Jet Propulsion Laboratory
California Institute of Technology

Exoplanets and the Search for Life in our Galaxy

Ray Lemus, Business Manager

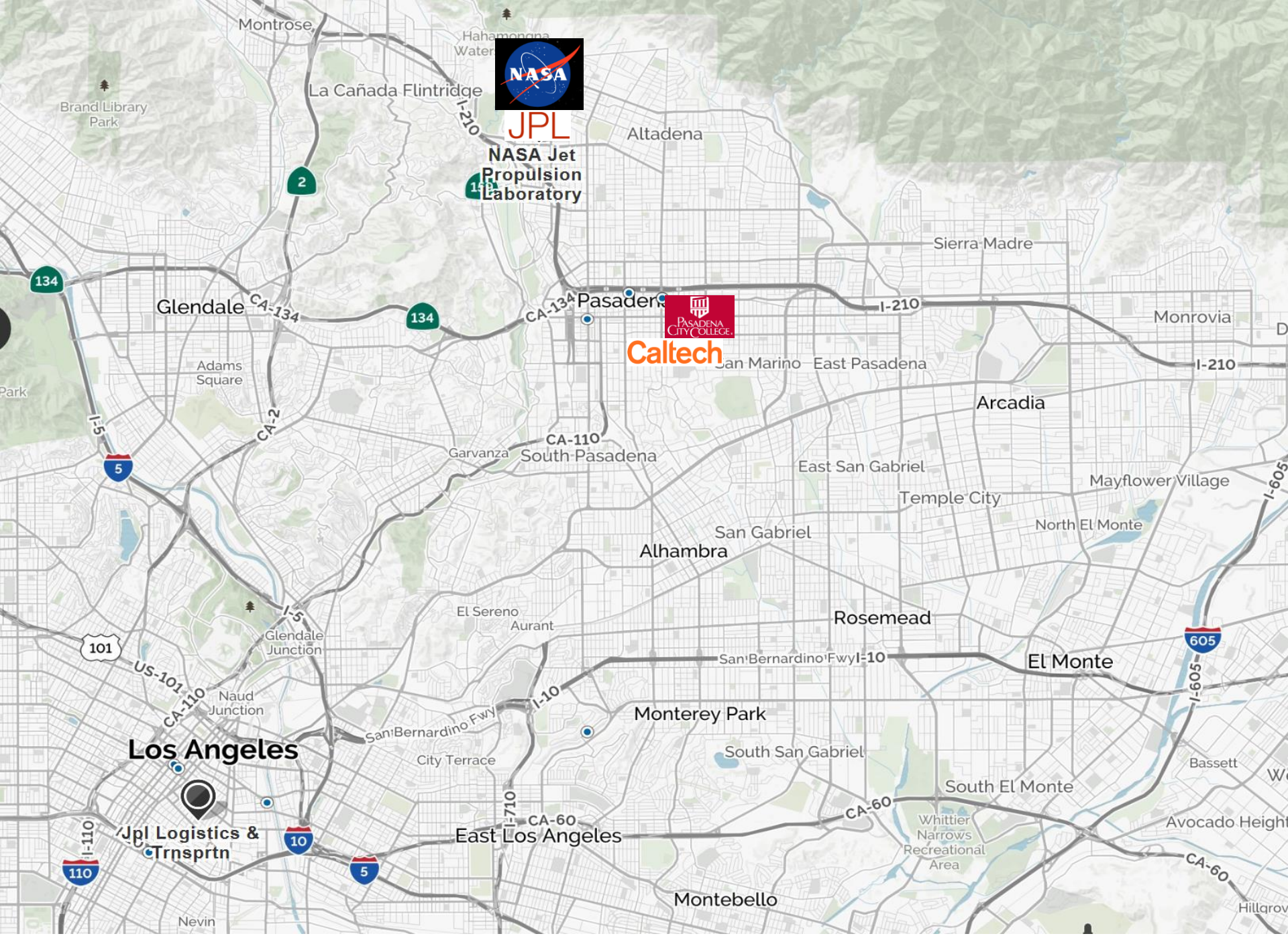
NASA Exoplanet Exploration Program

February 10, 2016

Pasadena City College

Agenda

- NASA's ExoPlanet Exploration Program
  - NASA and JPL
  - Program's Purpose
  - Approaches to search for Life in our Galaxy
  - How to Find Exoplanets
  - Amazing Results
  - Conclusions
  - Thoughts
  - More Q&Aliens



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NASA

Government Agency for

Aeronautics, Space Exploration and Earth Science

Caltech

Educational Institution

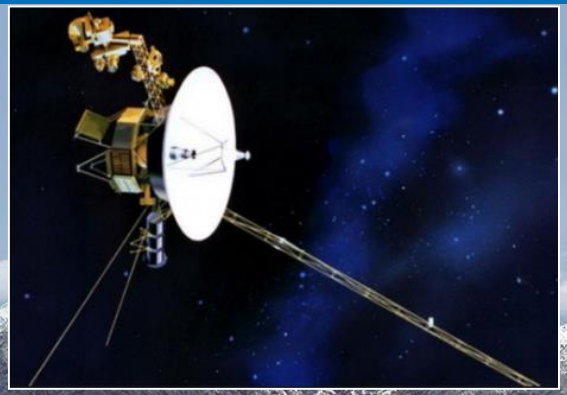
Jet Propulsion Laboratory

Operating Division of Caltech;

Federally Funded Research & Development Center

JPL has expertise in:

- Science
- Engineering
- Technology
- Programs/projects



FILM
VIBE

The NASA Exoplanet Exploration Program

Purpose described in
2014 NASA Science Plan

1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

The Search for Life in our Galaxy

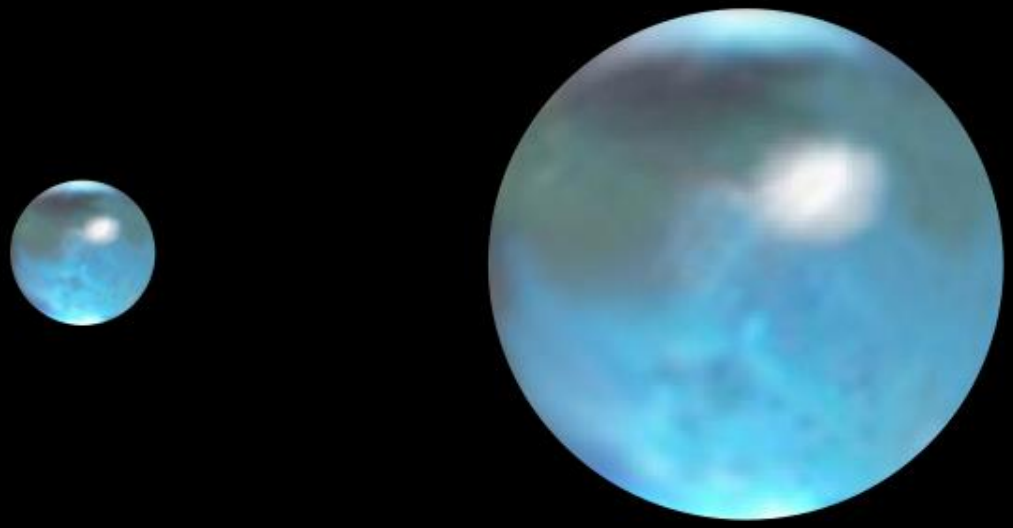
What we Know

Approach #1
The Search for Life in our Solar System

NASA/JPL-Caltech/Ken Kremer- kenkremer.com/Marco Di Lorenzo

Ocean Worlds

Credit: Kevin Hand



Earth

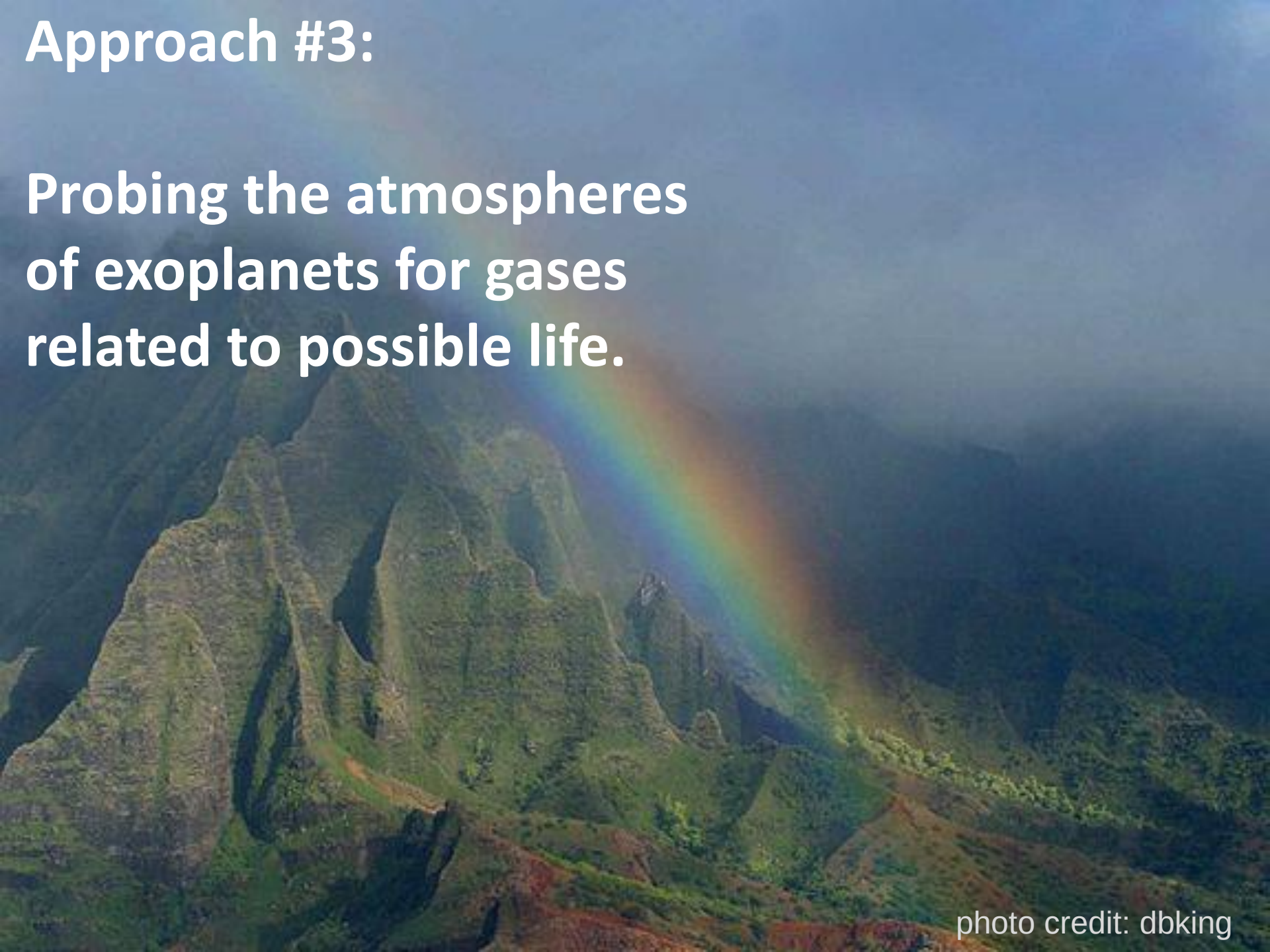
Ice-covered moons

Ocean Worlds

Credit: Kevin Hand

Approach #2

Listening and watching for signs of intelligent life



Approach #3:

Probing the atmospheres of exoplanets for gases related to possible life.

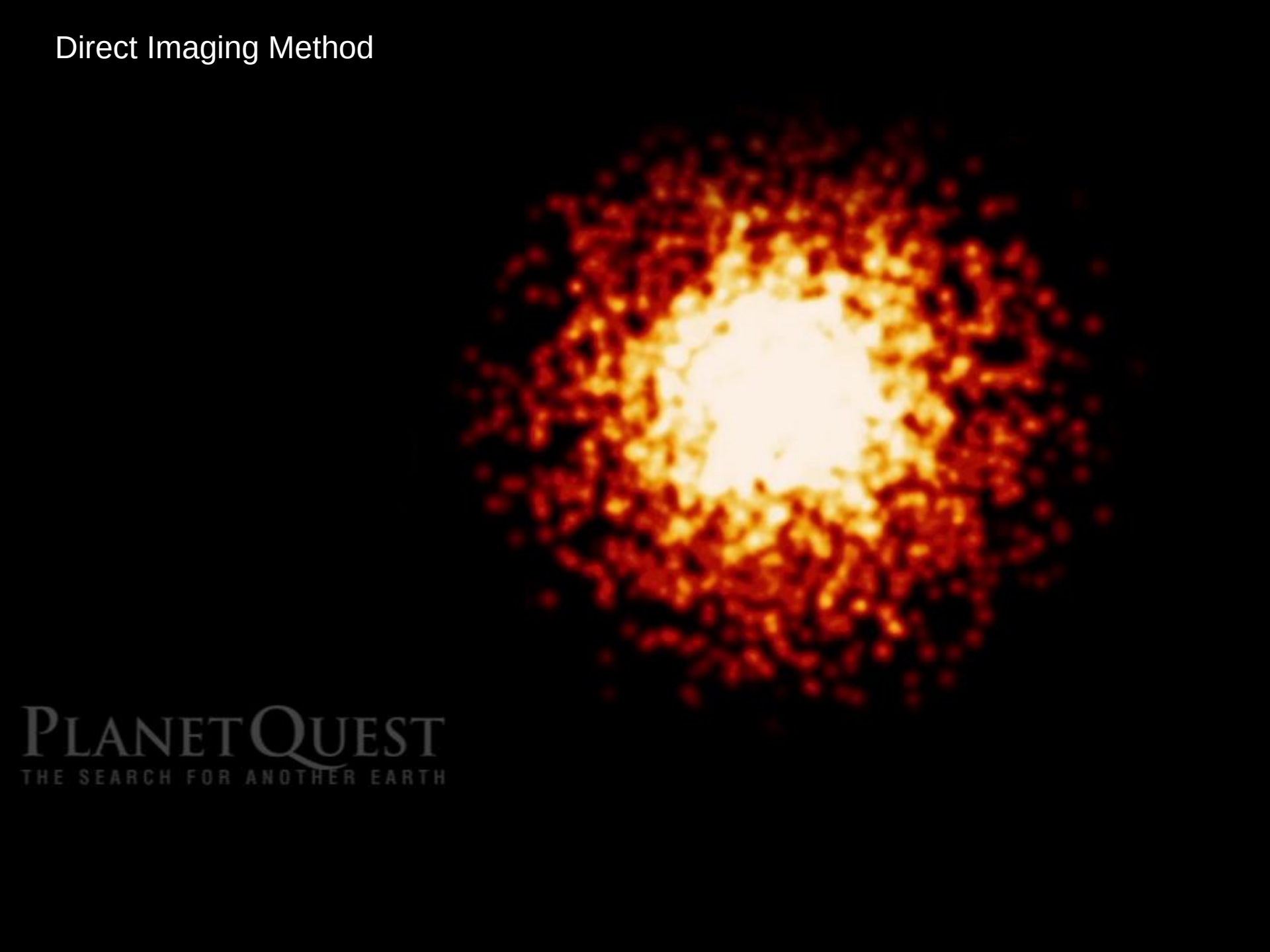
photo credit: dbking

1. Finding Exoplanets

Exoplanets 20/20

Transit Method

Direct Imaging Method



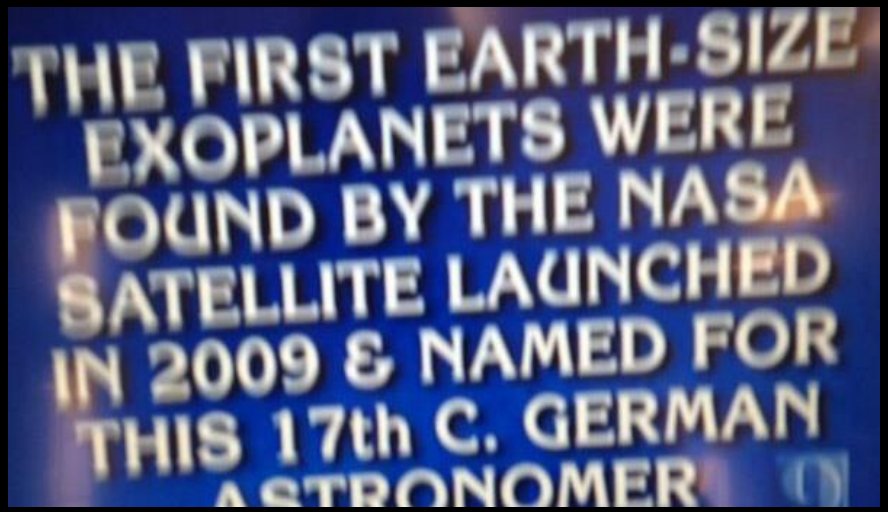
Radial Velocity Method

Gravitational Microlensing Method

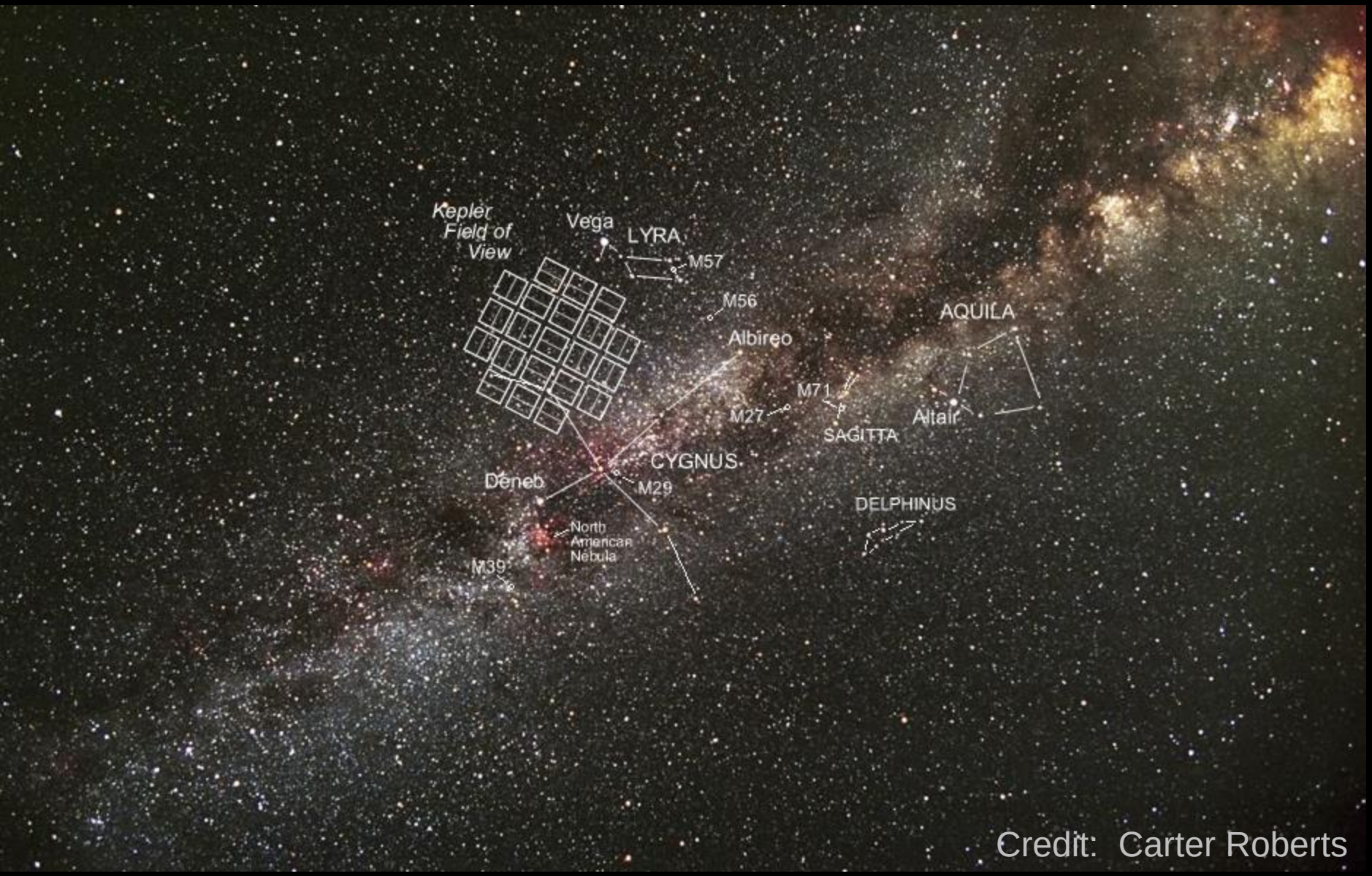
PlanetQuest
THE SEARCH FOR ANOTHER EARTH

Exoplanets for $1000, please!

May 2014

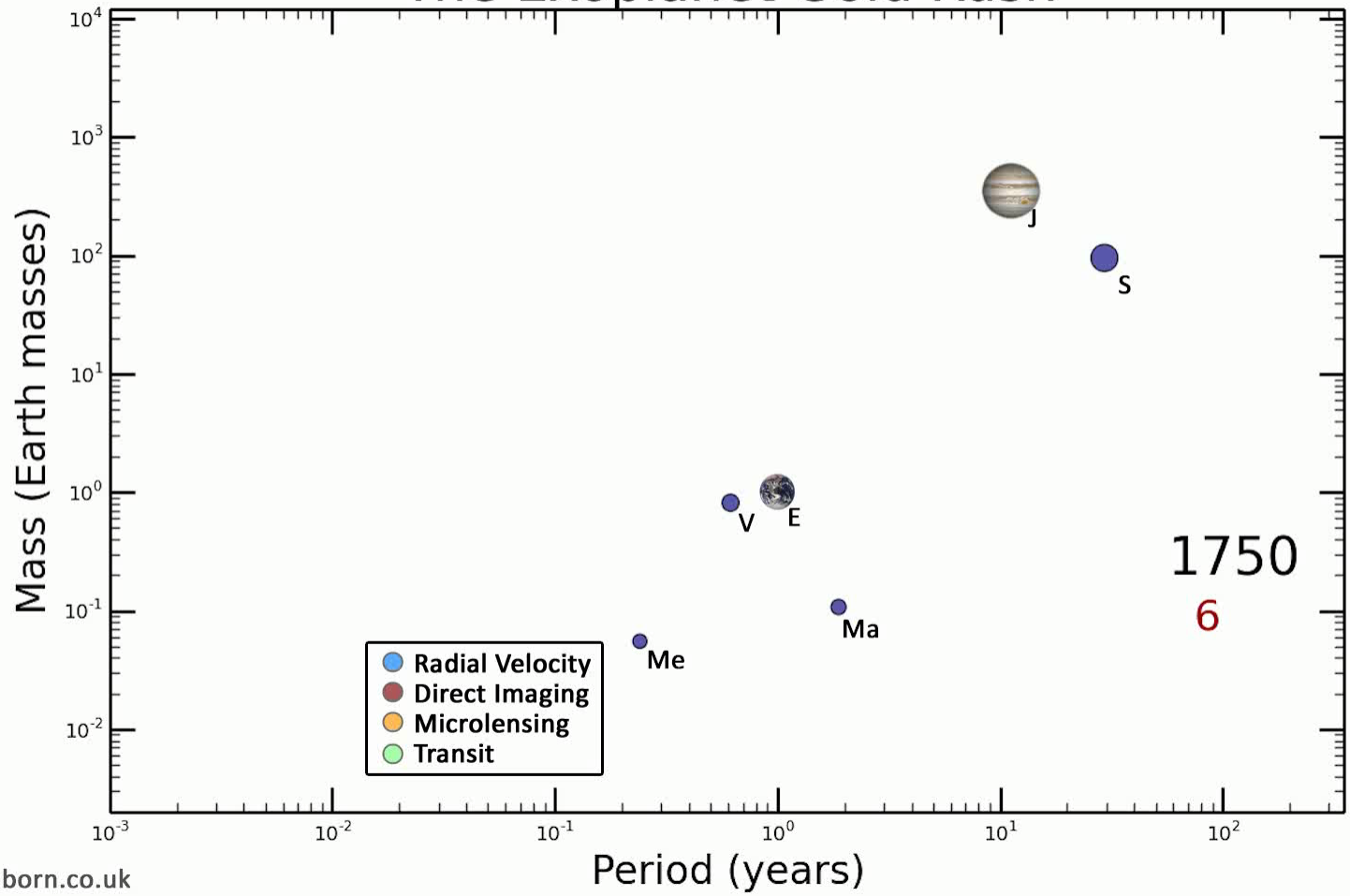


Kepler Field



Credit: Carter Roberts

The Exoplanet Gold Rush



www.hughosborn.co.uk

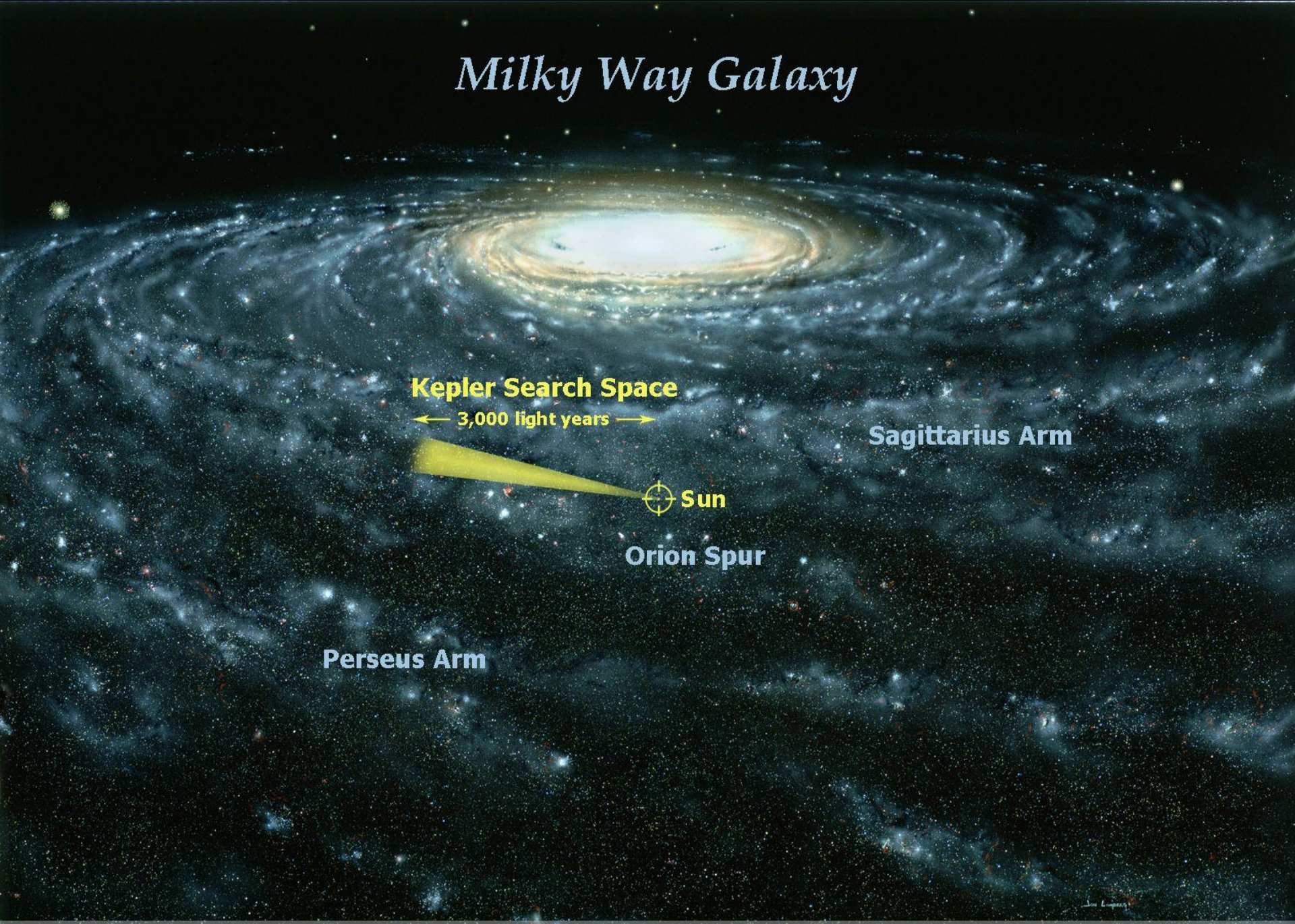
Kepler’s Amazing Results:

1

Planets orbiting other stars in the Galaxy are common

.

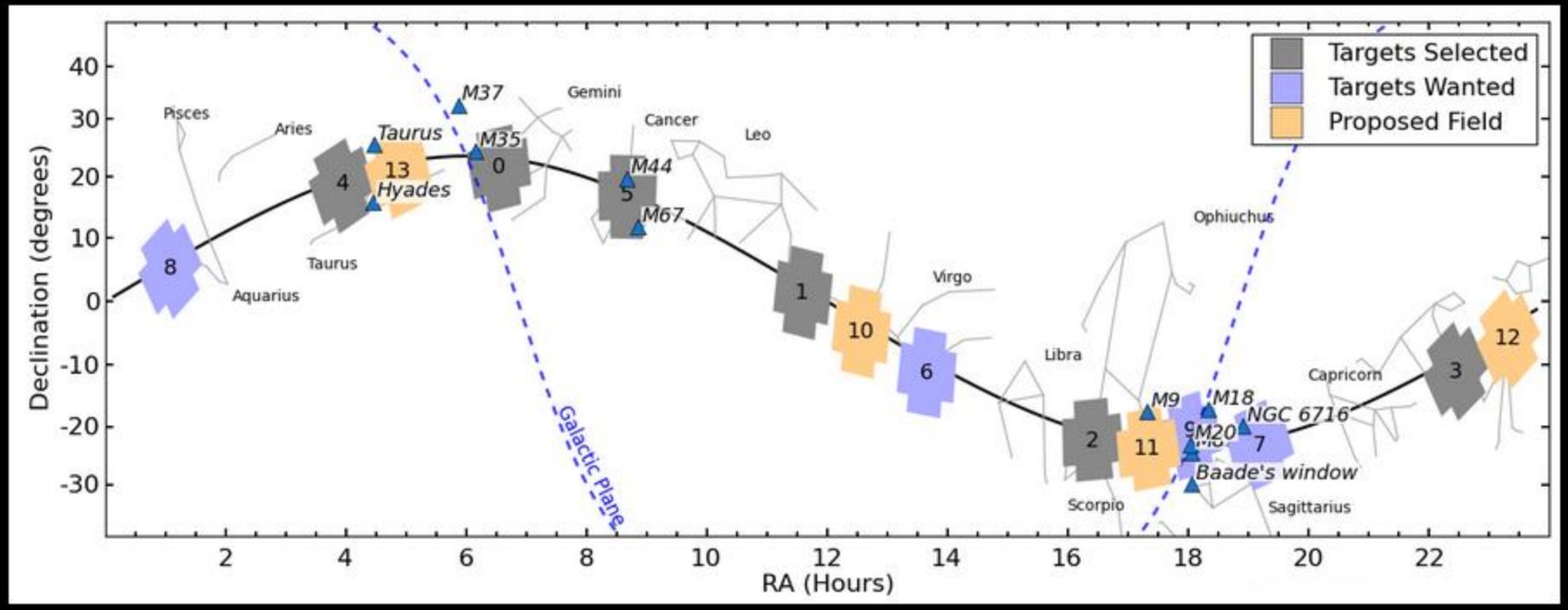
> 400 billion planets in our Galaxy



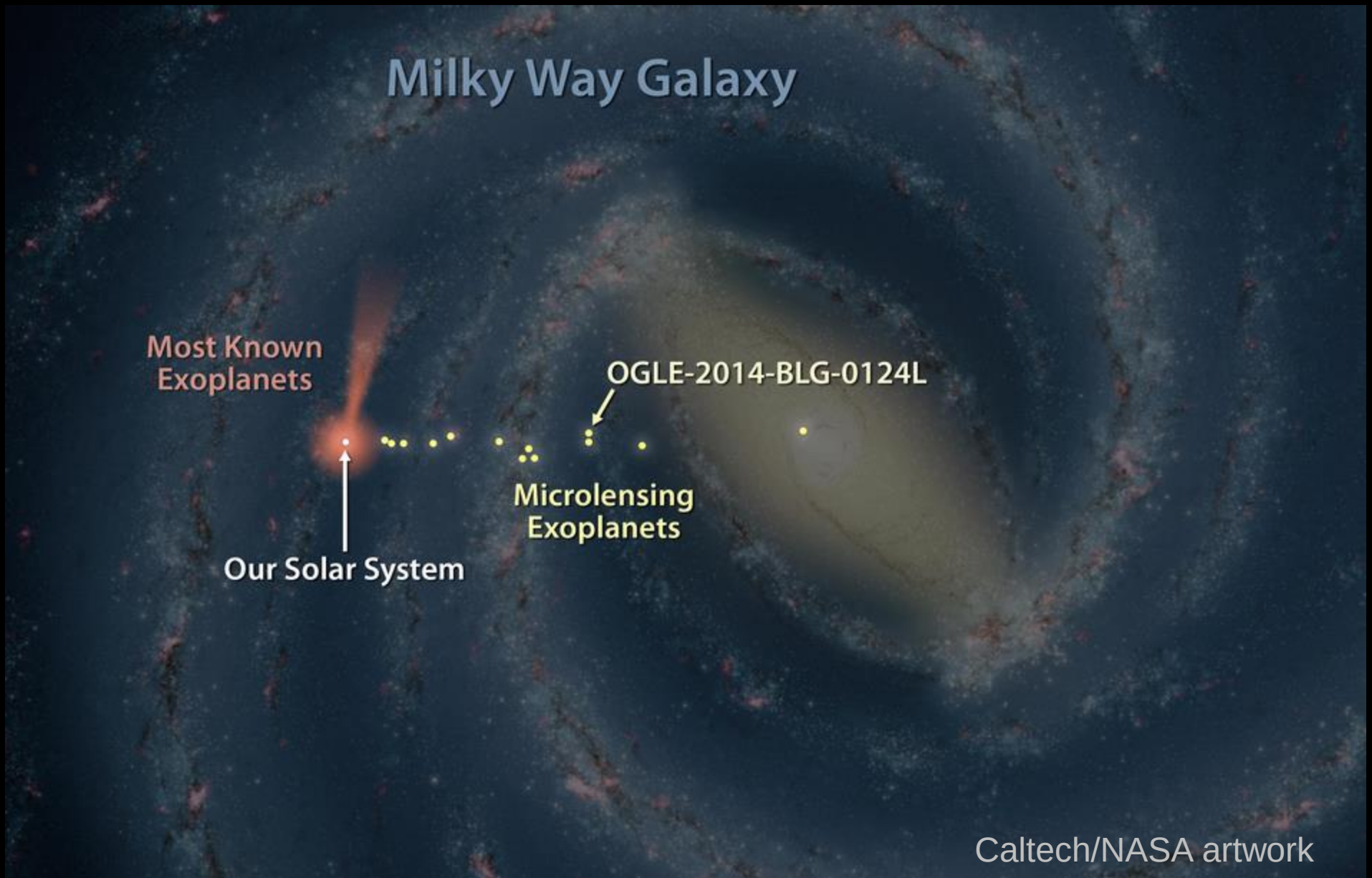
NASA Kepler Mission/Dana Berry

K2

Extending Kepler's Power to the Ecliptic

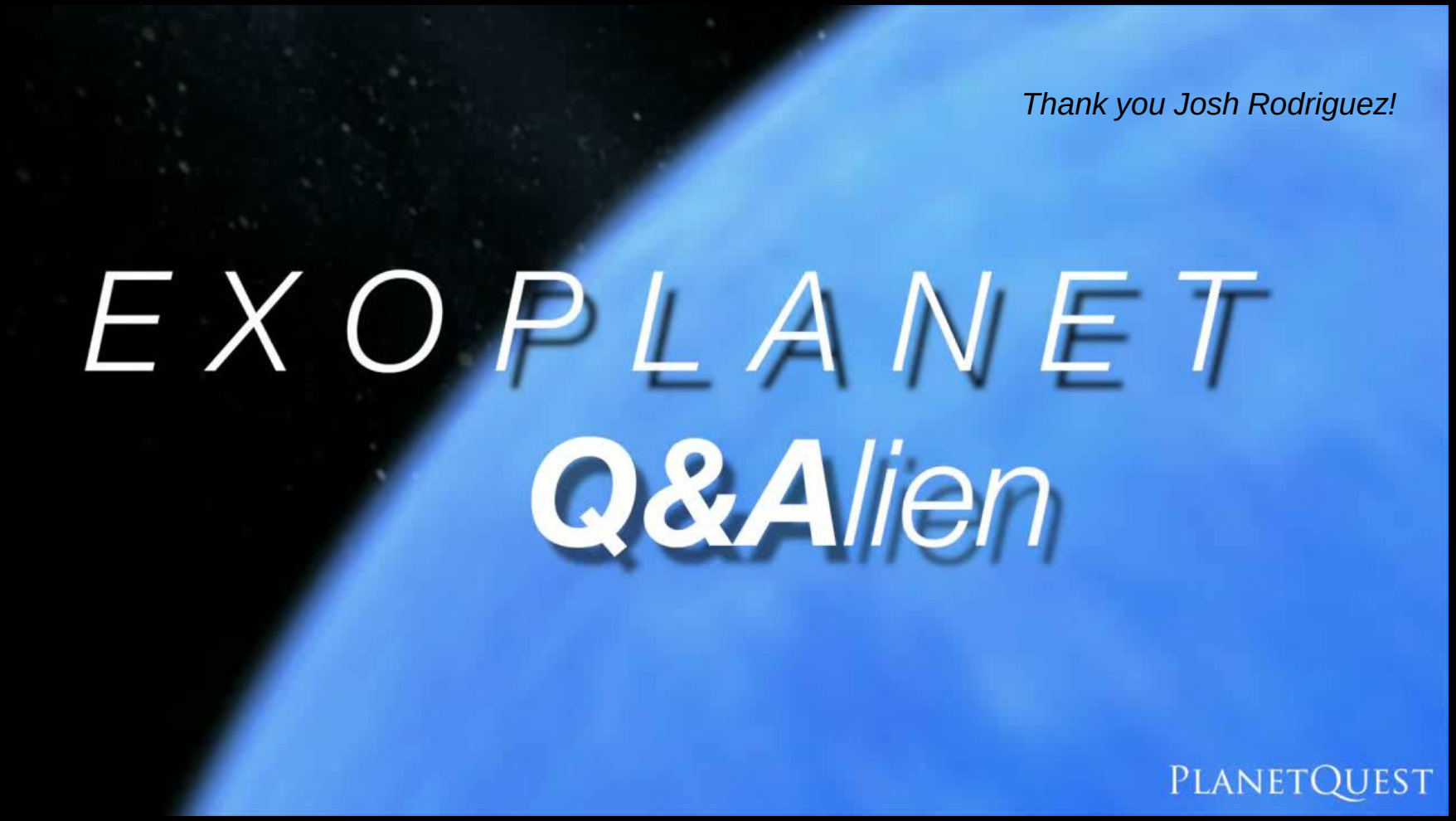


Where are the discovered Exoplanets?



Caltech/NASA artwork

Q&Alien Video Series: Exoplanet Names

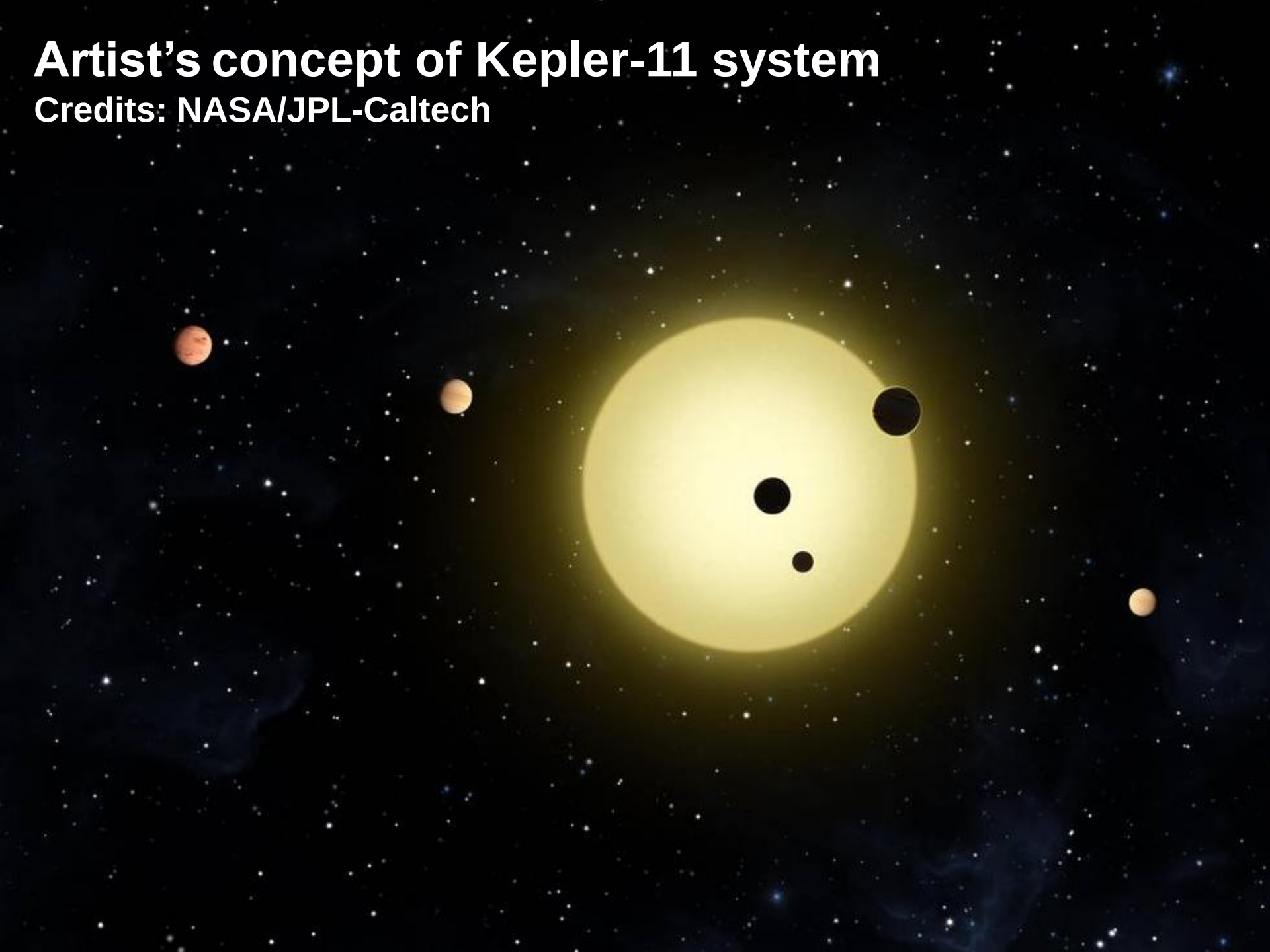


Thank you Josh Rodriguez!

2. What are Exoplanets Like?

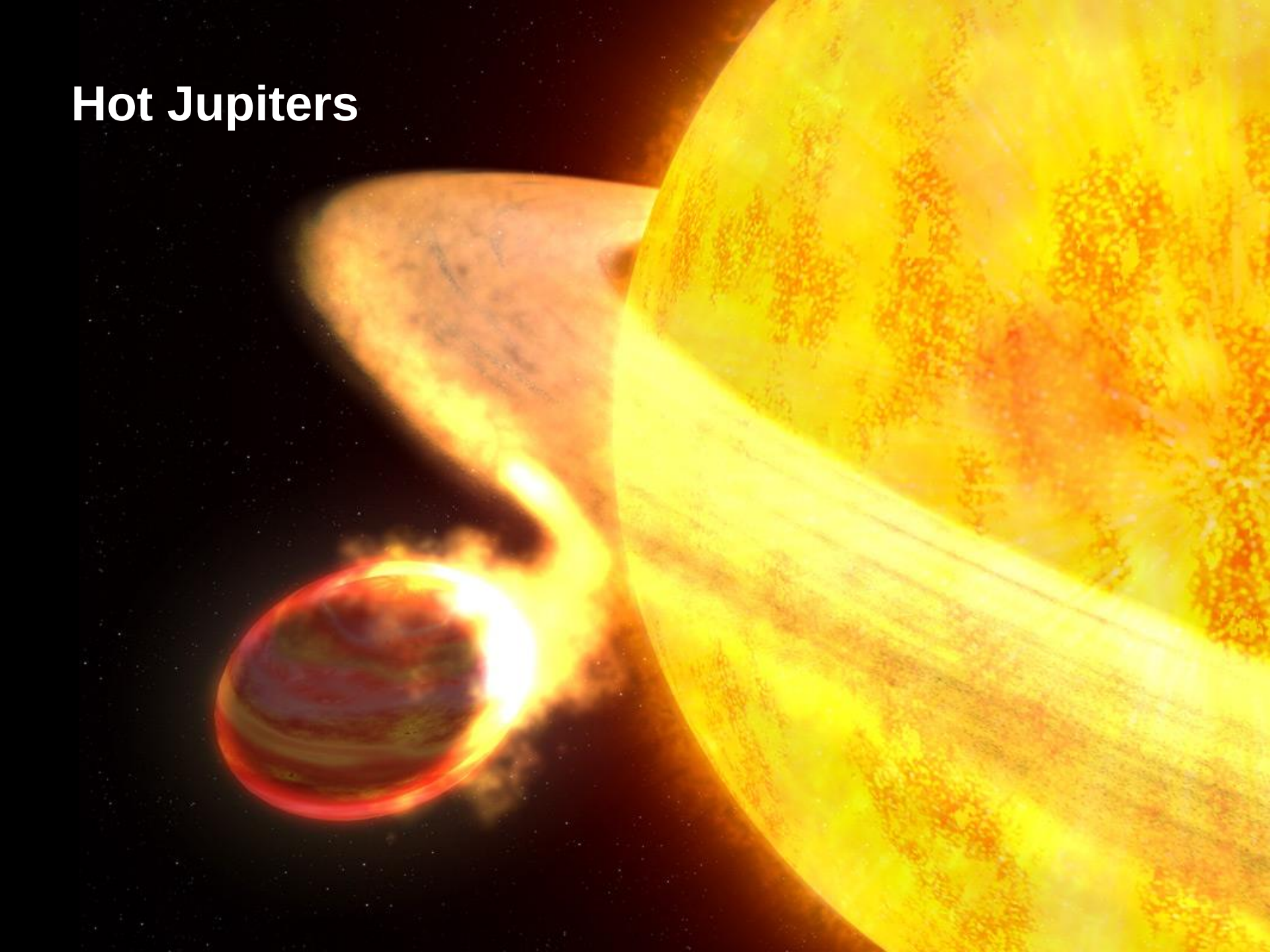
Artist’s concept of Kepler-11 system

Credits: NASA/JPL-Caltech



Planetary object transiting a white dwarf

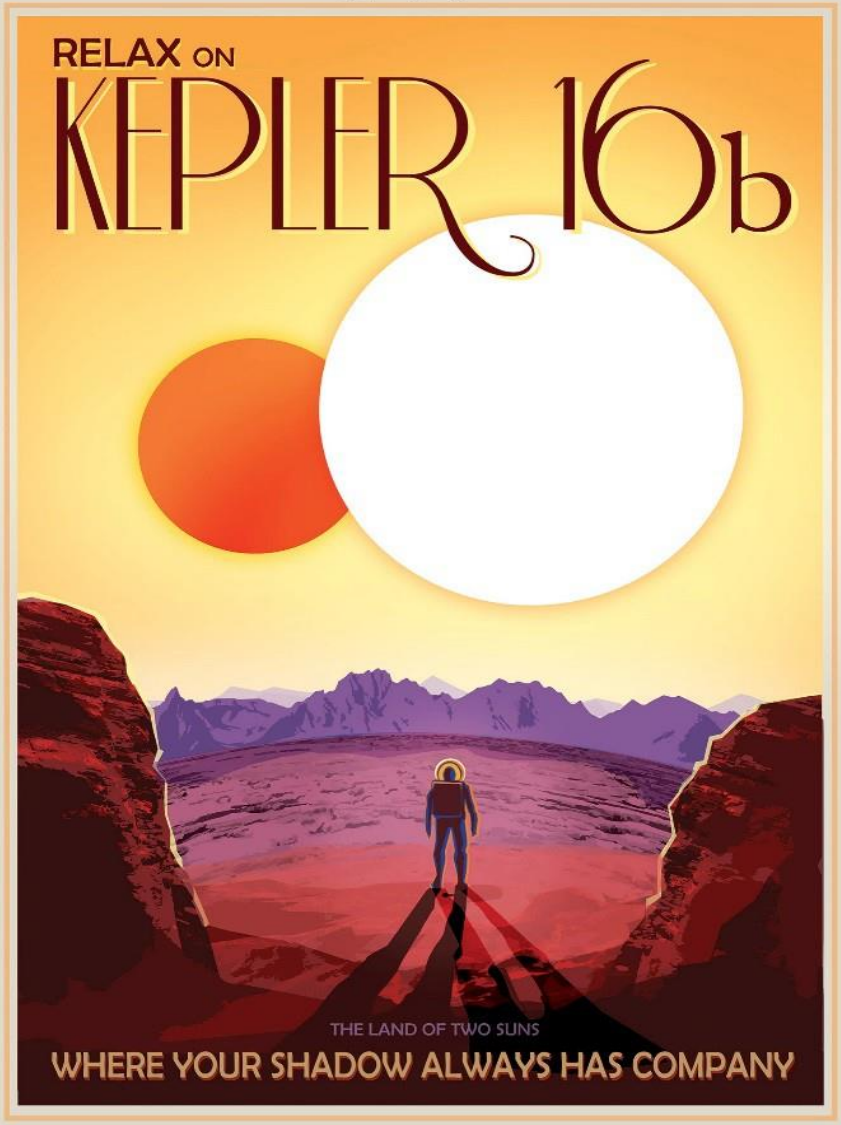
Hot Jupiters



Planets with Two Stars

National Aeronautics and Space Administration

Exoplanet Travel Bureau



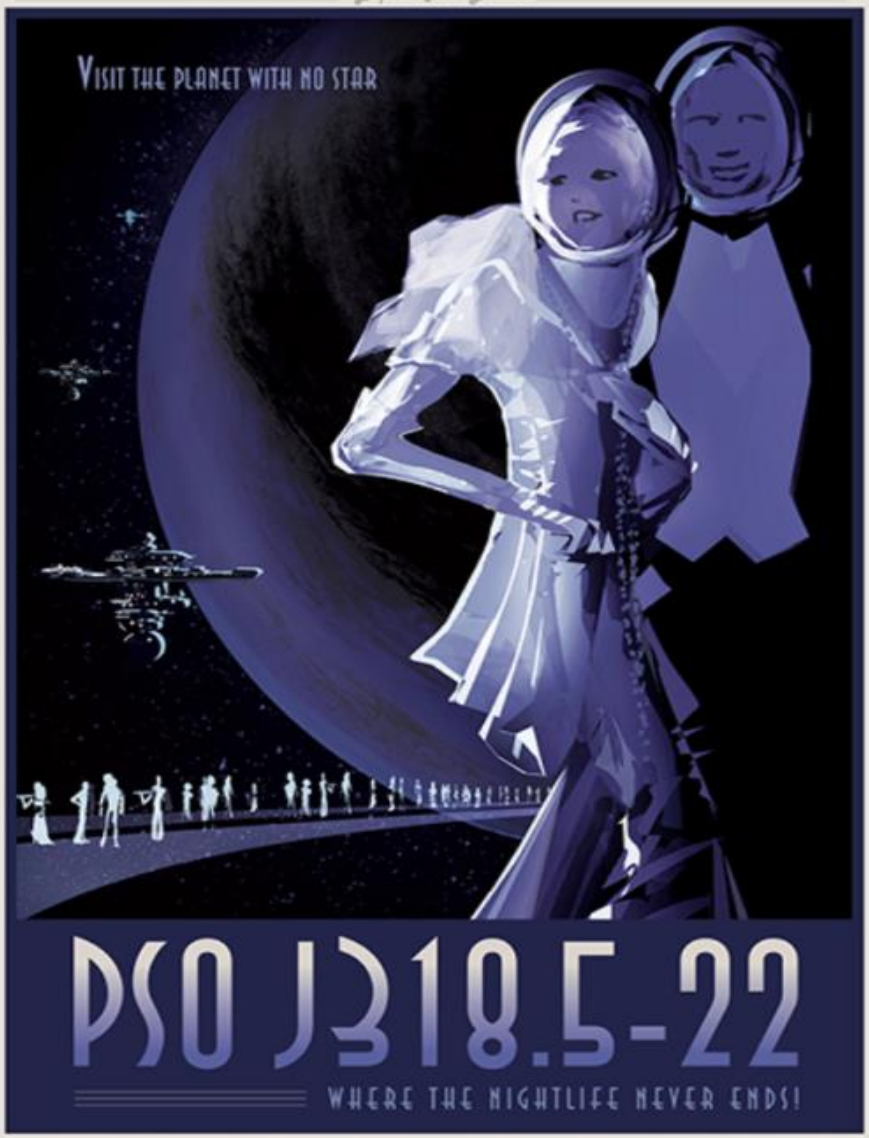
Like Luke Skywalker's home planet Tatooine in "Star Wars," Kepler 16 b orbits a pair of stars at a very close distance -- about 3 times farther from the center of the star pair than the stars are from each other. Depicted here as a terrestrial planet, Kepler 16 b might also be a gas giant like Saturn. Prospects for life on this unusual world aren't good, as it has a temperature similar to that of dry ice. But the discovery indicates that the movie's iconic double-sunset is anything but science fiction.

*The **Travel Bureau Series** is a product of NASA's Exoplanet Exploration Program Office (**exep.jpl.nasa.gov**) located at NASA's Jet Propulsion Laboratory (**jpl.nasa.gov**).*

www.nasa.gov

Nomad planets: not bound to any star at all!

Exoplanet Travel Bureau

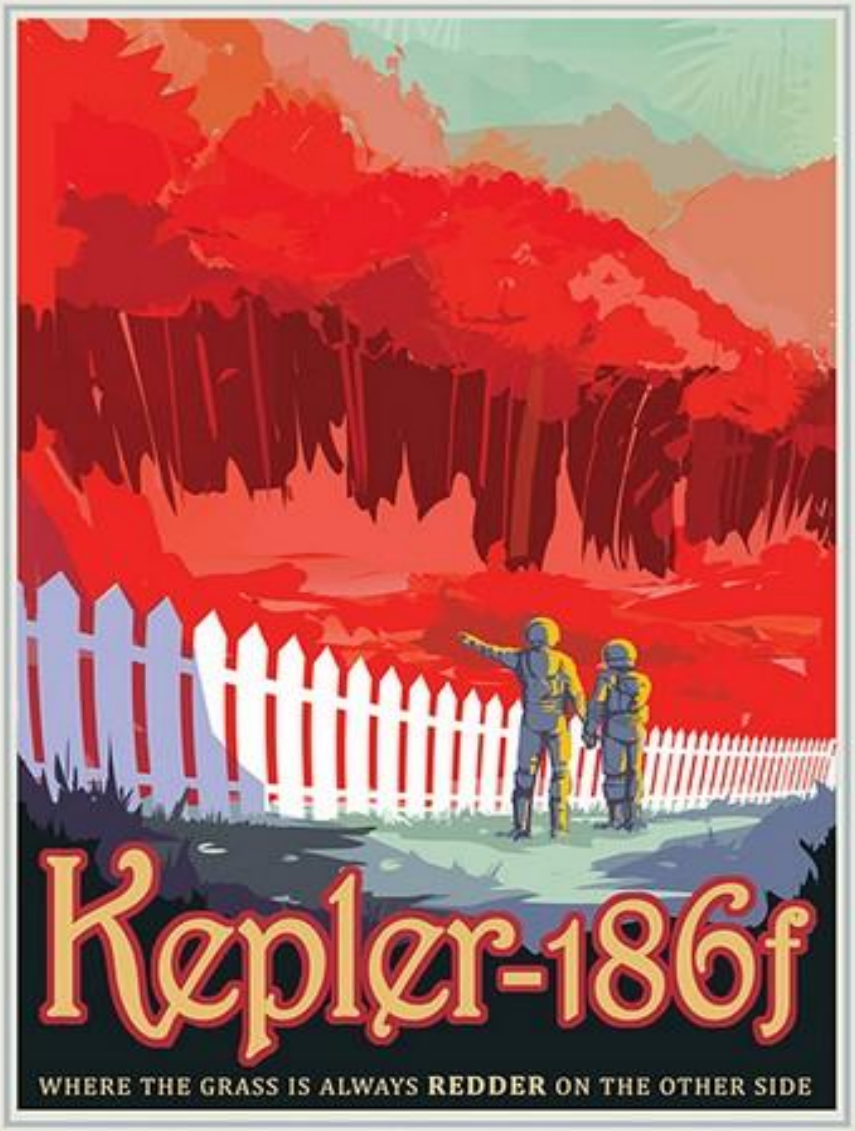


Discovered in October 2013 using direct imaging, PSO J318.5-22 belongs to a special class of planets called rogue, or free-floating, planets. Wandering alone in the galaxy, they do not orbit a parent star. Not much is known about how these planets come to exist, but scientists theorize that they may be either failed stars or planets ejected from very young systems after an encounter with another planet. These rogue planets glow faintly from the heat of their formation. Once they cool down, they will be dancing in the dark. Confirmed and candidate exoplanets and all available data are listed in the NASA Exoplanet Archive.

NASA's Exoplanet Exploration Program, Jet Propulsion Laboratory, Pasadena CA
www.jpl.nasa.gov

www.nasa.gov

Kepler-444

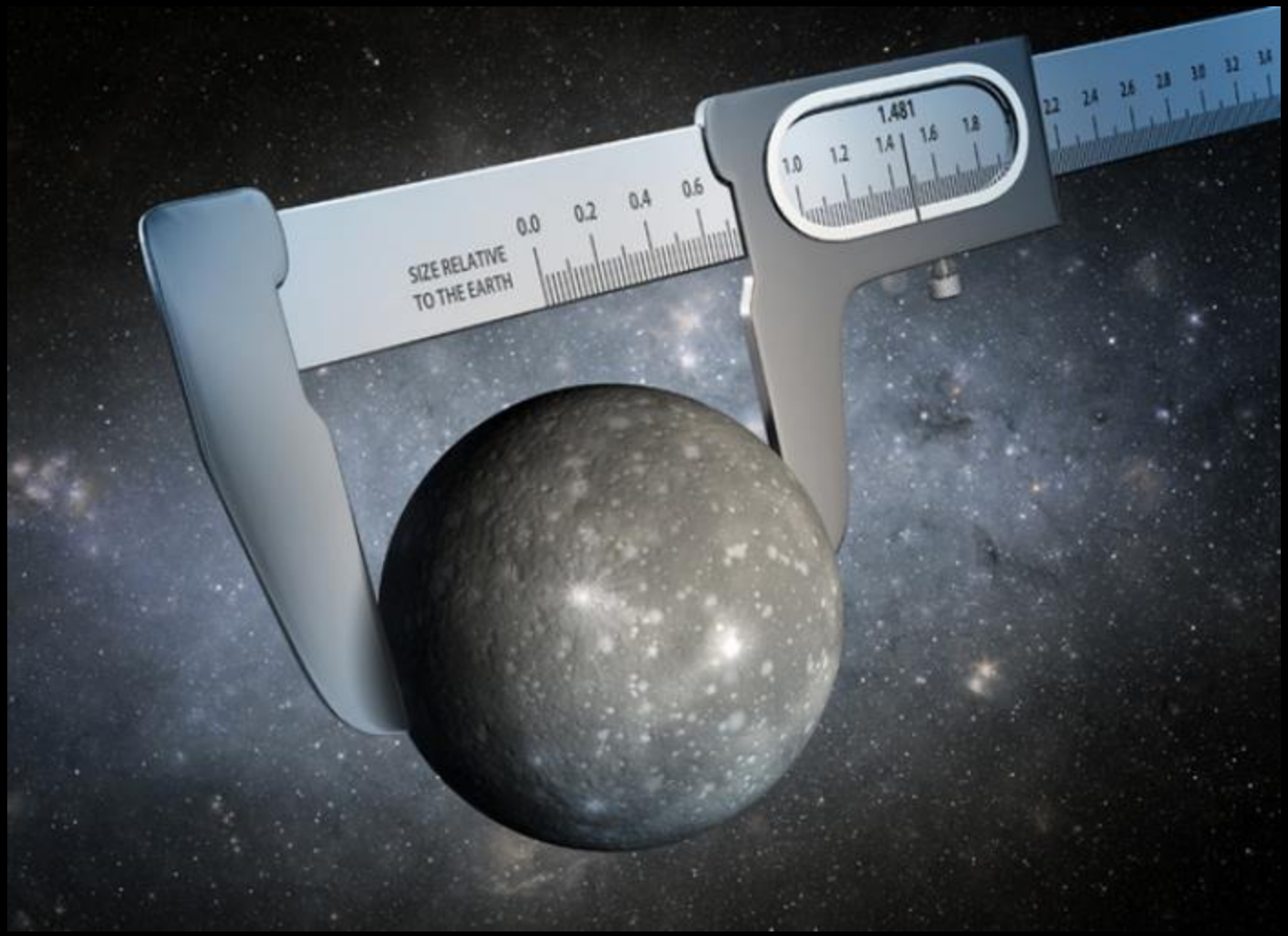

Kepler-186f
WHERE THE GRASS IS ALWAYS REDDER ON THE OTHER SIDE

Let’s visit *Kepler-186f* !

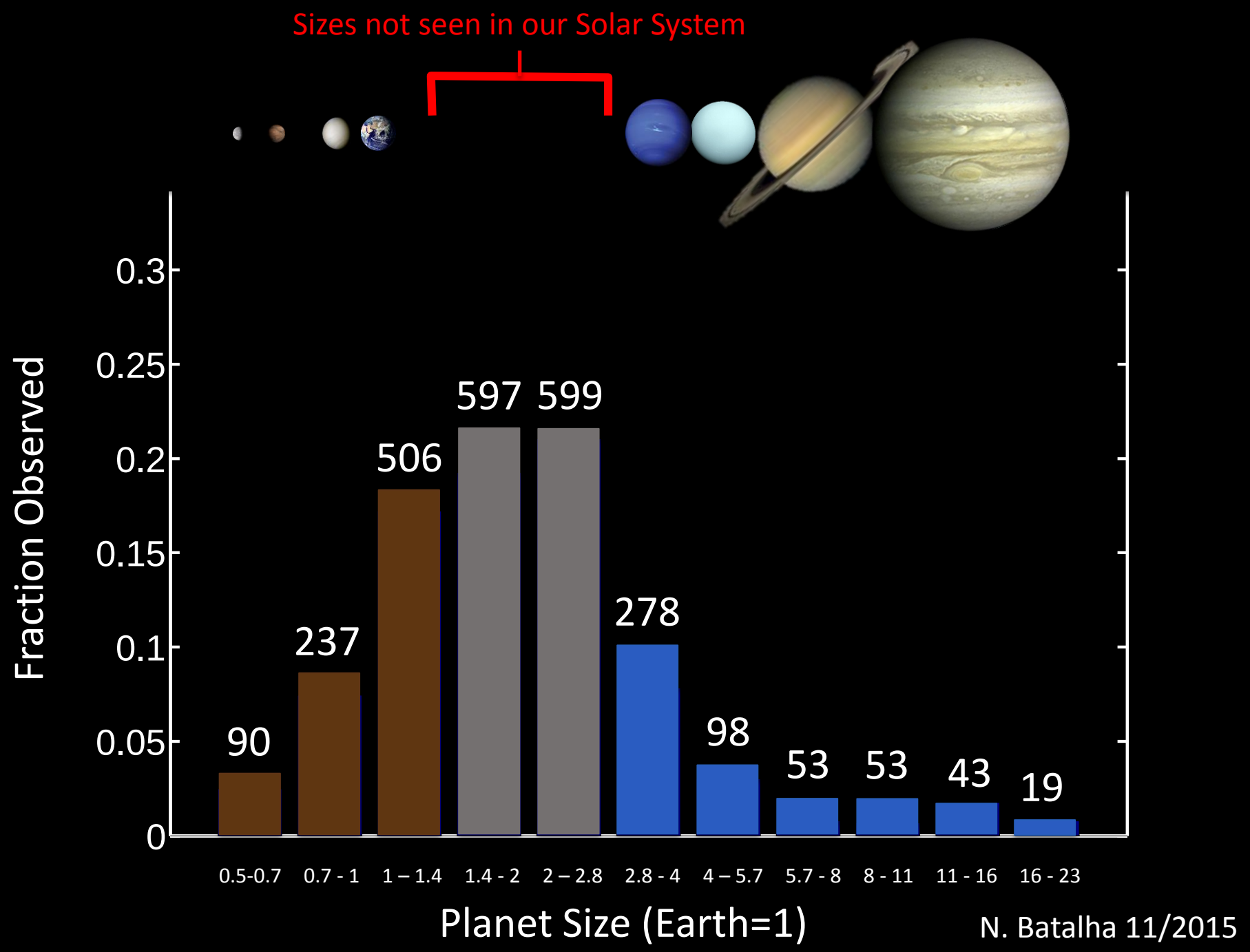
Latest Travel Poster

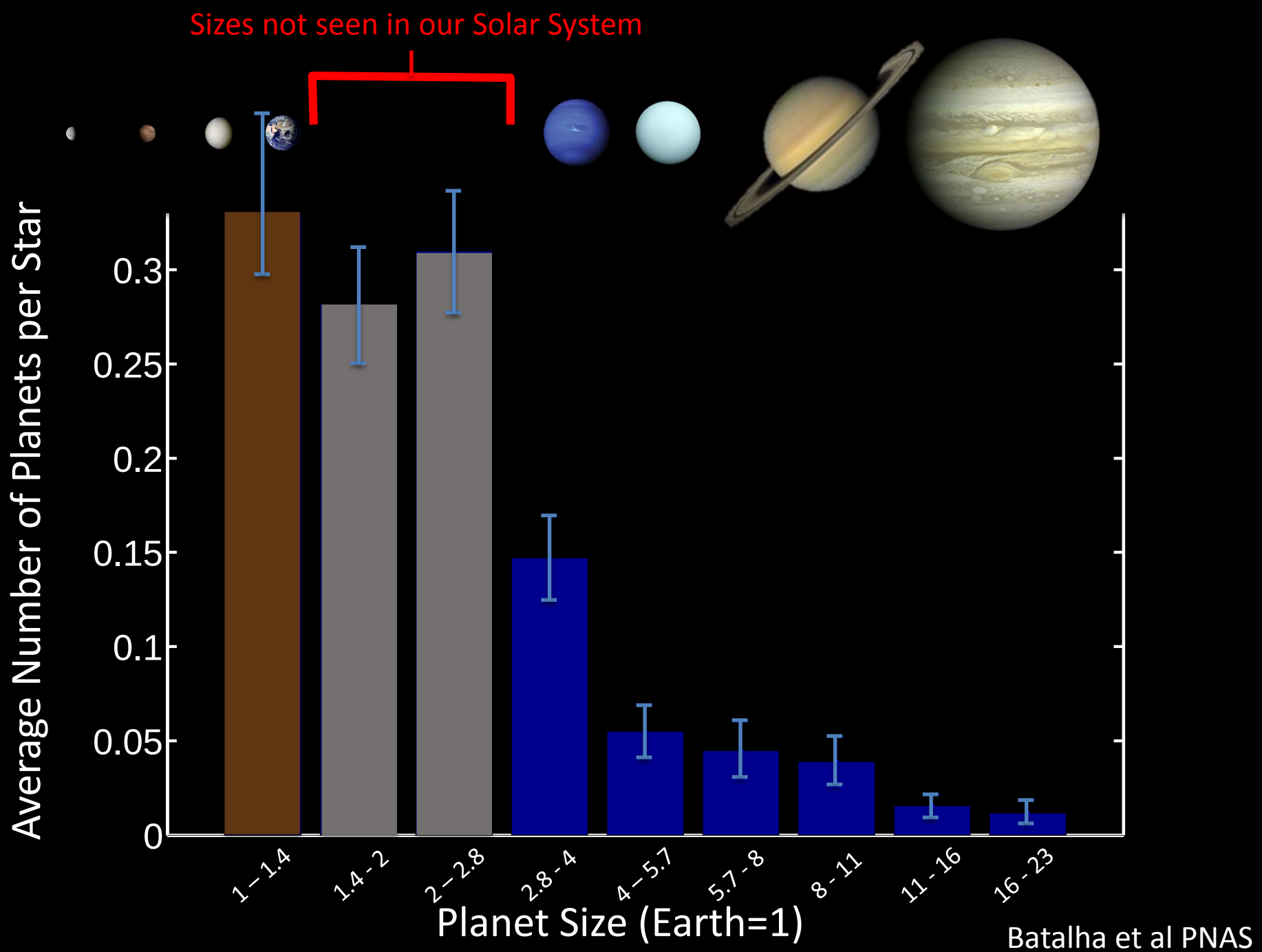
Commemorating the 20th Anniversary of the Discovery of the First Exoplanet (10-6-1995)

Gauging the Size of Alien Worlds



Credit NASA/JPL-Caltech


Sizes not seen in our Solar System
Fraction Observed
0.3
0.25
0.2
0.15
0.1
0.05
0
90
237
506
597
599
278
98
53
53
43
19
0.5-0.7
0.7 - 1
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)
N. Batalha 11/2015


Sizes not seen in 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)
Batalha et al PNAS

Kepler's Amazing Results:

1

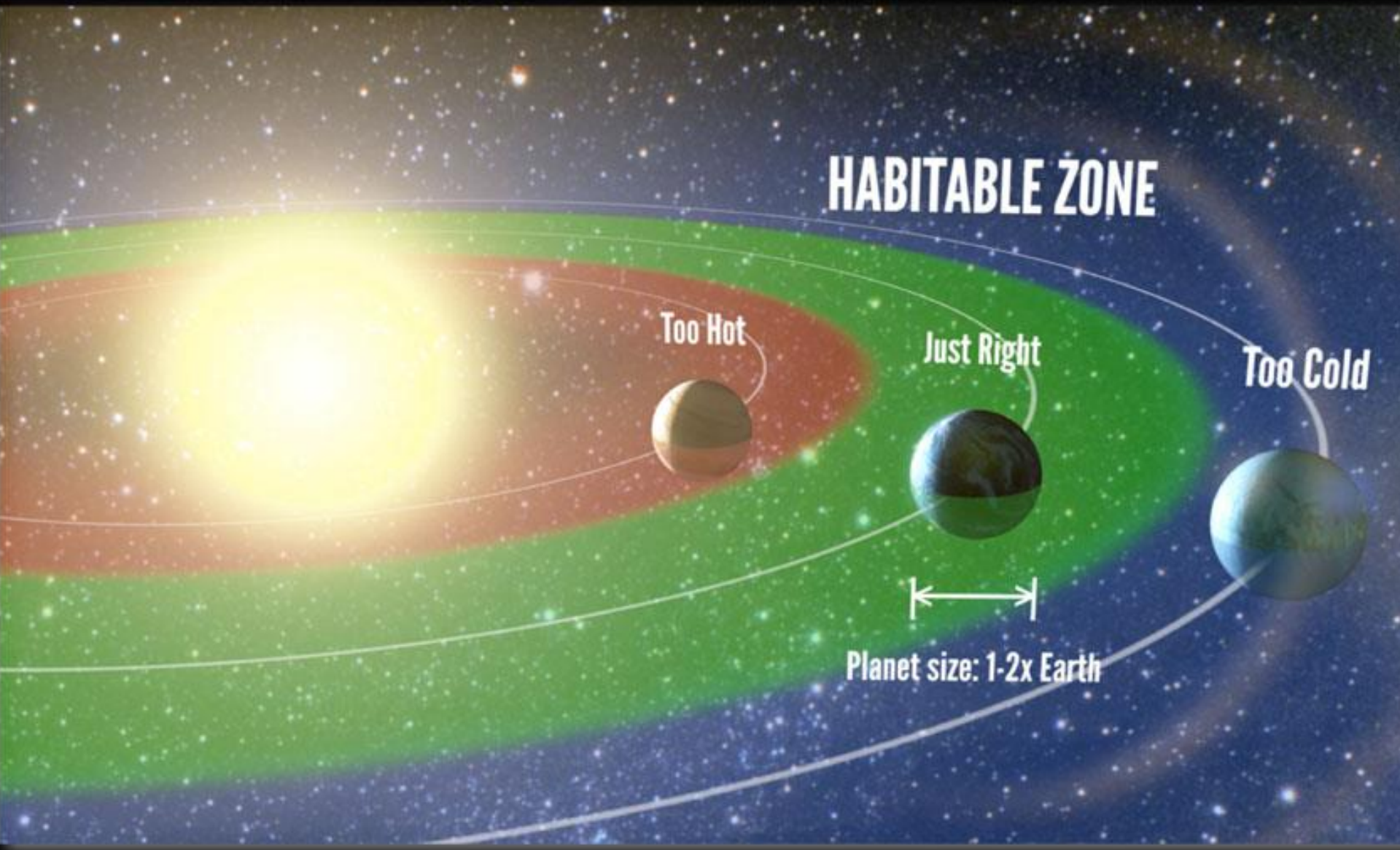
Planets orbiting other stars in the Galaxy are common

.

2

Planets with sizes between 0.5 and 2 times Earth are the most common

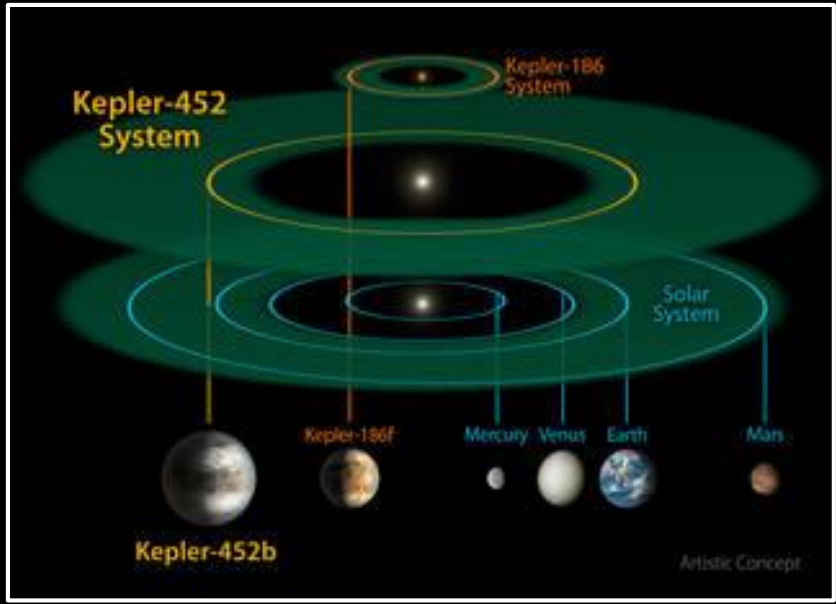
What about the Habitable Zone?

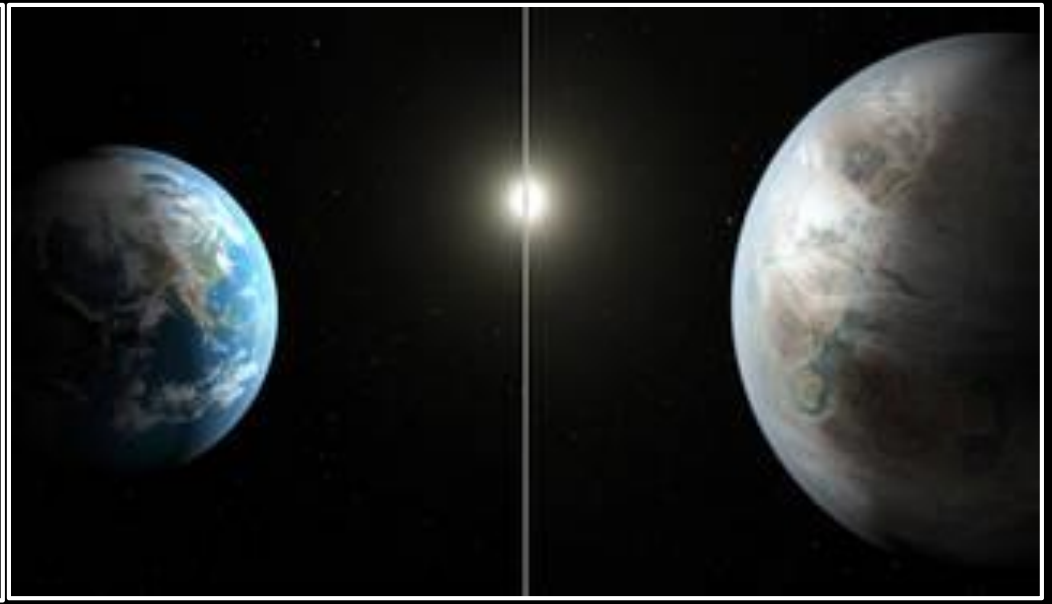


The habitable zone corresponds to the range of orbital distances where liquid water can exist on a planet's surface.

Q&Alien Video: Habitable Zones

Kepler 452 b: Earth's Bigger, Older Cousin





$2.00

JULY 24 - 26, 2015

Earth
7,926 miles

WHERE IS THE PLANET?
1,400 light-years away, or 8.4 quadrillion miles, in the constellation Cygnus. It is circling Kepler-452, a G-class star similar to our sun.

452b
12,700 MILES

HOW BIG?
Kepler-452b is roughly 60% larger than Earth.

USA TODAY WEEKEND
A GANNETT COMPANY

ARTIST CONCEPT OF WHAT 452b MAY LOOK LIKE

EARTH TO 452b

New planet found outside our solar system could harbor life

Traci Watson
Special for USA TODAY

Scientists have spotted a planet much the same size as our Earth orbiting a star that closely resembles our sun, making it the most likely known place outside our solar system to harbor life.

probably rocky, as Earth is. But those planets circle dim, cool stars very different from our own sun, whereas 452b is hitched to a star very much like ours. If we could send plants to 452b, Jenkins said, they could comfortably photosynthesize.

The new planet is about 60% bigger in diameter than Earth,

of light coming from stars in the constellations Lyra and Cygnus. The planet, which is some 1,400 light-years from Earth, is described in a new article in *The Astronomical Journal*.

Other scientists who were not involved in the research called 452b an exciting example of a planet in the "Goldilocks"

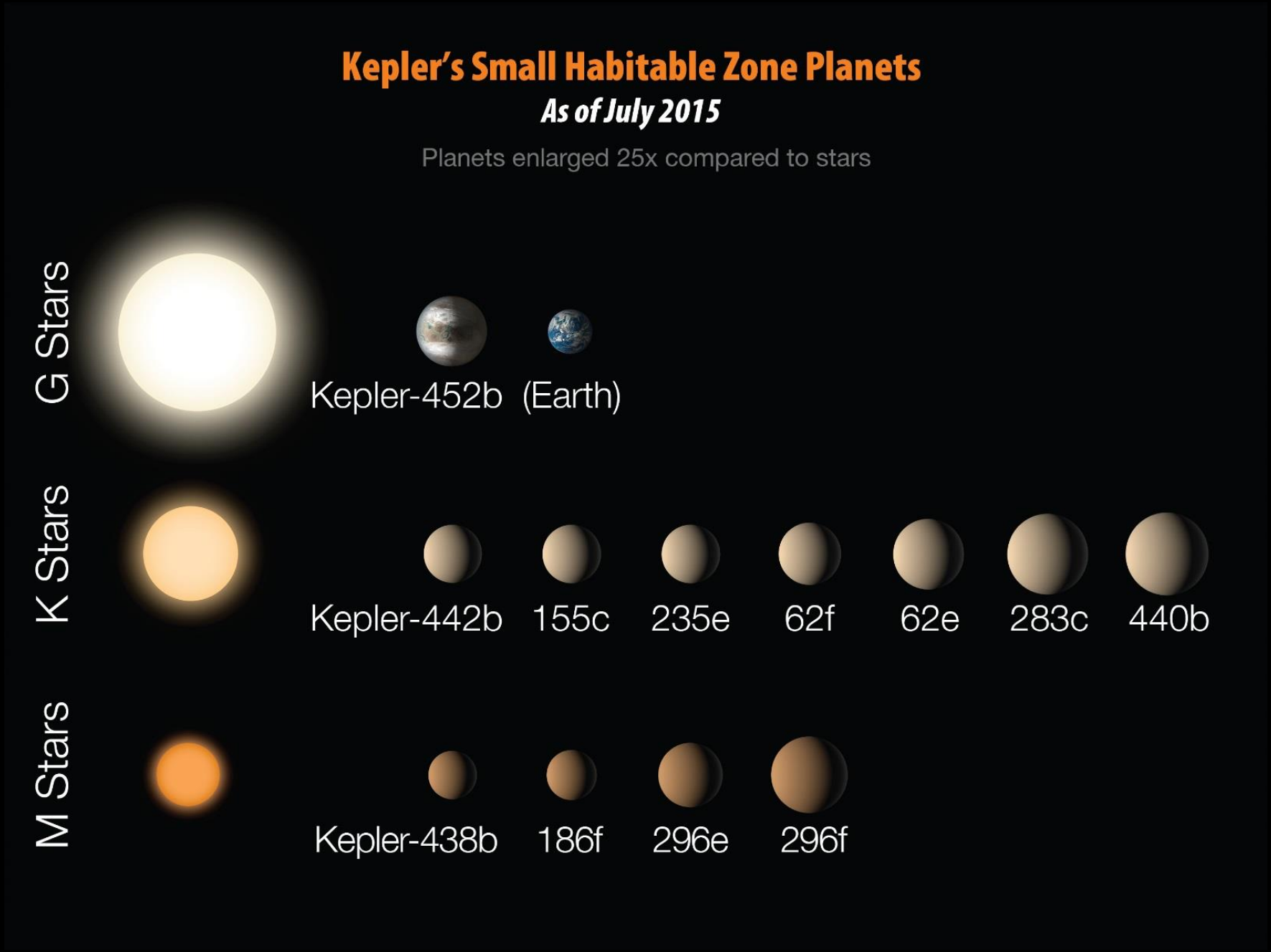
NEWSLINE

IN NEWS

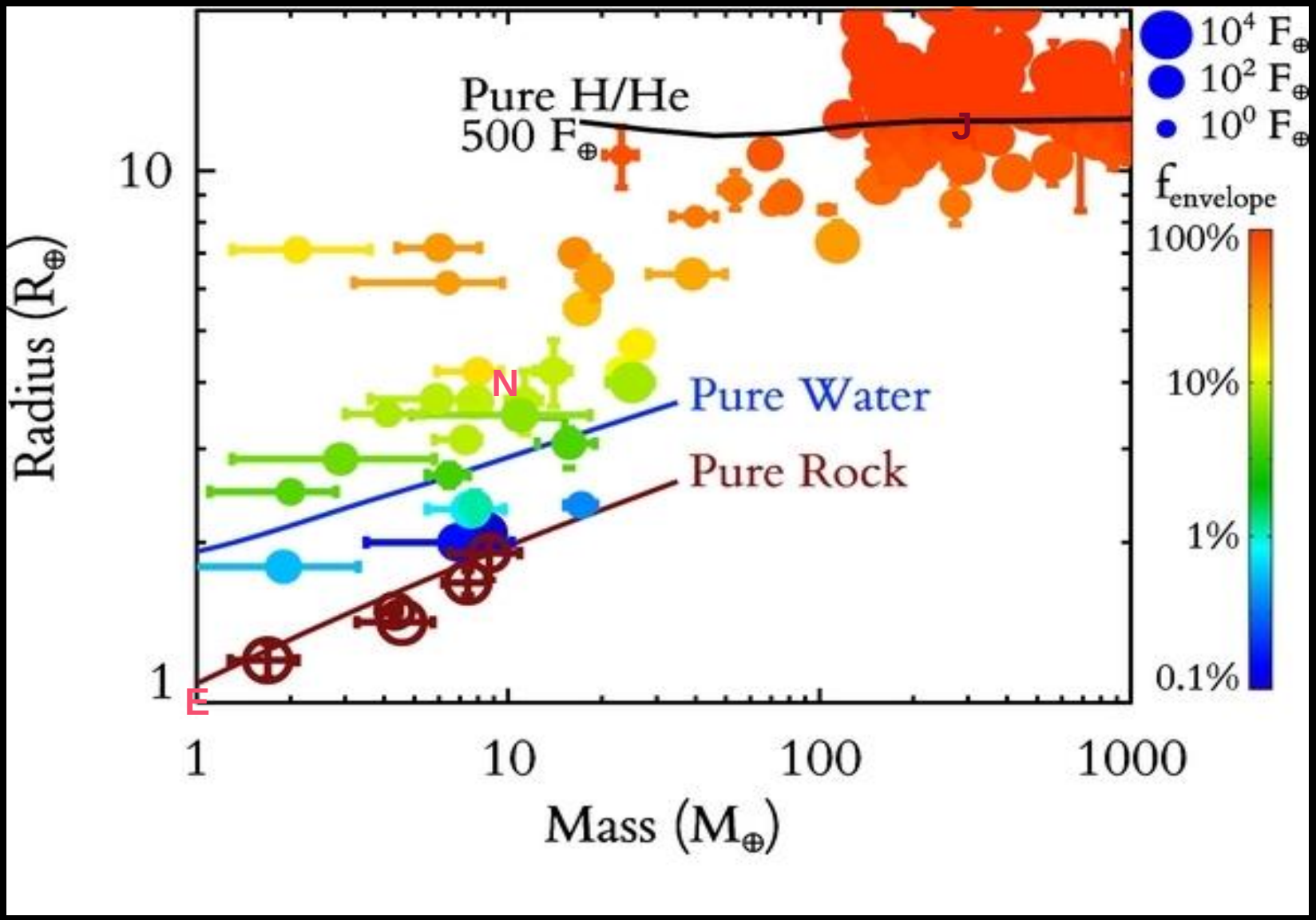
Chemo doesn't help end-stage cancer, study says
Quality of life actually made worse for some.

Angry Greeks say #BoycottGermany
Germany took lead in demanding tough bailout terms

41,500 VA HEALTH POSITIONS UNFILLED
Lack of medical


Kepler's Small Habitable Zone Planets
As of July 2015
Planets enlarged 25x compared to stars
G Stars
Kepler-452b
(Earth)
K Stars
Kepler-442b
155c
235e
62f
62e
283c
440b
M Stars
Kepler-438b
186f
296e
296f

What are Exoplanets Like?



Kepler's Amazing Results:

1

Planets orbiting other stars in the Galaxy are common

.

2

Planets with sizes between 0.5 and 2 times Earth are the most common

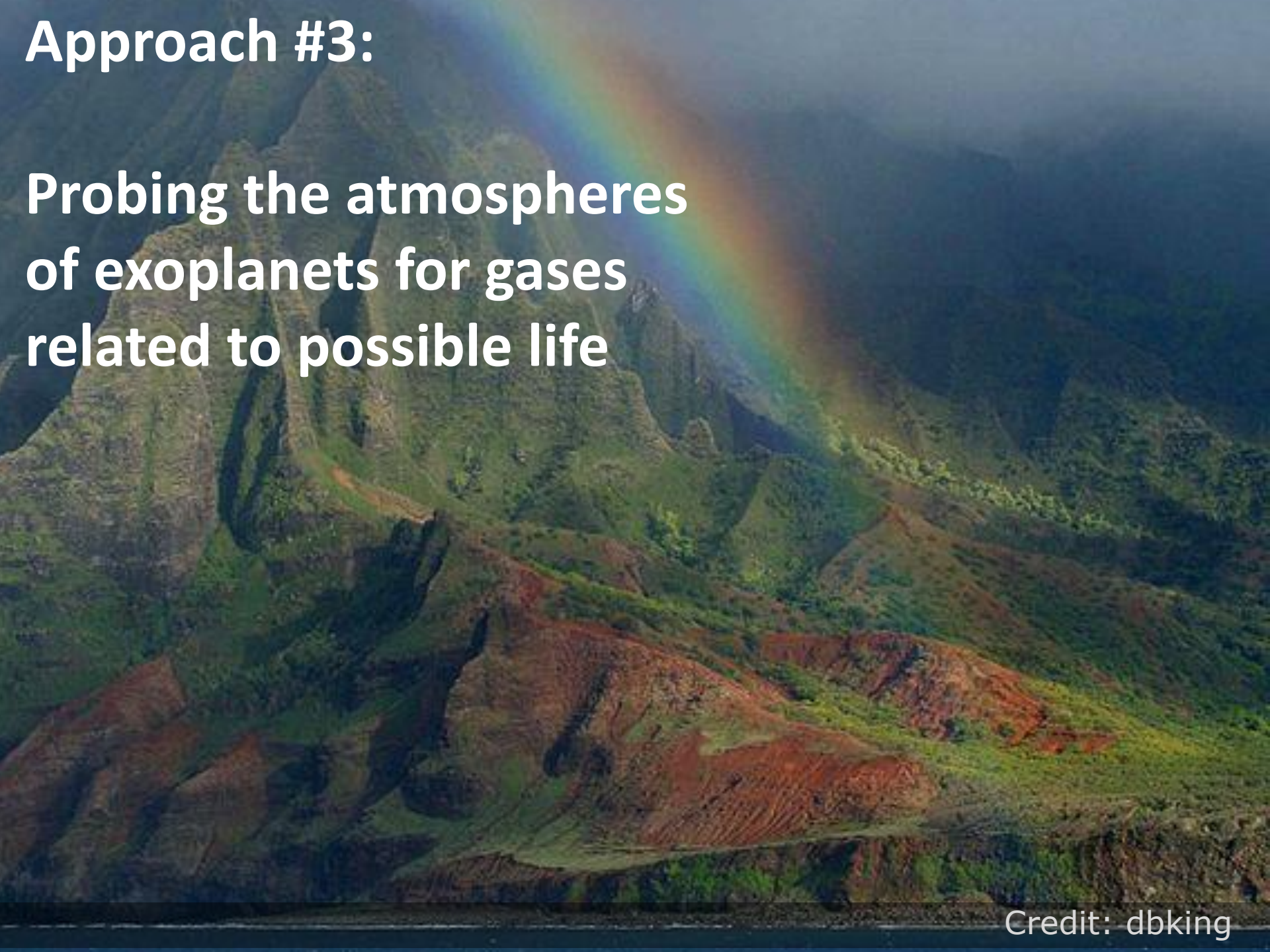
3

Planets with sizes between 0.5 and 2 times Earth that orbit in the Habitable Zone of their stars are common

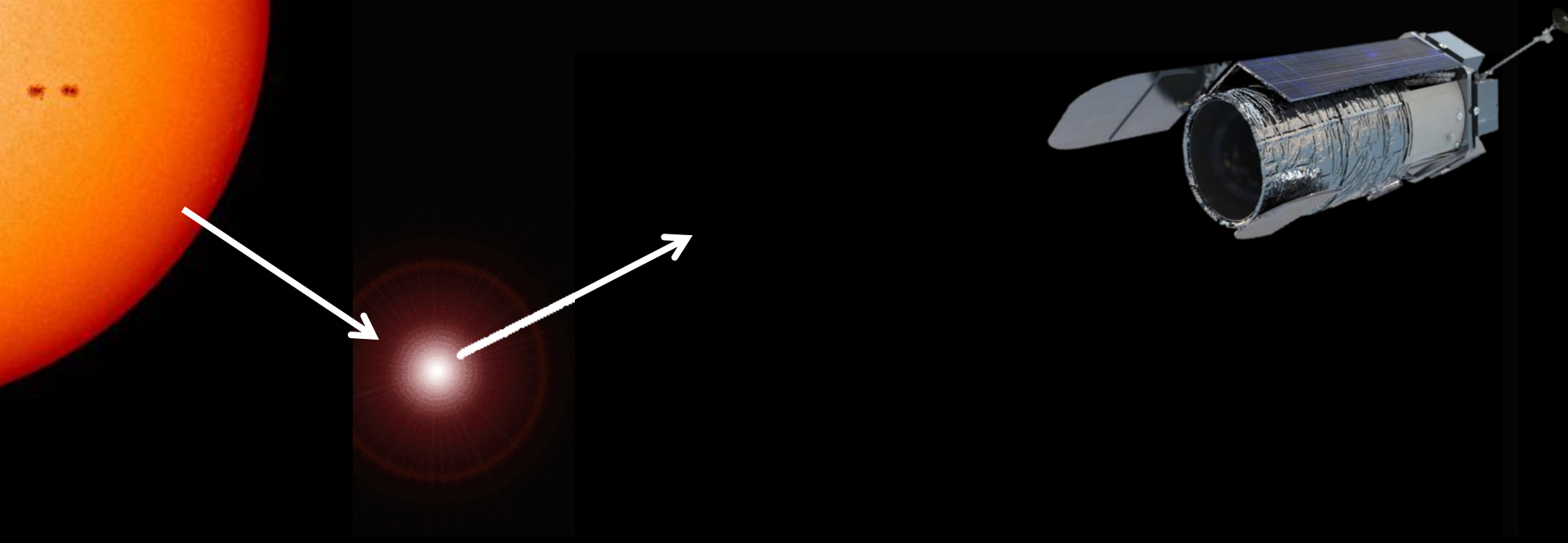
3. Search for Habitability and for Signs of Life

Approach #3:

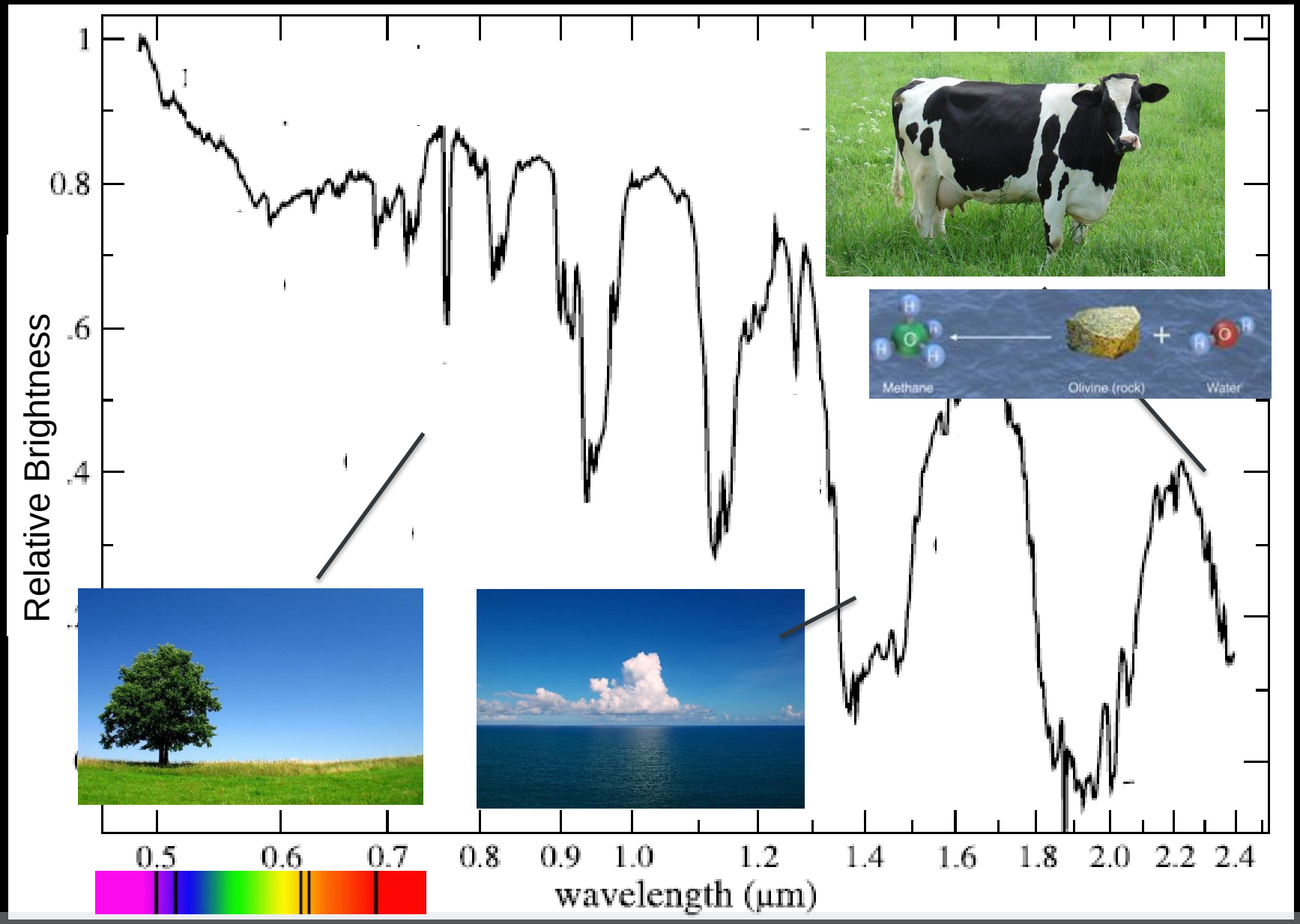
Probing the atmospheres of exoplanets for gases related to possible life



Credit: dbking



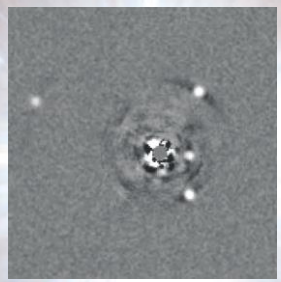
Detecting Life on an Exoplanet



Turnbull et al. 2006

Direct Imaging Exoplanets Challenge #1:

Contrast



An Earth-size planet in the habitable zone of a Sun-like star is very faint

- 10 billion times fainter!

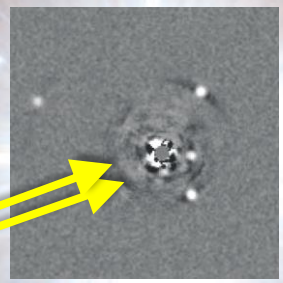
Marois et al. 2010

Direct Imaging Exoplanets Challenges #2:

Resolution

0.5º

Earth



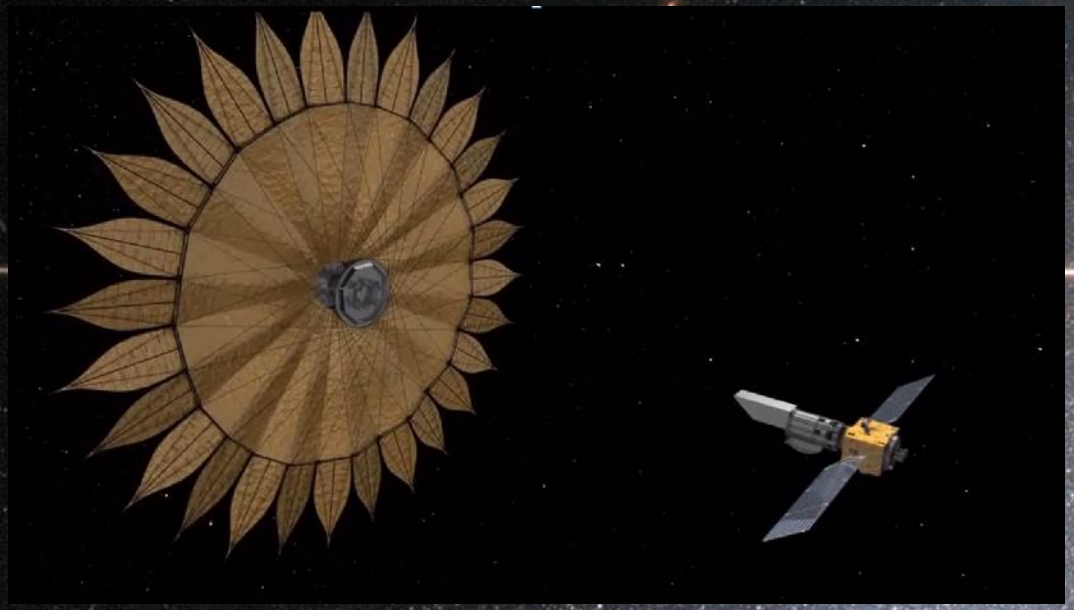
1/18,000 of a degree

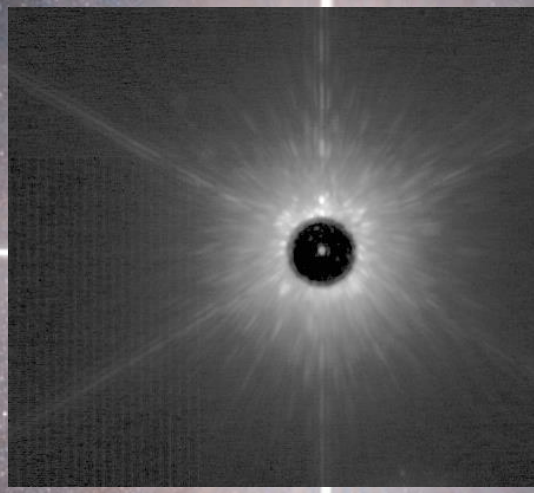
(1 AU at 33 lyr)

firefly

Two Direct Planet Imaging Techniques

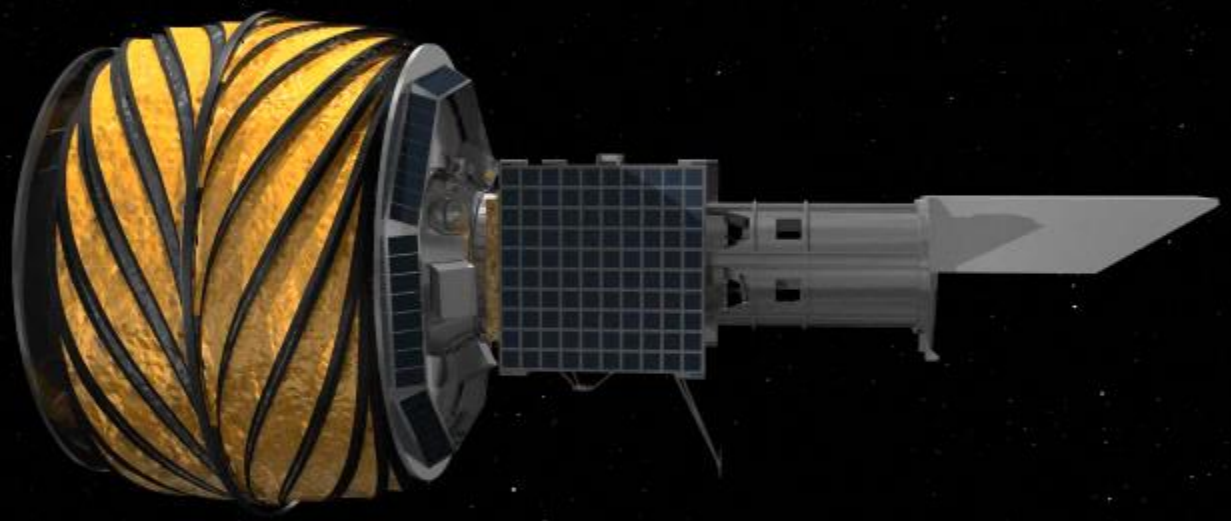
Starshade





Coronagraph

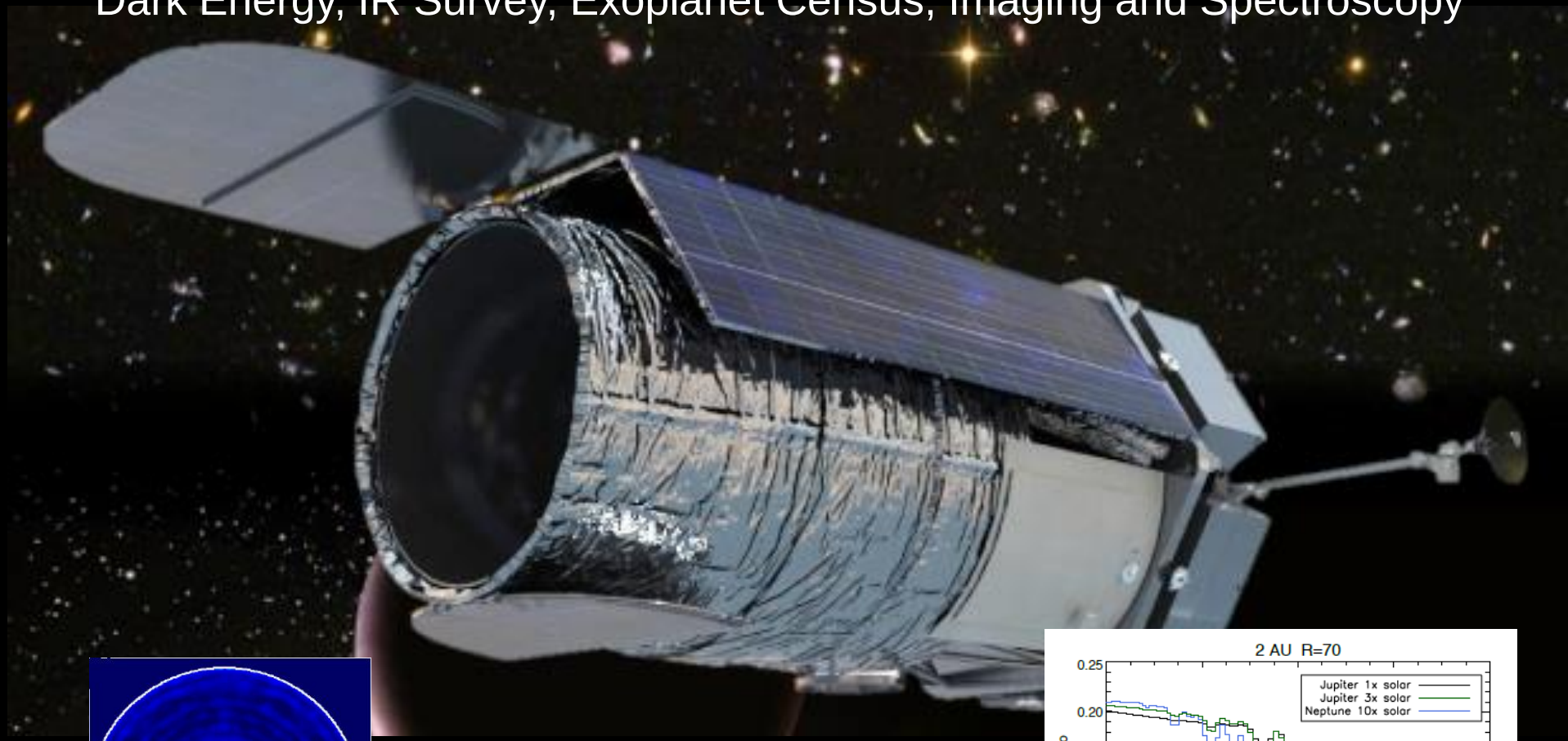
Starshade Animation

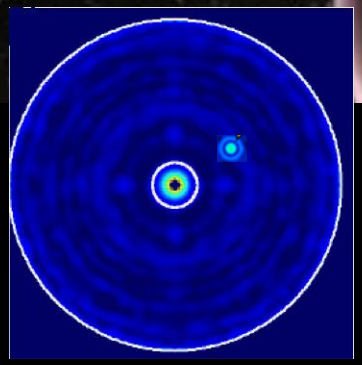


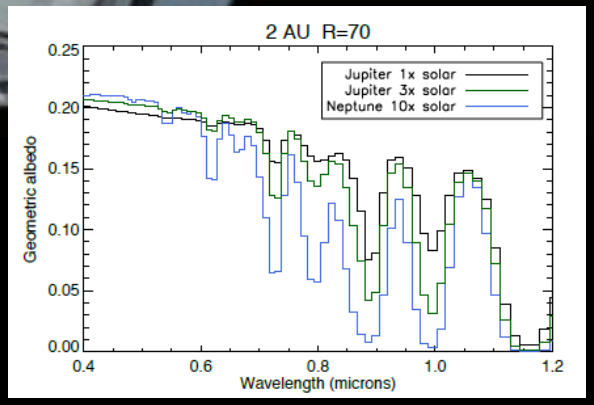
Coronagraph Animation

WFIRST / AFTA

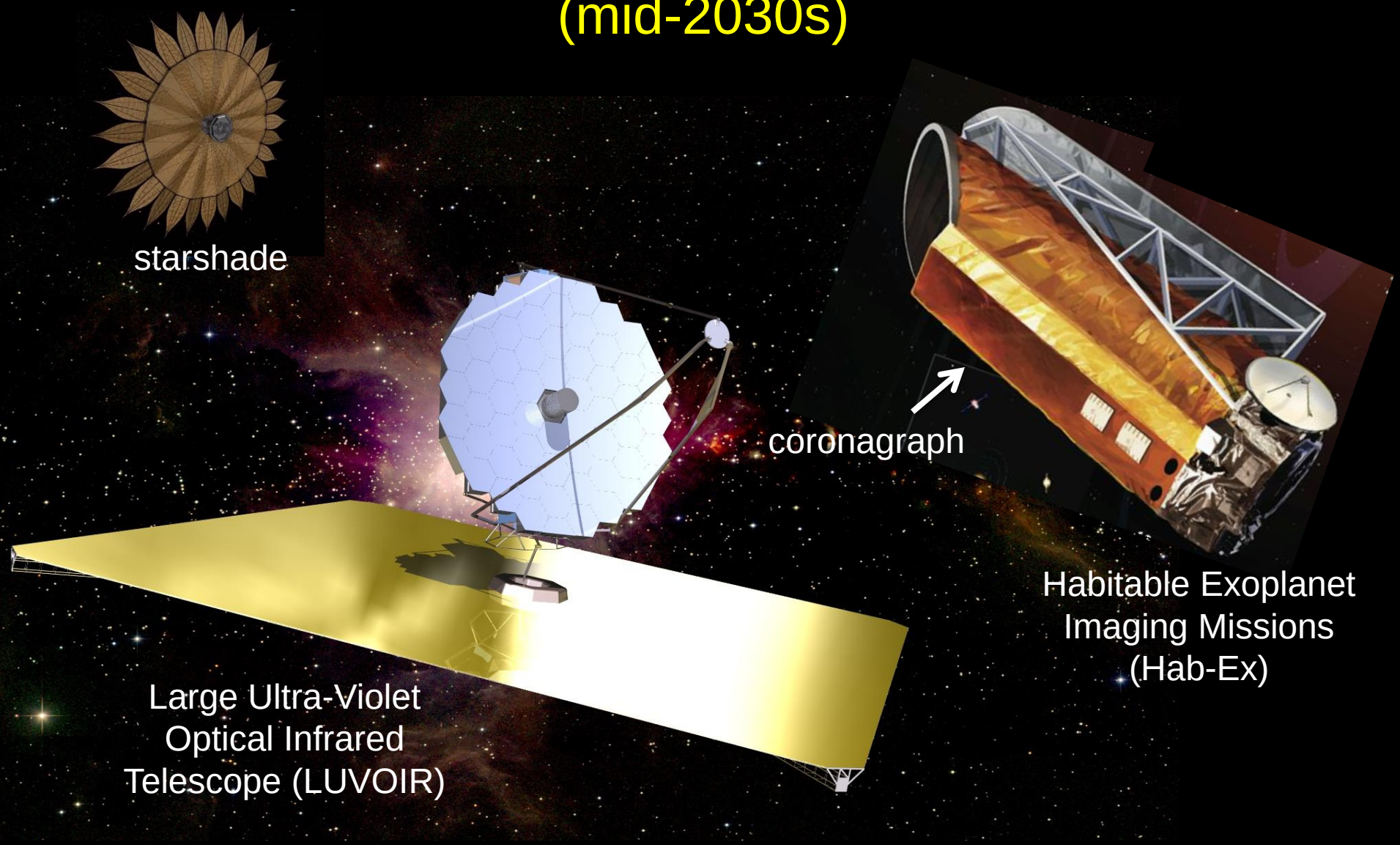
Dark Energy, IR Survey, Exoplanet Census, Imaging and Spectroscopy



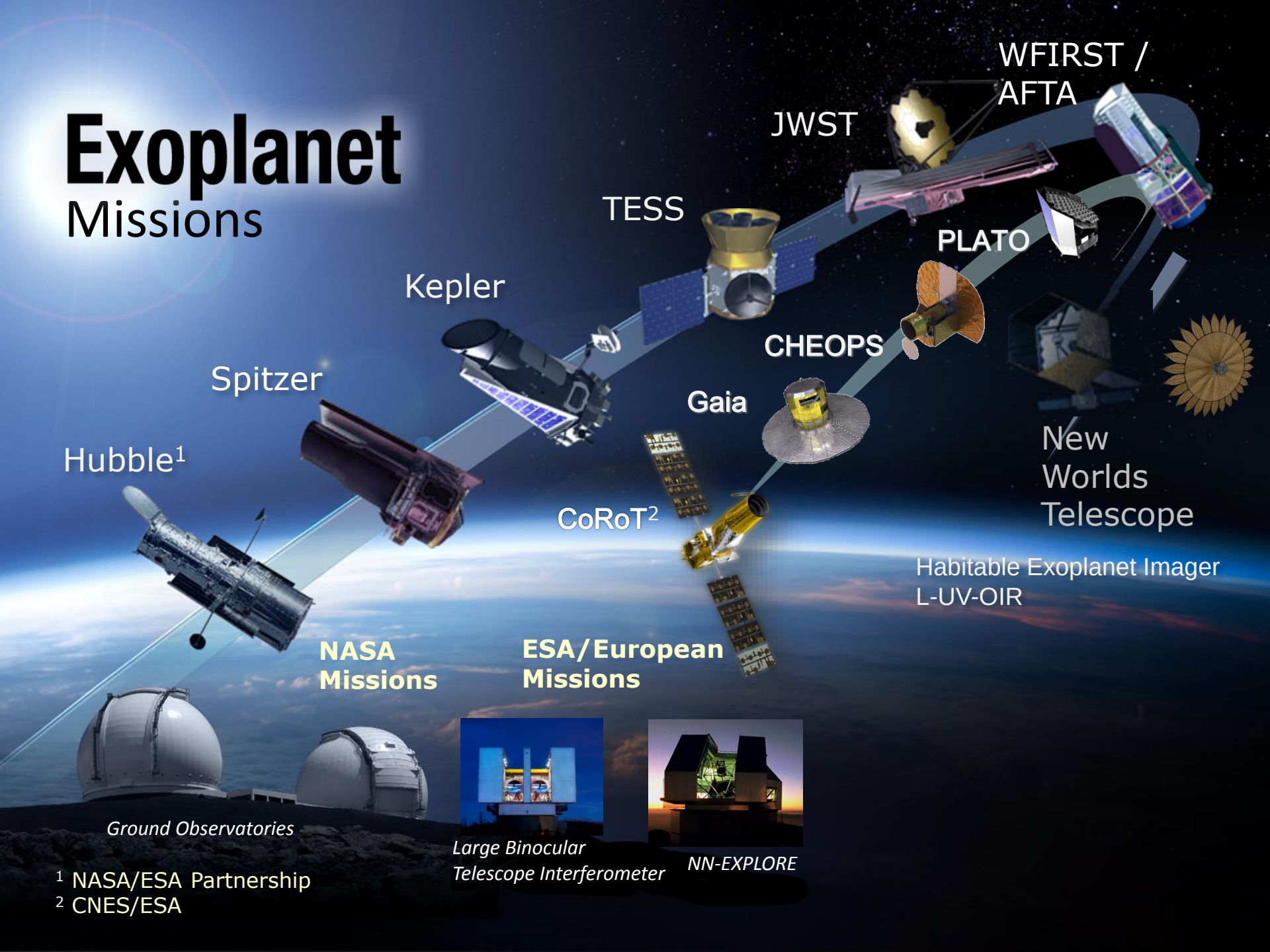




Possibilities for the New Worlds Telescope (mid-2030s)



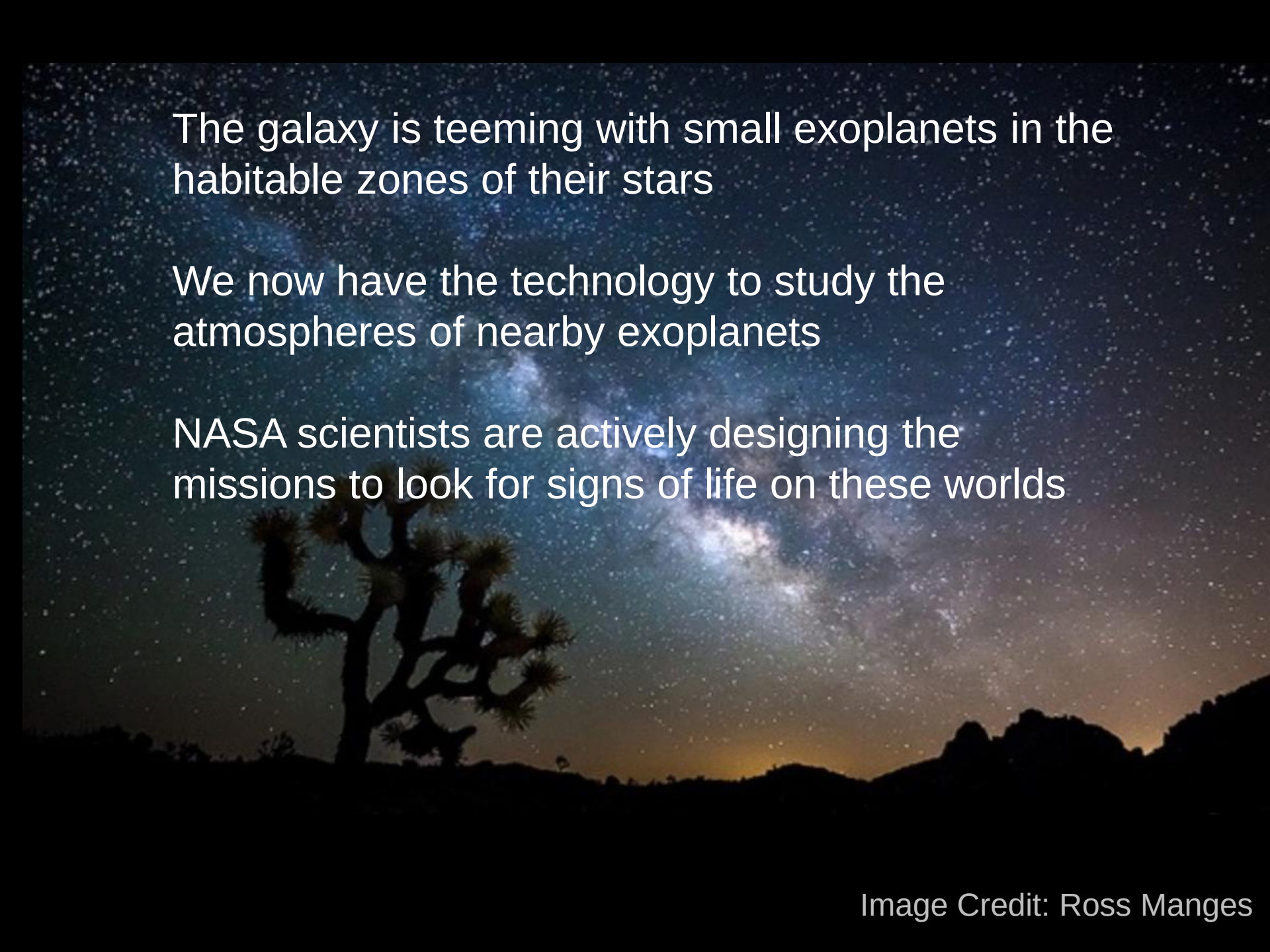
Exoplanet Missions



[1] NASA/ESA Partnership
[2] CNES/ESA

Coming Home…

We shall not cease from exploration, and the end of all our exploring will be to arrive where we started and know the place for the first time.
T. S. Eliot

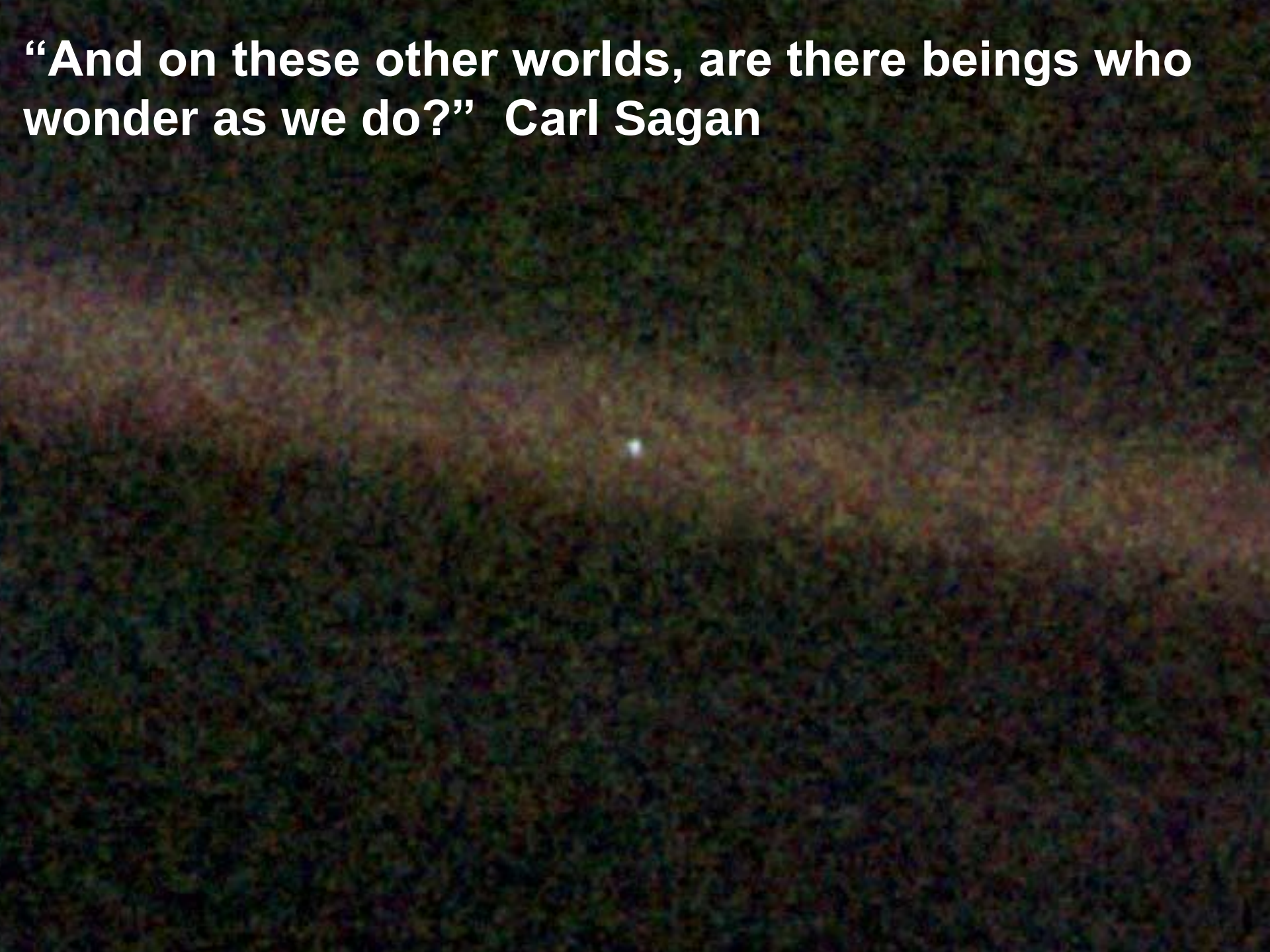


The galaxy is teeming with small exoplanets in the habitable zones of their stars

We now have the technology to study the atmospheres of nearby exoplanets

NASA scientists are actively designing the missions to look for signs of life on these worlds

Image Credit: Ross Manges


“And on these other worlds, are there beings who wonder as we do?” Carl Sagan

Jet Propulsion Laboratory
California Institute of Technology

Opportunities at JPL/Caltech

Summer Undergraduate Research Fellowships (SURF) Program

Caltech Student-Faculty Programs

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Program Description | Eligibility | Application Information | Announcements of Opportunity | FAQS

SURF

The Summer Undergraduate Research Fellowships (SURF) program is one of the "crown jewels" of Caltech. Since 1979, SURF students have had the opportunity to conduct research under the guidance of experienced mentors working at the frontiers of their fields. Students experience the process of research as a creative intellectual activity from beginning (defining and developing a project) to end (presenting their results at SURF Seminar Day).

Students - be sure to check out the links above for an in-depth program description; eligibility requirements; and application information.

Alumni - we invite you to re-connect and learn more about upcoming events and SURF alumni in the news.

Donors--thank you for your continued support. Learn more about how your donation makes an impact and upcoming donor events.

Announcement of Opportunities (AOs)

SURF Program

Caltech Student-Faculty Programs

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SURF | Amgen Scholars | WAVE Fellows | Exchanges | LIGO SURF | JPL/NASA Programs | Academic-Year Opportunities | Dates

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SURF: ANNOUNCEMENTS OF OPPORTUNITY

Below are Announcements of Opportunity posted by Caltech faculty and JPL technical staff for the SURF program. Additional AOs for the Amgen Scholars program can be found here.

Students pursuing opportunities at JPL must be U.S. citizens or U.S. permanent residents.

Each AO indicates whether or not it is open to non-Caltech students. If an AO is NOT open to non-Caltech students, please DO NOT contact the mentor.

Announcements of Opportunity are posted as they are received. Please check back regularly for new AO submissions! Remember: This is just one way that you can go about identifying a suitable project and/or mentor.

Announcements for external summer programs are listed here.

Project Title	Disciplines	Mentor	Posted
Mars 2020 Testbed Rover Perception System	Mechanical Engineering, Computer Science	Matthew Heverly (JPL)	01-Feb-16
Europa Core Flight Software Testing	Computer Science, Electrical Engineering	Cindy Oda (JPL)	29-Jan-16
Liquidity and Mutual Fund Manager Trading Skills	Business Economics and Management, Economics	Ben Gillen	29-Jan-16
Targeting Beta with Subset Portfolios	Business Economics and Management, Economics	Ben Gillen	29-Jan-16
Data Visualization Using Virtual Reality	Data Science, Computer Science	George Djorgovski	28-Jan-16
Machine Learning With TensorFlow	Data Science, Computer Science	George Djorgovski	28-Jan-16
Fluid-Structure Interaction Study on the Propagation of Acoustic Waves in Glass Tubes with Converging Geometries	Mechanical Engineering, Aeronautics	Joseph Shepherd	28-Jan-16
Early Object Detection in Video	Electrical Engineering	Truong Nguyen	27-Jan-16

National Aeronautics and Space Administration

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California Institute of Technology
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