



**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#TBD

URSTBD

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Monday, February 27, 2017

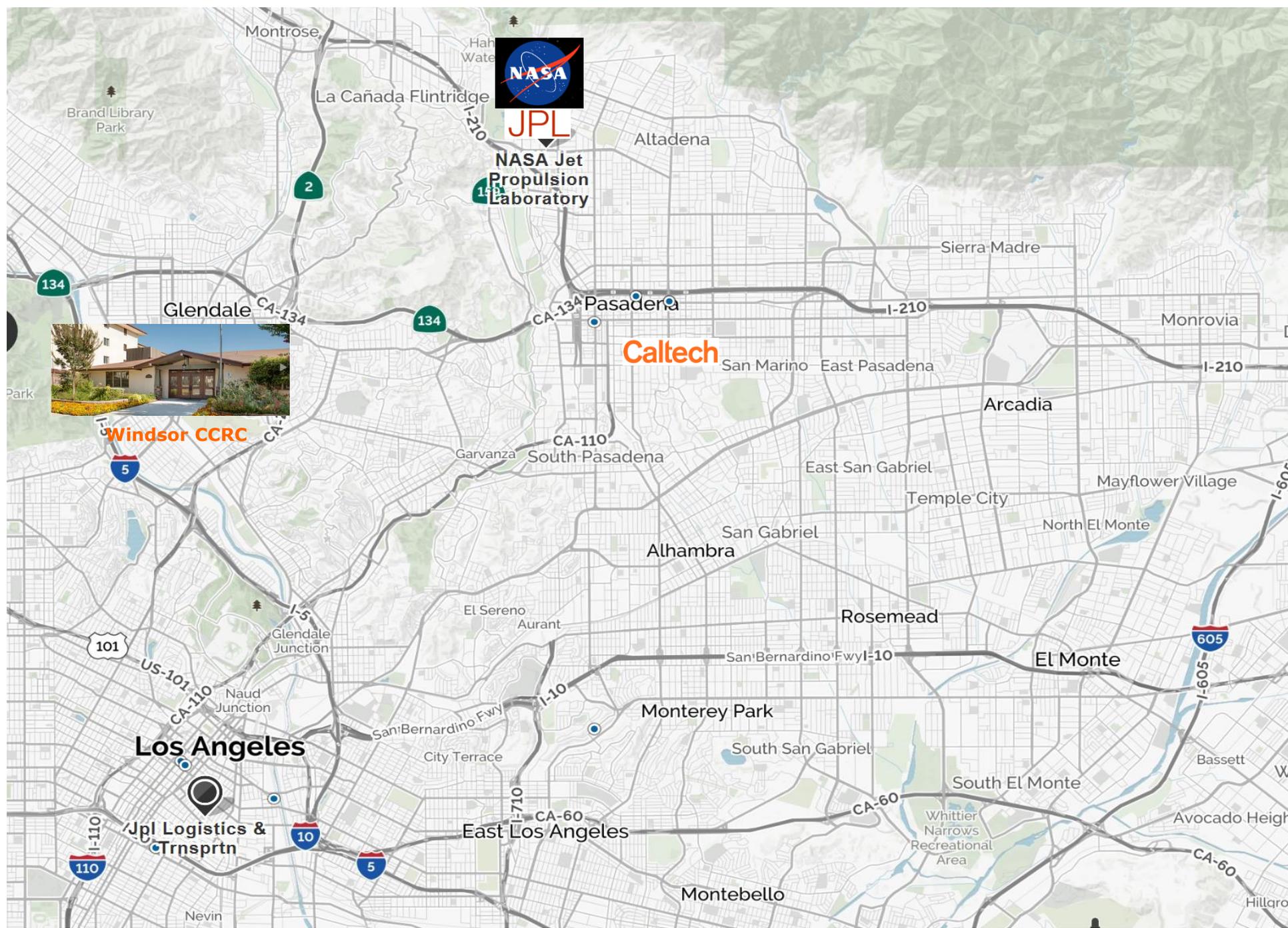
Windsor Community

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**





**JPL**

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Propulsion  
Laboratory**

**Caltech**

**Windsor CCRC**



## JPL has expertise in:

- Science
- Engineering
- Technology
- Programs/projects



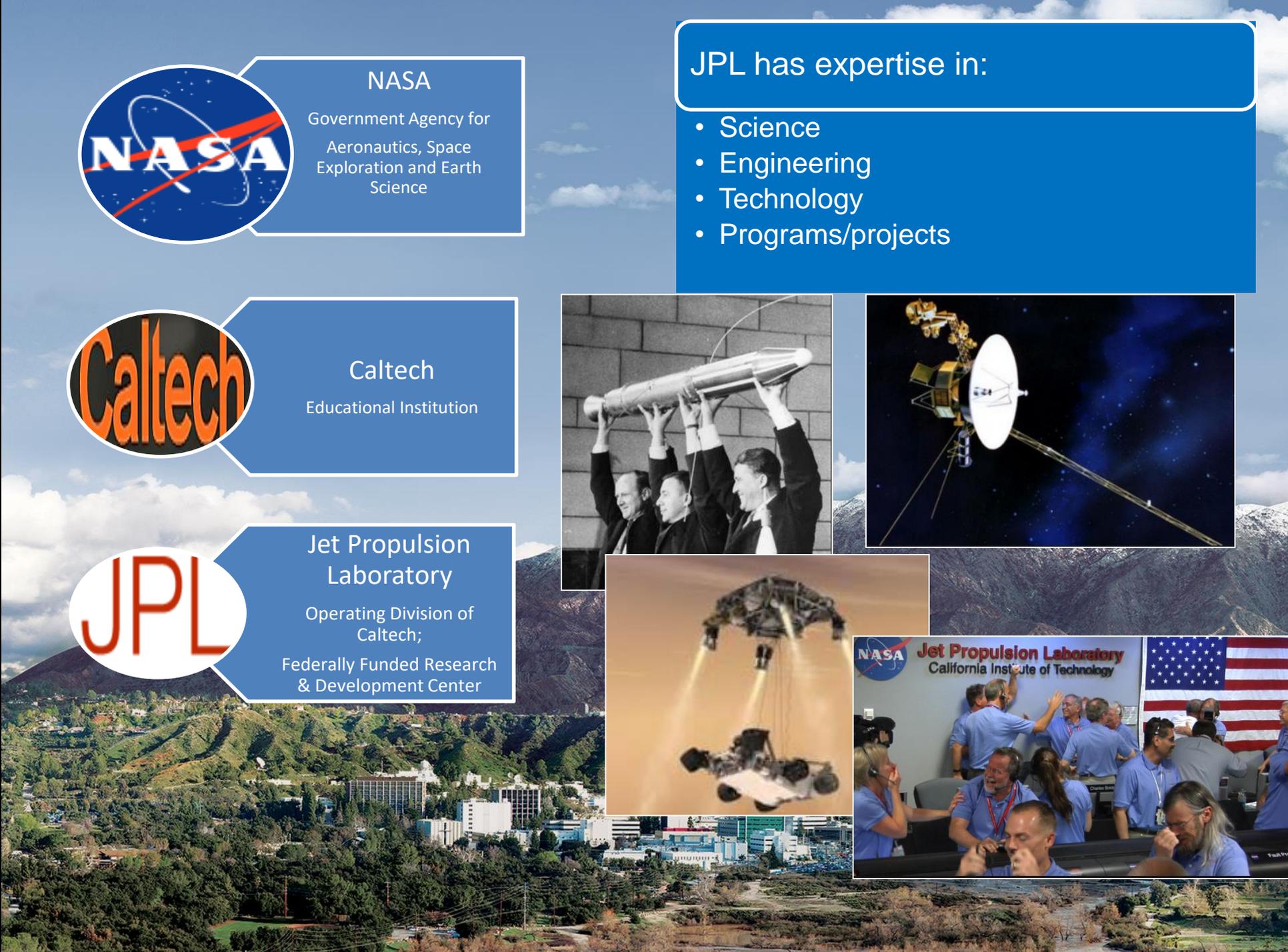
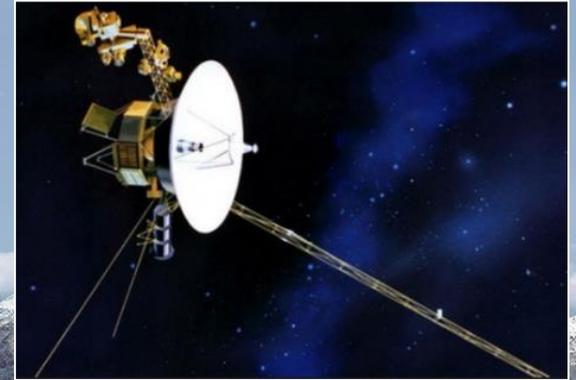
**NASA**  
Government Agency for  
Aeronautics, Space  
Exploration and Earth  
Science



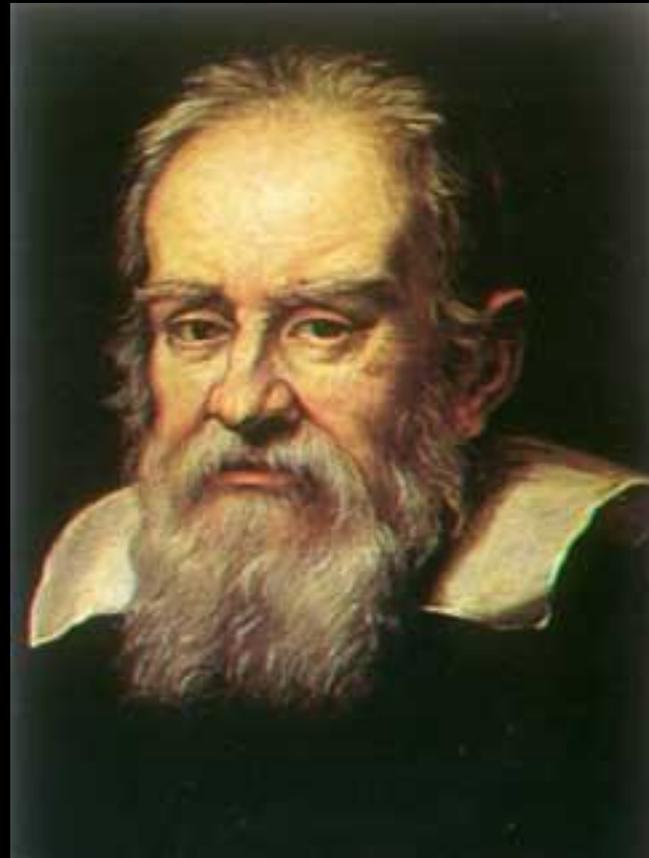
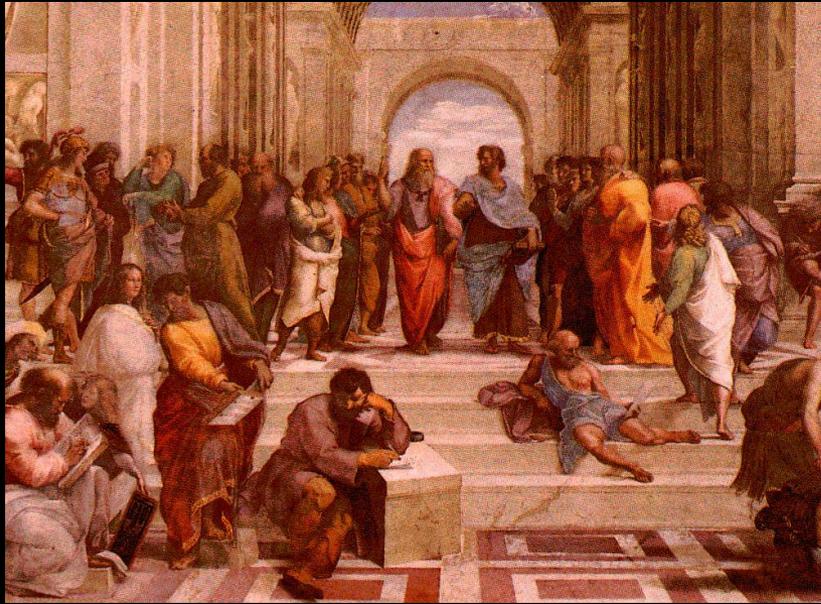
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Operating Division of  
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Federally Funded Research  
& Development Center



# 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

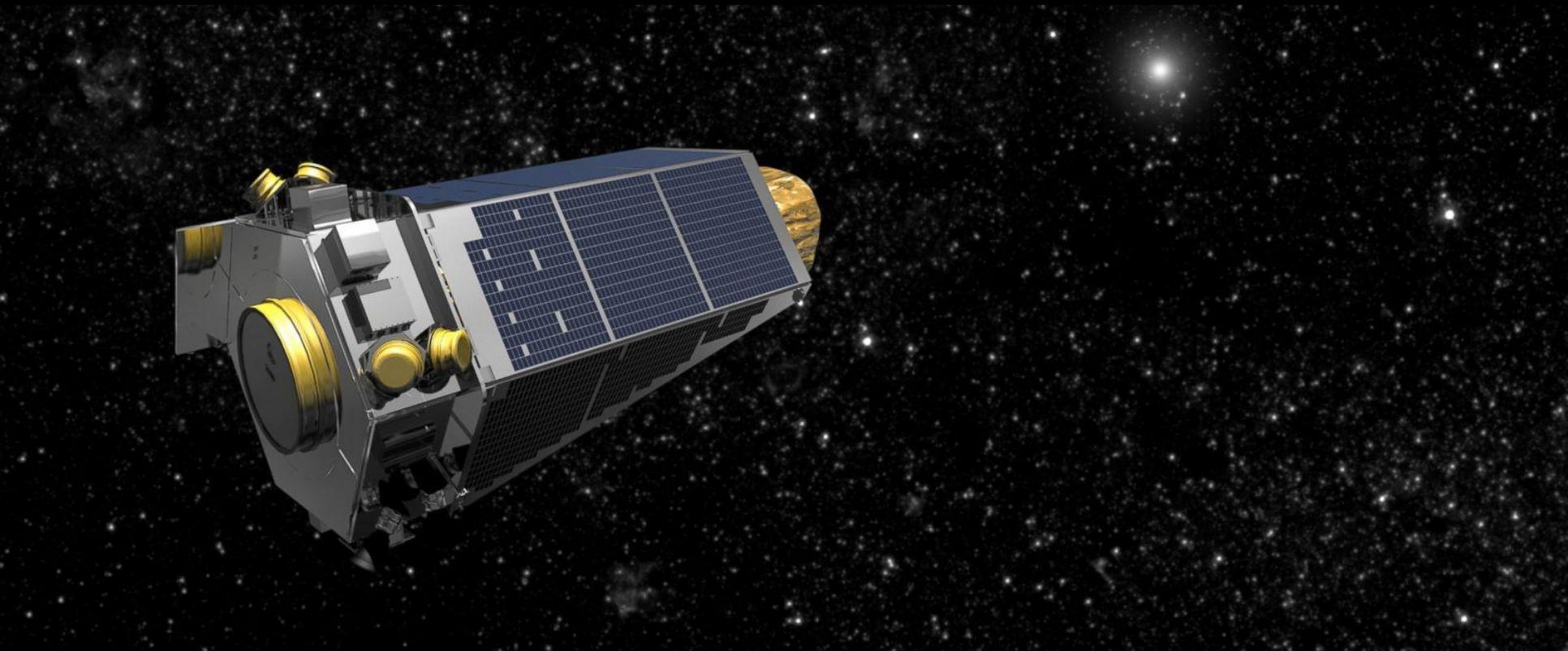


German astronomer Johannes Kepler used mathematics to calculate the path of the planets, finding that they traveled not in circles, as long expected, but in ellipses.

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

- Johannes Kepler was born in the late 16<sup>th</sup> 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



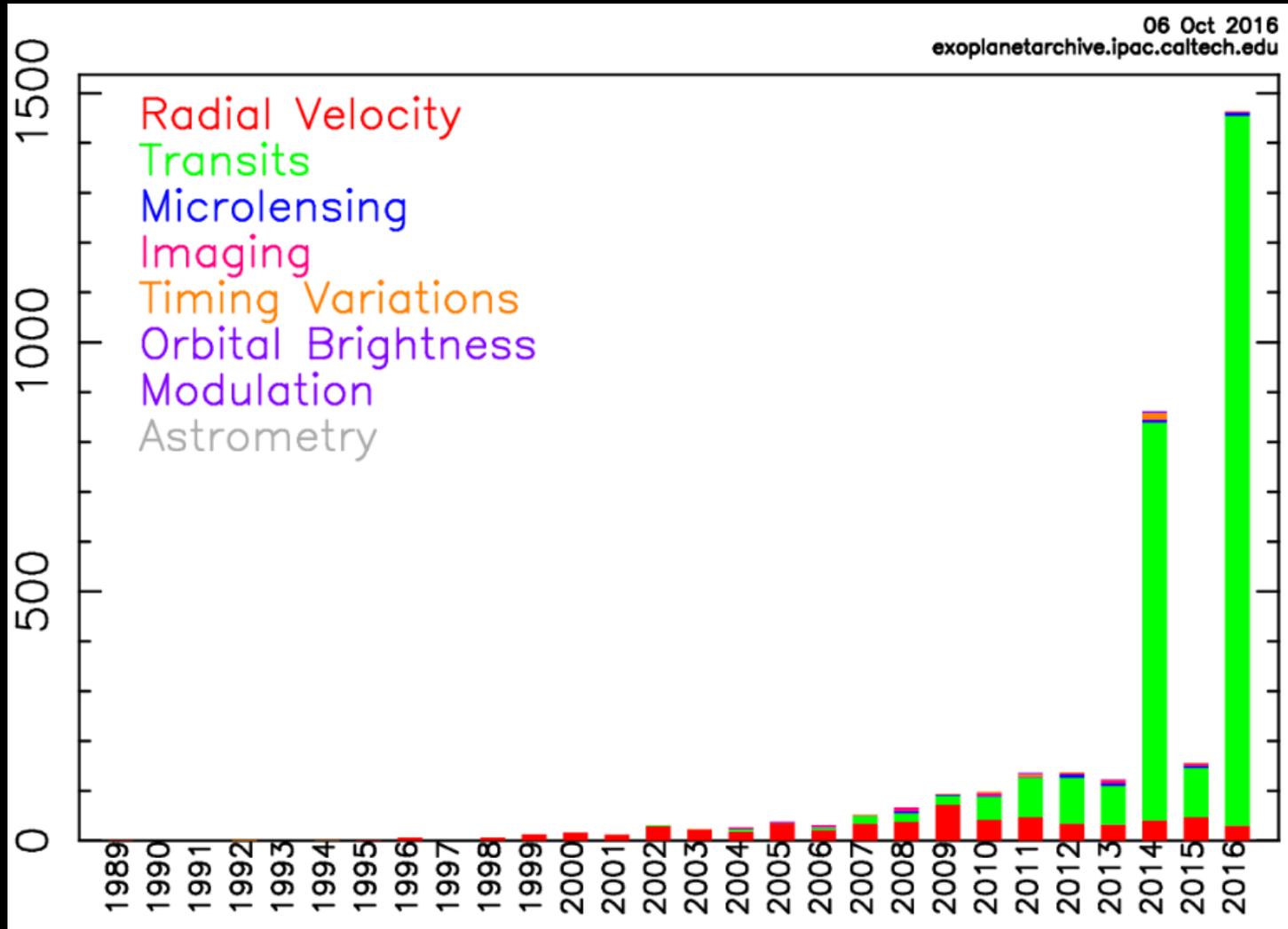
BRIGHTNESS



TIME IN HOURS

# 3,396 Confirmed Exoplanets (as of 10/8/16)

Number of Planets



Discovery Year

# 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/>

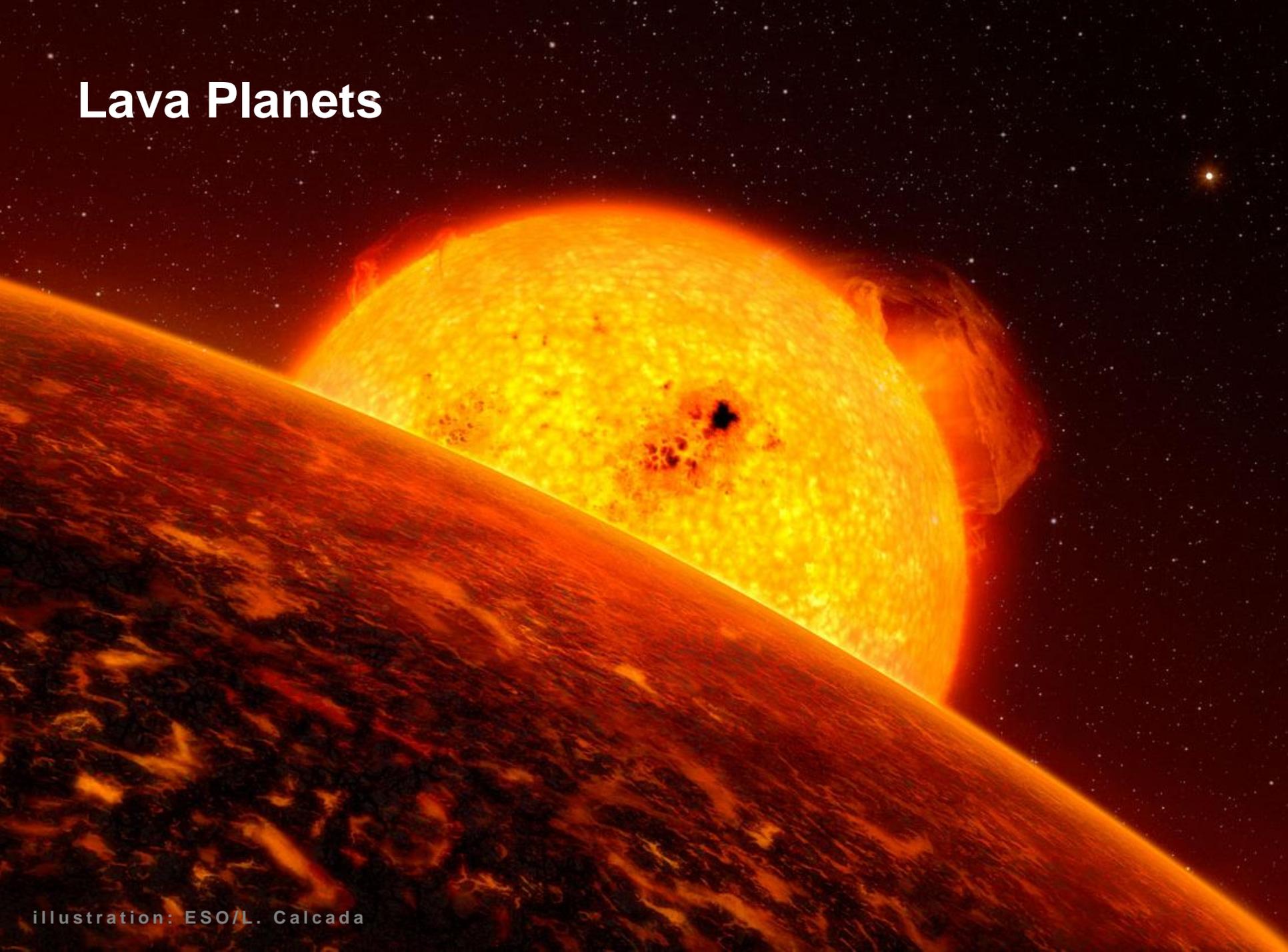


The screenshot shows the website interface for Science Trek. At the top, there are navigation links for HOME, CONTACT, and SHIP. Below that, a search bar and social media icons are visible. The main content area features a large image of a nebula and a sidebar with a 'Click on a Topic:' menu containing categories like Ages Past, Animals, Earth Science, Environment, Human Body, Science Fundamentals, Space, Technology, and Other. The main text area is titled 'Exoplanets' and includes a definition: 'Planets that orbit a star outside our solar system.' It also contains several paragraphs of text and a list of links for further exploration.

# Kepler's Amazing Results:

**1** Planets are diverse

# Lava Planets



# Ice Planets

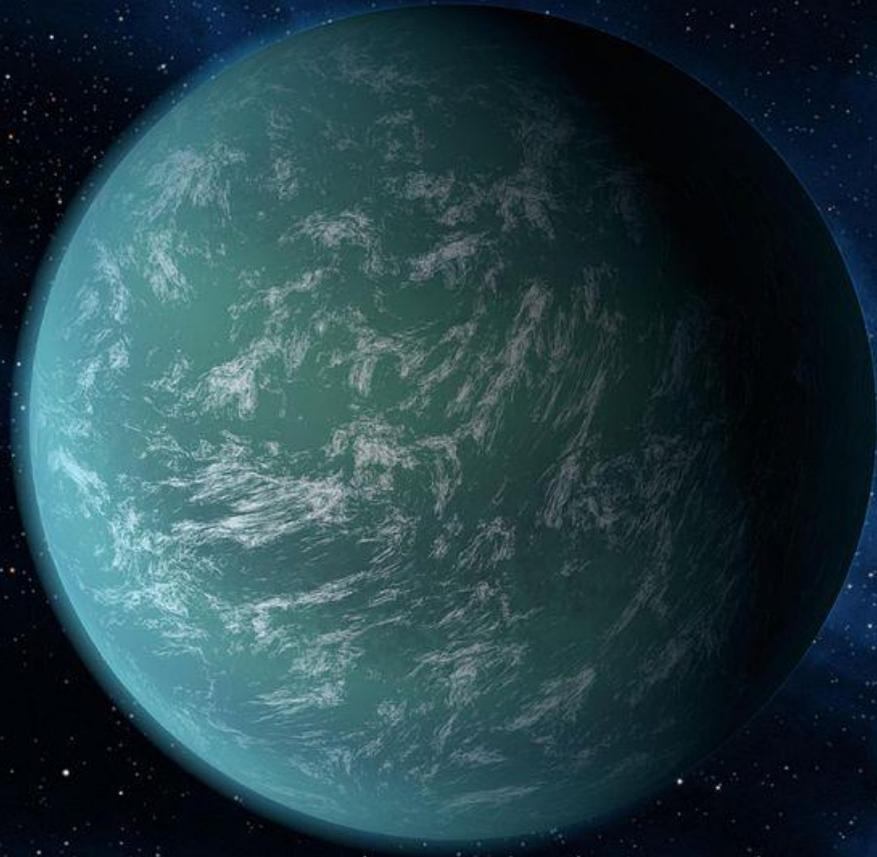


# Planets with two stars





# Water Worlds



**Nomad planets not bound to any star at all!**



# Kepler's Amazing Results:

2

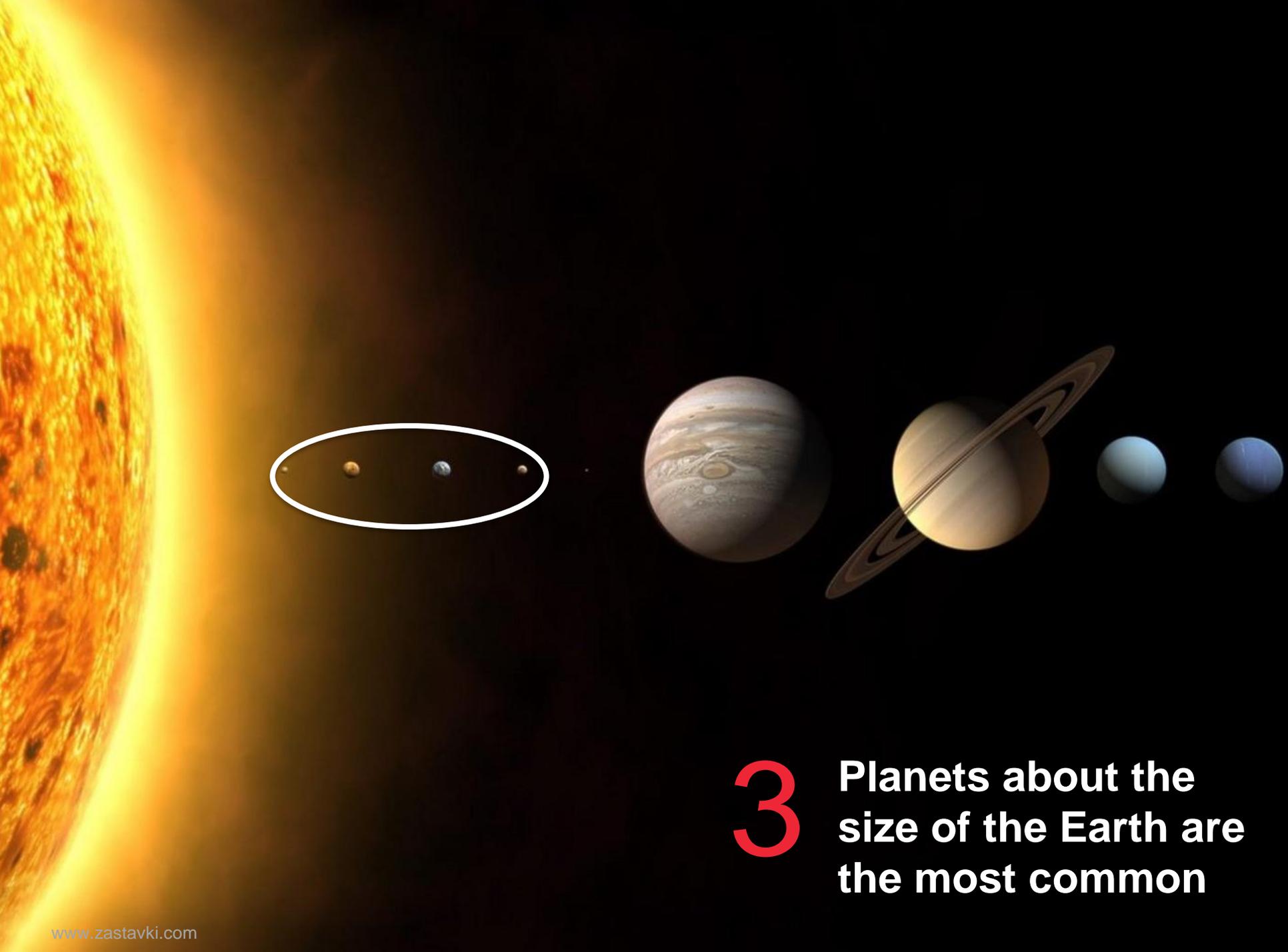
On average there is at least one planet for each star in our Galaxy

(and likely more...)

▪

> 200 billion exoplanets  
in our Milky Way Galaxy





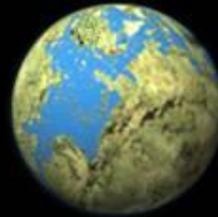
**3**

**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

## HABITABLE ZONE

Just Right



4

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

# Q&Alien Video: Habitable Zones

# Q & ALIEN

V I D E O S E R I E S

# 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)



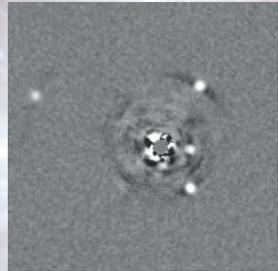
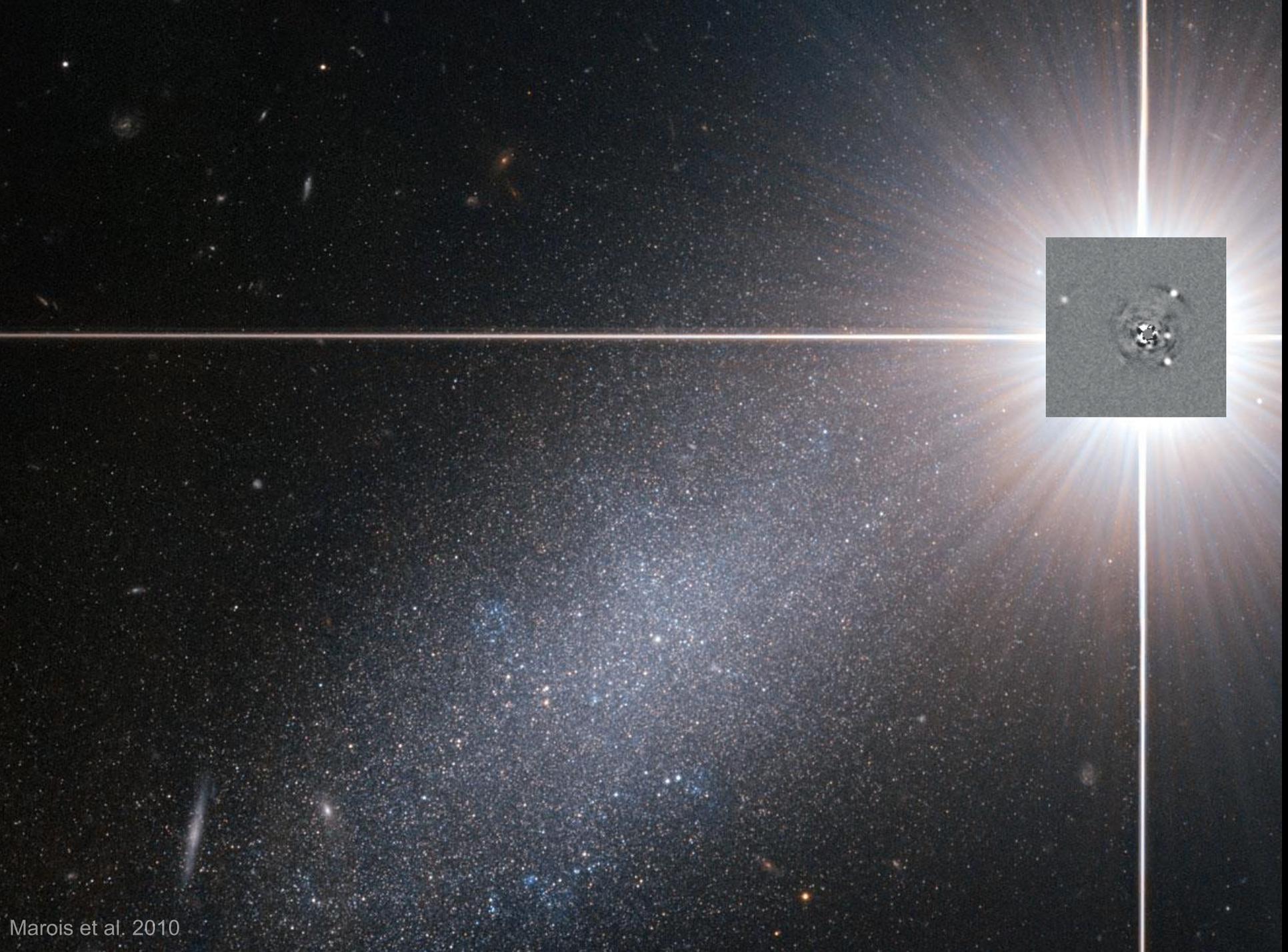
Show Me the Planets!  
You had me at Habitable



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](http://exoplanets.nasa.gov) website soon



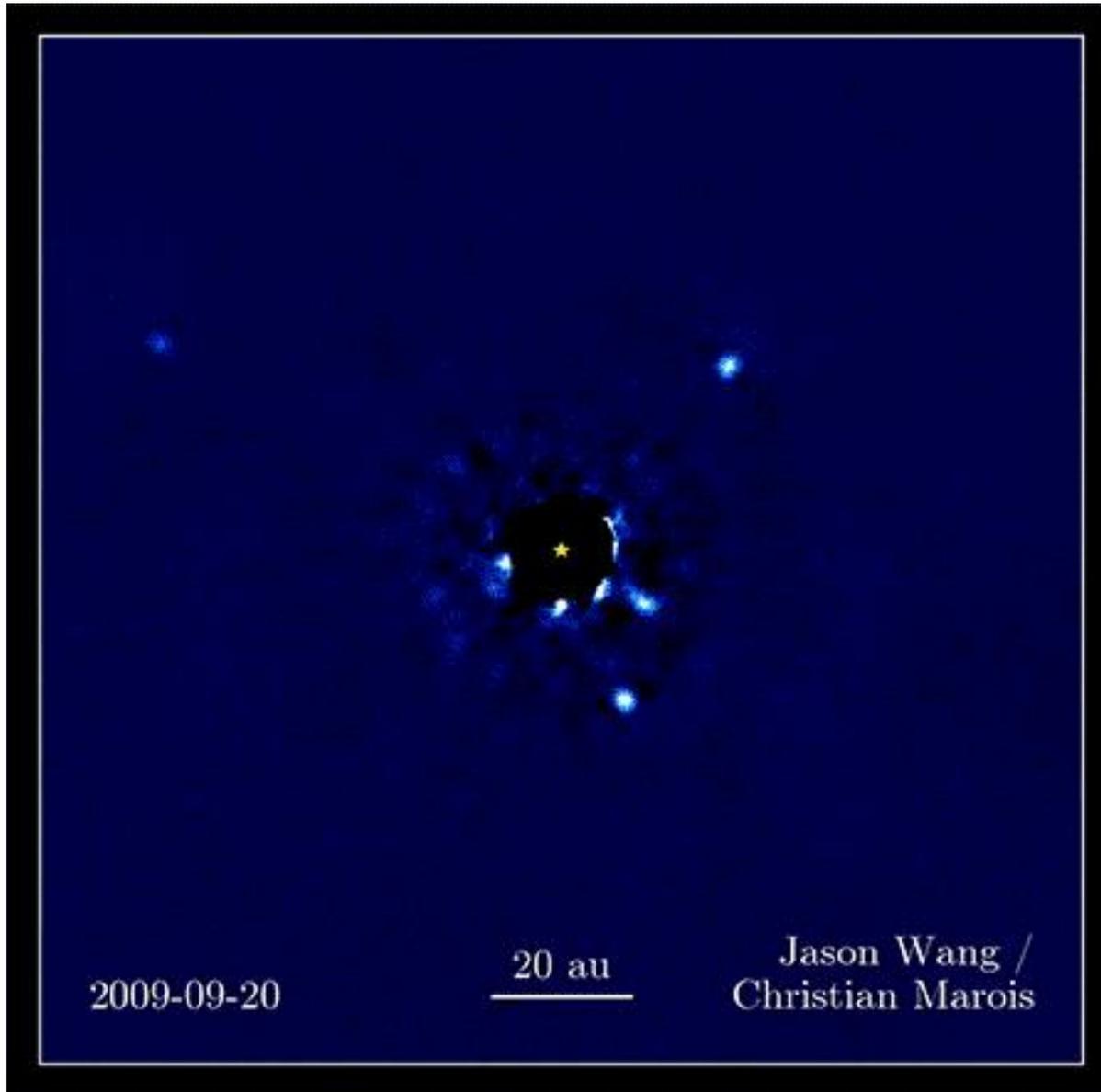


# Orbital Motion of Four Giant Planets around HR 8799

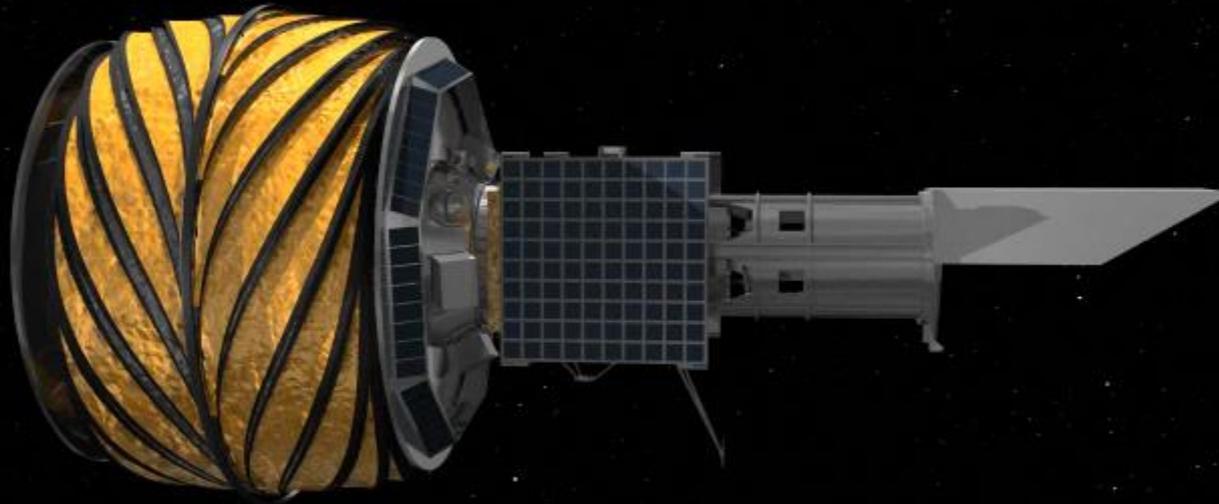
## Directly Imaged and Remarkable



ExoPlanet Exploration Program



# 1. Starshade Animation





$\pm 3.3$  ft lateral control

separation distance  
18,650 – 31,100 mi

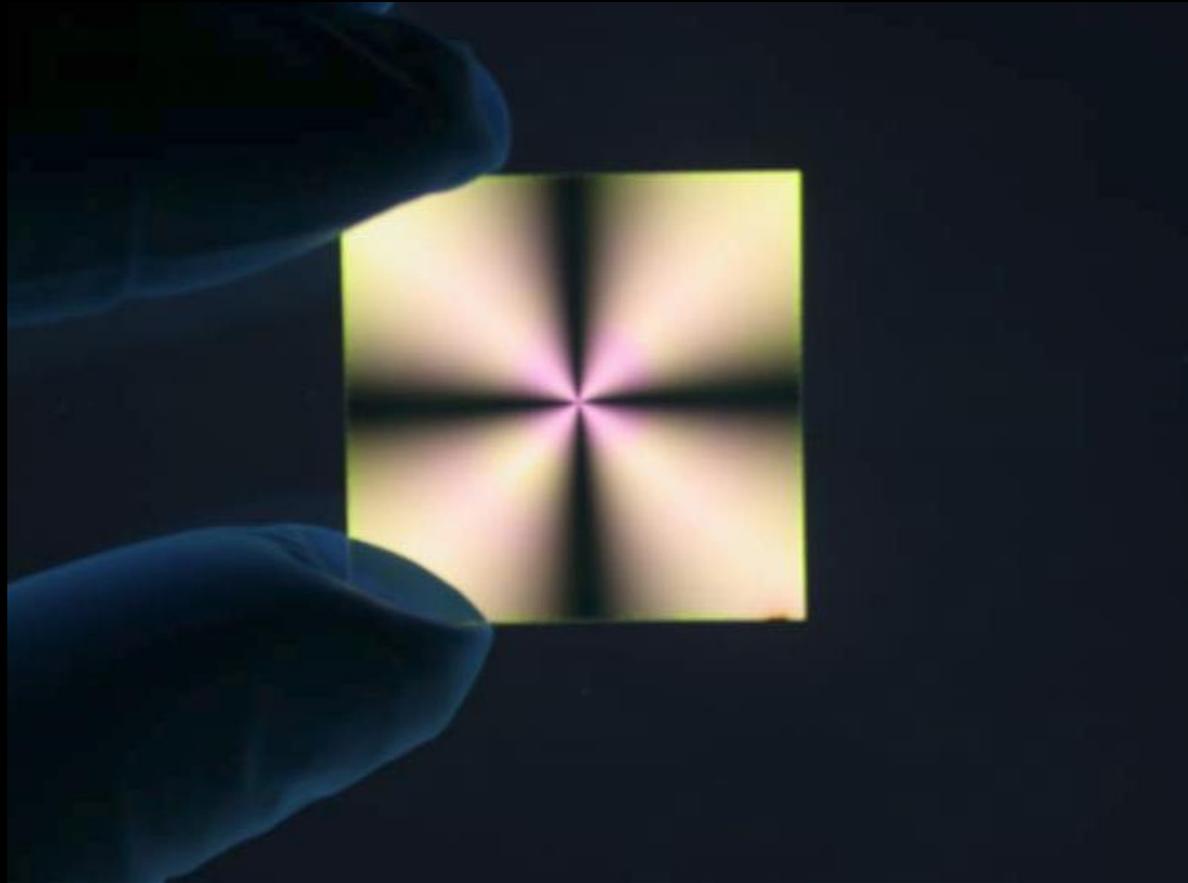


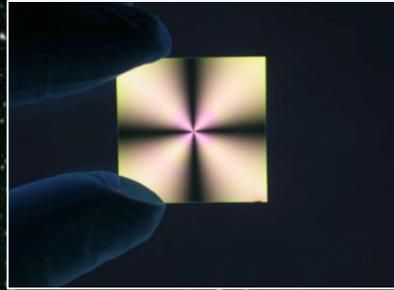
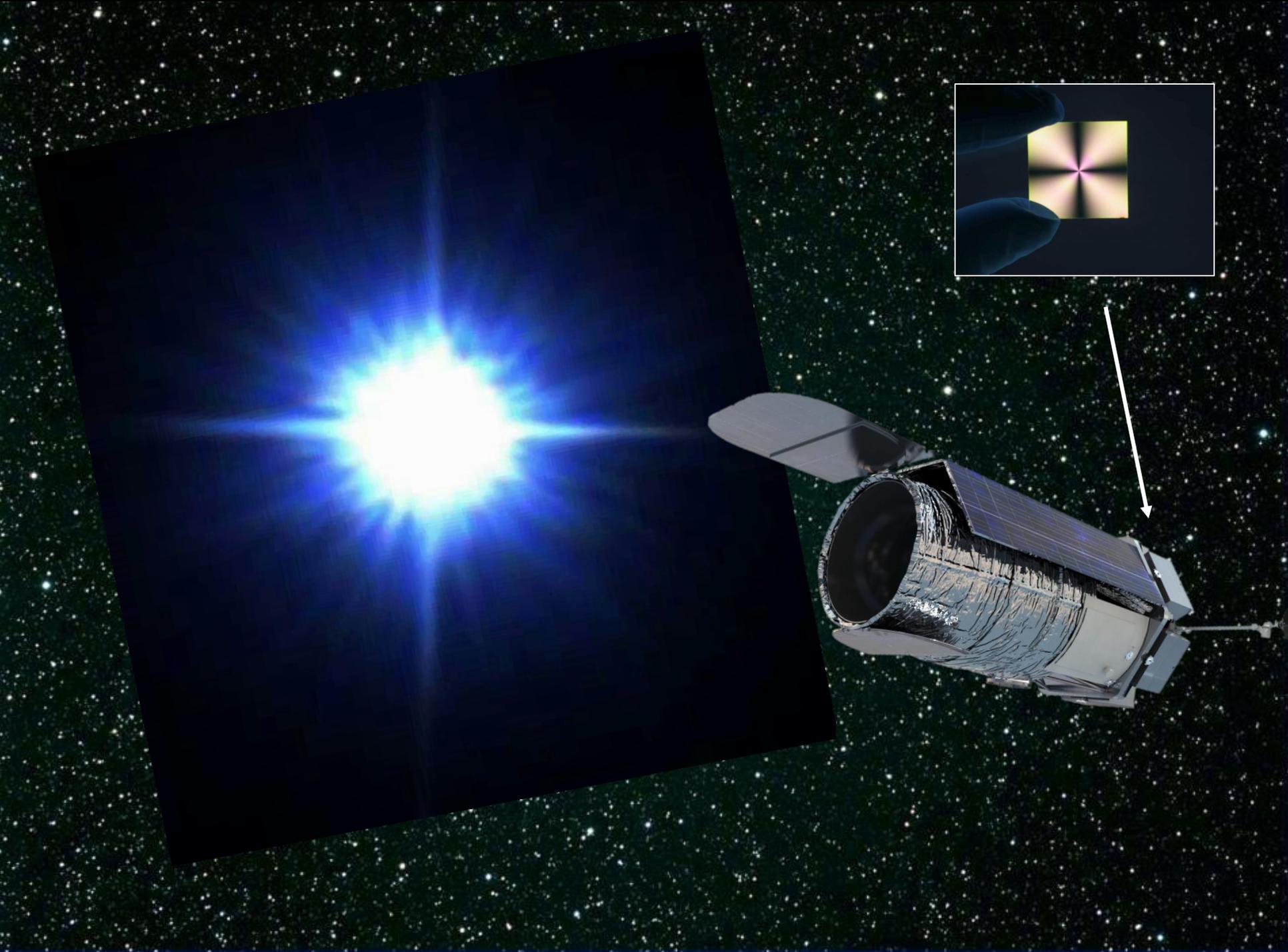
starshade  
diameter 111 ft





# The Coronagraph



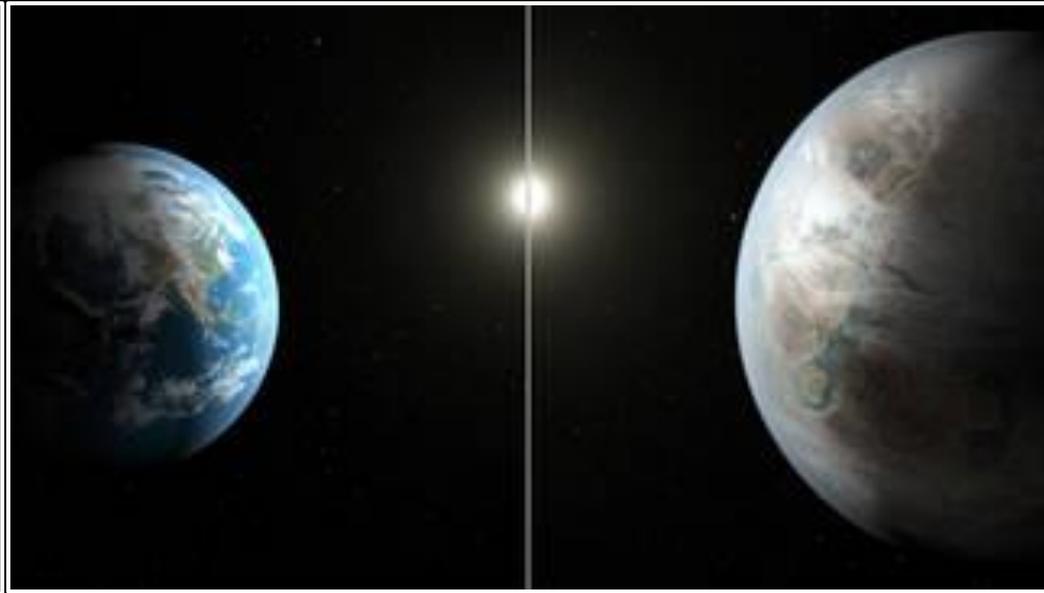
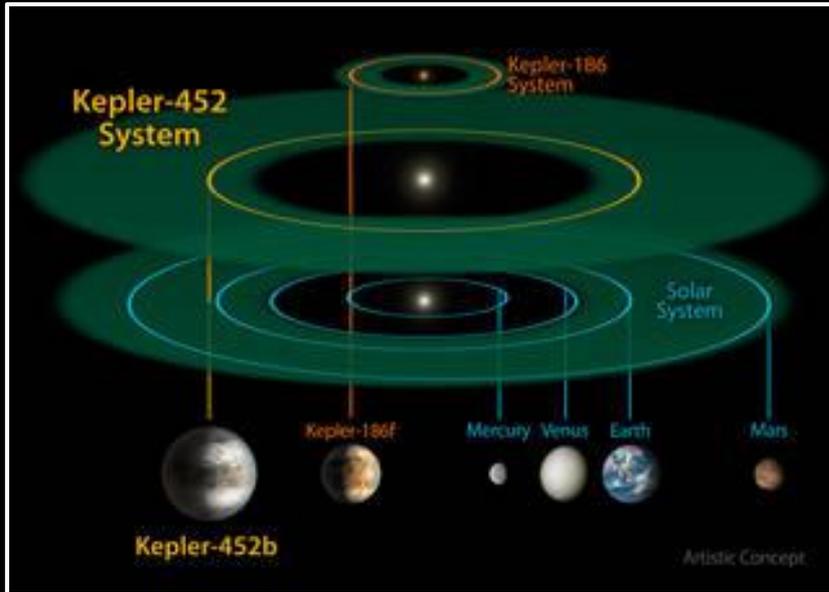


## 2. Coronagraph Animation



## 2. What are Exoplanets Like?

# Kepler 452 b: Earth's Bigger, Older Cousin



\$2.00

THE EARTH'S NEW NEIGHBOR

JULY 24 - 26, 2015

Earth  
7926 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  
12,040 MILES

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

**USA TODAY WEEKEND**  
A GANNETT COMPANY

**EARTH TO 452b**

New planet found outside our solar system could harbor life

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.

probally rocky, as Earth is. But those planets circle dim, cool stars very different from our sun, whereas 452b is hitched to a star very much like ours. Two could seed plants to life, 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 Igru and Cygnus. The planet, which is some 1400 light-years from Earth, is described in a new article in *The Astronomical Journal*.

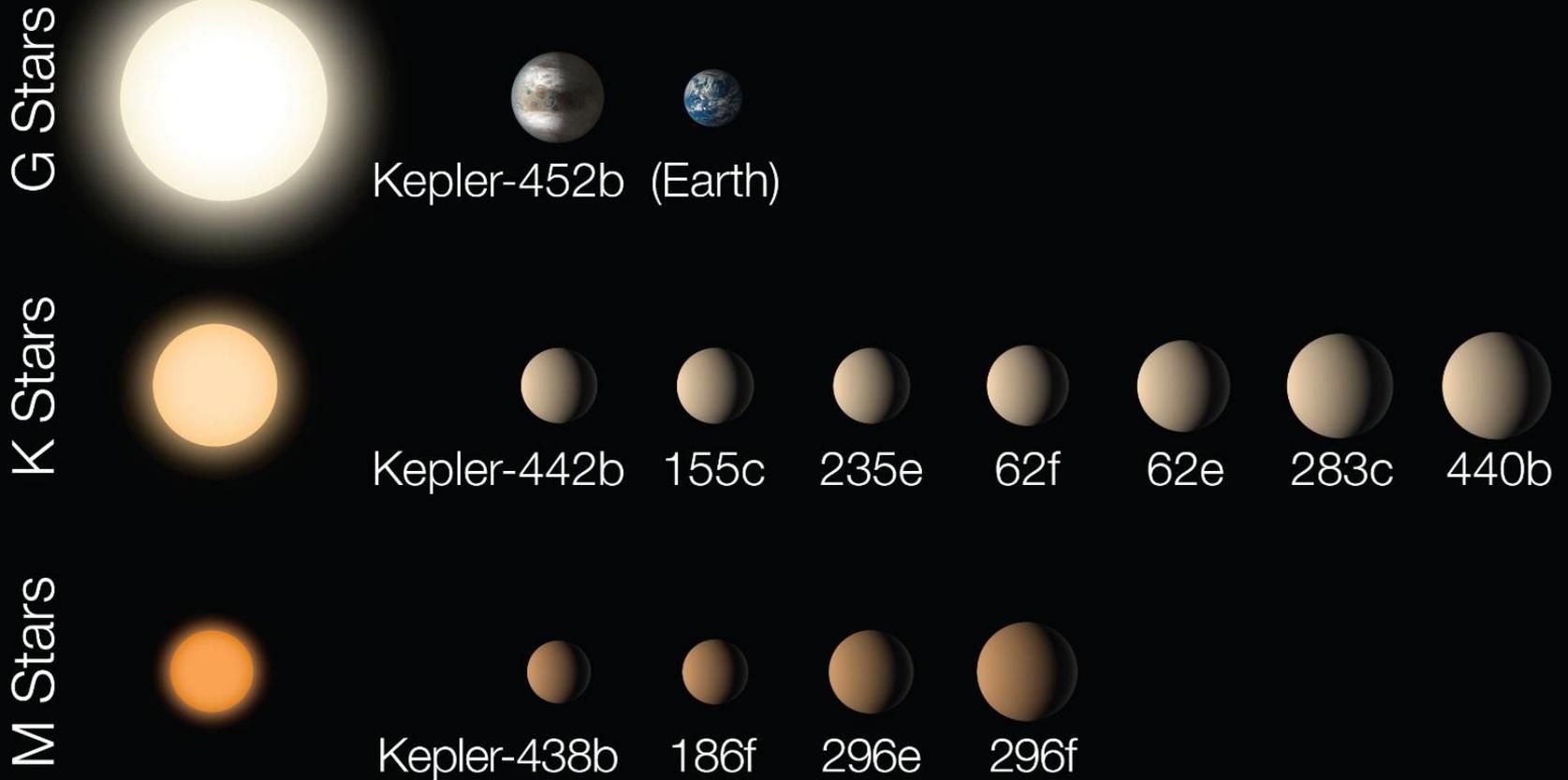
Other scientists who were not involved in the research called 452b an exciting example of a planet in the "Goldilocks"

**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



# 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



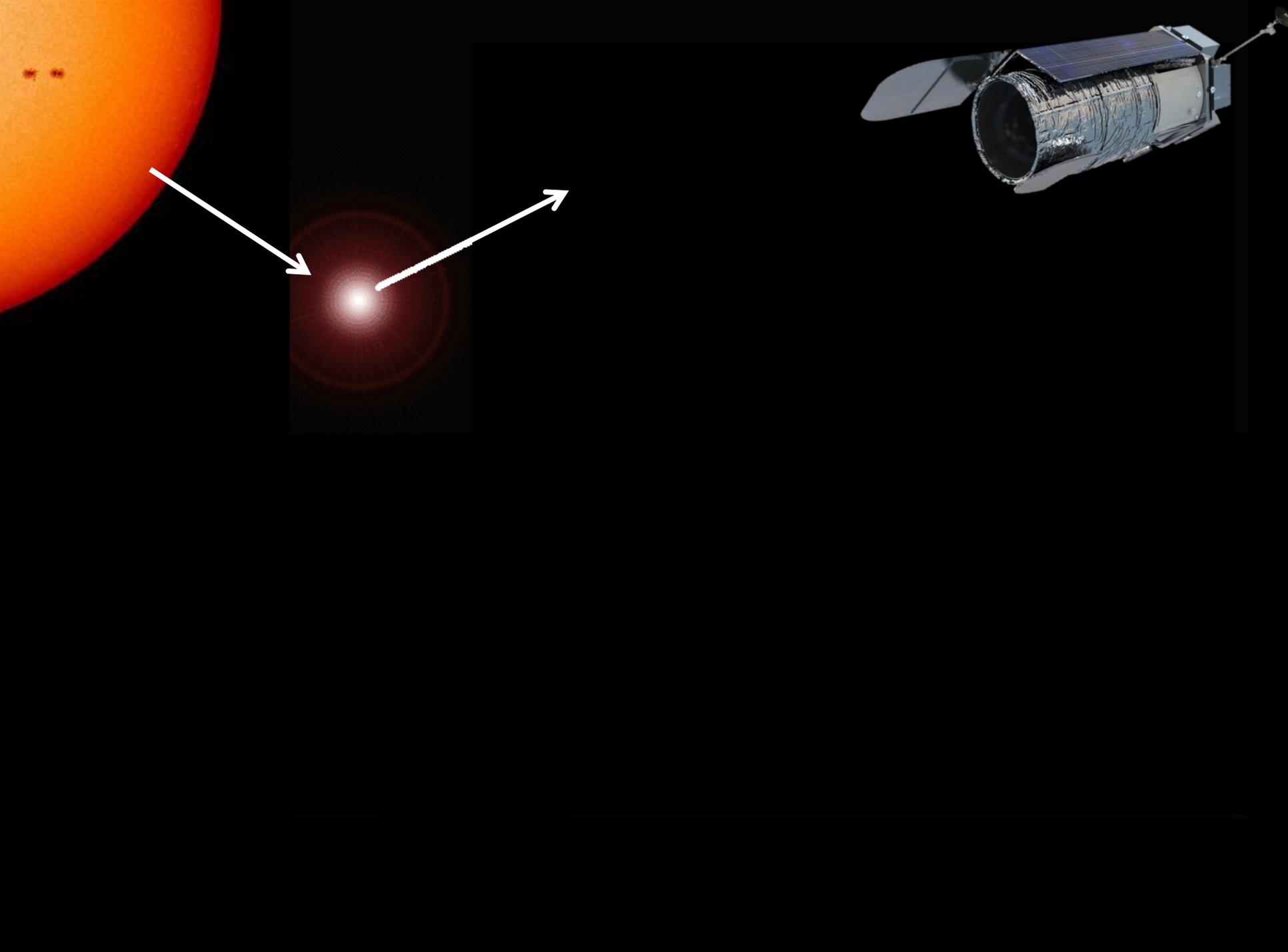
**Oxygen**

**Water Vapor**

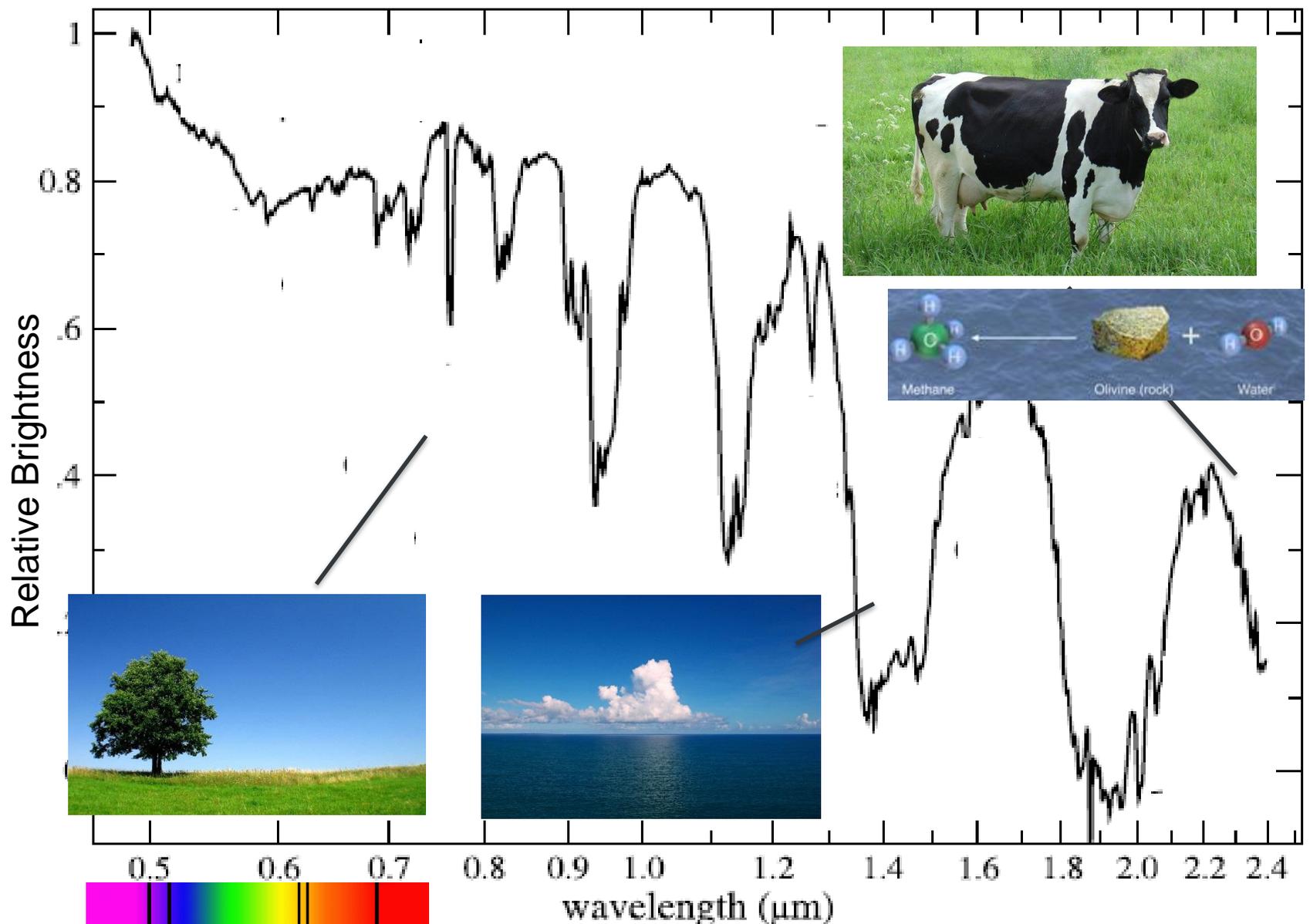


**Methane**



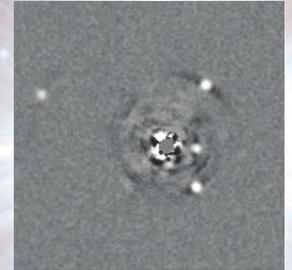


# Detecting Life on an Exoplanet



# Direct Imaging Exoplanets Challenge #1:

## Contrast

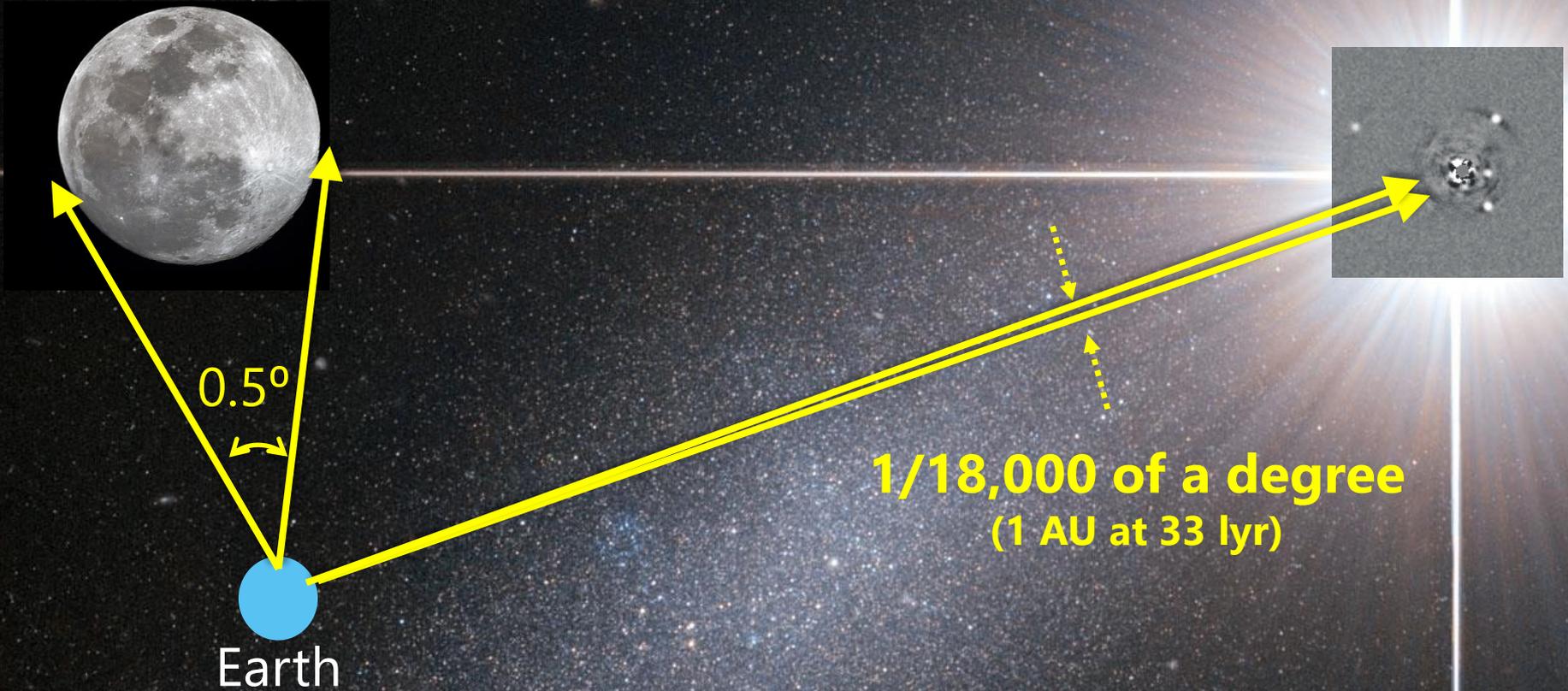


**An Earth-size planet in the  
habitable zone of a Sun-like  
star is very faint**

**- 10 billion times fainter!**

# Direct Imaging Exoplanets Challenges #2:

## Resolution





firefly





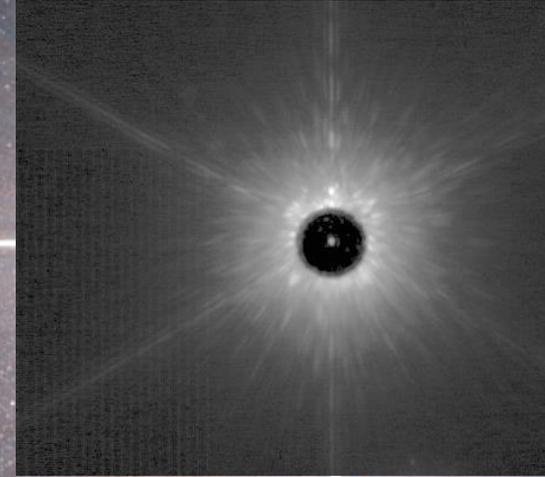
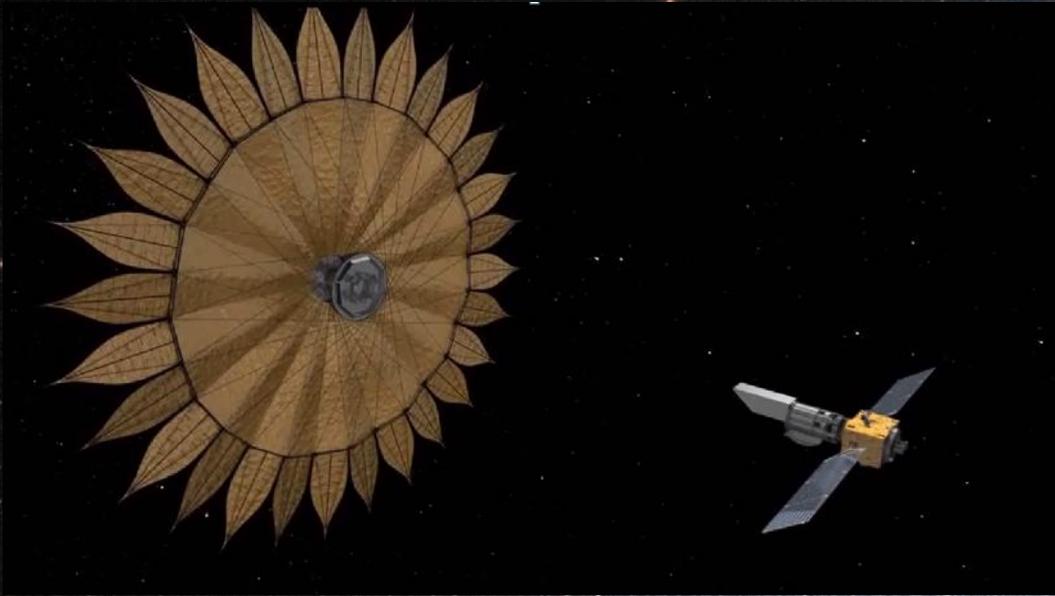


JPL



# Two Direct Planet Imaging Techniques

## 1. Starshade

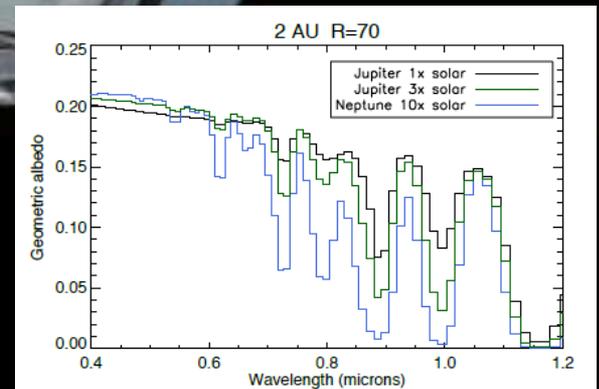
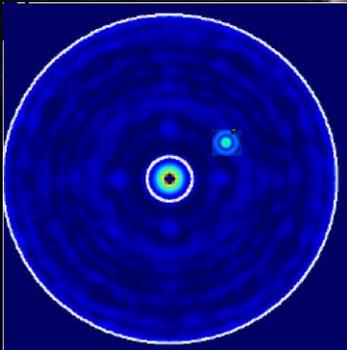
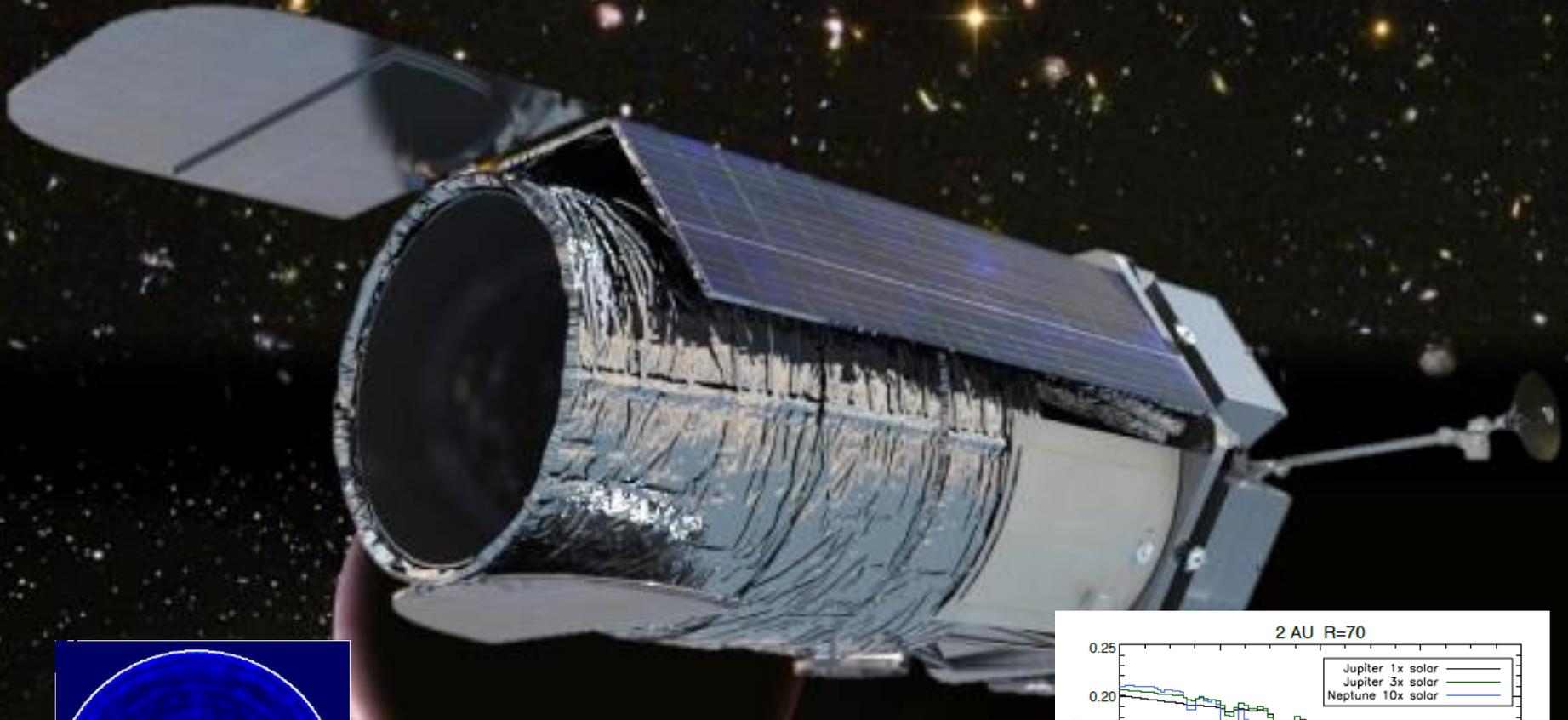


## 2. Coronagraphs

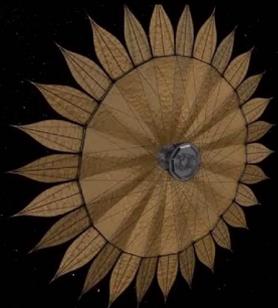


# WFIRST

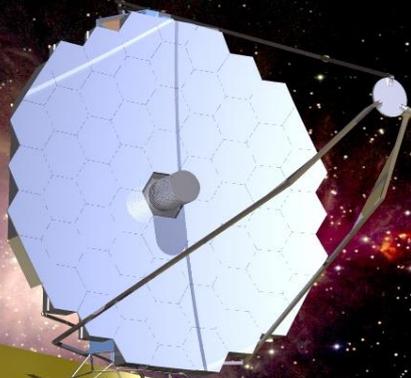
Dark Energy, IR Survey, Exoplanet Census, Imaging and Spectroscopy



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

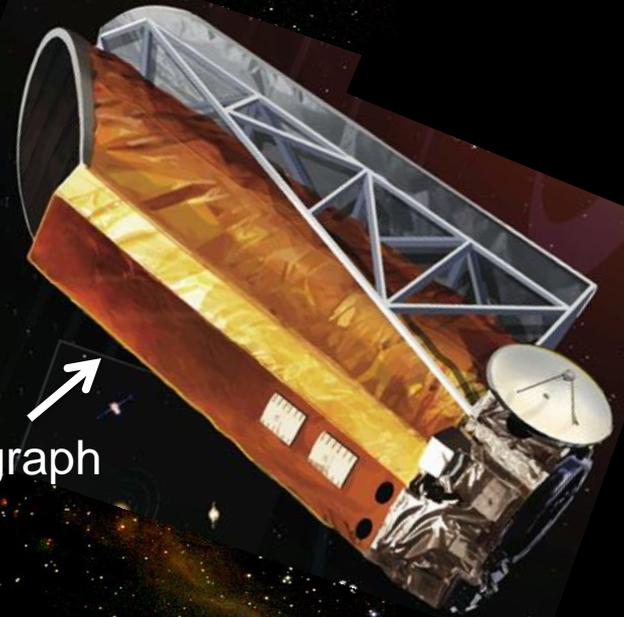


starshade



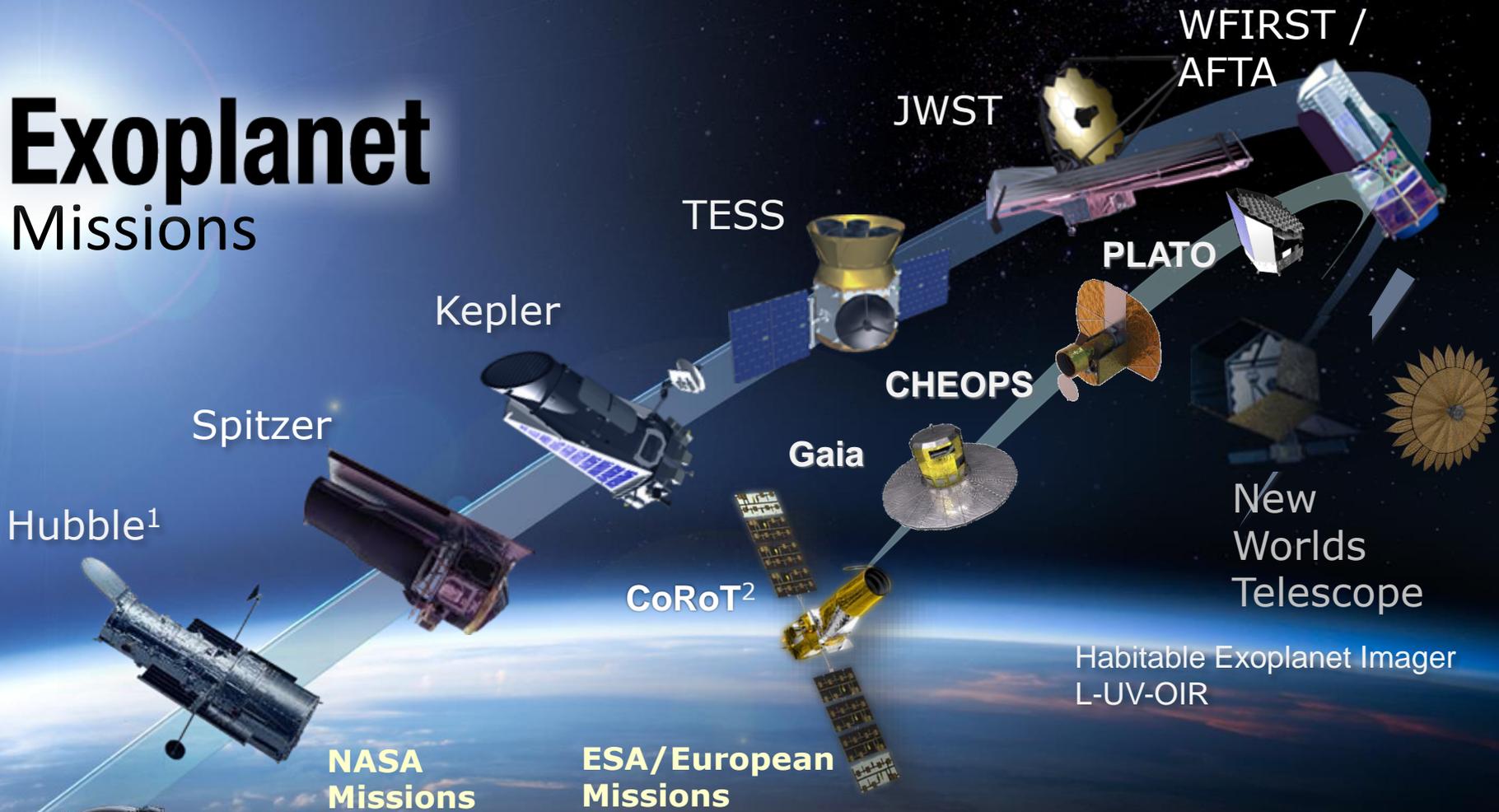
Large Ultra-Violet  
Optical Infrared  
Telescope (LUVOIR)

coronagraph



Habitable Exoplanet  
Imaging Missions  
(Hab-Ex)

# Exoplanet Missions



Ground Observatories



Large Binocular  
Telescope Interferometer



NN-EXPLORE

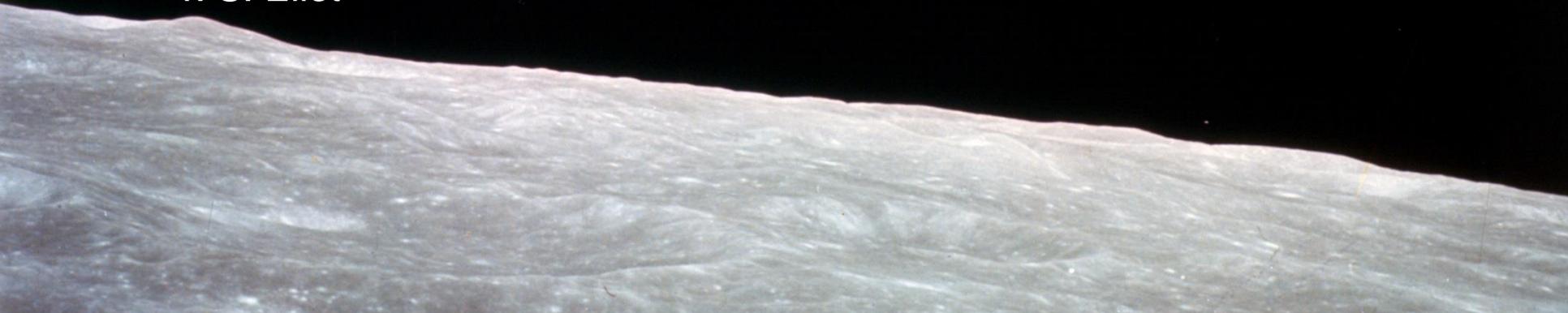
<sup>1</sup> NASA/ESA Partnership

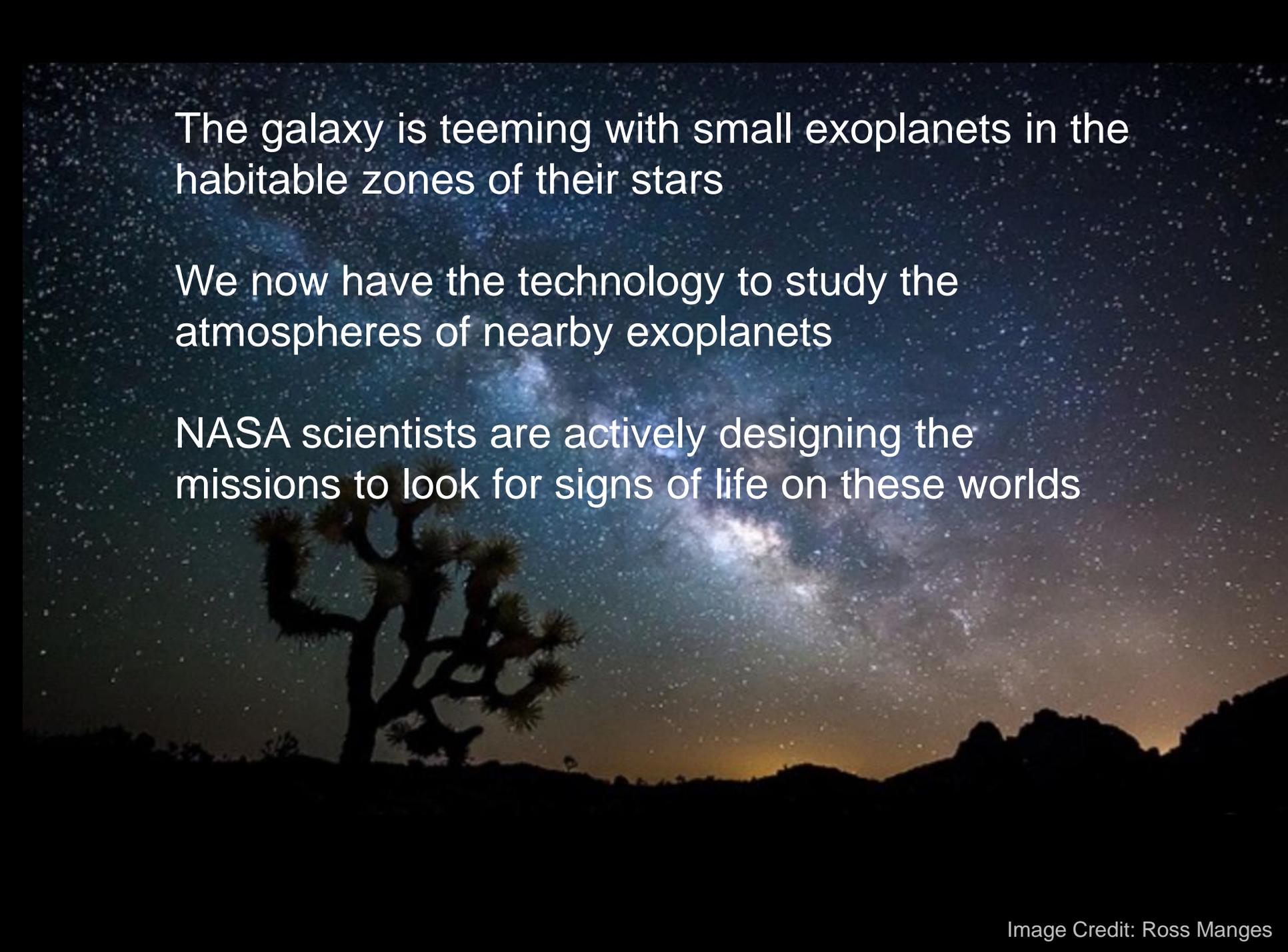
<sup>2</sup> CNES/ESA

# 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



A night sky with the Milky Way galaxy visible as a bright, hazy band of light. The sky is filled with numerous stars. In the foreground, the dark silhouette of a Joshua tree is visible on the left side, and the dark outlines of hills or mountains are visible along the bottom edge.

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

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





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# Acknowledgements

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The National Aeronautics and Space Administration has also conducted work at:  
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NASA's Ames Research Center

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- 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



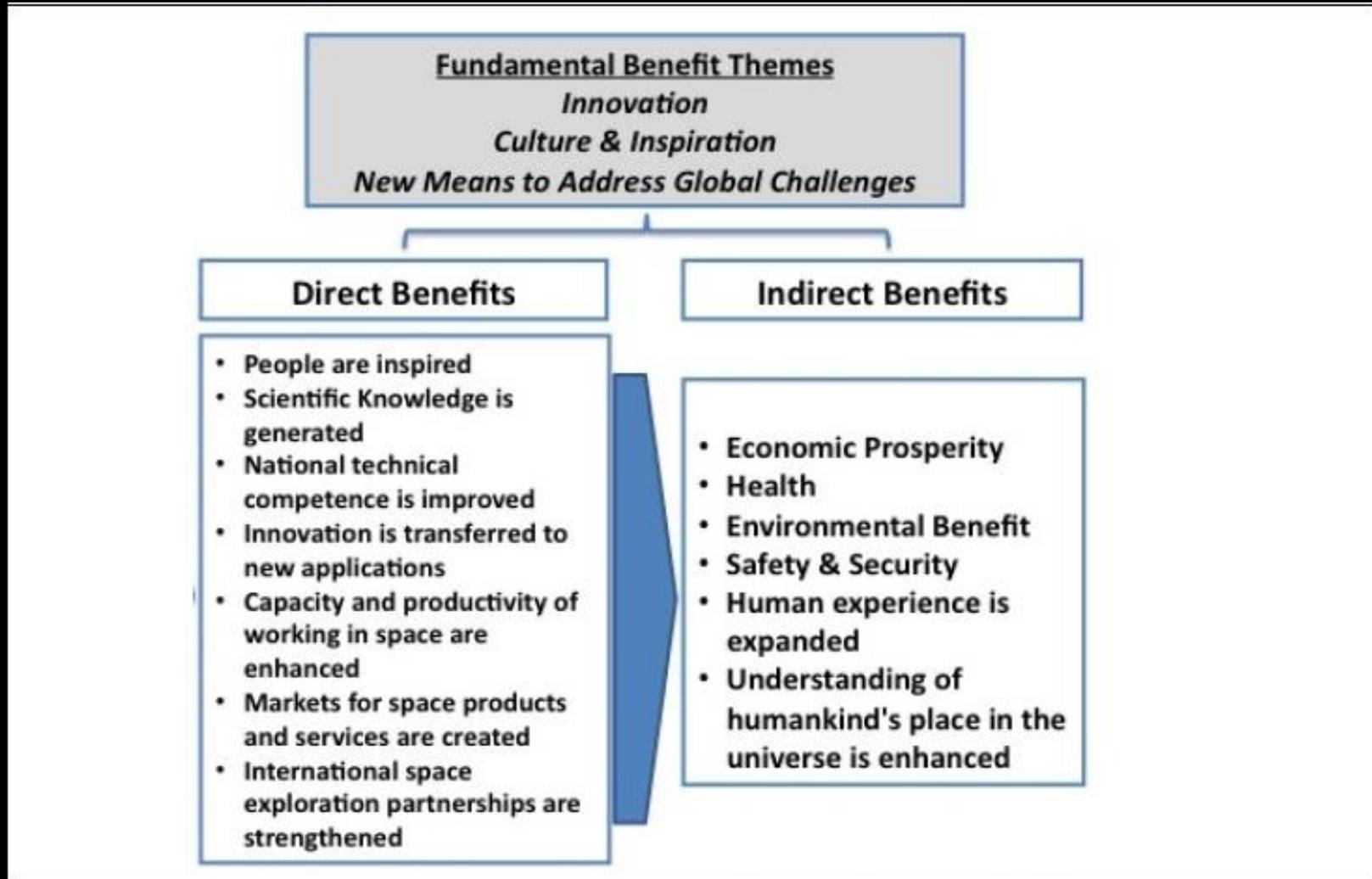
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# Benefits Stemming from Space Exploration Backup Charts



# Benefits Stemming from Space Exploration (Cont'd)





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# Benefits Stemming from Space Exploration (Cont'd)

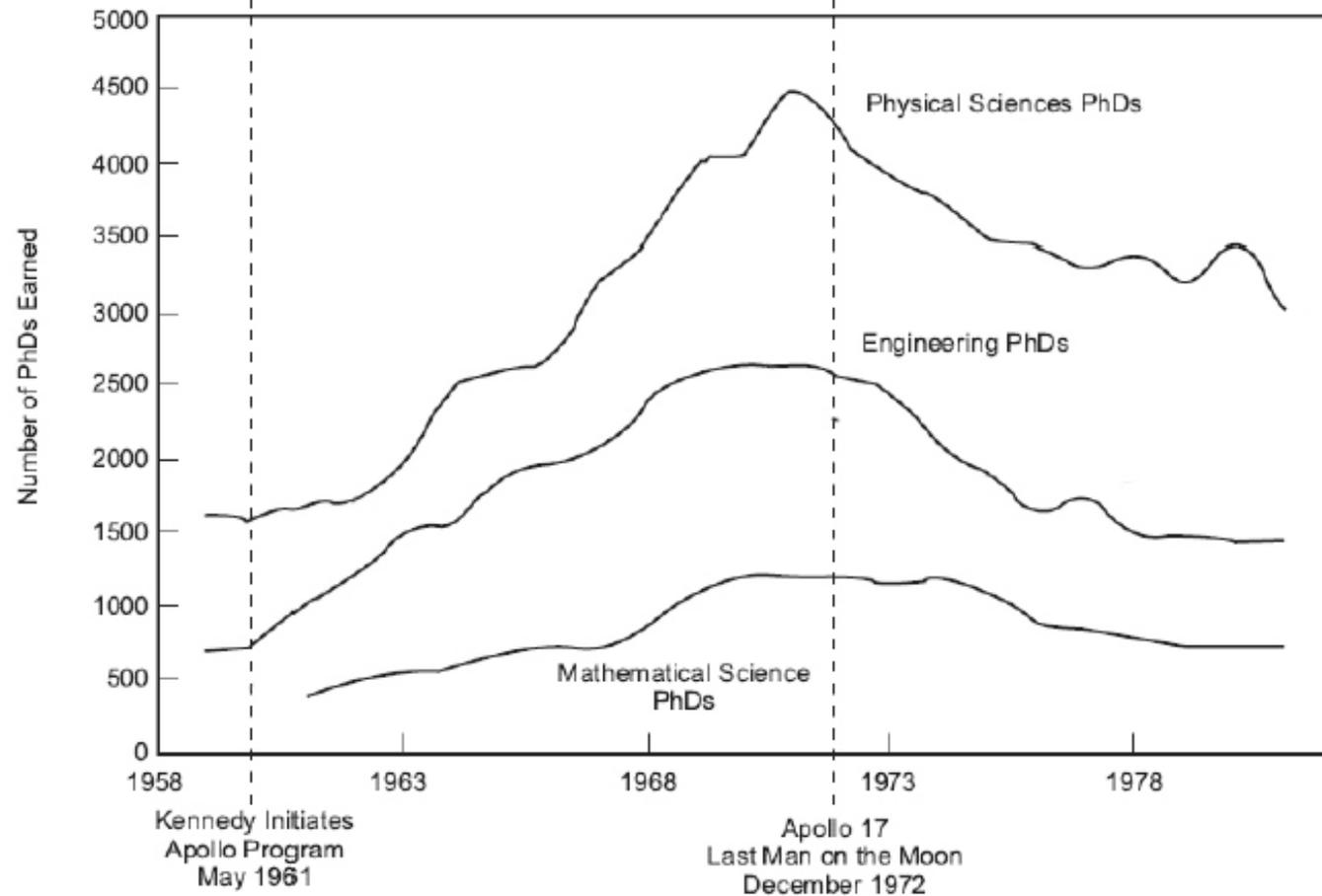


Figure 3. Space Exploration's Impact on Educational Achievement.<sup>16</sup>

<sup>16</sup> 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