Jet Propulsion Laboratory
California Institute of Technology

Exoplanets and the Search for Life in our Galaxy

Ray Lemus, Business Manager

NASA Exoplanet Exploration Program

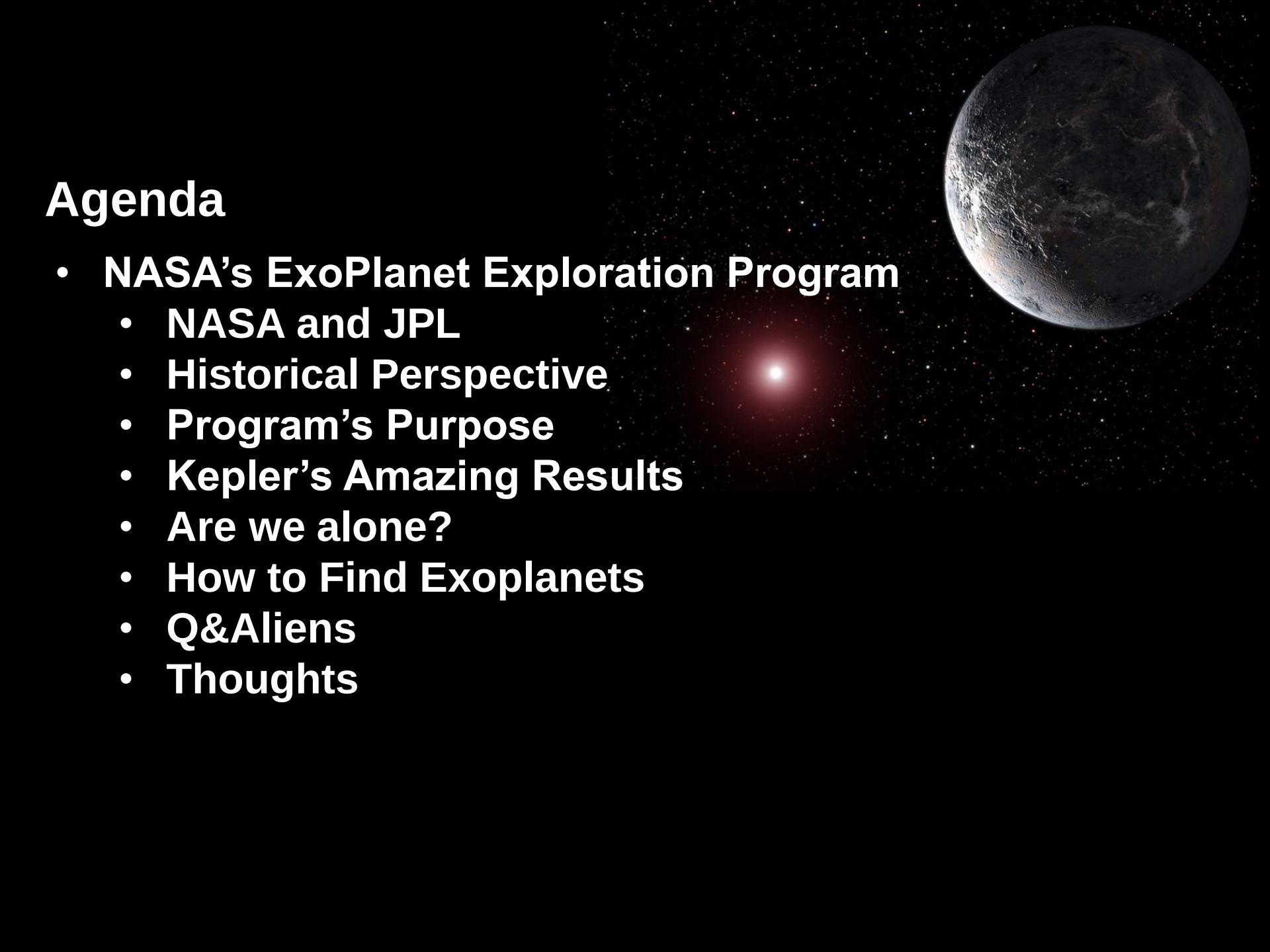
CL#17-0859

URS264096

Monday, February 27, 2017

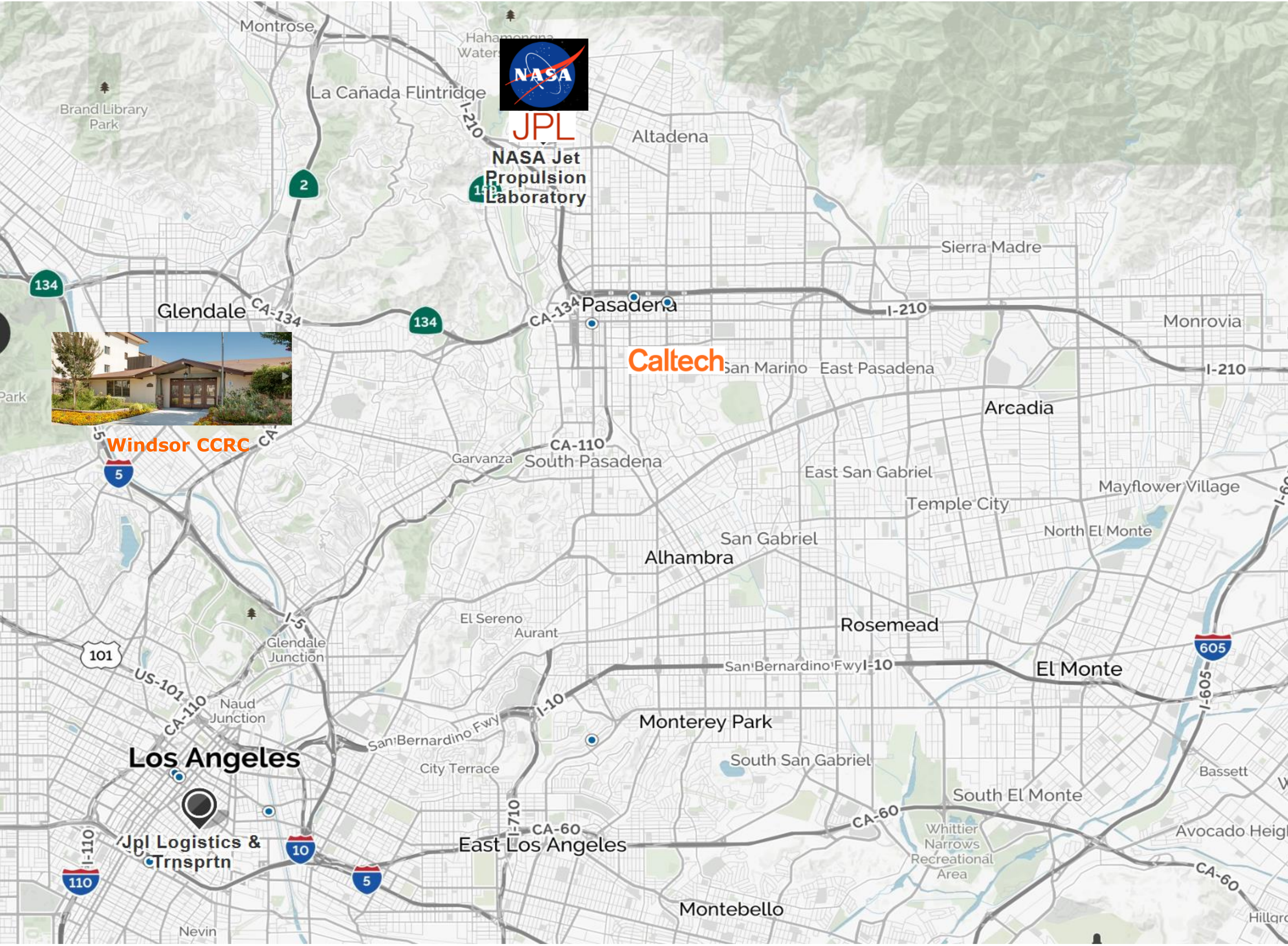
Windsor Community

Glendale, CA



Agenda

- NASA's ExoPlanet Exploration Program
  - NASA and JPL
  - Historical Perspective
  - Program's Purpose
  - Kepler's Amazing Results
  - Are we alone?
  - How to Find Exoplanets
  - Q&Aliens
  - Thoughts


NASA
JPL
NASA Jet Propulsion Laboratory
Caltech
Windsor CCRC
Jpl Logistics & Trnsprtn
Montrose
La Cañada Flintridge
Brand Library Park
Altadena
Sierra Madre
Glendale
Pasadena
Monrovia
San Marino
East Pasadena
Arcadia
Garvanza
South Pasadena
East San Gabriel
Mayflower Village
Temple City
North El Monte
San Gabriel
Alhambra
El Sereno
Aurant
Rosemead
Glendale Junction
Naud Junction
San Bernardino Fwy
El Monte
Monterey Park
Los Angeles
City Terrace
South San Gabriel
Bassett
South El Monte
Whittier Narrows Recreational Area
East Los Angeles
Avocado Height
Montebello
Nevin
Hillgrov
I-210
CA-134
CA-110
I-5
US-101
I-10
I-710
CA-60
I-605
I-110

NASA

Government Agency for

Aeronautics, Space Exploration and Earth Science

Caltech

Educational Institution

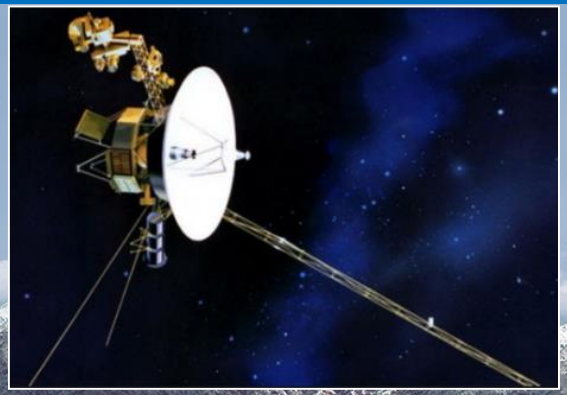
Jet Propulsion Laboratory

Operating Division of Caltech;

Federally Funded Research & Development Center

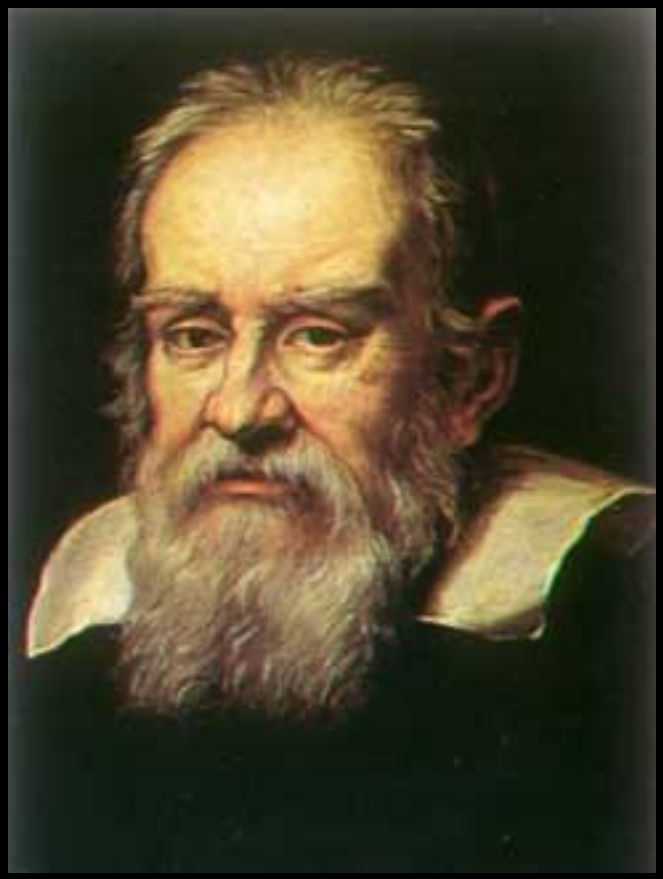
JPL has expertise in:

- Science
- Engineering
- Technology
- Programs/projects



The Ancient History of Comparative Planetology

"There are infinite worlds both like and unlike this world of ours...We must believe that in all worlds there are living creatures and plants and other things we see in this world"---
Epicurus (c. 300 BCE)
(died painfully 269 BCE)



"...false and damnable..."
G. Galilei (b. 1564)
(life imprisonment 1633)

"There are countless suns and countless earths ..."
Giordano Bruno (b. 1584)
in De L'infinito Universo E Mondi
(burned at the stake in Campo dei Fiore, Rome, 1600)

Image Credit: Ross Manges

NASA Exoplanet Exploration Program

Astrophysics Division, NASA Science Mission Directorate

NASA's search for habitable planets and life beyond our solar system

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

ExEP serves the science community and NASA by implementing NASA's space science vision for exoplanets

https://exoplanets.nasa.gov

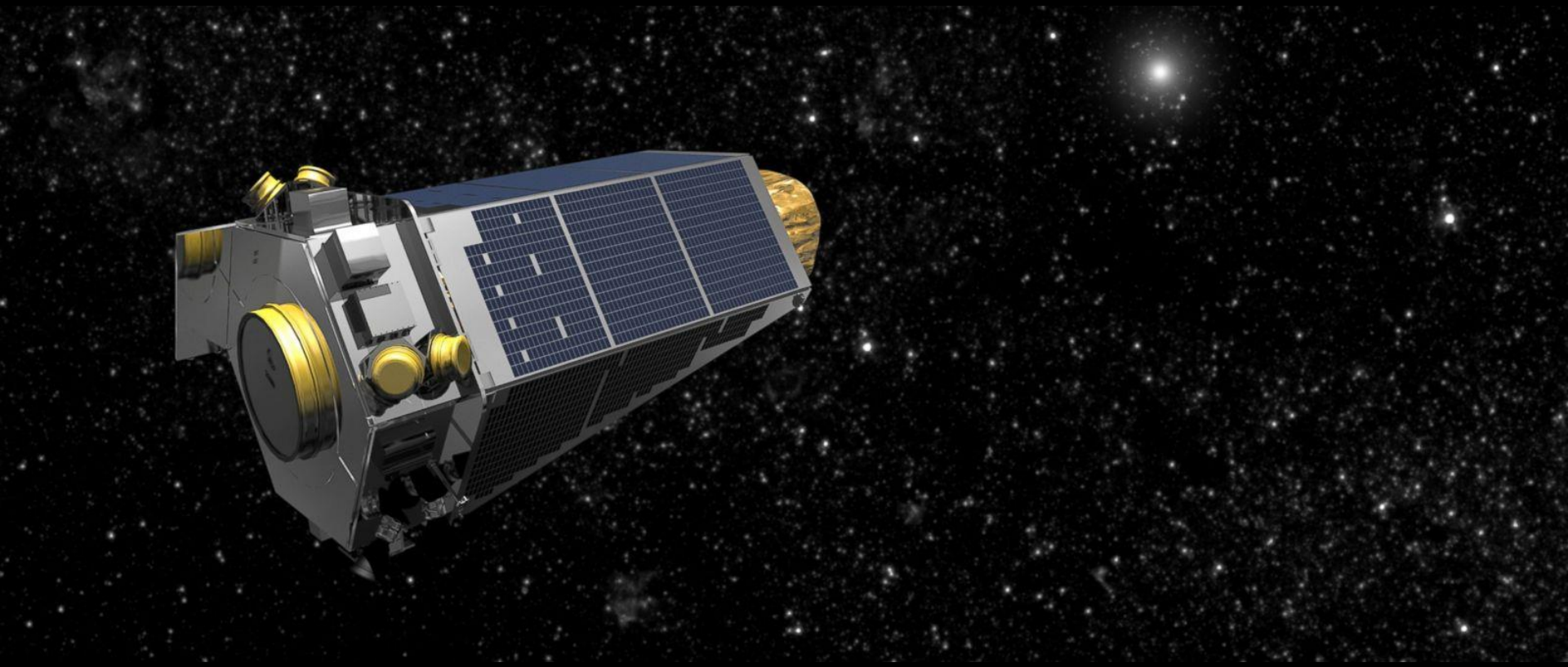
NASA Named Its Planet Finding Telescope After Johannes Kepler

German astronomer Johannes Kepler used mathematics to calculate the path of the planets, finding that they traveled not in circles, as long expected, but in ellipses.

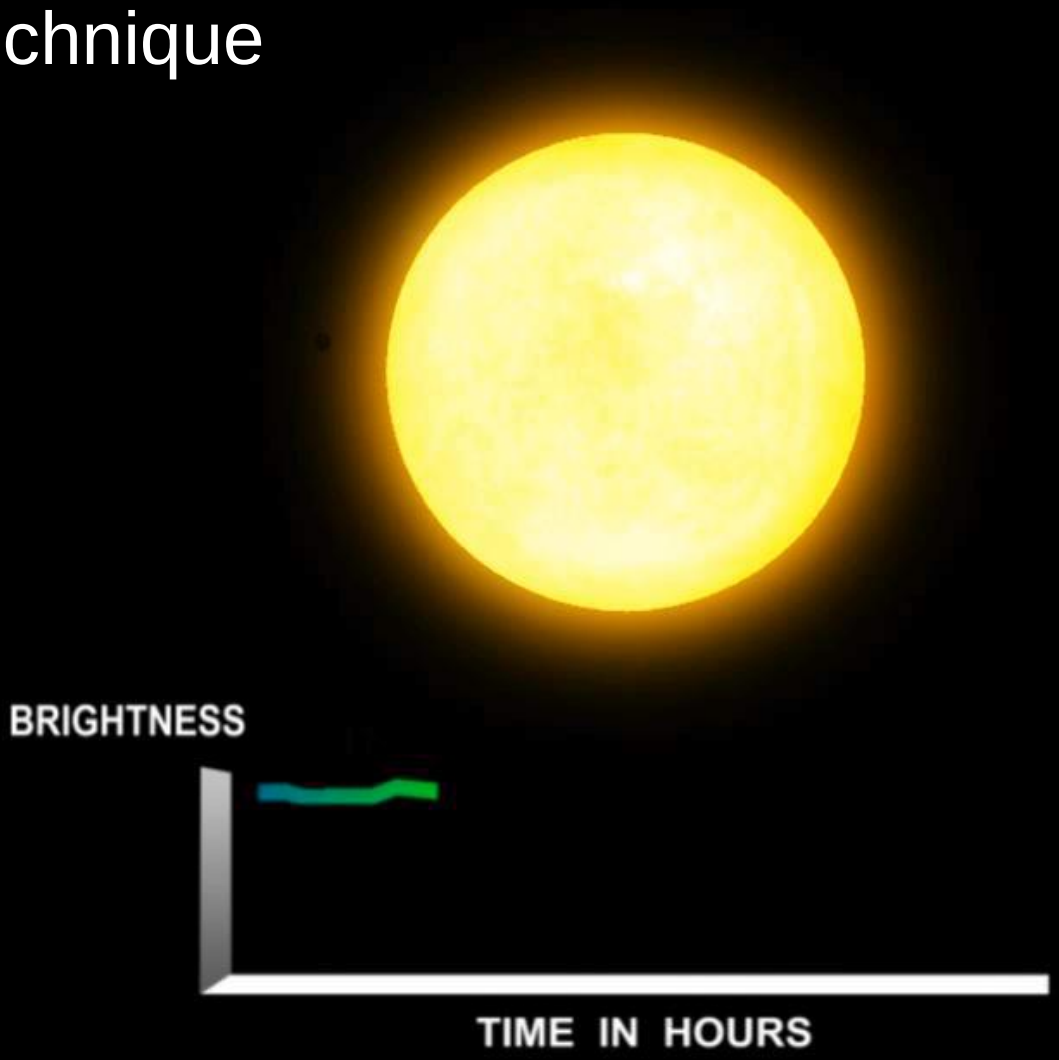
Credit: Johnnes Kepler Gesammelte Werke , C. H. Beck, 1937

- Johannes Kepler was born in the late 16th century
- Scientists believed that planets in the solar system traveled in circular orbits around the Earth
- Kepler adamantly defended the idea that planets orbit the sun instead, a heretical idea at the time
- Revealed that their paths were not perfect circles, but rather ellipses
- His descriptions of planetary motions became known as Kepler's laws

NASA’s Kepler Space Telescope

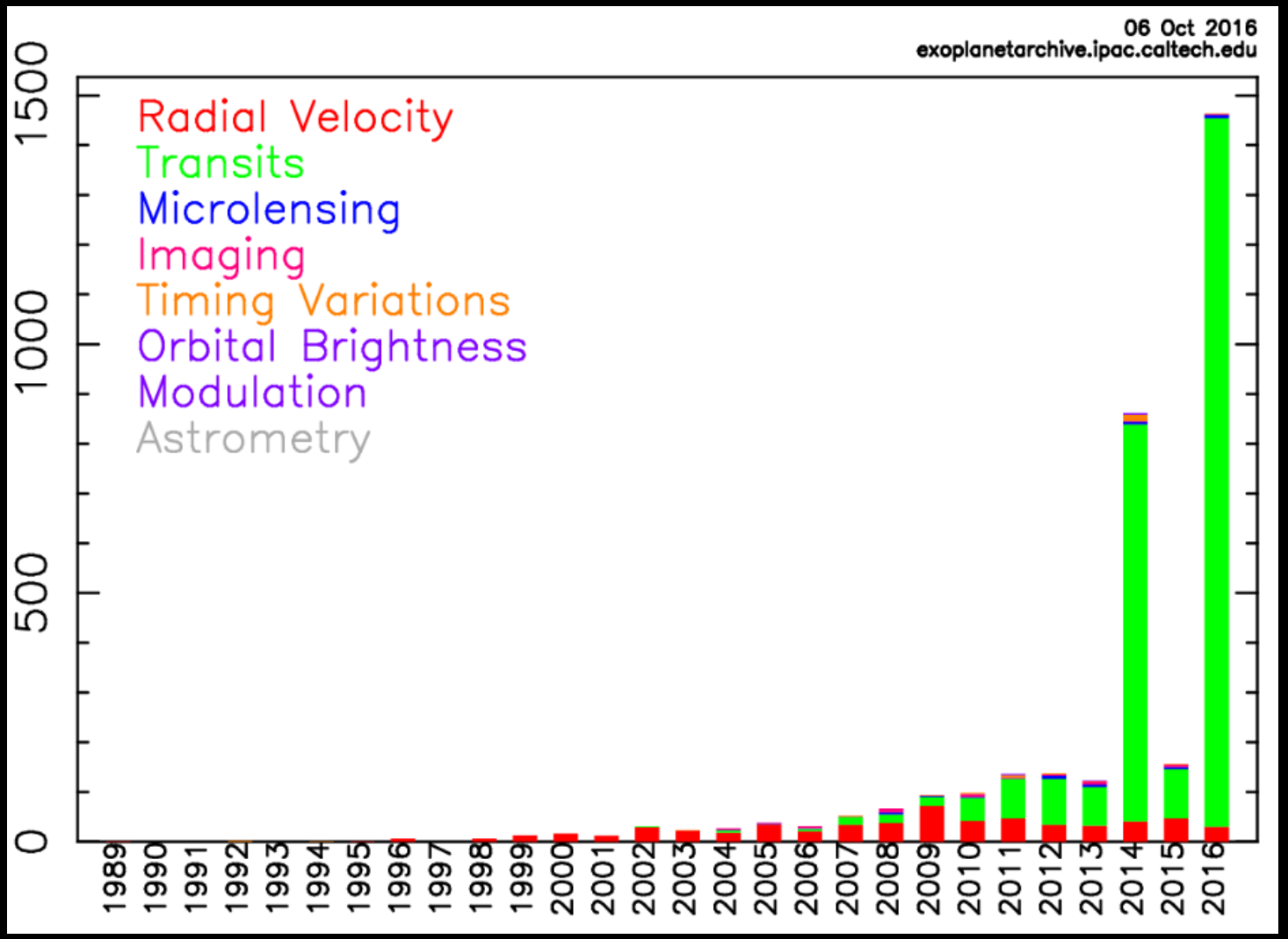


Transit Technique



3,396 Confirmed Exoplanets

(as of 10/8/16)



Number of Planets

Discovery Year

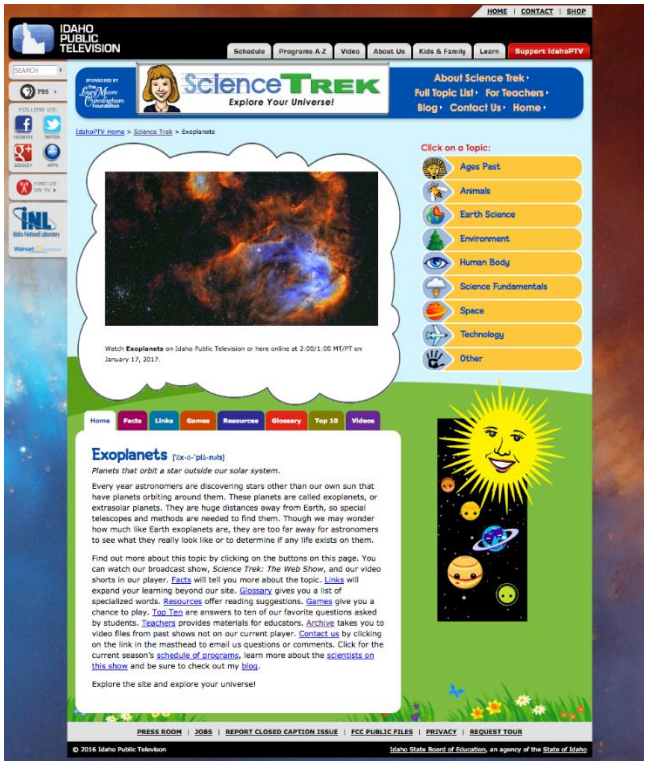
:http://exoplanetarchive.ipac.caltech.edu/exoplanetplots/

Idaho Public Television: Science Trek

Filming for Idaho Public Television: Science Trek
Tiffany Meshkat and Nick Siegler took part in a filmed Q&A for an exoplanets-themed episode of Idaho Public Television's kids series, Science Trek. Questions were posed by K-7 students.

The episode is scheduled to air in January 2017

- http://idahoptv.org/sciencetrek/topics/exoplanets/



Kepler's Amazing Results:

1. Planets are diverse

Lava Planets

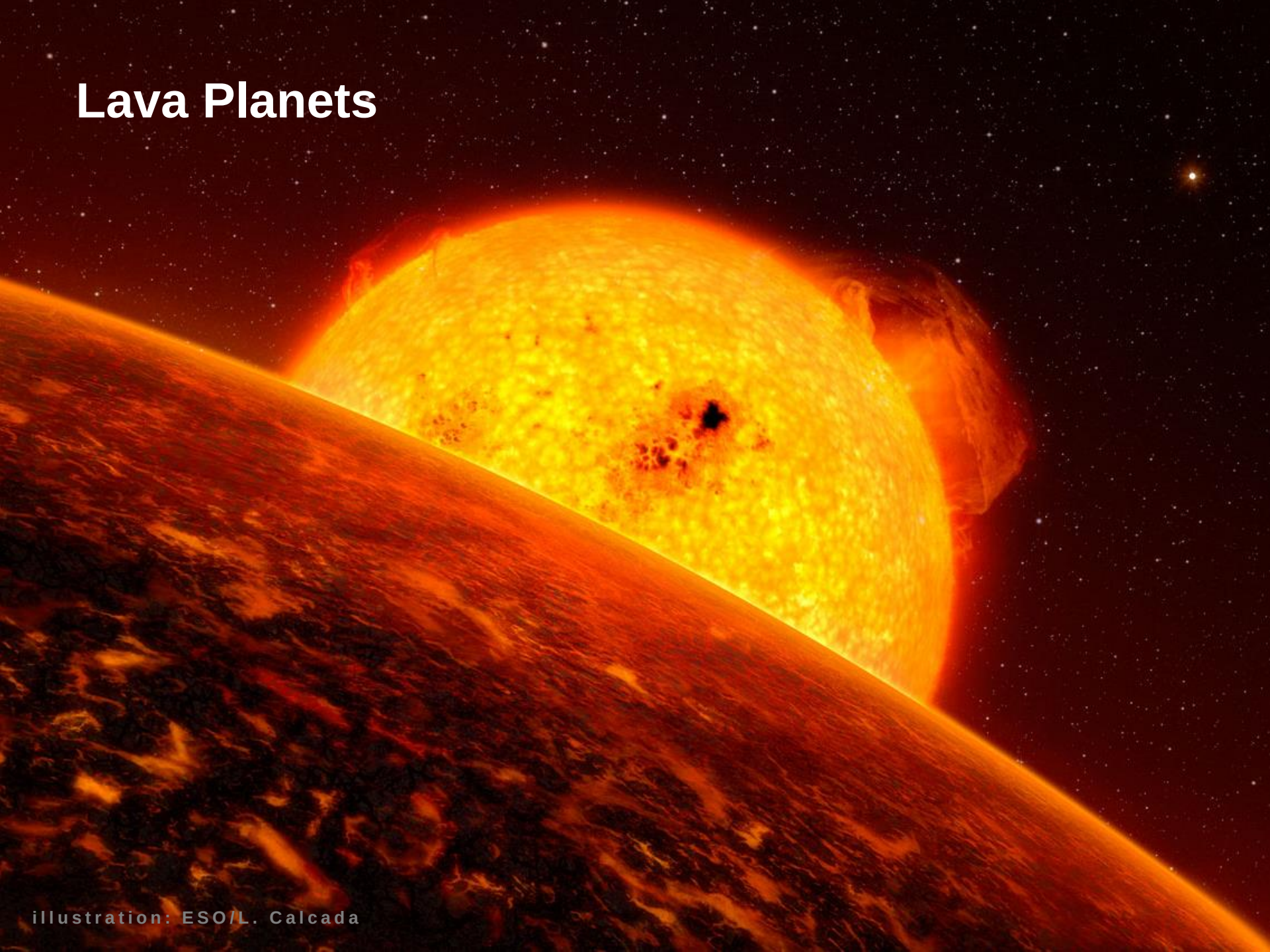
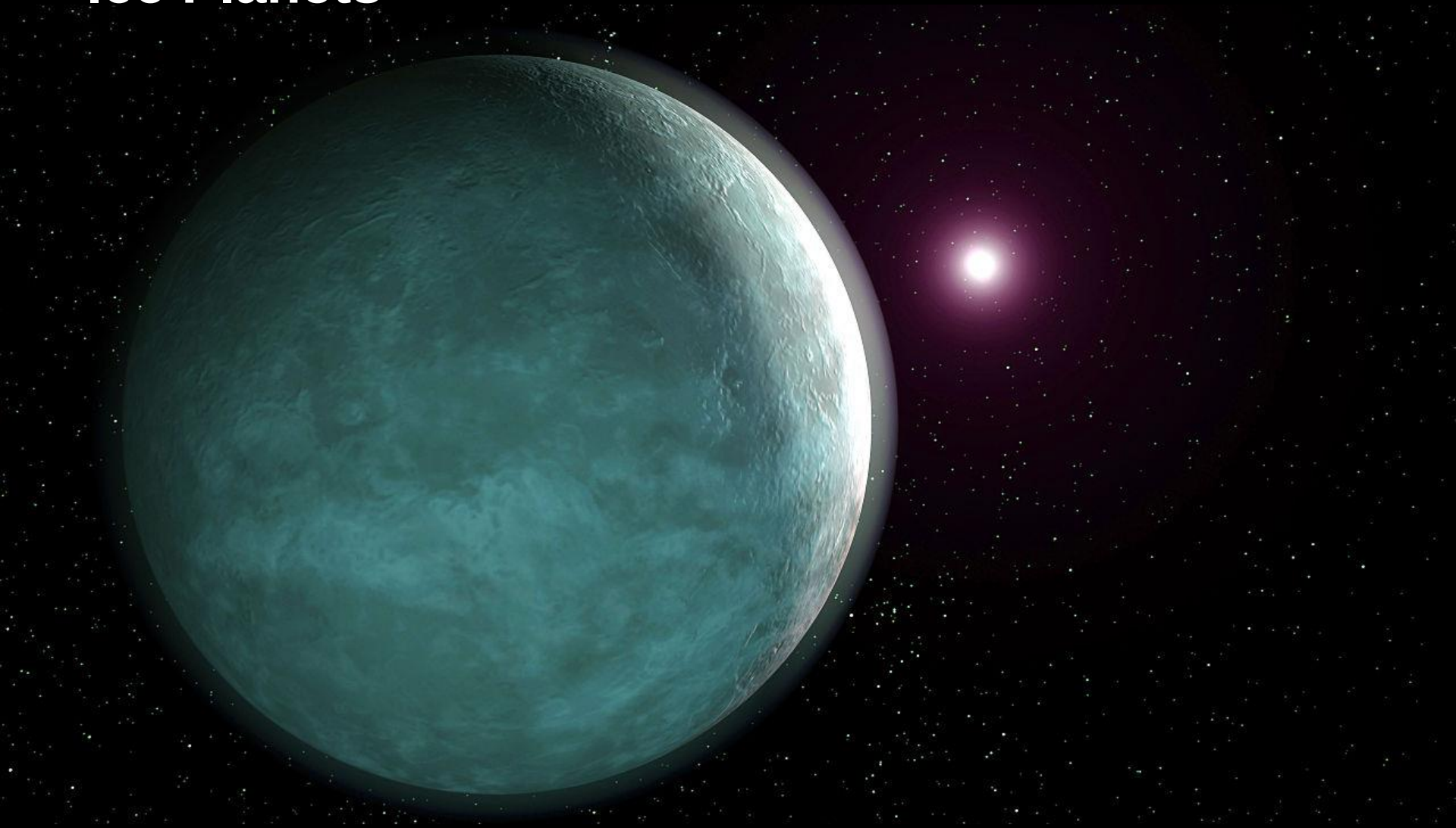
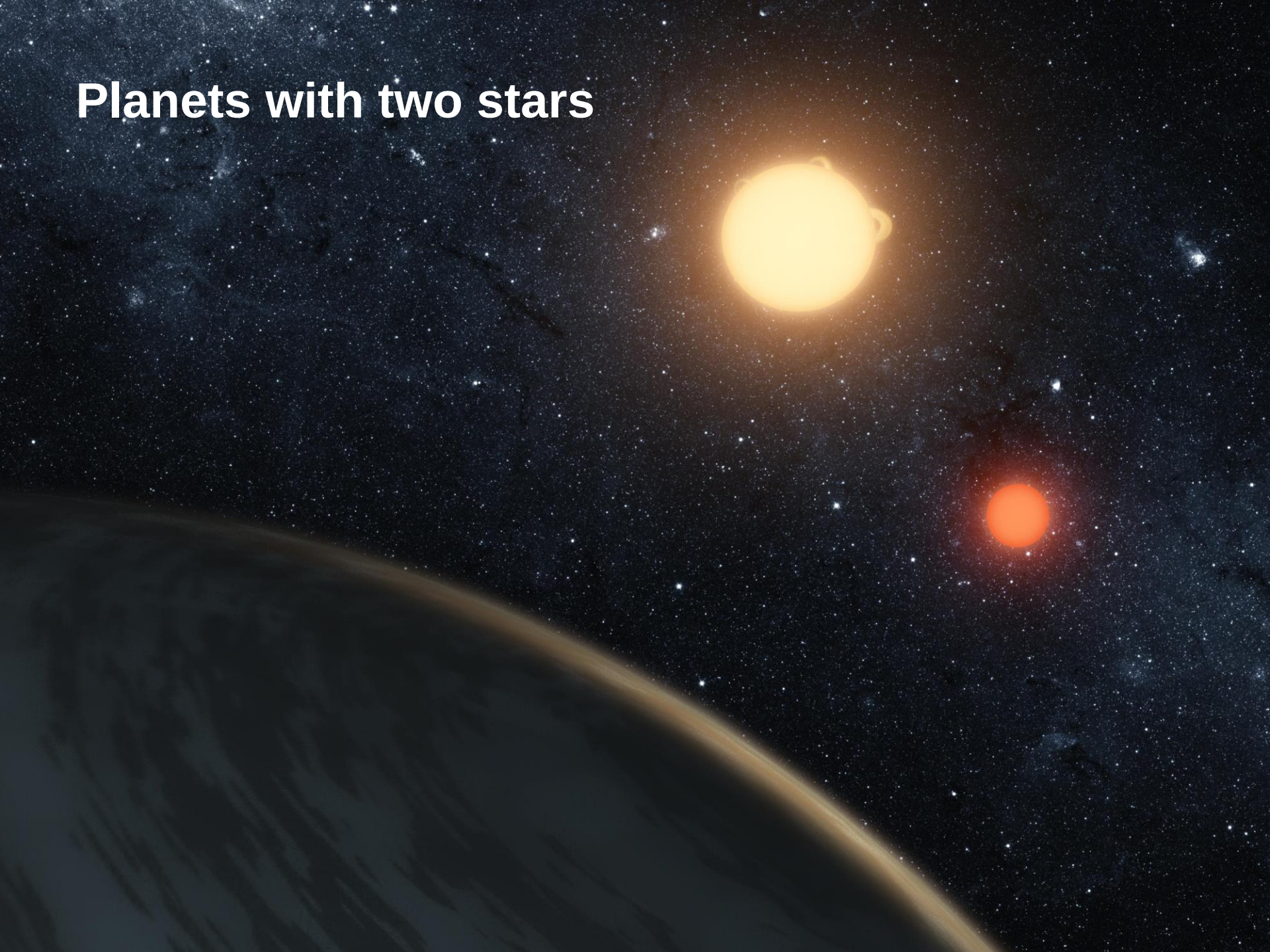


illustration: ESO/L. Calcada

Ice Planets

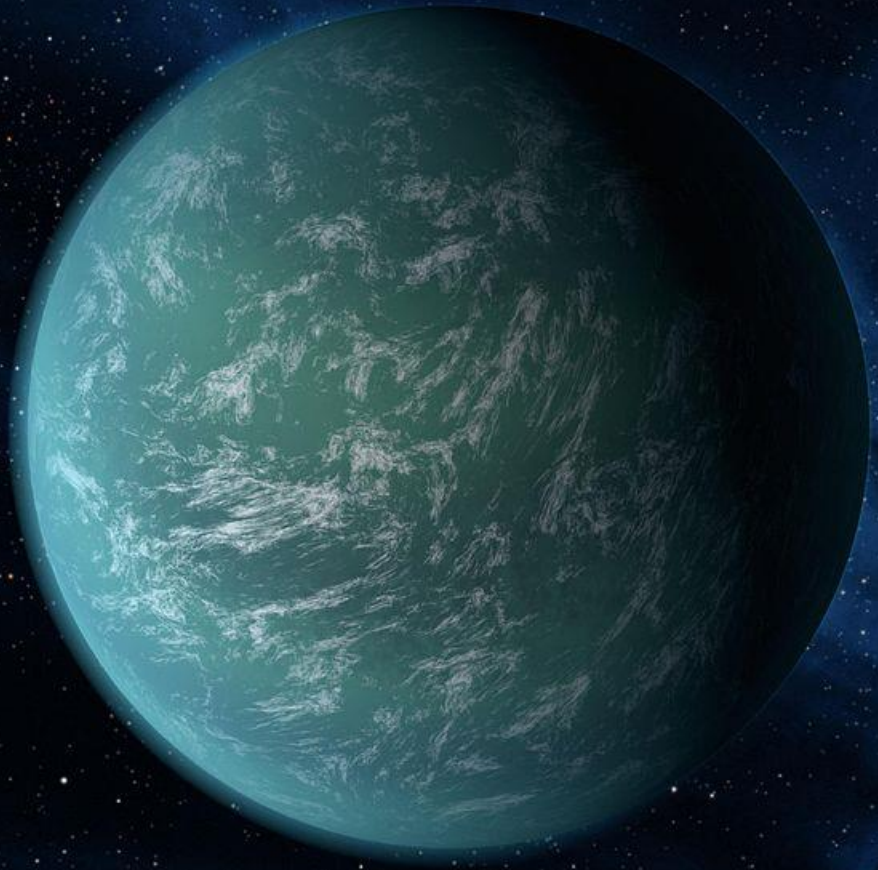


Planets with two stars



20th Century Fox/George Lucas

Water Worlds



Nomad planets not bound to any star at all!

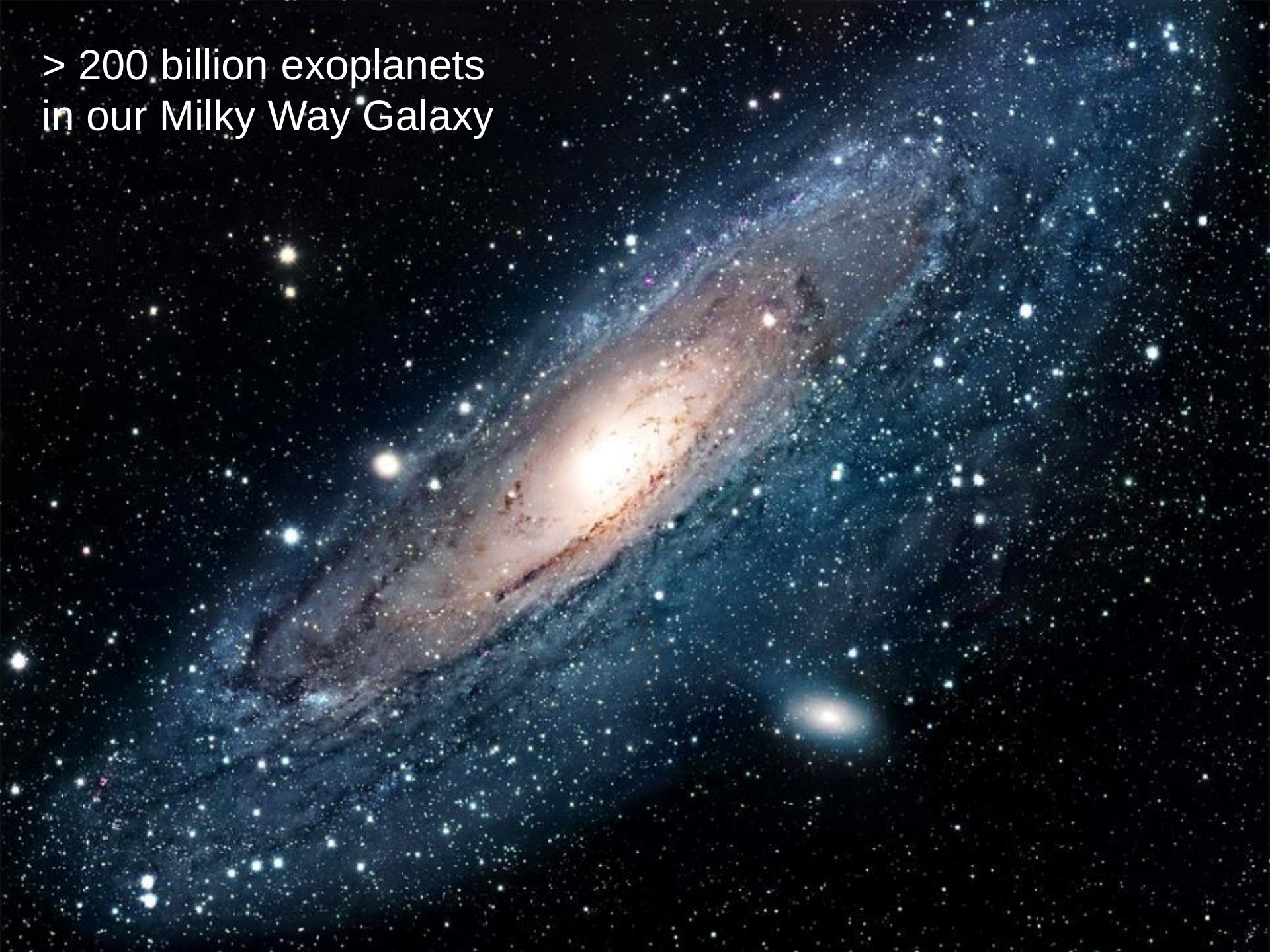
Kepler's Amazing Results:

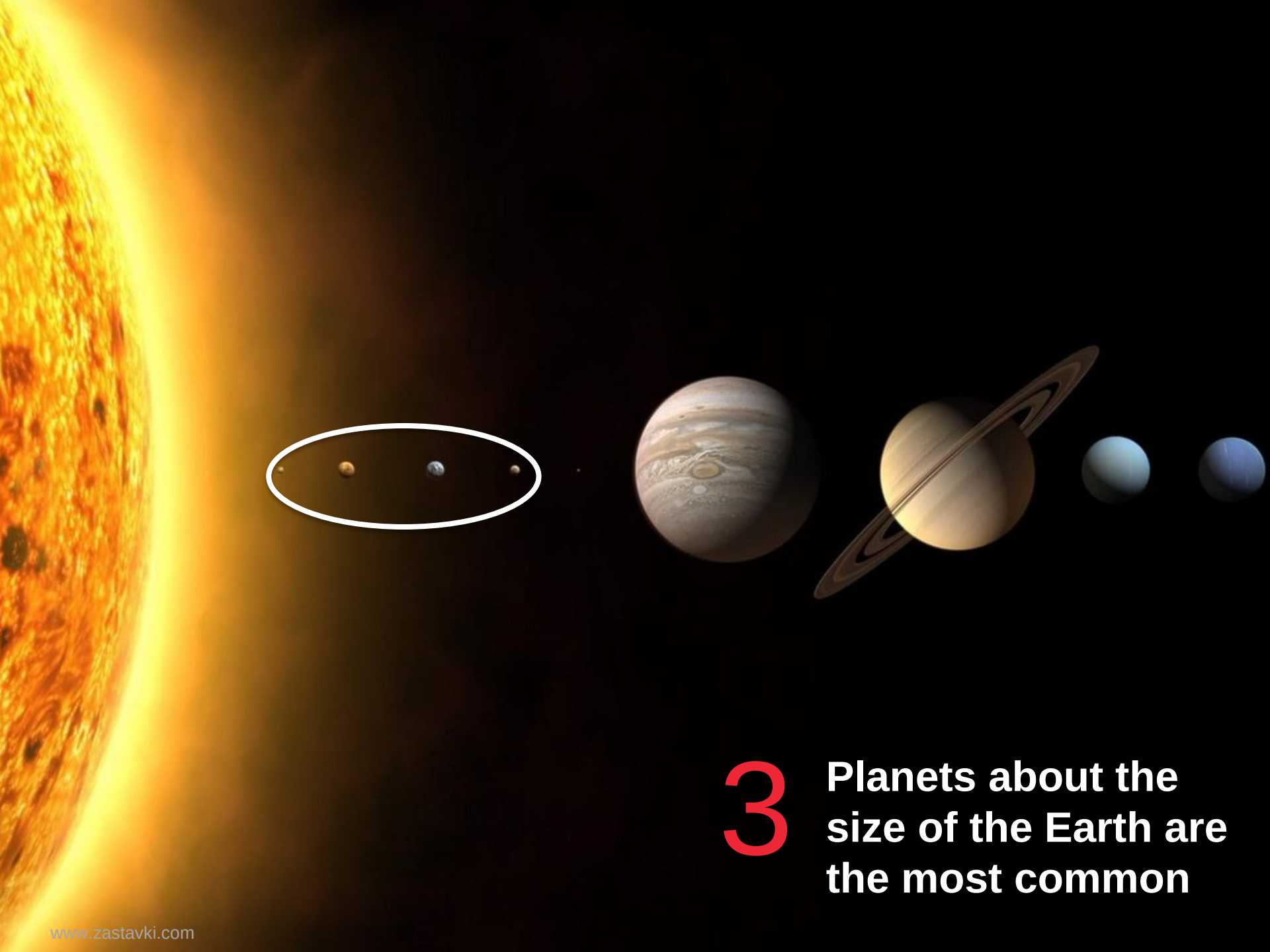
2

On average there is at least one planet for each star in our Galaxy

(and likely more…)

.

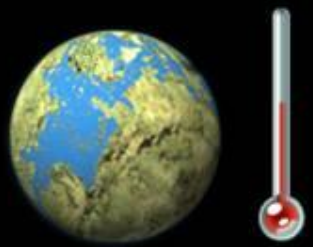

> 200 billion exoplanets
in our Milky Way Galaxy



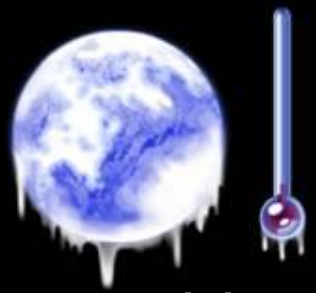
3 Planets about the size of the Earth are the most common

Many of the new planets get too hot or too cold to support life.

Too hot!

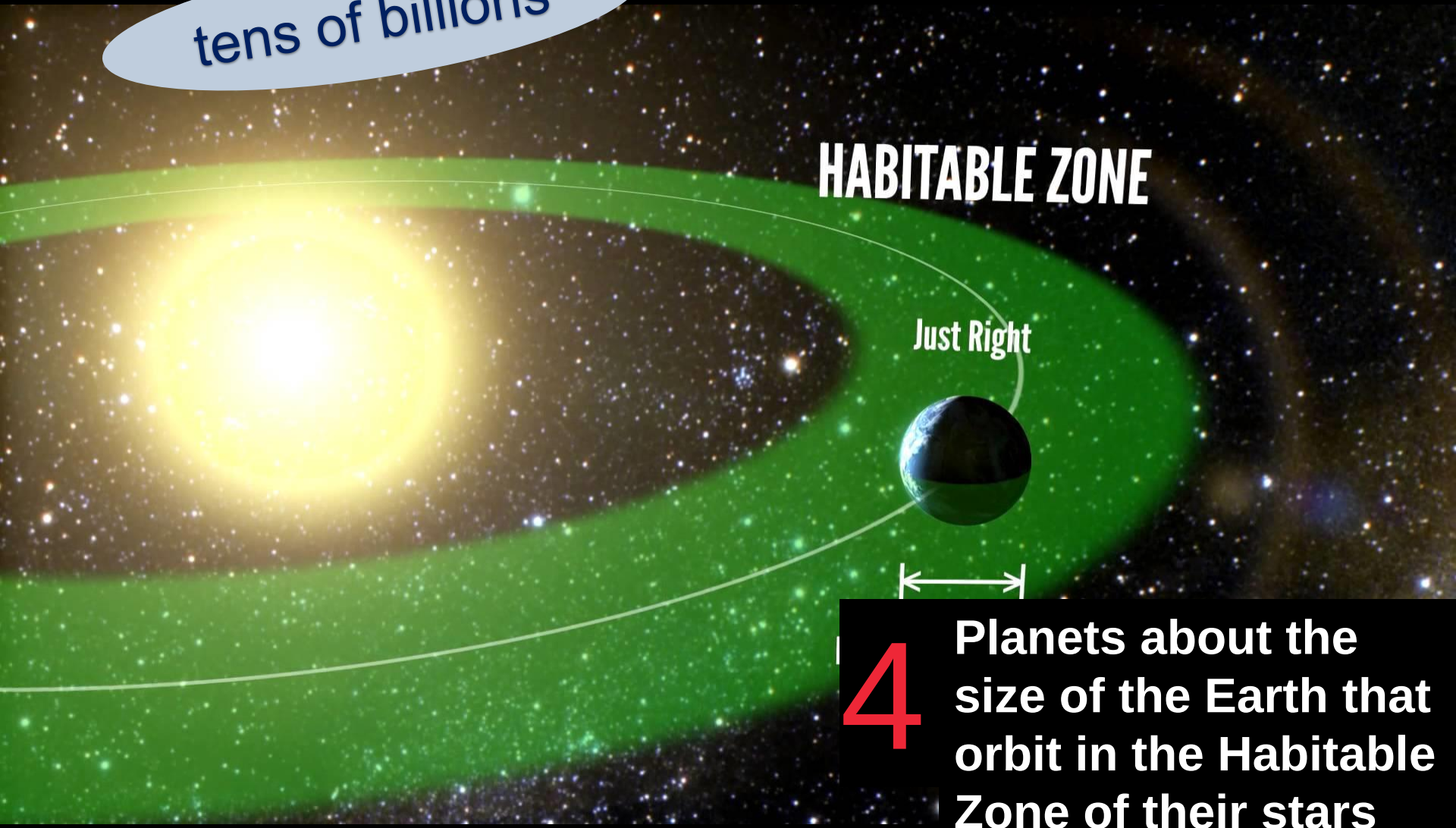


Just right!



Too cold!

tens of billions



4 **Planets about the size of the Earth that orbit in the Habitable Zone of their stars are common**

illustration: Petigura/UC Berkeley, Howard/UH-Manoa, Marcy/UC Berkeley

Q&Alien Video: Habitable Zones

Summary of Kepler's Amazing Results:

1. Planets are diverse

2. On average there is at least one planet for each star in our Galaxy

3. Planets about the size of the Earth are the most common

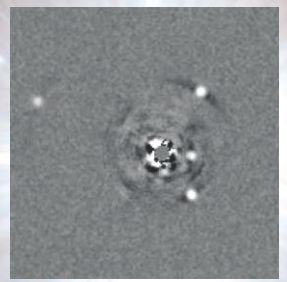
4. Planets about the size of the Earth that orbit in the Habitable Zone of their stars are common.

Exploring a Galaxy of Worlds While Inspiring our Own

Introducing Baby Kepler! (Cloutier)

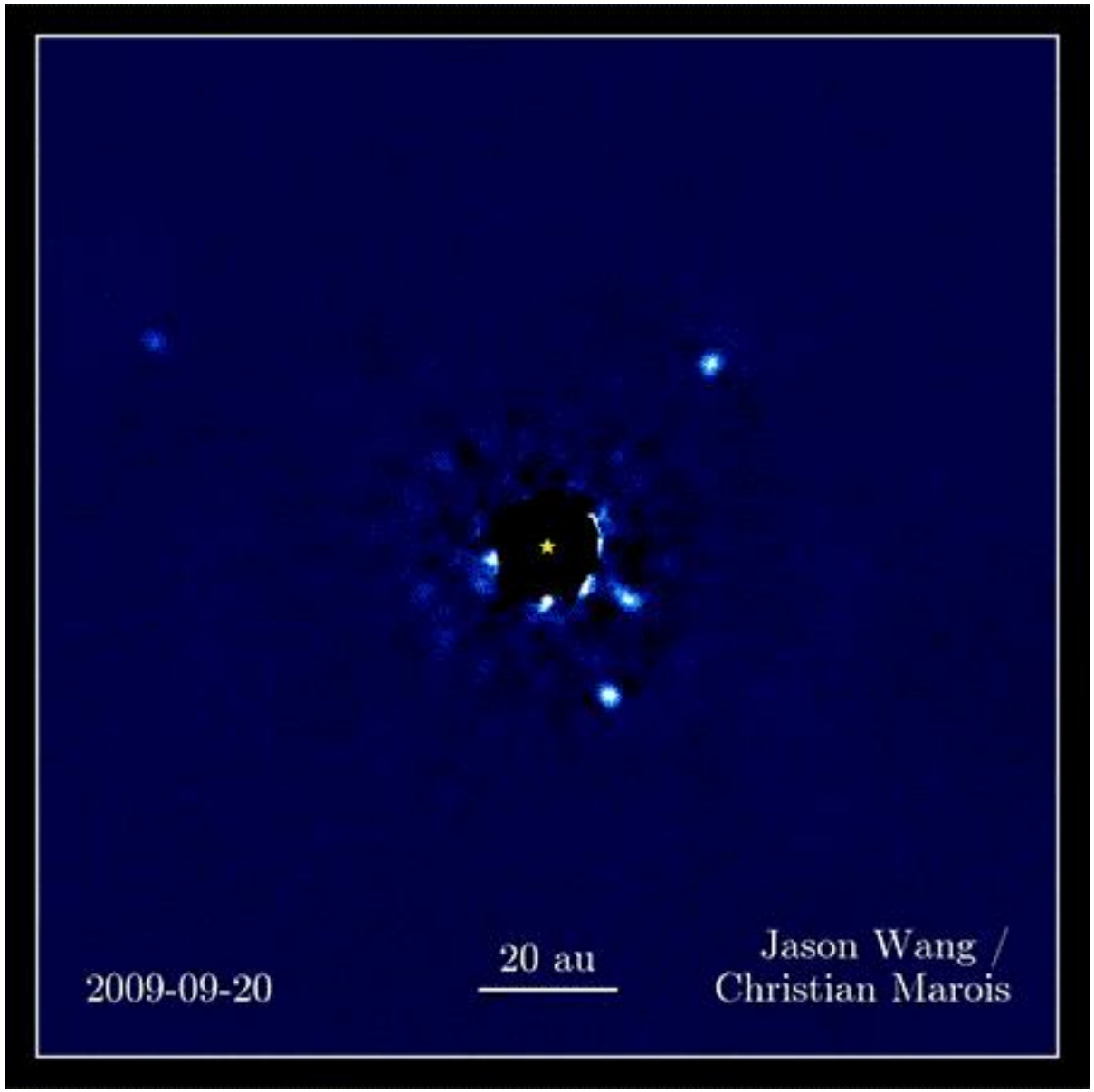
DOB 2/6/16. Age on Earth: (1), Kepler 16b: (1.5), Proxima b (33), Trappist-1b (243)

After meeting the Cloutier family at the Pasadena Astronomy Festival in October 2016, ExoComm brought the family to tour JPL with ExEP Program Manager Gary Blackwood and Steve Howell of Ames on January 17, 2017. A story will follow to be published on the exoplanets.nasa.gov website soon

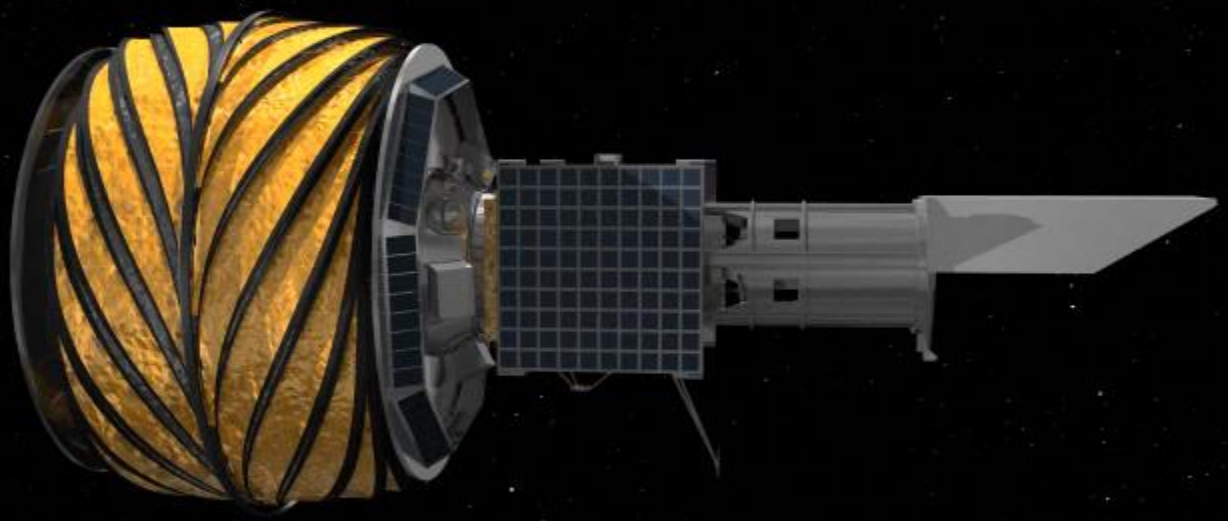


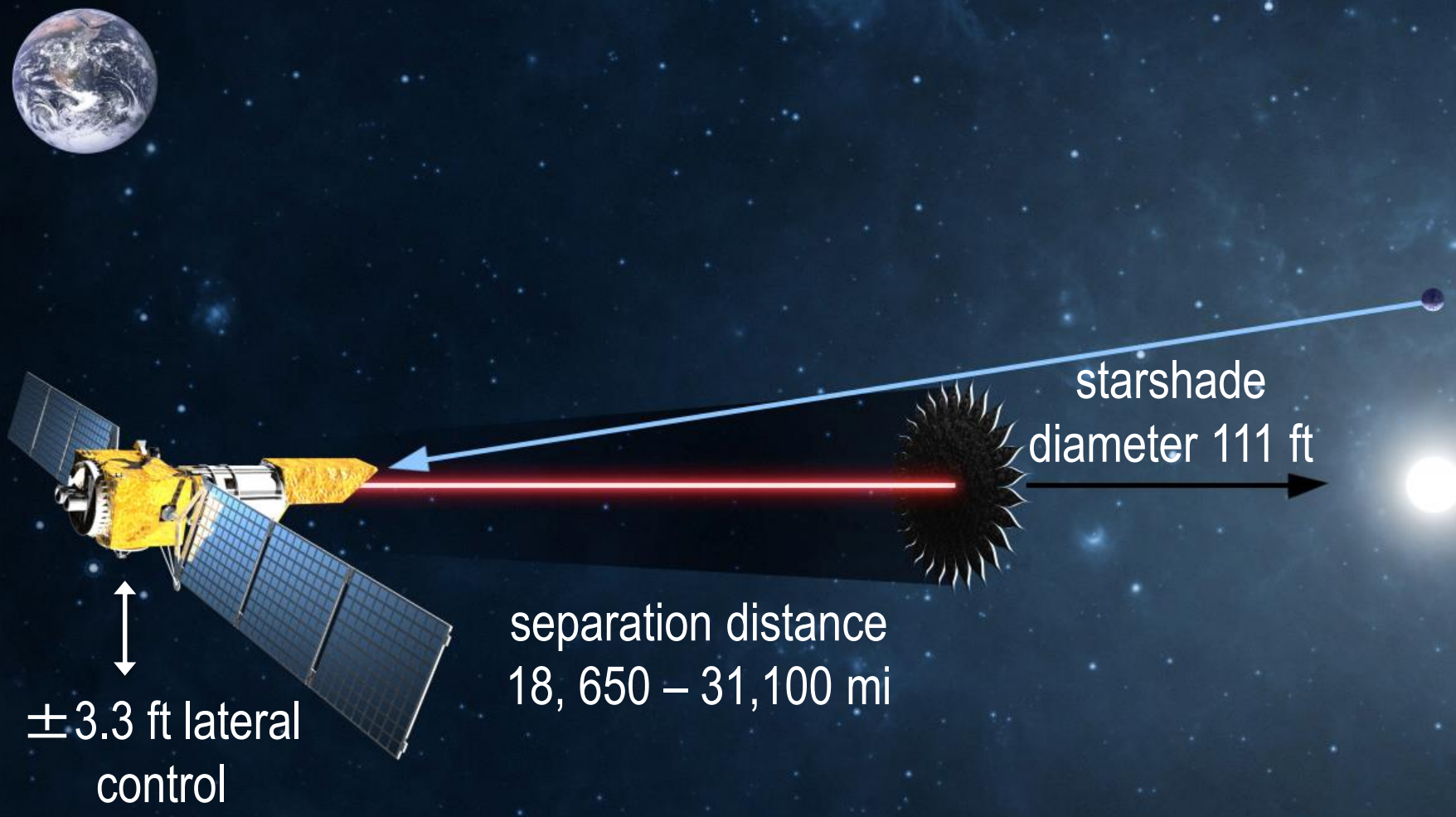
Marois et al. 2010

Orbital Motion of Four Giant Planets around HR 8799 Directly Imaged and Remarkable

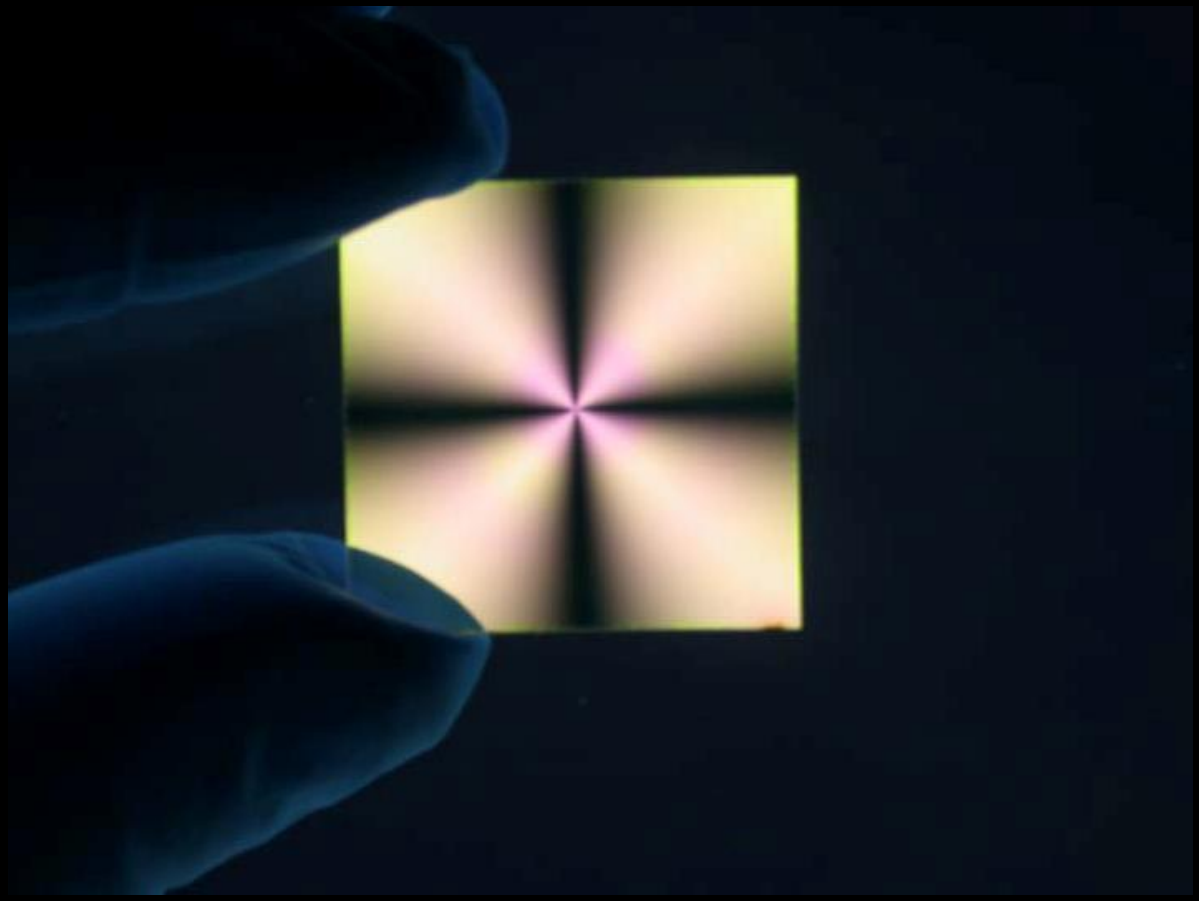


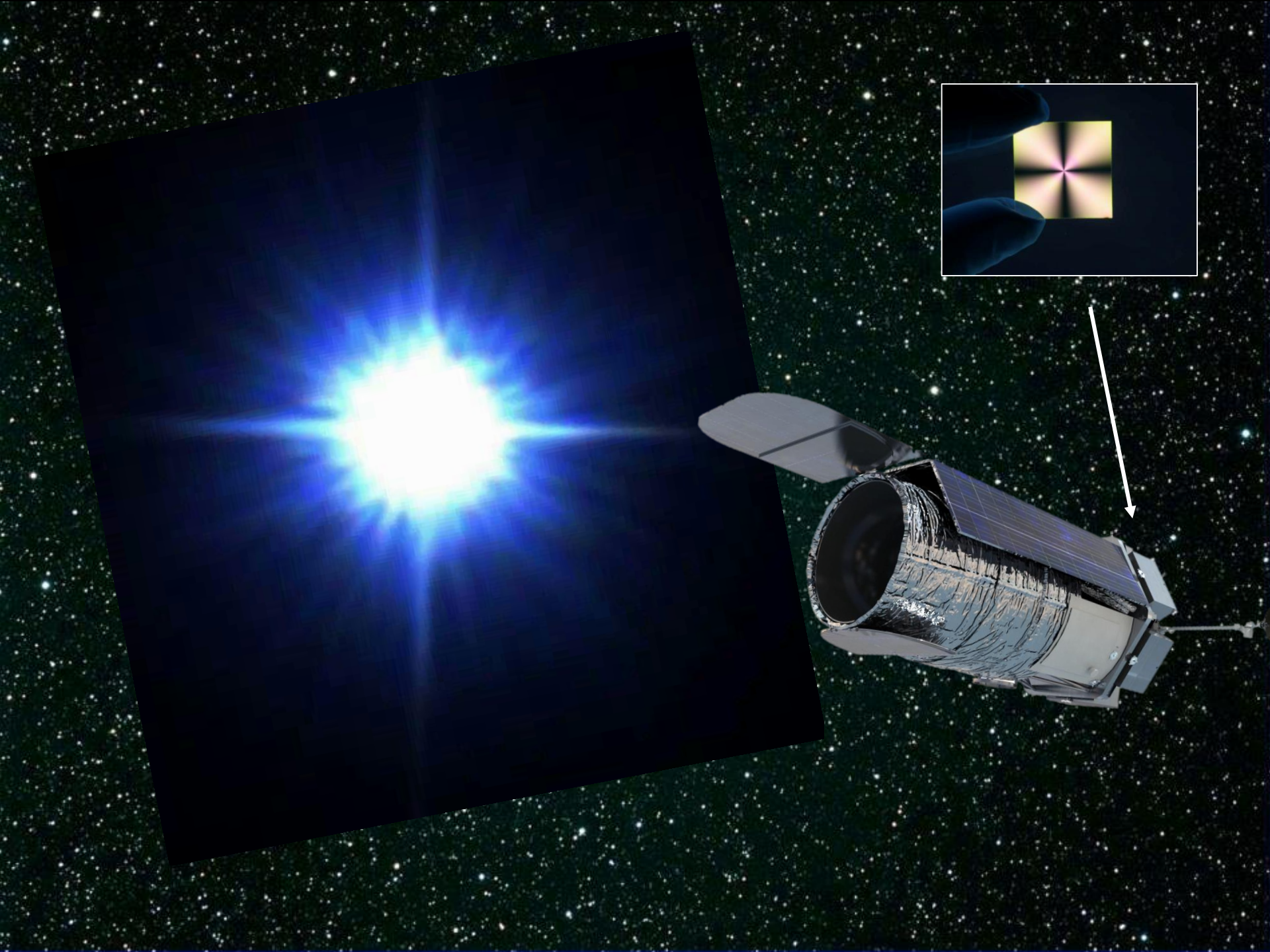
1. Starshade Animation




starshade
diameter 111 ft
separation distance
18, 650 – 31,100 mi
±3.3 ft lateral
control

The Coronagraph

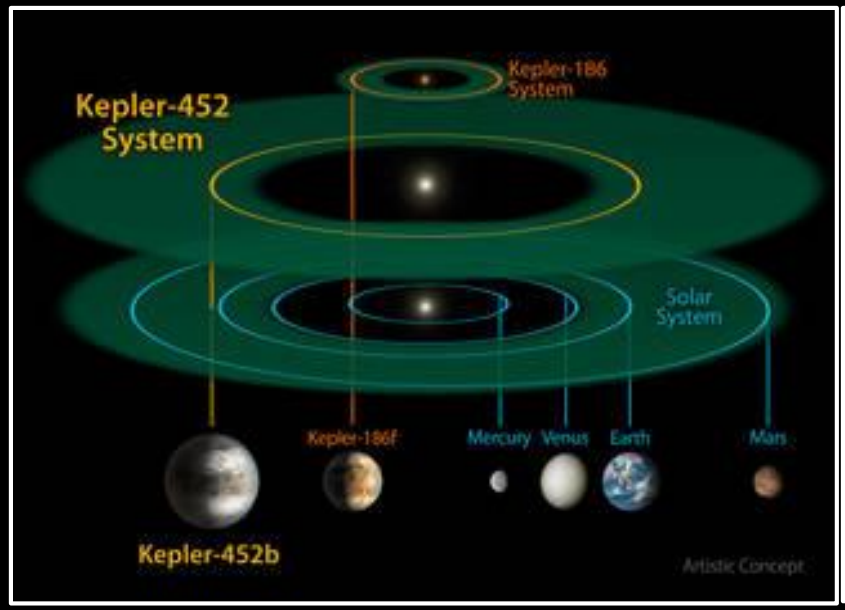


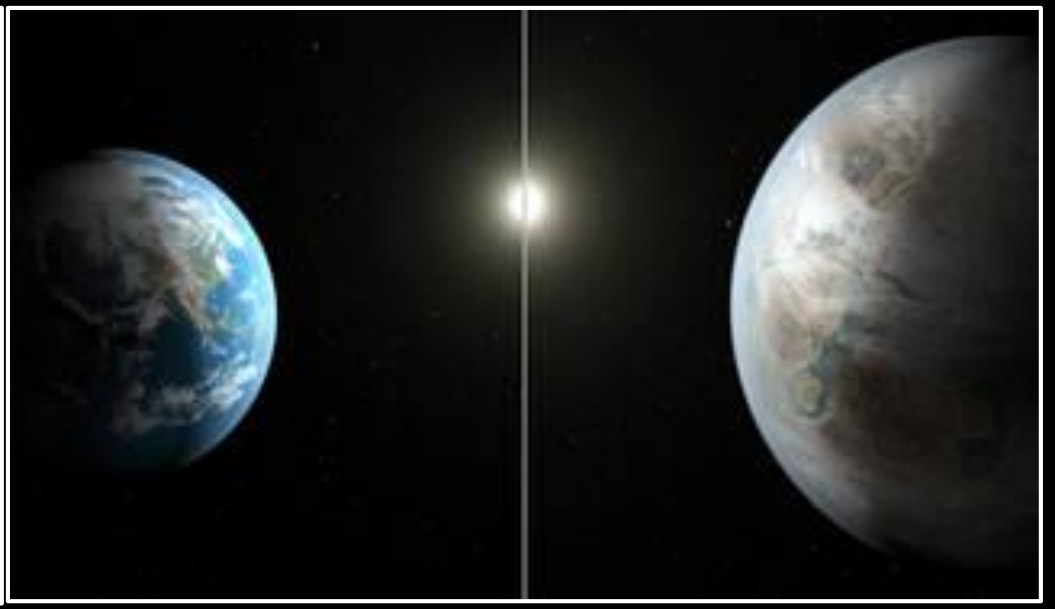


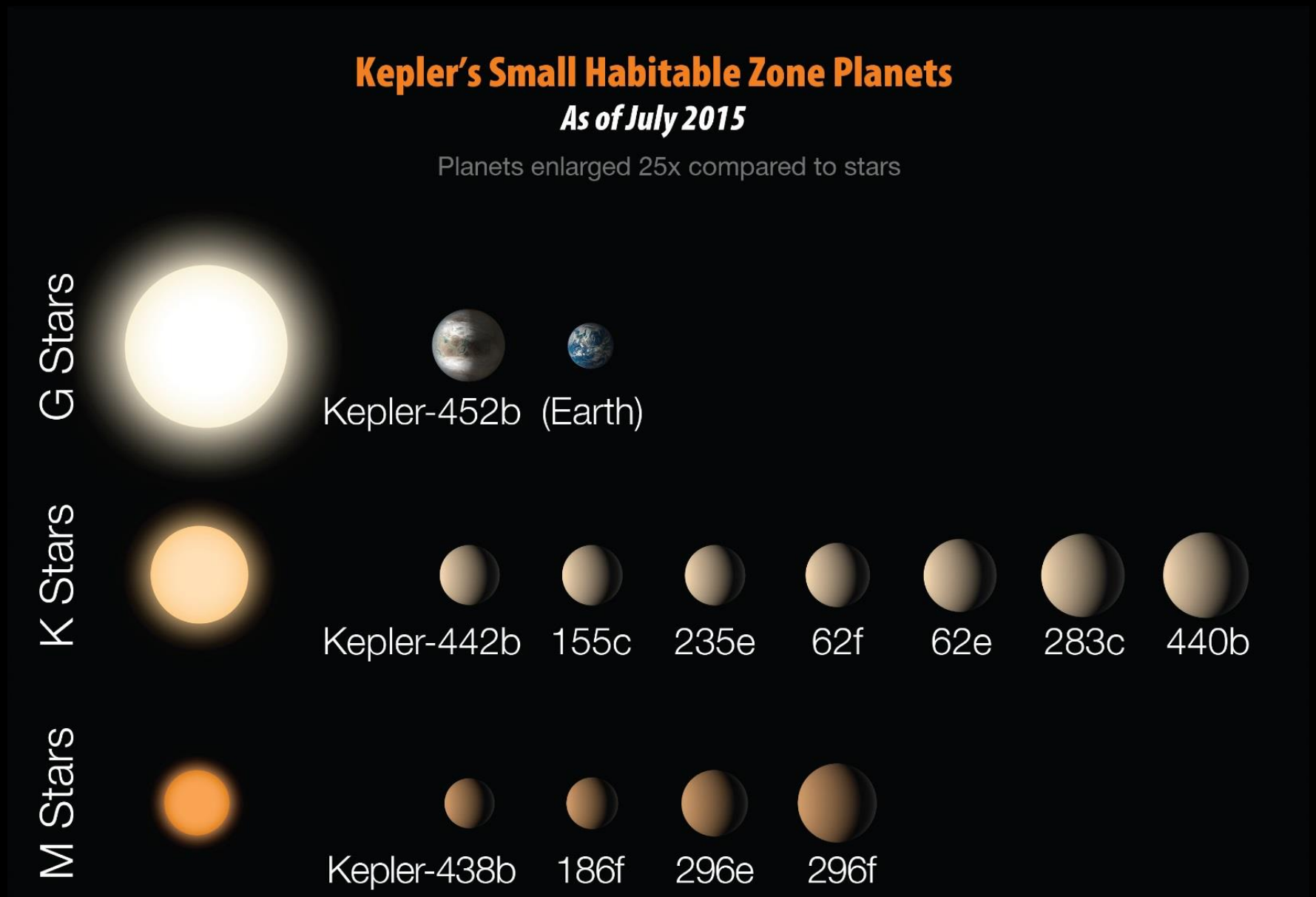
2. Coronagraph Animation

2. What are Exoplanets Like?

Kepler 452 b: Earth's Bigger, Older Cousin





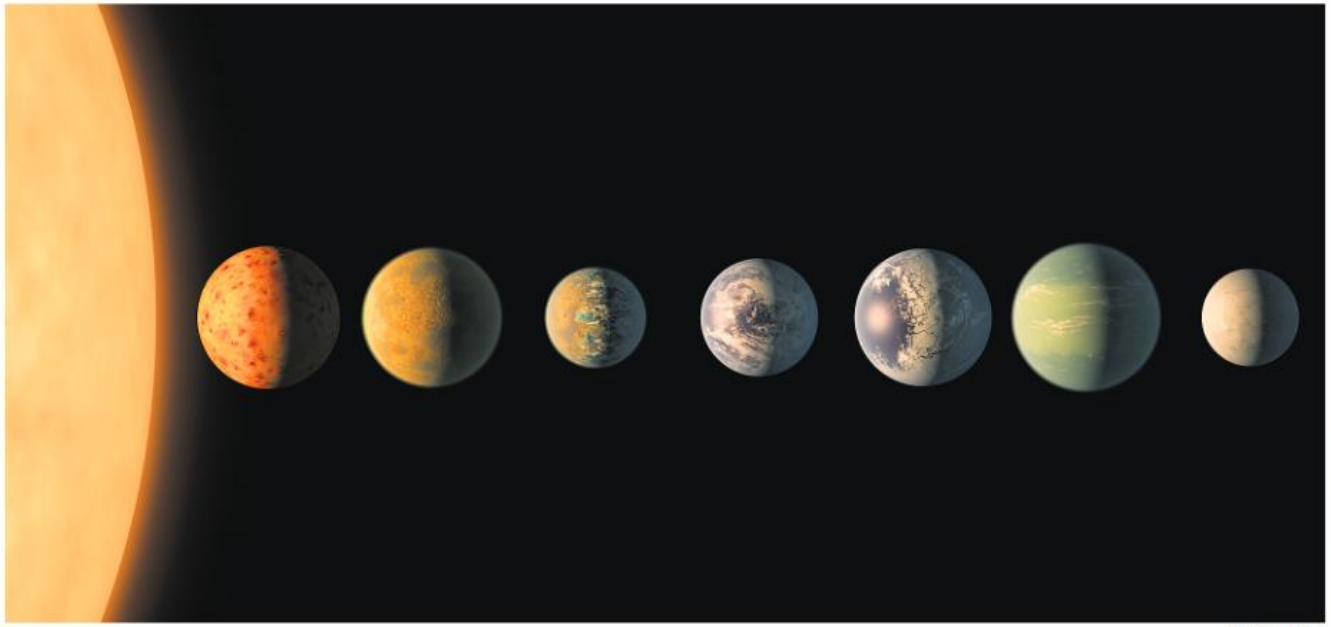

Kepler's Small Habitable Zone Planets
As of July 2015
Planets enlarged 25x compared to stars
G Stars
Kepler-452b
(Earth)
K Stars
Kepler-442b
155c
235e
62f
62e
283c
440b
M Stars
Kepler-438b
186f
296e
296f

"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 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.

Circling a Star Not Far Away, 7 Shots at Life

By KENNETH CHANG

Not just one, but seven Earth-size planets that could potentially harbor life have been identified orbiting a tiny star not too far away, offering the first realistic opportunity to search for signs of alien life outside the solar system.

The planets orbit a dwarf star named Trappist-1, about 40 light-years, or 235 trillion miles, from Earth. That is quite close in cosmic terms, and by happy accident, the orientation of the orbits of the seven planets allows them to be studied in great detail.

Uber's Culture Of Gutsiness Under Review

By MIKE ISAAC

SAN FRANCISCO — When new employees join Uber, they are asked to subscribe to 14 core company values, including making bold bets, being "obsessed" with the customer, and "always be hustlin'." The ride-hailing service particularly emphasizes "meritocracy," the idea that the best and brightest will rise to the top based on their efforts, even if it means stepping on toes to get there.

Those values have helped propel Uber to one of Silicon Valley's biggest success stories. The com-

Migrants Hide, Fearing Capture on 'Any Corner'

By VIVIAN YEE

No going to church, no going to the store. No doctor's appointments for some, no school for others. No driving, period — not when a broken taillight could deliver the driver to Immigration and Customs Enforcement.

It is happening in the Central Valley of California, where undocumented immigrants pick the fields for survival wages but are keeping their children home from school; on Staten Island, where fewer day laborers haunt street corners in search of work; in West Phoenix's Isaac School District, where 13 Latino students have dropped out in the past two weeks; and in the horse country of northern New Jersey, where one of the many undocumented grooms who muck out the stables is thinking of moving back to Honduras.

If deportation has always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump administration intent on curbing illegal immigration — two memos outlining the federal government's plans to accelerate deportations were released Tuesday, another step toward making good on one of President Trump's signature campaign pledges — that threat, for many people, has now begun to distort every movement.

Continued on Page A14

IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE A14

MEXICO The secretary of state pays a visit at a time of rising tensions. PAGE A15

TRUMP RESCINDS OBAMA DIRECTIVE ON BATHROOM USE

ENTERING CULTURE WARS

Question of Transgender Rights Splits DeVos and Sessions

This article is by ***Jeremy W. Peters, Jo Becker*** *and* ***Julie Hirschfeld Davis.***

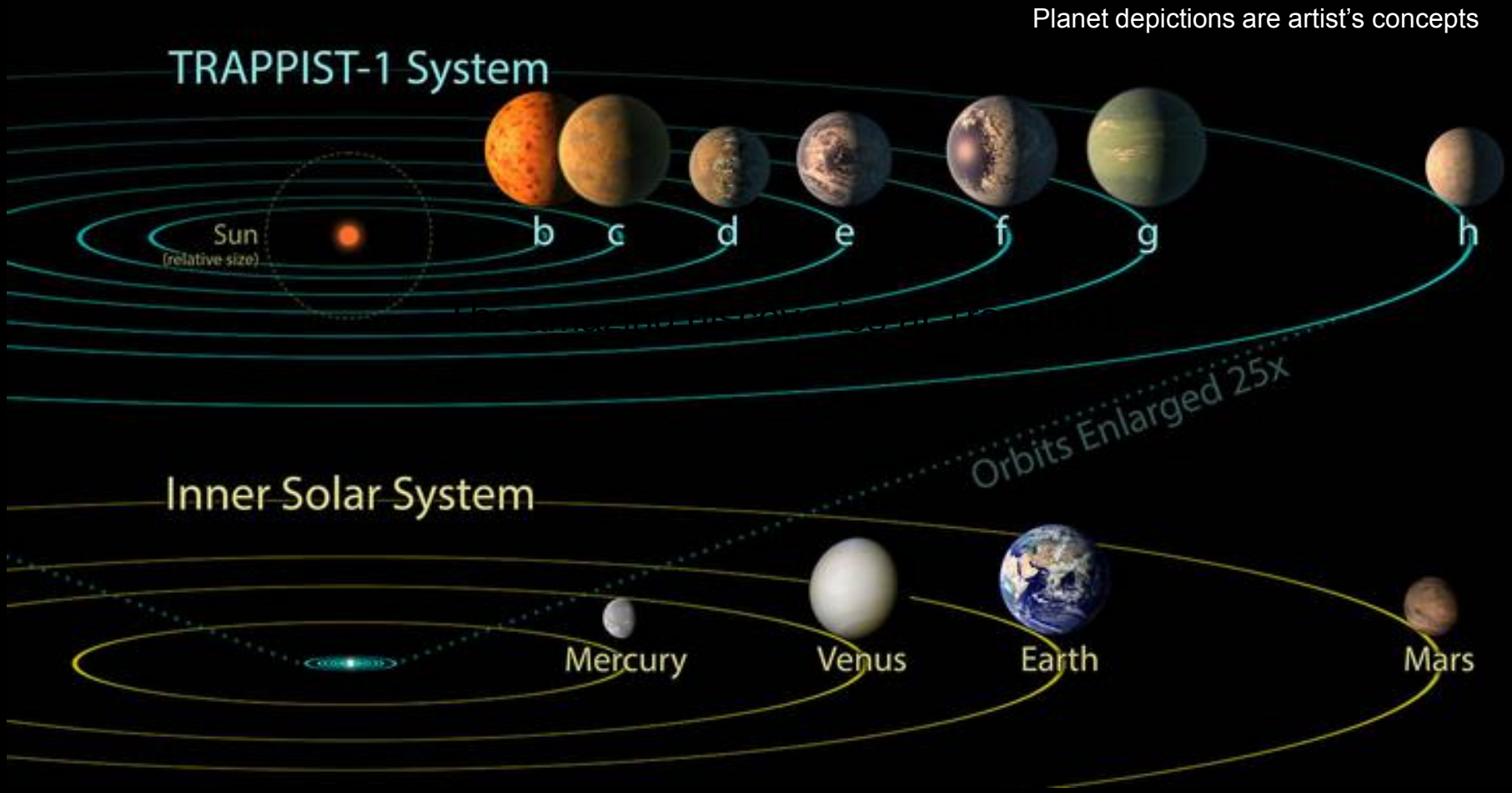
WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, overruling his own education secretary and placing his administration firmly in the middle of the culture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice Department and the Education Department rejected the Obama administration's position that nondiscrimination laws require schools to allow transgender students to use the bathrooms of their choice.

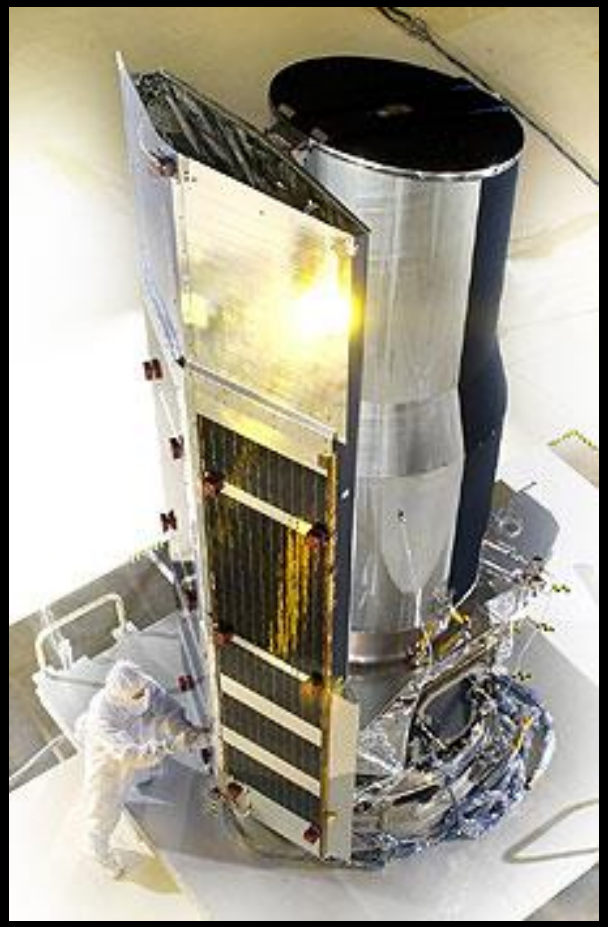
That directive, they said, was improperly and arbitrarily devised, "without due regard for the primary role of the states and local school districts in establishing educational policy."

The question of how to address the "bathroom debate," as it has become known, opened a rift inside the Trump administration, pitting Education Secretary Betsy DeVos against Attorney General Jeff Sessions. Mr. Sessions, who had been expected to move quickly to roll back the civil rights expansions put in place under his Democratic predecessors, wanted to act decisively because of two pending court cases that could have upheld the protections and

The amazing discoveries at Trappist-1

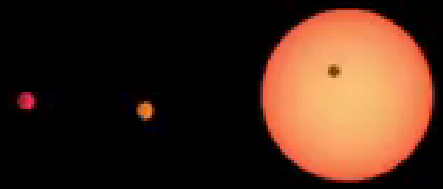


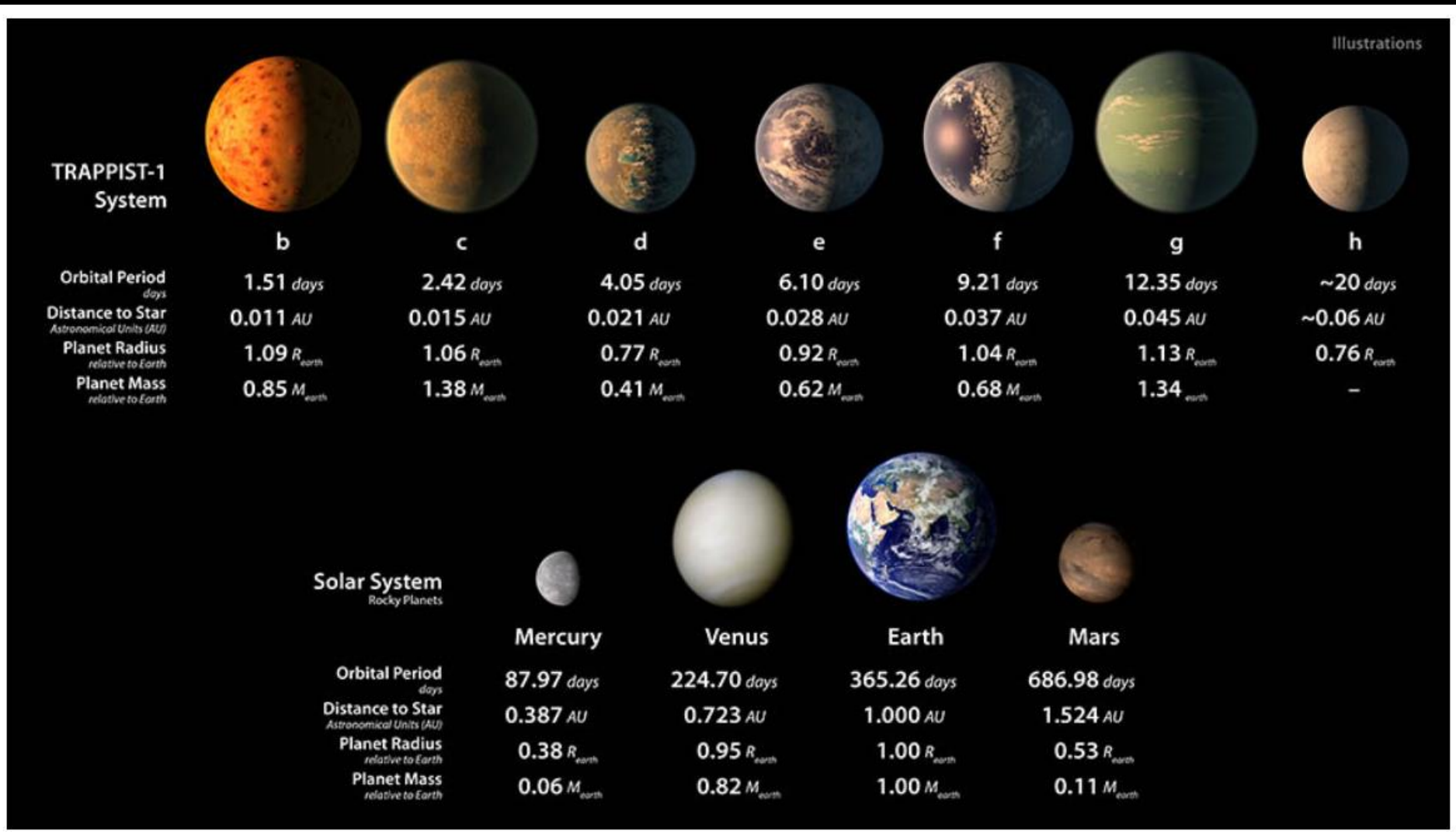
Spitzer: Discovery machine for the Trappist-1 planetary system



- 33.4 inch diameter infrared telescope
- Instrumented with 2 cameras and 1 spectrograph
- Launched August 2003
- Conducted broad science program in all areas of astrophysics, most observing time for the general community
- In 2005 made first-ever detection of light emitted by an exoplanet
- Operated at -449° Fahrenheit until 2009 when liquid helium was exhausted
- Since 2009 has operated “warm” at -388° F
- Mission development & operations led by JPL

How Spitzer Observed the Trappist-1 System




Illustrations
TRAPPIST-1 System
b
c
d
e
f
g
h
Orbital Period
days
1.51 days
2.42 days
4.05 days
6.10 days
9.21 days
12.35 days
~20 days
Distance to Star
Astronomical Units (AU)
0.011 AU
0.015 AU
0.021 AU
0.028 AU
0.037 AU
0.045 AU
~0.06 AU
Planet Radius
relative to Earth
1.09 R_{earth}
1.06 R_{earth}
0.77 R_{earth}
0.92 R_{earth}
1.04 R_{earth}
1.13 R_{earth}
0.76 R_{earth}
Planet Mass
relative to Earth
0.85 M_{earth}
1.38 M_{earth}
0.41 M_{earth}
0.62 M_{earth}
0.68 M_{earth}
1.34 M_{earth}
–
Solar System
Rocky Planets
Mercury
Venus
Earth
Mars
Orbital Period
days
87.97 days
224.70 days
365.26 days
686.98 days
Distance to Star
Astronomical Units (AU)
0.387 AU
0.723 AU
1.000 AU
1.524 AU
Planet Radius
relative to Earth
0.38 R_{earth}
0.95 R_{earth}
1.00 R_{earth}
0.53 R_{earth}
Planet Mass
relative to Earth
0.06 M_{earth}
0.82 M_{earth}
1.00 M_{earth}
0.11 M_{earth}

Key Takeaways from Trappist Discovery

- Richest set of Earth-sized exoplanets ever found orbiting a single star, with 3 in the habitable zone. Liquid H_2O possible
- Red dwarf stars, most common type of star, can host rich planetary systems. More discoveries like this can be expected, such as from the 2018 NASA TESS Explorer mission
- Trappist exoplanets will be top targets for future observations with the James Webb Space Telescope
  - Presence and composition of an atmosphere can be measured through infrared spectra taken during transit. But the observations will be difficult
- Most exoplanets do not transit their star. In general, direct imaging remains essential for measuring atmospheres and possible biosignatures

More of Kepler's Amazing Results:

1

Planets orbiting other stars in the Galaxy are common

.

2

Planets with sizes between 1/2 and 2 times Earth are the most common

3

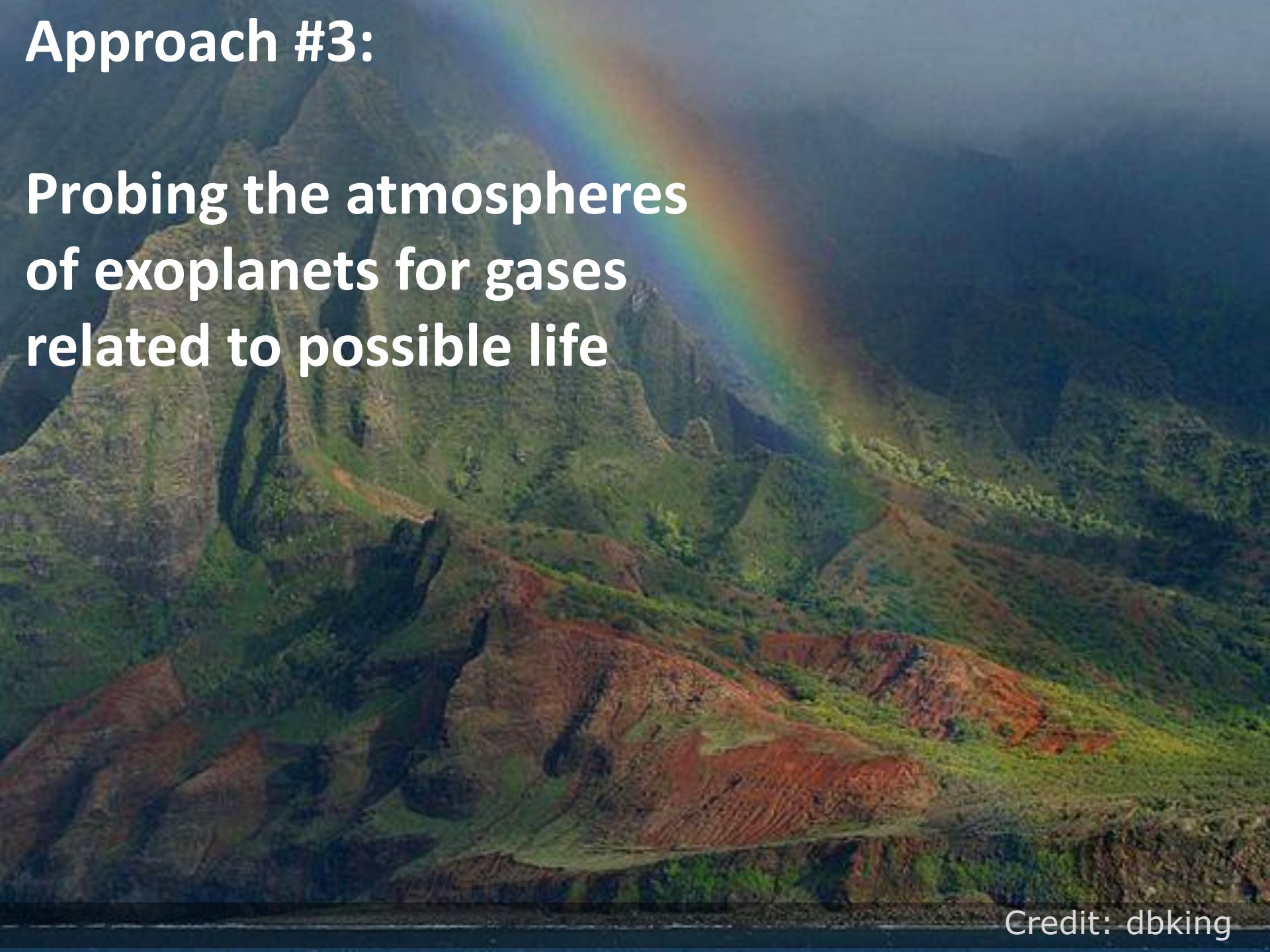
Planets with sizes between 1/2 and 2 times Earth that orbit in the Habitable Zone of their stars are common

Are we alone?

3. Search for Habitability and for Signs of Life

Approach #3:

Probing the atmospheres of exoplanets for gases related to possible life

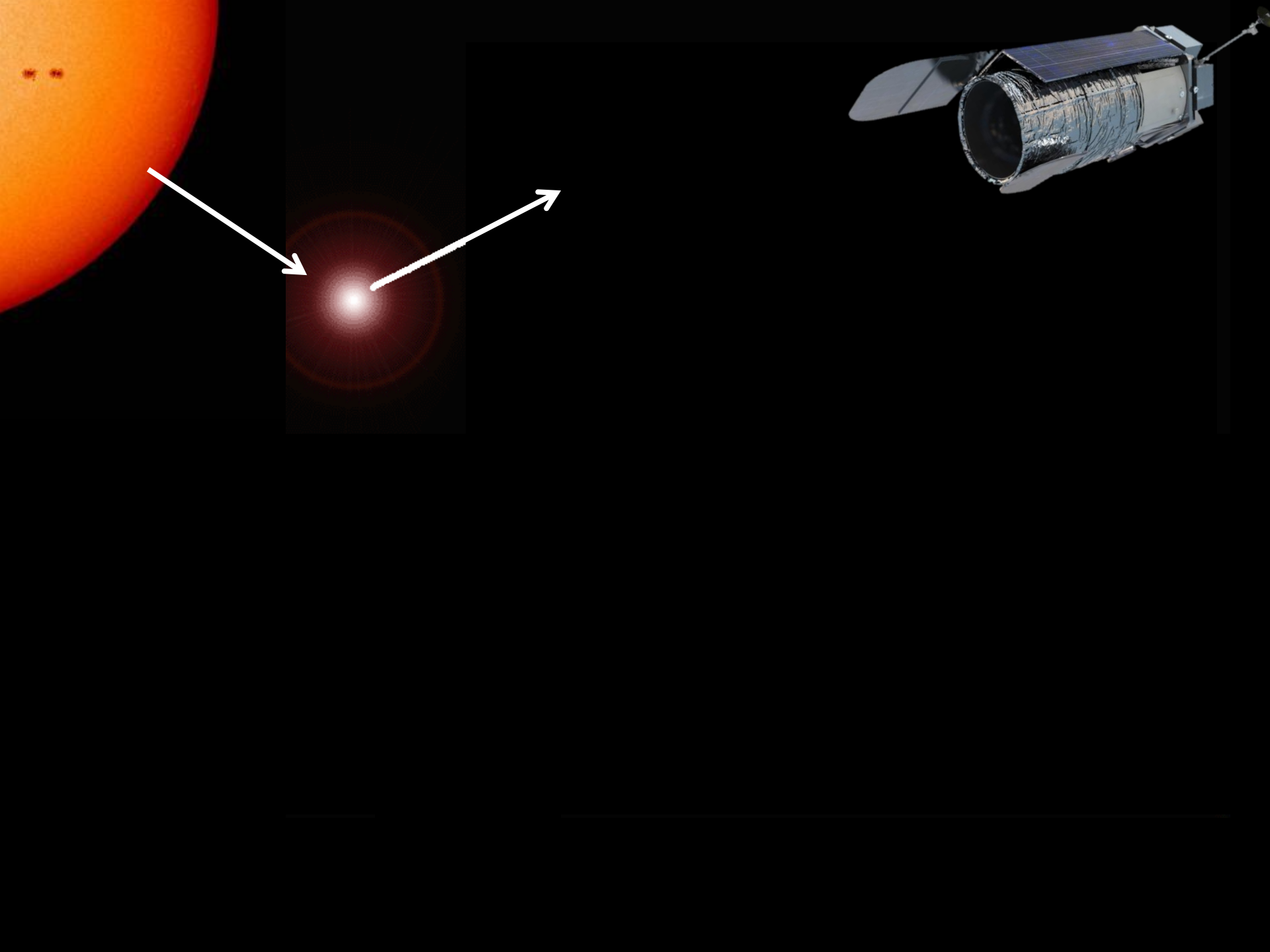


Credit: dbking

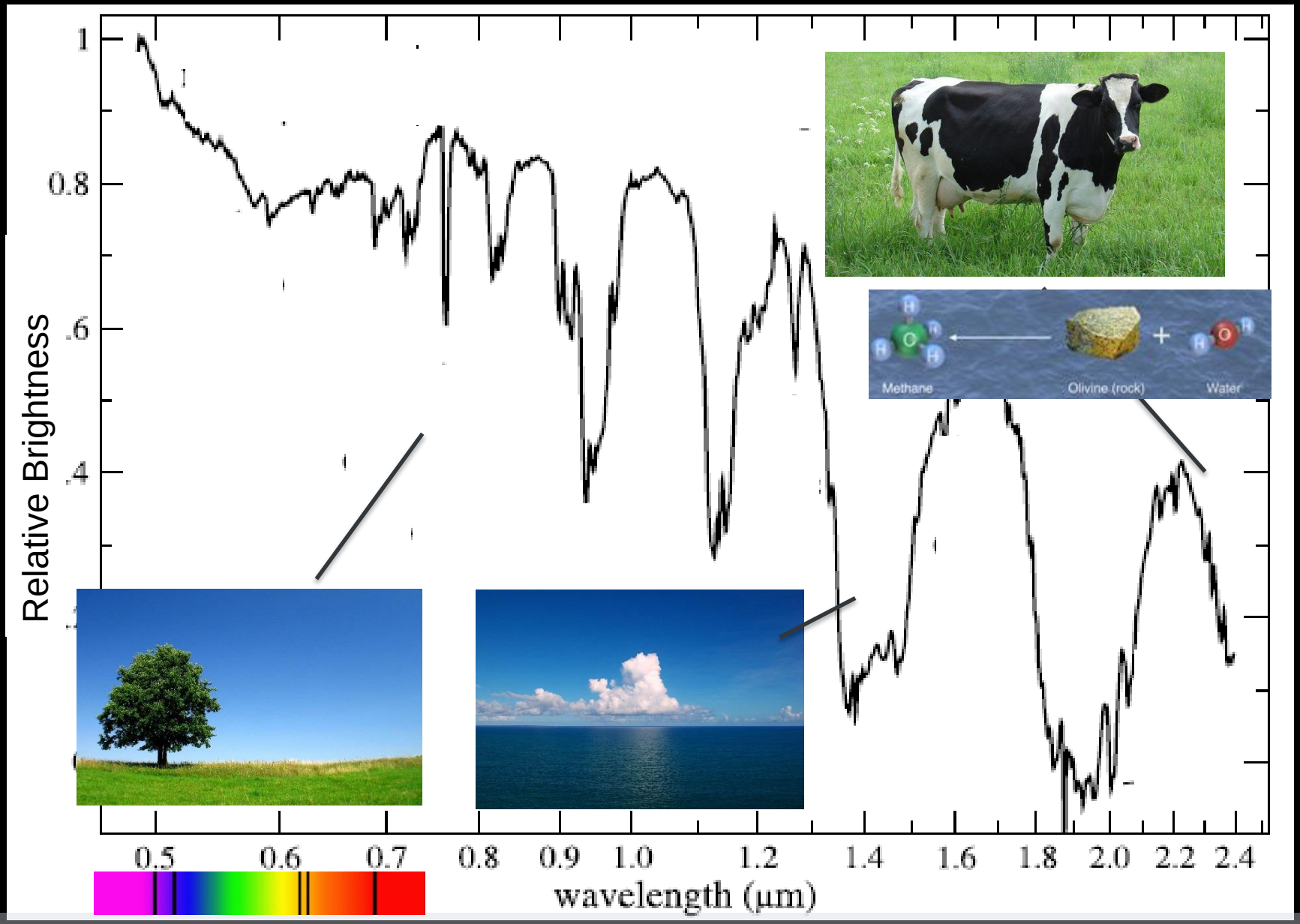
Oxygen

Water Vapor

Methane



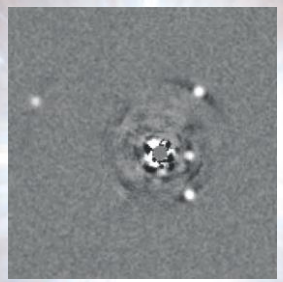
Detecting Life on an Exoplanet



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!

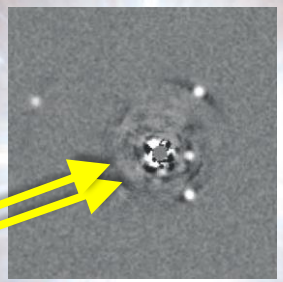
Marois et al. 2010

Direct Imaging Exoplanets Challenges #2:

Resolution

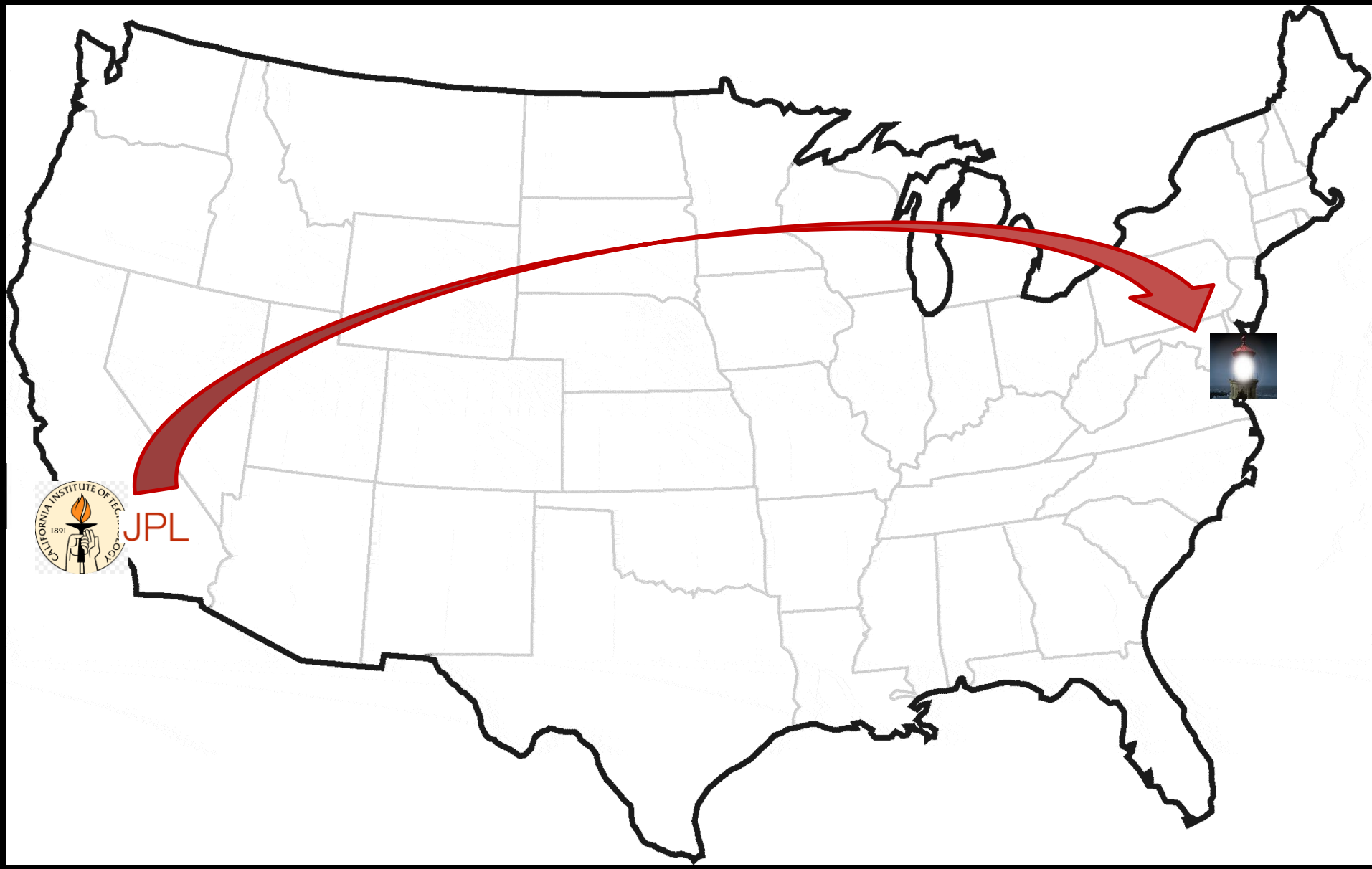
0.5º

Earth



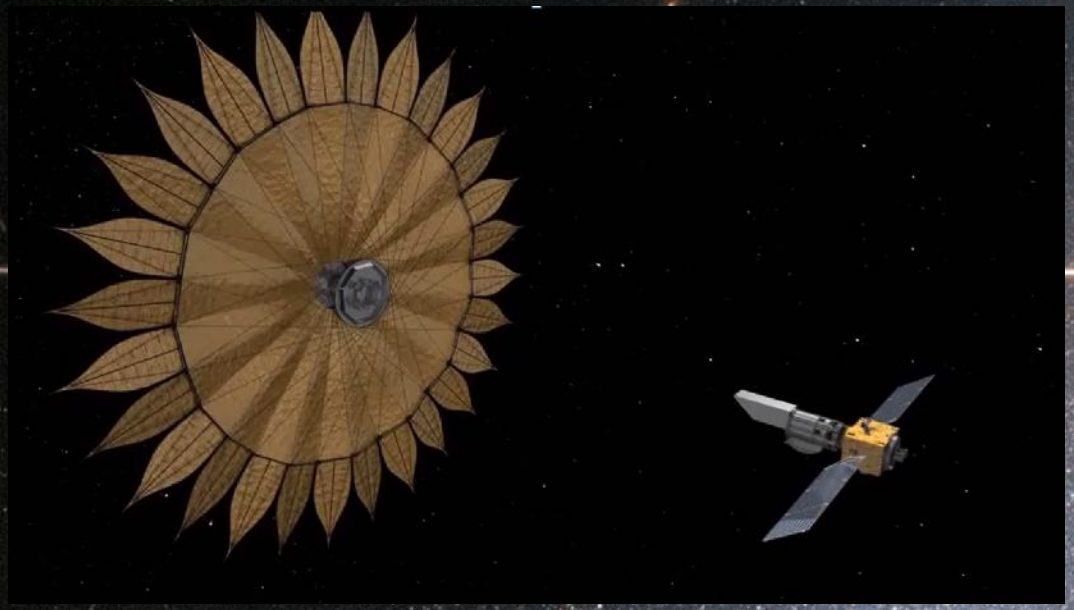
1/18,000 of a degree
(1 AU at 33 lyr)

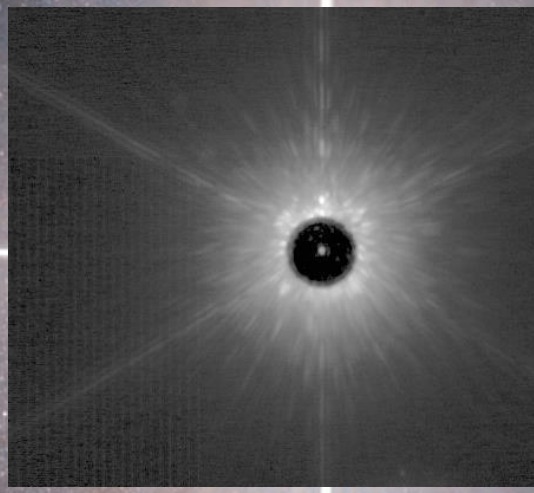

firefly


JPL

Two Direct Planet Imaging Techniques

1. Starshade

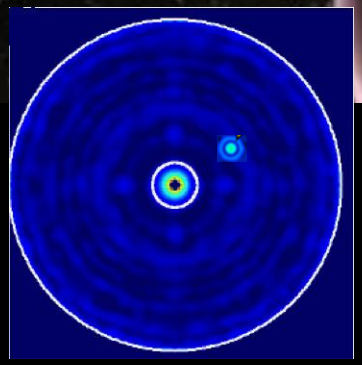


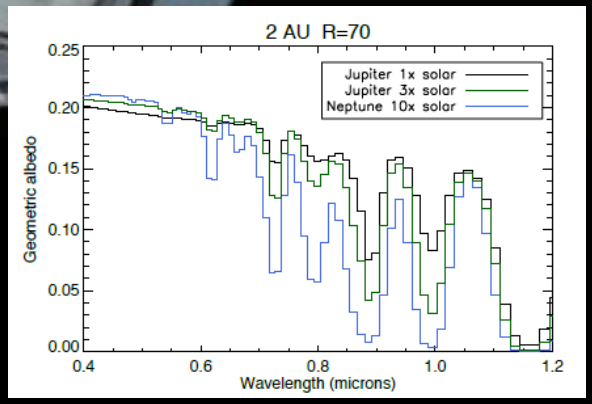


2. Coronagraphs

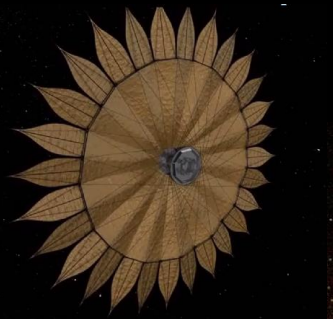
WFIRST

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

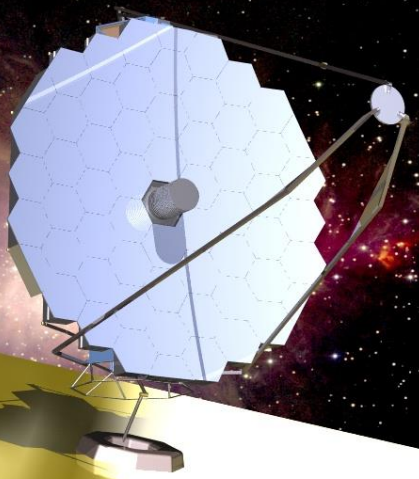


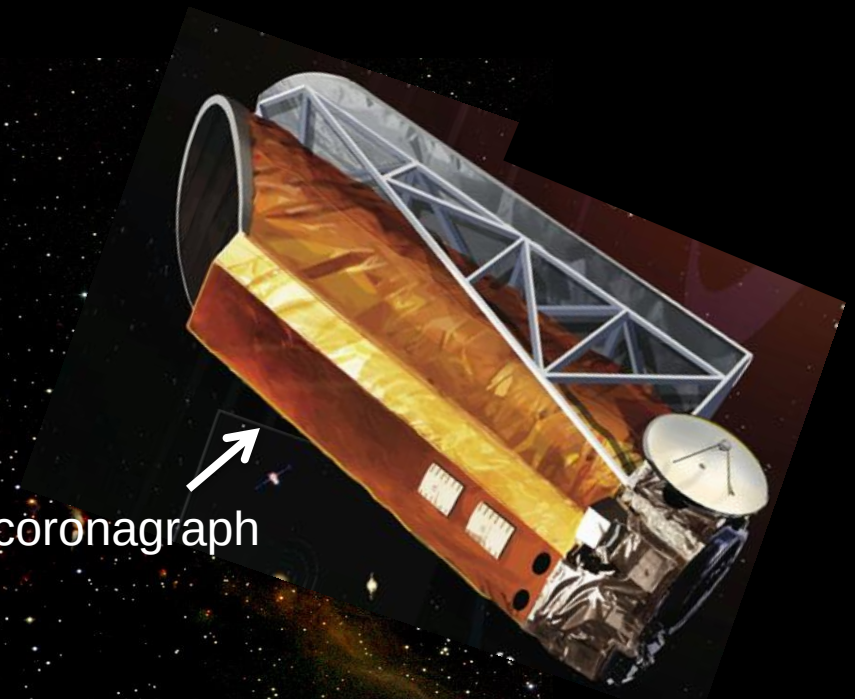


Possibilities for the New Worlds Telescope (mid-2030s)



starshade





coronagraph

Habitable Exoplanet Imaging Missions (Hab-Ex)

Large Ultra-Violet Optical Infrared Telescope (LUVOIR)

Exoplanet Missions

WFIRST / AFTA

JWST

TESS

PLATO

Kepler

CHEOPS

Spitzer

Gaia

Hubble[1]

CoRoT[2]

New Worlds Telescope

Habitable Exoplanet Imager
L-UV-OIR

NASA Missions

ESA/European Missions

Ground Observatories

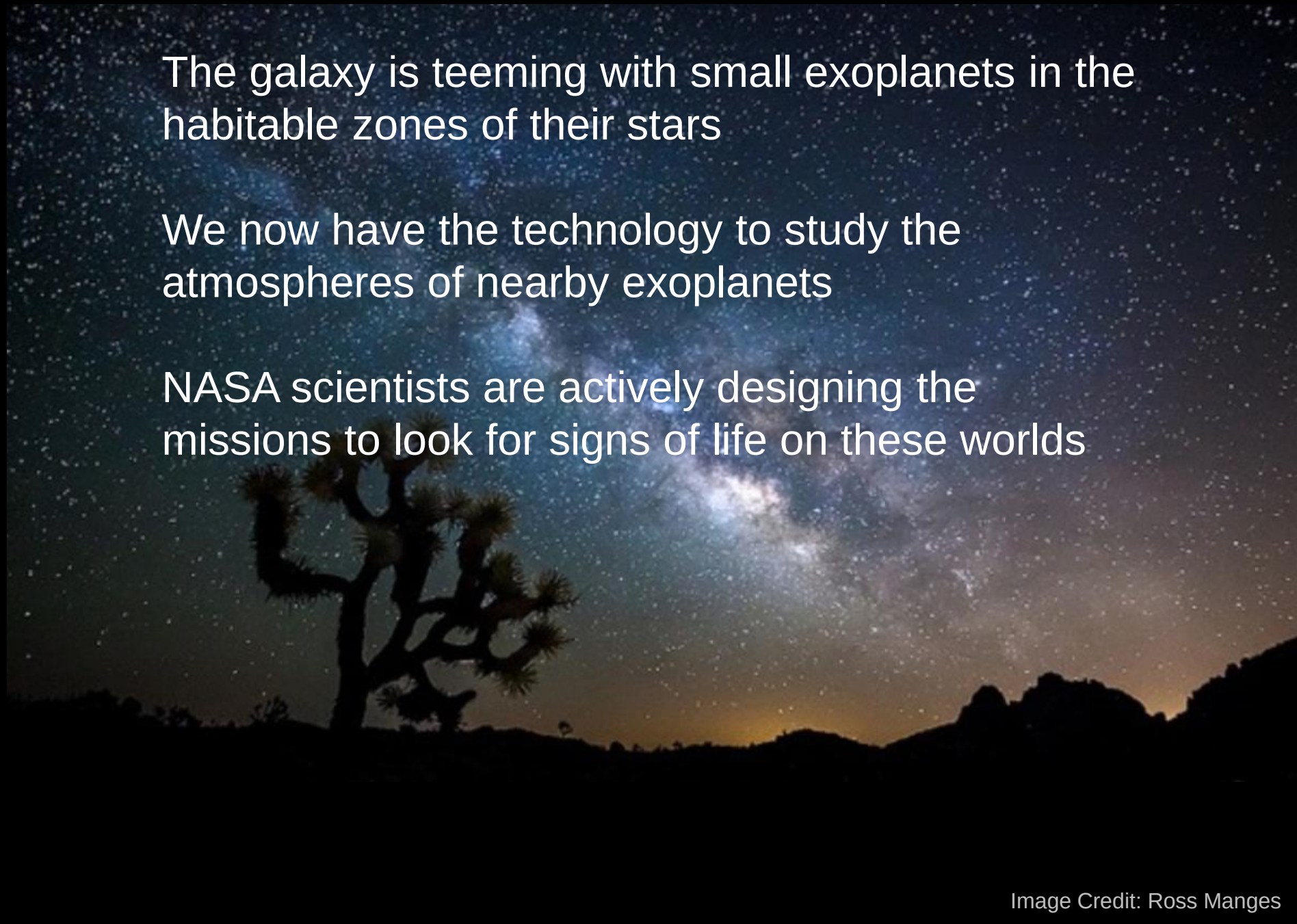
Large Binocular Telescope Interferometer

NN-EXPLORE

[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

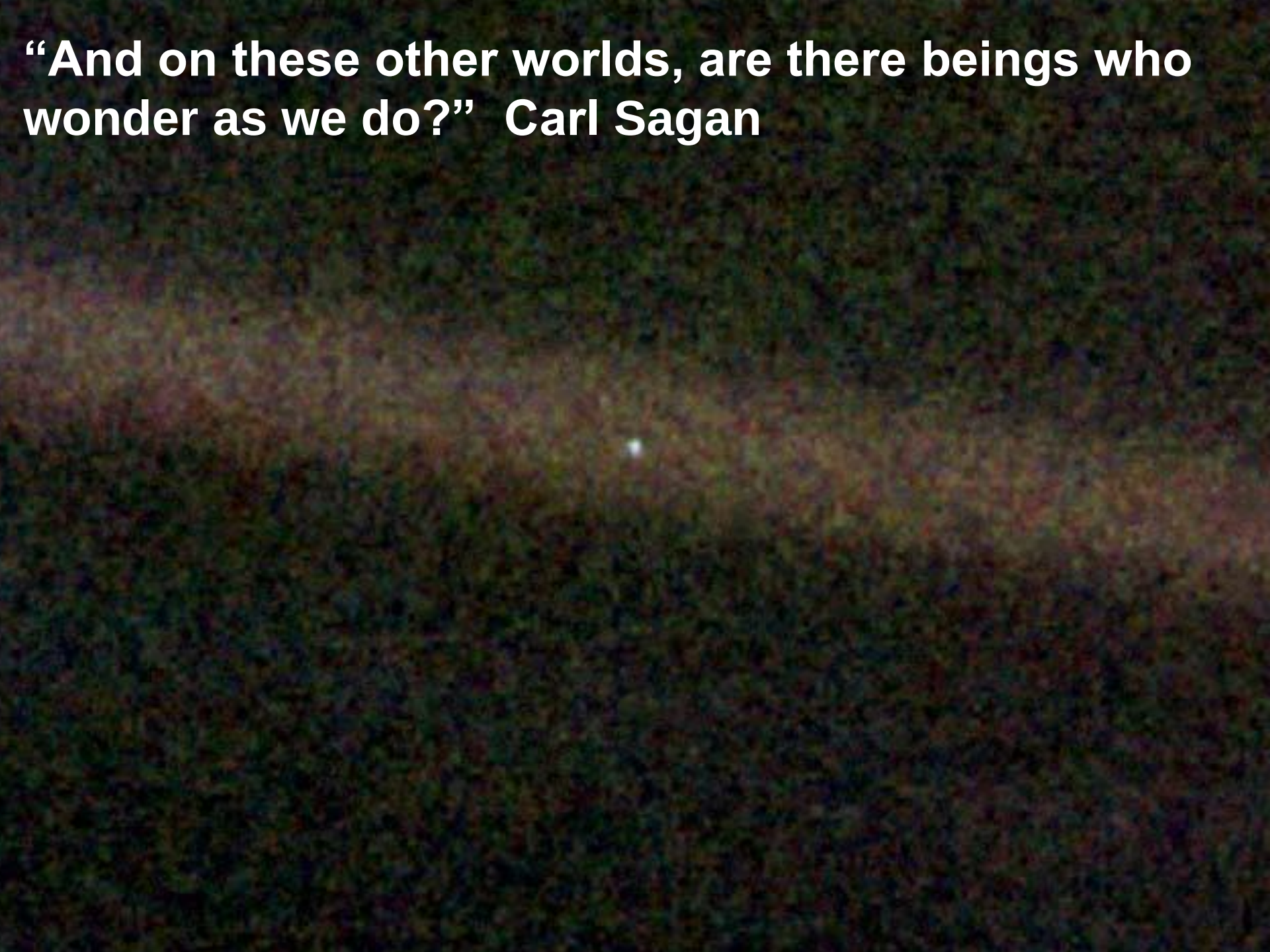


The galaxy is teeming with small exoplanets in the habitable zones of their stars

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

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California Institute of Technology
Pasadena, California

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

The National Aeronautics and Space Administration has also conducted work at:

- NASA's Goddard Space Flight Center
- NASA's Ames Research Center

Work has also been carried out under contract by:

- Princeton University
- University of Arizona
- Northrop Grumman Aerospace Systems
- National Optical Astronomy Observatory (NOAO)
- Massachusetts Institute of Technology
- Pennsylvania State University

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Benefits Stemming from Space Exploration

Backup Charts

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Benefits Stemming from Space Exploration*

- Innovation
  - Advances in science and technology
  - Global technical workforce development
  - Enlarged economic sphere
- Culture and Inspiration
  - What is the nature of the Universe?
  - Is the destiny of humankind bound to Earth?
  - Are we and our planet unique?
  - Is there life elsewhere in the Universe?
- New means to address global challenges
  - Partnerships and capabilities developed
  - Worldwide endeavor with broad international interest

http://www.nasa.gov/sites/default/files/files/Benefits-Stemming-from-Space-Exploration-2013-TAGGED.pdf

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Benefits Stemming from Space Exploration
Backup Charts

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Benefits Stemming from Space Exploration (Cont'd)

Fundamental Benefit Themes
Innovation
Culture & Inspiration
New Means to Address Global Challenges

Direct Benefits	Indirect Benefits
• People are inspired • Scientific Knowledge is generated • National technical competence is improved • Innovation is transferred to new applications • Capacity and productivity of working in space are enhanced • Markets for space products and services are created • International space exploration partnerships are strengthened	• Economic Prosperity • Health • Environmental Benefit • Safety & Security • Human experience is expanded • Understanding of humankind's place in the universe is enhanced

http://www.nasa.gov/sites/default/files/files/Benefits-Stemming-from-Space-Exploration-2013-TAGGED.pdf

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Benefits Stemming from Space Exploration (Cont'd)

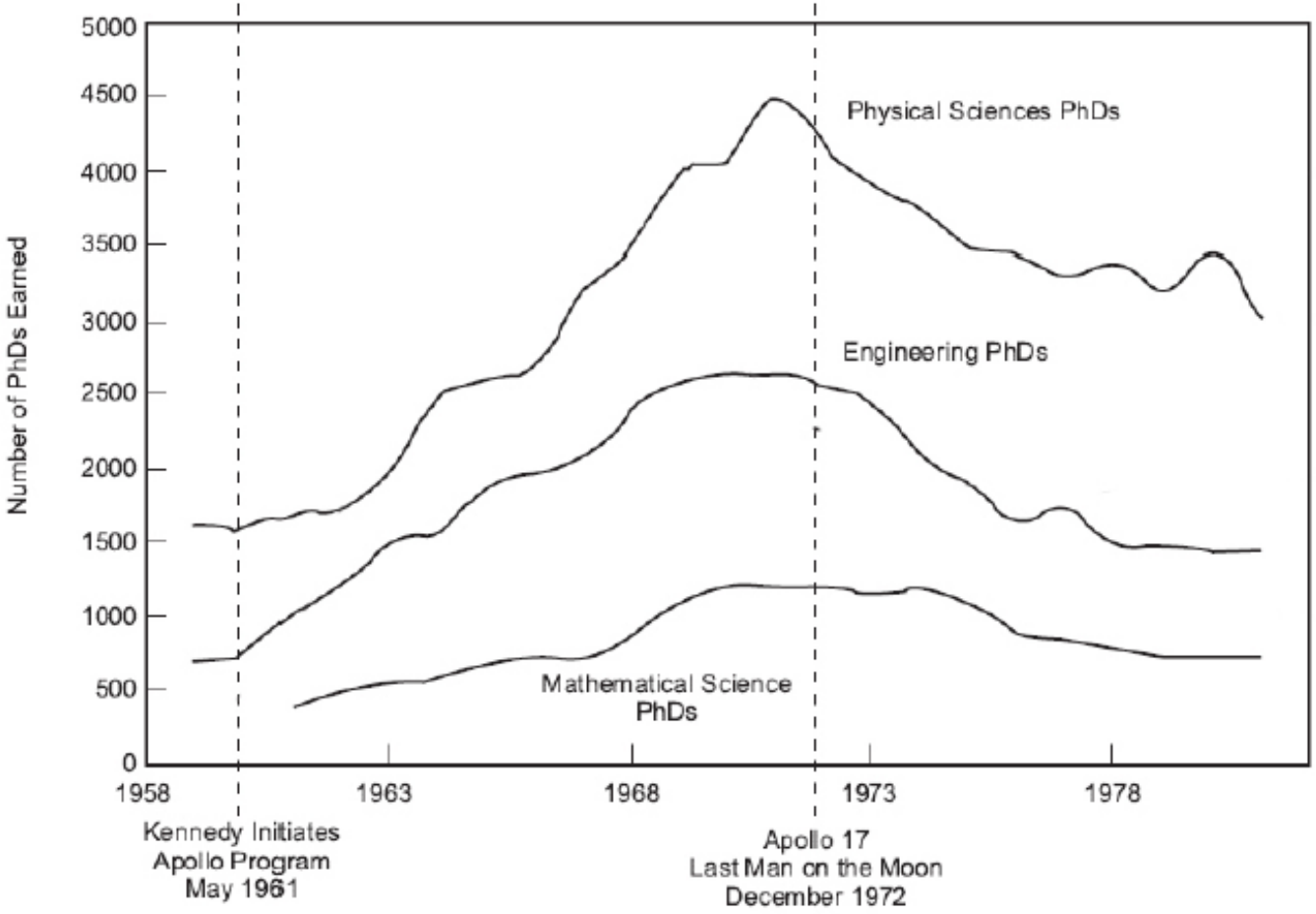

Figure 3. Space Exploration's Impact on Educational Achievement.[16]

[16] Siegfried, W.H., "Space Colonization—Benefits for the World", Space Technology and Applications International Forum, 2003.

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Benefits Stemming from Space Exploration (Cont'd)

- Health and medicine:
  - Infrared ear thermometers
  - Ventricular assist device for patients awaiting heart transplants
  - Artificial limbs
  - Light-emitting diodes in medical therapies to treat tumors
  - Invisible braces
  - Scratch-resistant lenses
  - Space blankets

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Benefits Stemming from Space Exploration (Cont'd)

- Transportation:
  - Aircraft anti-icing systems
  - Highway safety and runways
  - Improved radial tires
  - Chemical detection of corrosive environments in atmospheres

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Benefits Stemming from Space Exploration (Cont'd)

- Public safety
  - Video enhancing and analysis systems for surveillance
  - Fire-resistant reinforcement
  - Firefighting equipment
- Consumer, home, and recreation
  - Temper foam
  - Enriched baby food
  - Portable cordless vacuums
  - Freeze drying

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Benefits Stemming from Space Exploration (Cont'd)

- Environmental and agricultural resources
  - Water purification
  - Solar cells
  - Pollution remediation
- Computer technology
  - Structural analysis software
  - Remotely controlled ovens
  - NASA Visualization Explorer
  - OpenStack cloud computing platform
  - Software catalog open to public at no charge

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Benefits Stemming from Space Exploration (Cont'd)

- Industrial productivity
  - Powdered lubricants
  - Improved mine safety
  - Food safety