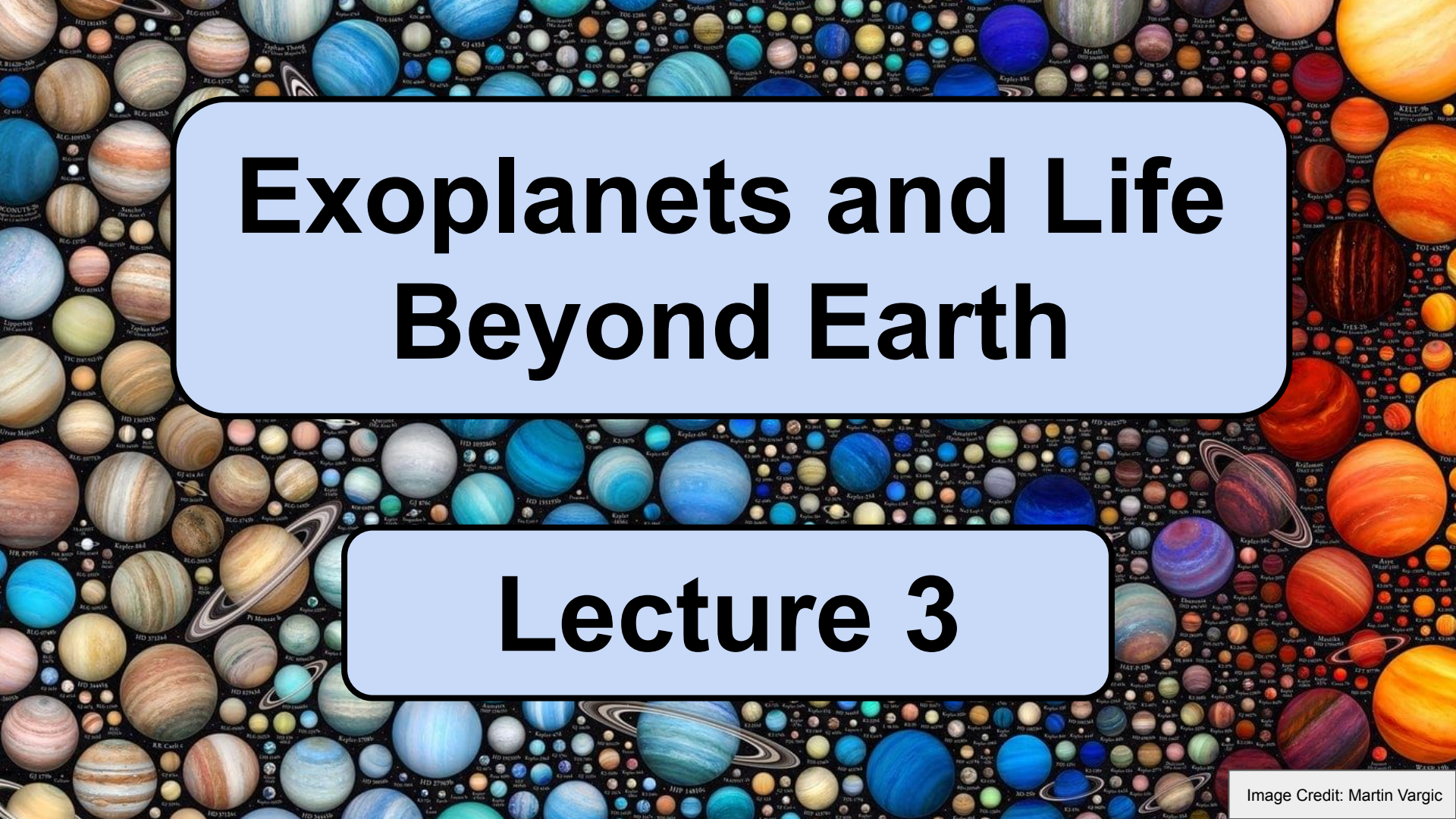
Exoplanets and Life Beyond Earth

Lecture 3



Last Week's Topic: What is Life?

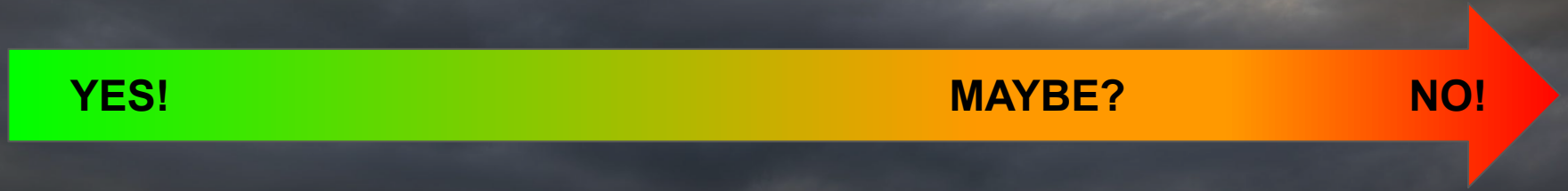
NASA:
"Life is a self-sustaining chemical system capable of darwinian evolution"

Meaning:
"Life is something that can keep itself going and make children that are a little different from itself."

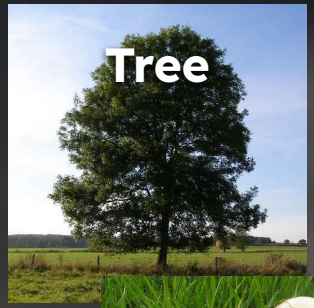
Textbook: Something that has all of these:

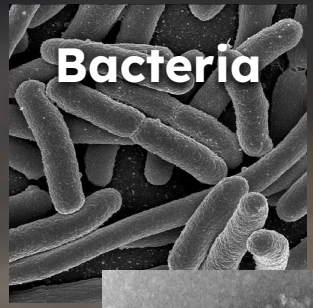
1) Body regulation
2) Made from cells
3) Eats "food"
4) Growth
5) Evolution
6) Reacts
7) Has children

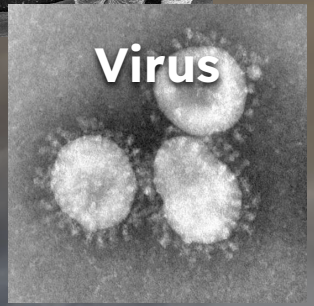
What is Life?

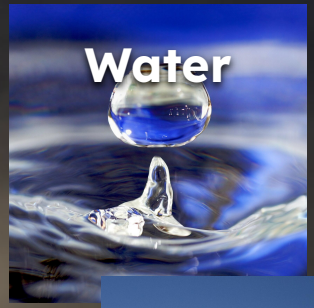


Last Week's Topic: What is Life?





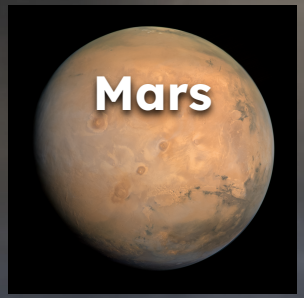


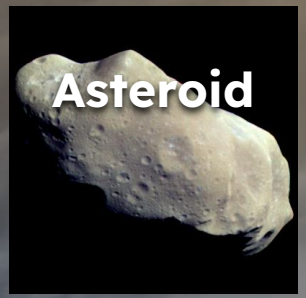


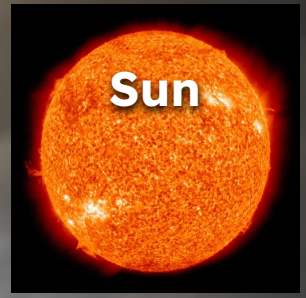
YES! ALSO YES! MAYBE? NO!

Where can we find life?

Could we find life there?







YES! MAYBE? PROBABLY NOT? NO!

Today's Topic: How do we find exoplanets?

The Sun has 8 planets.

Other stars have planets too!

Exoplanets are planets that orbit other stars.

https://exoplanets.nasa.gov/internal_resources/750

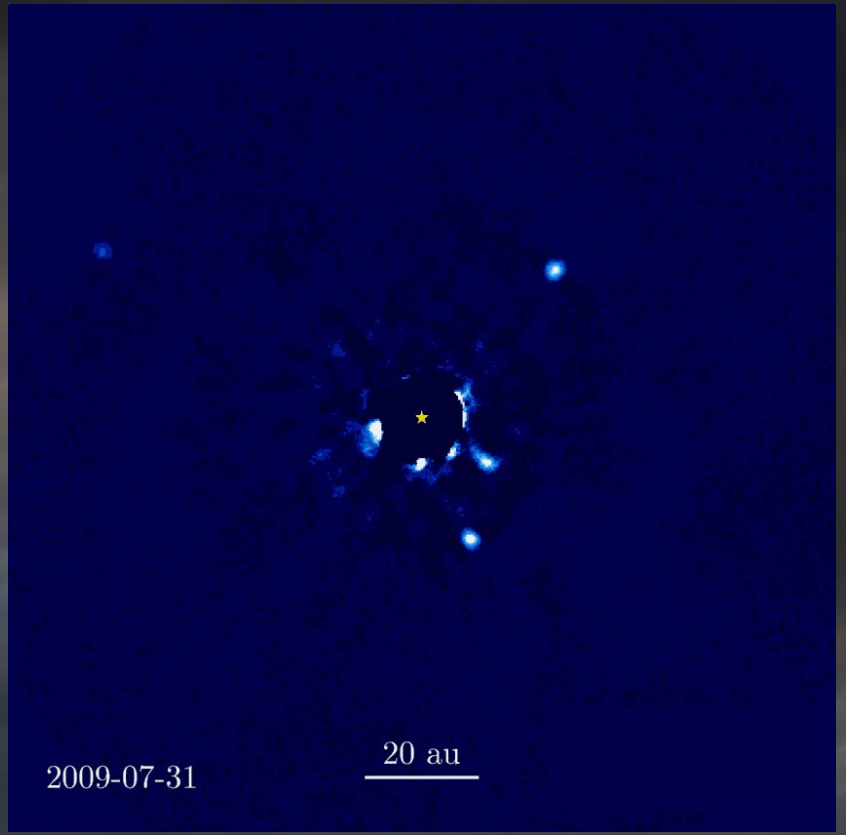
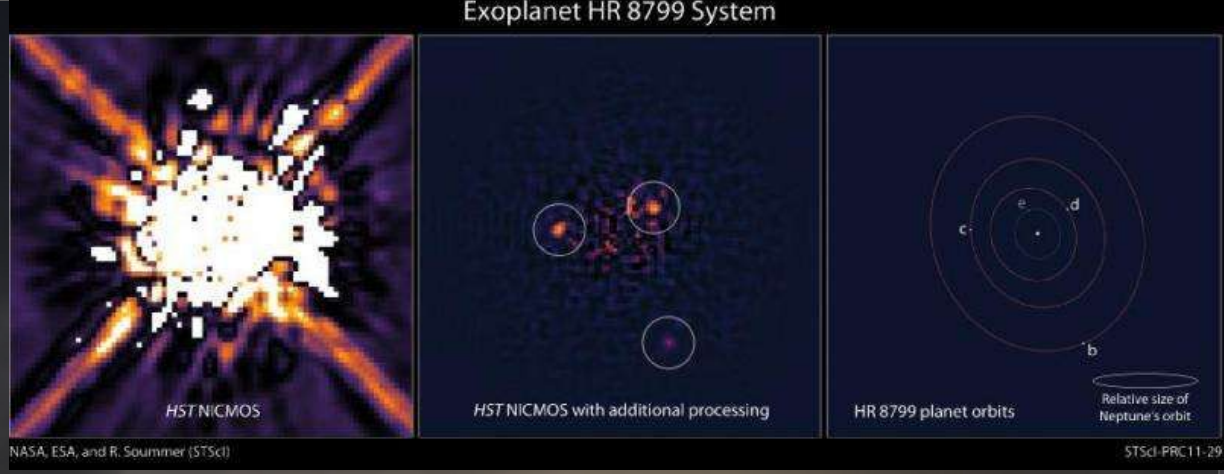


Image credit: Christian Marois

Direct Imaging

How do we find exoplanets? Direct Imaging



Steps:

Take a very very long image of a star that you want to search for a planet around

Take a very very long image of a star without any planets

Subtract image of the star without a planet from the image of the star you want to study and see if you can find the signal from the planet!

We can see planets like Jupiter emitting their own light and directly detect them this way

How do we find exoplanets? Direct Imaging

James Webb Space Telescope NIRCam coronagraph.

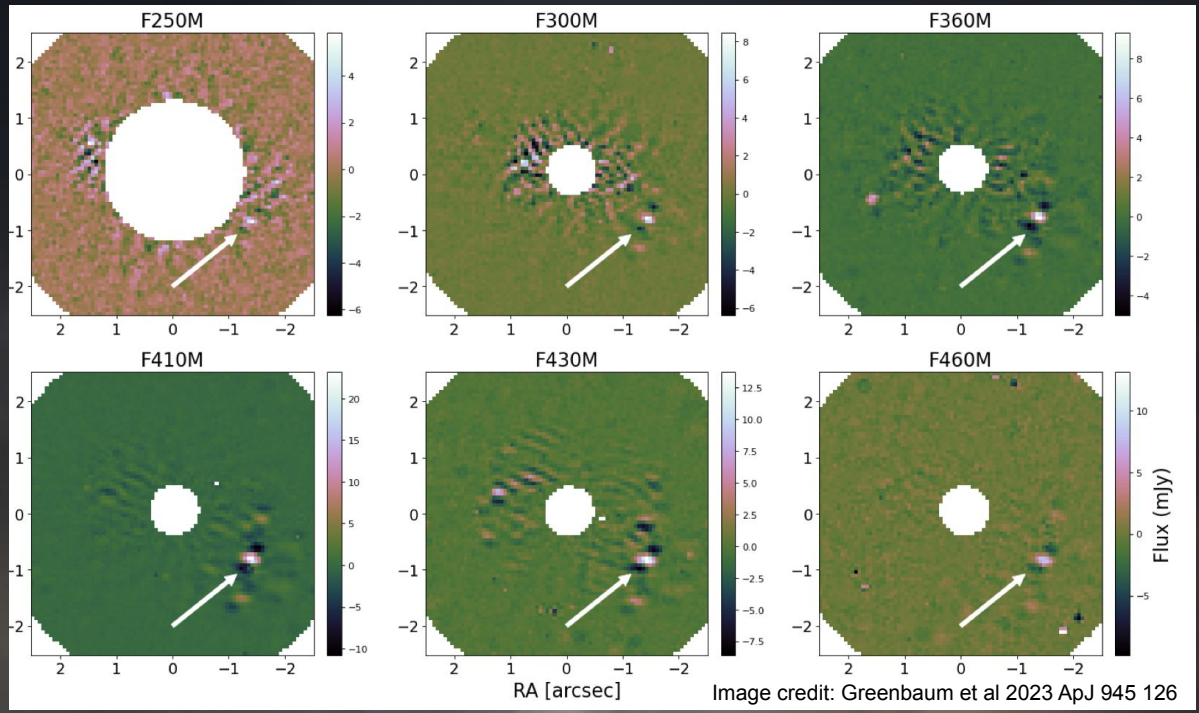
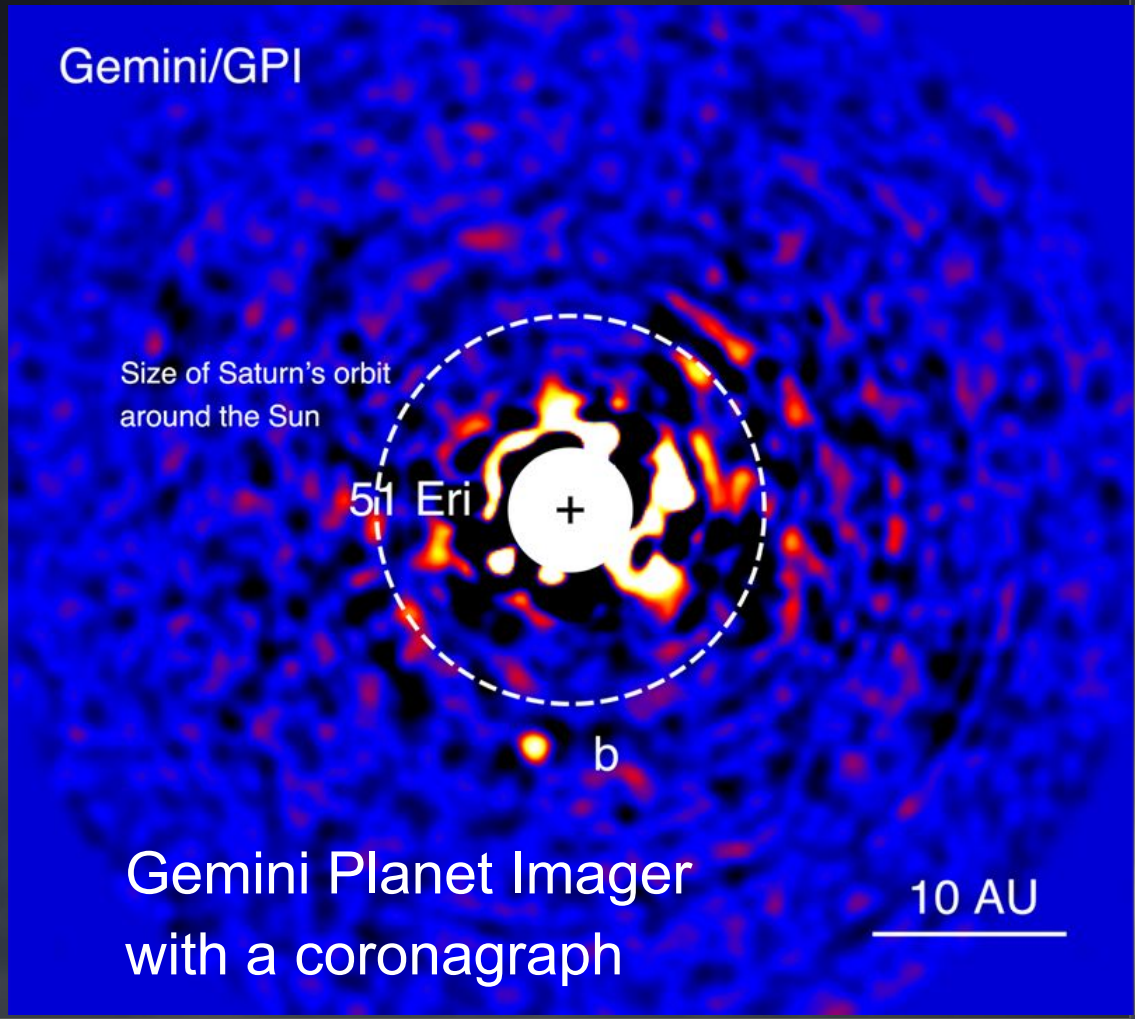


Image credit: Greenbaum et al 2023 ApJ 945 126

- Can even use a mask that blocks the starlight to look for planets.
- Works just like putting your hand up in the sky to block sunlight.
- Called a coronagraph.
- These are on many telescopes including the Hubble and James Webb Space Telescopes.

How do we find exoplanets? Direct Imaging

- It evens works from telescopes on the ground.



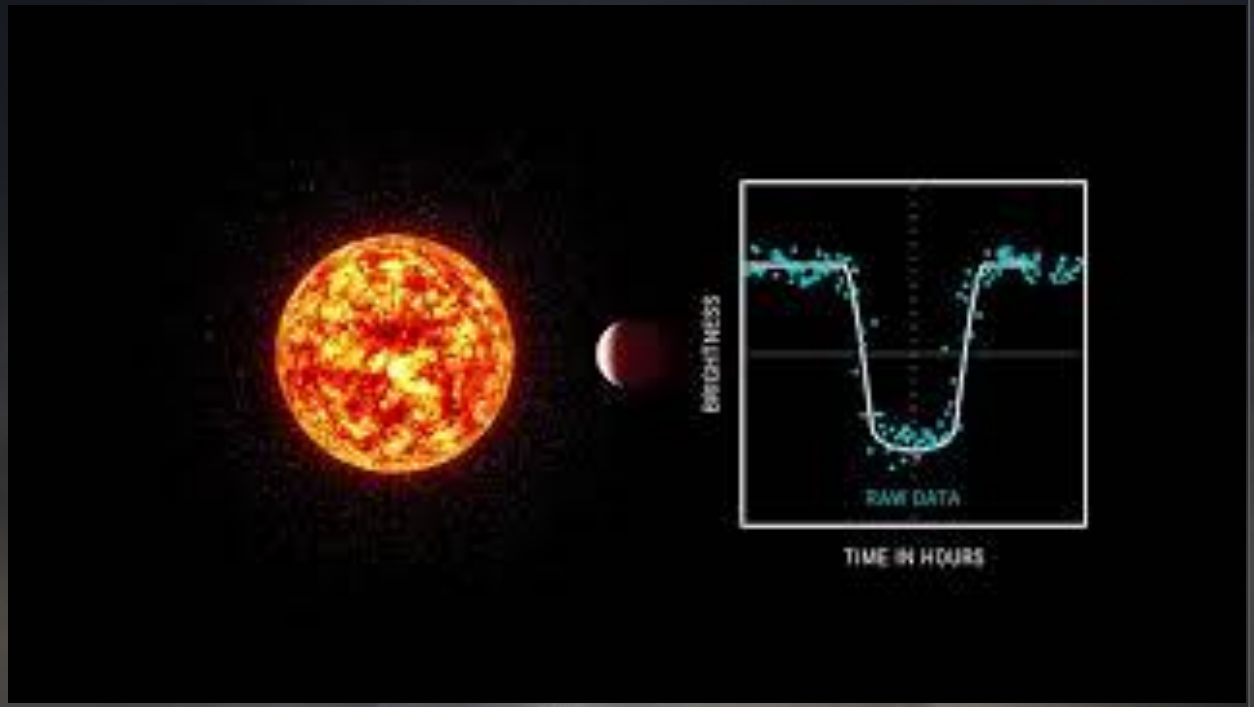
How do we find exoplanets? Direct Imaging

- Direct imaging is a main motivator for future 30m telescopes.
- They plan to detect Earth twin planets around Sun-like stars, where we think life is most common
- https://elt.eso.org/about/webcams/

Image credit: ESO

Transit Method

How do we find exoplanets? Transit Method



Steps:

1) Find star that you want to search for a planet around
2) Stare at the star for a very very long time
3) See if you can find a dip in the amount of light coming from the planet
4) Any dips that happen frequently must be from an object blocking the light from the star

How do we find exoplanets? Transit Method

- Demonstrate with phone light
- Space telescopes like Transiting Exoplanet Survey Satellite (TESS) and the Kepler Space Telescope stare at many parts of the sky to try to find these dips in starlight.

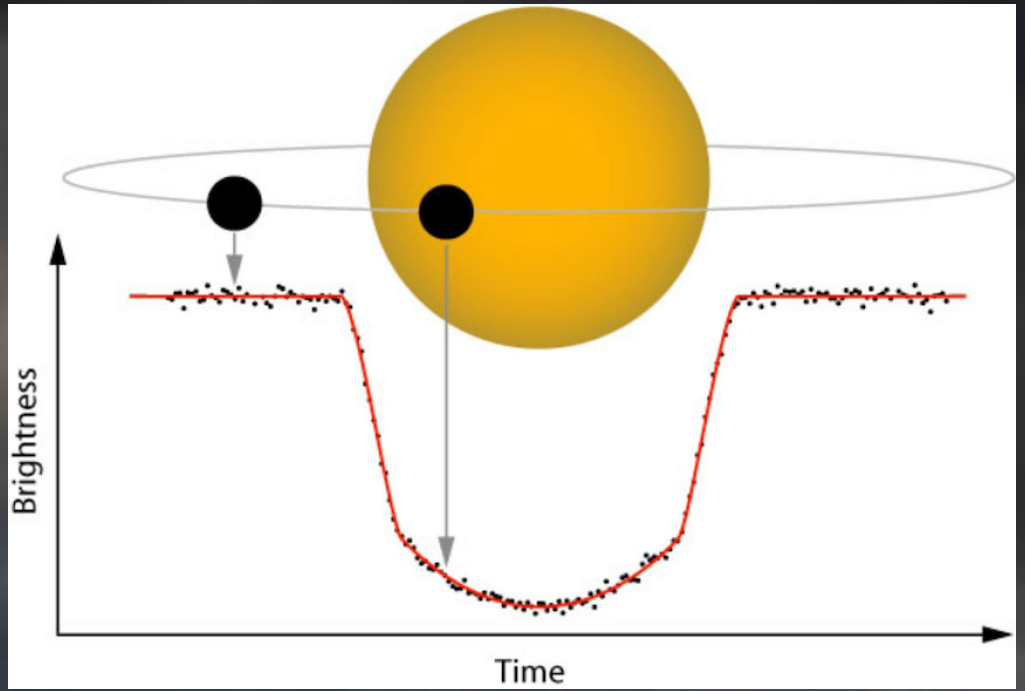
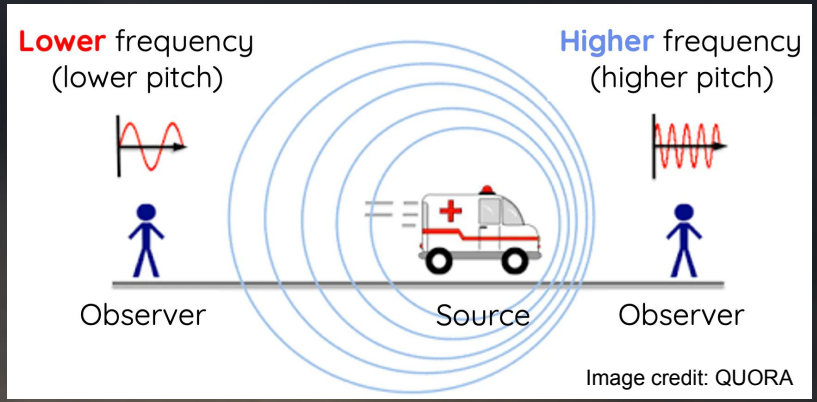


Image credit: NASA

10 min break

Doppler Method

How do we find exoplanets? Doppler Method



This method depends on the Doppler effect.

The Doppler effect impacts light and sound.

An example in sound:

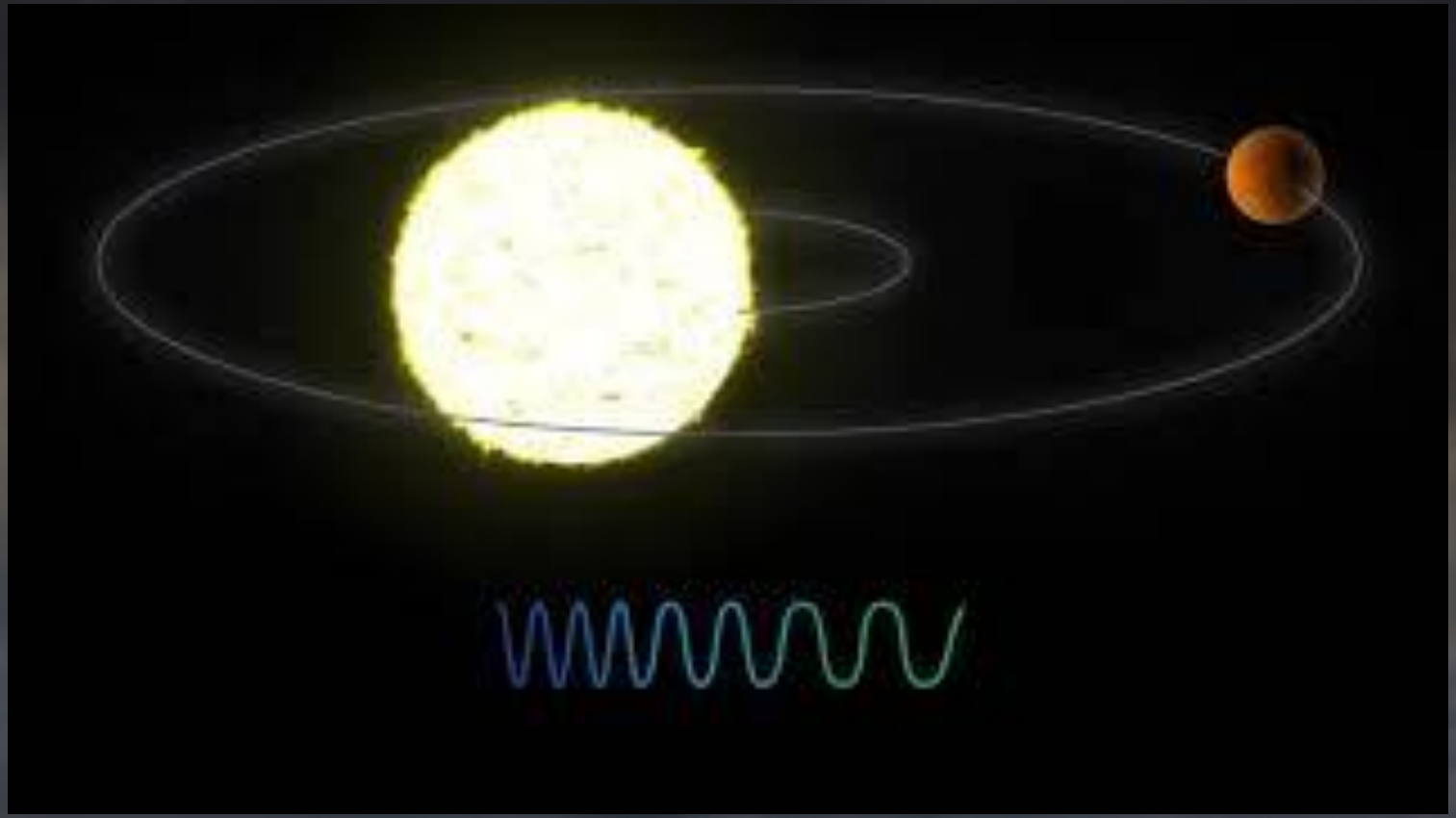
When an ambulance moves towards you with its siren on, the sound waves bunch up and sound high pitched. When it moves away, the sound waves stretch out and it has a lower pitch.

The same happens with light. When an object emitting light moves towards you, the light waves bunch up and look bluer. When it moves away, the light stretches out and looks redder.

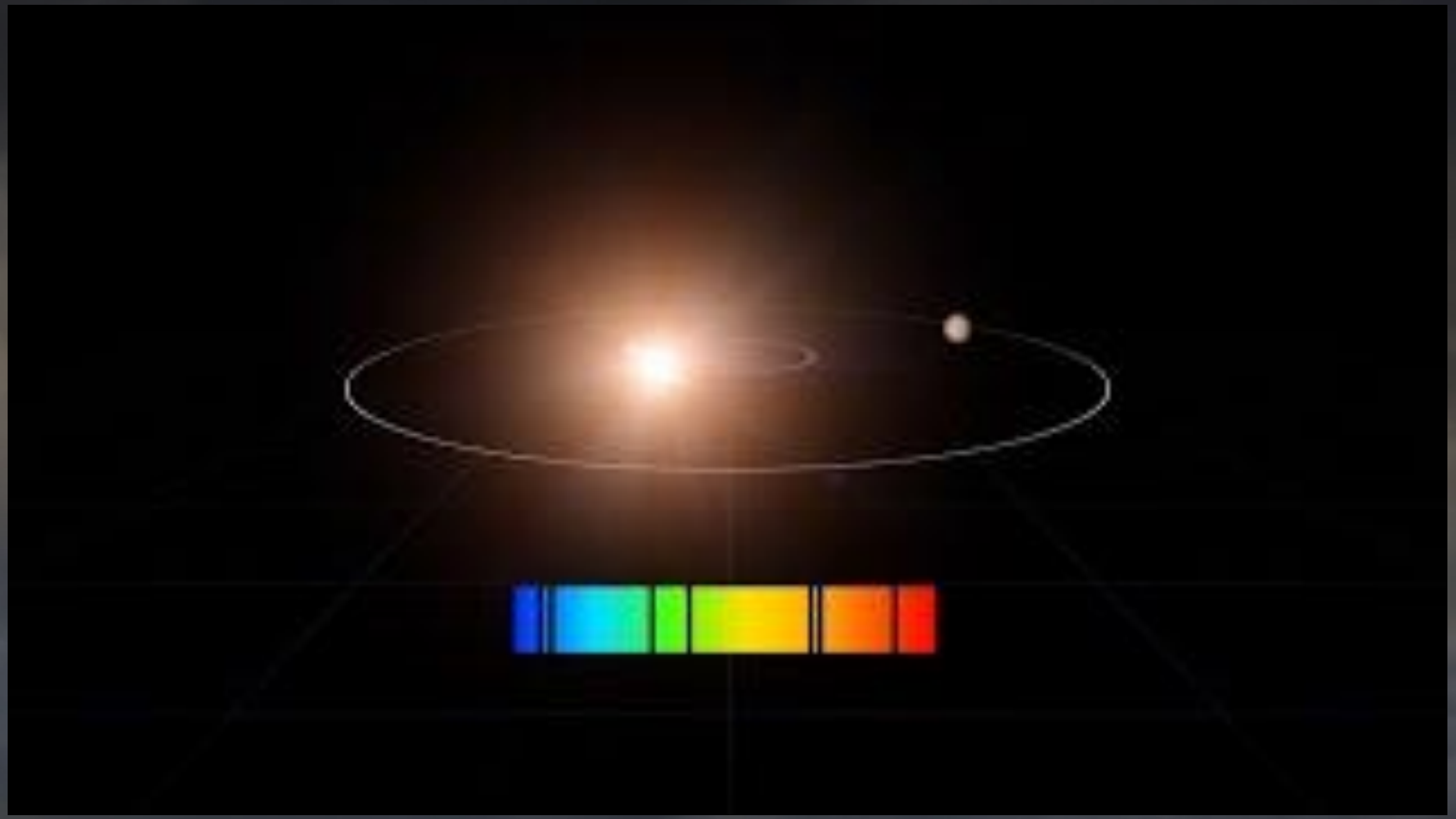
Planets pull on their stars with gravity moving them back and forth during their orbit. This makes the star look bluer and redder throughout the orbit.

We can stare at stars and see if they get redder or bluer that can only happen from the planet pulling on it with gravity.

How do we find exoplanets?
Doppler Method



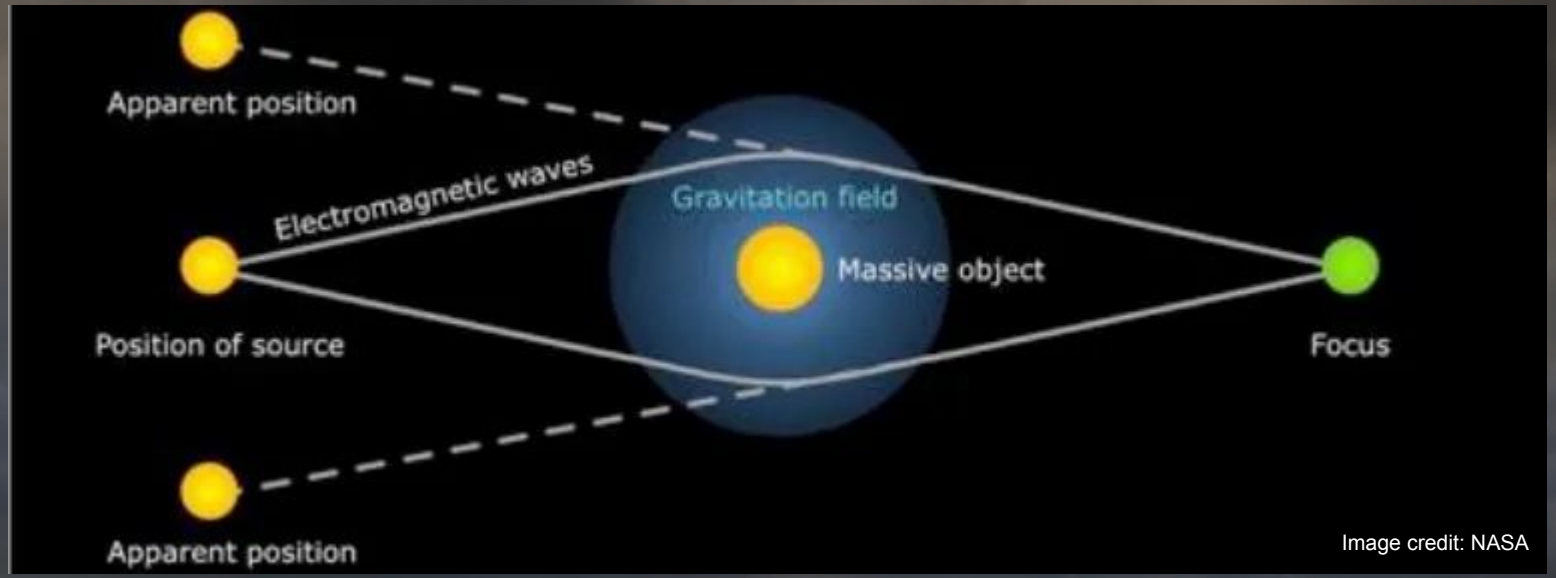
How do we find exoplanets?
Doppler Method



Microlensing

How do we find exoplanets? Microlensing

- Gravity impacts light
- Gravity can bend light
- If light is bent by gravity in a perfect configuration, it will be focused right on Earth, and the object will look much brighter



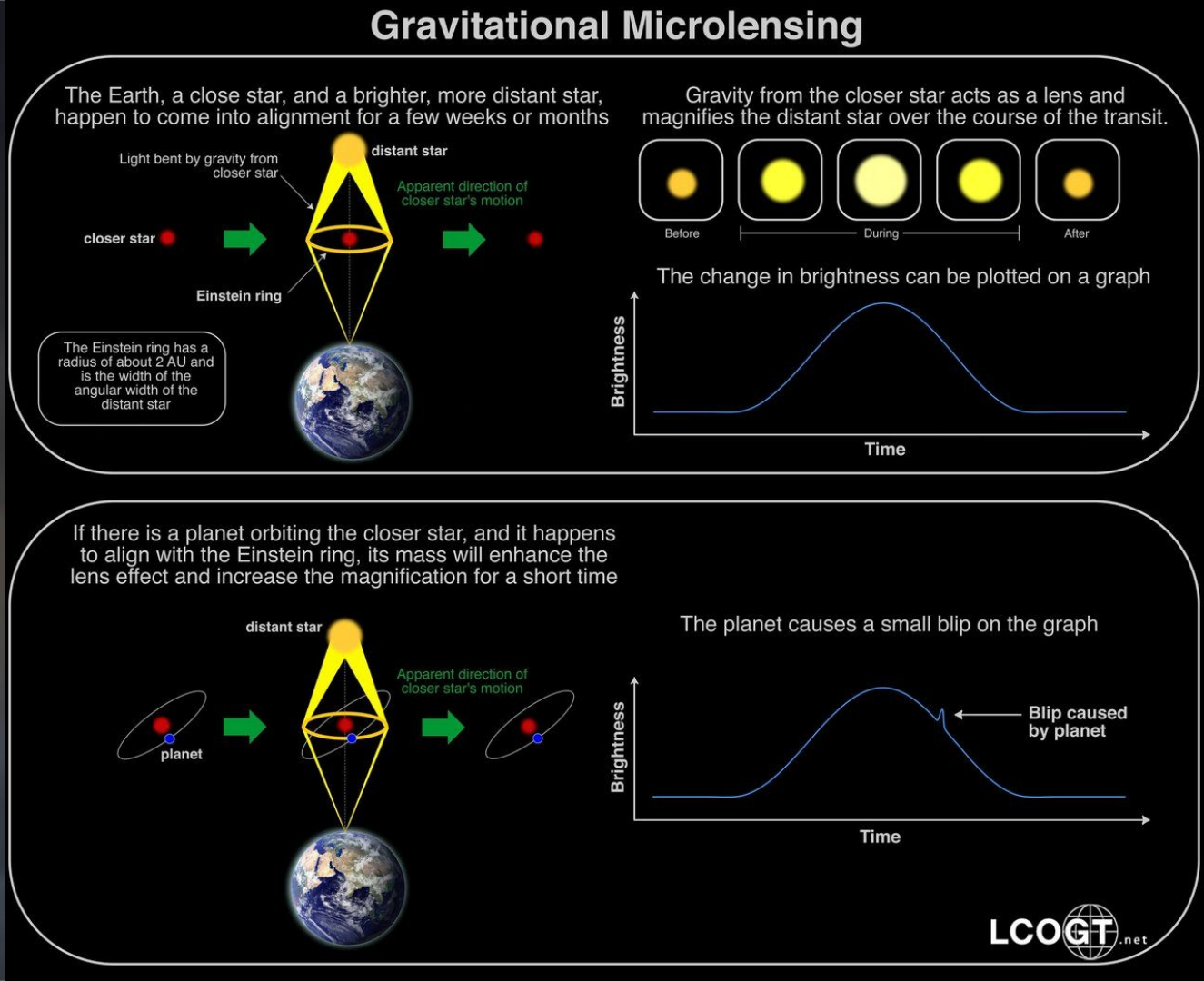
How do we find exoplanets? Microlensing

A moving star passes between a far away star and Earth.

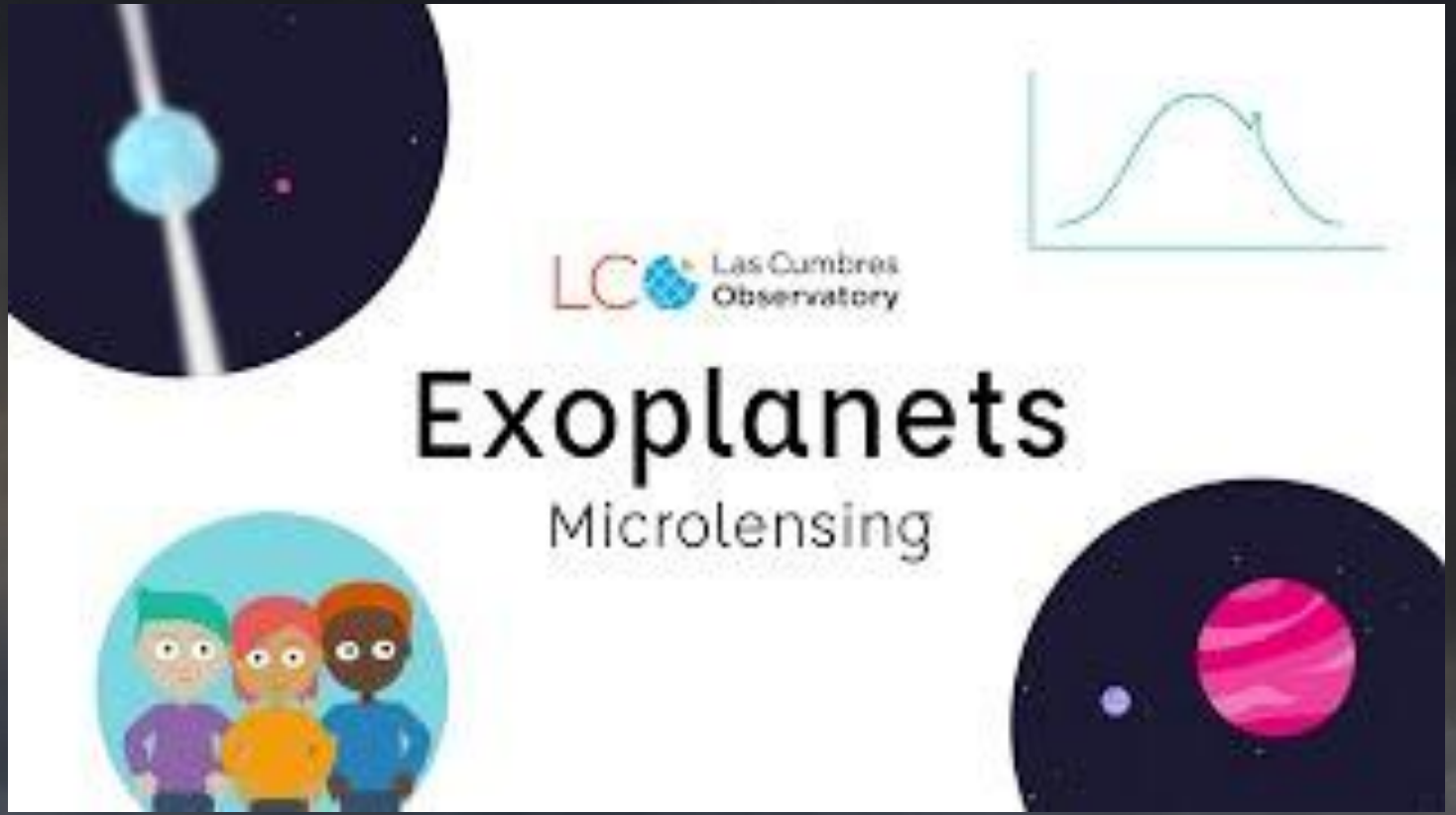
That moving star acts as a magnifying glass and makes the far away star look brighter.

If the moving star has a planet it will act like a magnifying glass too but much smaller.

We can stare at many stars to try to find one of these events to detect planets.



How do we find exoplanets? Microlensing



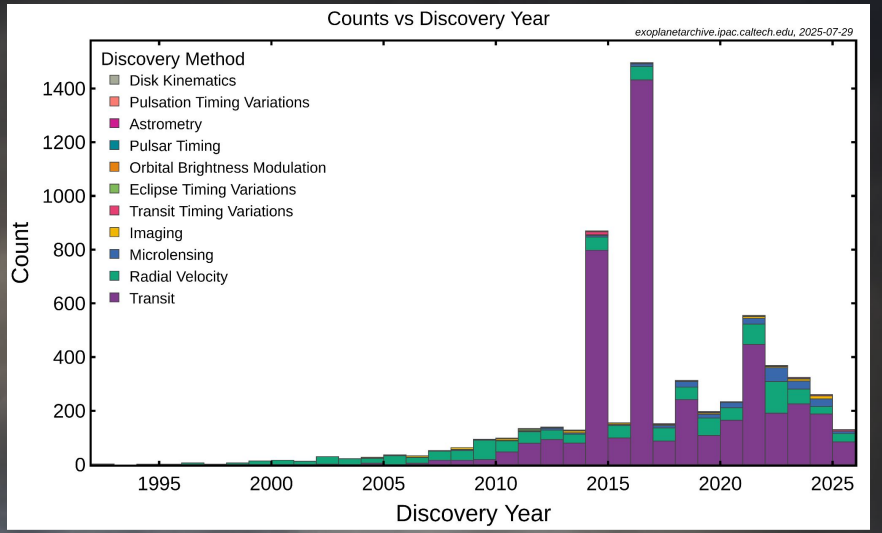
How do we know about exoplanets?

The first exoplanet was found in 1992 around a neutron star.

The first exoplanet around a Sun-like star was found in 1995.

We have found thousands of exoplanets in the last 15 years.

Most planets are found by the transit method.



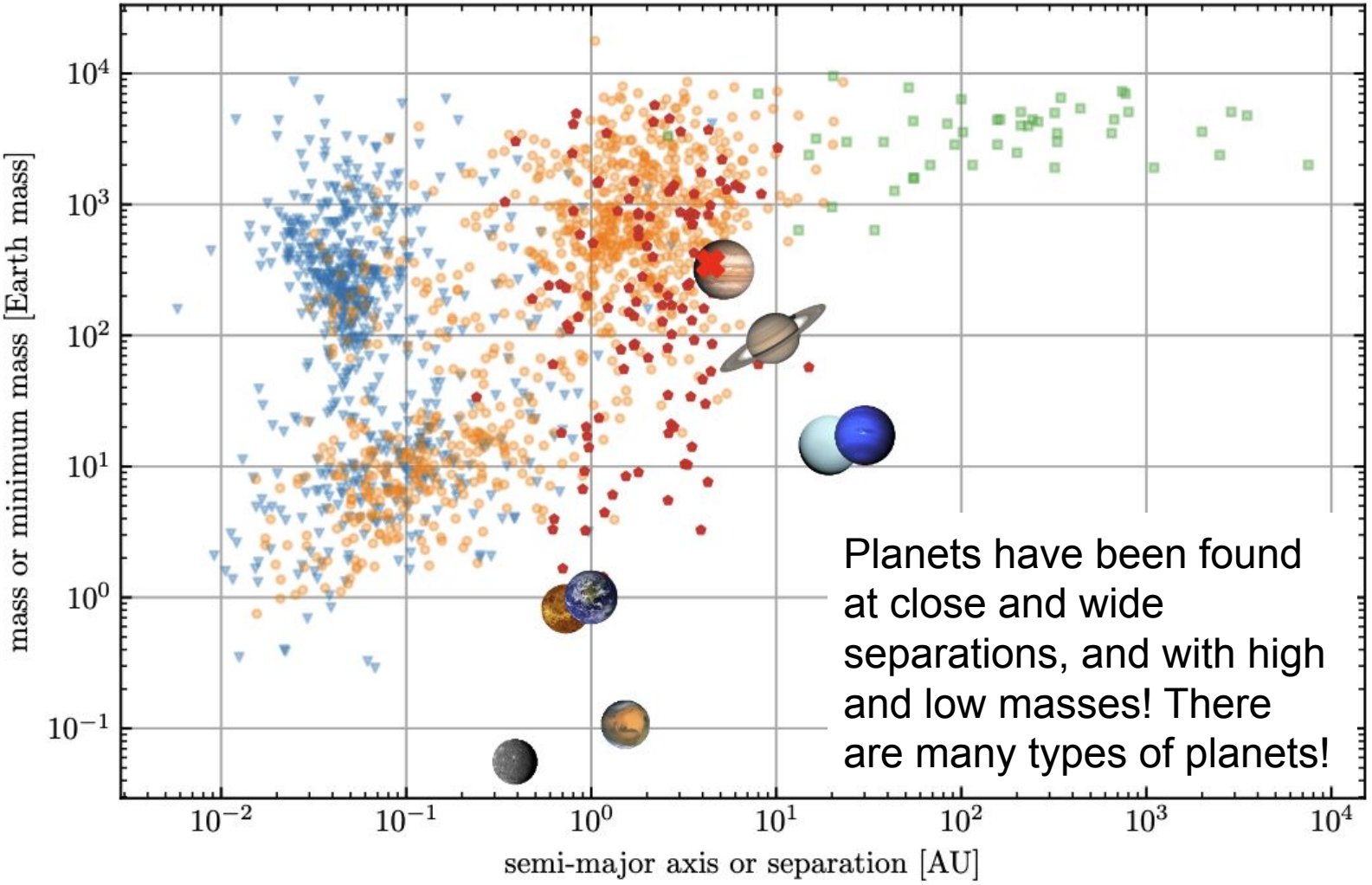


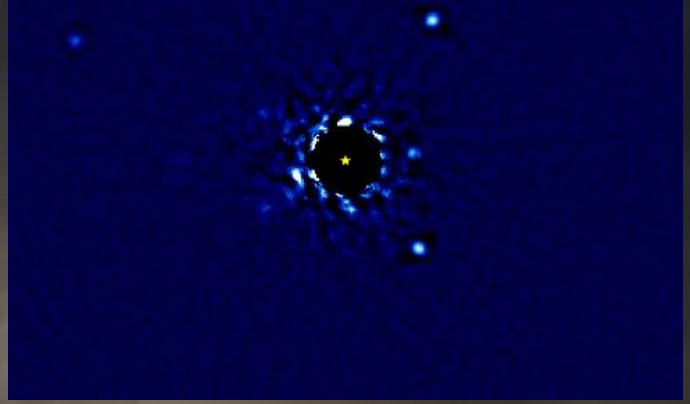
Image credit: Specht et al. 2022

What types of planets are found with each technique?

Microlensing

Image credit: S. Liebes et al. (1964)

Direct Imaging



Doppler Method

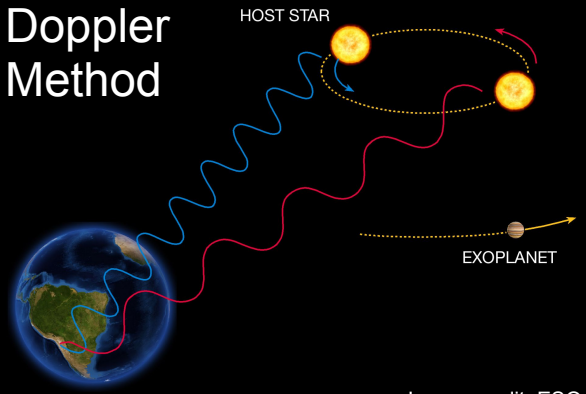
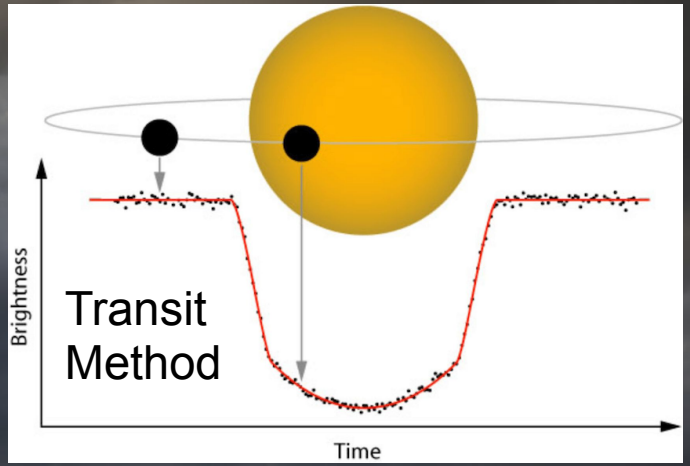
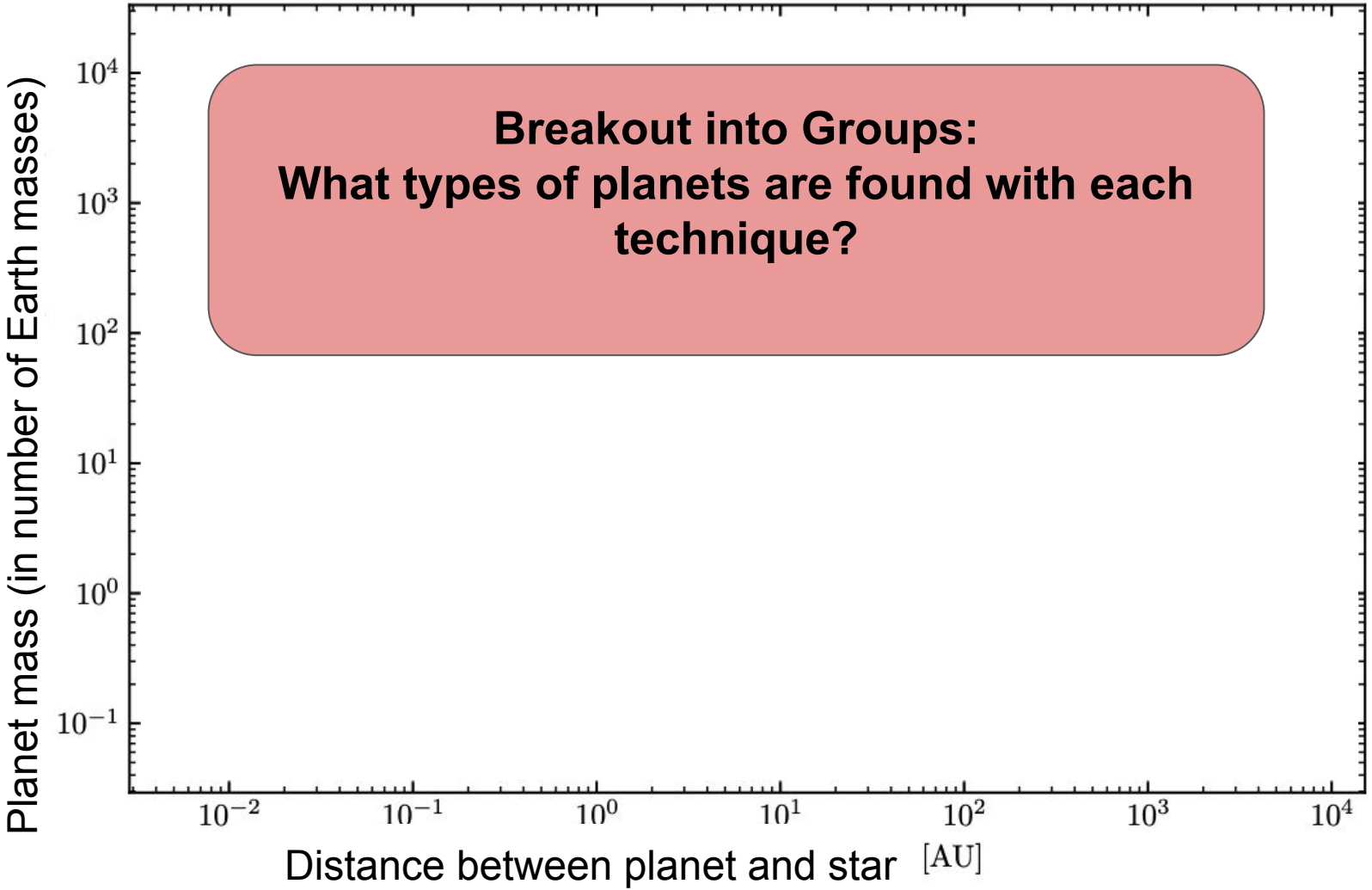
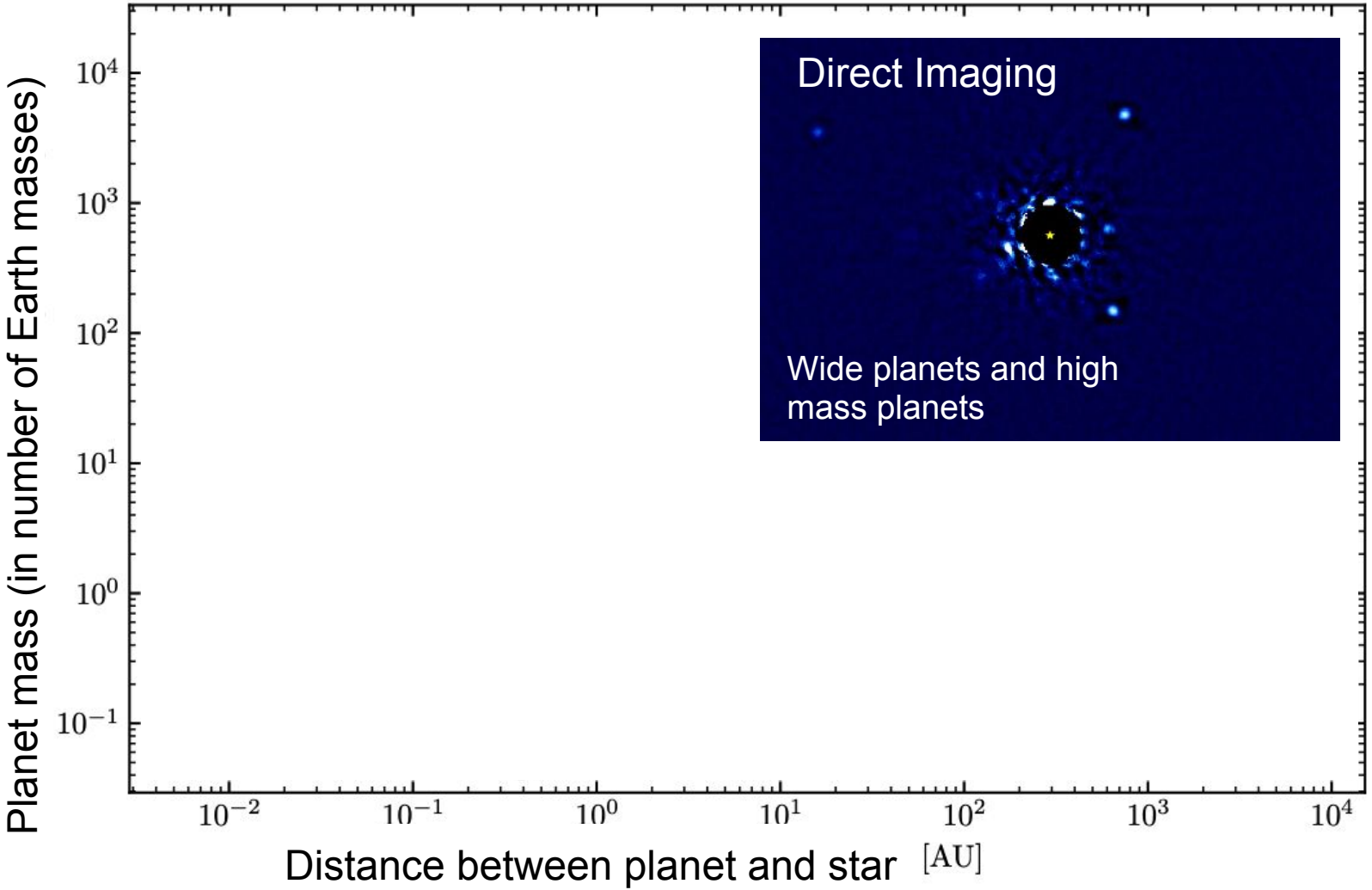


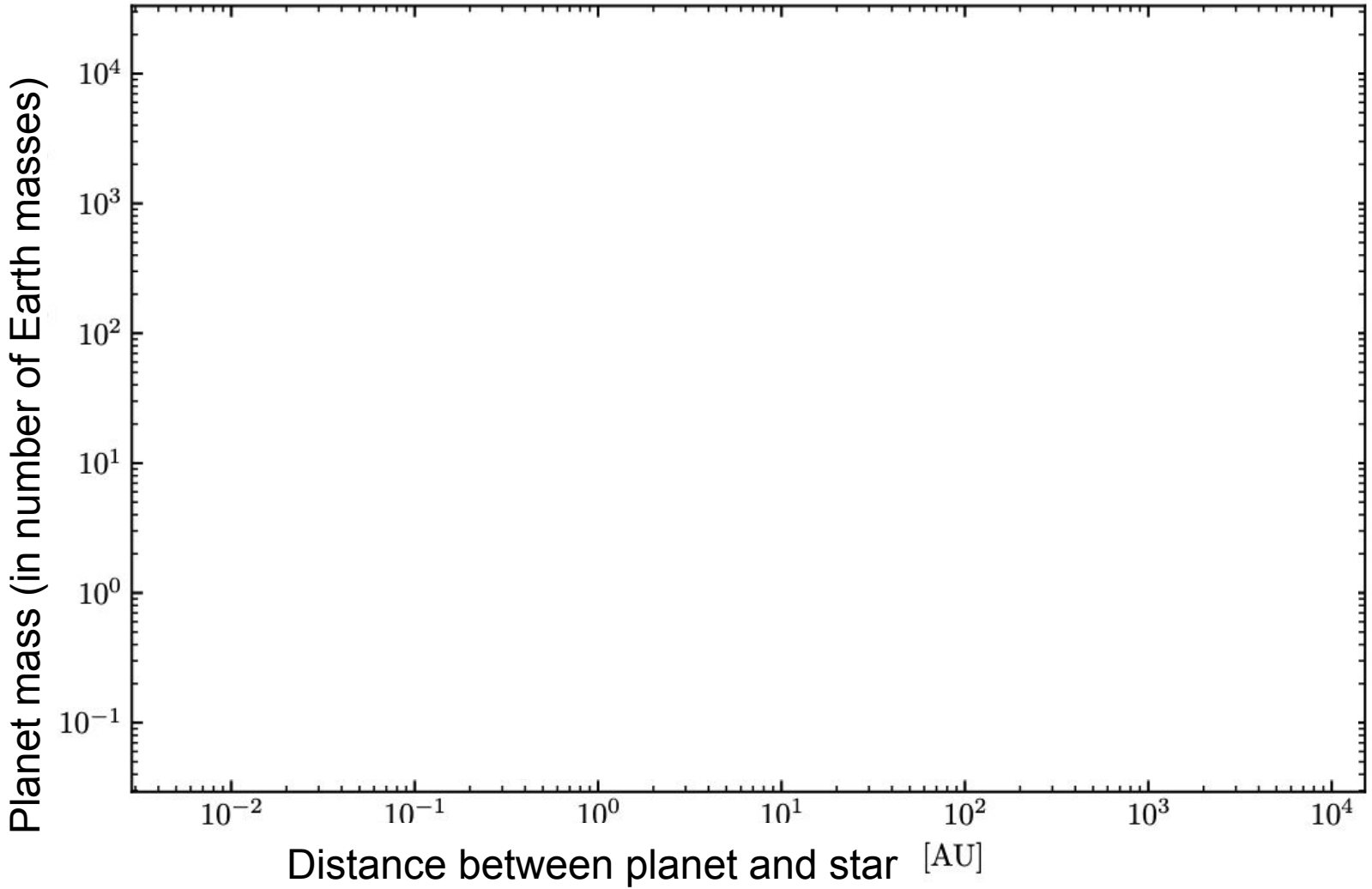
Image credit: ESO

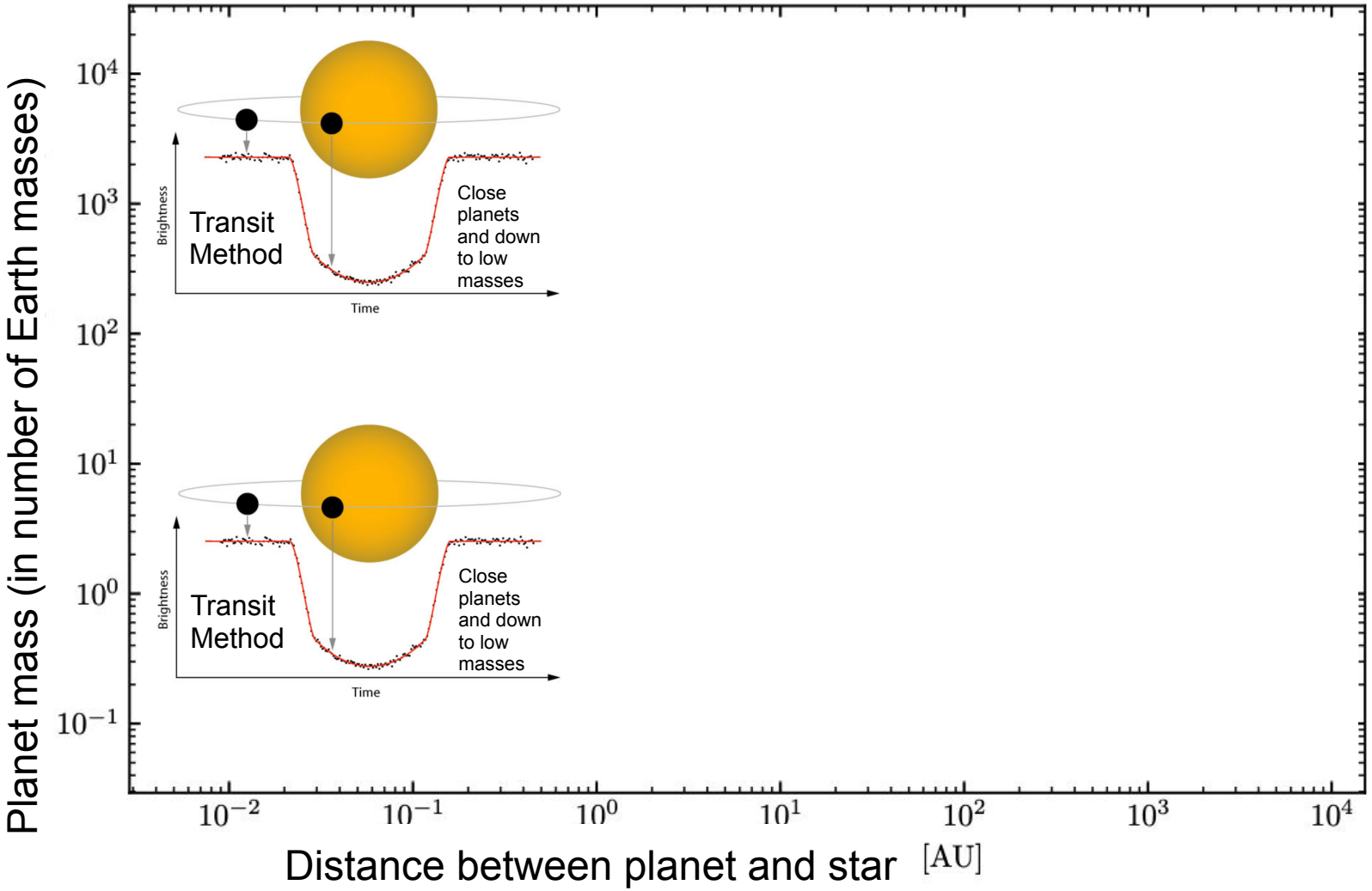
Transit Method

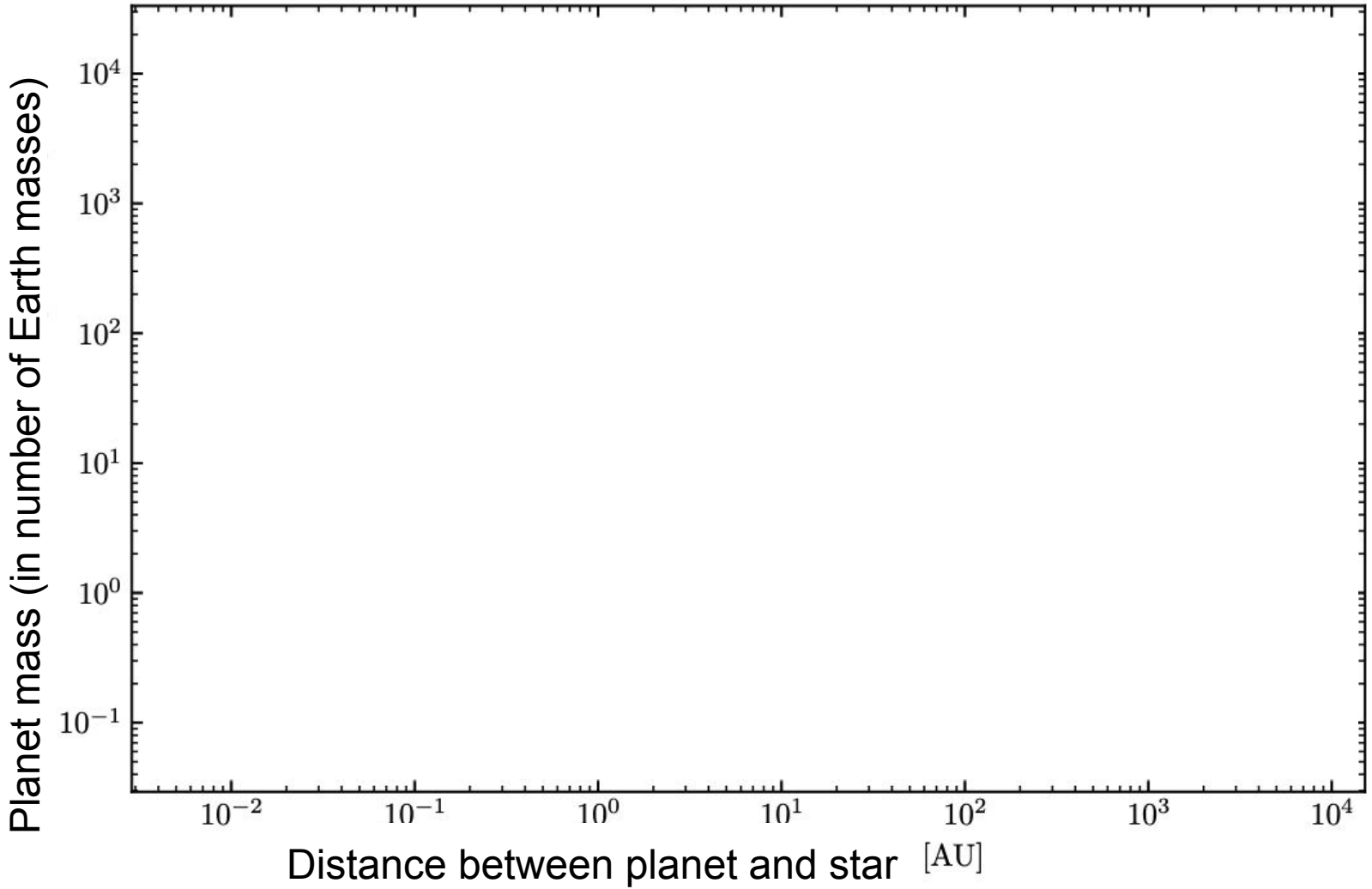


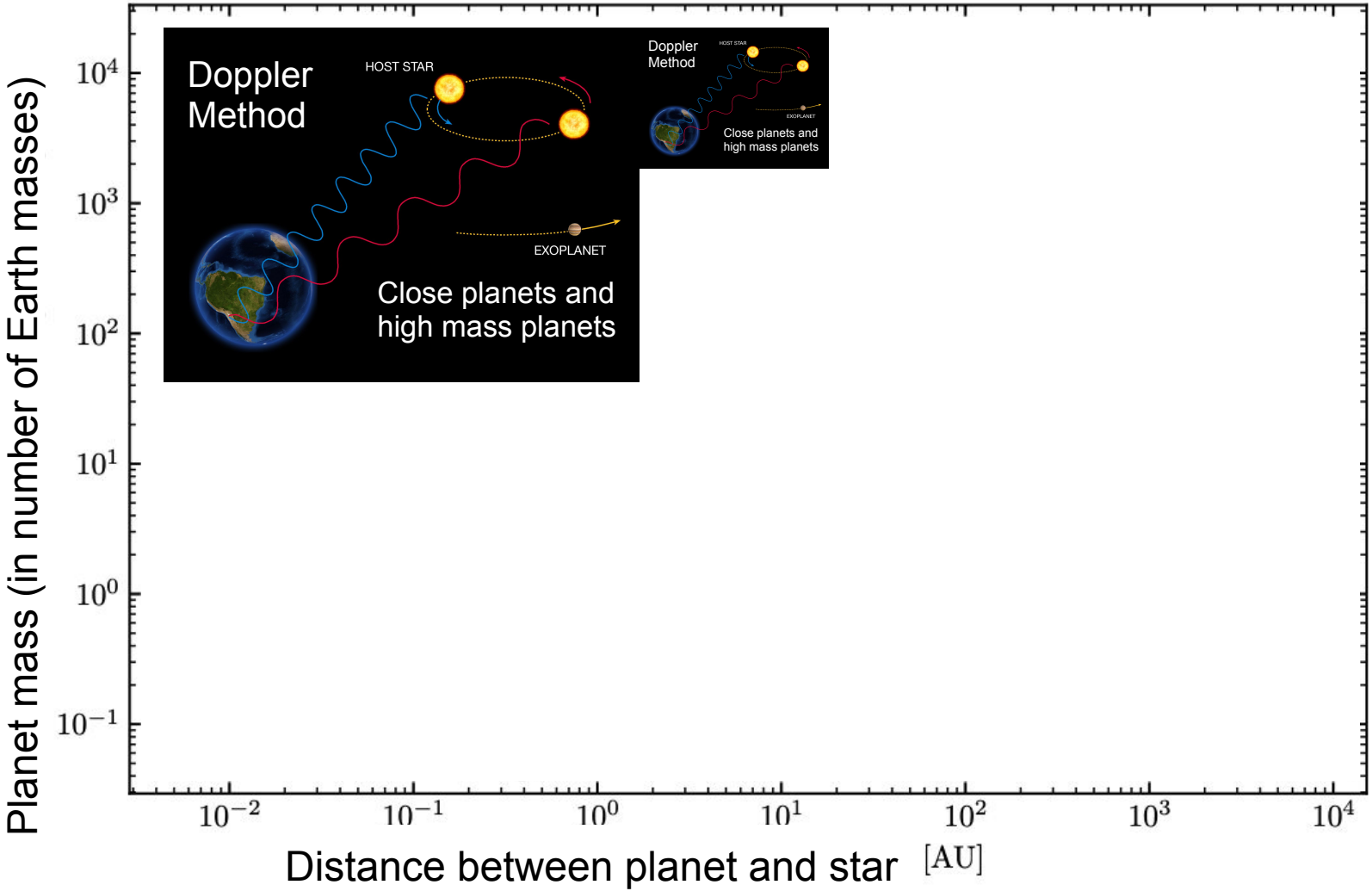

Breakout into Groups:
What types of planets are found with each technique?
Planet mass (in number of Earth masses)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Distance between planet and star [AU]

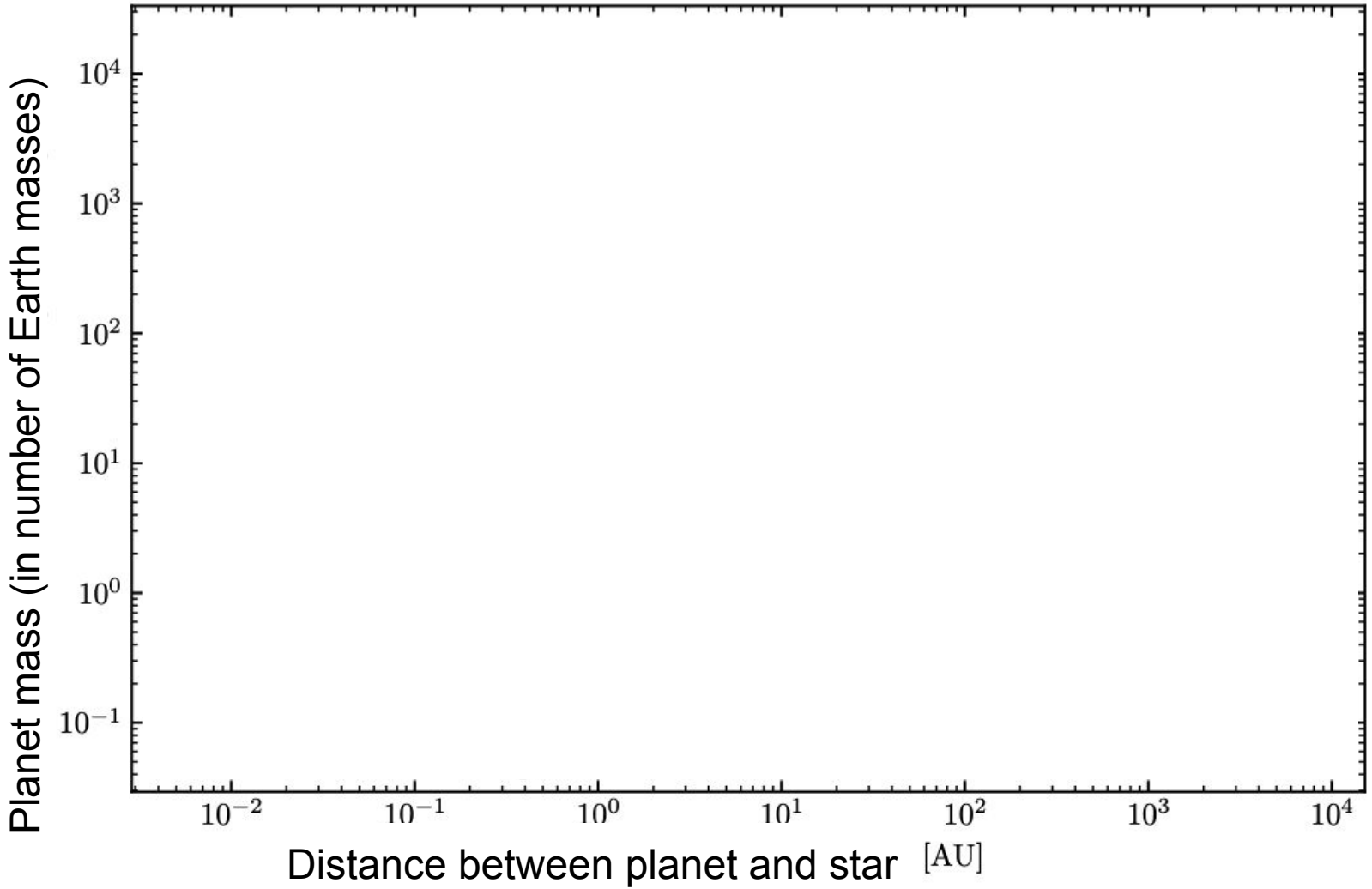

Direct Imaging
Wide planets and high mass planets
Planet mass (in number of Earth masses)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Distance between planet and star [AU]

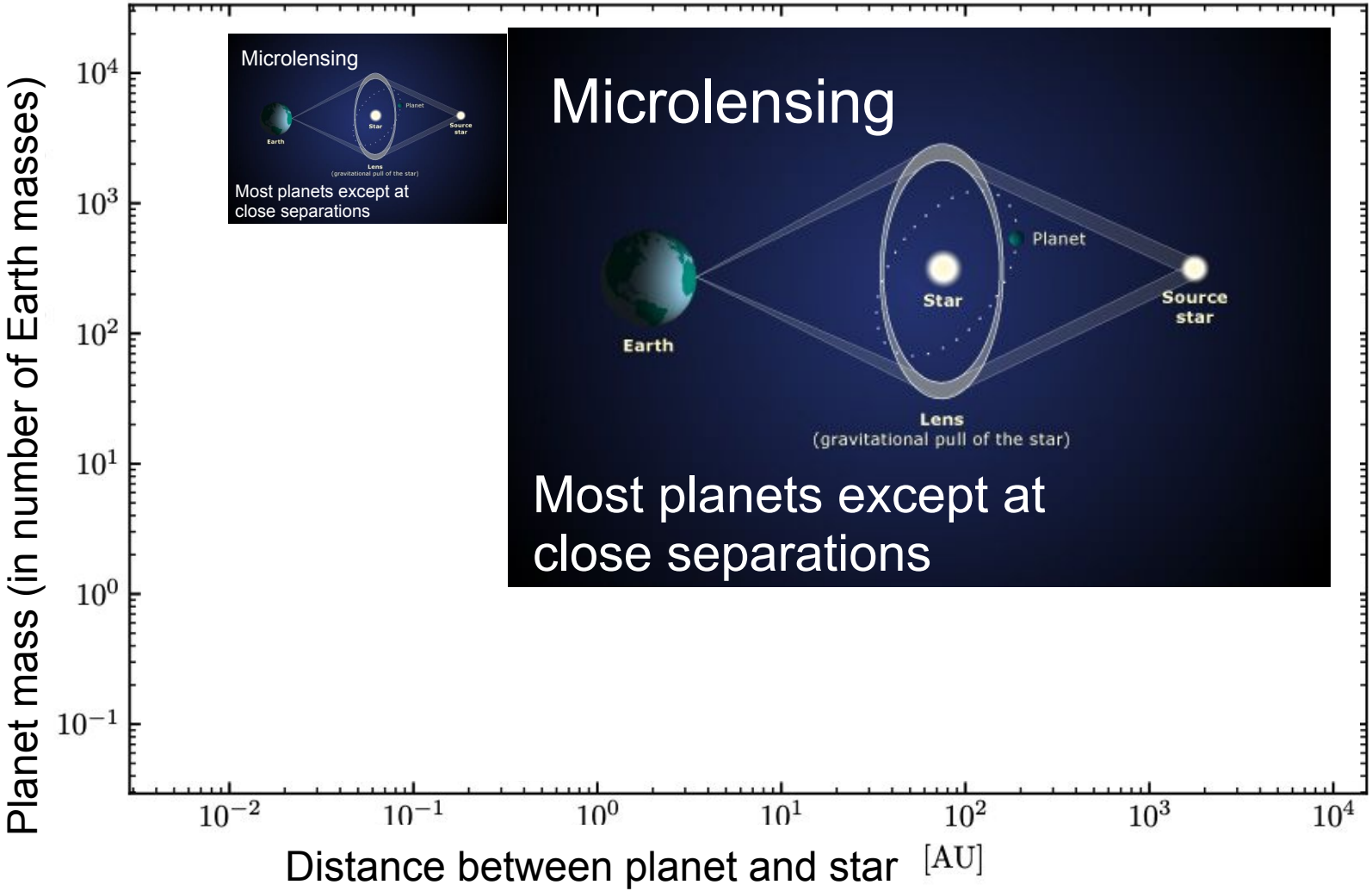

Planet mass (in number of Earth masses)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
Distance between planet and star [AU]


Planet mass (in number of Earth masses)
10^4
10^3
10^2
10^1
10^0
10^{-1}
Transit Method
Brightness
Time
Close planets and down to low masses
Transit Method
Brightness
Time
Close planets and down to low masses
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
Distance between planet and star [AU]


Planet mass (in number of Earth masses)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
Distance between planet and star [AU]


Doppler Method
HOST STAR
EXOPLANET
Close planets and high mass planets
Doppler Method
Close planets and high mass planets
Planet mass (in number of Earth masses)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Distance between planet and star [AU]


Planet mass (in number of Earth masses)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
Distance between planet and star [AU]

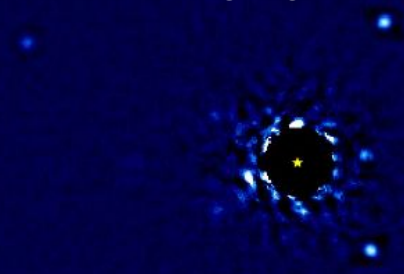

Microlensing
Most planets except at close separations
Microlensing
Earth
Star
Planet
Source star
Lens
(gravitational pull of the star)
Most planets except at close separations
Planet mass (in number of Earth masses)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Distance between planet and star [AU]

What types of planets are found with each technique?

Microlensing

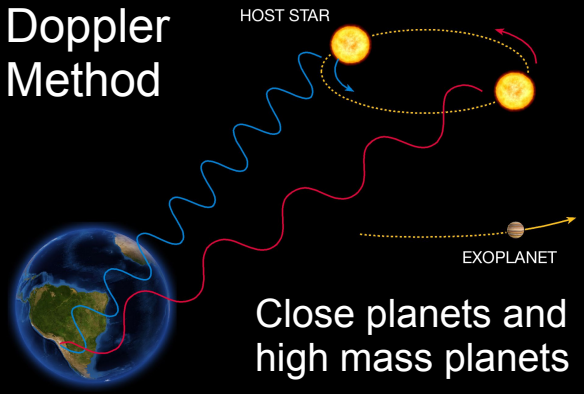
Most planets except at close separations

Direct Imaging



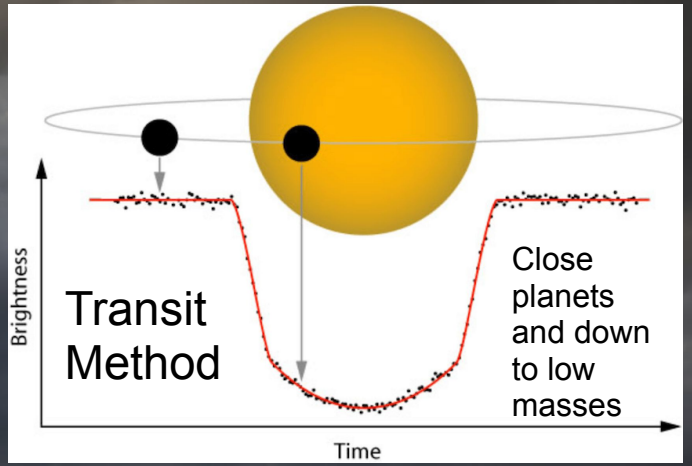
Wide planets and high mass planets

Doppler Method



Close planets and high mass planets

Transit Method



Close planets and down to low masses

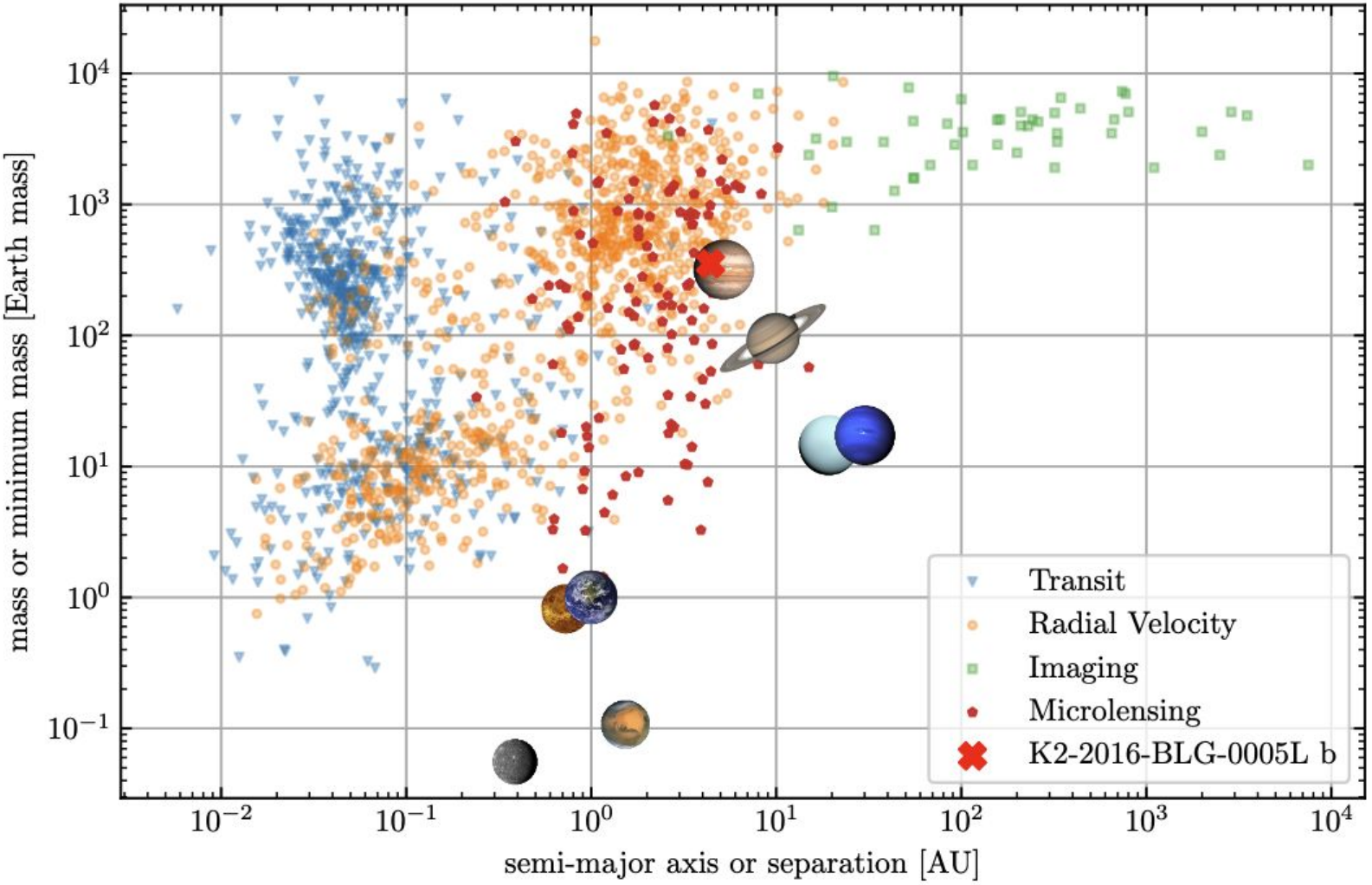


Image credit: Specht et al. 2022

Roman Space Telescope Microlensing

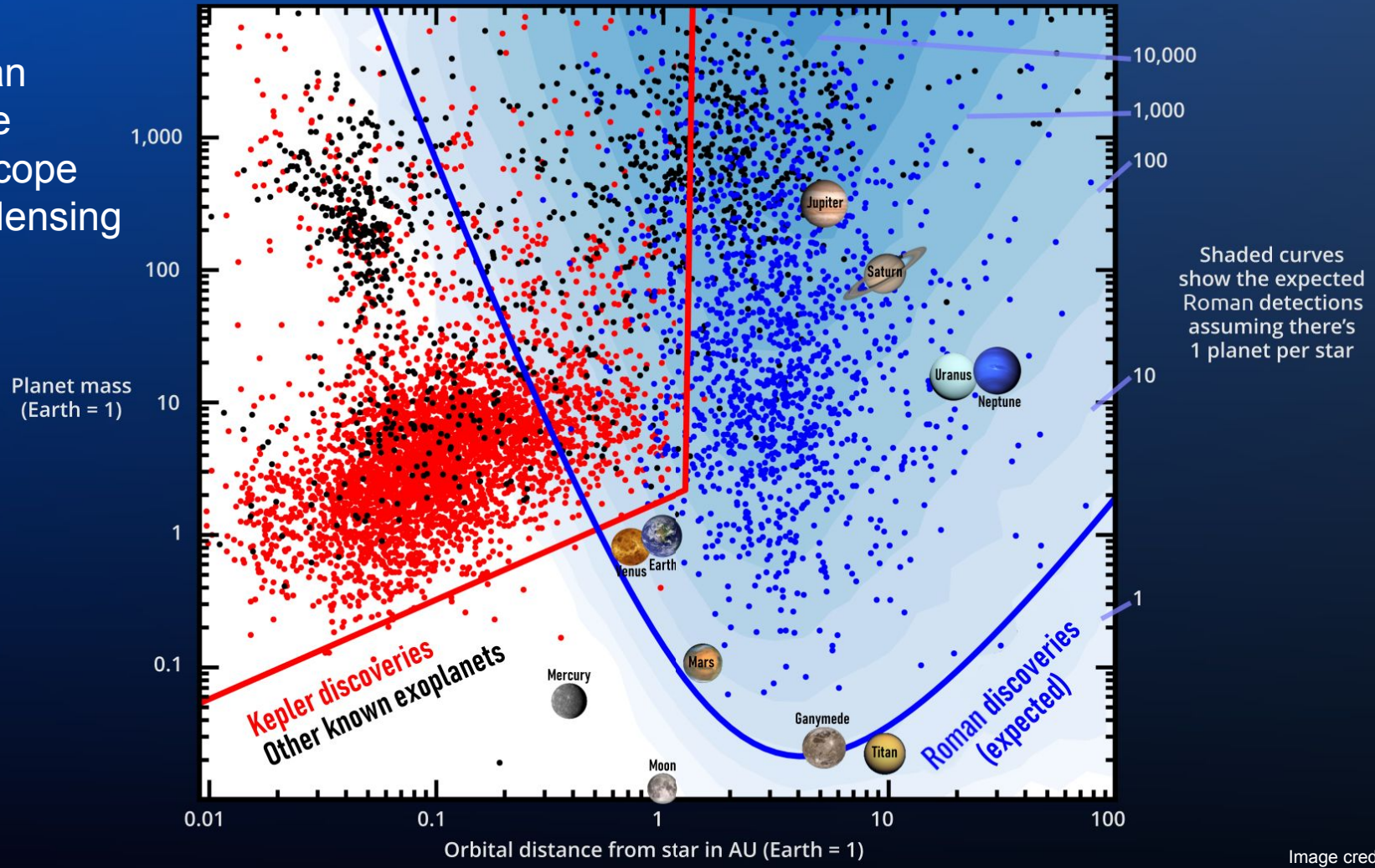
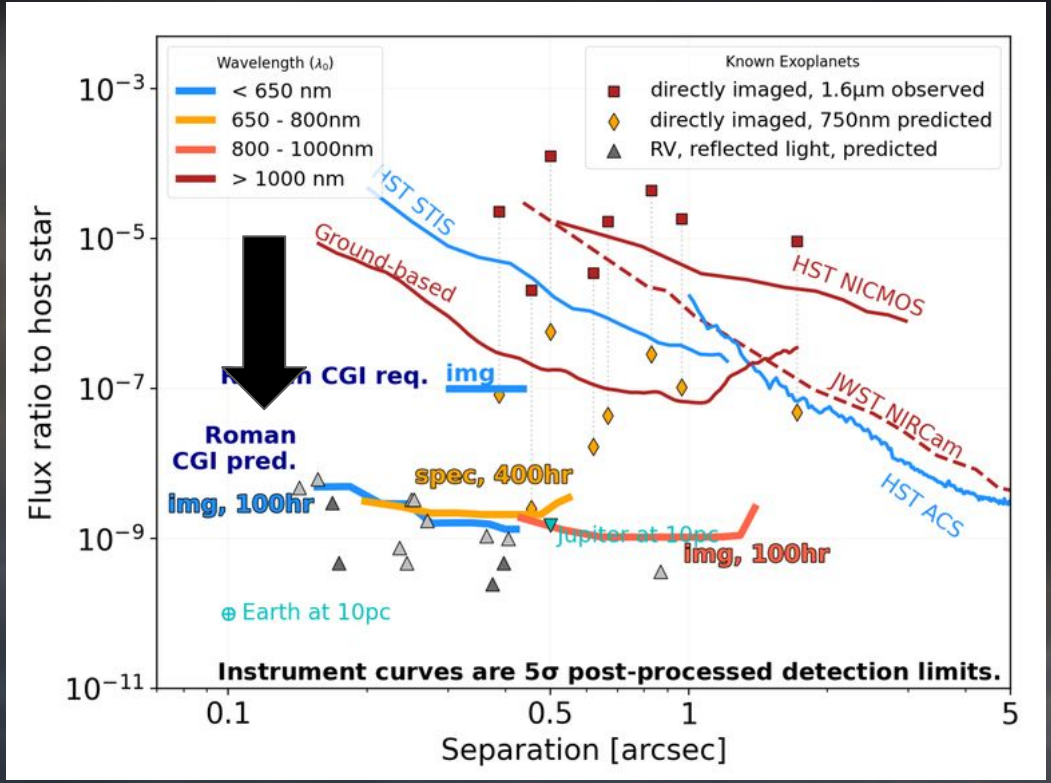


Image credit: NASA

Direct Imaging in the Future

Future telescope like the Nancy Grace Roman Space Telescope and the Habitable Worlds Observatory will try to find more Earth-like planets.



Optional Homework

Let's Make our Own Planet System!
https://stefanom.org/spc/game.php

Learn about the Kepler Space Telescope, the most successful planet finding telescopes ever made:
https://www.youtube.com/watch?v=_V7J05fK5e0

Learn about the Transiting Exoplanet Survey Satellite (TESS), one of the most successful planet finding telescopes ever made:
https://www.youtube.com/watch?v=Q4KjvPIbgMI

Learn about the Nancy Grace Roman Space Telescope and its search for exoplanets:
https://www.youtube.com/watch?v=lNjBQAoLRWs
https://www.youtube.com/watch?v=TM26_fVTNWM