Jet Propulsion Laboratory
California Institute of Technology

Show Me the Planets!
NASA's Search for Exoplanets and for Life in our Galaxy

Dr. Gary H. Blackwood
Manager, NASA Exoplanet Exploration Program
Jet Propulsion Laboratory
California Institute of Technology

February 2, 2019
The Queen's Space Conference
Queens University, Kingston, Ontario

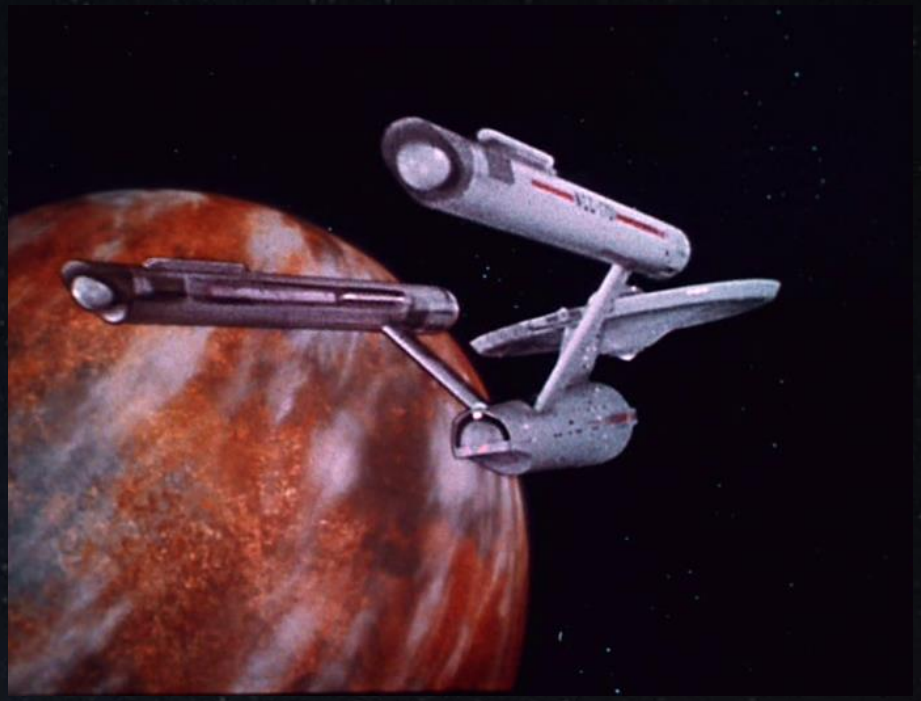
Artist concept of Kepler-16b


There Are More Planets than Stars
“And on those other worlds,
are there beings
who wonder as we do?”
- Carl Sagan

ex·o·plan·et

[ˈeksōˌplanət]

a planet which orbits a star outside our solar system



NASA Highlights

Show ~~Me~~ You the ^ Exo Planets!

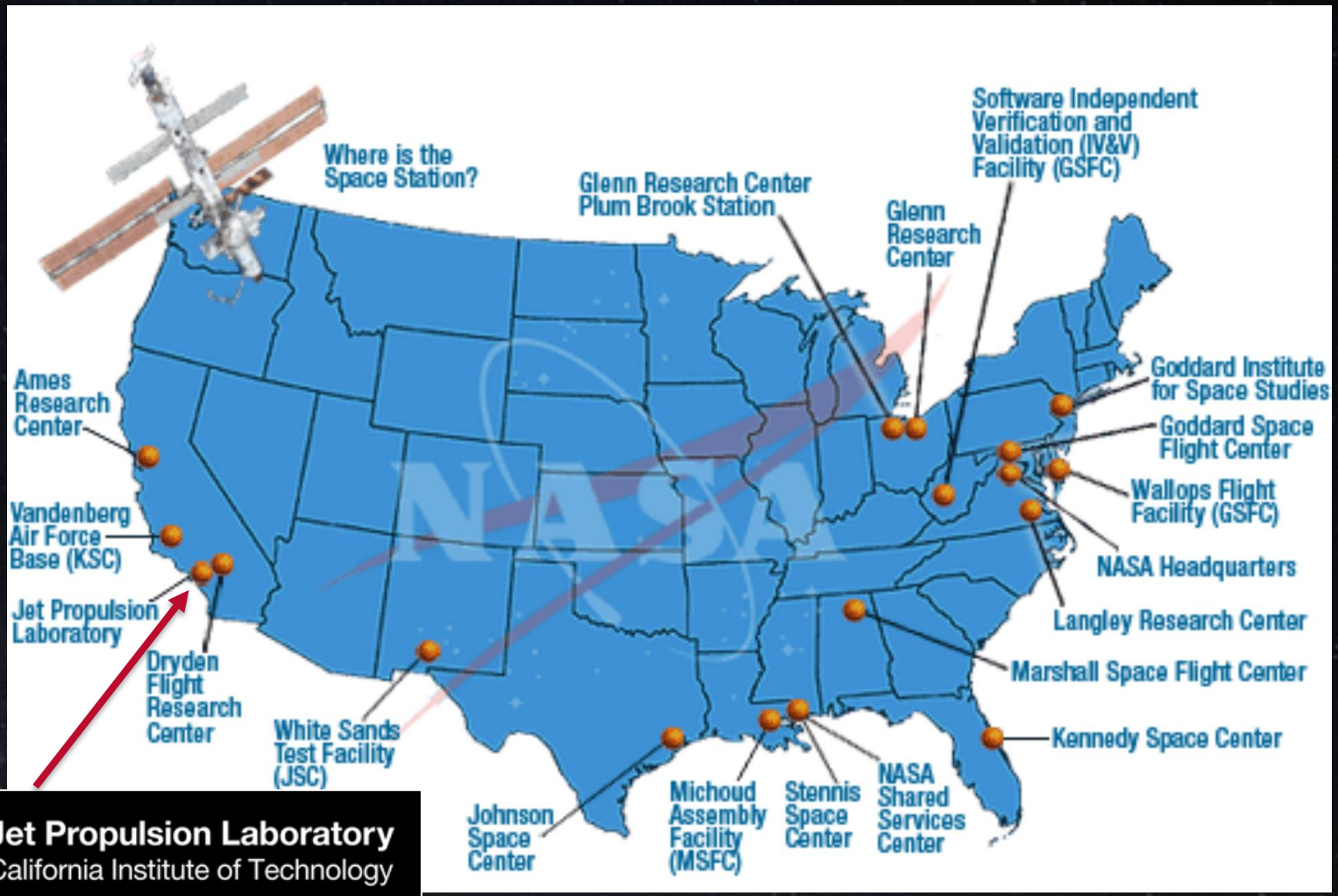
Search for Life in our Galaxy

Explore!

On the Brink of a New World: Outer Space!

NASA Highlights

Where's NASA?



Jet Propulsion Laboratory
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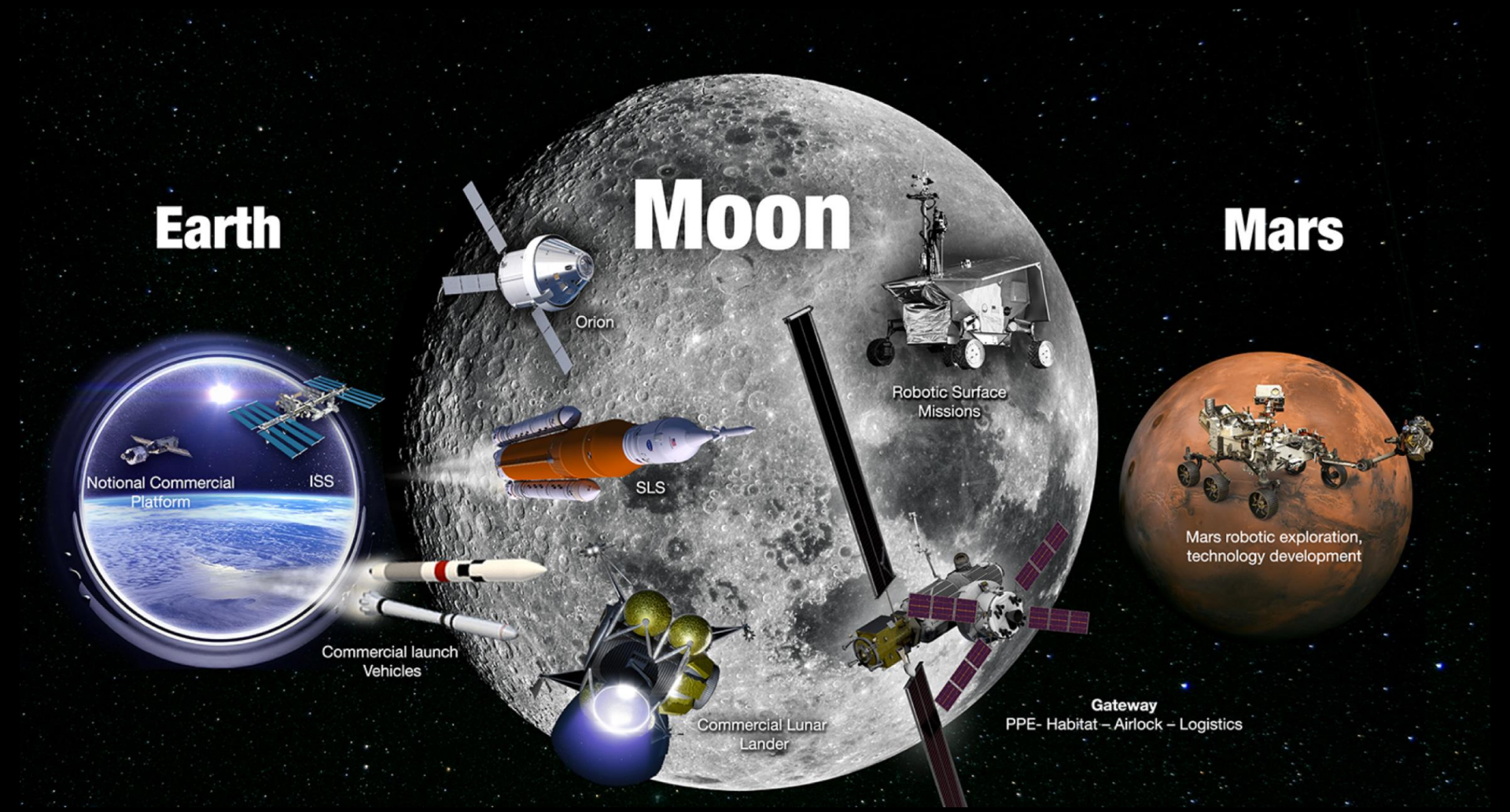
Caltech

How is NASA Organized?

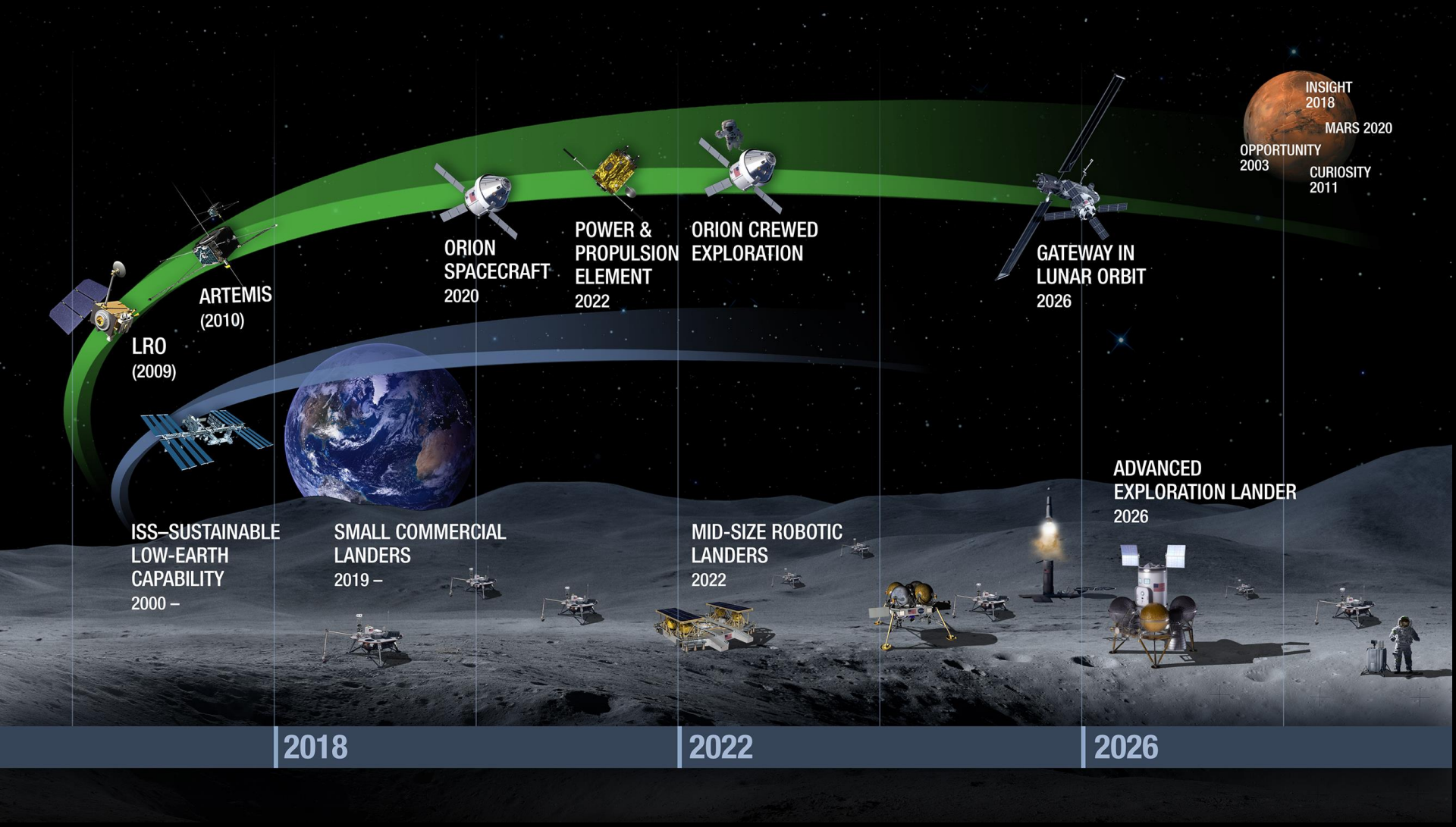
Mission Directorates:

- Human Exploration and Operations
- Science
- Space Technology
- Aeronautics Research

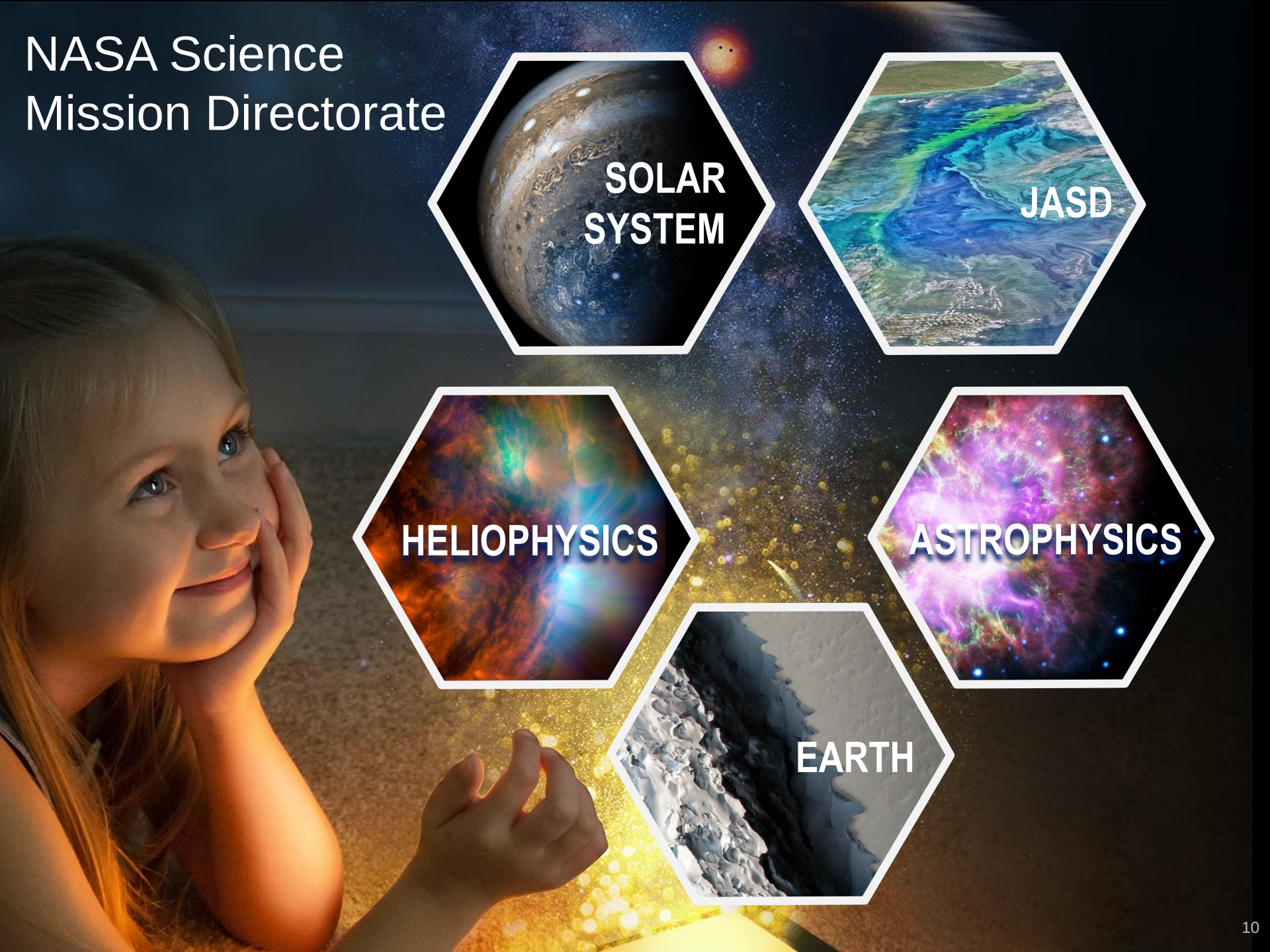
Moon to Mars


Earth
Moon
Mars
Orion
Robotic Surface Missions
Notional Commercial Platform
ISS
SLS
Mars robotic exploration, technology development
Commercial launch Vehicles
Commercial Lunar Lander
Gateway
PPE- Habitat – Airlock – Logistics

NASA Exploration Campaign



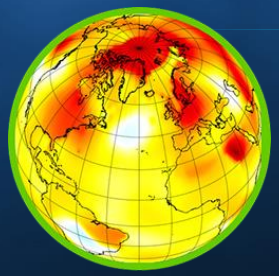
NASA Science Mission Directorate



NASA Key Science Themes

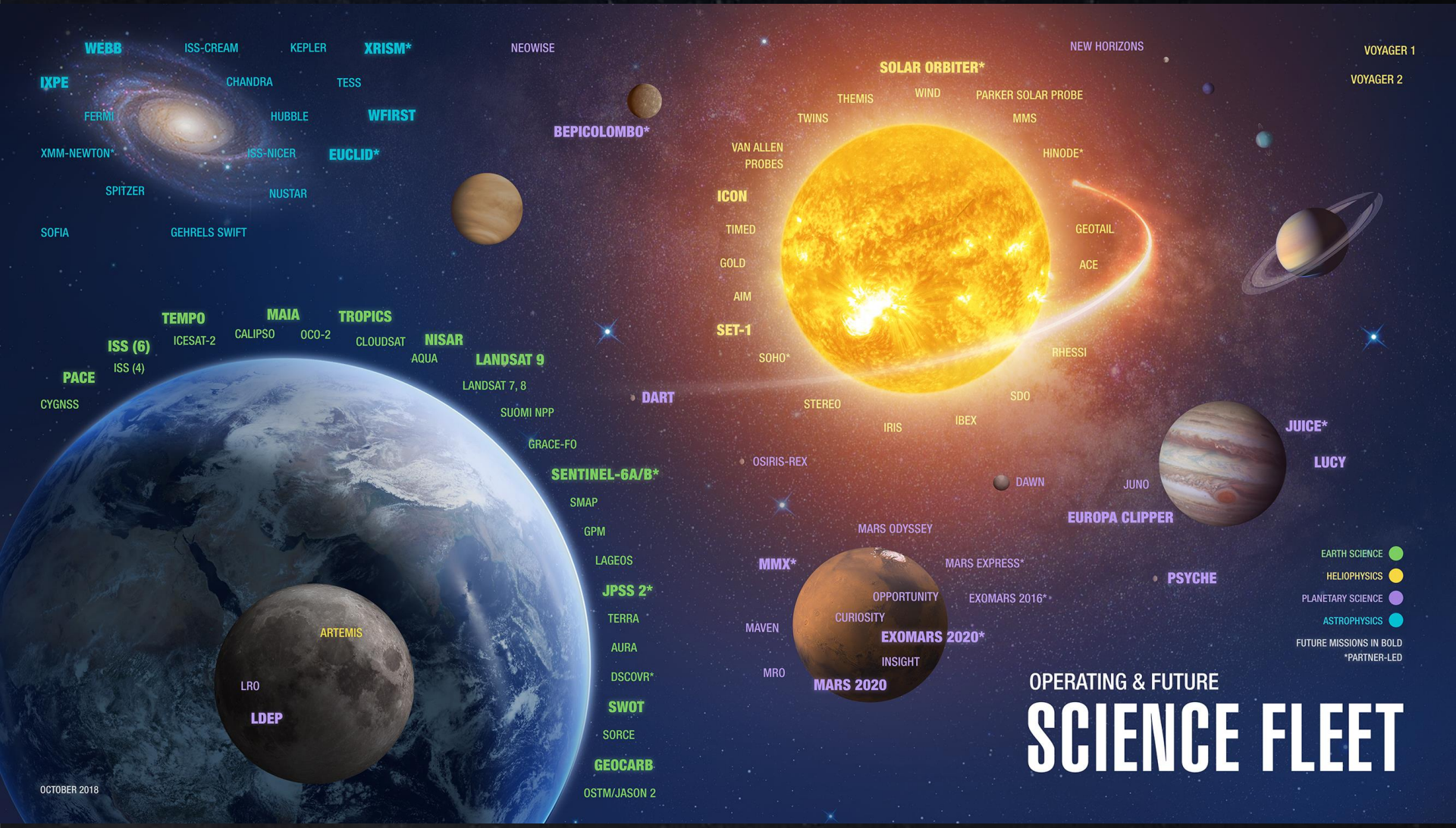
Discovering the Secrets of the Universe

Searching for Life Elsewhere



Safeguarding and Improving Life on Earth

NASA Science Fleet



Science Mission Directorate

Science by the NUMBERS

TECHNOLOGY INNOVATION
~$400M Invested Annually

RESEARCH
~10,000 U.S. Scientists Funded
~3,000 Competitively Selected Awards
~$600M Awarded Annually

SPACECRAFT
105 Missions
85 Spacecraft

SMALLSATS/CUBESATS
31 Science Missions
24 Technology Demos

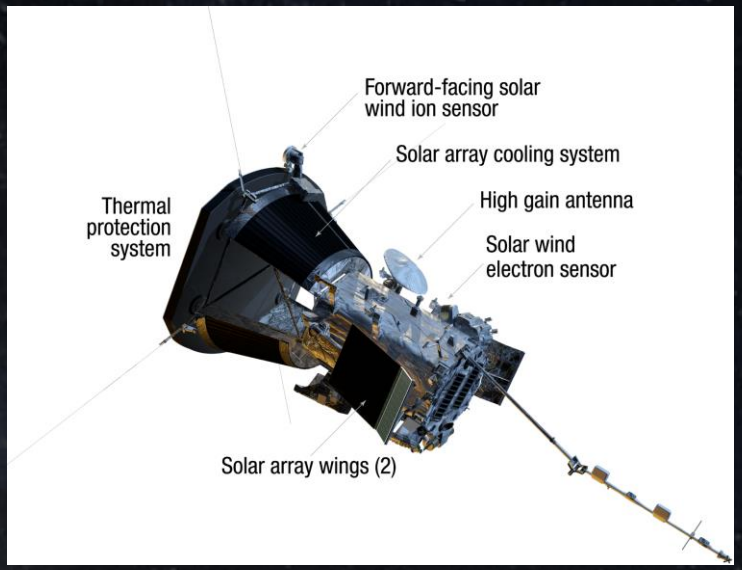
SOUNDING ROCKETS
16 Science Missions
3 Tech/Student Missions

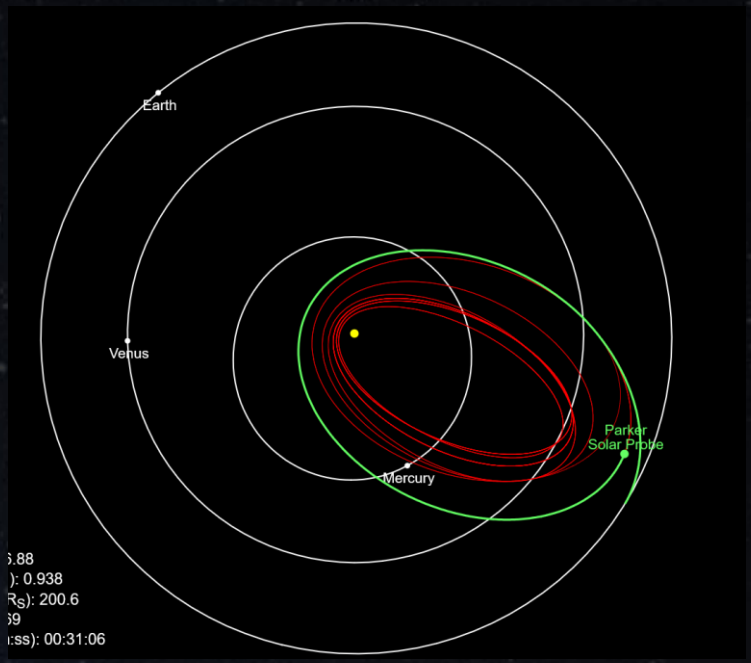
EARTH-BASED INVESTIGATIONS
25 Major Airborne Missions
8 Global Networks

BALLOONS
13 Science Payloads
1 HASP with up to
12 student experiments

Parker Solar Probe

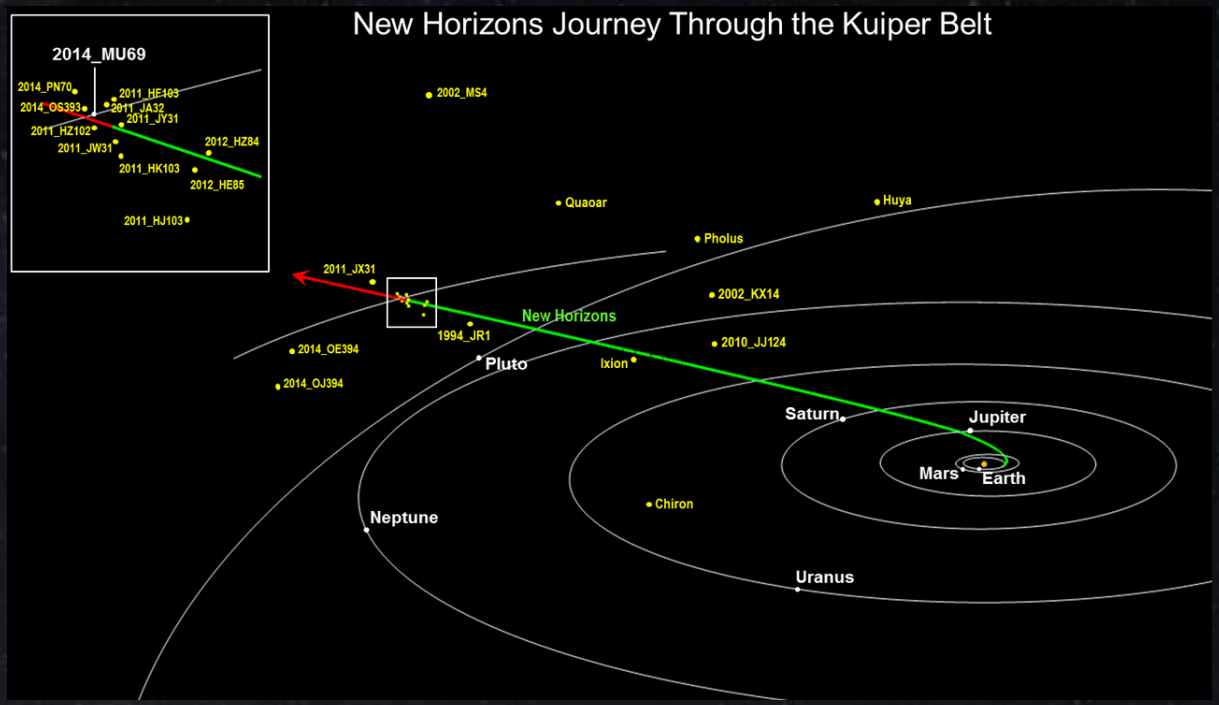
A NASA Mission to Touch the Sun

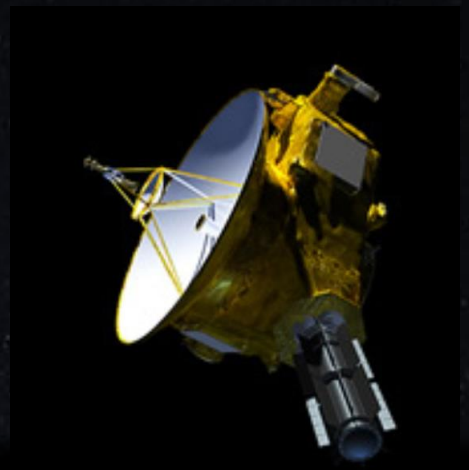


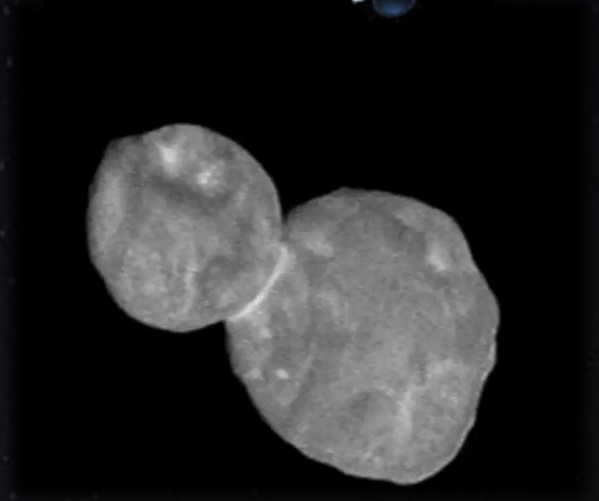


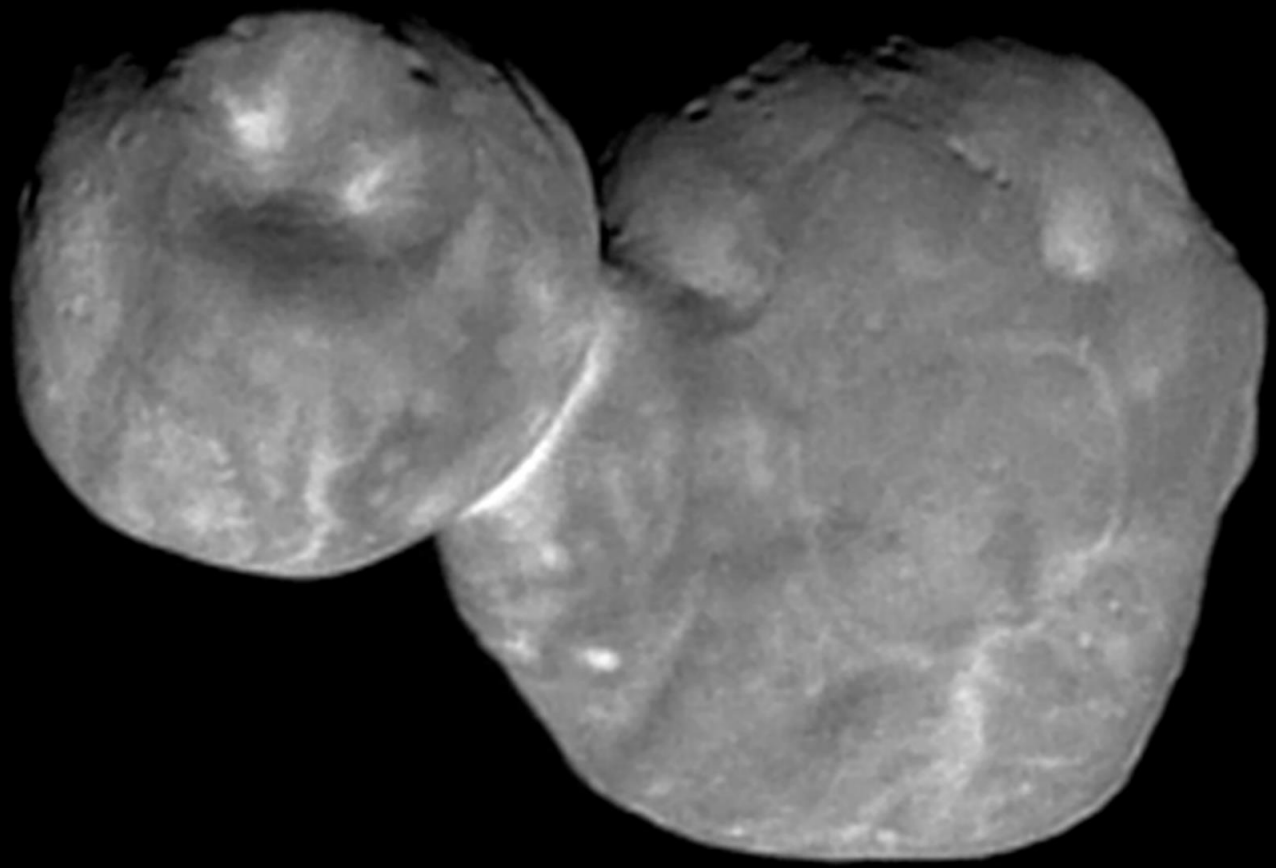
New Horizons at Ultima Thule (2014 MU69)

"Beyond the Borders of the Known World"



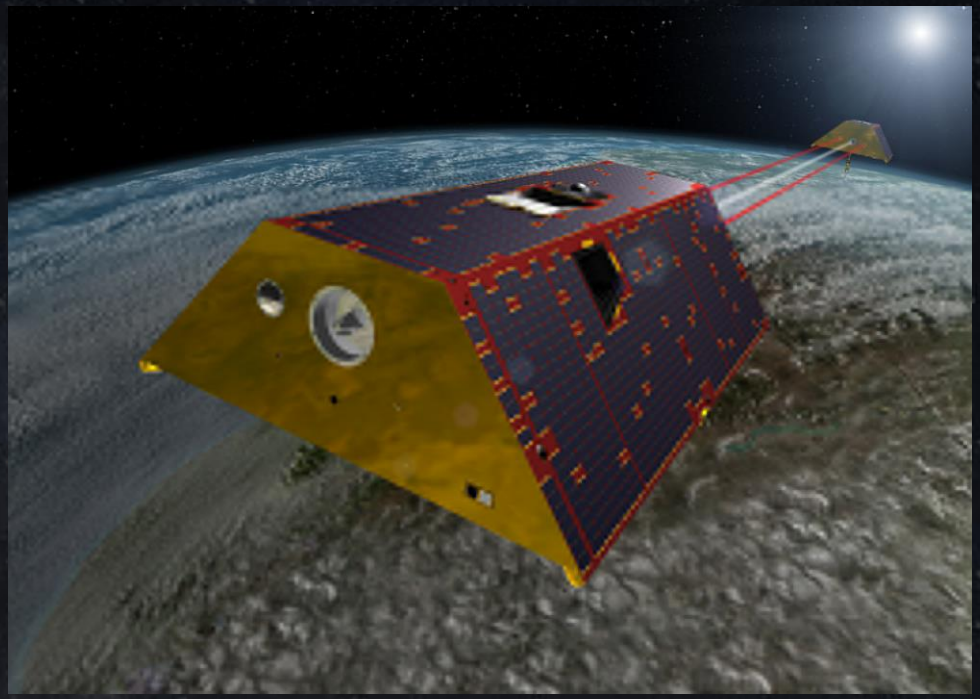






GRACE Follow-On

Tracking Earth's Water Movement across the Whole Planet

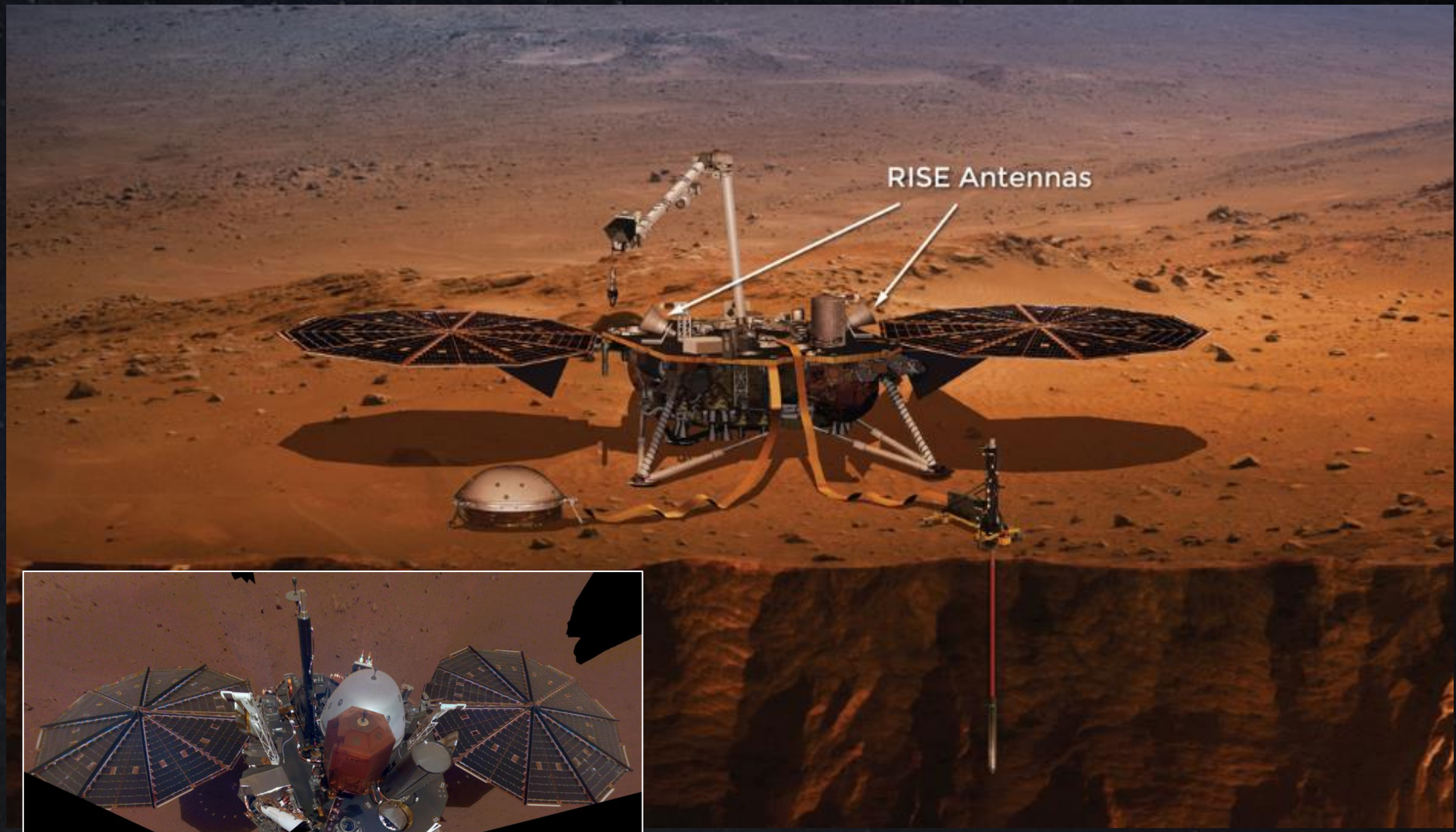


GRACE Data 2002–2017

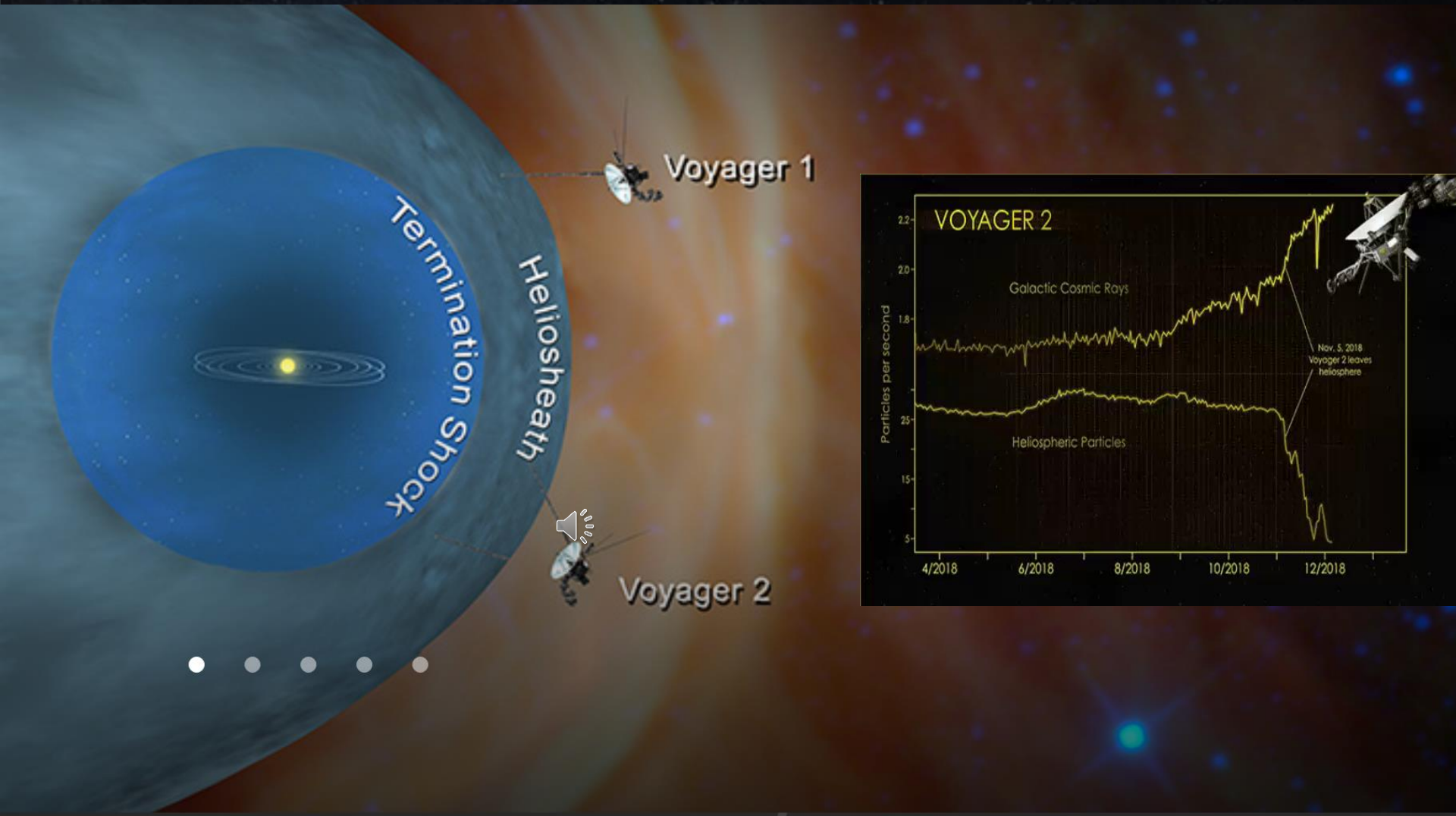
give the Red Planet its first thorough checkup since it formed 4 billion years ago

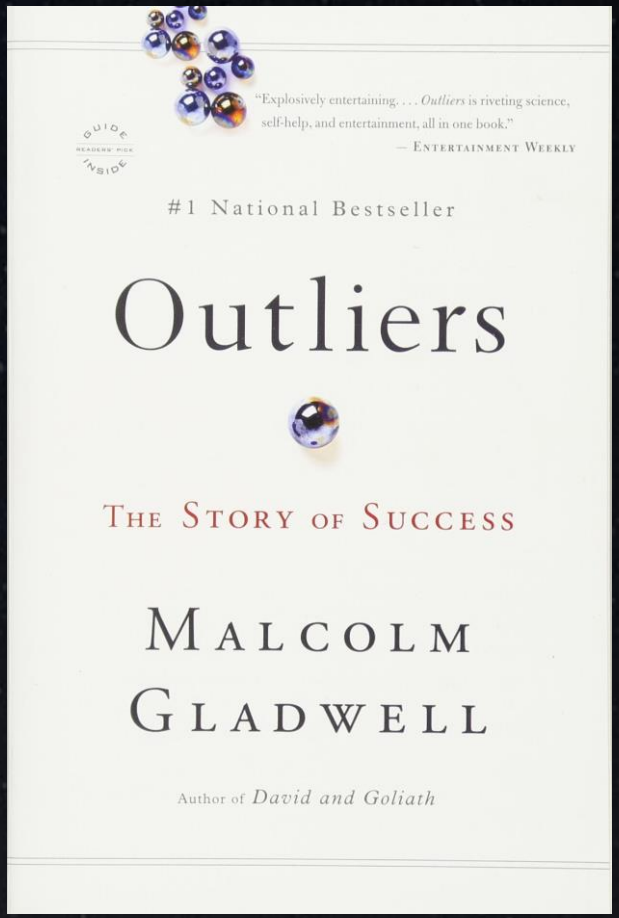
InSight Landing on Mars

November 2018

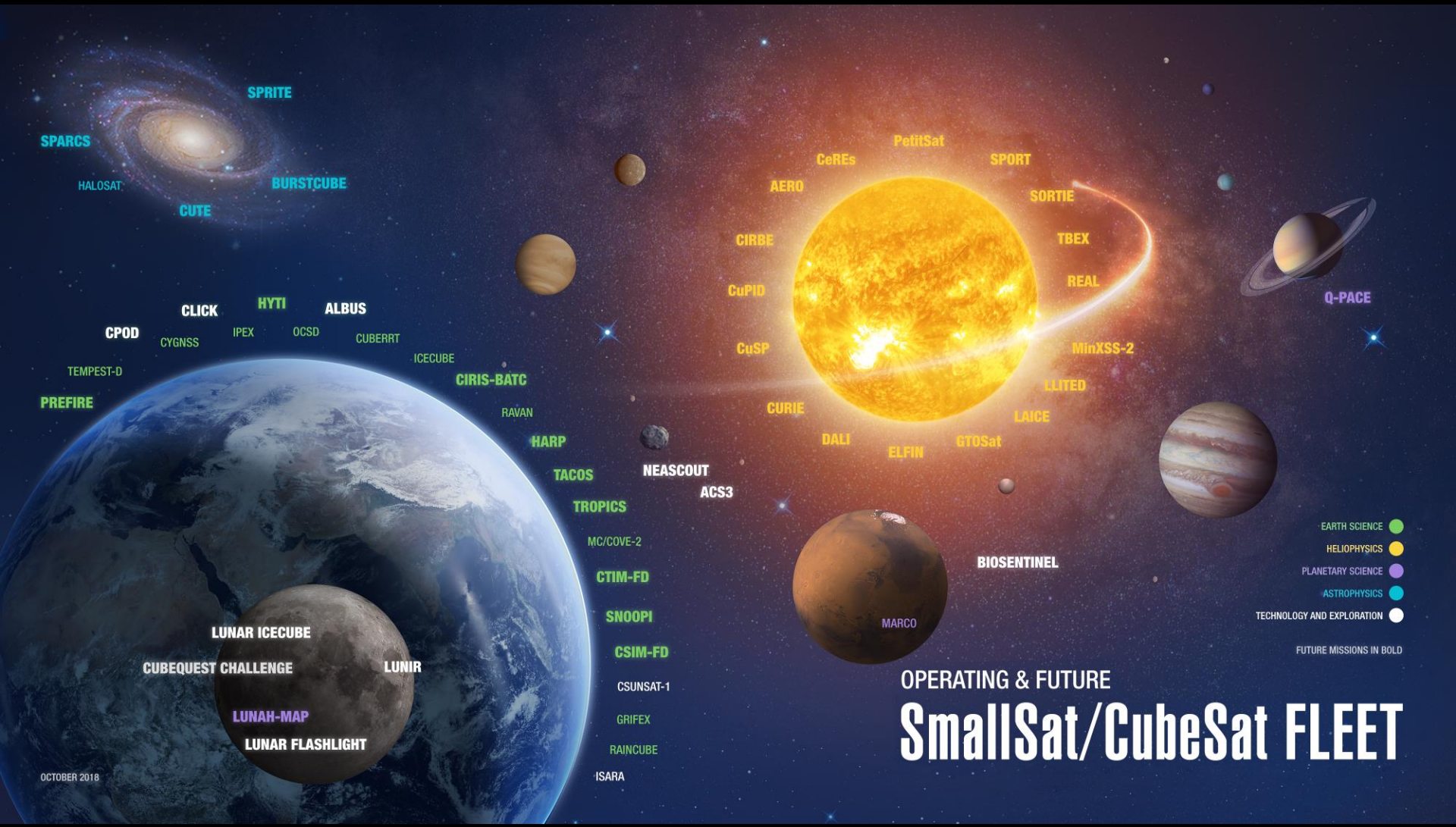


Voyager 2 Enters Interstellar Space

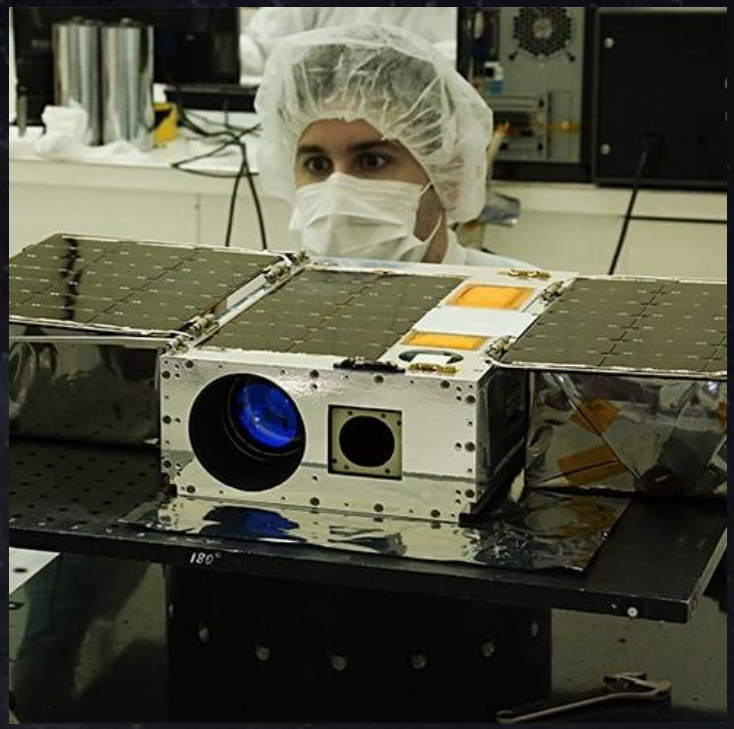



"Explosively entertaining. . . . Outliers is riveting science, self-help, and entertainment, all in one book."
— Entertainment Weekly
#1 National Bestseller
Outliers
The Story of Success
Malcolm Gladwell
Author of David and Goliath

SmallSat / CubeSat Fleet

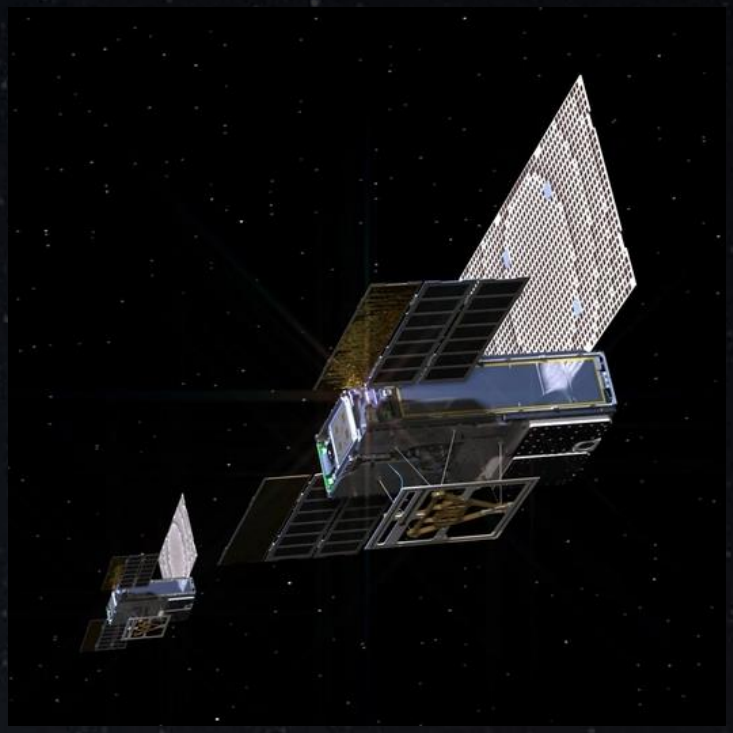


Two Recent Cube Sats



ASTERIA

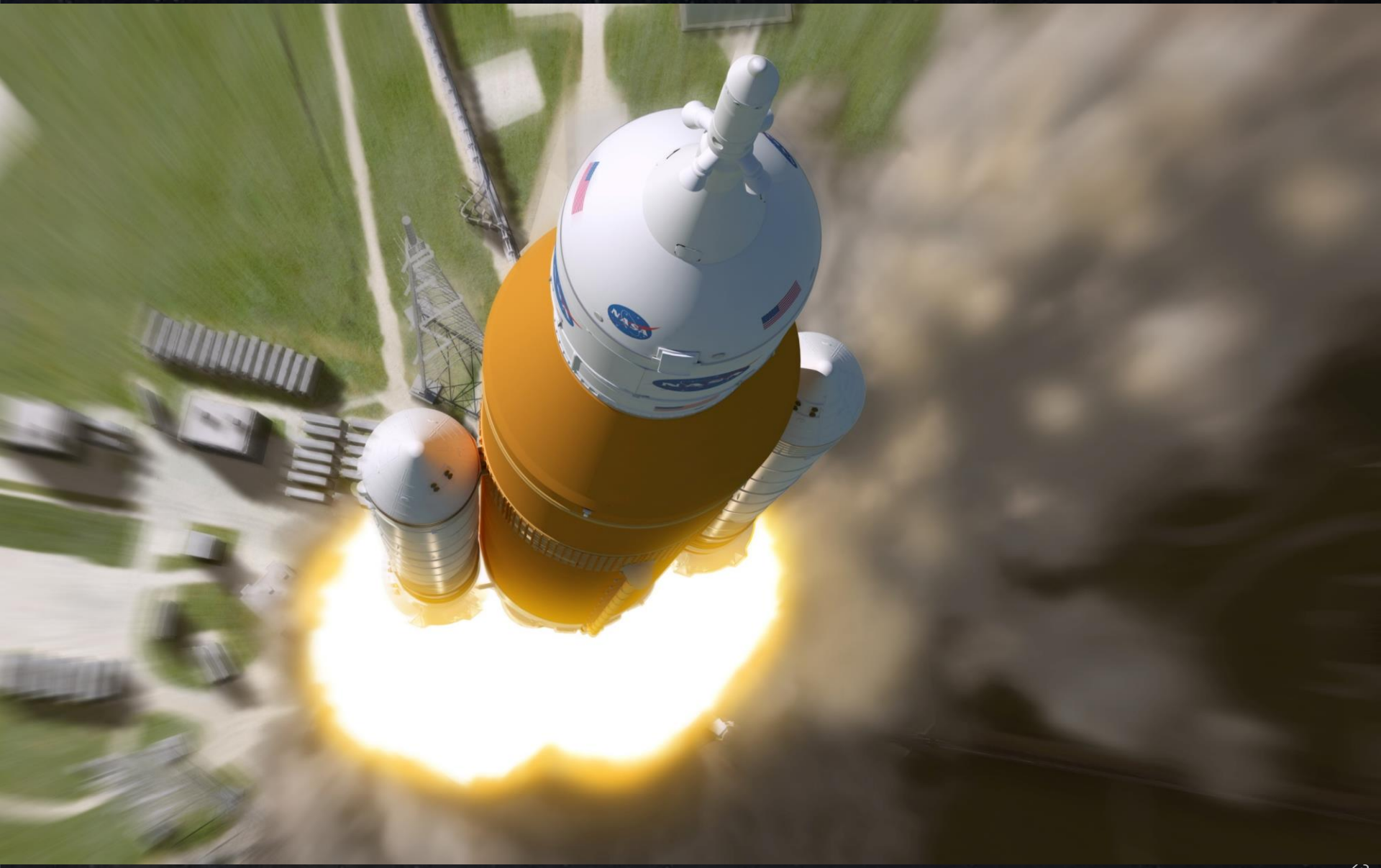
Arcsecond Space Telescope



MarCO

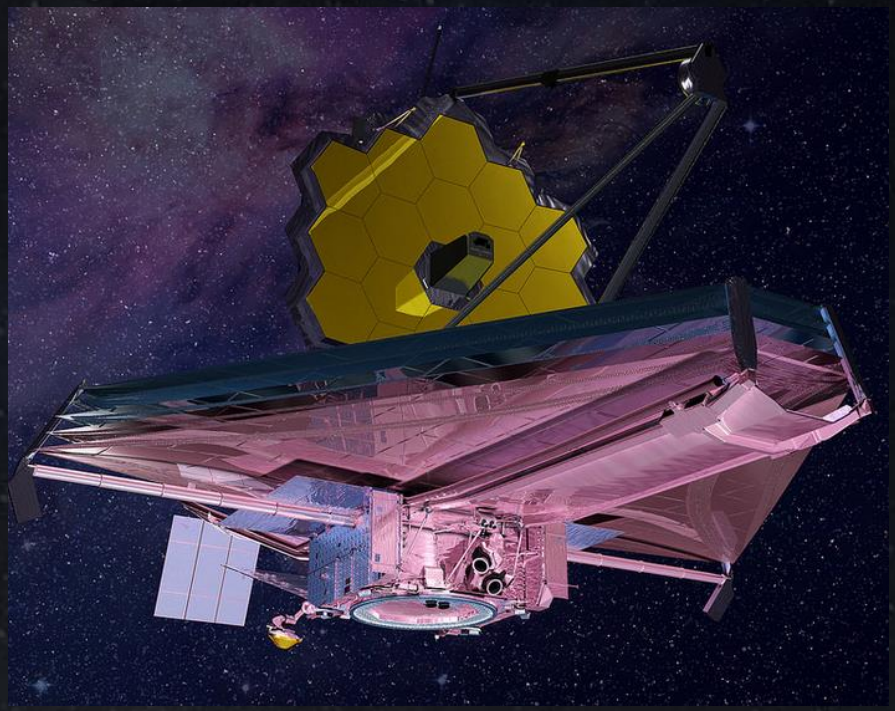
Mars Cube One

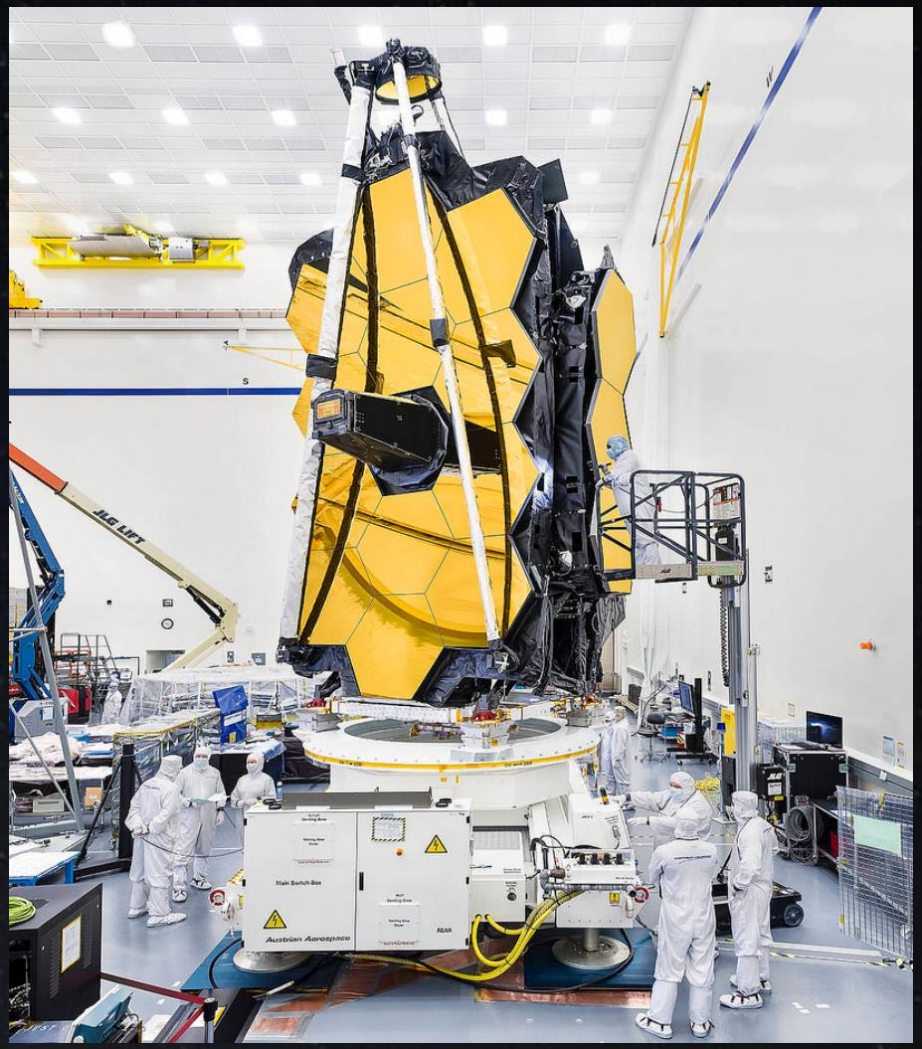
Space Launch System



James Webb Space Telescope

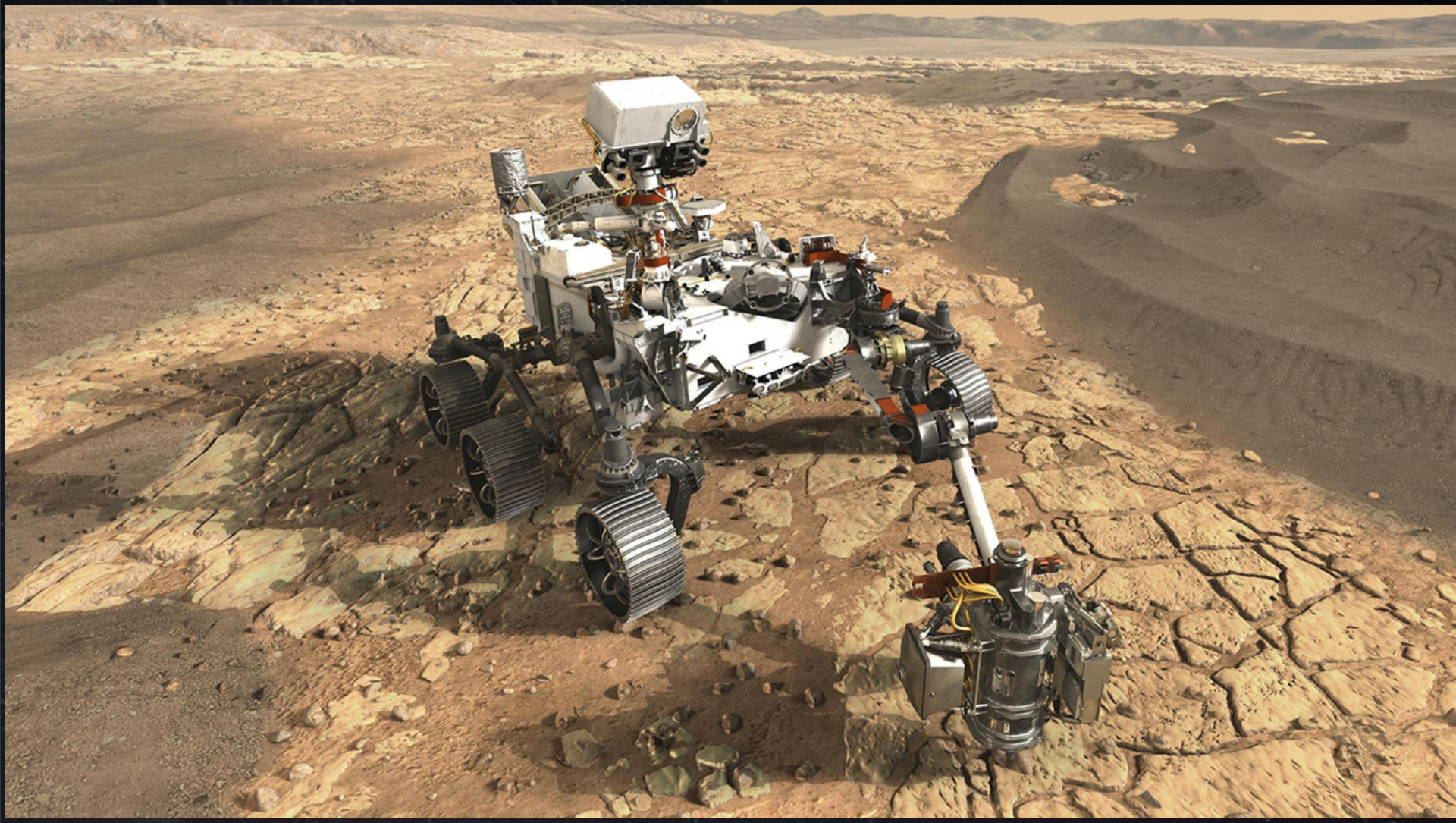
2021 Launch





Mars 2020

July 2020 Launch



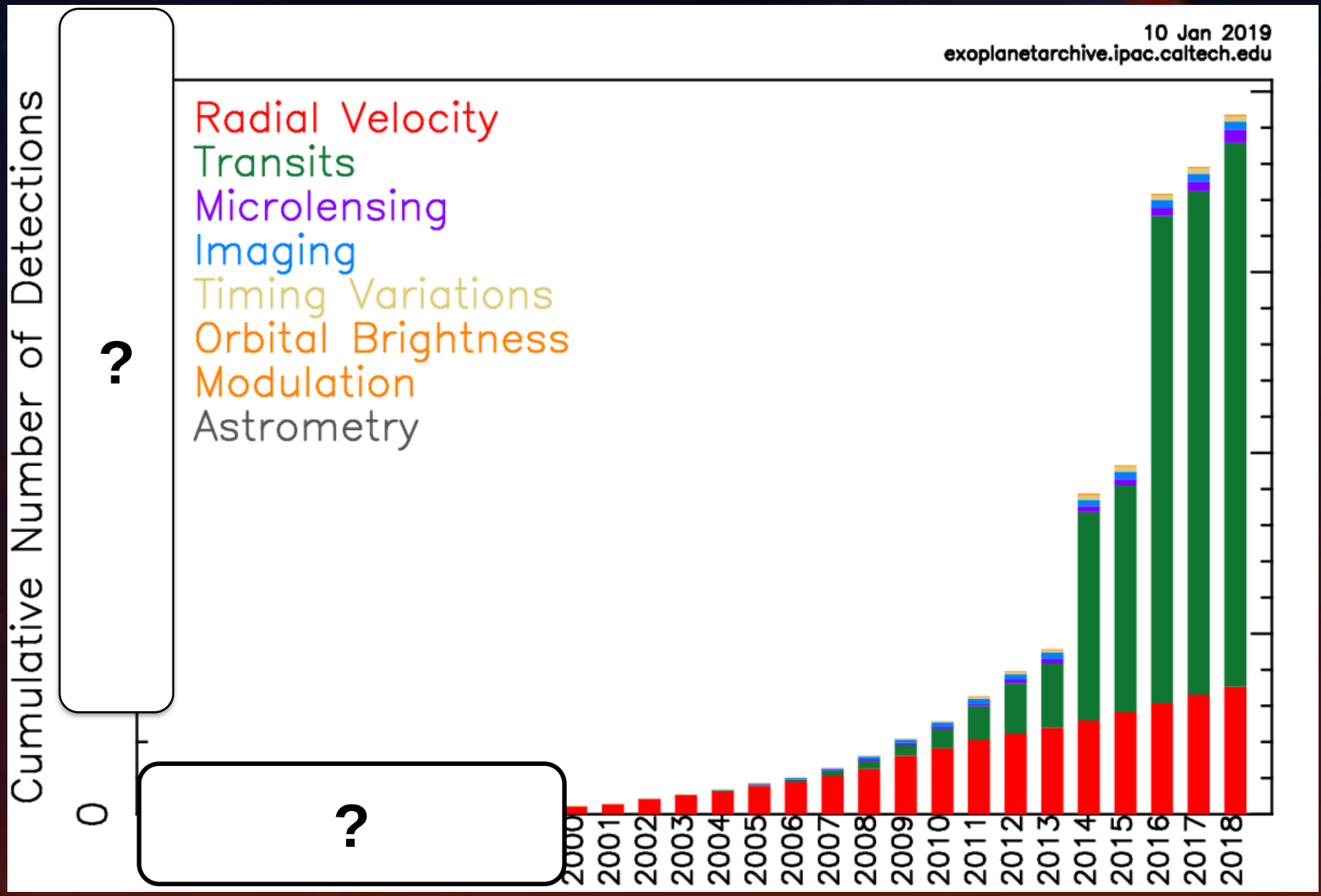
Jet Propulsion Laboratory

Pasadena, California

Show Me the Planets!

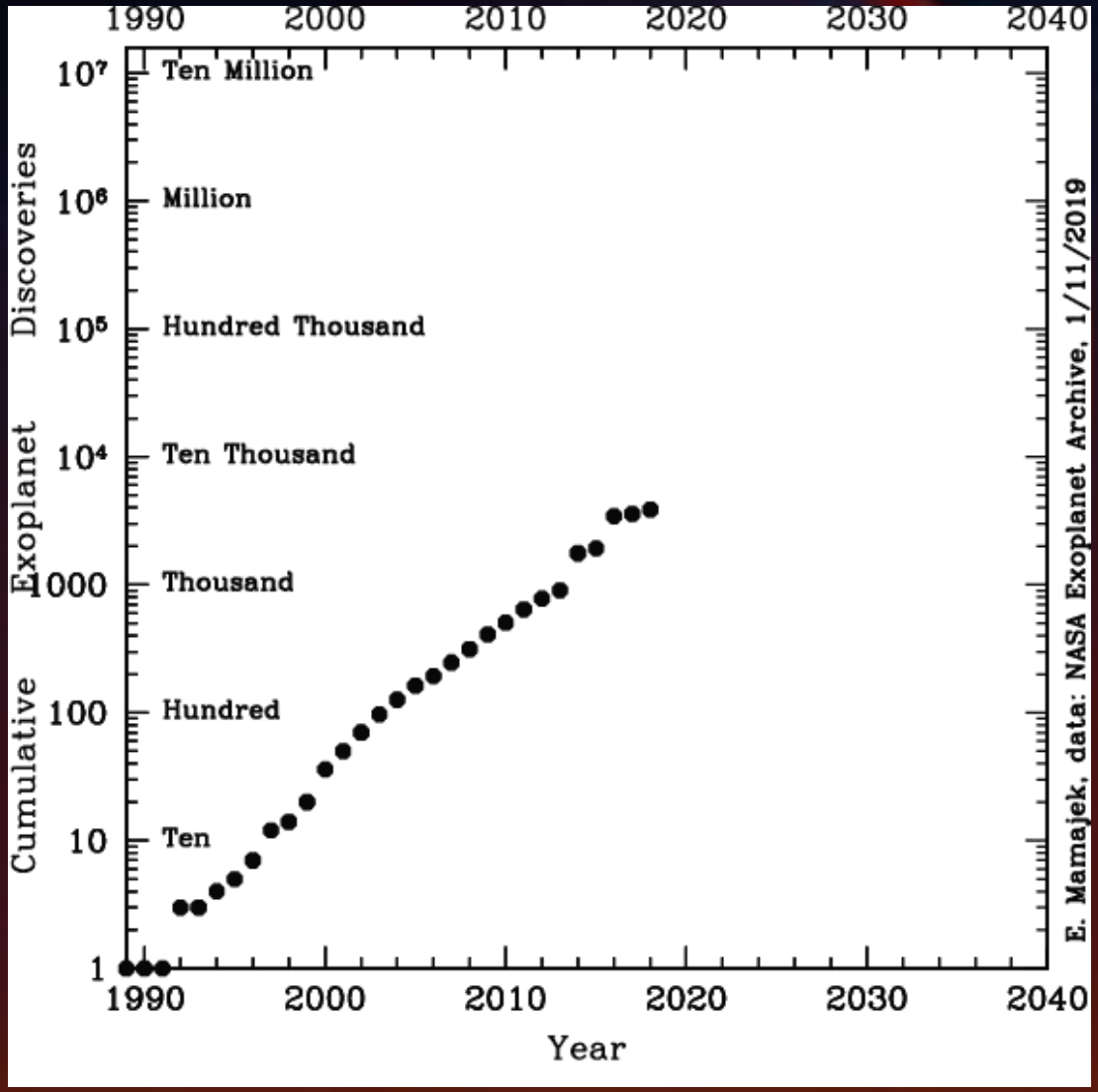
The Early Exoplanet Explorers

How Many Exoplanets Are Confirmed?



Mamajek's Law

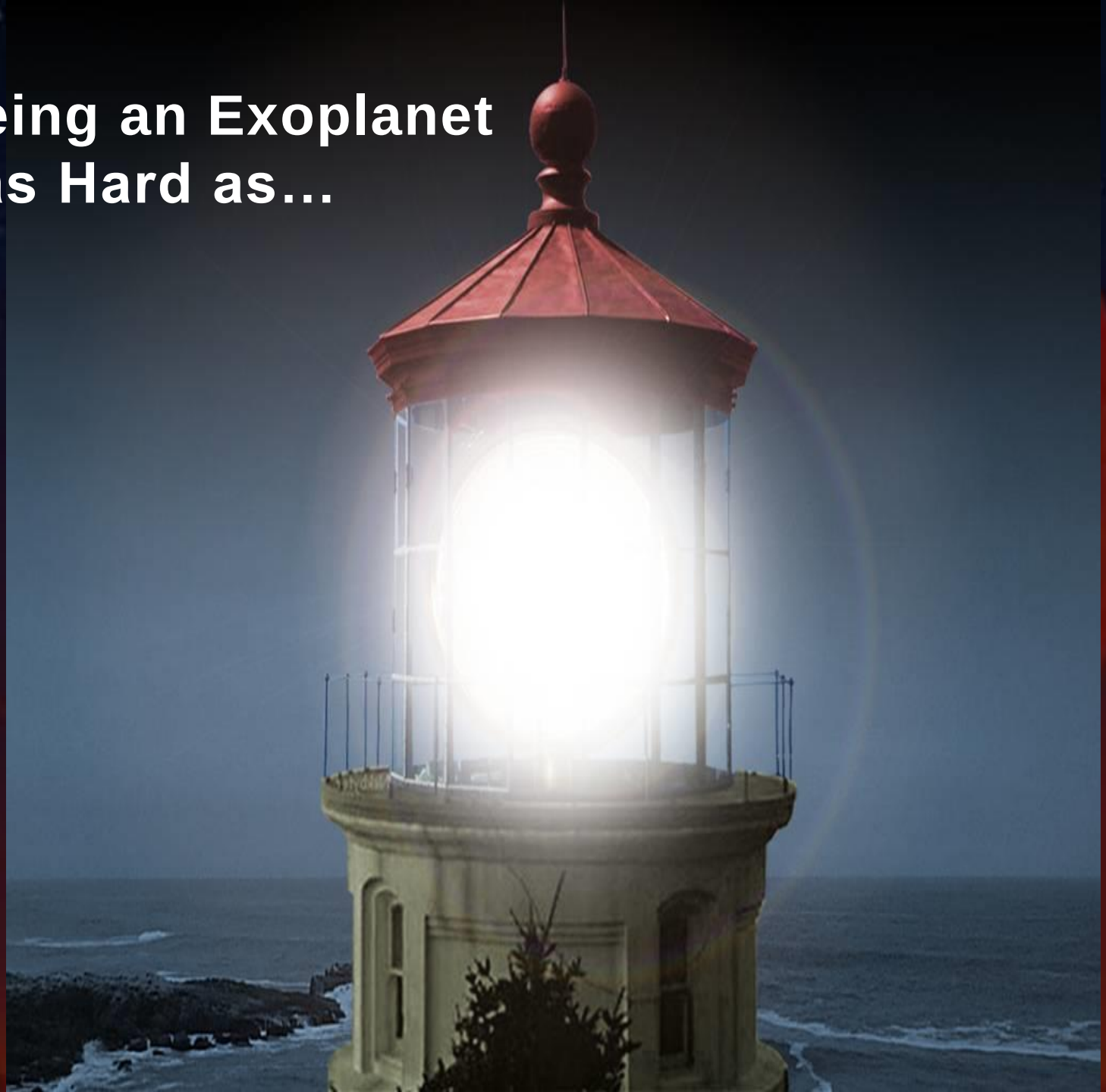
Doubling Time for Confirmed Exoplanets



Credit: NASA/JPL
Eric Mamajek

How Are Exoplanets Named?

Seeing an Exoplanet Is as Hard as…

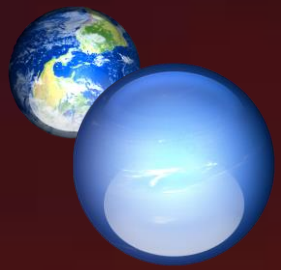


How Are Exoplanets Discovered?

Two Popular Methods

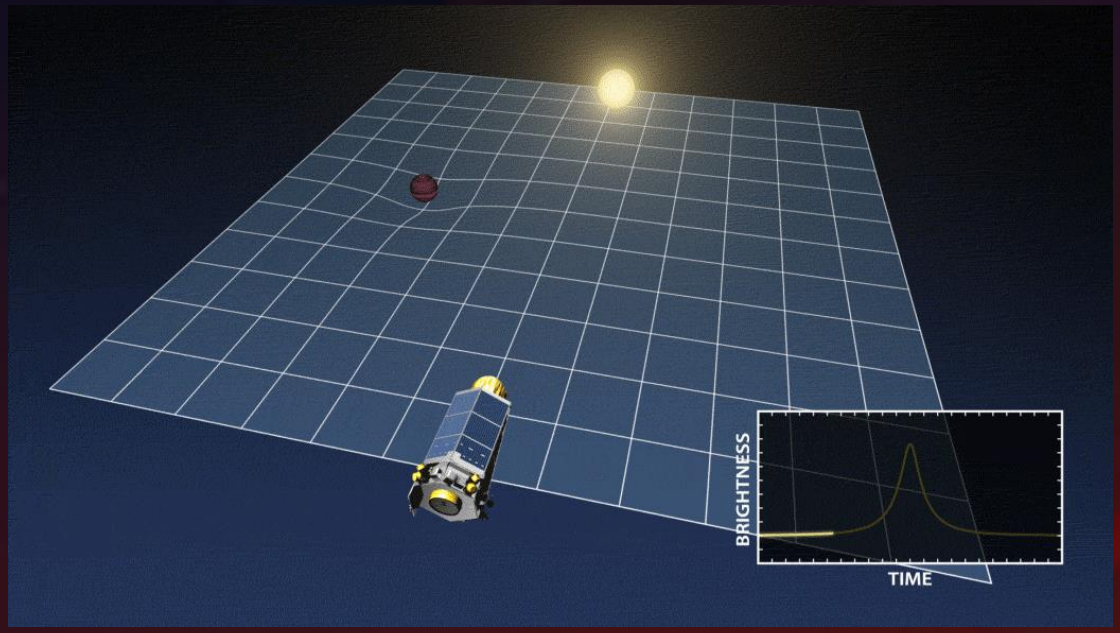
Doppler Spectroscopy
(Radial Velocity)

Transit

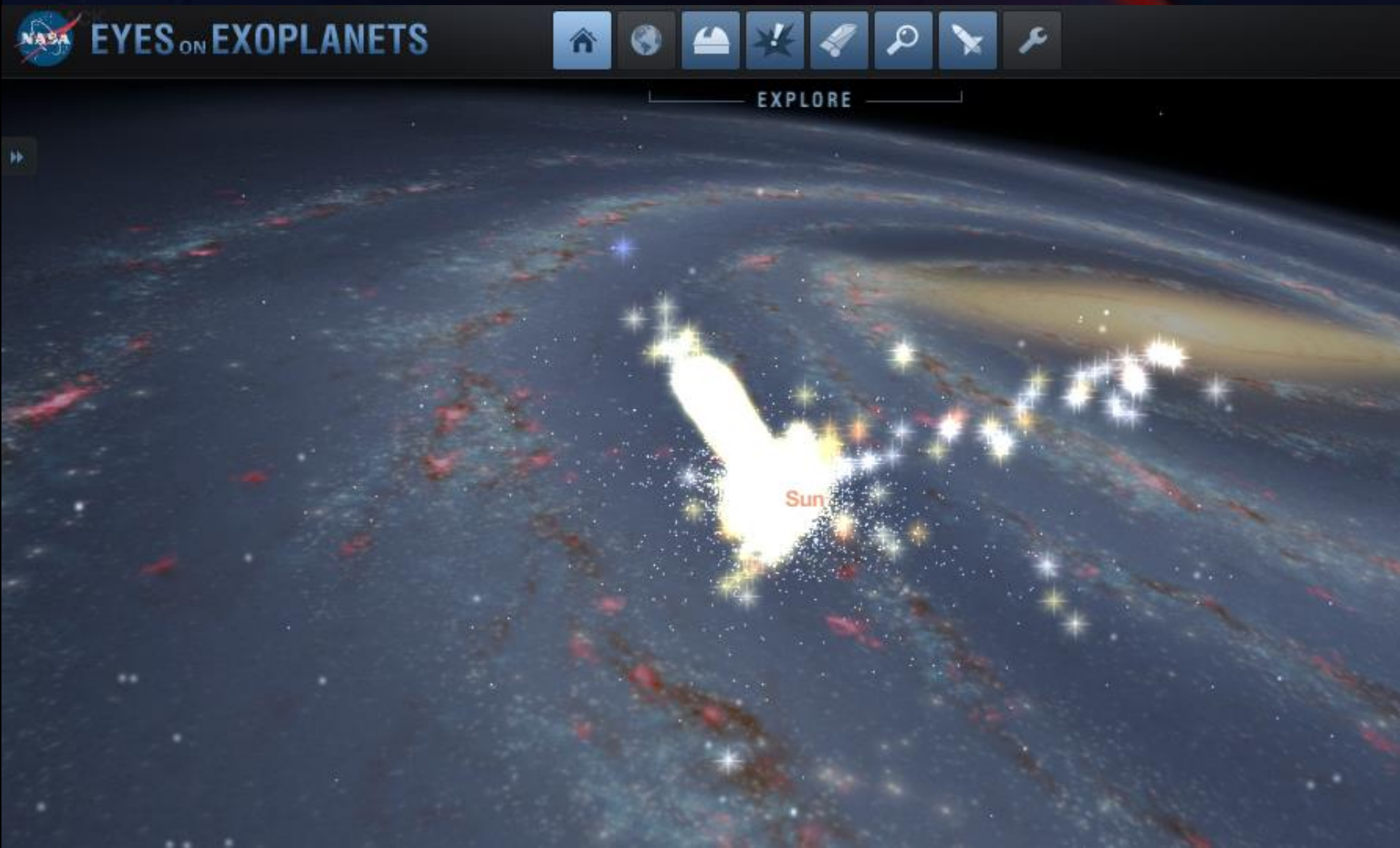


Microlensing Method

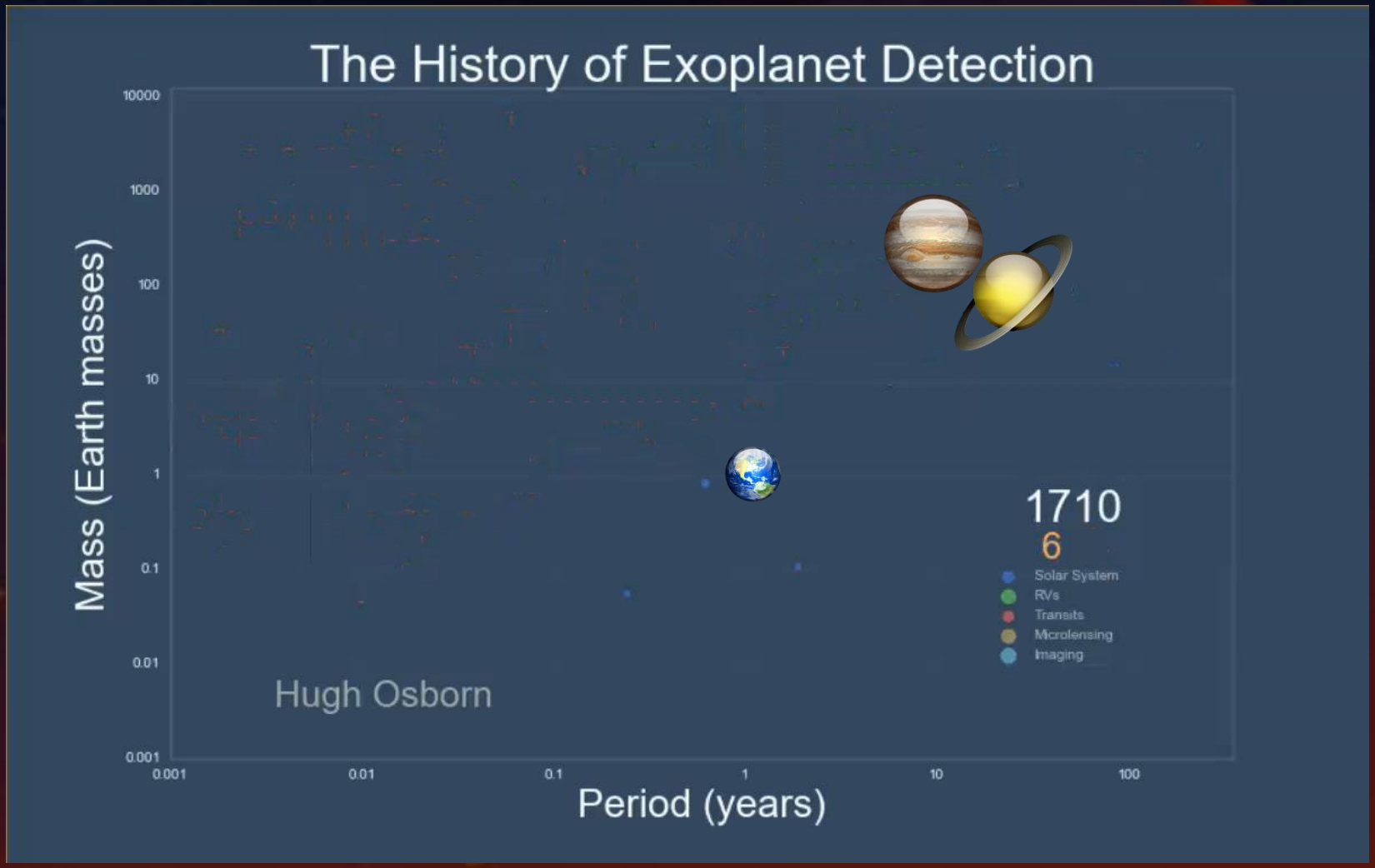
Another Way to Find Exoplanets



Where Are the Exoplanets?



When Were Exoplanets Discovered?



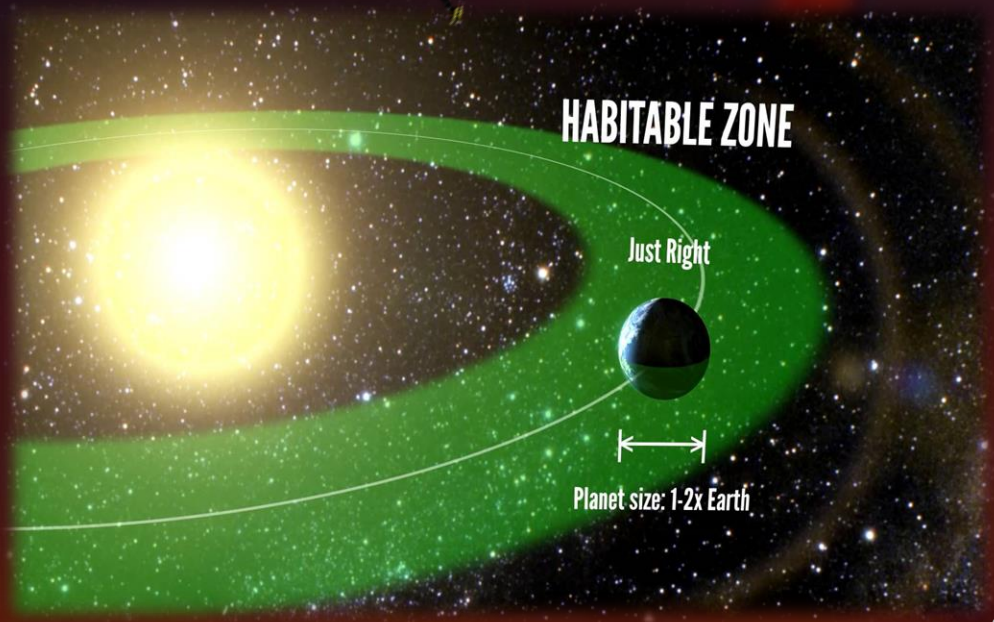
Credit: Hugh Osborn

Kepler Mission: Three Key Results

1. There are more planets than stars in the galaxy

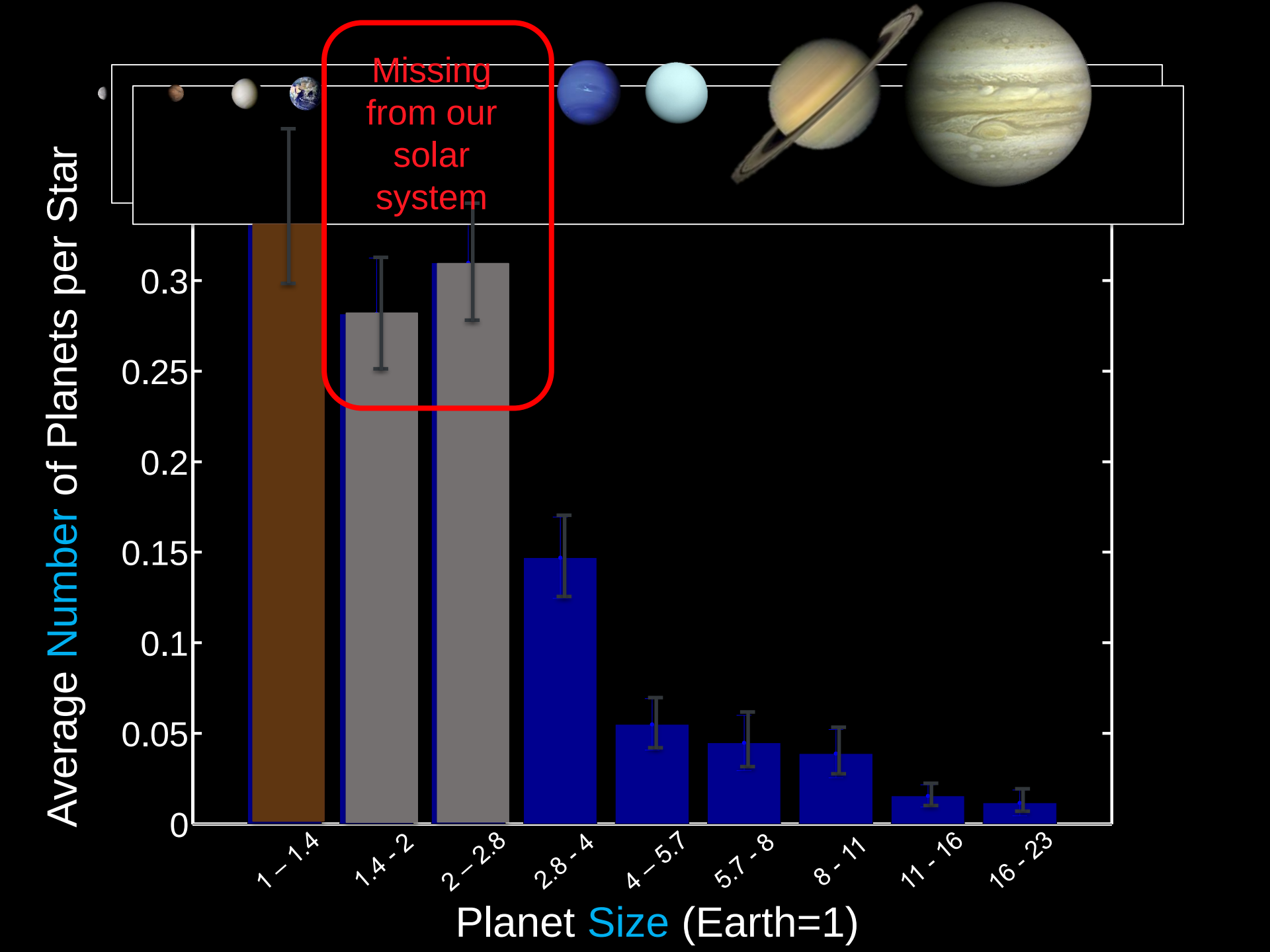
2. Small planets are common

3. Small planets in the Habitable Zone are common

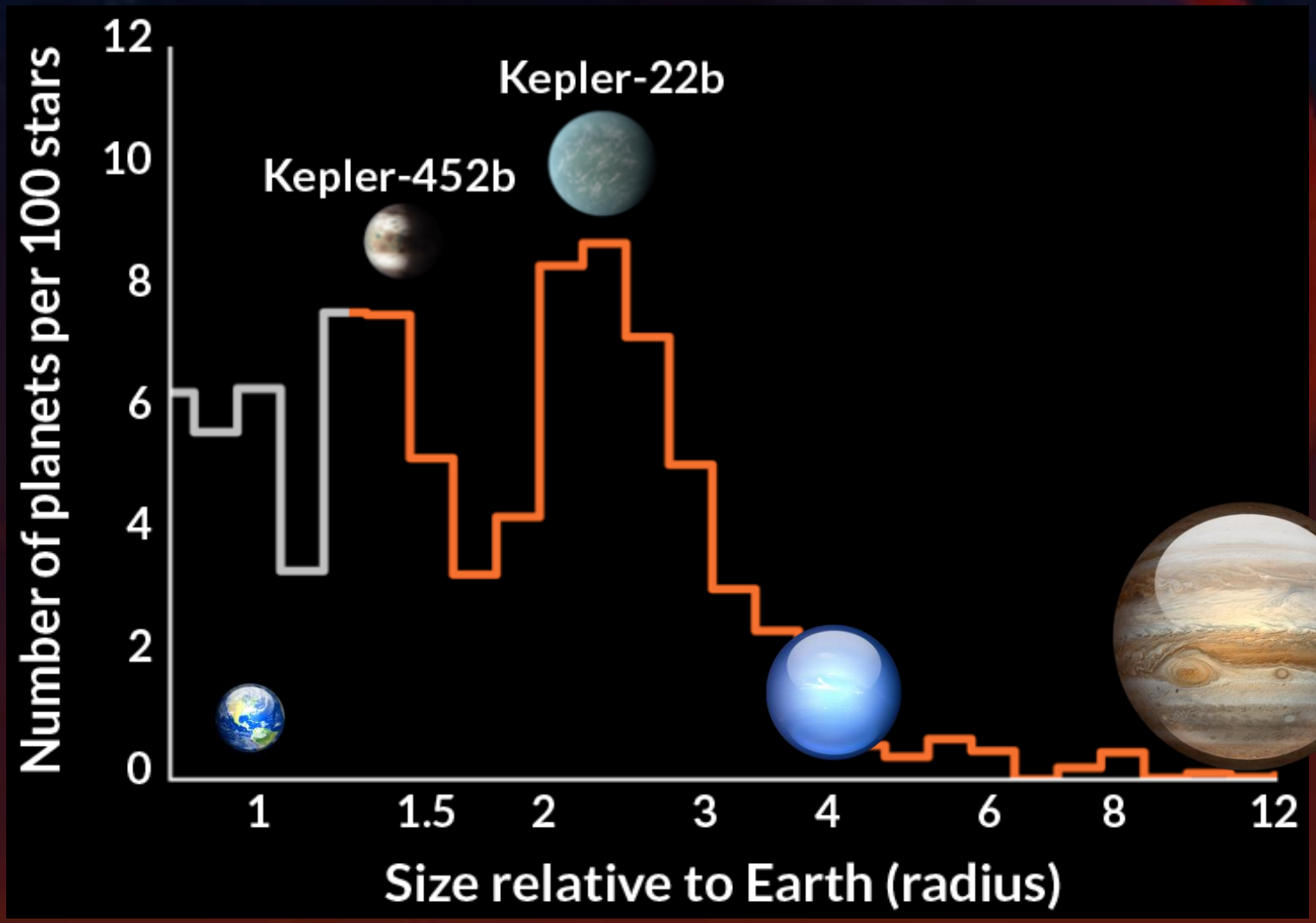


A Familiar Habitable Zone

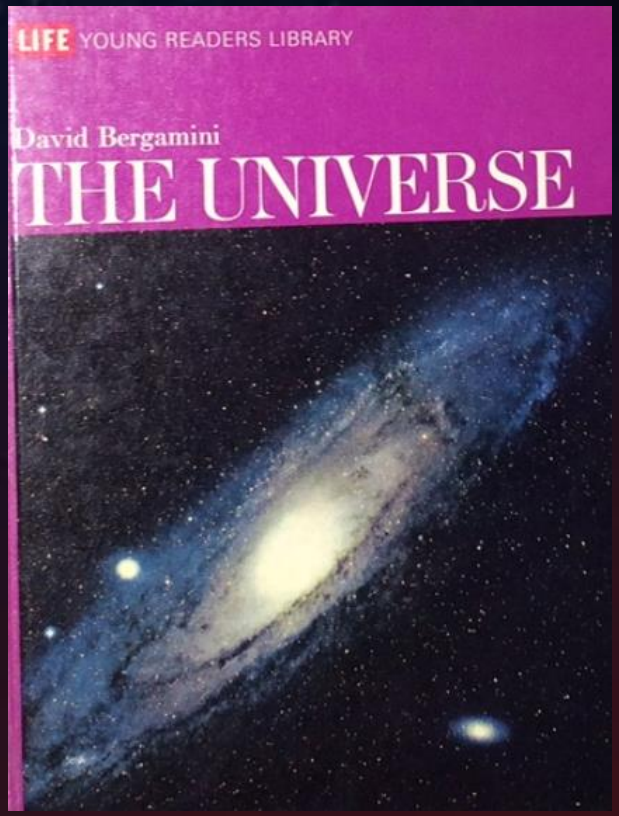
Habitable Zones


Missing from our solar system
Average Number of Planets per Star
0.3
0.25
0.2
0.15
0.1
0.05
0
1 – 1.4
1.4 - 2
2 – 2.8
2.8 - 4
4 – 5.7
5.7 - 8
8 - 11
11 - 16
16 - 23
Planet Size (Earth=1)

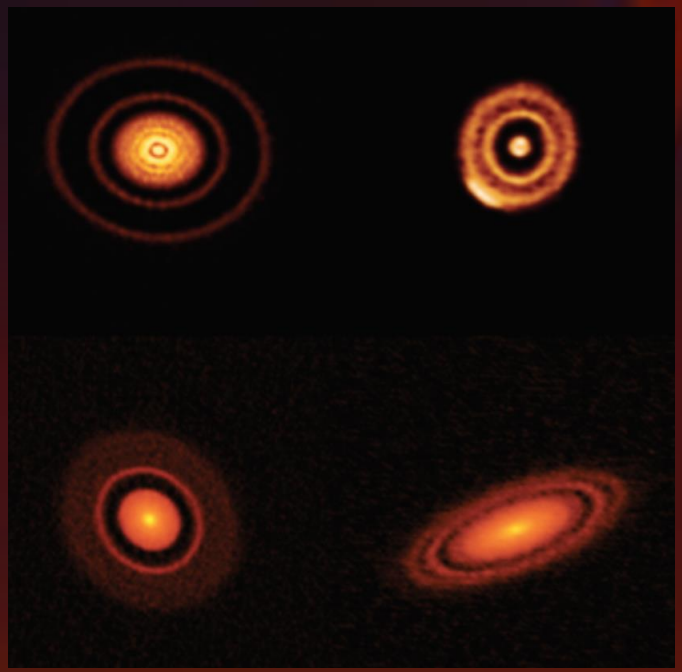
The Fulton Gap



Credit: Fulton et al. 2017



1962



2018

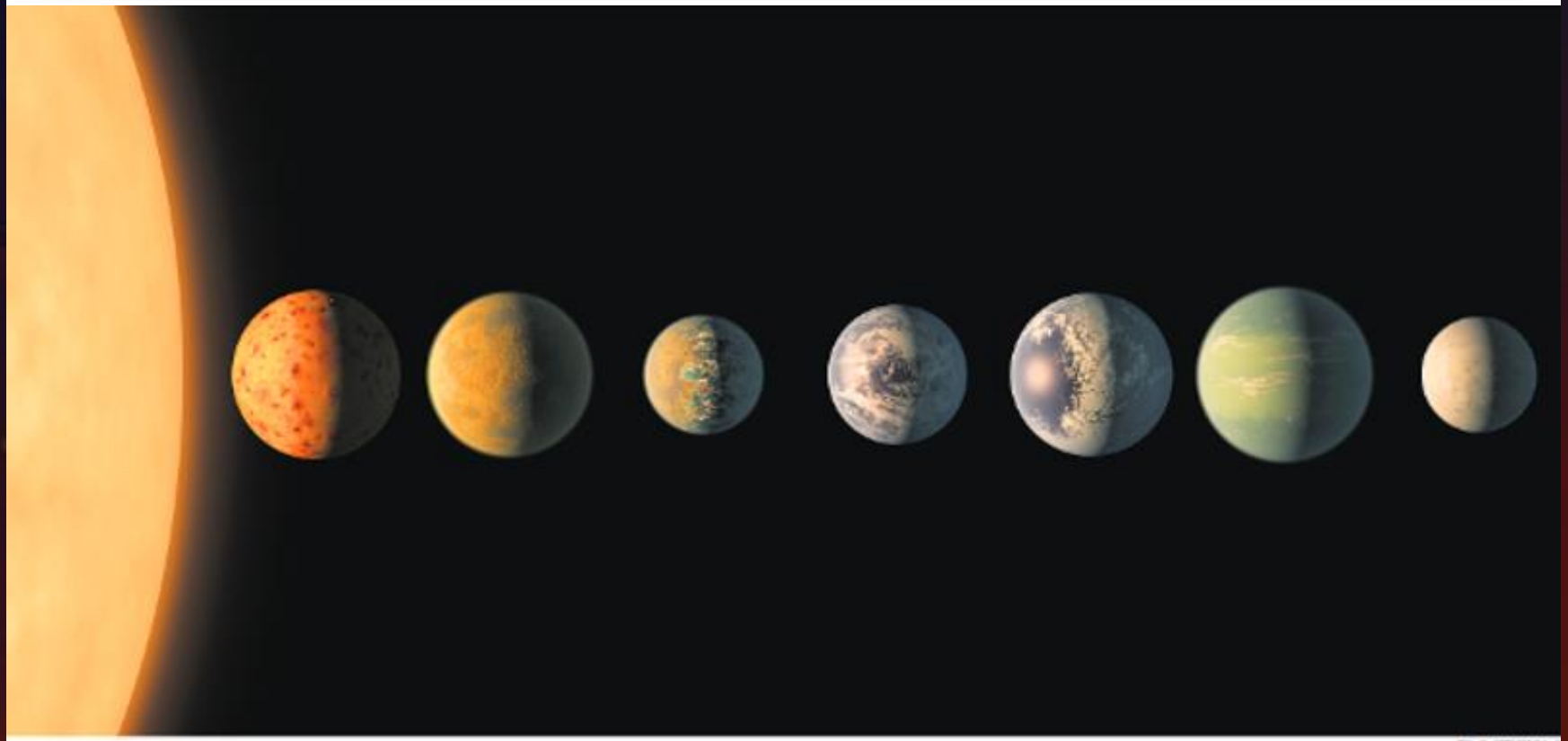
Trappist-1

"All the News That's Fit to Print"

The New York Times

Late Edition
Today, patchy morning fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B9.

VOL. CLXVI ... No. 57,517 © 2017 The New York Times Company NEW YORK, THURSDAY, FEBRUARY 23, 2017 $2.50

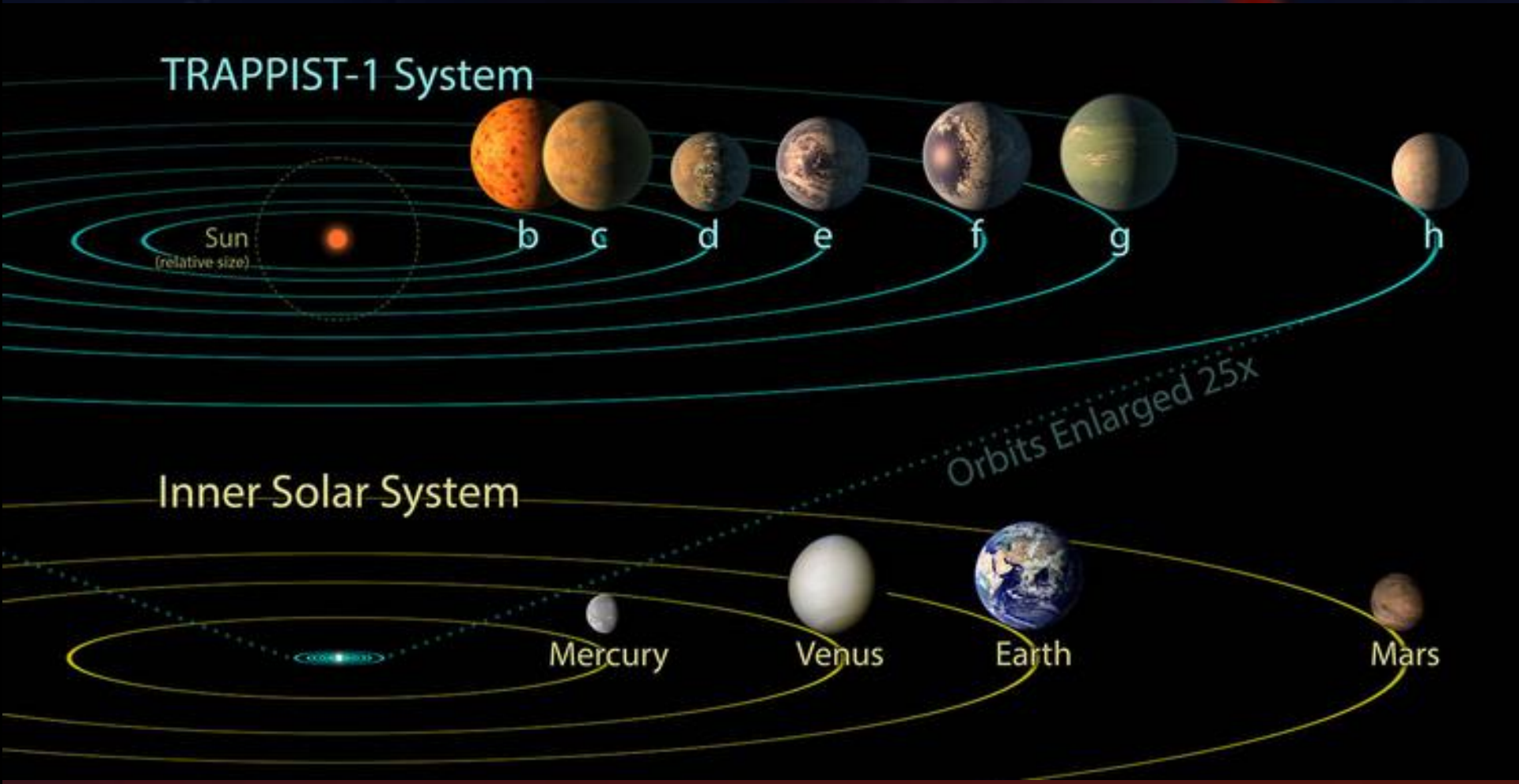


JPL-CALTECH/NASA

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

Trappist-1 System

The Richest Set of Earth-sized Planets Ever Found



Exoplanet Travel Bureau

"All the News That's Fit to Print"

The New York Times

Late Edition

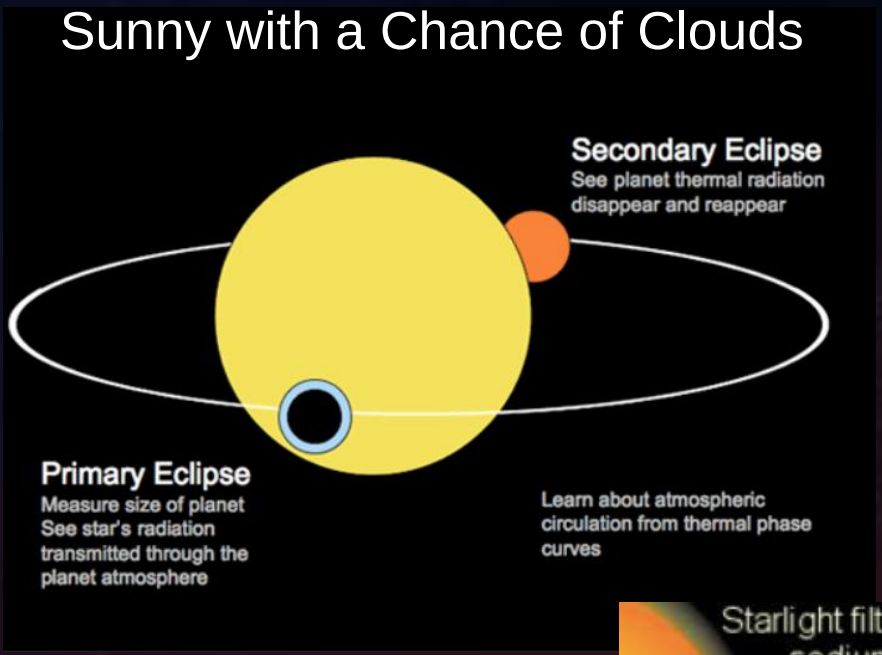
Today, patchy morning fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B8.

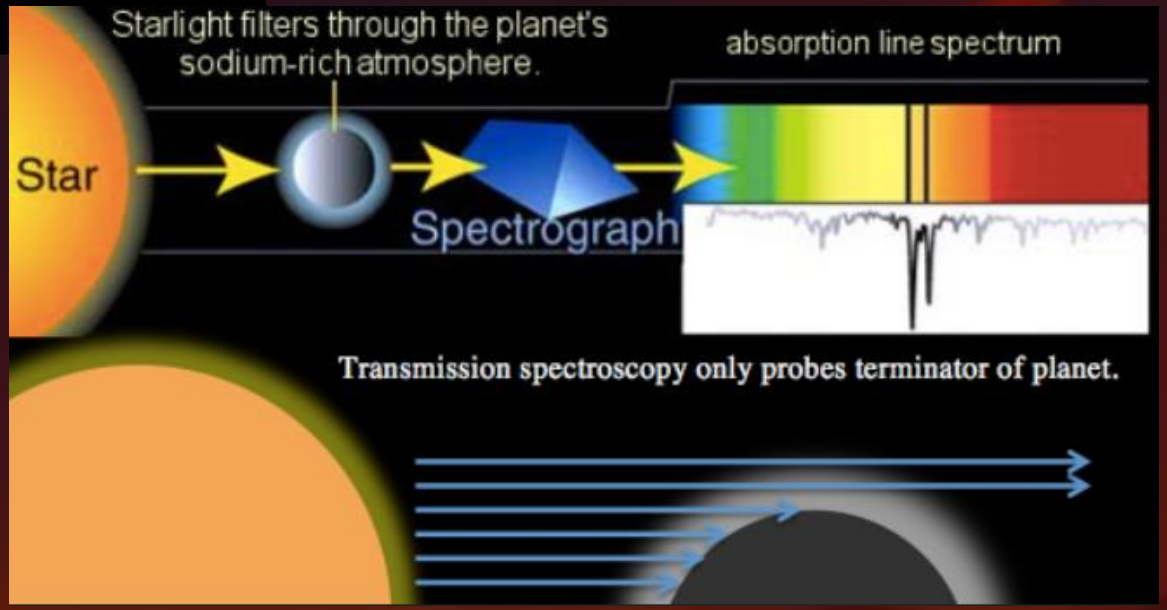
VOL. CLXVI ... No. 57,517 © 2017 The New York Times Company NEW YORK, THURSDAY, FEBRUARY 23, 2017 $2.50

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

Transmission Spectroscopy

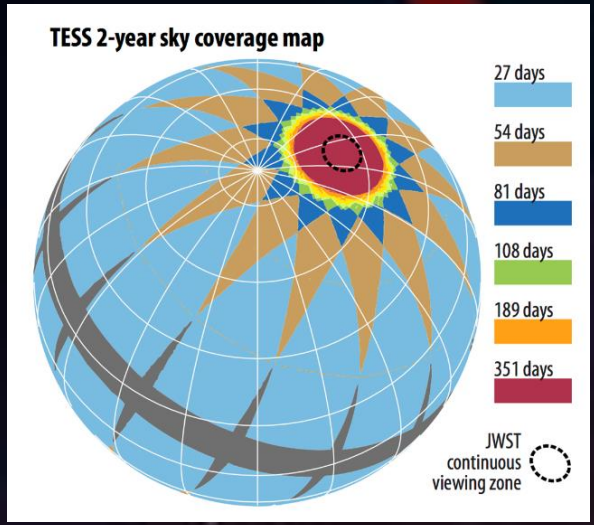
Sunny with a Chance of Clouds

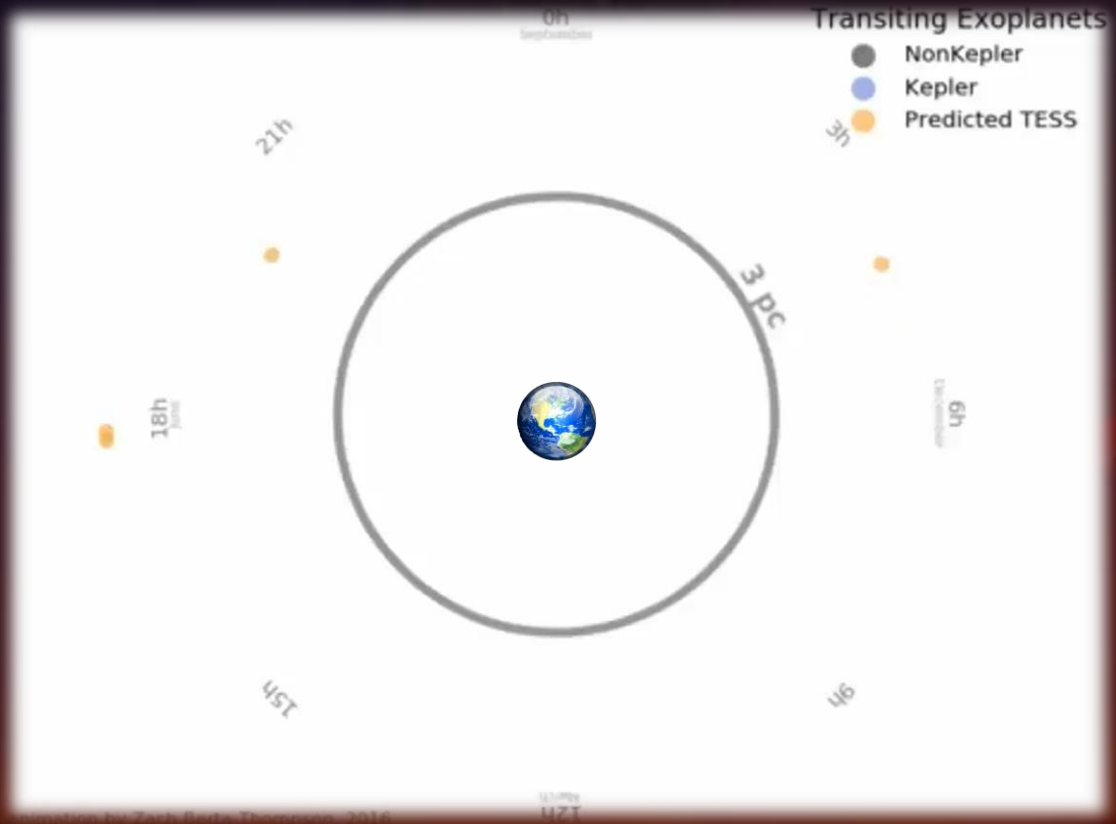




TESS

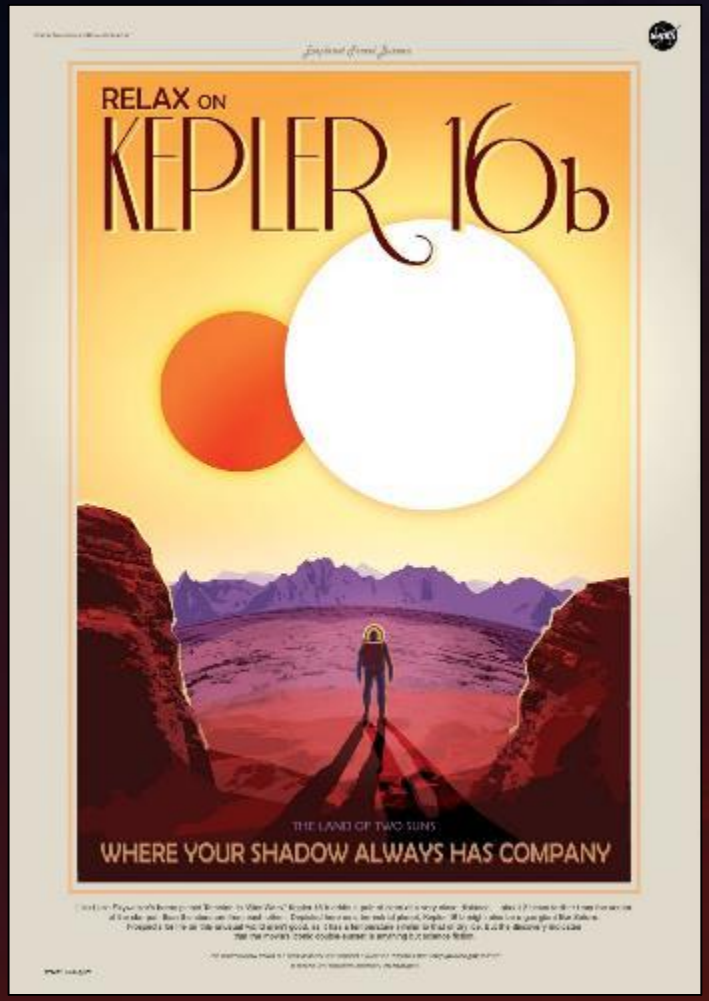
TESS Planet Predictions

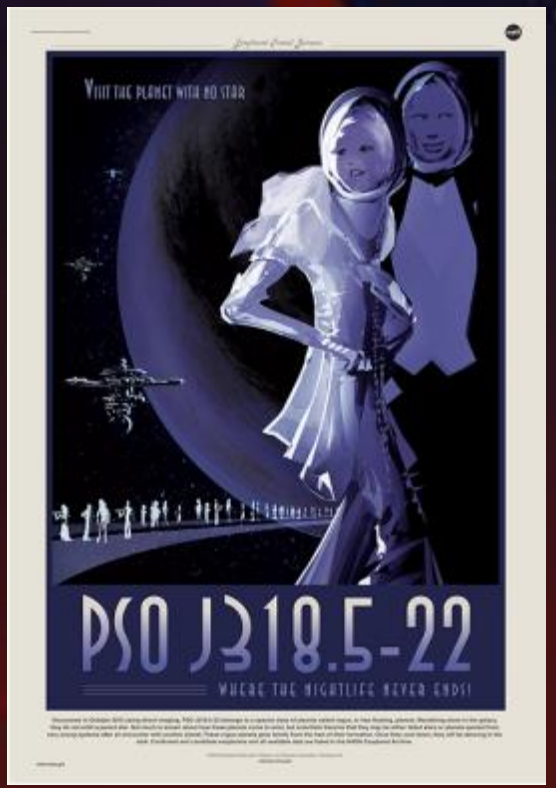




ExoComm

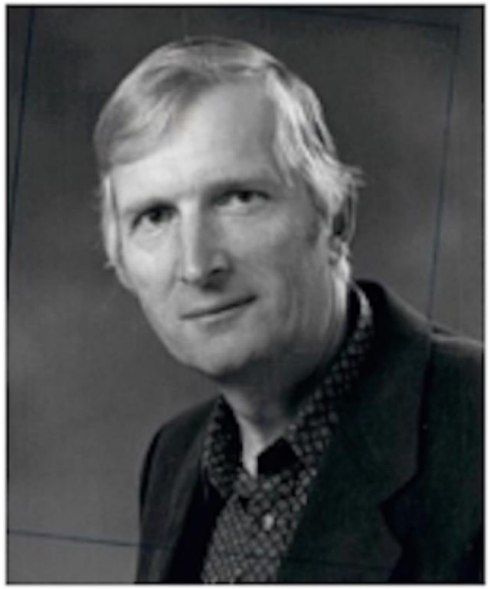
Exploring a Galaxy of Worlds while Inspiring Our Own

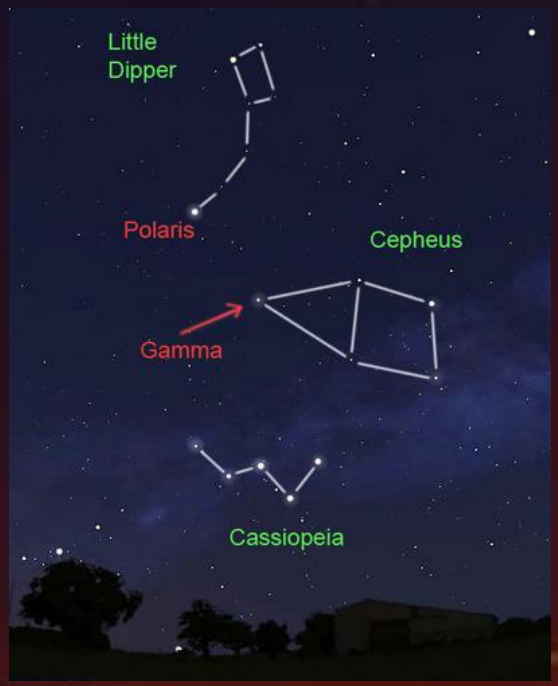


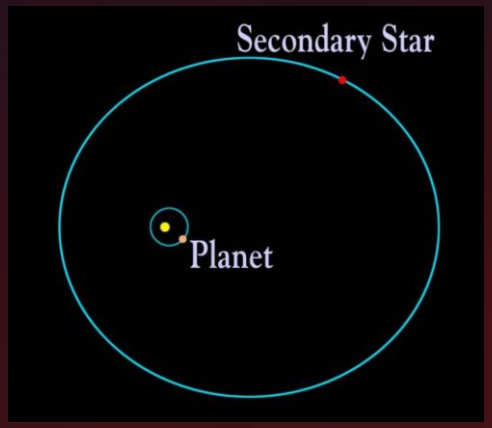


“Exoplanet Earth” Edition

We Are a Leo Sun from Trappist-1




Little
Dipper
Polaris
Cepheus
Gamma
Cassiopeia


Secondary Star
Planet


51 Pegasi b
SINCE 1995
HD 114762 b
PSR
1257+12 B,C,D
VISIT
Gamma Cephei Ab
GREETINGS FROM YOUR
FIRST EXOPLANET

The Search for Life in Our Galaxy

Are We Alone?

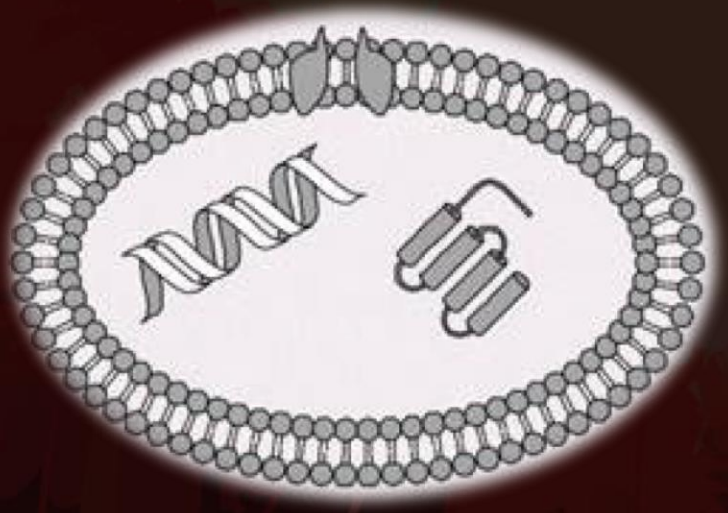
Do We Understand Life?

NASA/Joyce Definition:

“A self-sustaining chemical system capable of Darwinian evolution”

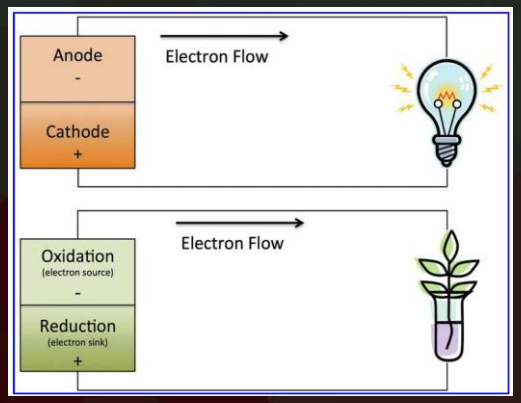
Traits Common to Life on Earth

- Ordered structure
- Reproduction
- Growth and development
- Response to environment
- Homeostatis
- Evolutionary adaptation
- Energy utilization

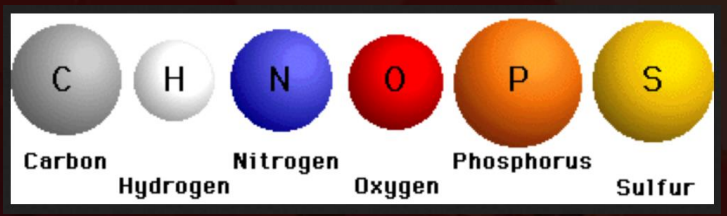


What Is Essential for Life?

Source of Energy



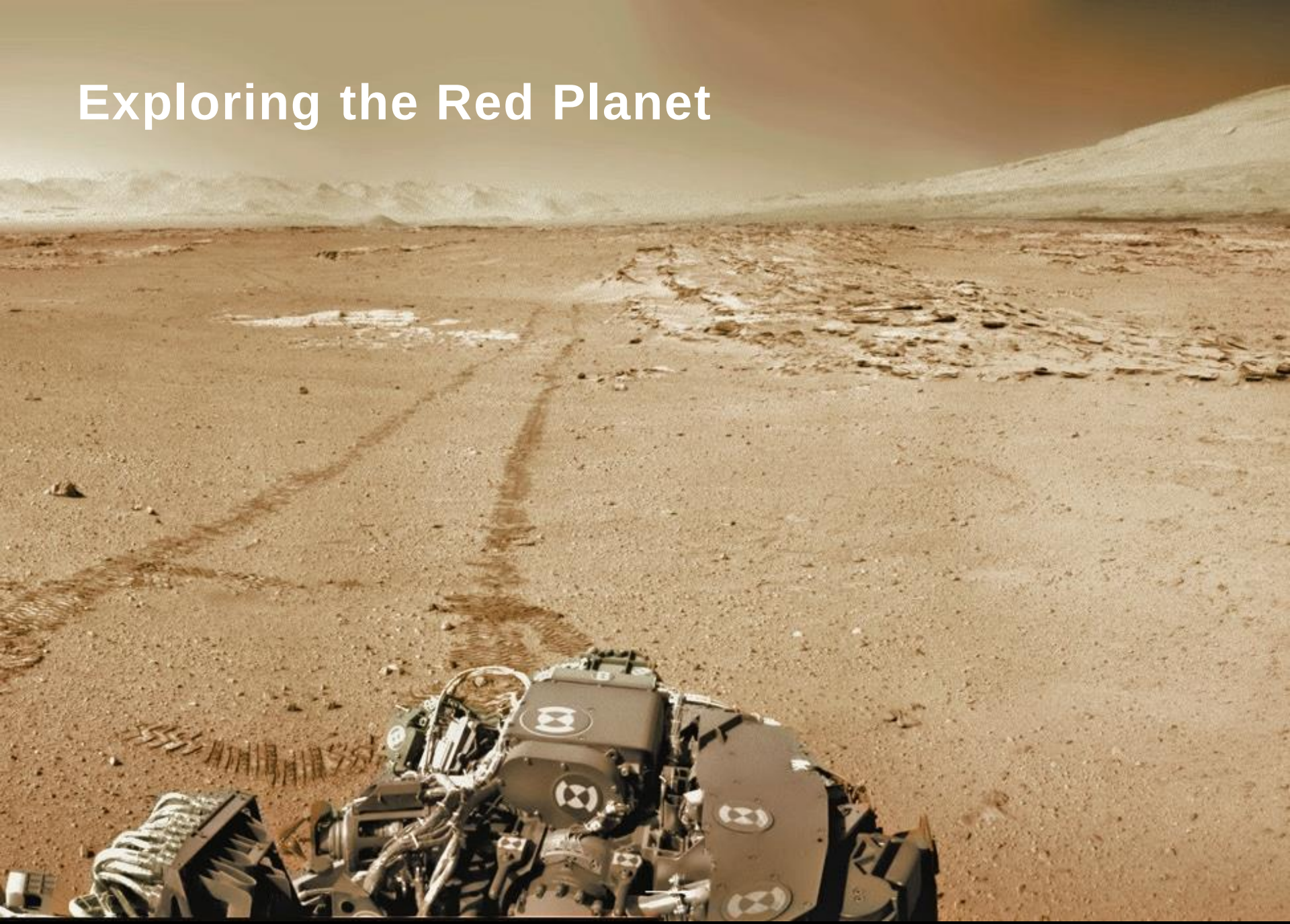
Essential Elements



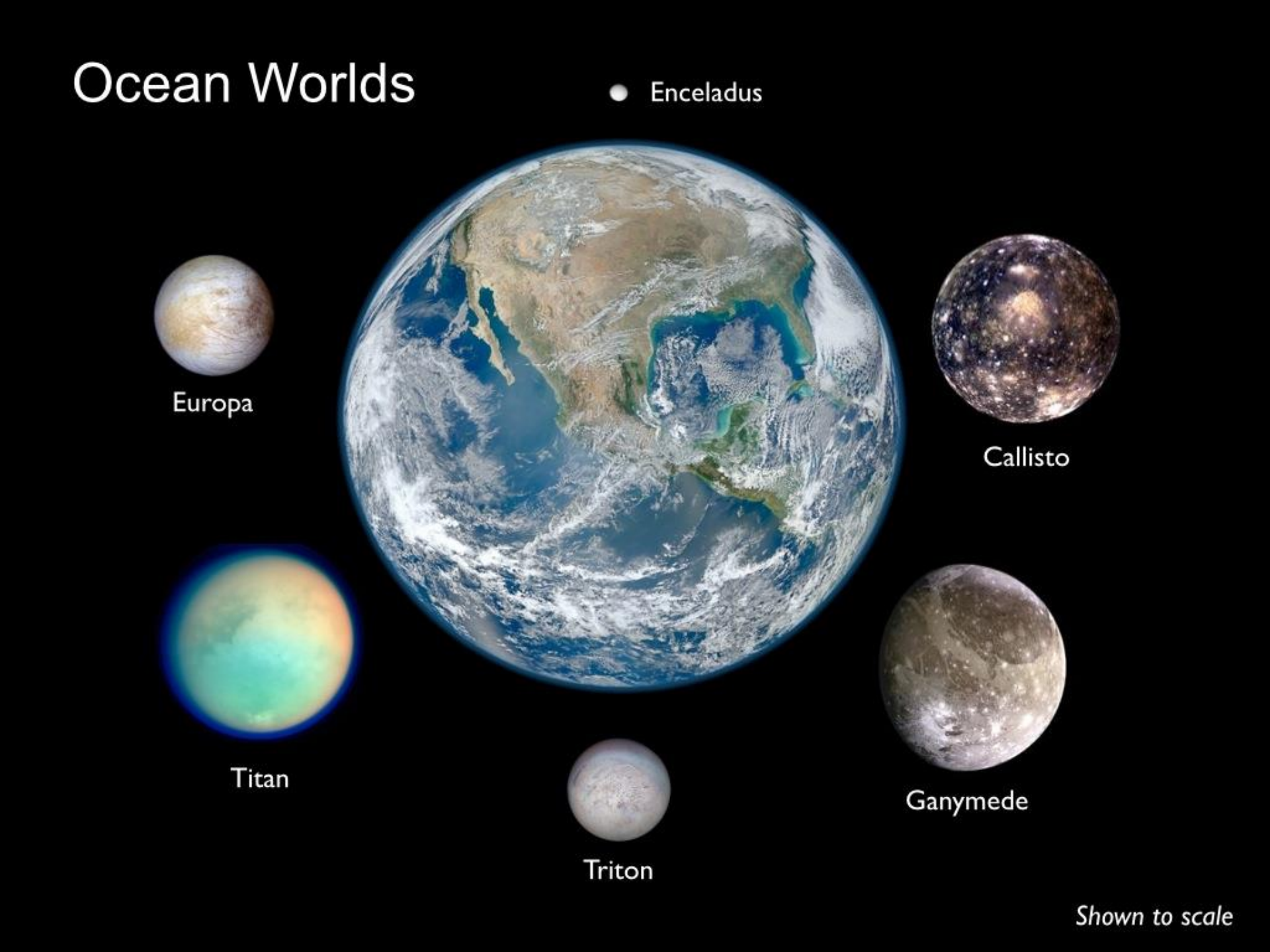
Solvent to Host Chemical Reactions

Extreme Environments Support Life

Exploring the Red Planet

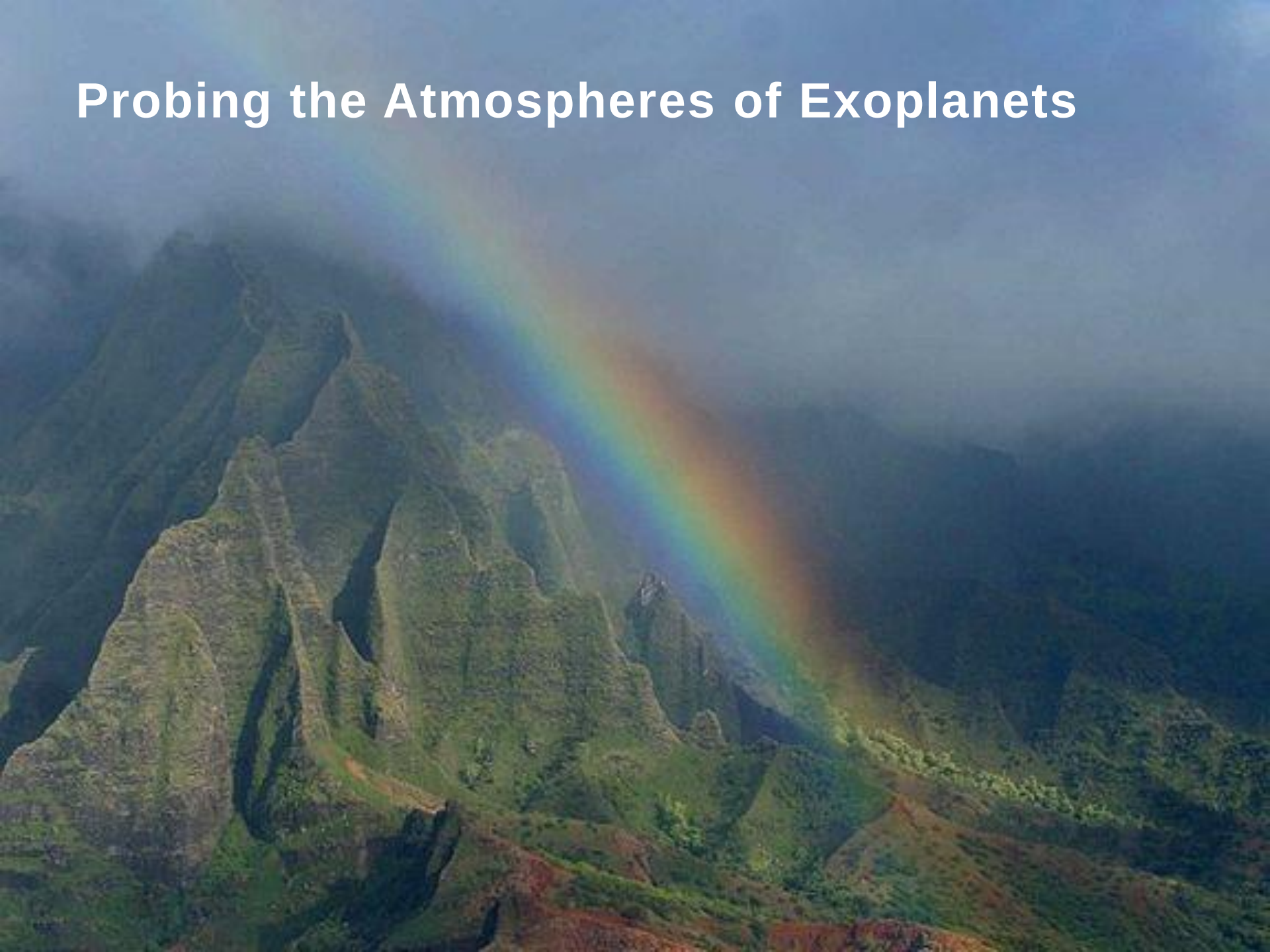


Ocean Worlds

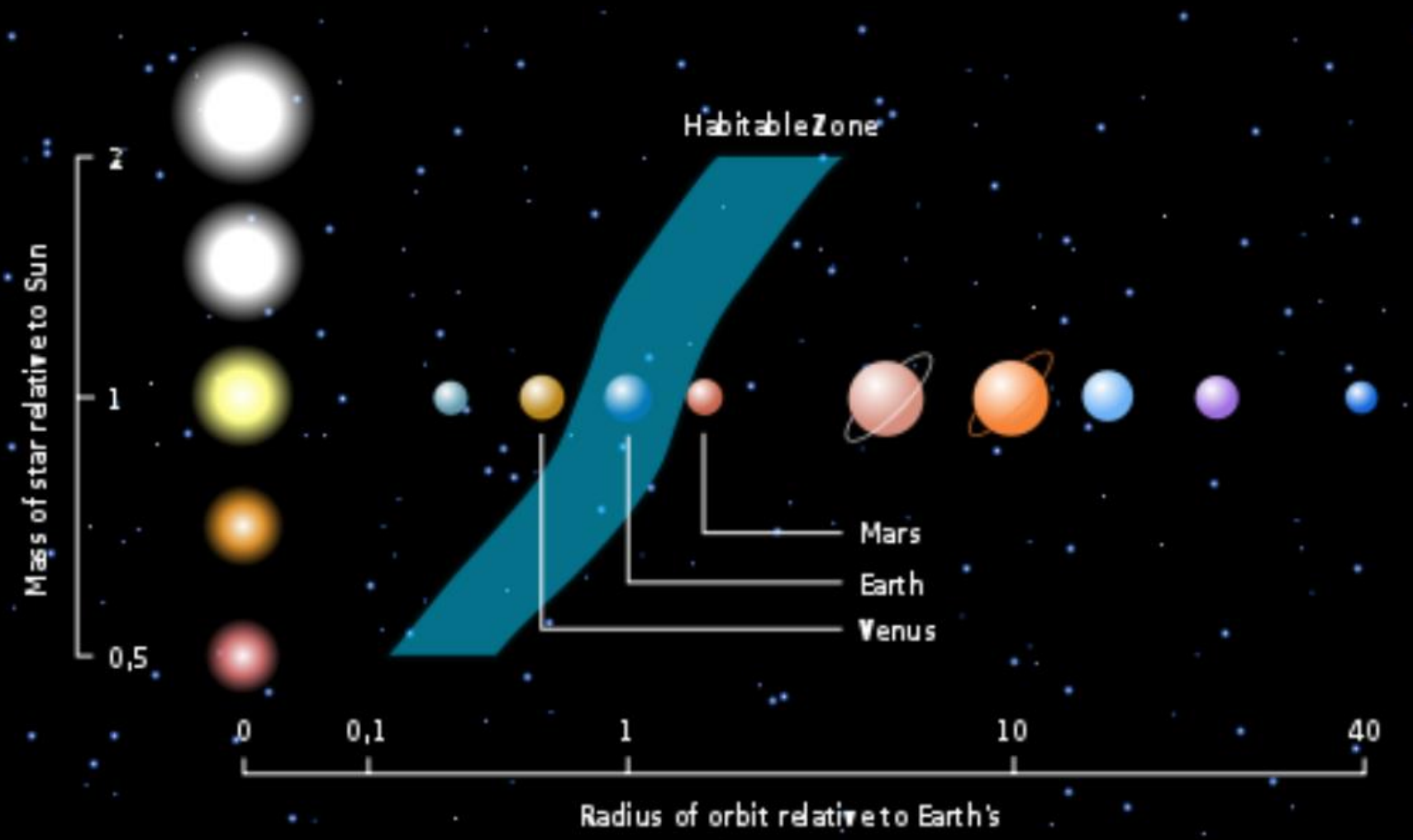


Search for Technosignatures

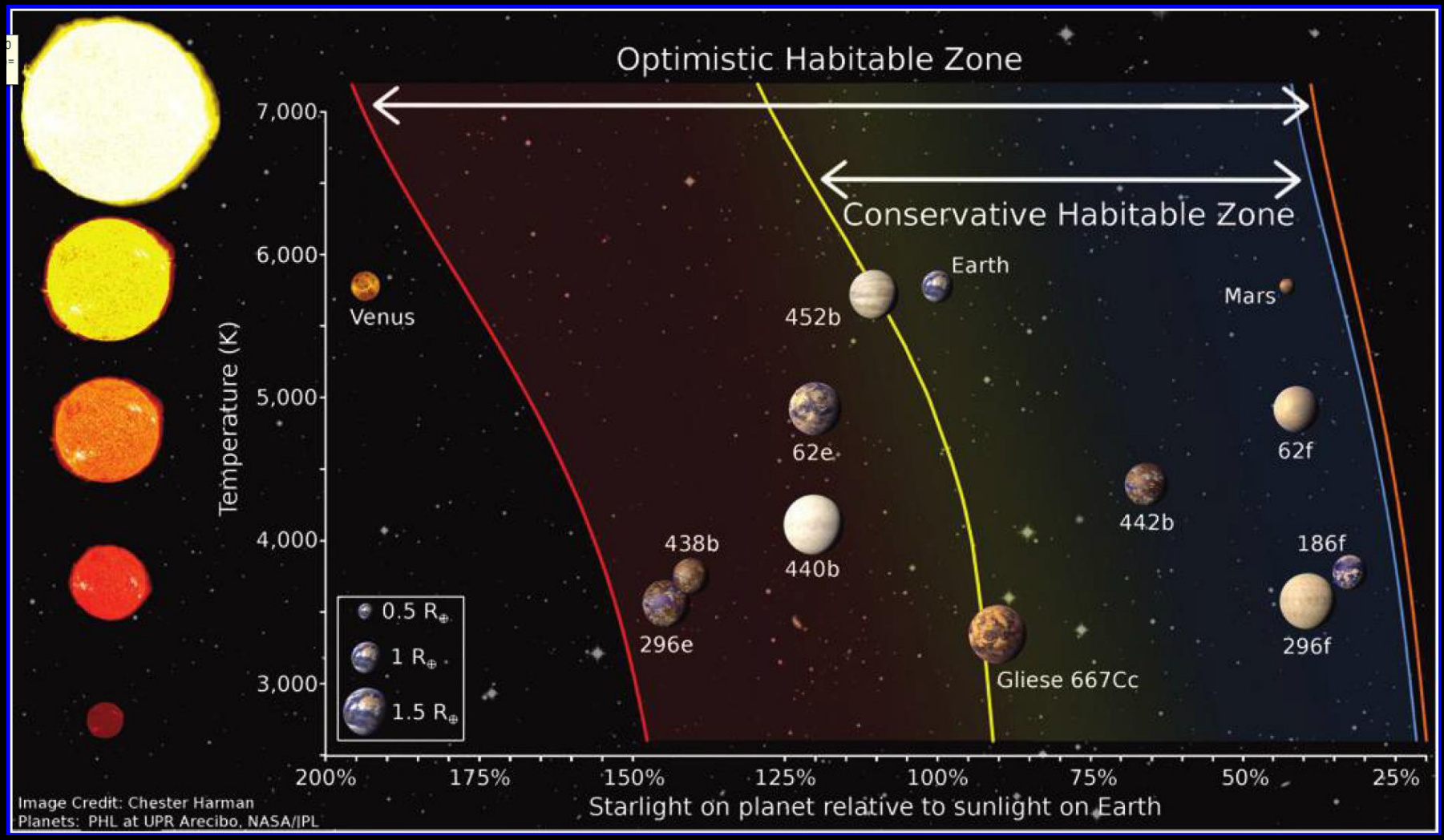
Probing the Atmospheres of Exoplanets



Habitable Zone



Exoplanets in the Habitable Zone



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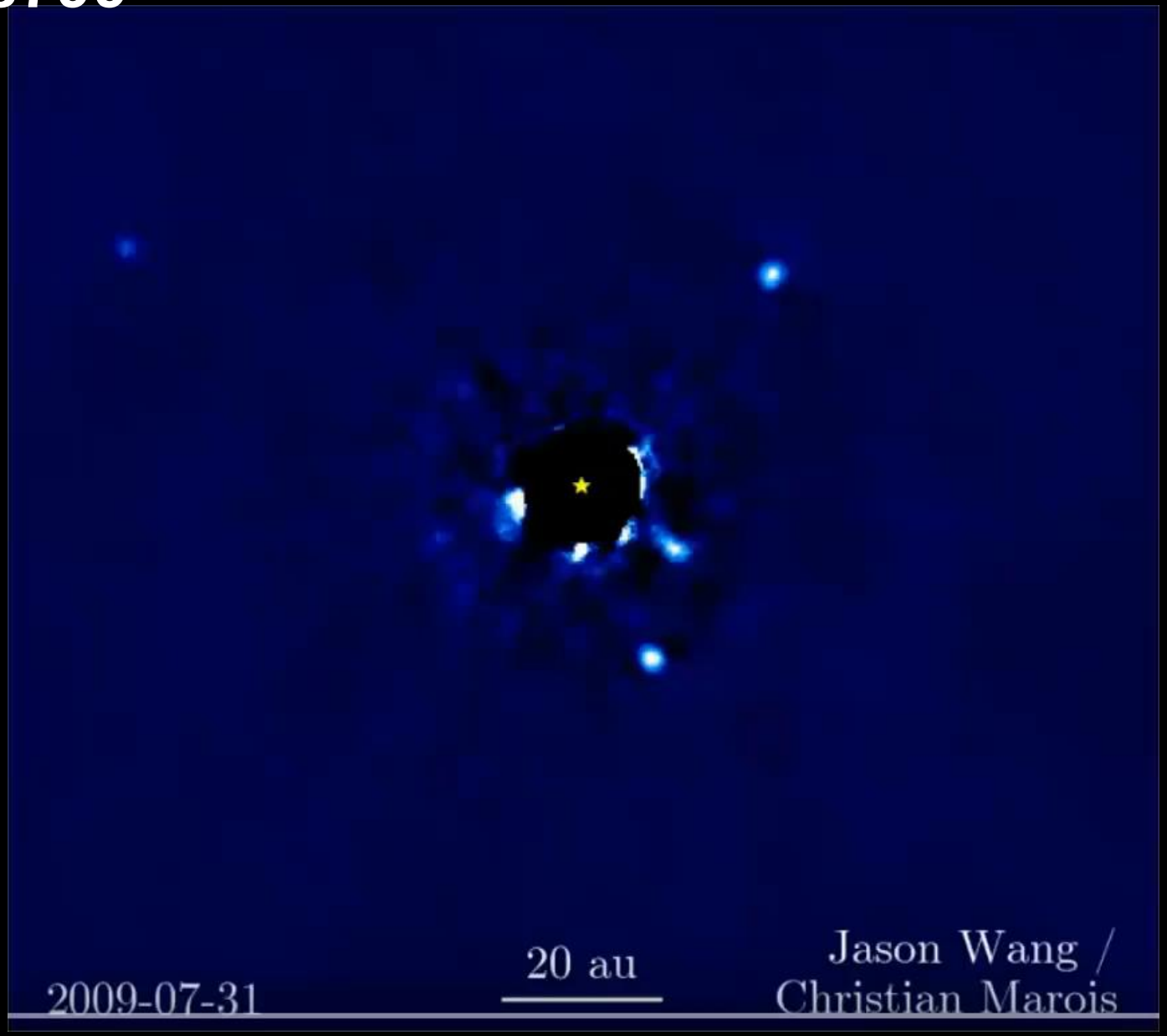
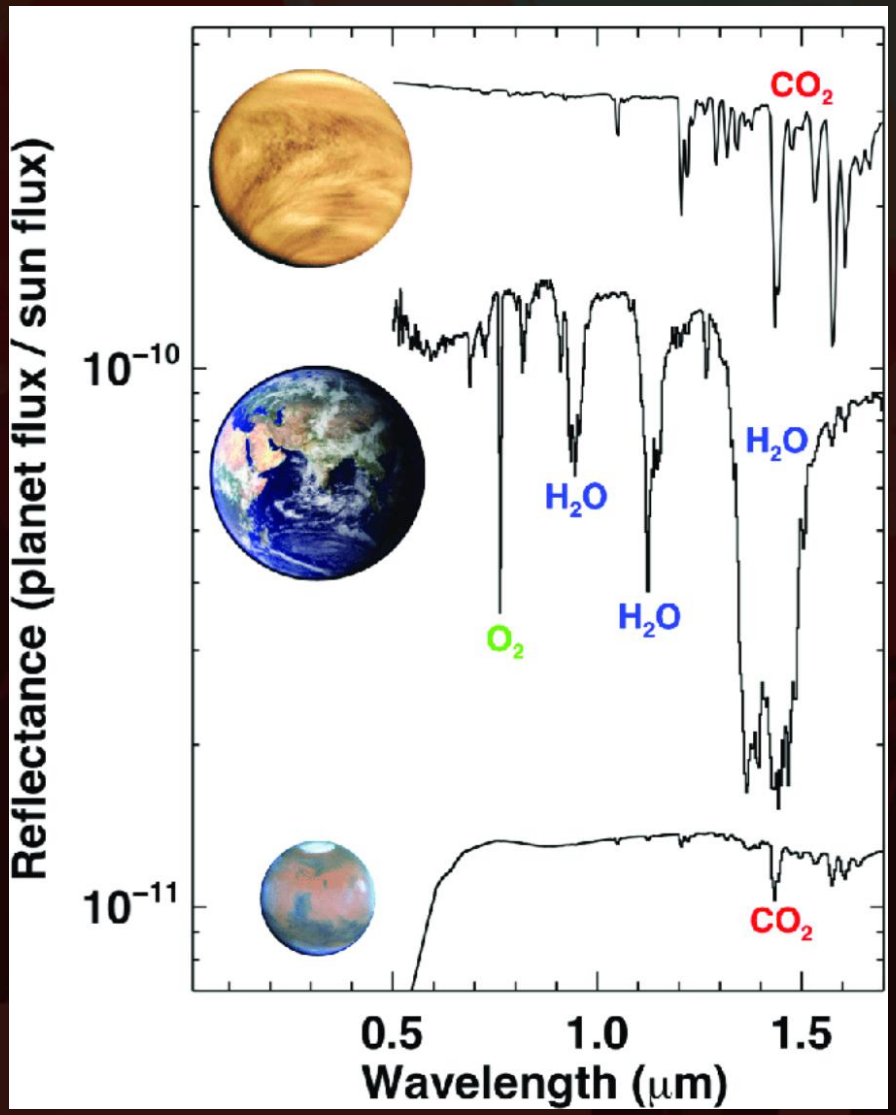
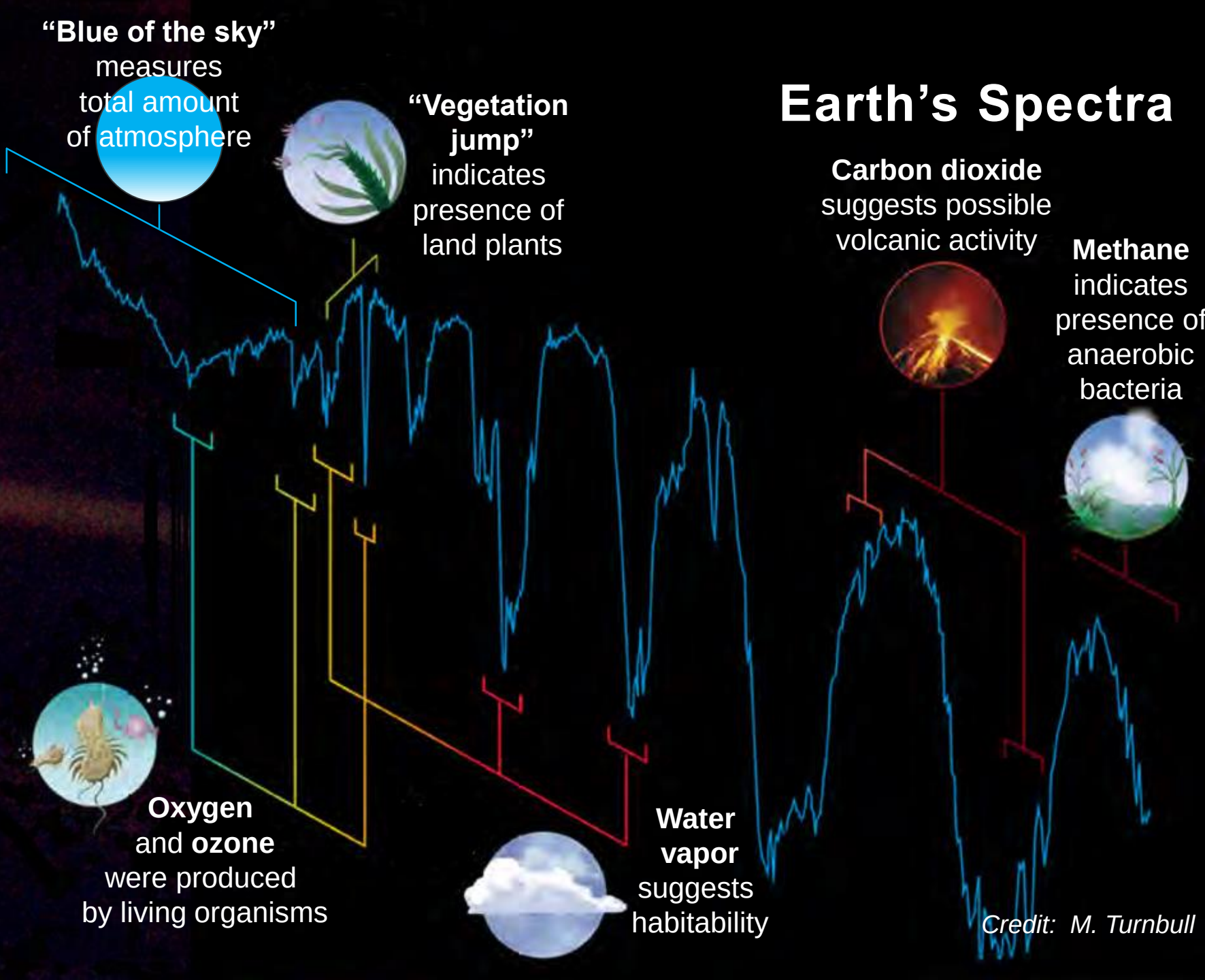


Spectra of Our Solar System Planets



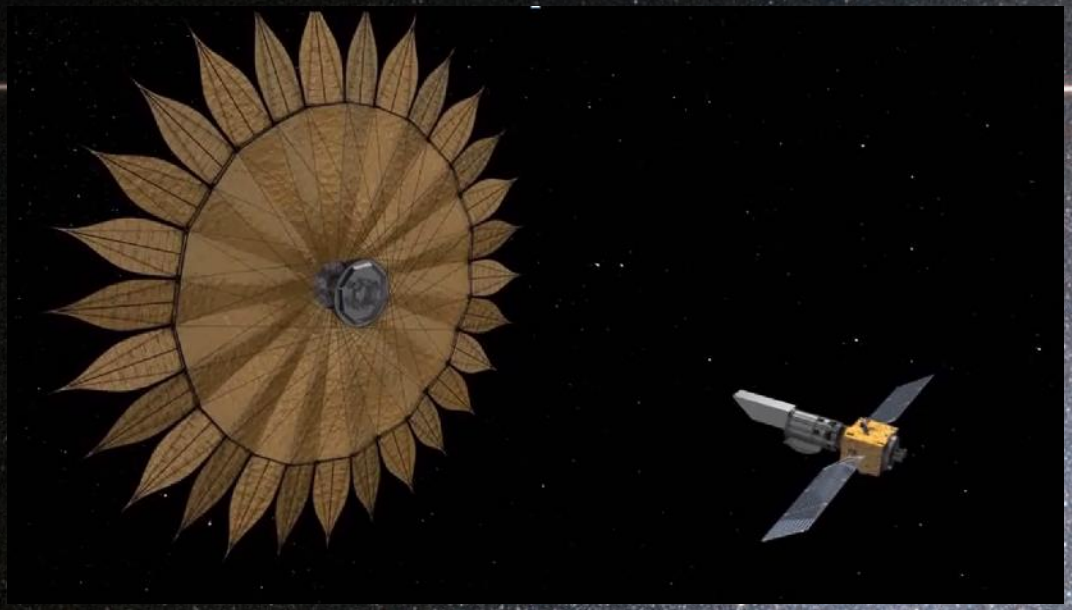
Earth's Spectra

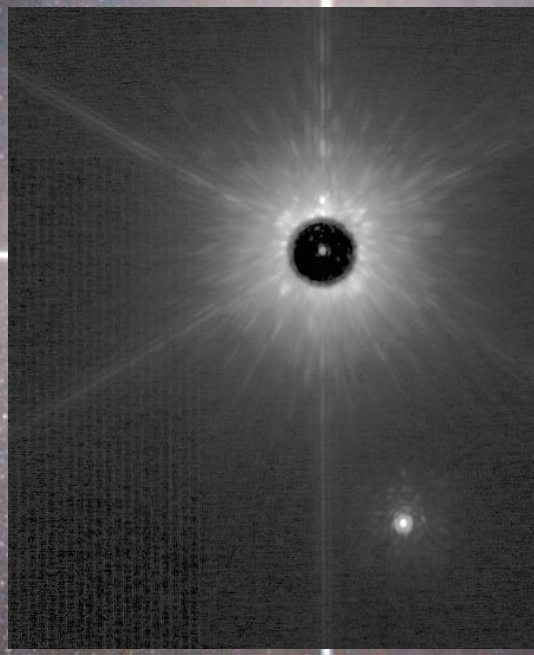


Credit: M. Turnbull

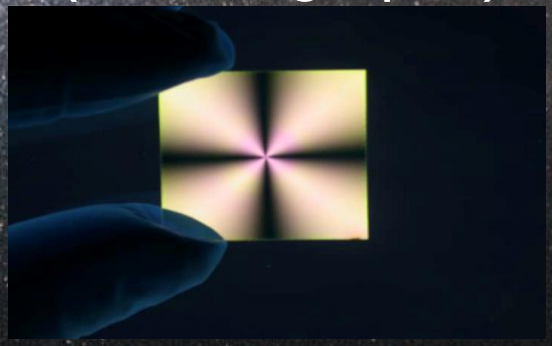
Starlight Suppression

External Occulters
(Starshades)

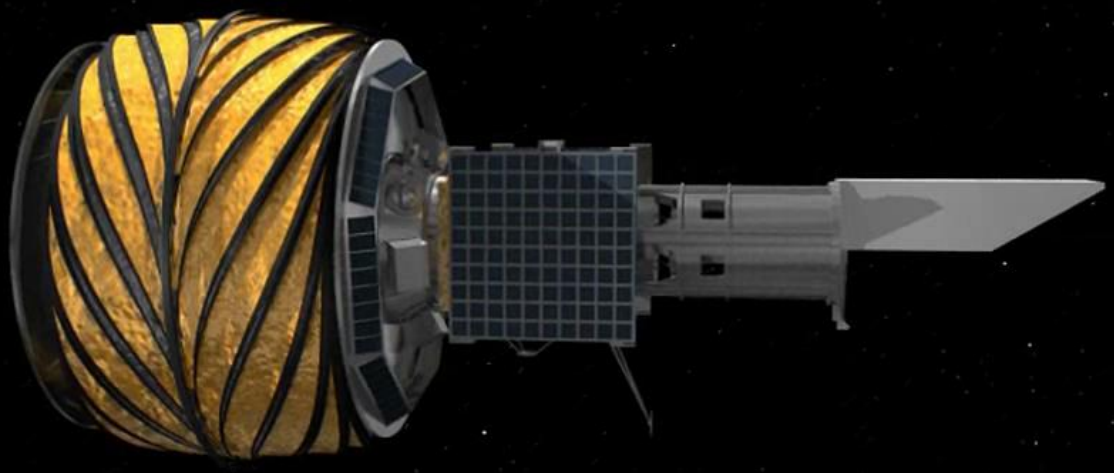




Internal Occulters
(Coronagraphs)

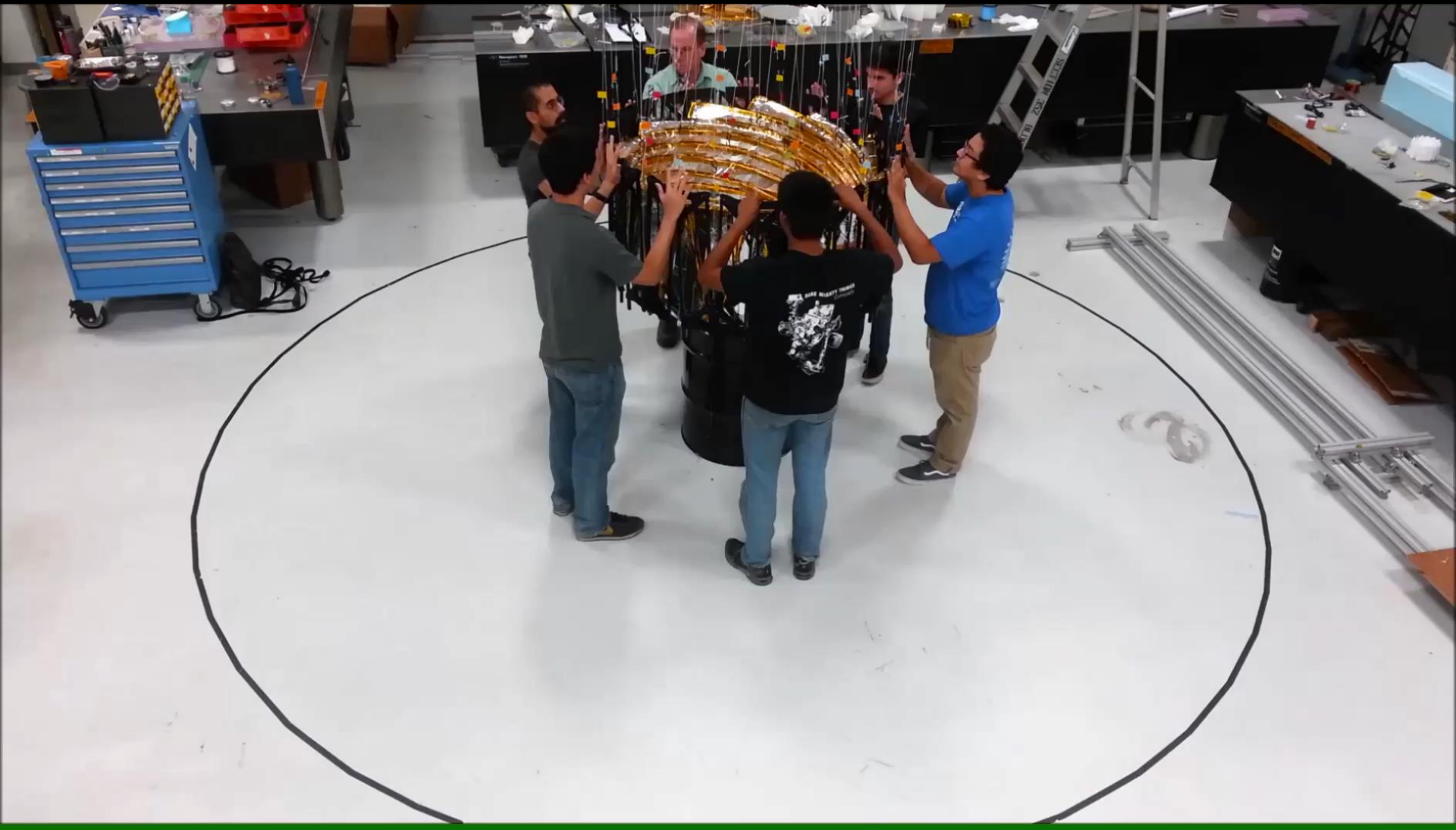


Starshade (External Occulter)

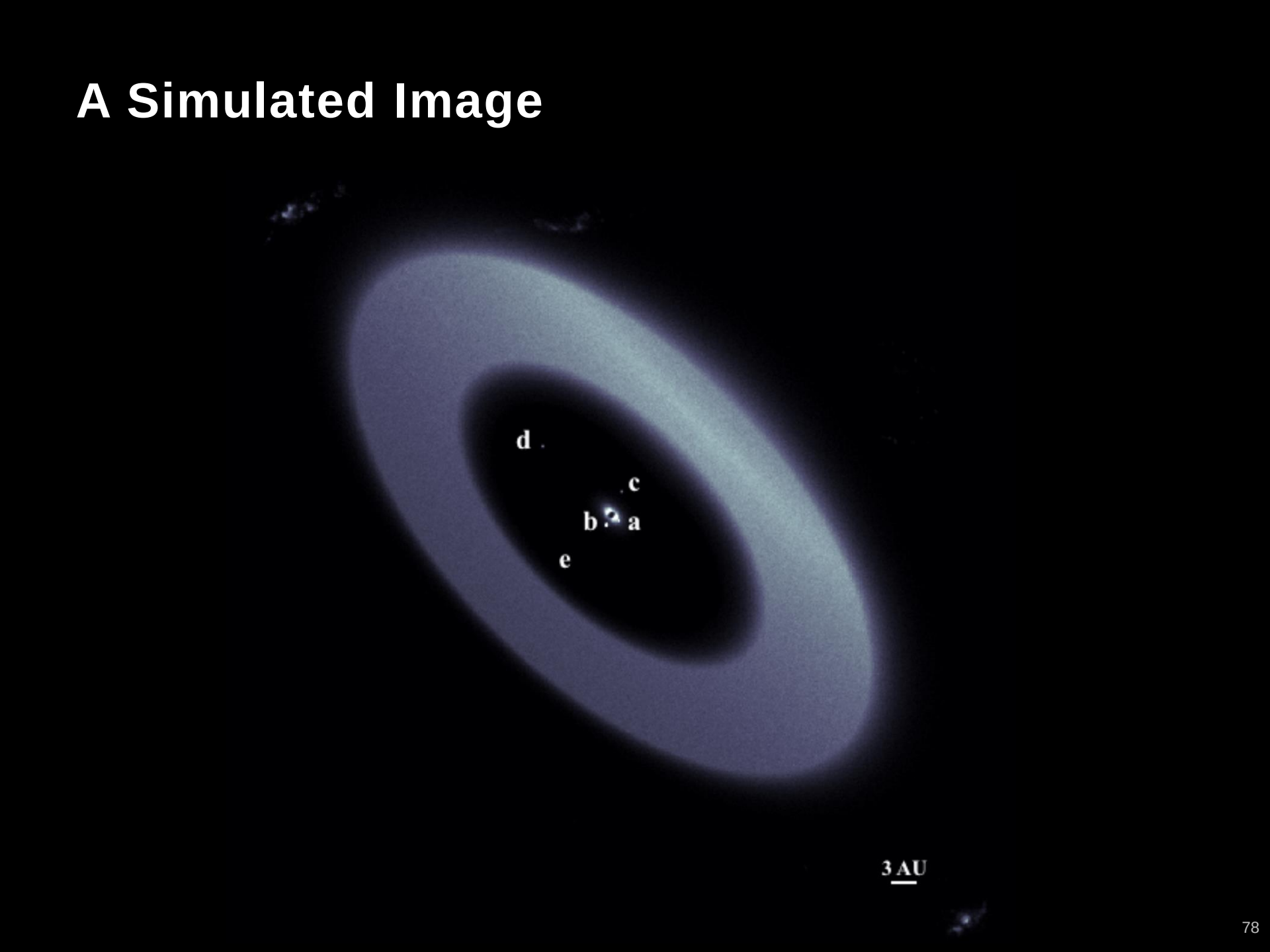


Starshade Inner Disk Deployment

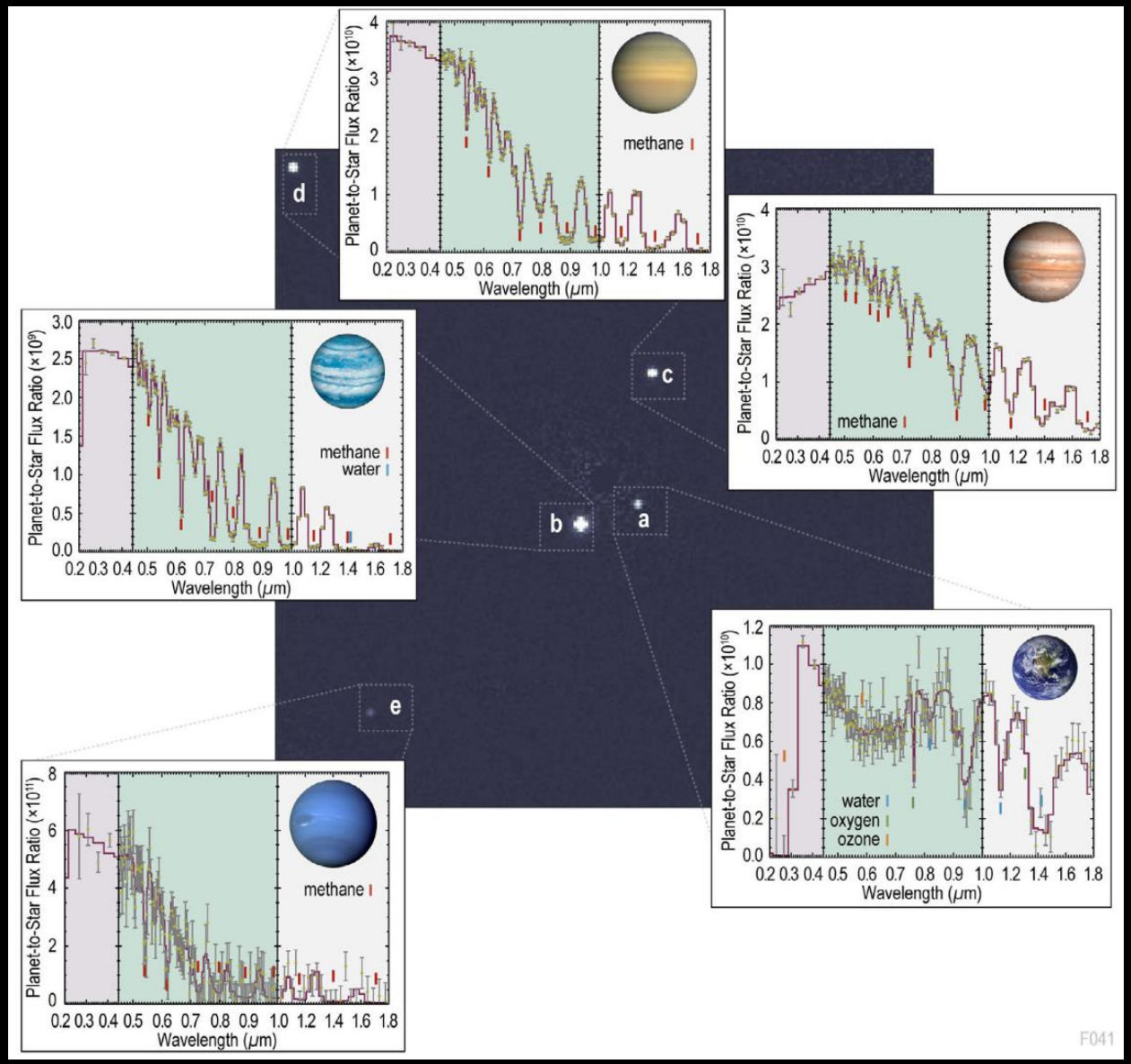
Starshade Optical Shield



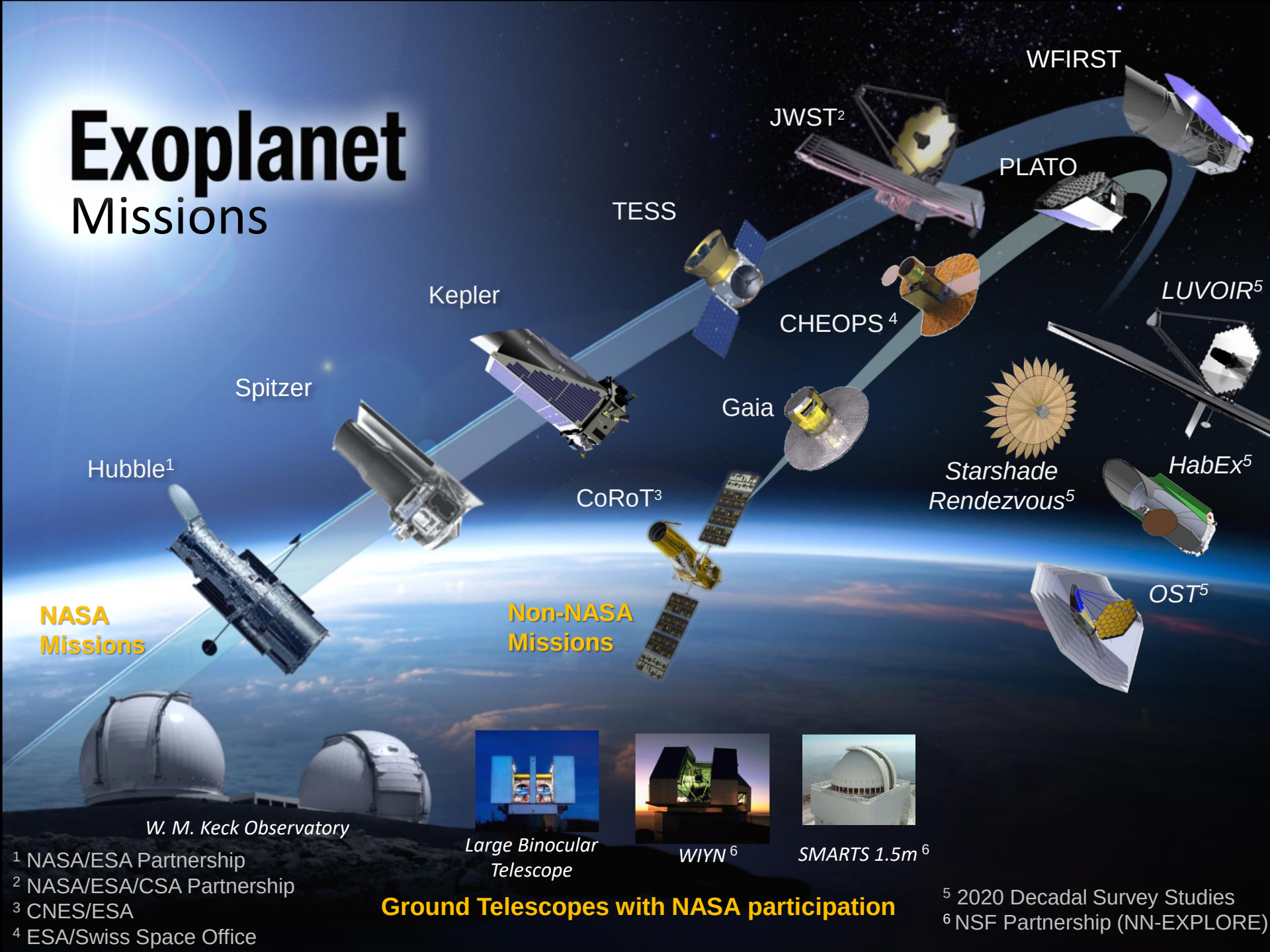
A Simulated Image



Spectra Reveals the Type of Planet



Exoplanet Missions

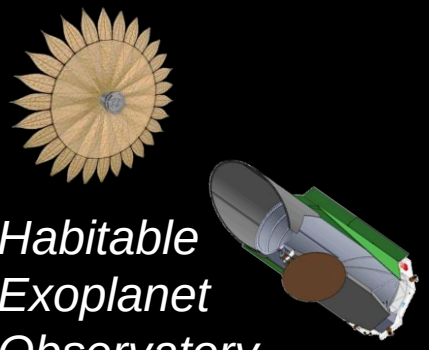


Ground Telescopes with NASA participation

[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
[4] ESA/Swiss Space Office
[5] 2020 Decadal Survey Studies
[6] NSF Partnership (NN-EXPLORE)

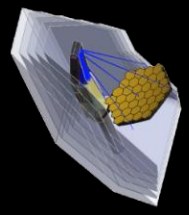
Exoplanet Mission Concepts

Large Scale



Habitable Exoplanet Observatory

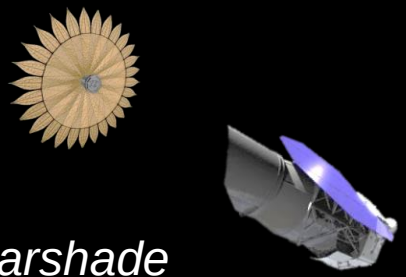
LUVOIR



Origins Space Telescope

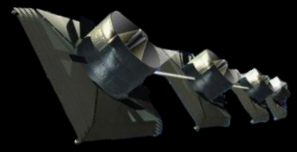
Medium Scale Concepts

EarthFinder



Starshade Rendezvous

Visionary

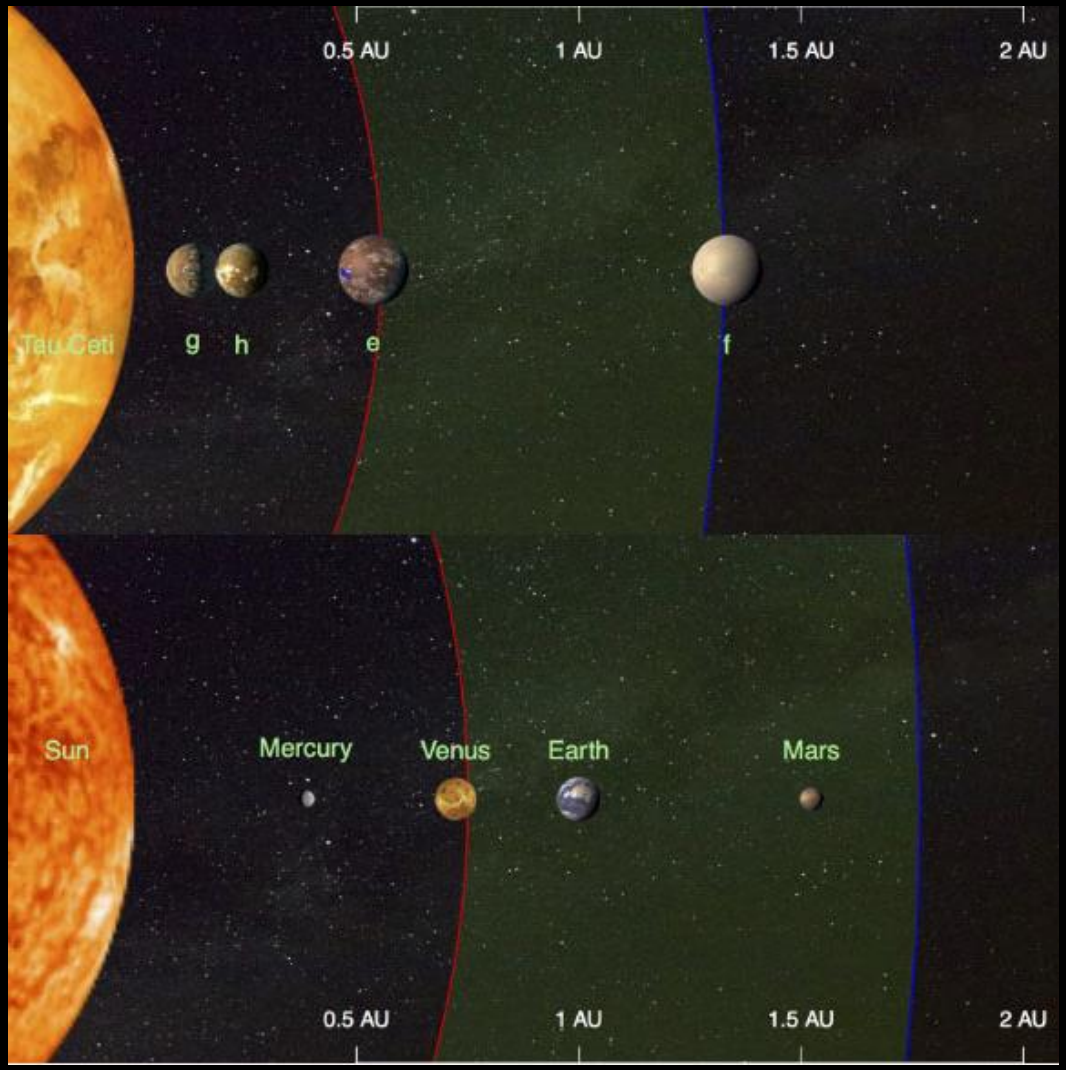


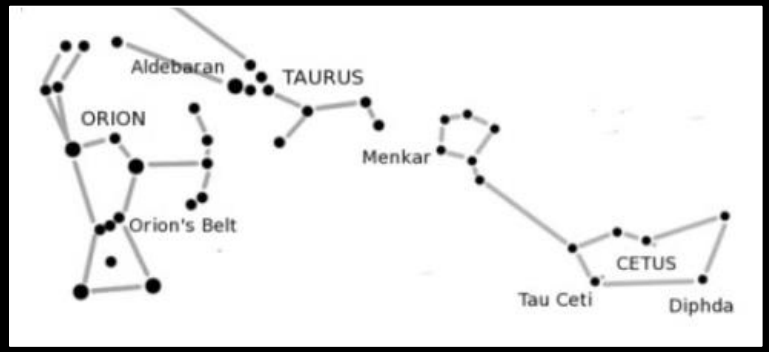
Life-Finder Interferometer

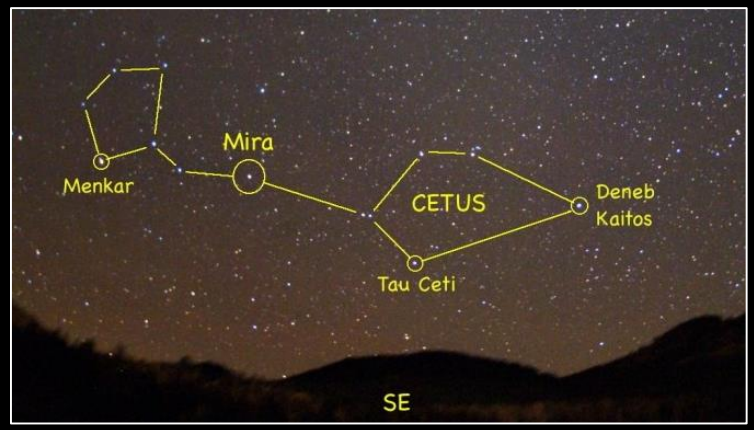
https://science.nasa.gov/astrophysics

Tau Ceti e

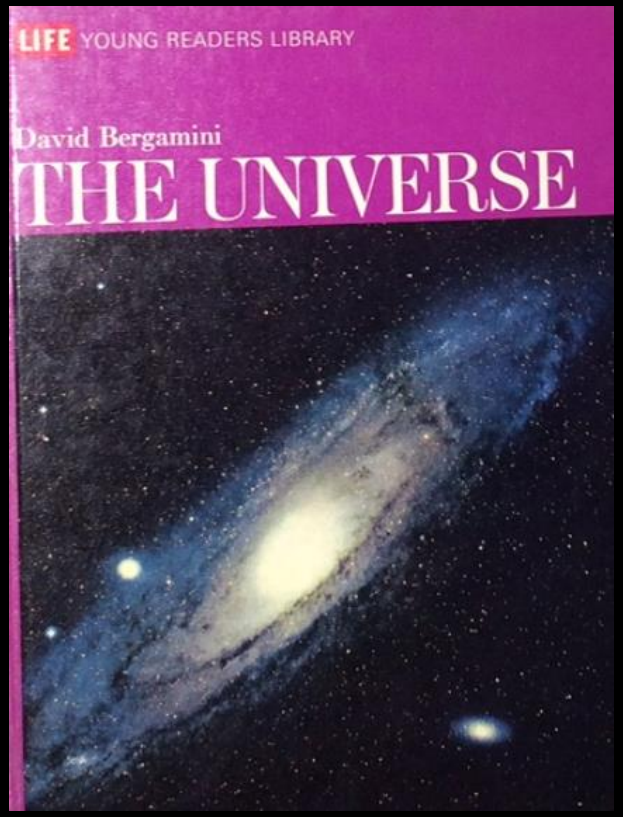
Likely Rocky Super-Earth Orbiting a Nearby Sun-like Star





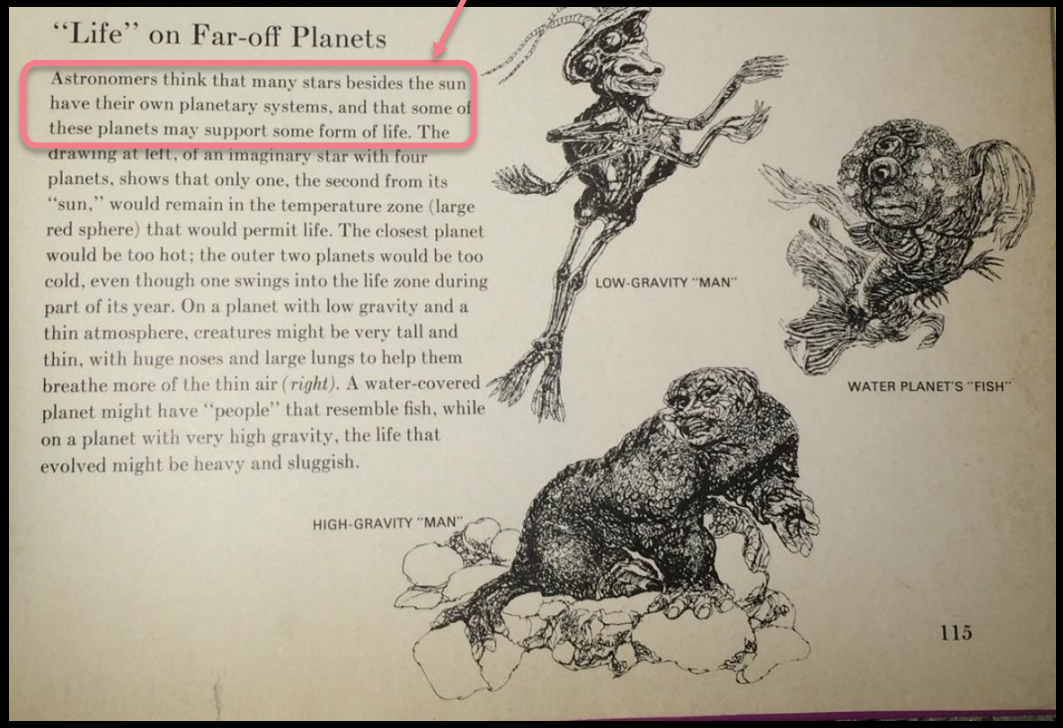


Credit: F. Feng, University of Hertfordshire



1962

"Astronomers think that many stars besides the sun have their own planetary systems, and that some of these planets may support some form of life"



"Life" on Far-off Planets

Astronomers think that many stars besides the sun have their own planetary systems, and that some of these planets may support some form of life. The drawing at left, of an imaginary star with four planets, shows that only one, the second from its "sun," would remain in the temperature zone (large red sphere) that would permit life. The closest planet would be too hot; the outer two planets would be too cold, even though one swings into the life zone during part of its year. On a planet with low gravity and a thin atmosphere, creatures might be very tall and thin, with huge noses and large lungs to help them breathe more of the thin air (*right*). A water-covered planet might have "people" that resemble fish, while on a planet with very high gravity, the life that evolved might be heavy and sluggish.

LOW-GRAVITY "MAN"

WATER PLANET'S "FISH"

HIGH-GRAVITY "MAN"

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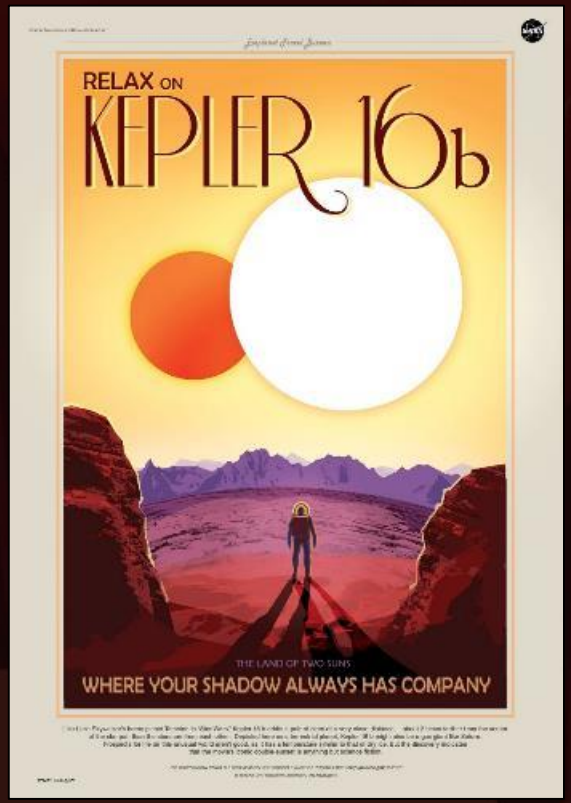
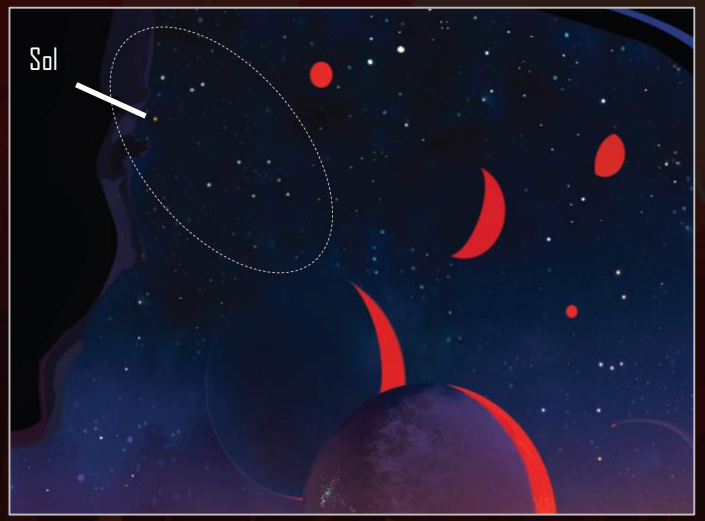
Why Explore Exoplanets?





Explore!

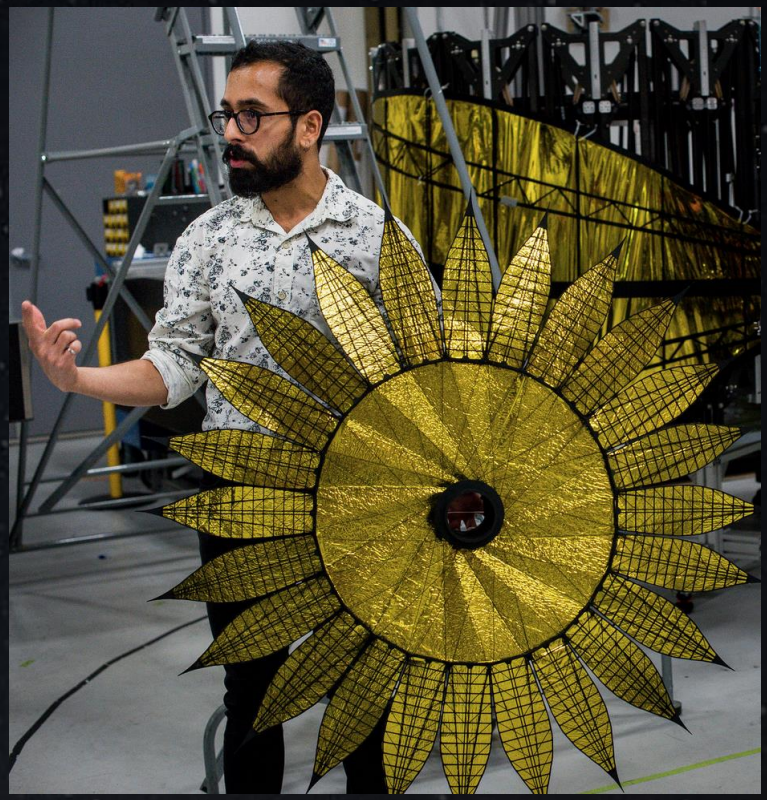
Sagan Exoplanet Summer Workshop

Caltech, Pasadena CA

- Last Year: Did I really just find an Exoplanet?
- This Year: Astrobiology for Astronomers

On the Brink: Your Path to a New World!

- Canadian Space Agency
- Space Industry
- Universities: small satellites, interdisciplinary programs
- US universities => institutions like the Jet Propulsion Laboratory



Credit: Paramount Pictures

"All these worlds are yours"

- Arthur C. Clarke

On the Brink of a New World: Outer Space!

Jet Propulsion Laboratory
California Institute of Technology

exoplanets.nasa.gov

Acknowledgements

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