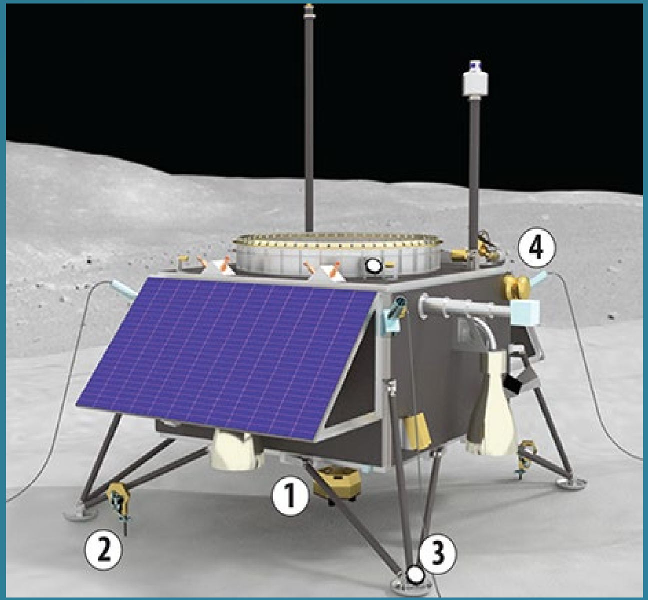
The full Endurance Report is available at https://tinyurl.com/2p88fx4f

Planetary Science Decadal Survey
Lunar Geophysical Network (LGN)

The Decadal prioritized the following eight mission themes for the NASA *New Frontiers 6* competition (no specific order):

- Centaur orbiter and lander
- Ceres sample return
- Comet surface sample return
- Enceladus multiple flyby
- **Lunar Geophysical Network**
- Saturn probe
- Titan orbiter
- Venus In Situ Explorer





Each of the >4 landers would have an instrument suite consisting of:

1. Seismometers (VBB & SP)
2. Heat Flow Probe
3. Retroreflectors
4. Magnetotelluric Sounder

Science Objectives for LGN:

- Define the interior structure of the Moon
- Constrain the interior and bulk composition of the Moon.
- Delineate the vertical and lateral heterogeneities within the interior of the
- Moon as they relate to surface features and terranes.
- Evaluate the current seismo-tectonic activity of the Moon

https://forum.nasaspaceflight.com/index.php?PHPSESSID=fn6g45gba0f2n0ejno21v9dfo2&action=dlattach;topic=52714.0;attach=2002410;sess=0

A different era

50 years ago, Apollo astronauts performed field geology on lunar surface missions, with support from a “back room” of researchers. Scientific instruments since that time have advanced, both in earth-based laboratories and on spacecraft. There have been many robotic missions to planetary bodies since Apollo: i.e., teleoperated rovers on the surface of Mars that employ a variety of measurement instruments, including imagers, spectrometers, X-ray diffraction, and fluorescence techniques.

With NASA’s planned Artemis surface missions, several remote sensing missions could supply contemporaneous data in the Moon’s orbit. Astronaut operations on the ISS have developed and employed new techniques for extra-vehicular activities (EVA) and intra-vehicular activities (IVA) that may be applicable to Artemis science operations: e.g., high-resolution imaging from the point of view of the astronaut, robotic assistants, and direct communications to science support rooms during missions.

Questions related to Astronaut / Robotic Science

- What human/robotic exploration hybrid modalities can be employed during Artemis surface missions to maximize scientific value and productivity in addressing high priority Planetary Science and Astrobiology decadal survey questions?
- Should astronauts focus on tradition field geology or making in-situ measurements while on the surface of the moon? How does this compare to modern field work in other, earth-based remote locations?
- What is the role of the astronaut as “explorer” on the lunar surface, and how is this different from the astronaut role on the International Space Station or in Low Earth Orbit?
- What is the framework for science done by humans on the surface vs. robotic presence? Is there value to having remote-sensing data made available to the astronauts in near real-time?
- What types of measurements should be done in-situ during the astronaut surface EVAs, and what matter or samples specifically need to be brought back to Earth for analyses? What equipment should astronauts have available to make those measurements?
- How can NASA optimize between robotic capability or remote sensing and use of valuable crew time on the surface?
- What will the concepts of operations be for combined humans-in-the-loop and robotic/teleoperated explorers?


National Aeronautics and
Space Administration
NASA
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National Aeronautics and Space Administration

Human Exploration Utilization Planning

Jacob Bleacher, Ph.D.

Chief Exploration Scientist

Exploration Systems Development Mission Directorate

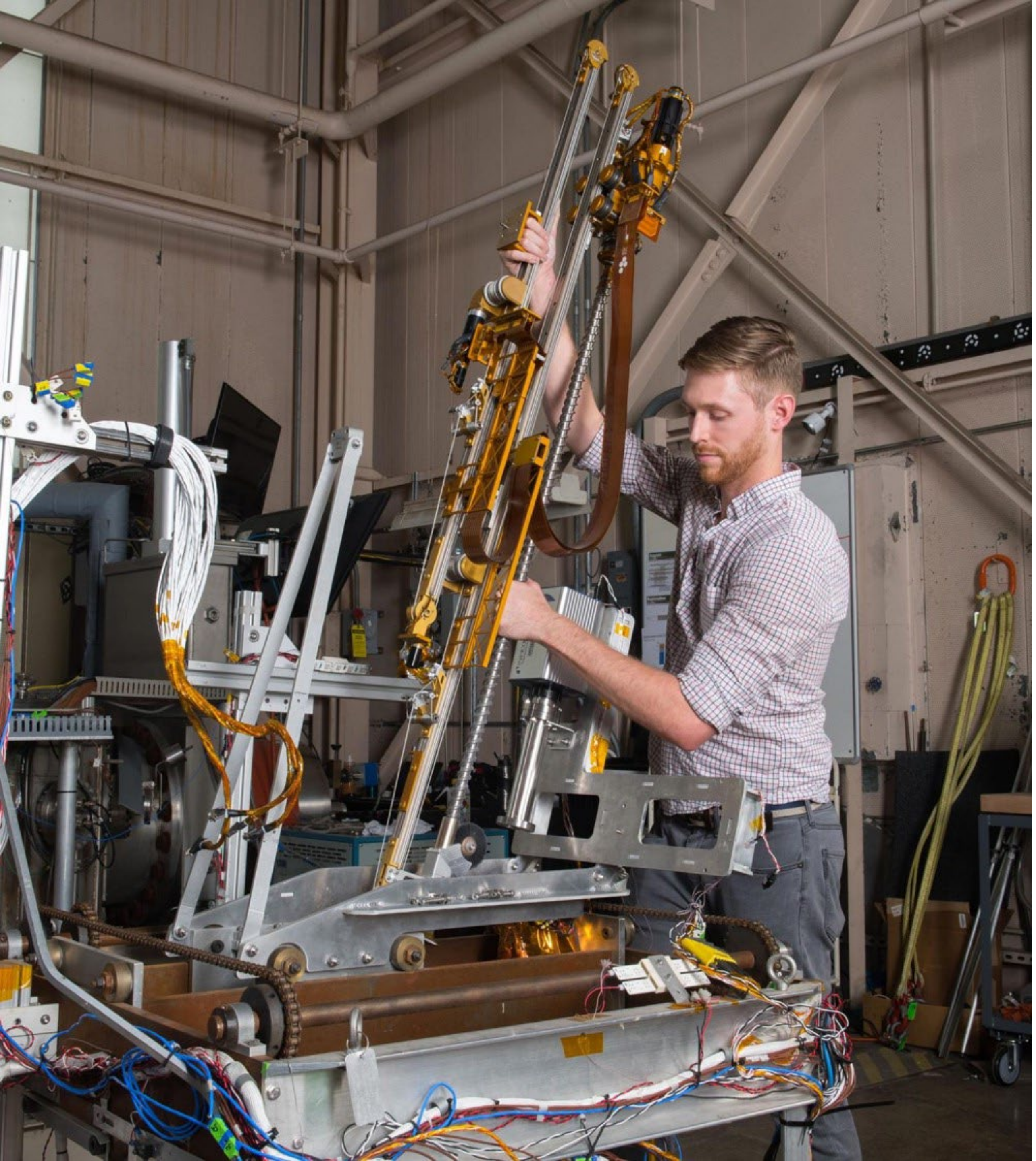
NASA HQ

June 7, 2022

Artemis Science Objectives

- Understand planetary processes
- Understand the character and origin of lunar polar volatiles
- Interpret impact history of Earth-Moon system
- Reveal the record of the ancient sun and our astronomical environment
- Observe the universe and the local space environment from a unique location
- Conduct experimental science in the lunar environment
- Investigate and mitigate exploration risks

Pictured left: NASA astronaut candidates and field instructors hike during geology training in Arizona



Artemis Technology Objectives

The **Lunar Surface Innovation Initiative (LSII)** works across industry, academia and government through in-house efforts and public-private partnerships to develop transformative capabilities like:

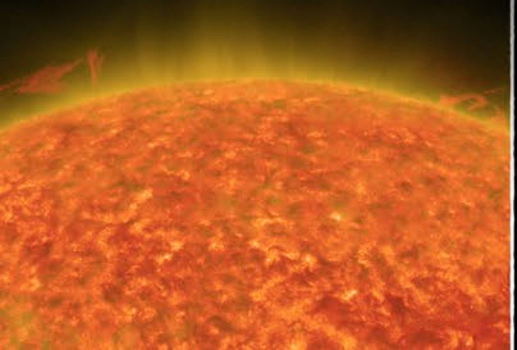
- In-situ resource utilization (ISRU)
- Surface power
- Dust mitigation
- Extreme environment
- Extreme access
- Excavation and construction

Pictured left: A Honeybee Robotics systems engineer installs The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) on a trolley for thermal vacuum chamber testing. TRIDENT will drill up to three feet deep, extracting lunar soil and demonstrating a critical capability for future ISRU.

Hazards of Human Spaceflight

1 Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.



2 Isolation and Confinement

Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3 Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.

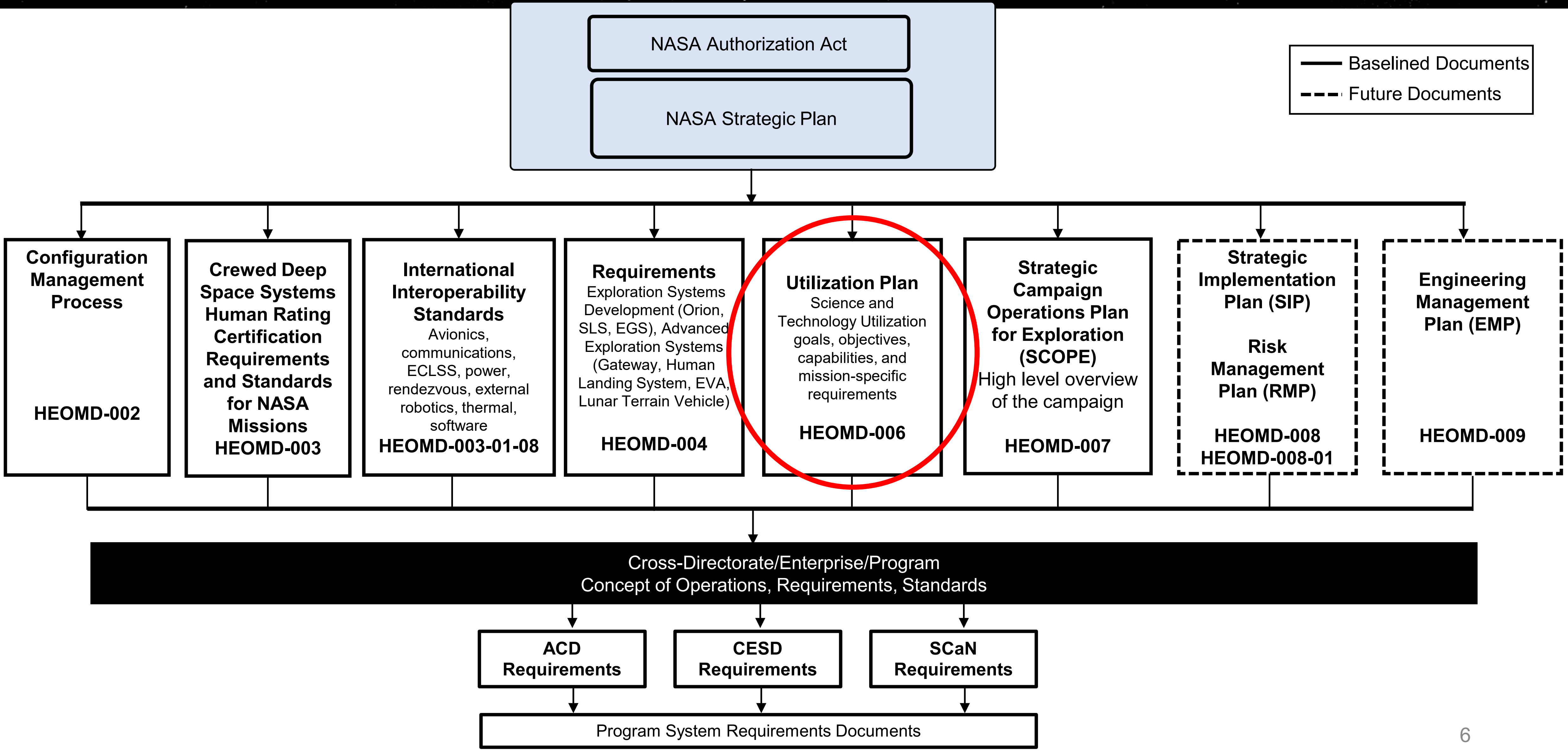
4 Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.

5 Hostile/Closed Environments

The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.

ESDMD/SOMD Directorate-level Technical Documentation – Current and Planned



Human Spaceflight Utilization Plan (HEOMD-006)

Identifies and describes NASA's science and technology utilization goals and objectives that will be enabled by human missions.

Authority Quad-Directorate:
- Science Mission Directorate (SMD),
- Space Technology Mission Directorate (STMD),
- Space Operations Mission Directorate (SOMD)
- Exploration Systems Development Mission Directorate (ESDMD)

Purpose:
Identify how human missions will support the science and technology communities to conduct fundamental research about our universe and solve the scientific and technological challenges for sustaining and expanding human exploration

Scope: Utilization of ISS/LEO, Artemis, Mars

https://ntrs.nasa.gov/citations/20220005087


National Aeronautics and Space Administration

Exploration Systems Development Mission Directorate (ESDMD)
HEOMD-006
REVISION A
RELEASE DATE: 03/30/2022

EXPLORATION SYSTEMS DEVELOPMENT MISSION DIRECTORATE
UTILIZATION PLAN

This document has been reviewed for Proprietary, CUI, and Export Control (ITAR/EAR) and has been determined to be non-sensitive. It has been released to the public via the NASA Scientific and Technical Information (STI) Process DAA #20220005087

This document was approved by NASA's Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), Space Technology Mission Directorate (STMD)

March 2022

Utilization Plan
Main Body Goals By NASA Directorate

Goals and Objectives are owned by each mission directorate and updated as needed (e.g., Decadal Survey inputs, Agency Strategic Planning, etc.)

Mission Directorate		Utilization Goals
3.1 SMD	SMD Utilization Goal 1	Enable scientific investigations from the lunar surface, including field relationships, in-situ observations, and sample return, to address the multidisciplinary objectives of the Science Mission Directorate
	SMD Utilization Goal 2	Enable scientific investigations from human spaceflight platforms to address the multidisciplinary objectives of the Science Mission Directorate
	SMD Utilization Goal 3	Enable science investigations on the surface of Mars, in Mars orbit, and in Mars transit
3.2 STMD	STMD Utilization Goal 1	Enable sustainable living and working farther from Earth ("Live")
	STMD Utilization Goal 2	Enable transformative missions and discoveries ("Explore")
3.3 ESDMD / SOMD	ESDMD/SOMD Utilization Goal 1	Advance knowledge to support safe, productive human space travel, and enable systems development and testing to reduce health and performance risks for future human exploration
	ESDMD/SOMD Utilization Goal 2	Advance the operational capabilities required for sustainable lunar operations and the first human missions to Mars *including demonstrating approaches to planetary protection.*
3.4 NASA Multi-directorate	Multi-directorate Utilization Goal 1	Enable commercial, interagency, and international partnerships to make space exploration more affordable and sustainable, grow new markets, and increase capabilities

HEOMD-006 Utilization Plan
Annex 1: Cornerstone Capabilities that Enable Multiple Objectives

1.1 MODEL TRAVERSE APPROACHES

1.2 END-TO-END SAMPLE RETURN

1.3 INTEGRATED PLANETARY PROTECTION STRATEGY

1.4 EXTENDED MISSIONS

1.5 INTEGRATED CREW RESEARCH

1.6 ROBOTIC UTILIZATION FOR HEO ASSETS

1.7 INTEGRATED INSTRUMENT STRATEGY

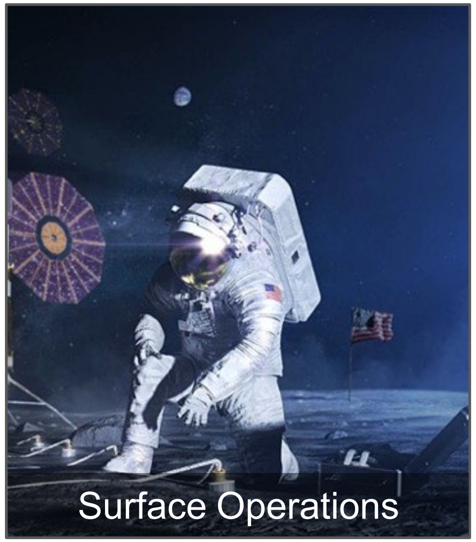
1.8 OPERATIONS IN COLD & SHADOWED REGIONS

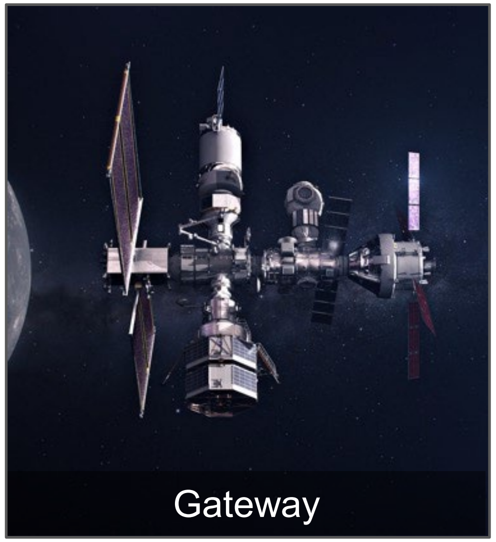
Artemis: A Foundation for Deep Space Exploration


Space Launch System


Orion spacecraft


Human Landing System


Surface Operations

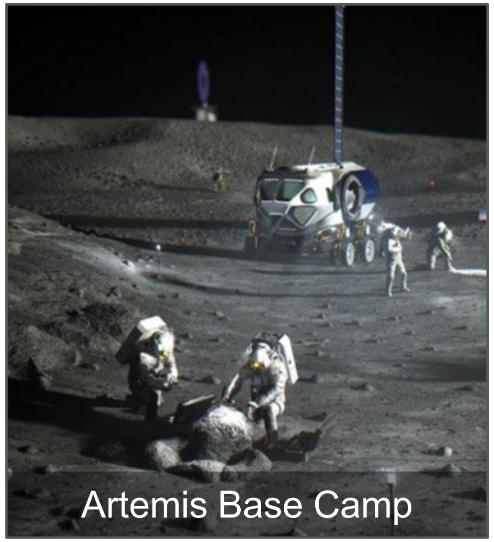

Gateway

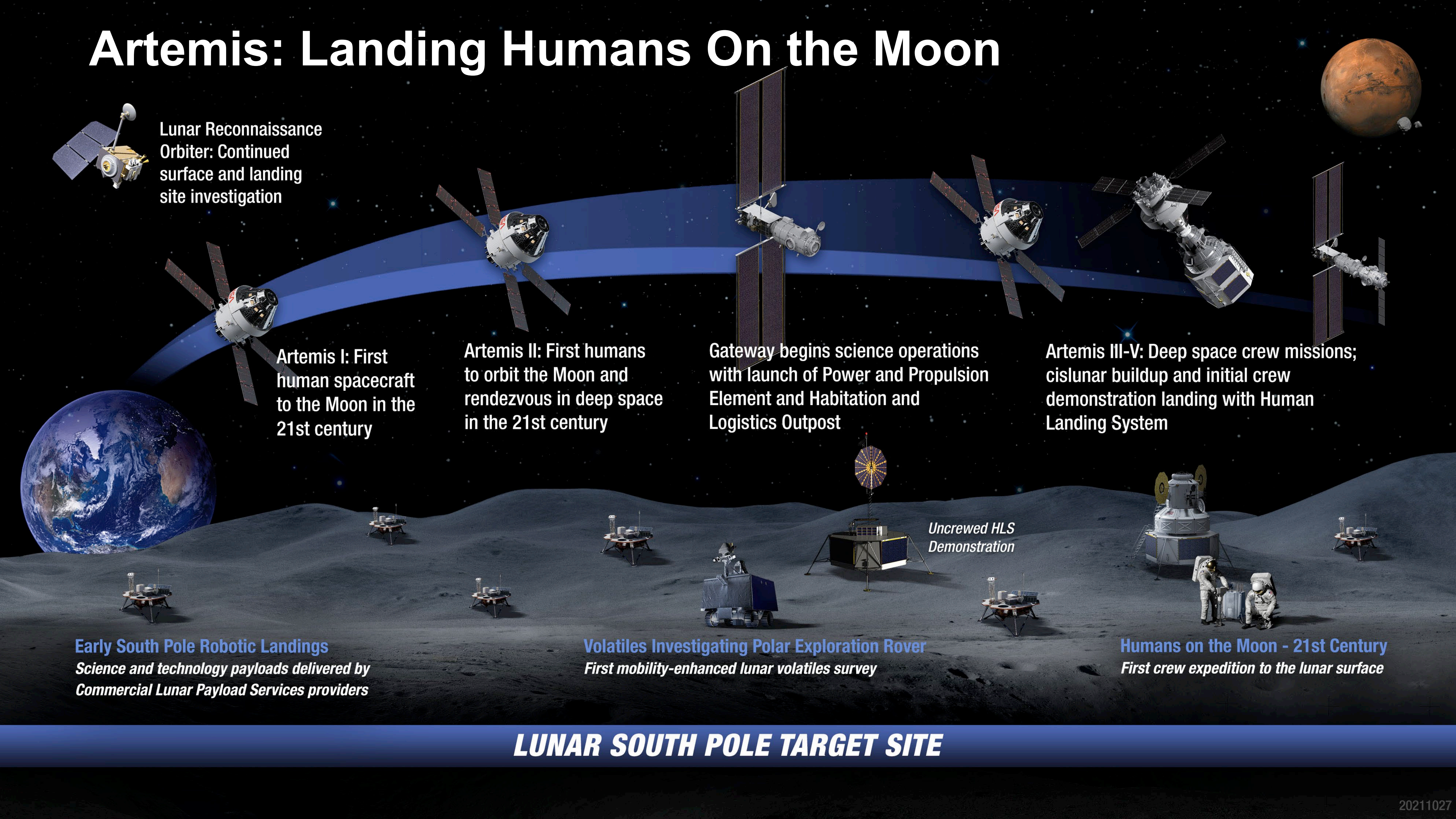

Exploration Ground Systems


Space Communications & Navigation


Surface Mobility


Space Suits


Artemis Base Camp

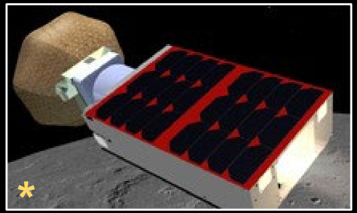

Artemis: Landing Humans On the Moon
Lunar Reconnaissance Orbiter: Continued surface and landing site investigation
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st century
Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System
Uncrewed HLS Demonstration
Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers
Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey
Humans on the Moon - 21st Century
First crew expedition to the lunar surface
LUNAR SOUTH POLE TARGET SITE
20211027

Artemis I Secondary Payloads

Science and technology investigations and demonstrations paving the way for future, deep space human exploration

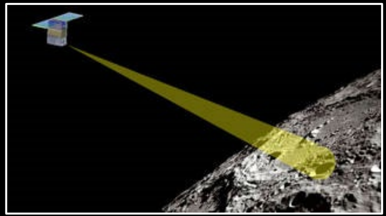
ArgoMoon

Photograph the Interim Cryogenic Propulsion Stage (ICPS) CubeSat deployment, the Earth and Moon using HD cameras and advanced imaging software.



OMOTENASHI

Develop world's smallest lunar lander and observe lunar radiation environment.



LunIR

Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface.

LunaH-Map

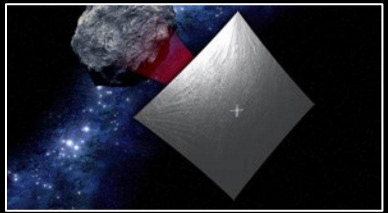
Perform neutron spectroscopy to characterize abundance of hydrogen in permanently shaded craters.

Lunar IceCube

Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer.

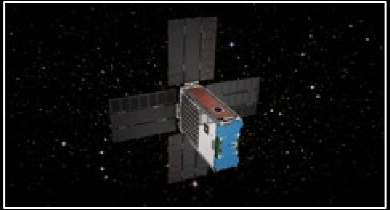
Team Miles

Demonstrate propulsion using plasma thrusters; compete in NASA's Deep Space Derby.



Near-Earth Asteroid Scout (NEA Scout)

Detect target NEA, perform reconnaissance and close proximity imaging.

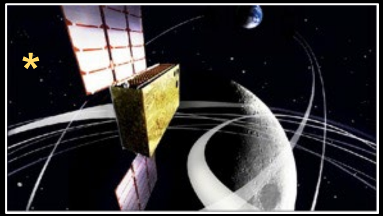


BioSentinel

Use yeast as a biosensor to evaluate the effects of ambient space radiation on DNA.

CubeSat to Study Solar Particles (CuSP)

Measure incoming radiation that can create a wide variety of effects on Earth.



EQUULEUS

Demonstrate trajectory control techniques within the Sun-Earth-Moon region and image Earth's plasmasphere.

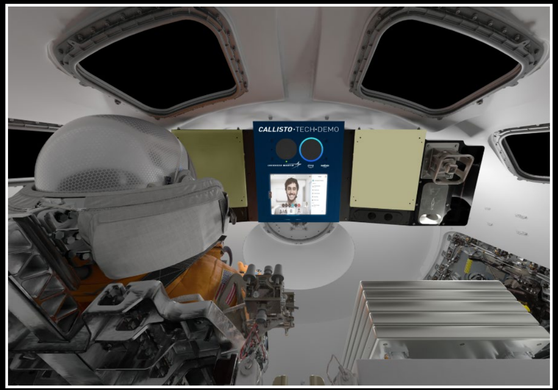
* INTERNATIONAL COLLABORATION

Artemis I Pressurized Payloads

Secondary payloads that will fly inside of the Orion crew module

Radiation Sensors*

There will be three types of sensors, including the ESA Active Dosimeters, Hybrid Electronic Radiation Assessor (HERA), and the Radiation Area Monitor (RAM).

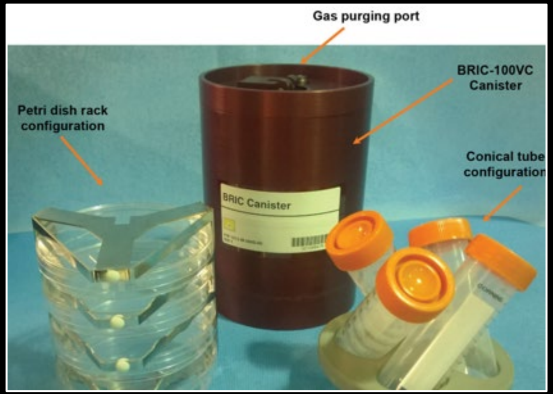


Callisto

Demonstrate voice activated virtual assistant which enables hands free crew interface. Evaluate effectiveness of on board vs. ground supported crew assisted capabilities.

Matroshka AstroRad Radiation Experiment (MARE)*

Investigation with DLR and ISA for to evaluation radiation protection vest for astronauts.



Bio-Experiment-1

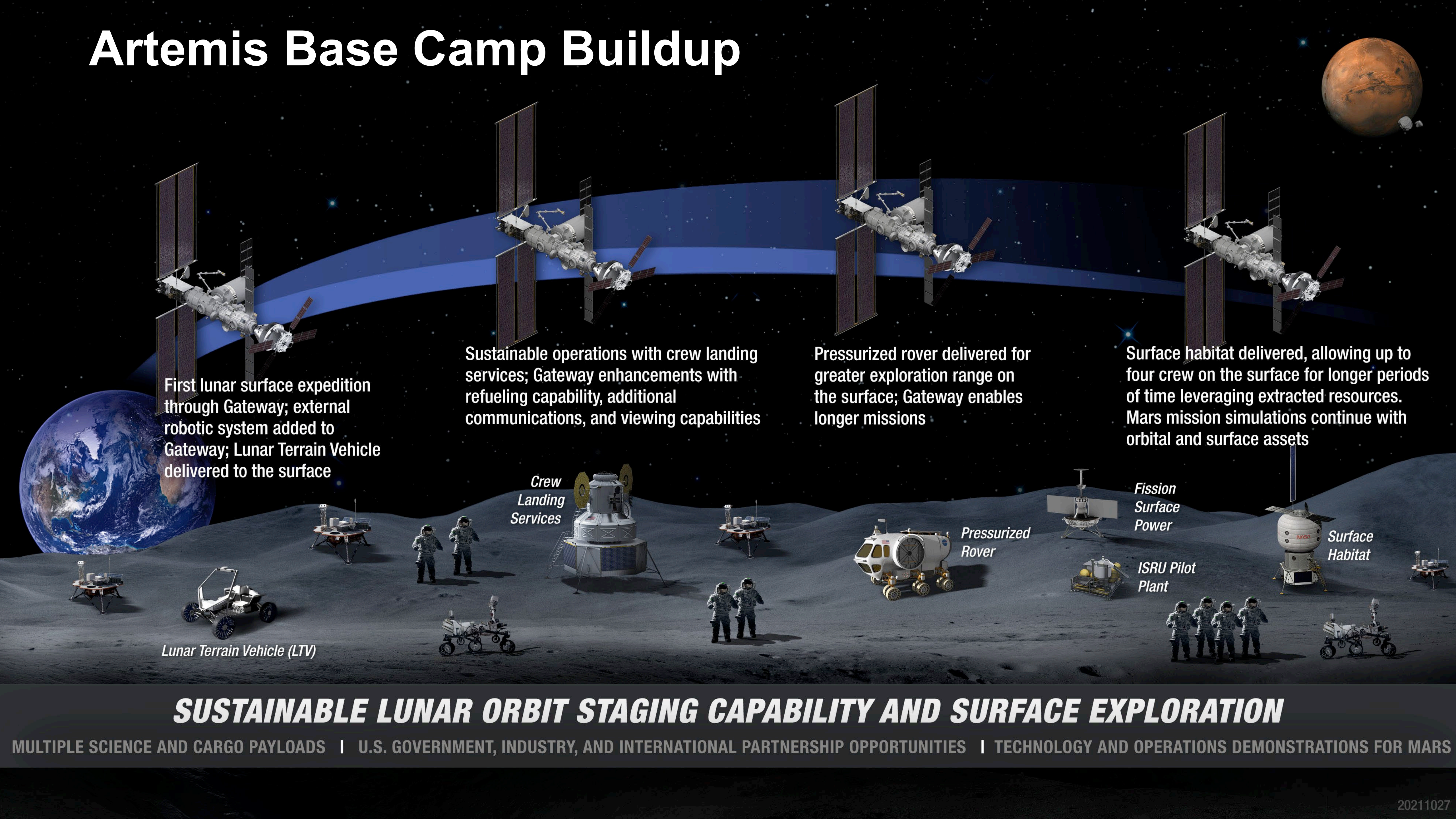
A battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO). May be as many as four investigations.

* INTERNATIONAL COLLABORATION

Early Gateway Science Payloads

Launched with PPE and HALO

- **ERSA:** The European Space Agency's (ESA) radiation instrument package will help provide an understanding of how to keep astronauts safe by monitoring the radiation exposure in Gateway's unique orbit.
- **HERMES:** NASA's space weather instrument suite will observe solar particles and solar wind created by the Sun.
- ESA **Internal Dosimeter Array**, including instruments provided by the Japan Aerospace Exploration Agency. Data provided will allow for the study of radiation shielding effects and improve radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew risk on exploration missions.


Artemis Base Camp Buildup
First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface
Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities
Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions
Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets
Crew Landing Services
Fission Surface Power
Pressurized Rover
Surface Habitat
ISRU Pilot Plant
Lunar Terrain Vehicle (LTV)
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS
20211027

NASA

Unique Science from the Moon: An Overview

James L. Green
NASA Senior Advisor [redacted]

June 7, 2022

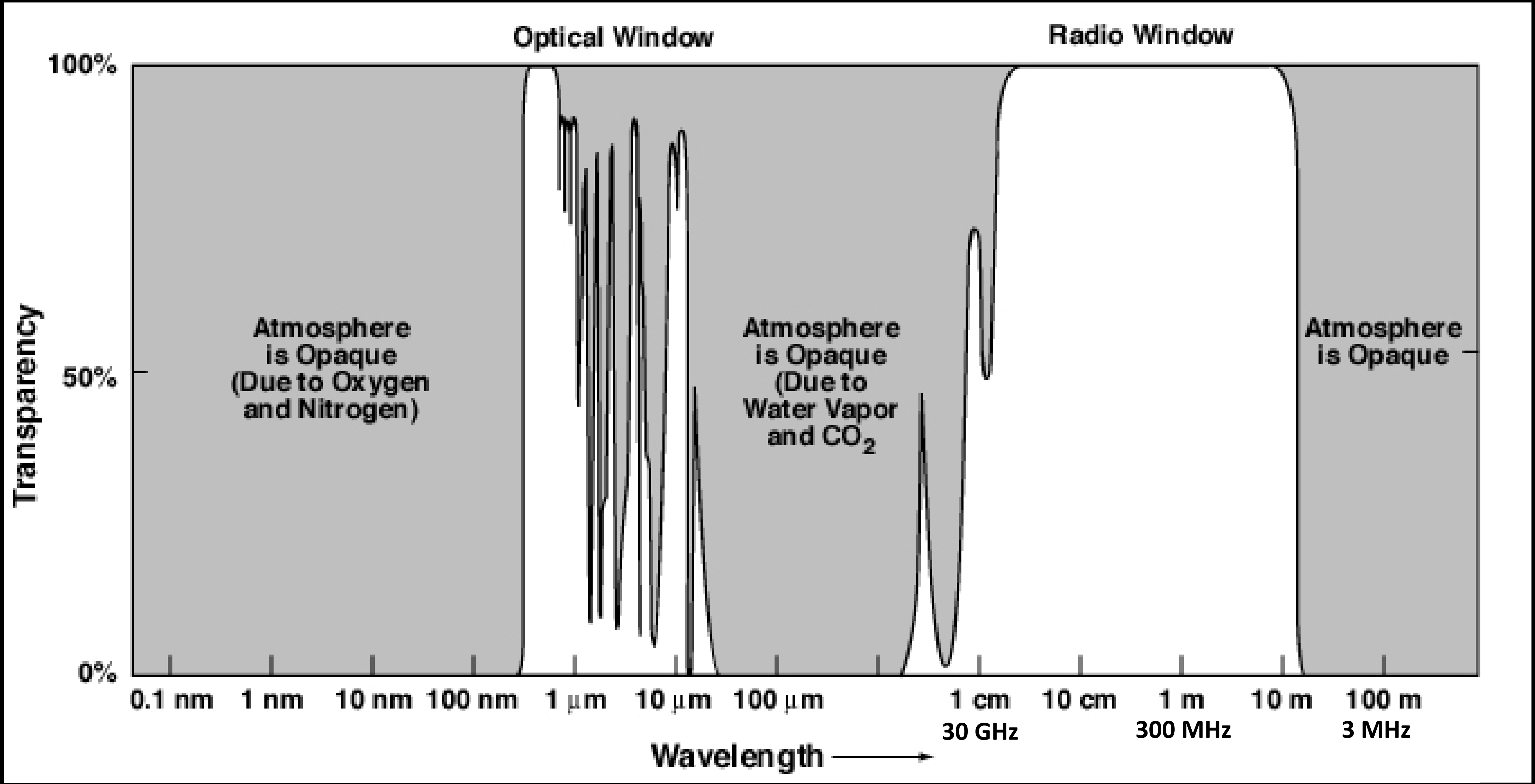
Outline

- Atmospheric Windows
- Early Cosmic Timeline
- Radio emissions from stars and planets
  - Star formation (non-thermal processes)
  - The Sun as a star
  - Planetary Magnetospheres
- Black Hole Observations
- The Far-Infrared Sky

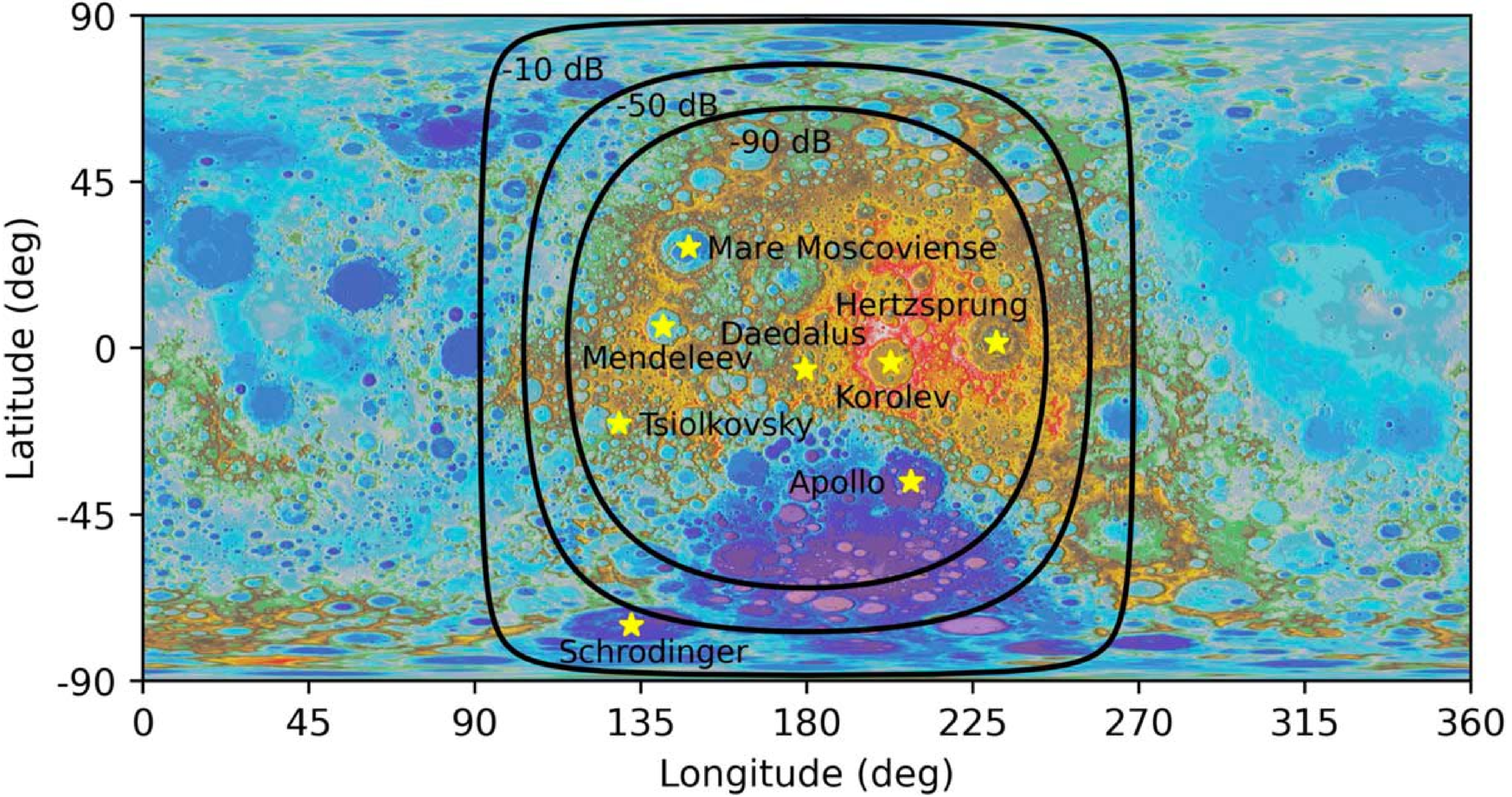
The next horizon of the Planetary and Astrophysics Decadals

Theme: Using the Lunar Surface as a platform

Atmospheric Windows



Map of RFI Suppression at 100 kHz

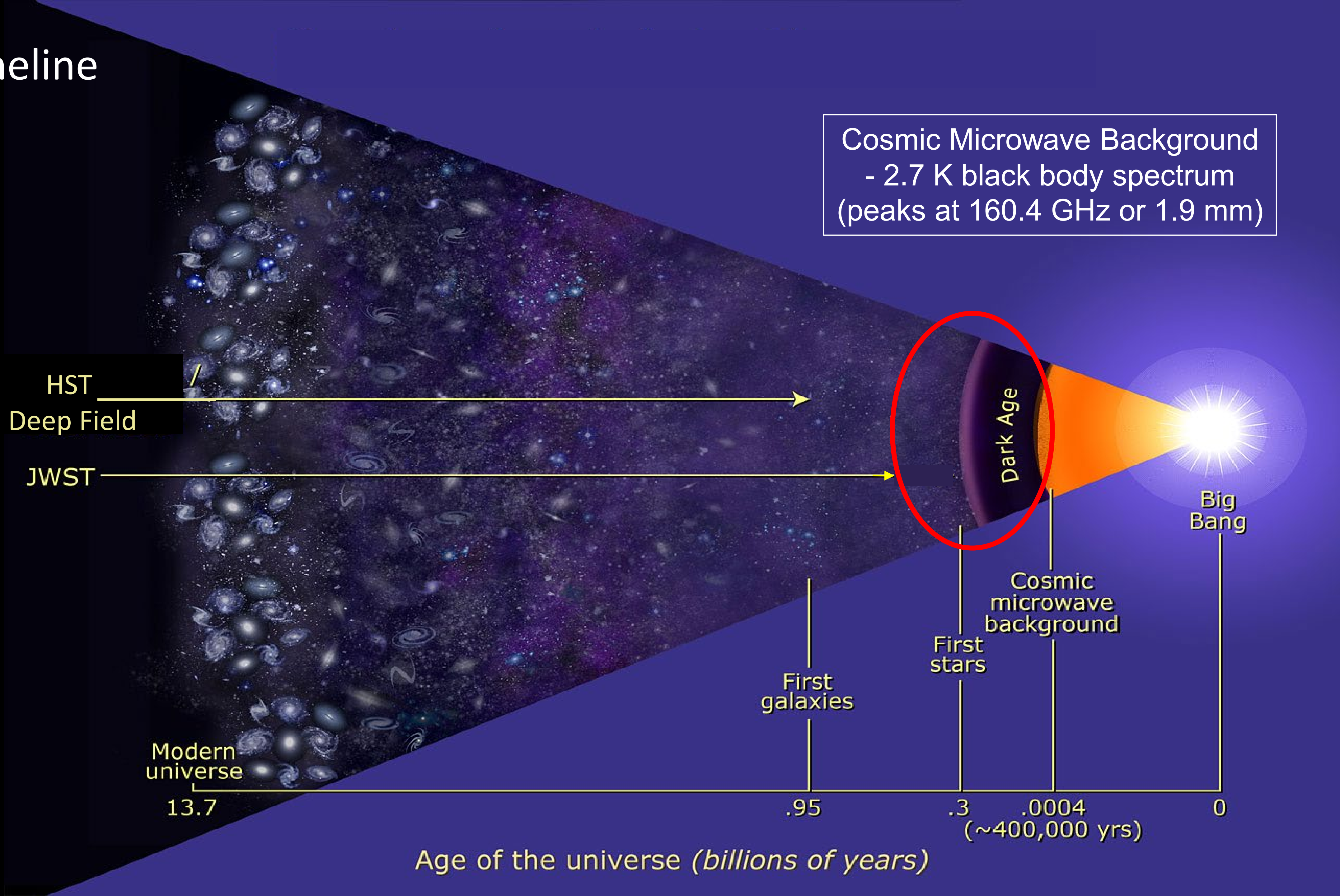


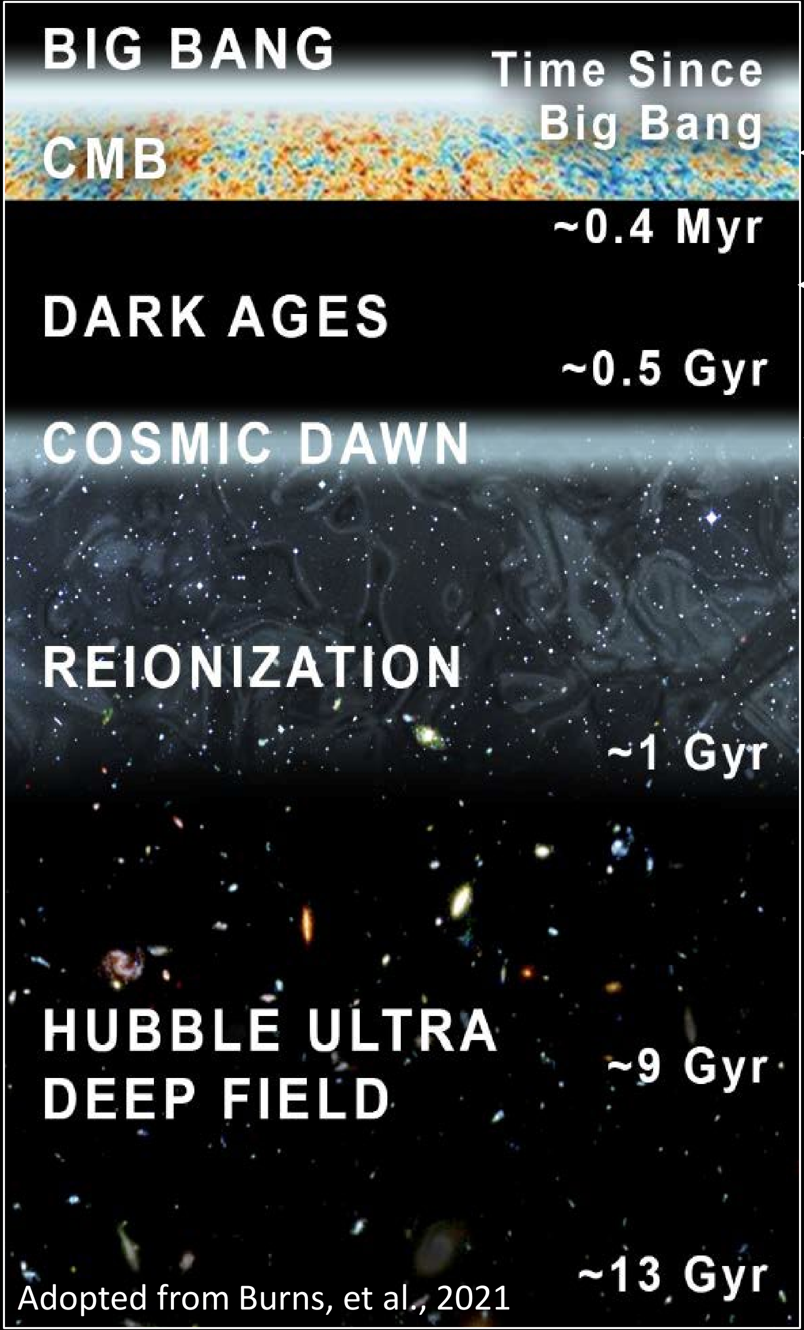
Burns, et al., 2021

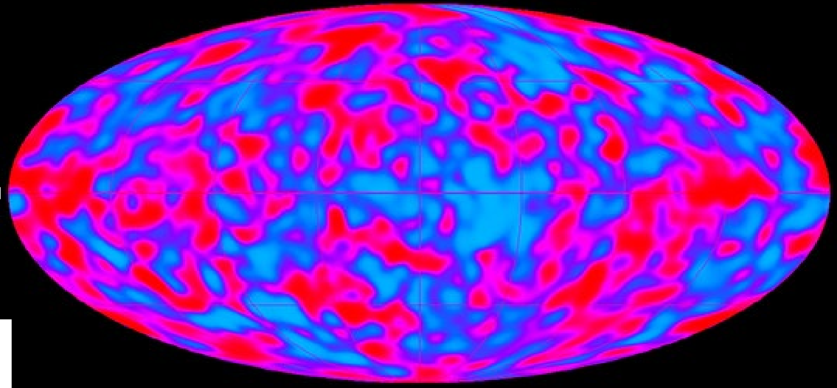
Early Cosmic Timeline

Cosmic Timeline

Cosmic Microwave Background
- 2.7 K black body spectrum
(peaks at 160.4 GHz or 1.9 mm)

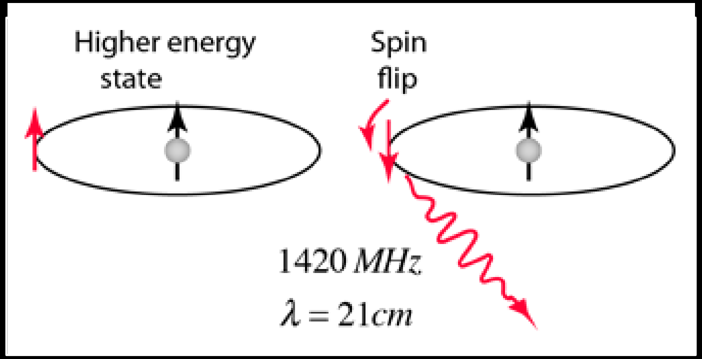






CMB is a snapshot view of the distribution of matter

No visible or infrared light (no stars). Expect simple matter like: Neutral Hydrogen, photons, and dark matter



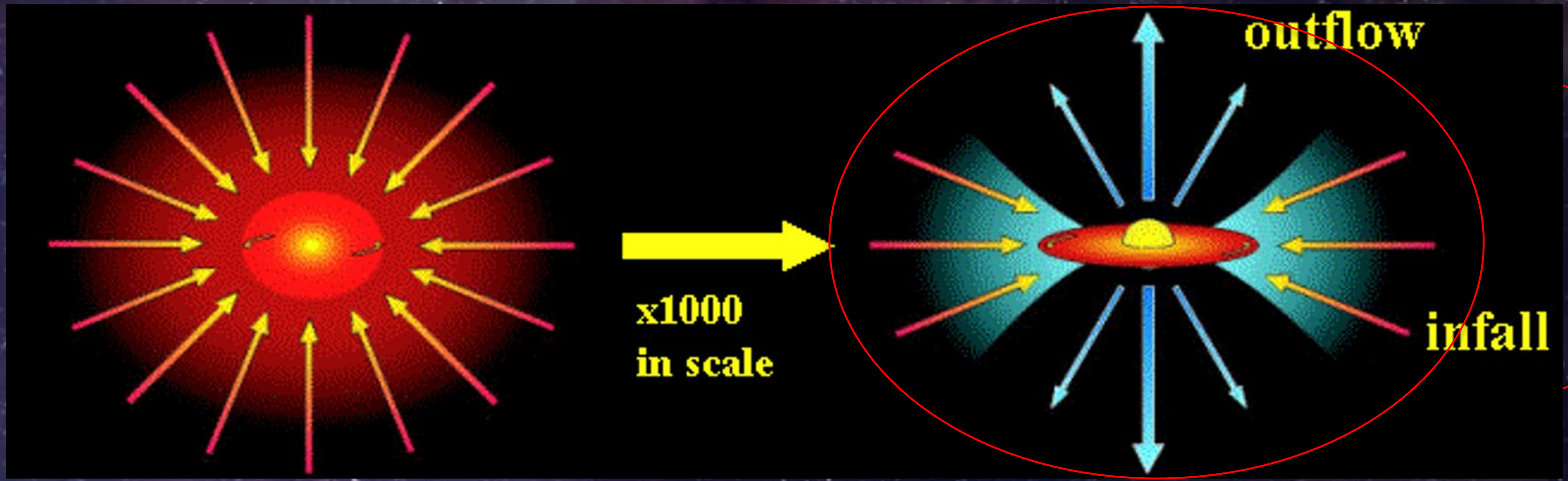
Longer the wavelength the older it is. Look for this emission at 10 to 100 m or From 30 MHz to 3 MHz

The very first stars

James Webb Space Telescope – observing the first galaxies

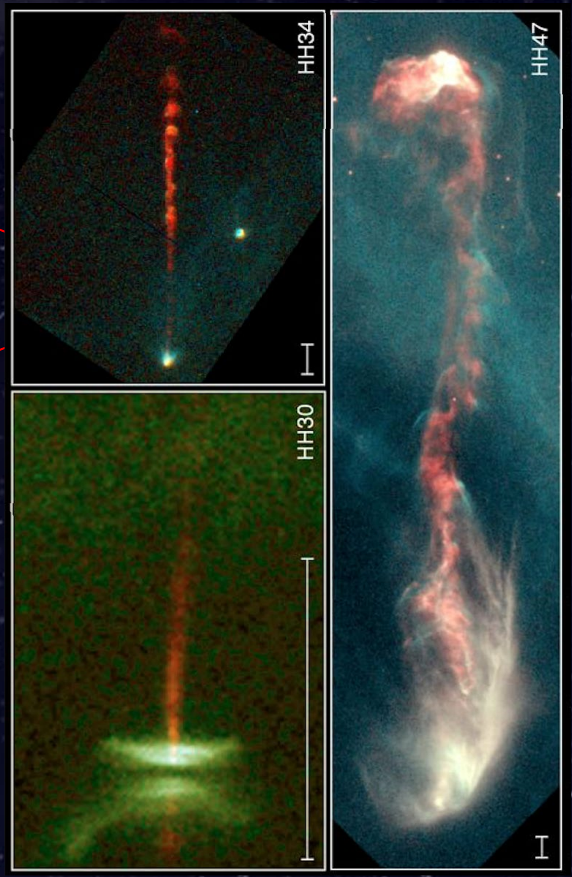
Radio Emissions from Other Stars and the Sun

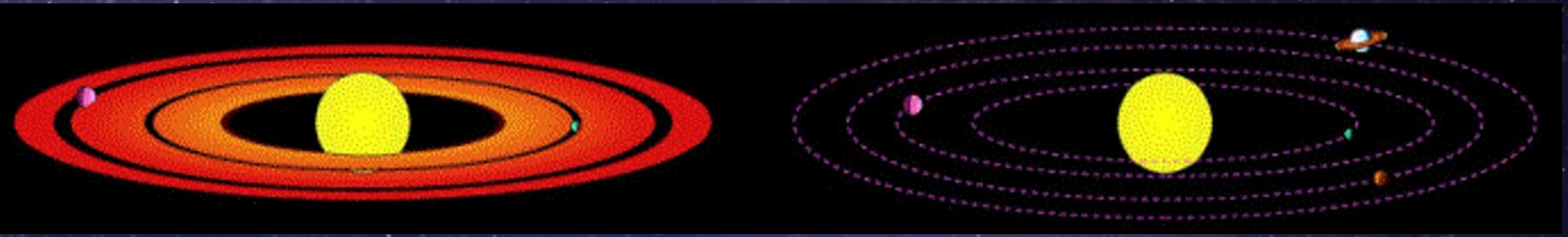
Star Formation Processes



Cloud Collapse

Rotating Disk Phase





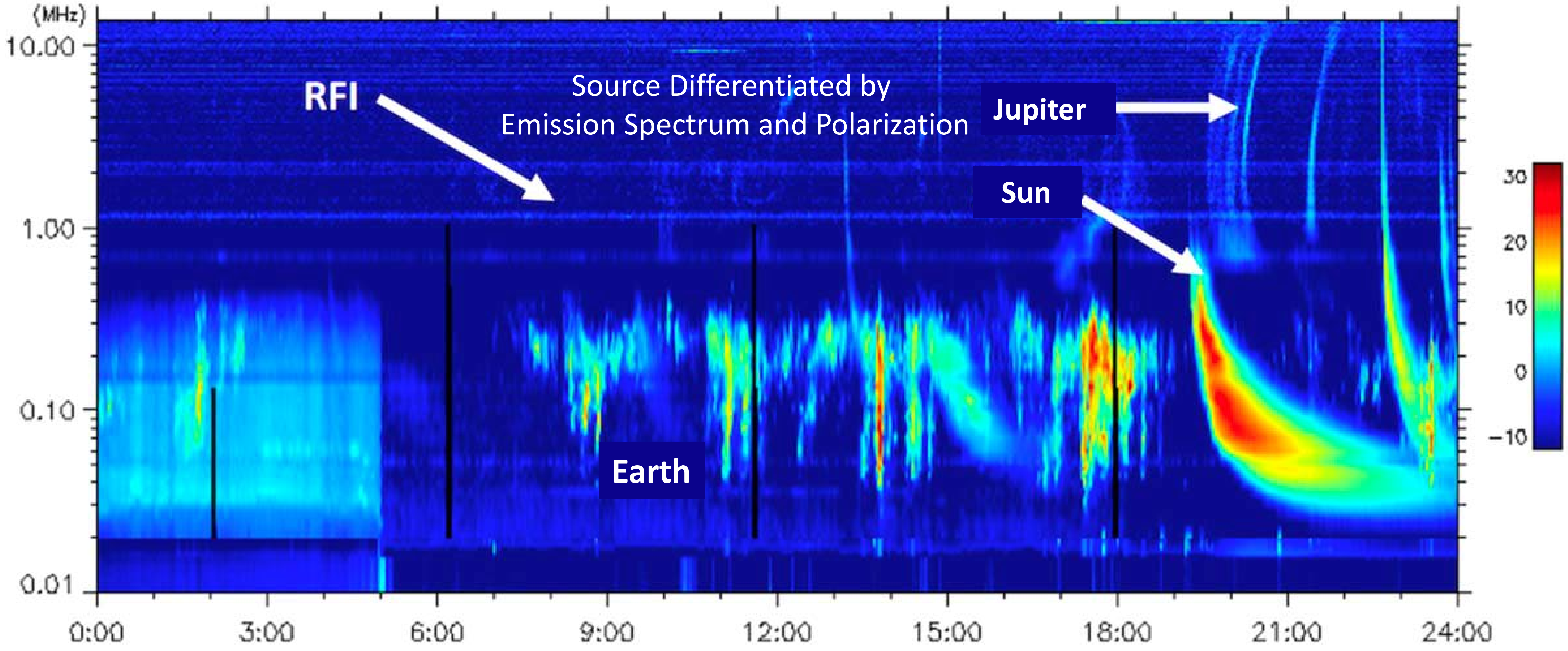
Planet Formation

Mature Solar System

Observations with improved sensitivity and Image quality are needed by combining arrays (Radio emissions below 1 MHz needed)

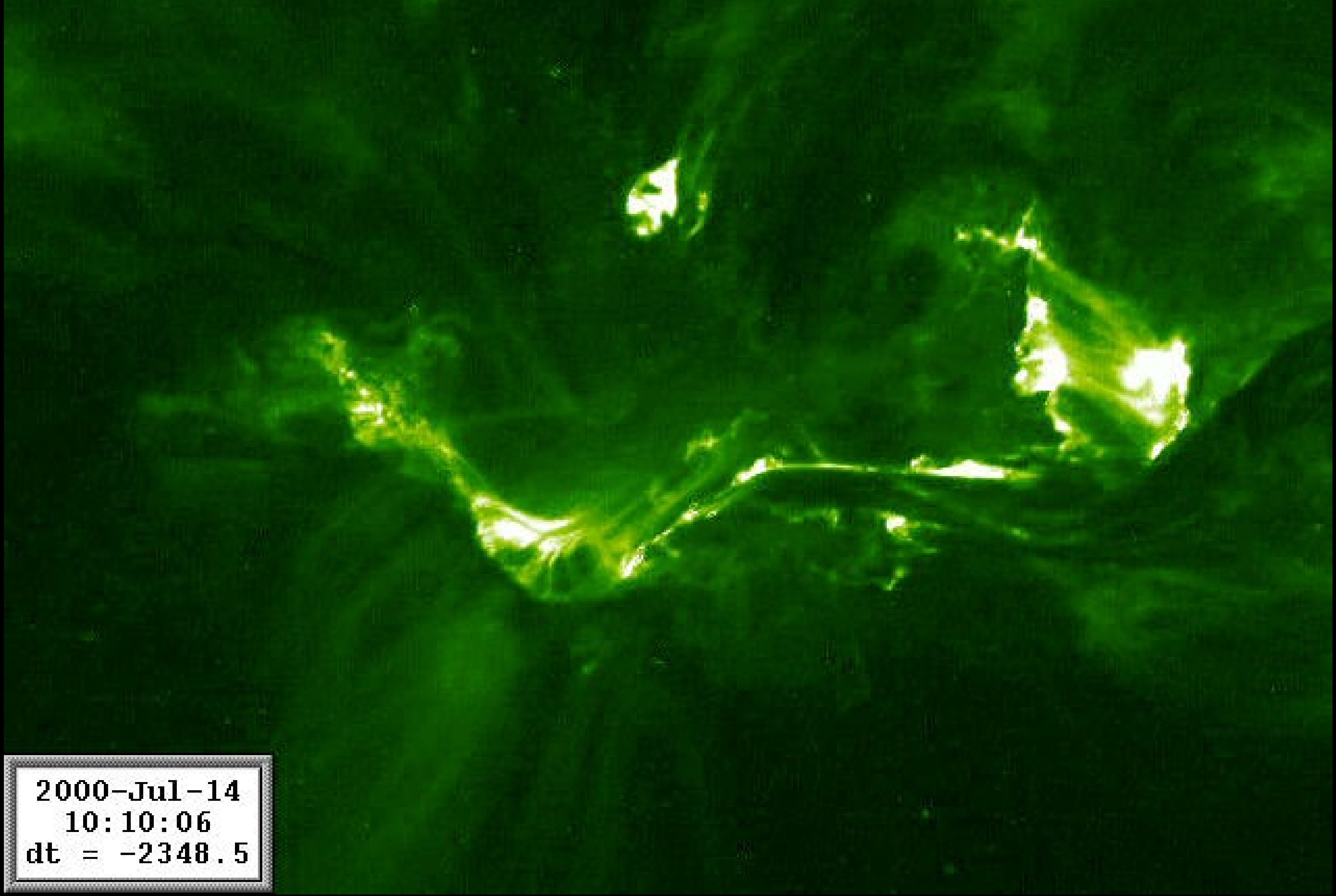
Radio Frequency Spectrum in the Solar System

(All frequencies not observed from the ground)



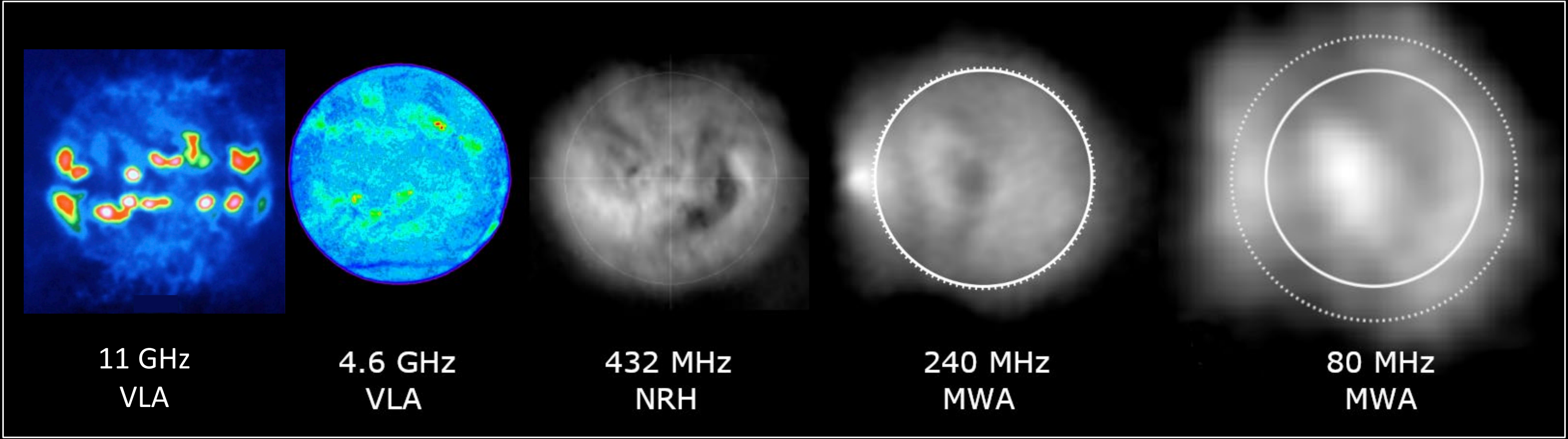
Adopted from Burns, et al., 2021

Solar Flares

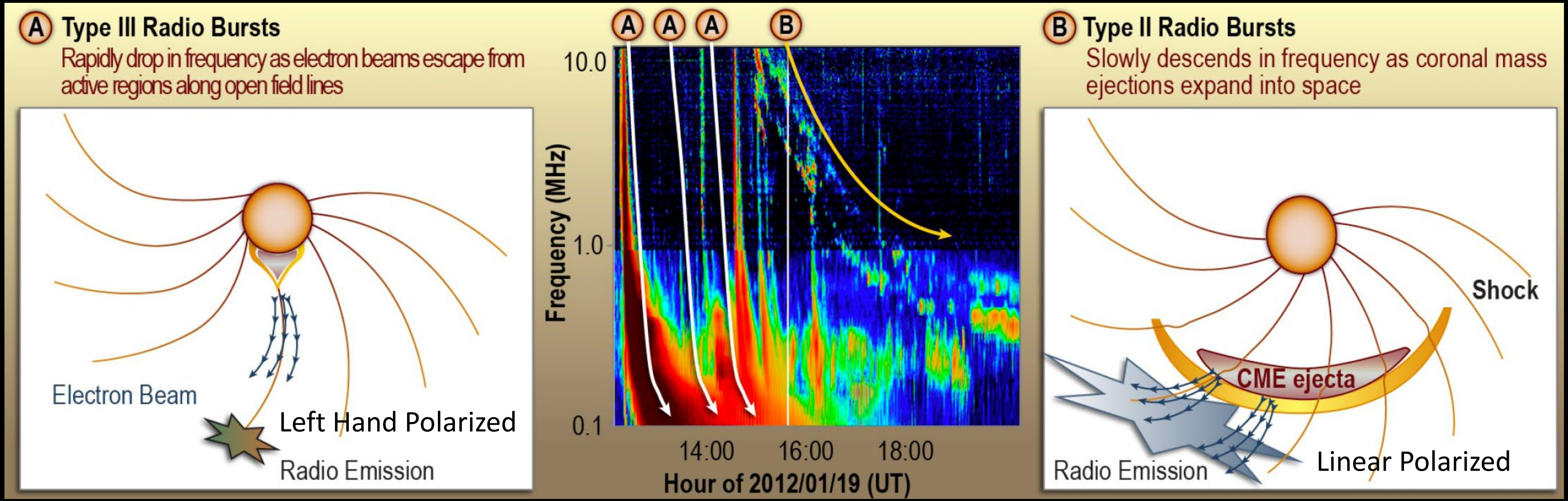


Coronal Mass Ejection

Solar Radio Emissions



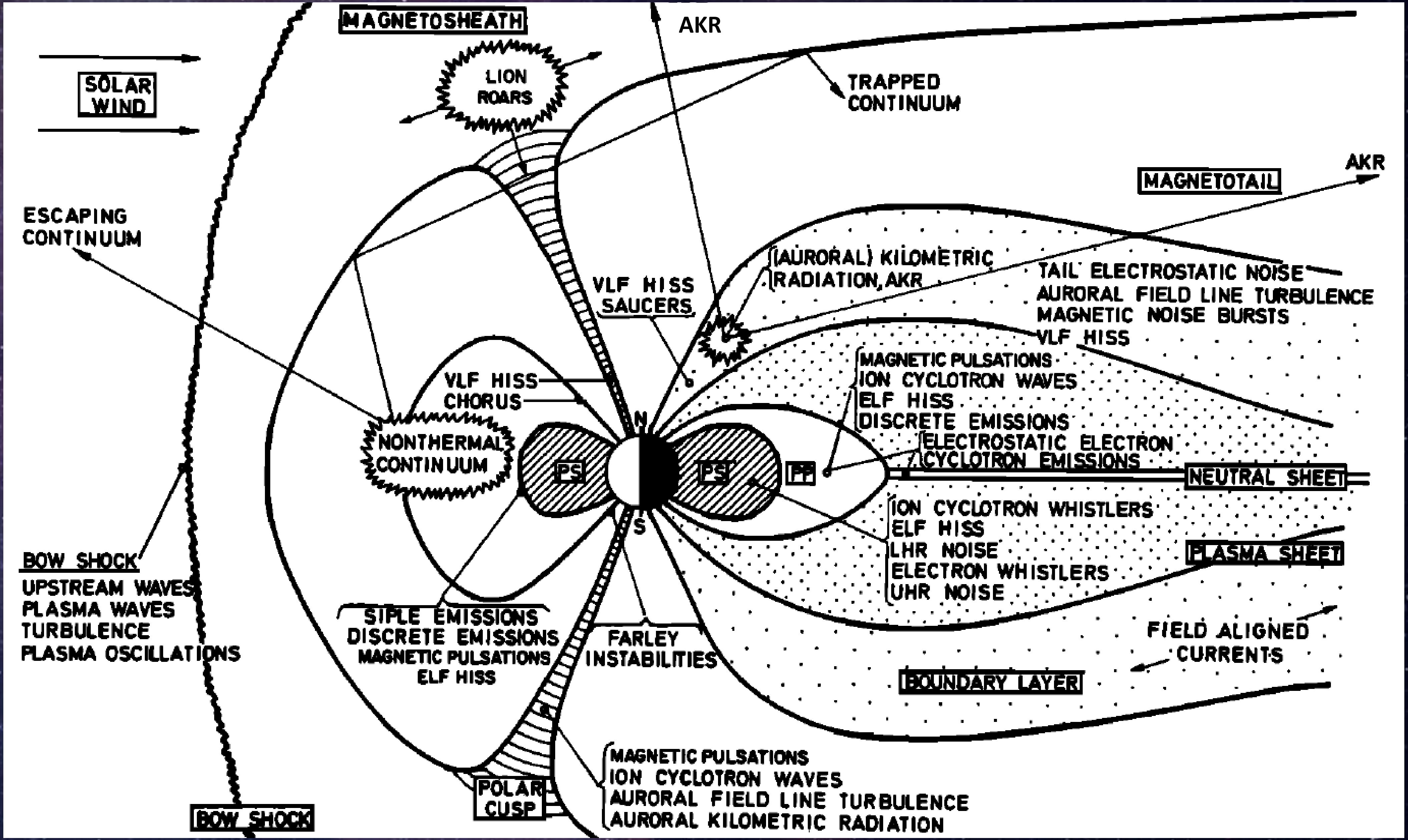
Not Observed From Earth



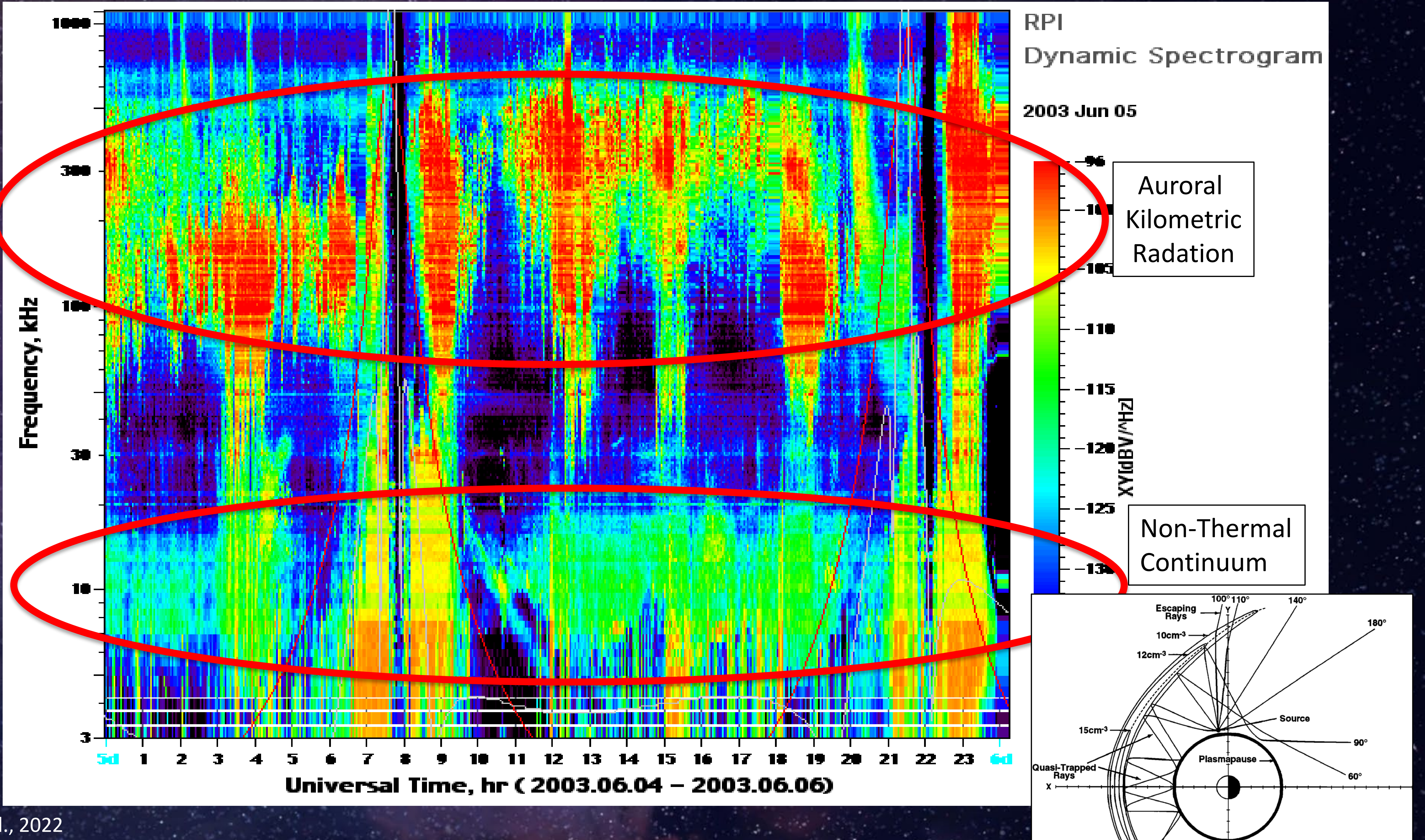
Lazio, et al., 2017

Radio Emissions from Planets

Magnetospheric Plasma Waves

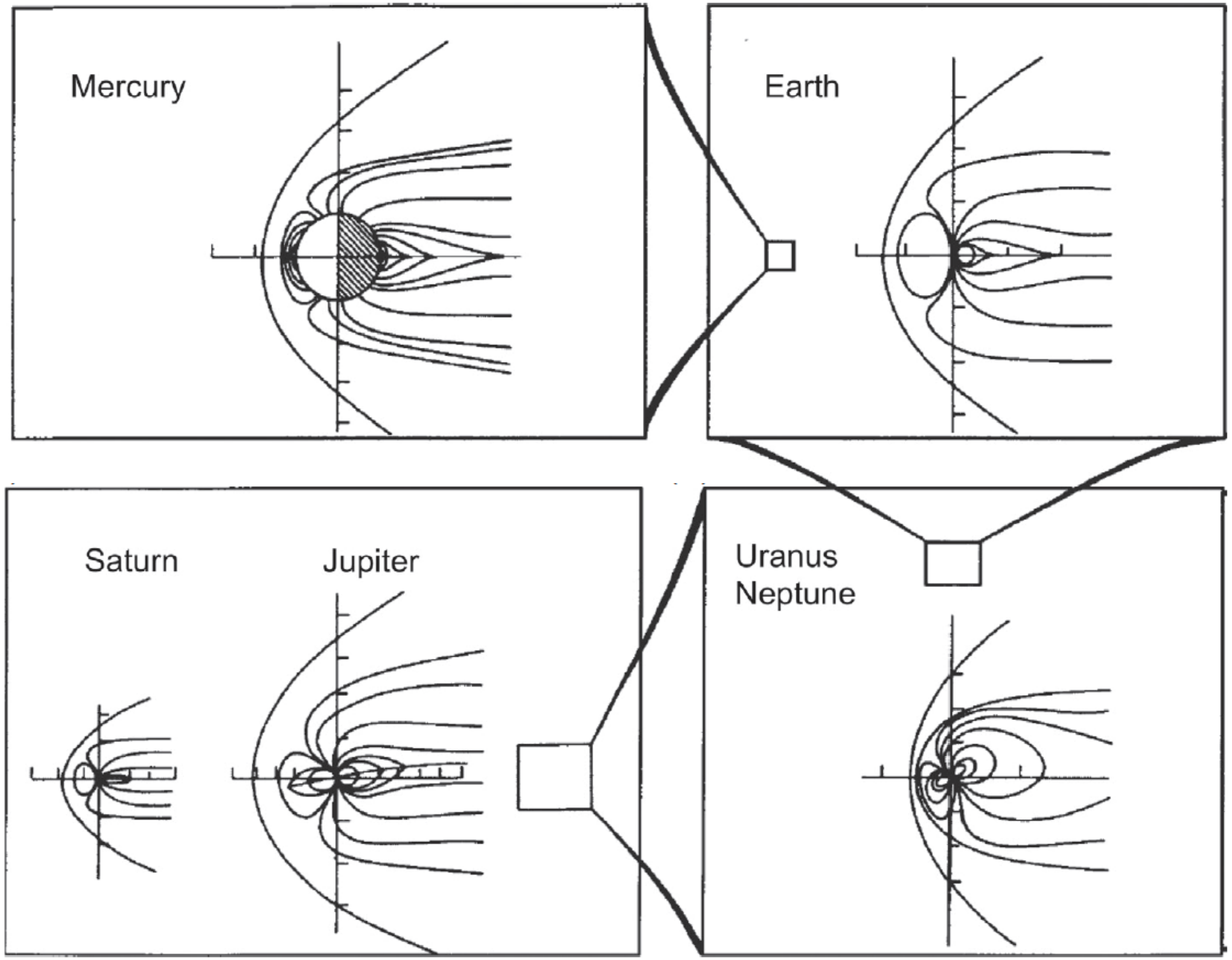


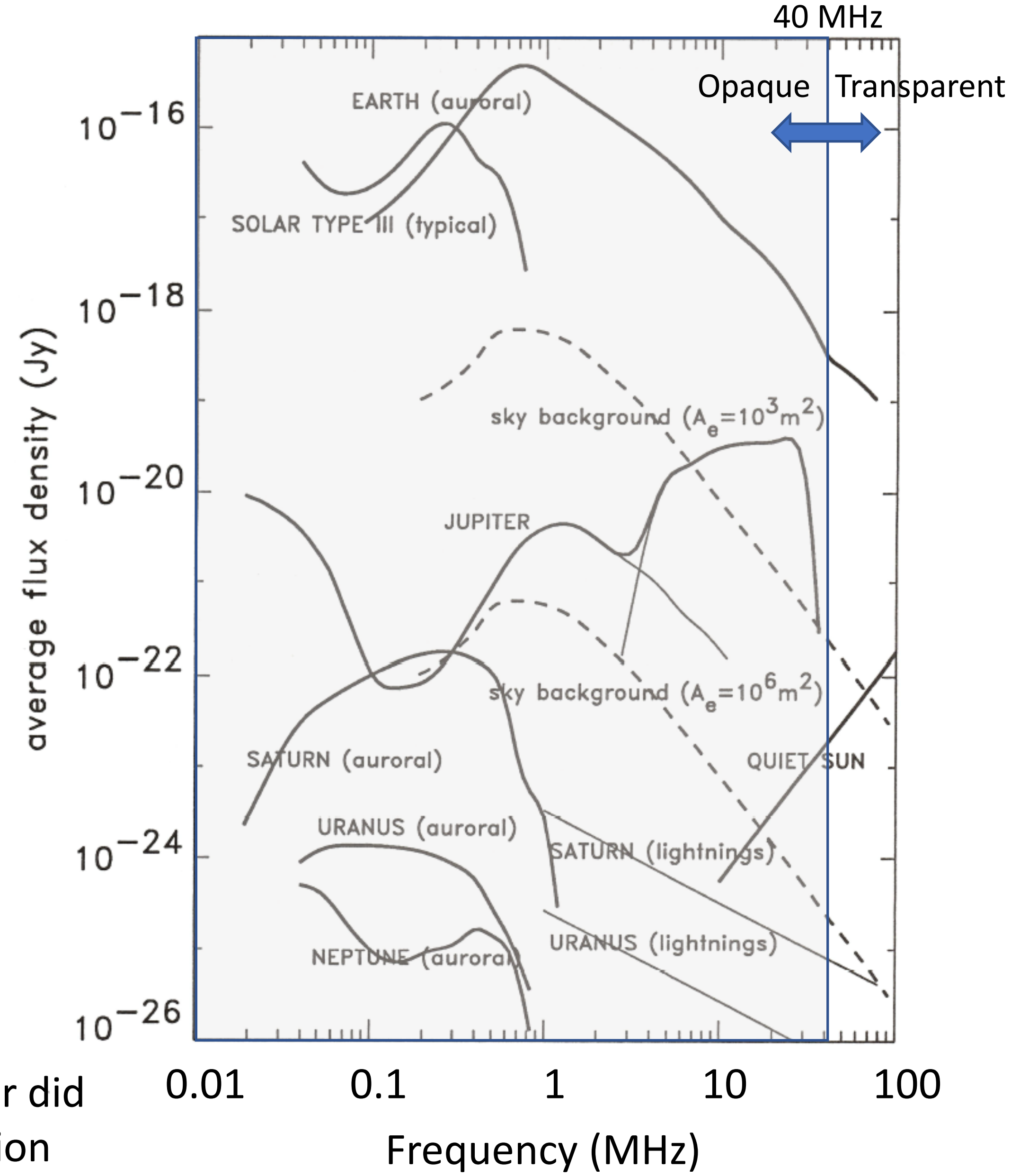
Shawhan, RG, 1978



Fung et al., 2022

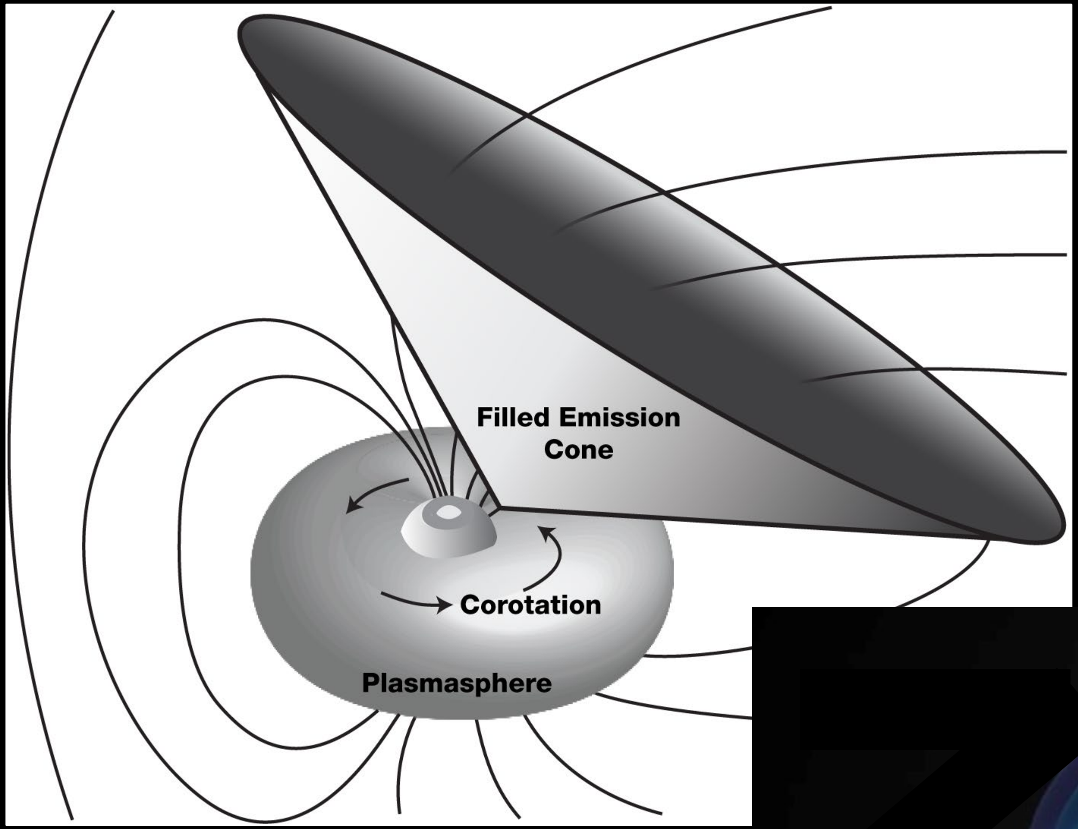
VLF Emission from the Solar System Magnetospheres

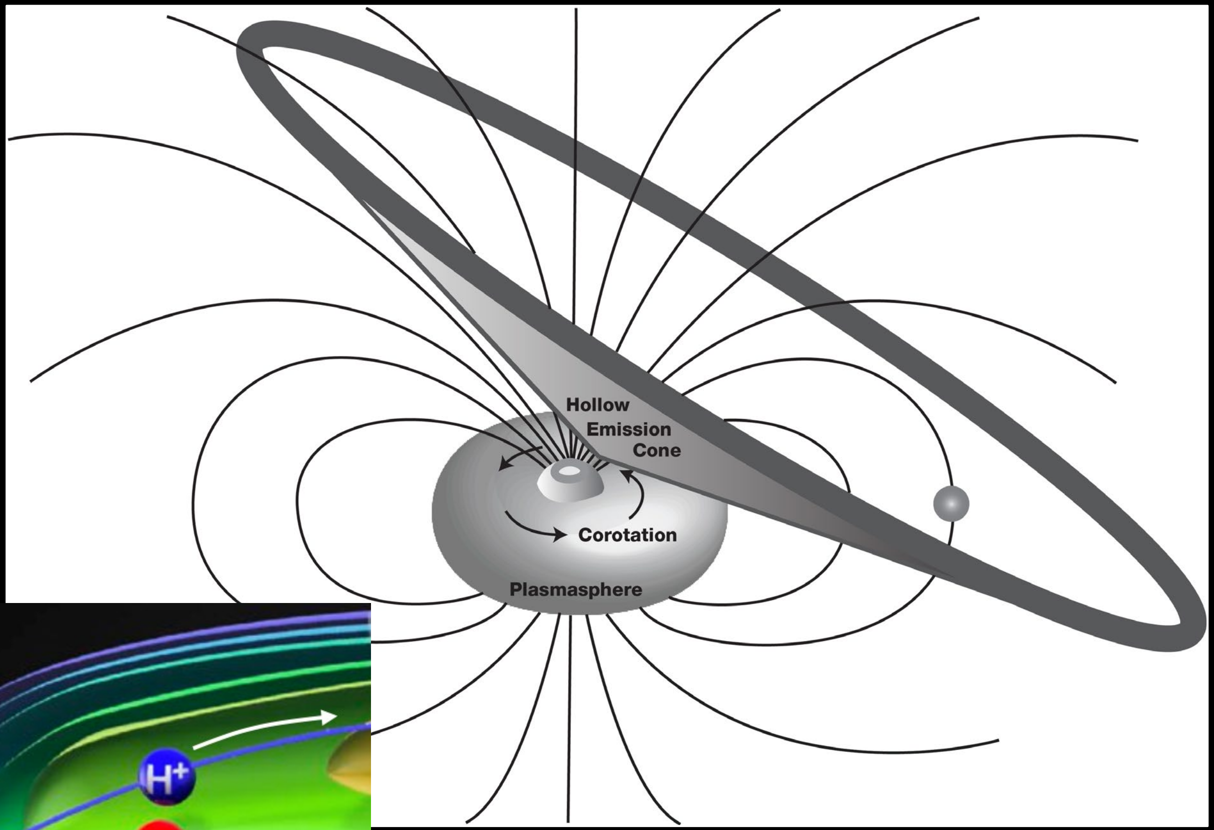


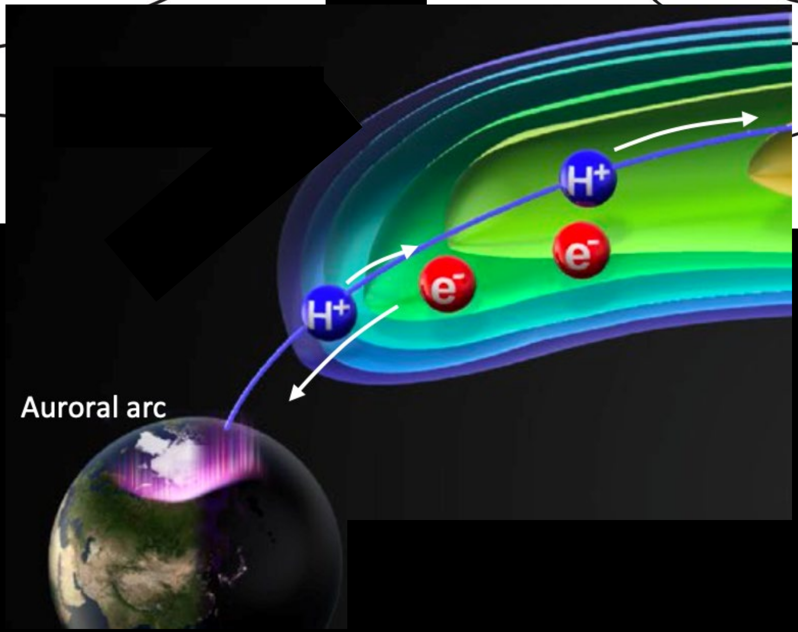


- Mars had a magnetosphere but lost it 3 By ago; Unknown if Venus ever did
- Magnetospheres may be a fundamental feature of early planet evolution

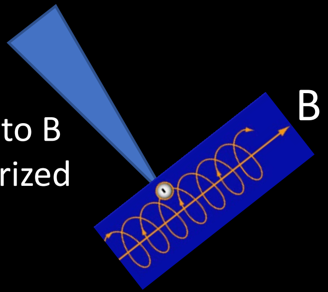
Magnetospheric Auroral Emissions







Emission Perpendicular to B
Right-Hand Circular Polarized



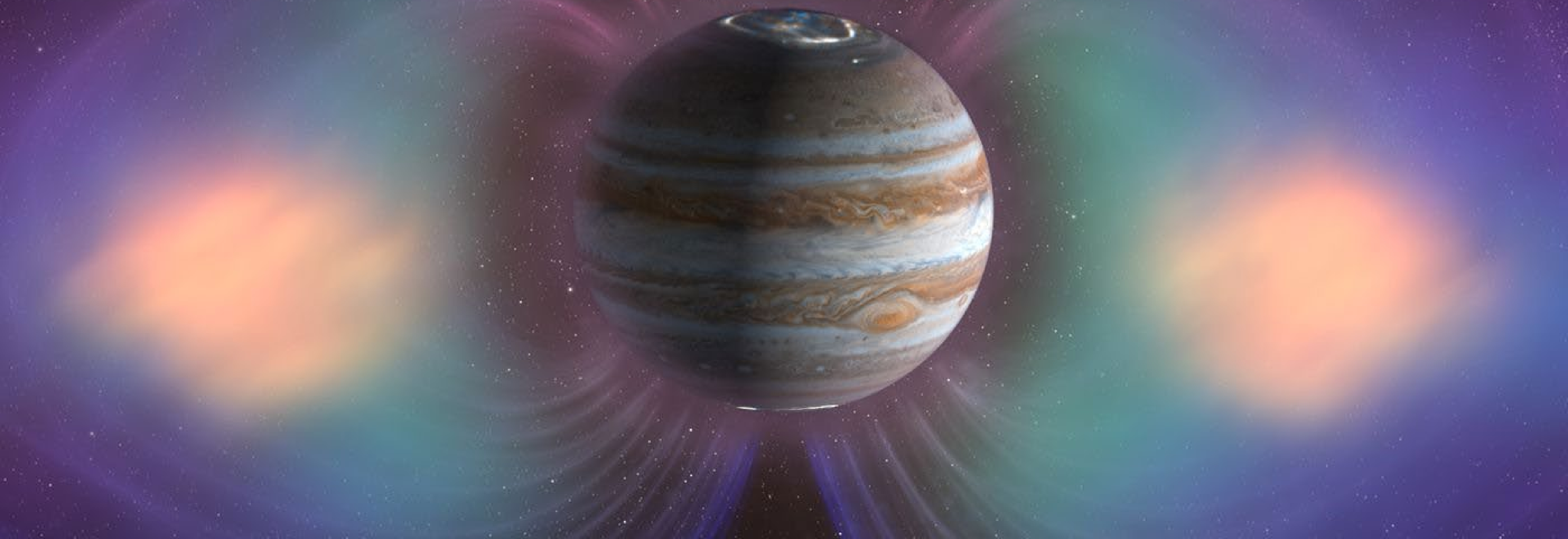
f_{ge} =2.8B MHz

Magnetic field (B) in Gauss

Green et al., 2021

Jupiter’s Escaping High Frequency Radiation

Jovian Decametric radiation - 10 and 40 MHz − Auroral related

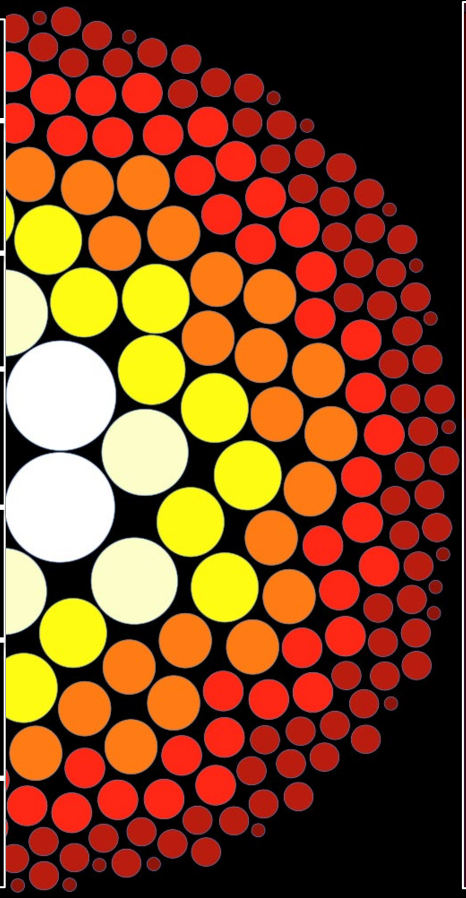


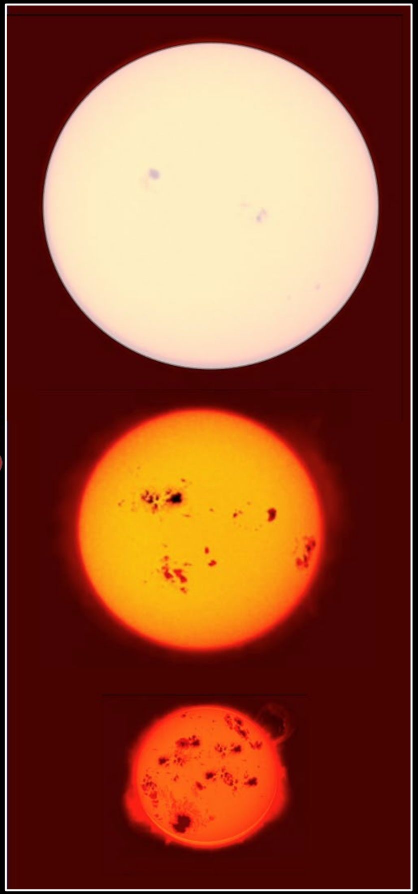
Jovian Decimetric radiation - 0.1–15 GHz – Radiation Belts
(wavelength 3 m to 2 cm)

Why are Planets around M-dwarfs so Important?

Stars within
10 pc of the Sun

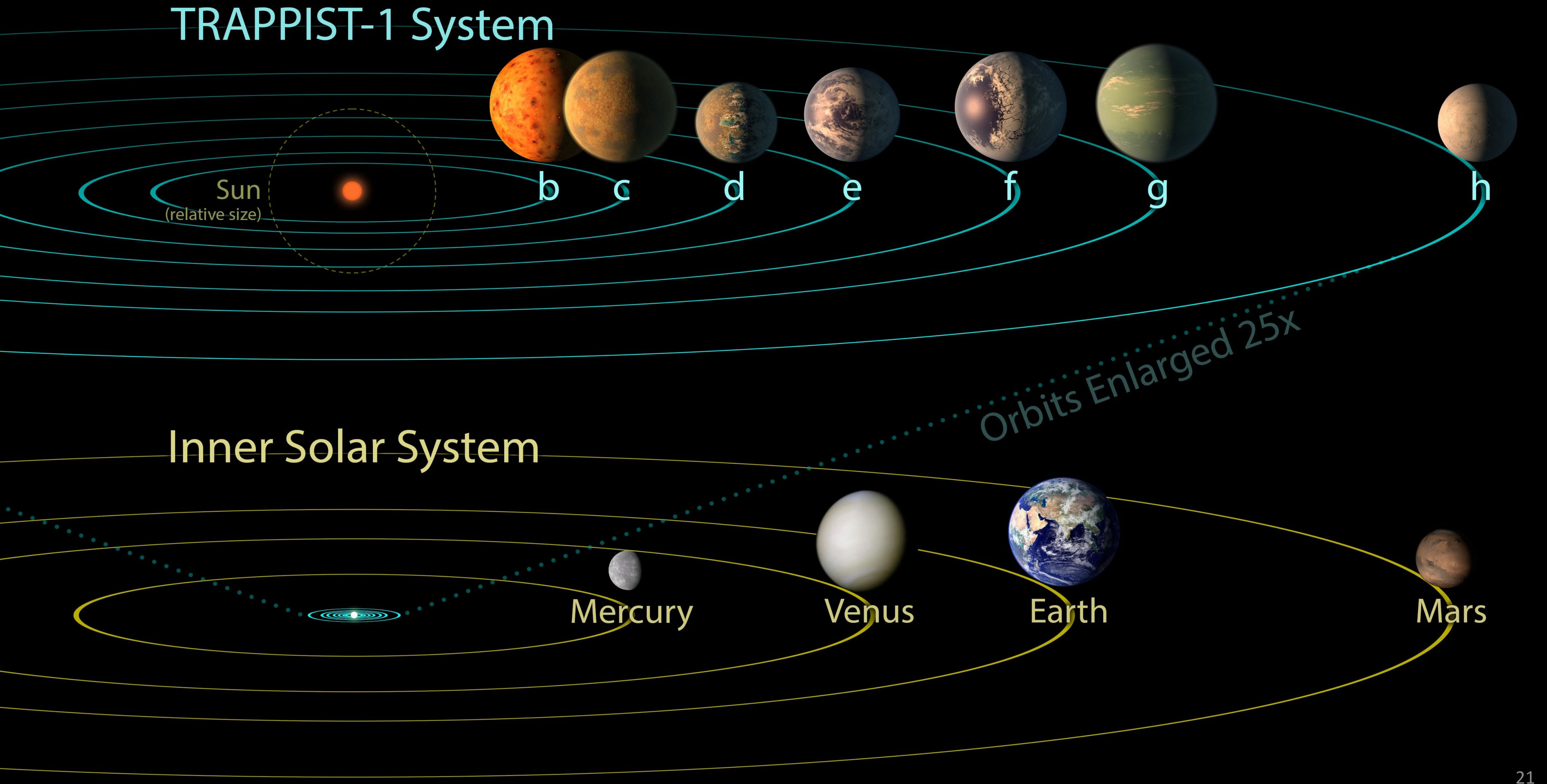
O	0
B	0
A	4 (1%)
F	6 (2%)
G	20 (6%)
K	44 (14%)
M	246 (77%)





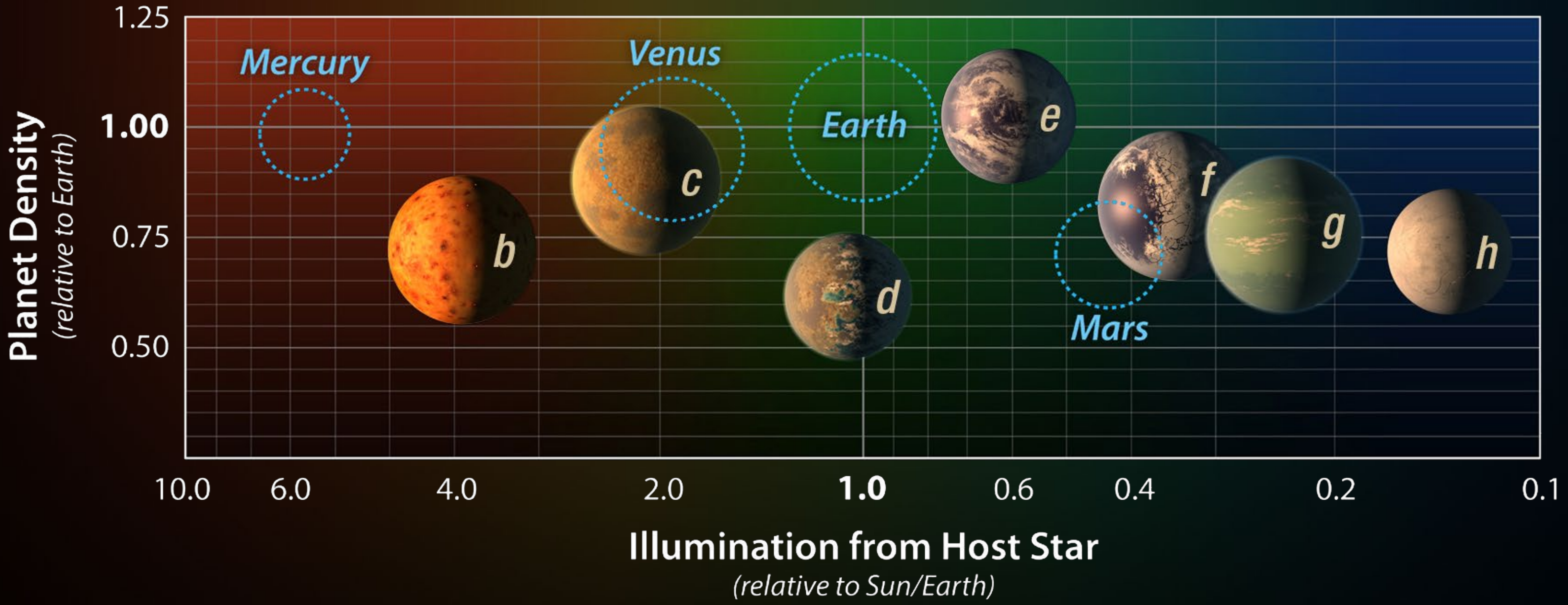
- There are ~250 M-dwarfs within 10 pc
- Milky Way has ~100-400 billion stars
  - M-stars are ~70% of all stars
  - There are > 70 billion M-dwarfs
- If 50% of M-dwarfs have an Earth-sized planet in the Habitable Zone
  - Then ~35 billion potentially habitable planets in our Galaxy
- Space Weather varies significantly with star type with M-dwarfs having significant activity

Understanding the Trappist-1 system
is fundamental to our exoplanet life search


TRAPPIST-1 System
Sun
(relative size)
b
c
d
e
f
g
h
Orbits Enlarged 25x
Inner Solar System
Mercury
Venus
Earth
Mars

TRAPPIST – 1

Similar density to terrestrial planets and lack extended primitive Hydrogen atmospheres



Illustrations

TRAPPIST-1 System

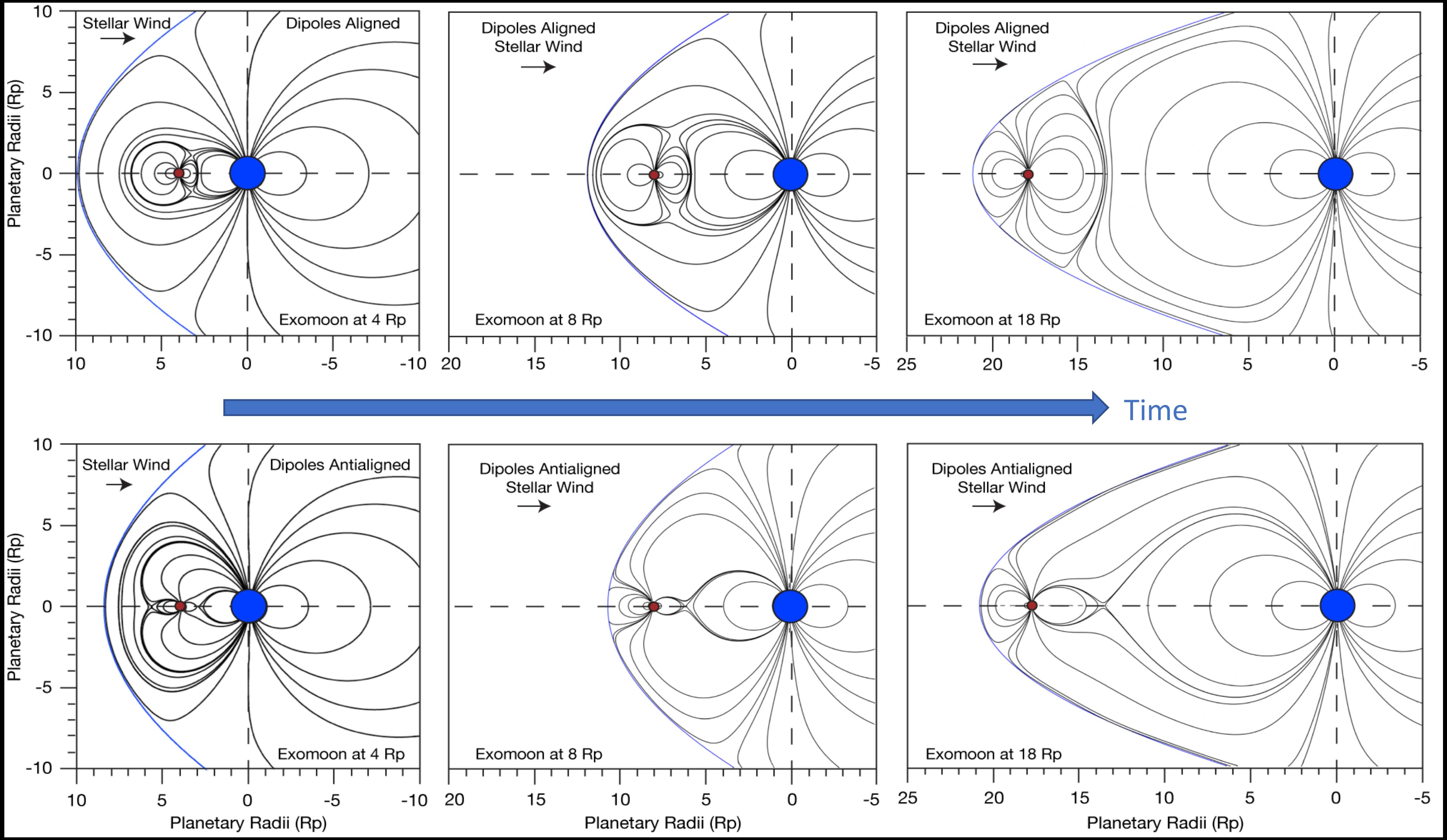
Feb. 2018

	b	c	d	e	f	g	h
			65 hours	97 hours	147 hours		
Orbital Period	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.36 *days*	18.76 *days*
Distance to Star	0.0115 *AU*	0.0158 *AU*	0.0223 *AU*	0.0293 *AU*	0.0385 *AU*	0.0469 *AU*	0.0619 *AU*
Planet Radius	1.12 R_{earth}	1.10 R_{earth}	0.78 R_{earth}	0.91 R_{earth}	1.05 R_{earth}	1.15 R_{earth}	0.77 R_{earth}
Planet Mass	1.02 M_{earth}	1.16 M_{earth}	0.30 M_{earth}	0.77 M_{earth}	0.93 M_{earth}	1.15 M_{earth}	0.33 M_{earth}
Planet Density	0.73 ρ_{earth}	0.88 ρ_{earth}	0.62 ρ_{earth}	1.02 ρ_{earth}	0.82 ρ_{earth}	0.76 ρ_{earth}	0.72 ρ_{earth}
Surface Gravity	0.81 *g*	0.96 *g*	0.48 *g*	0.93 *g*	0.85 *g*	0.87 *g*	0.55 *g*

Solar System

Rocky Planets

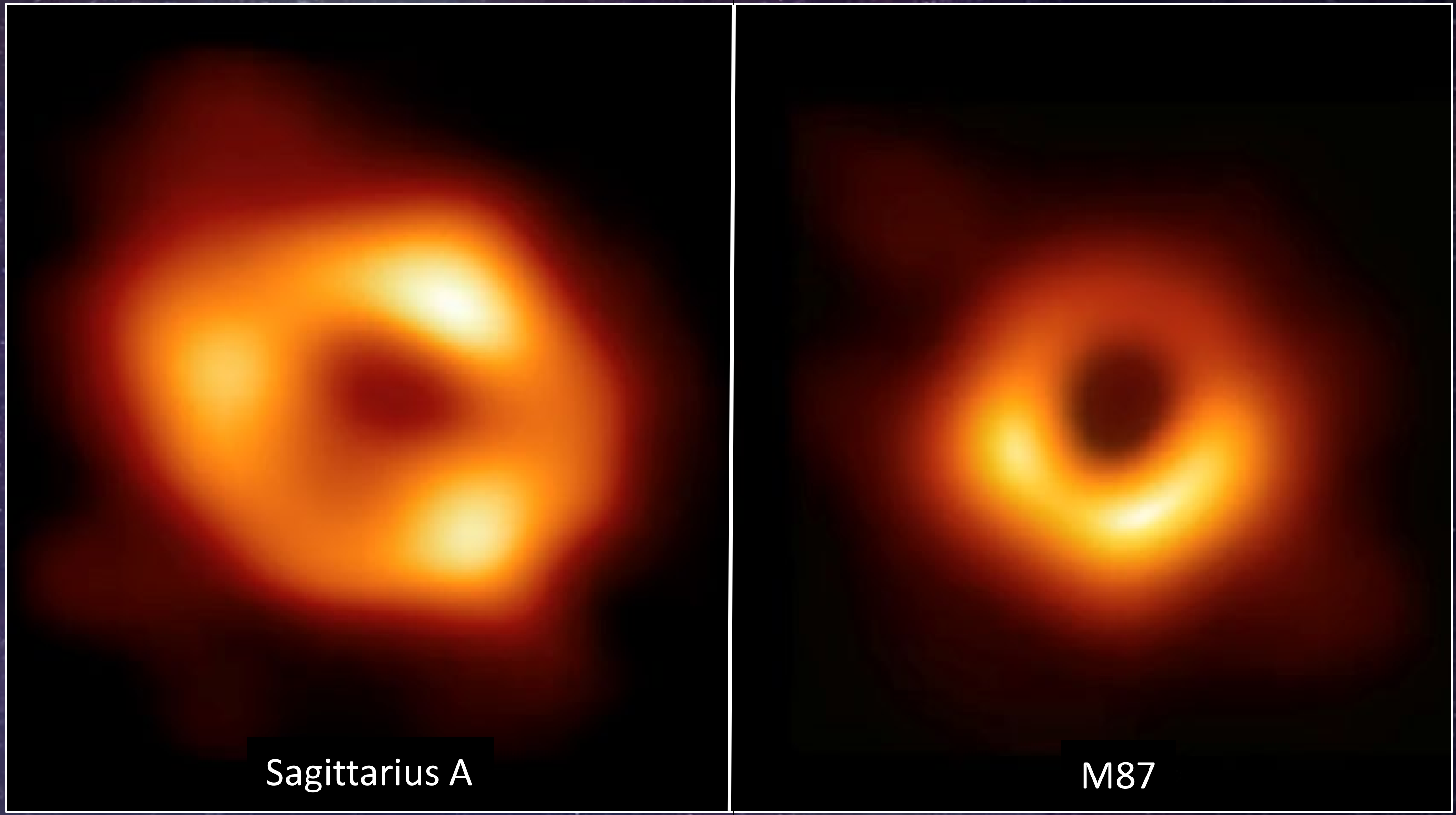
	Mercury	Venus	Earth	Mars
Orbital Period	87.97 *days*	224.70 *days*	365.26 *days*	686.98 *days*
Distance to Star	0.387 *AU*	0.723 *AU*	1.000 *AU*	1.524 *AU*
Planet Radius	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
Planet Mass	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}
Planet Density	0.98 ρ_{earth}	0.95 ρ_{earth}	1.00 ρ_{earth}	0.71 ρ_{earth}
Surface Gravity	0.38 *g*	0.90 *g*	1.00 *g*	0.38 *g*

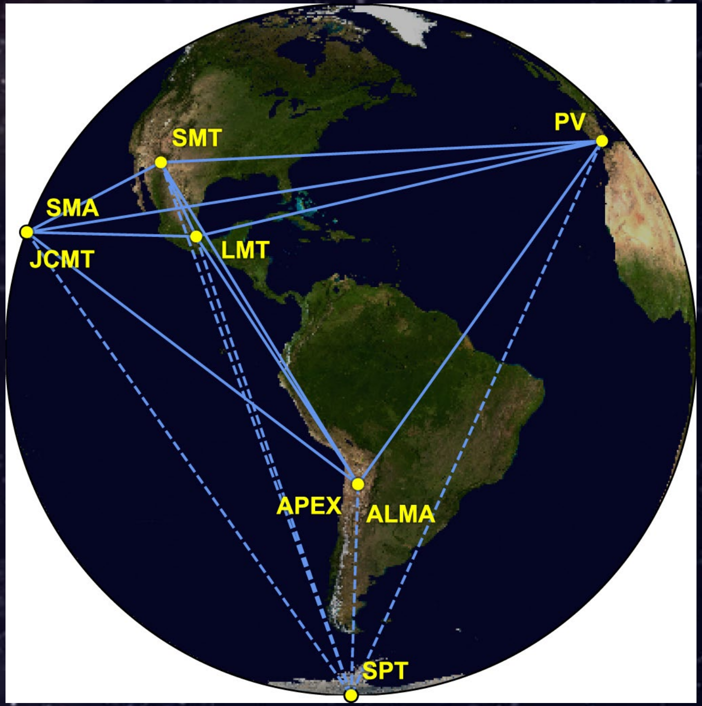


Green et al., 2021

Black Hole Observations
Far-Infrared

Black Holes imaged by the Event Horizon Telescope (EHT)





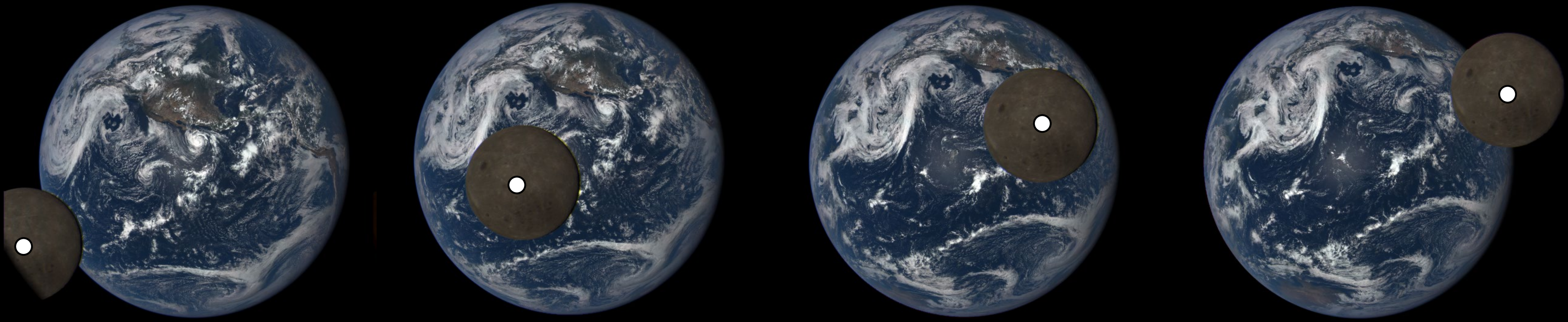
Event Horizon Telescope uses 8 telescopes at 1.3 mm (230 GHz)

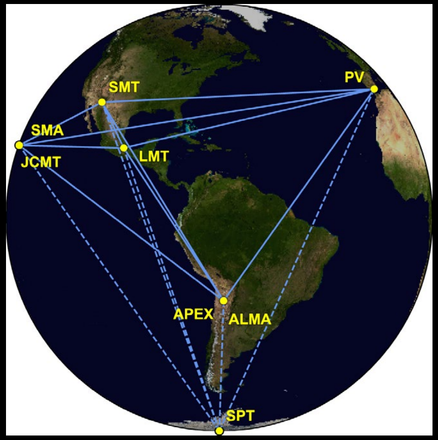
Interferometer at the size of the Earth (for M87 it is less than 1 pixel of HST)

Radio astronomy pioneered interferometry imaging techniques, when the signal from different telescopes at large distances are combined.

The resolving power is determined by the **<u>distance between the telescopes.</u>**

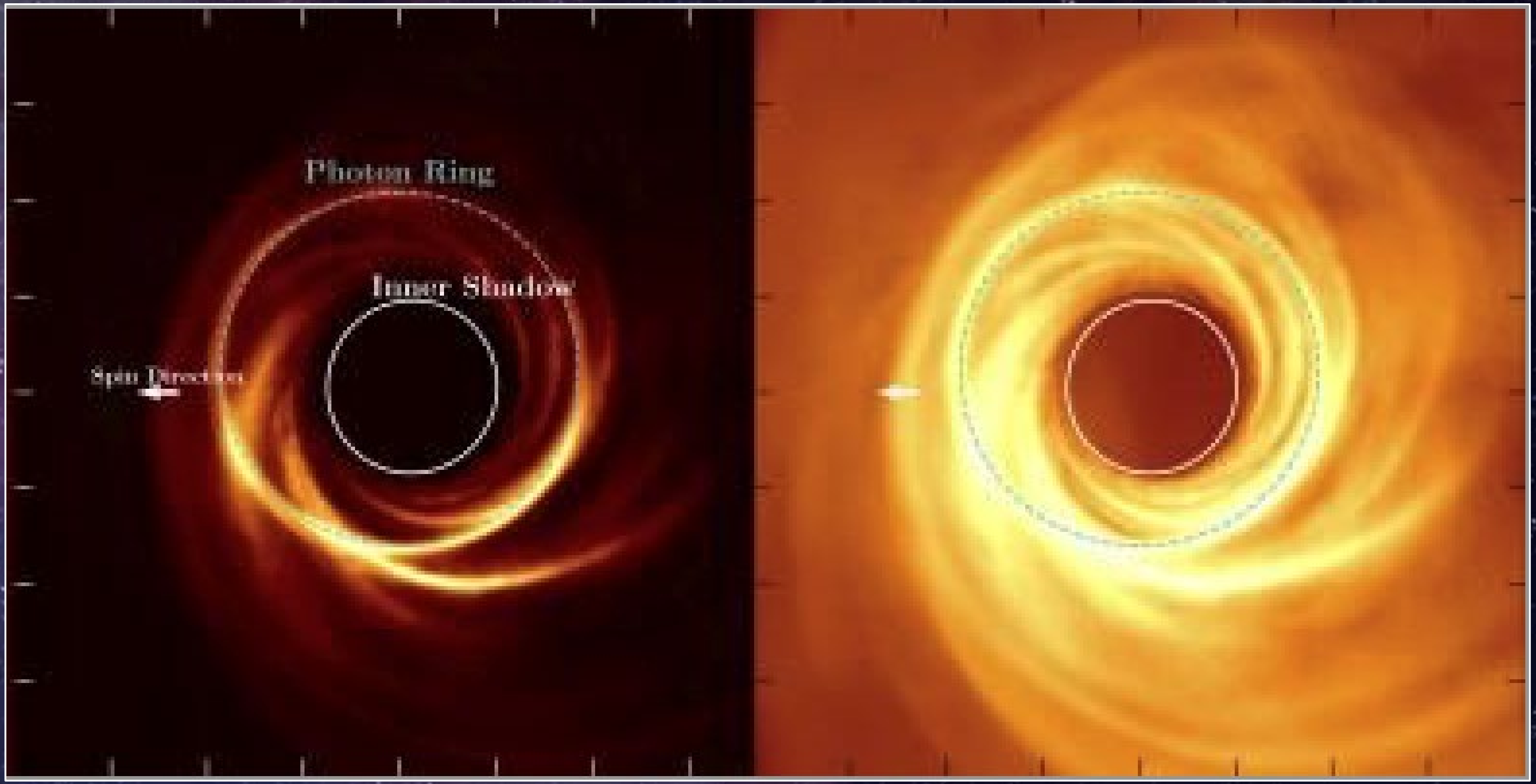
Very-Long Baseline Interferometry (VLBI) Including the Lunar Farside





Slow Moving Lunar Farside Radio Telescope with significant expanded baseline (resolution)

Very-Long Baseline Interferometry (VLBI)



Simulation Images with Larger Baselines

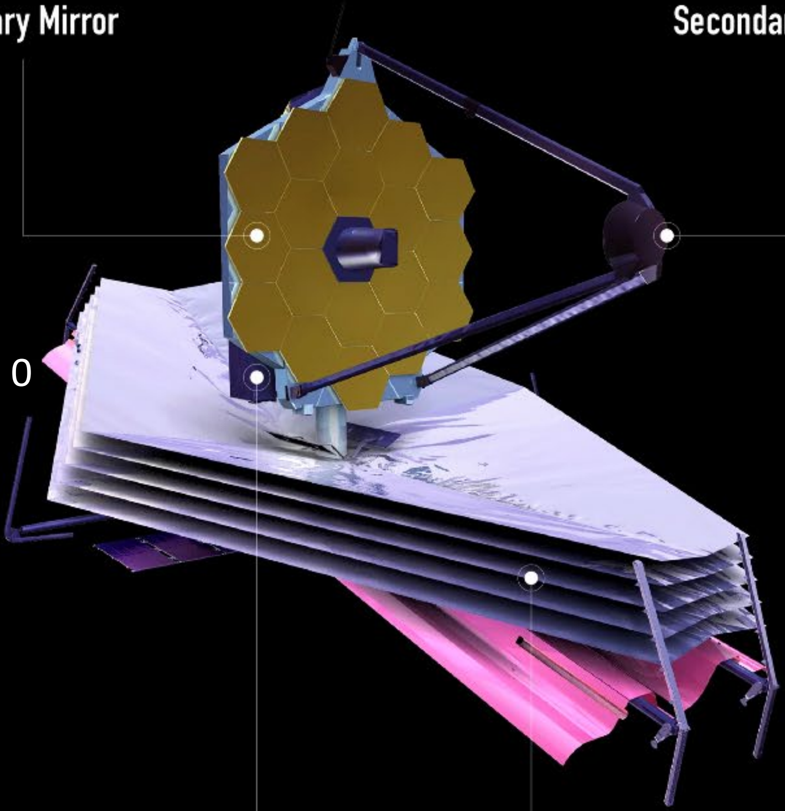
The resolving power is determined by the **distance between the telescopes.**

Infrared Universe

Observing Side

Cold side

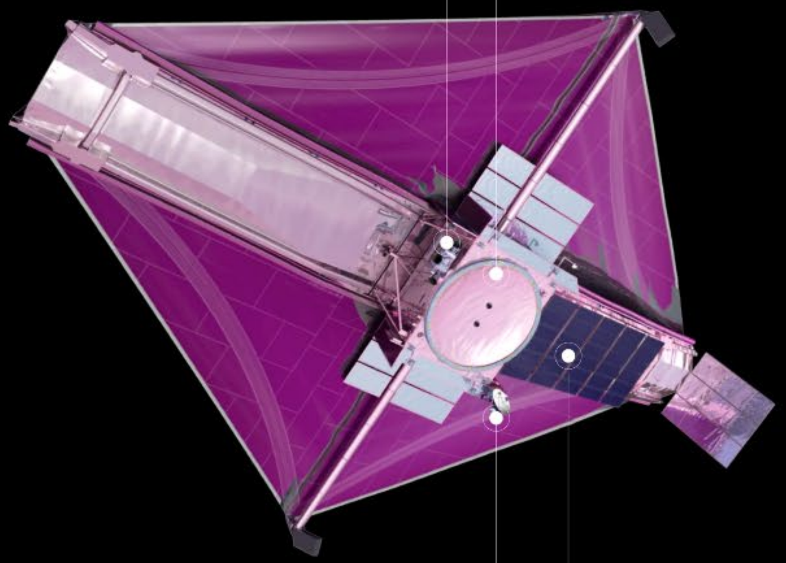
T= -370° F
Then cooled
to -447° F
2° above absolute 0



Sun-Facing Side

Warm side

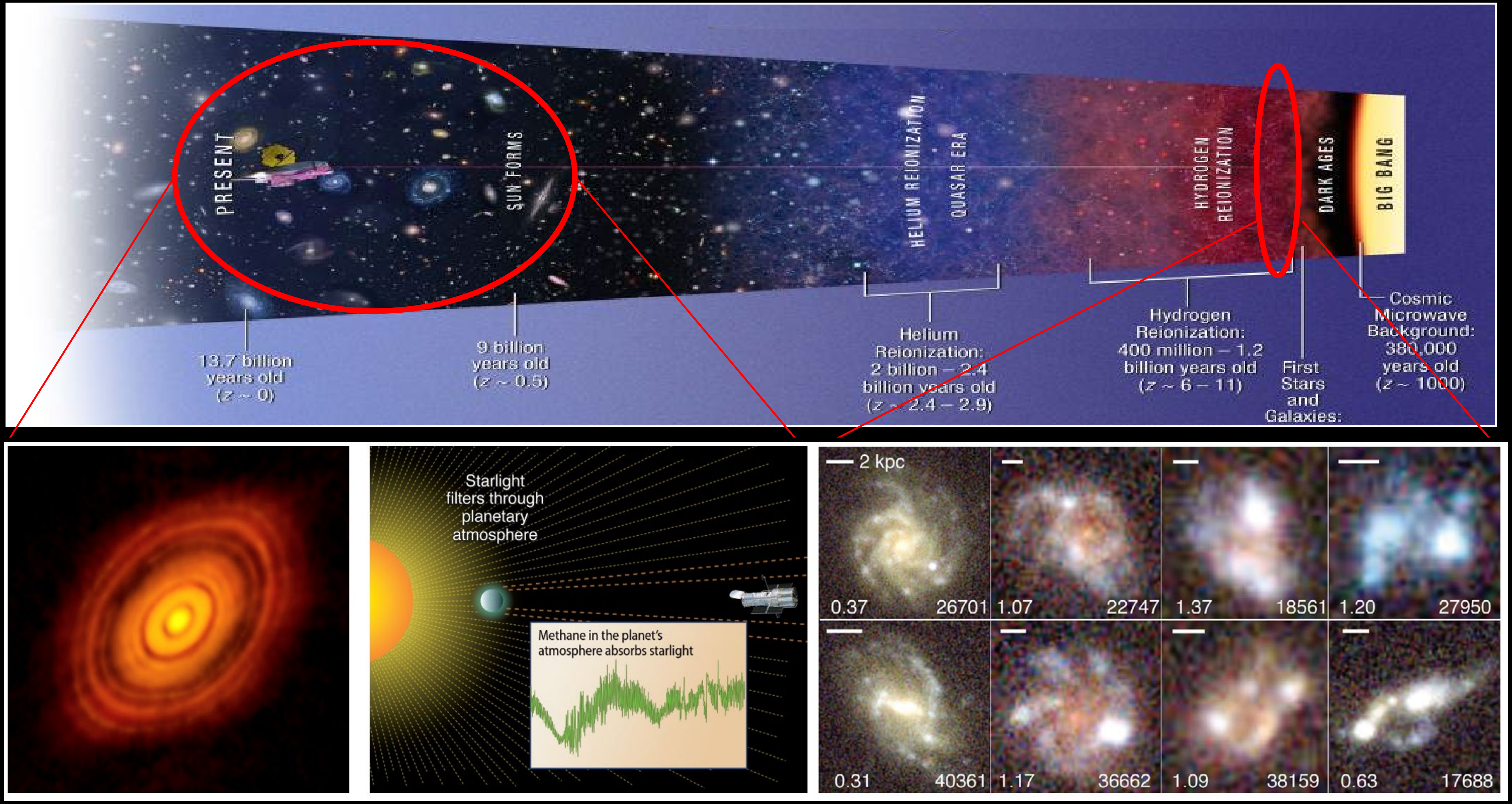
T= 230° F



We are her

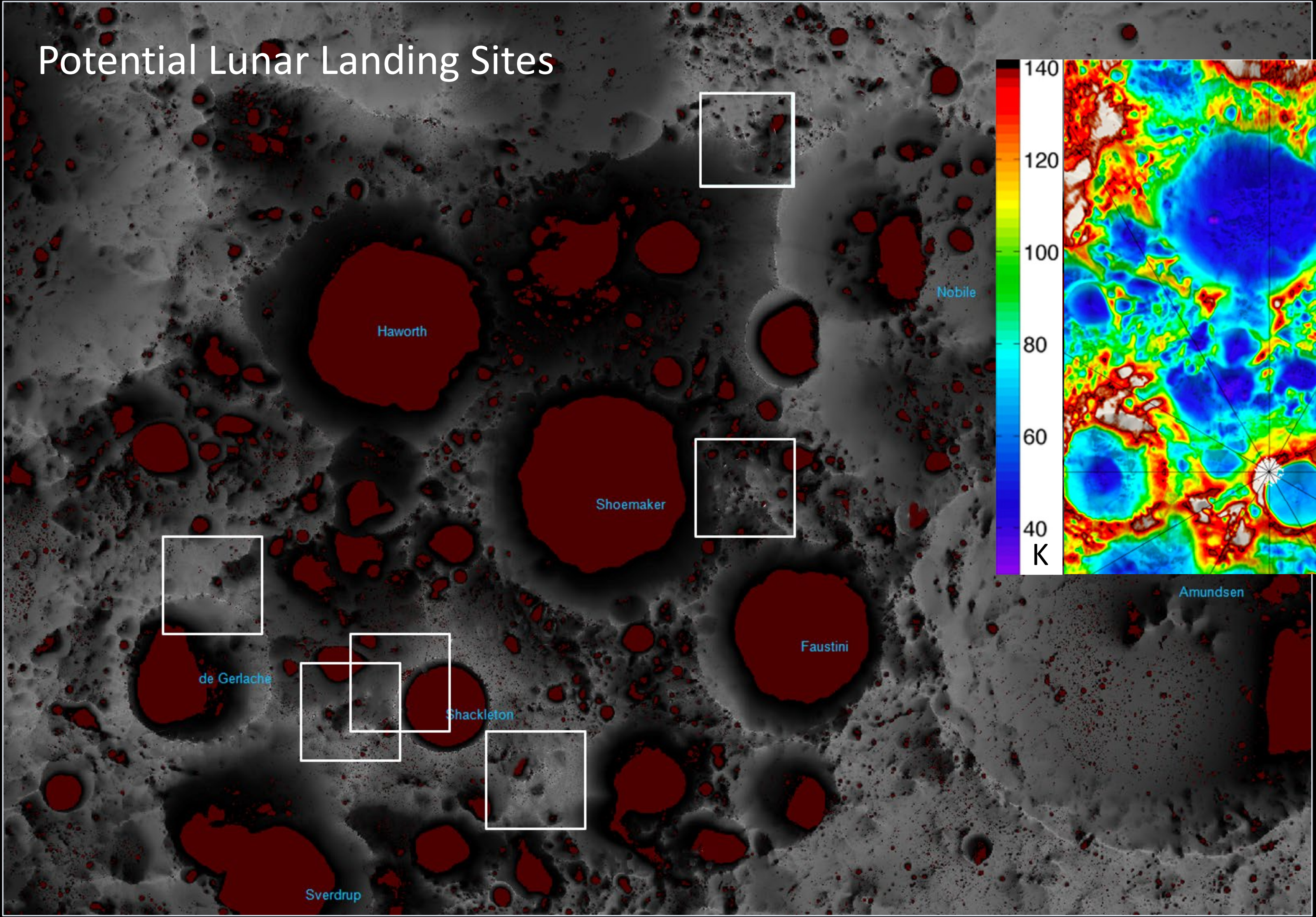
SC Commissioning Launch – L+30 days	Transition	Telescope Commissioning L+40 days to L+118 days	Science Instrument Commissioning L+119 days to L+ 180 days

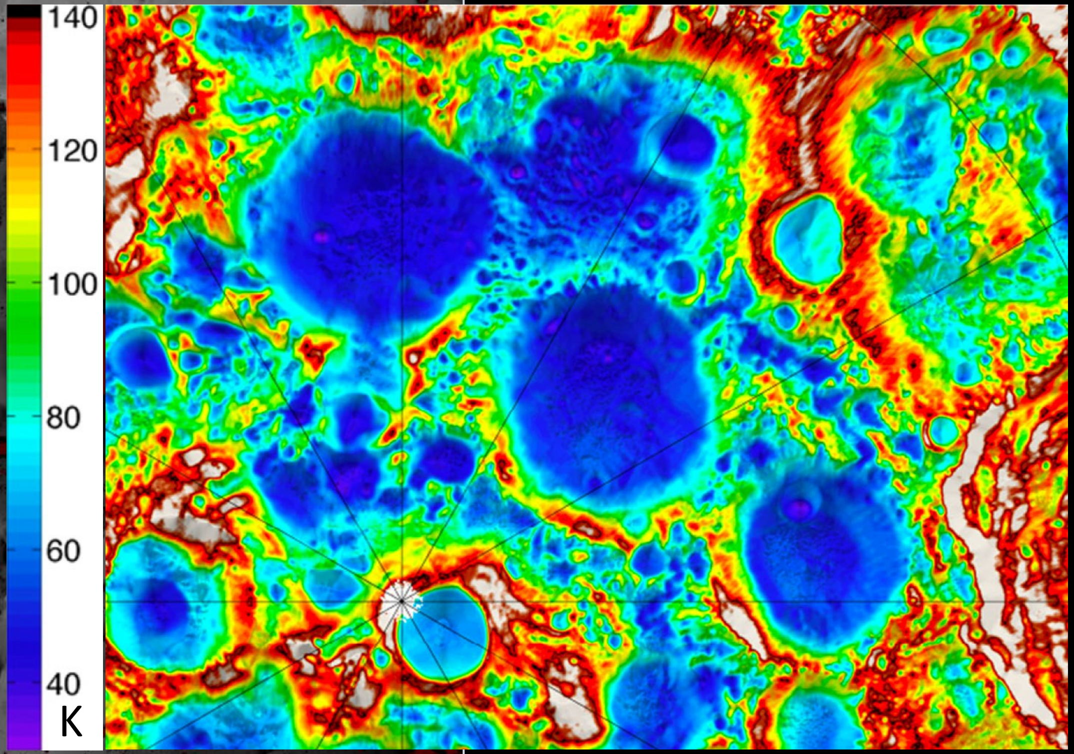
James Webb Space Telescope - Science



Hayne et al., 2015

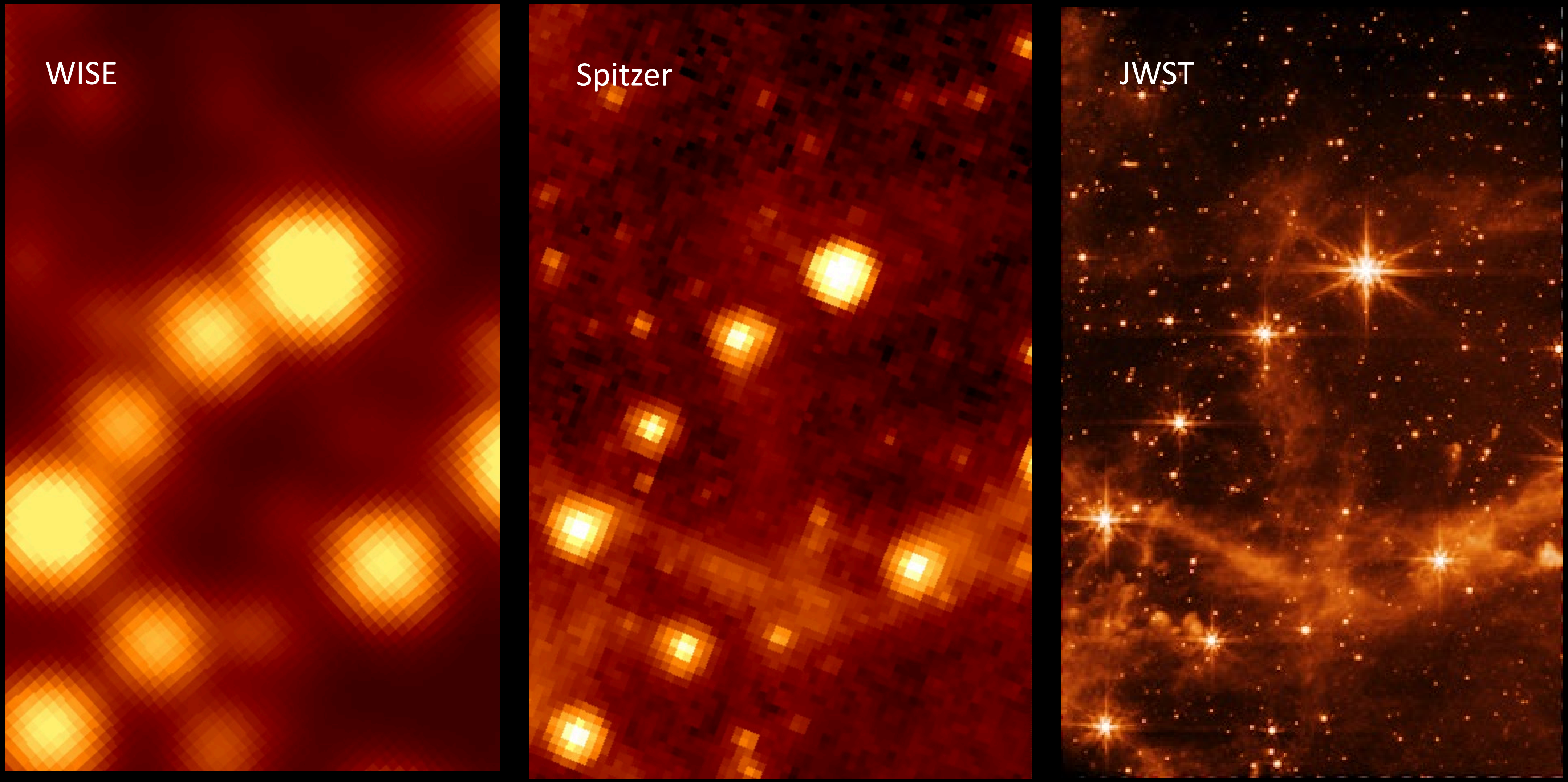
Potential Lunar Landing Sites



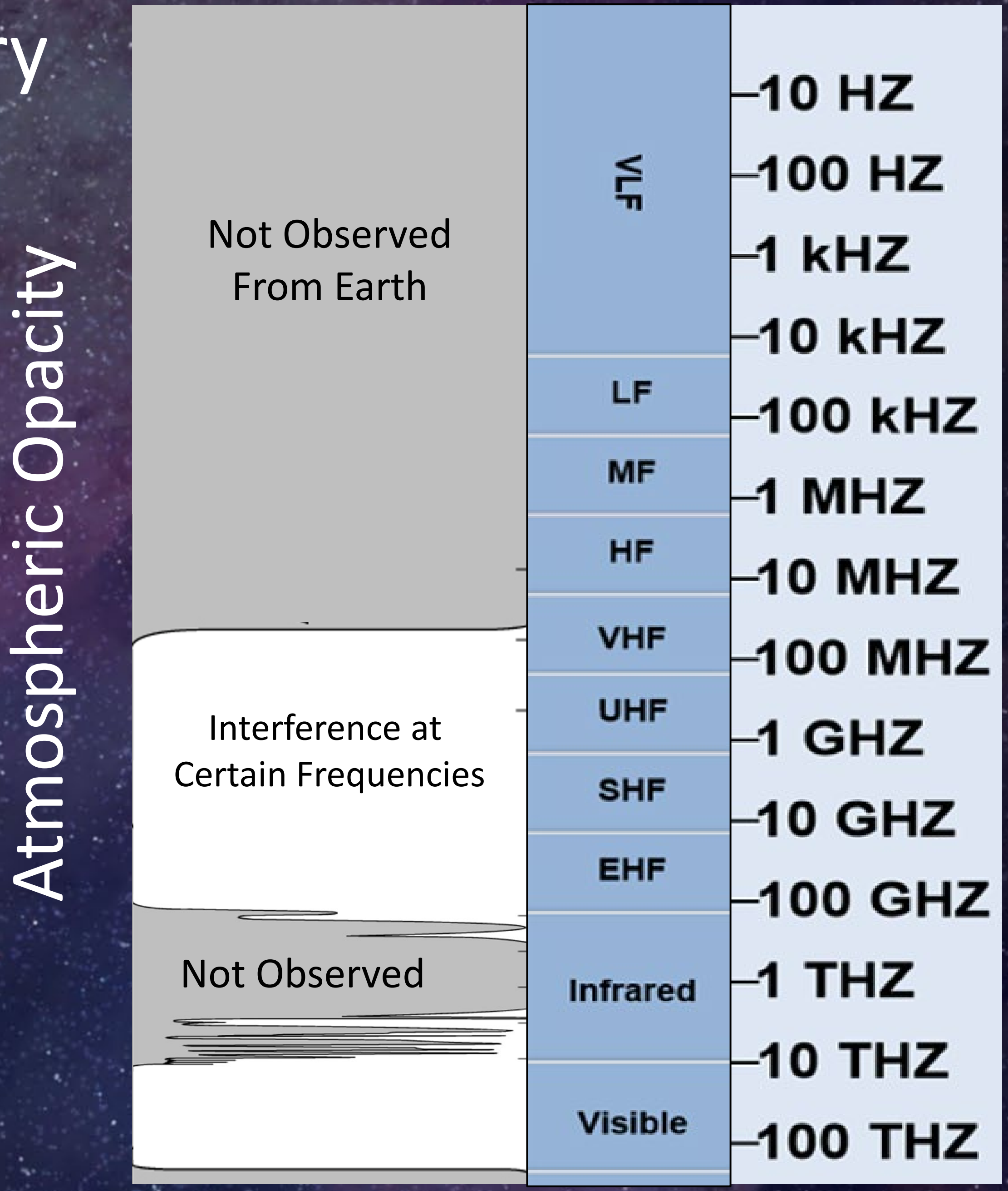


PSRs are very cold, all below the volatility temperature of H_2O (T < 110 K)

Infrared Space Telescopes – Cooling & Aperture



Summary



Science Objectives

Planetary Magnetospheres – plasma waves

Planetary Magnetospheres – Aurora Radio

Stellar Radio Emissions

Early Stage of Star Formation (non-thermal)

Cosmic Dawn and the Dark Ages

Planetary Magnetospheres – Radiation Belts

Solar activity monitor (maps to EUV region)

Fast Radio Bursts (neutron star, black hole …?)

Imaging Black Holes

Star formation (thermal radiation)

Active Galactic Nuclei emissions

QUESTIONS?


SCIENCE
HUMAN EXPLORATION AND OPERATIONS
SPACE TECHNOLOGY