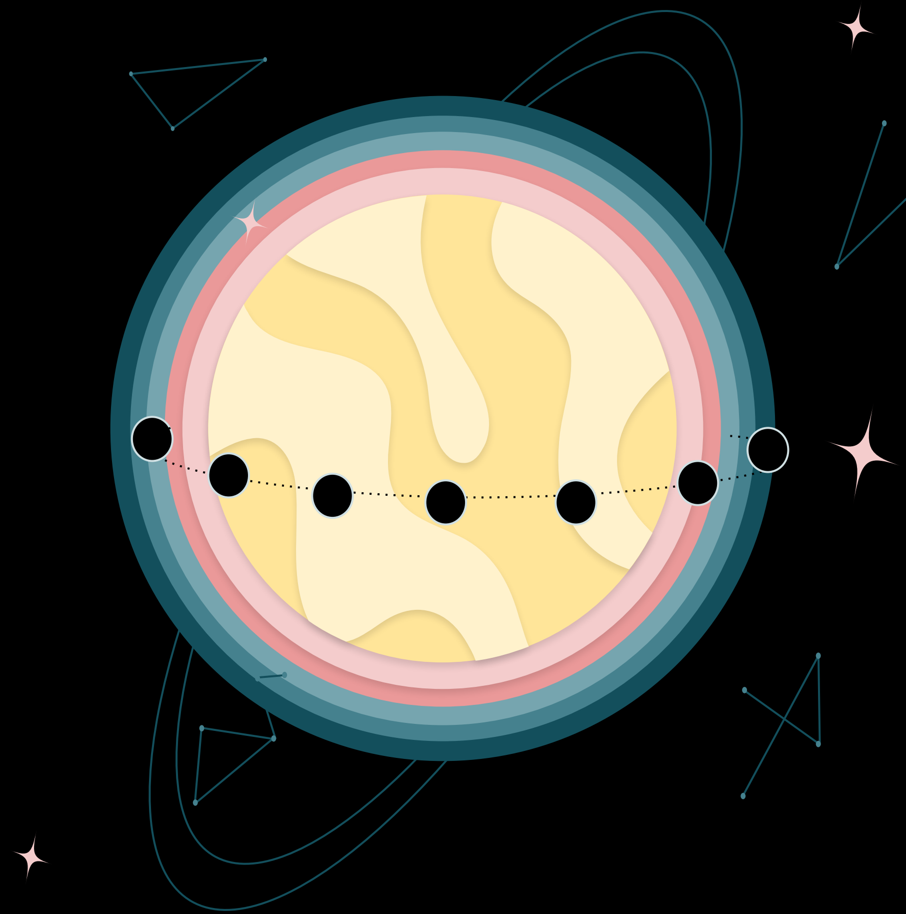
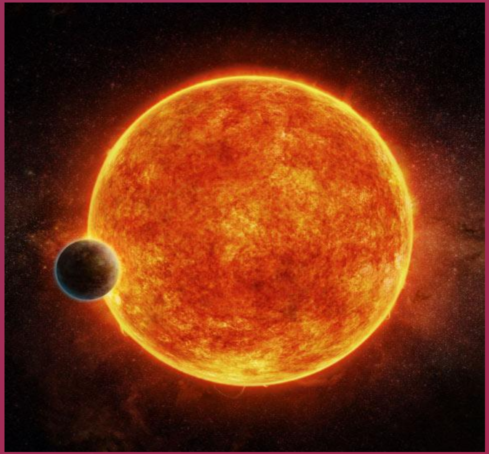


Exoplanet Host Stars

By George Kharchilava, Geet Purohit, and Anish Seth

Background

- Studying exoplanet host stars provides research in star/planet formation, planetary system dynamics, evolution of systems
- Our ability to discover exoplanets correlates with our likelihood of discovering alien life, as it would likely exist on another planet orbiting a star
- The majority of stars in the Milky Way galaxy have at least one orbiting planet
- Rule of planetary systems: Stars are orbited by planets



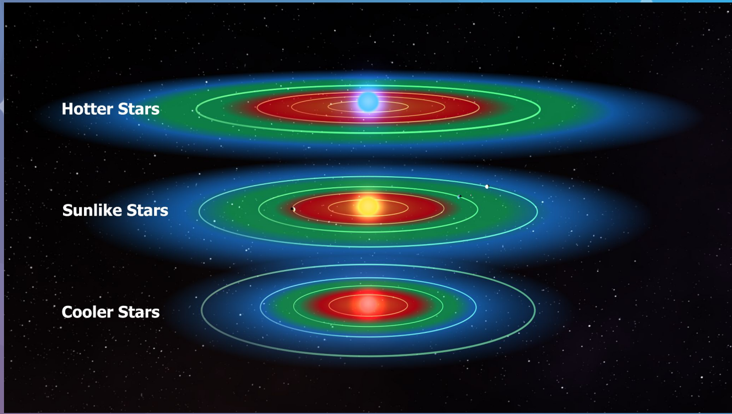
http://cdn.sci-news.com/images/2017/04/image_4792-LHS-1140b.jpg

Background

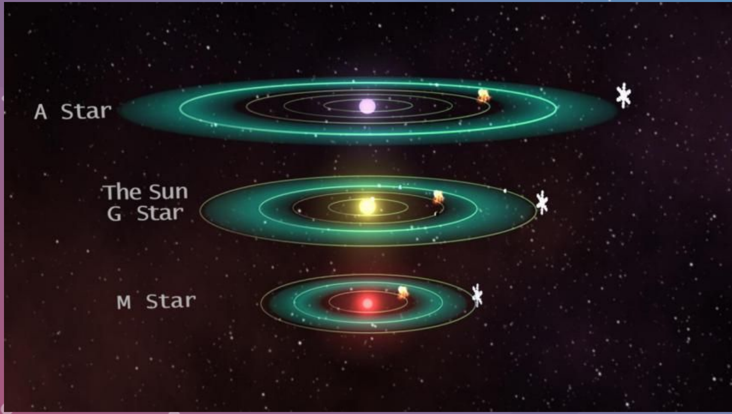
- Observational study of extrasolar planetary systems is a fairly new area of astrophysics
- Instruments capable of detecting the radial-velocity variations of a solar-like star induced by orbiting Jupiter-like planets were built in the 1970s
- These led to the detection of the first extrasolar planet in 1995, a hot Jupiter in a very close orbit around the star 51 Peg
- During the following years, the radial velocity method was the most successful method for planet discovery, with steadily increasing detection numbers
- Until 2002, 60 planets had been detected, and from 2002 to 2010, about 30 to 80 planets per year were detected

Exoplanet Host Stars

- Stars that host exoplanets are usually found with planetary systems
- One or more bound planets per Milky Way star from microlensing observations
- For most of the “observed” exoplanets, most of them orbit Sun-like stars (biased statistic because of KOI)
- There are more planets in large orbits than small, based on observation. Why?
- 1/5th of Sun-like stars have at least 1 giant planet whereas at least 2/5th of Sun-like have a chance of lower mass planets



https://www.physics.uu.se/research/astronomy-and-space-physics/research/planets/exoplanet-hosts/



https://phys.org/news/2015-06-habitable-zone.html

Kepler 22 – Host Star to Kepler 22-b

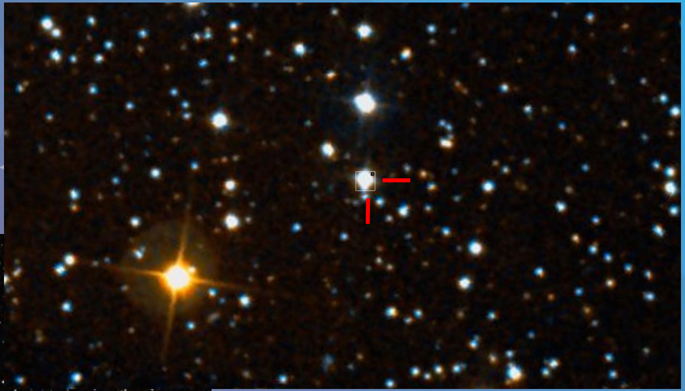
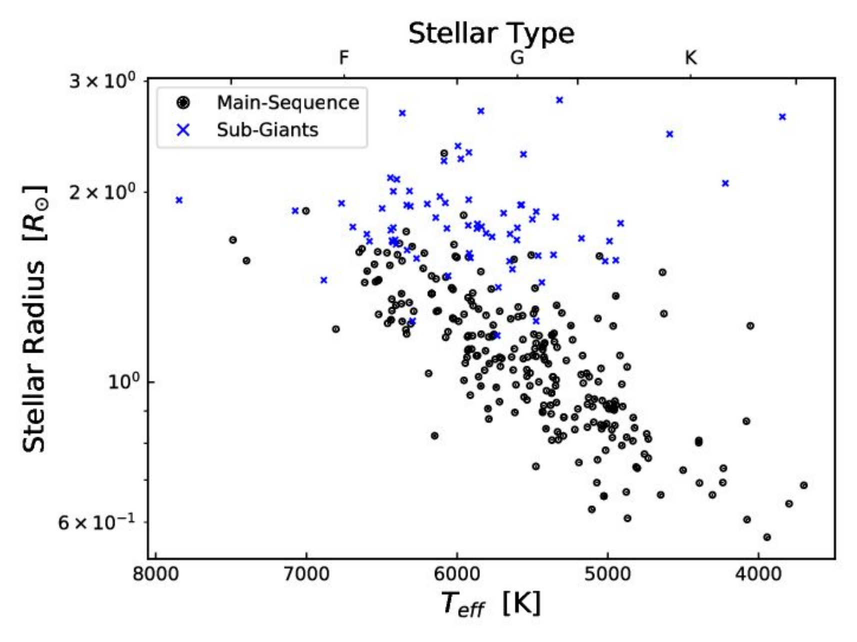


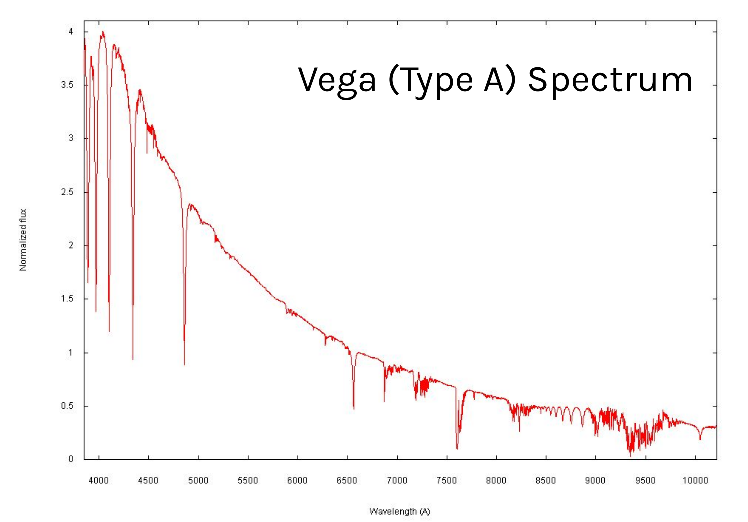
Image Credit - http://www.wikisky.org/

Properties of Exoplanet Host Stars



Known exoplanets' main-sequence stars of spectral categories F, G, K, or M

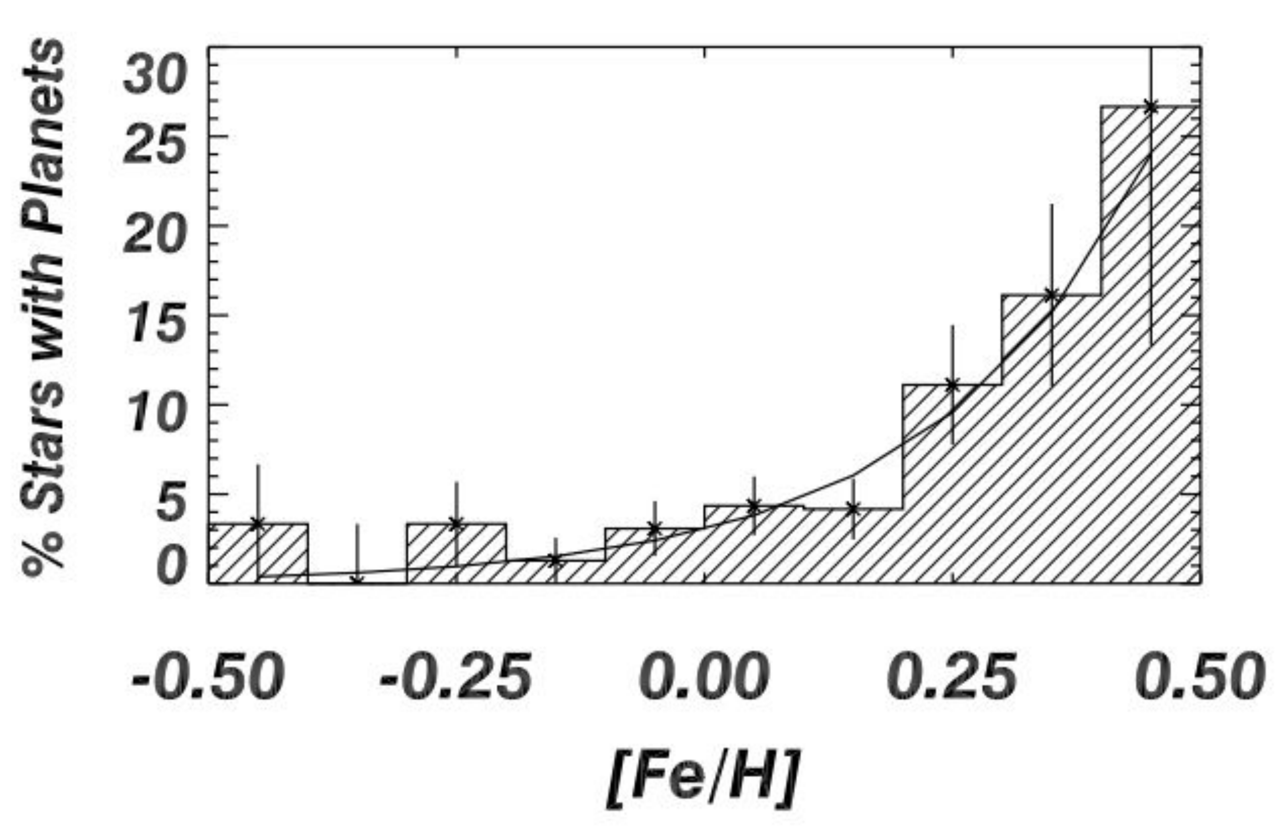
Spectral lines of A type stars are too broad, making it difficult to measure Doppler shifts induced by the orbiting planet(s)



http://www.astrosurf.com/buil/us/vatlas/vatlas.htm

Stellar Metallicity vs. Planet Occurrence

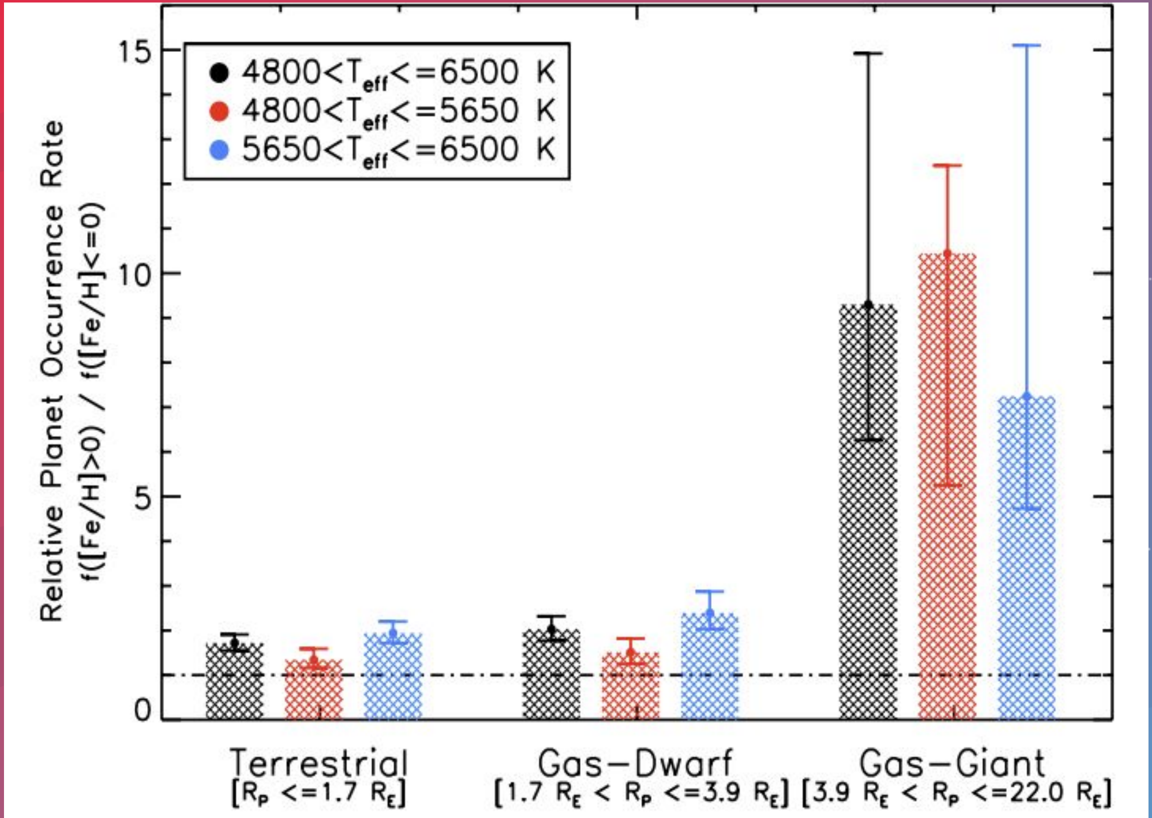
- The greater the metallicity of a star, the more likely it is to have planets orbiting it
- Higher metallicity means there are more heavy elements available to form celestial objects, like planets
- Population III stars only had H and He during their formation, meaning they were much less likely to have exoplanets orbiting them
- Larger exoplanets tend to be found near stars with higher metallicities
- Smaller exoplanets are more commonly found near stars, regardless of metallicity
    - Small exoplanet -> radius less than 3.883 Earth radii (1 Neptune Radius)
    - 6 times more common than large exoplanets in low metallicity stars
    - 3 times more common than large exoplanets in high metallicity stars



$$\mathcal{P}(\text{planet}) = 0.03 \times \left(\frac{(\mathrm{N_{Fe}}/\mathrm{N_H})}{(\mathrm{N_{Fe}}/\mathrm{N_H})_\odot} \right)^2$$

The occurrence of exoplanets vs iron abundance [Fe/H] of the host star measured spectroscopically.21) The occurrence of observed giant planets increases strongly with stellar metallicity.

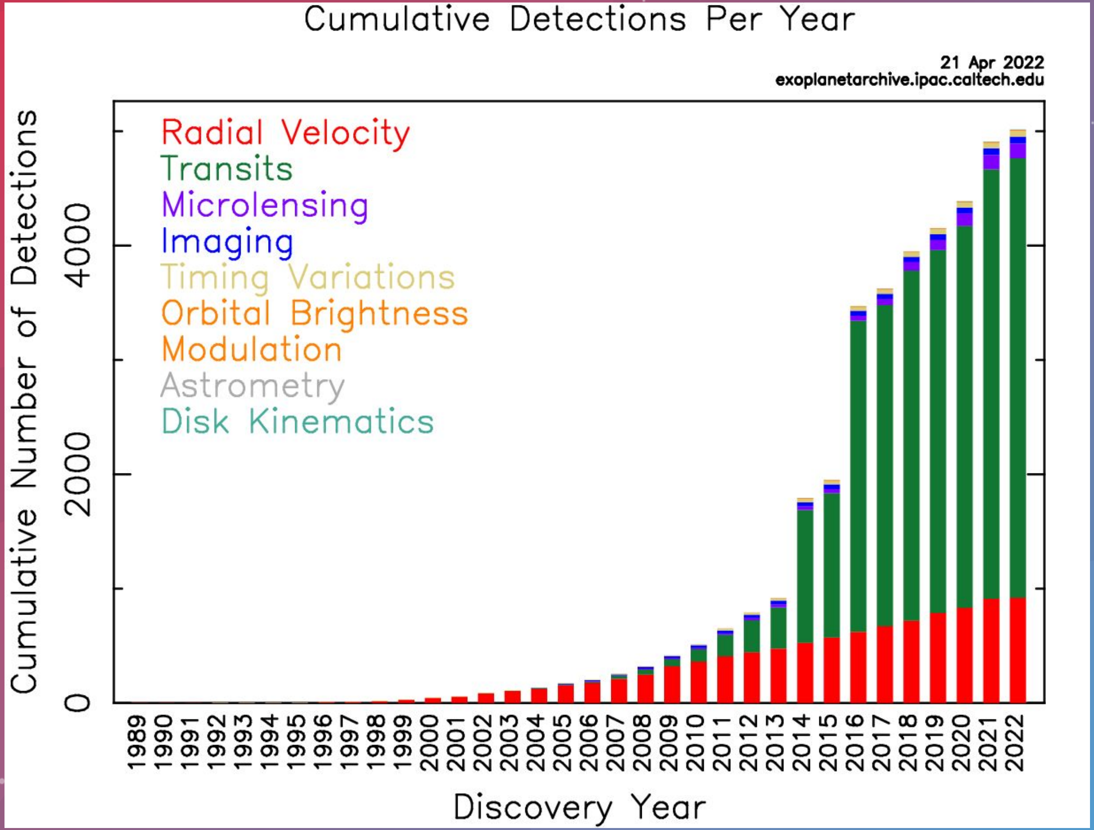
Credit: Marcy et. al., (2005)



The relative planet occurrence rate as a function of planet size. The relative planet occurrence rate is the ratio of the planet occurrence rate for metal-rich stars to metal-poor stars. A value of 1 (dash-dotted line) indicates no metallicity dependence of the planet occurrence rate.

Credit: Wang & Fischer (2009)

Methods of Detection



https://exoplanetarchive.ipac.caltech.edu/exoplanetplots/exo_dischist_cumulative.png

Radial Velocity Method

- Stars are not stationary when things orbit them!
- Objects in orbit both move, and if one is much more massive it will wobble
  - Example: Earth-Moon system
- This wobbling can change the wavelength of light observed from the star
  - Doppler shift: When the star is moving in the direction towards Earth, the light will be blue shifted. If moving away, the light will be redshifted
- Telescopes watch stars for these periodic changes in wavelength in their light
- High-sensitivity instruments:
  - ESPRESSO on the Very Large Telescope
  - EXPRES on the Lowell Observatory Discovery Channel telescope
  - HARPS3 on the Isaac Newton Telescope at La Palma (Under development)

Radial Velocity Method

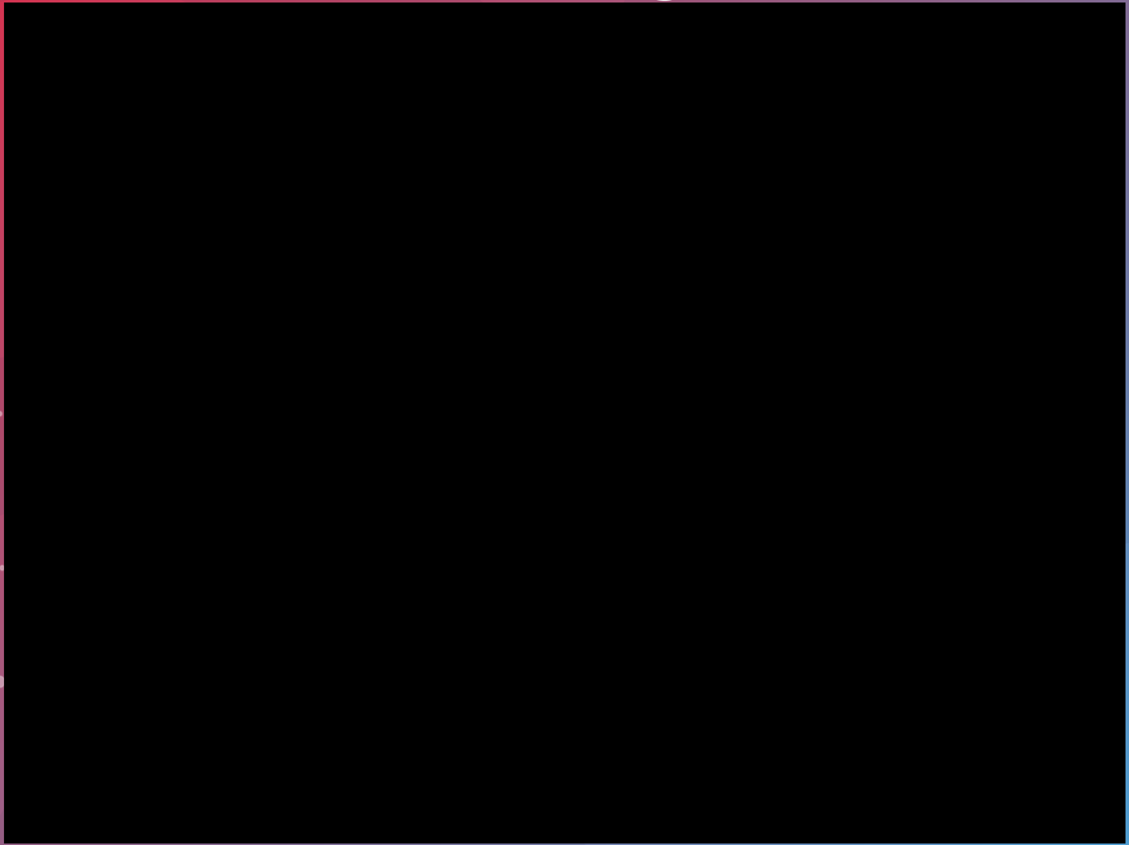


Image credit: NASA https://exoplanets.nasa.gov/resources/2285/radial-velocity/

Transit Method

- More recently, a large number of extrasolar planets have been detected with the transit method using:
  - SuperWASP (Ground)
  - HATNet (Ground)
  - CoRoT (Space)
  - Kepler (Space)
- This method works by measuring the change of light that occurs when a planet passes in front of their host star
- Most prominent method today, owing its success to better modern instrumentation
- Can help determine planetary properties through the light passing through the atmosphere

Transit Method

https://exoplanets.nasa.gov/faq/31/whats-a-transit/#:~:text=Most%20known%20exoplanets%20have%20been,between%20us%20and%20the%20Sun

Gravitational Microlensing Method

- Gravitational microlensing occurs when a massive object (the lens), passes in front of a source of light
  - The lens can be any massive object such as another star, a blackhole, and in this (most) case(s), a planet
  - The source of light is almost always a star, but clusters can also be sources of light
- Once the lens (planet) moves in front of the light source (star), the gravitational influence of the lens will bend the source light
  - The light we would otherwise not see is now adding to the flux!

Gravitational Microlensing Method

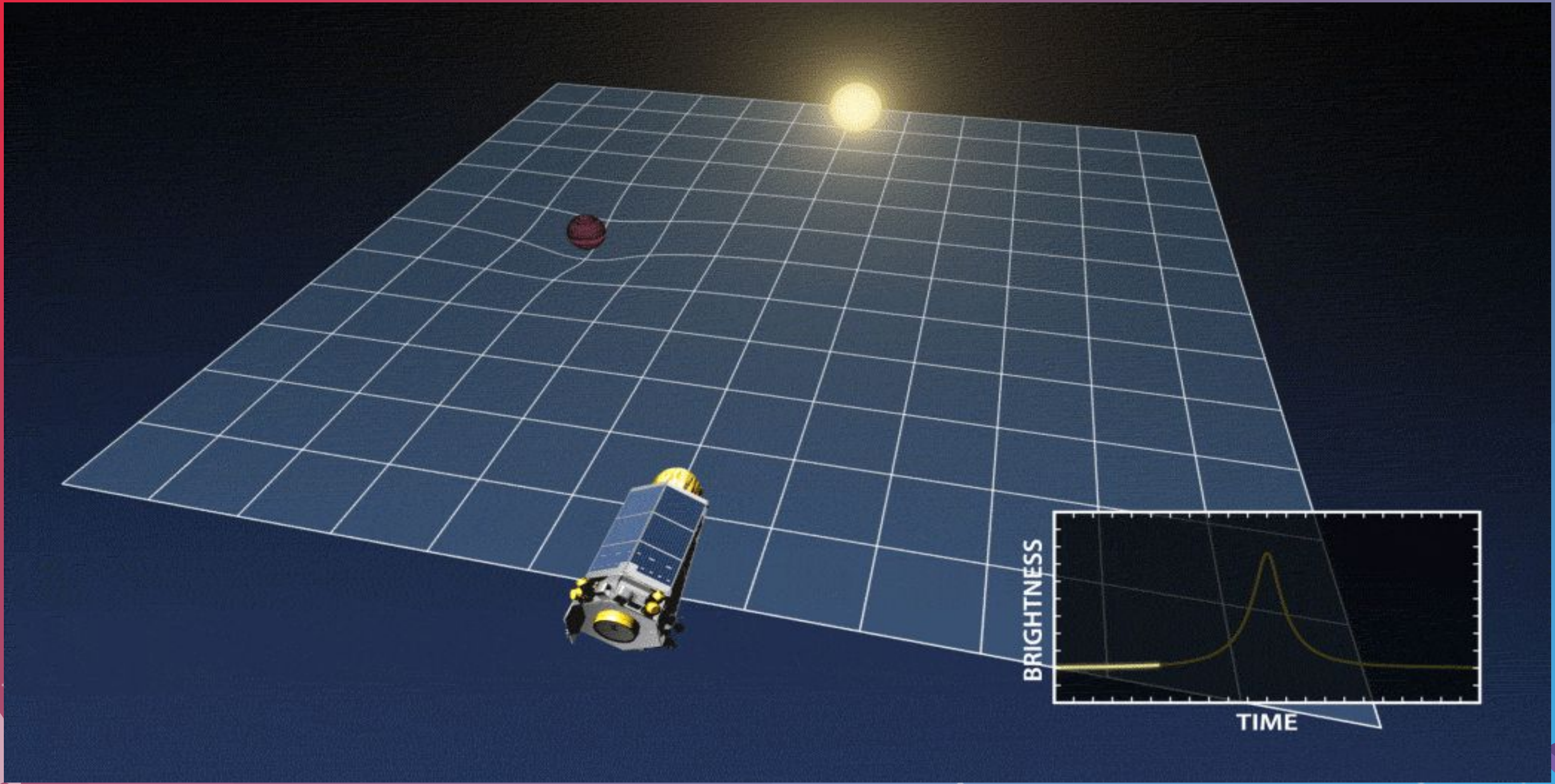


Image credit: NASA Ames/JPL-Caltech/T. Pyle, https://www.jpl.nasa.gov/news/news.php?feature=6314

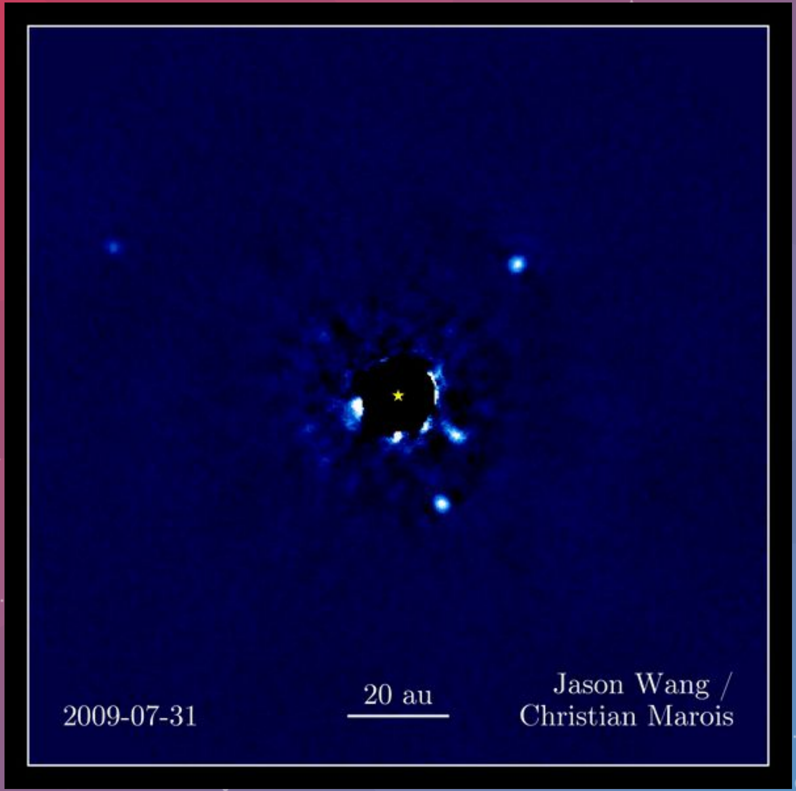
Imaging Method

- Exoplanets can be billions of times dimmer than their host stars
  - How can we image such small cosmic objects?
- By dimming the main light coming from a star, an exoplanet can then be detected through residual light
- This is one of the most difficult methods compared to transit or radial velocity method, as it's primarily used for young stars close by
- Implications of this method however are huge!
  - Can perform spectroscopy on planetary atmospheres
  - Find possible signs of life
  - Helps construct how planetary systems such as the Solar System formed

Imaging Method

https://roman.gsfc.nasa.gov/exoplanets_direct_imaging.html

Imaging Method

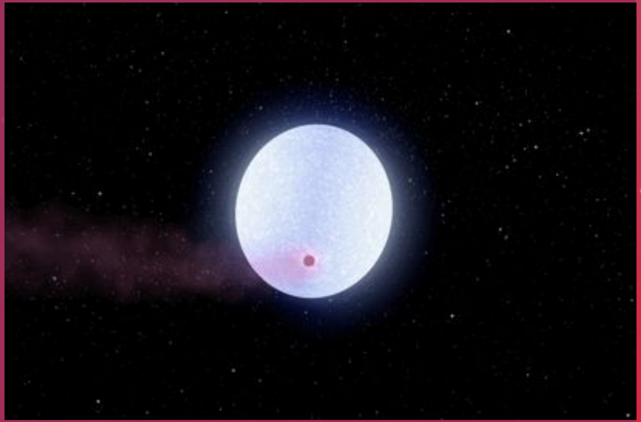


Credit: Jason Wang (Caltech)/Christian Marois (NRC Herzberg)

Four planets orbiting star HR 8799 found using imaging method.

Summary

- A planet orbiting a star makes it a host star
- Precise imaging methods to find exoplanet host stars include Microlensing, Transit, Radial-Velocity, and other minor methods
- Observed exoplanets roughly fall under the spectral categories F, G, K, or M in the Main Sequence
- Higher metallicity stars tend to have more exoplanets
- These precise detection methods, along with the focus on higher metallicity stars, aim to better determine the properties of host stars



References

Cain, F. (2015, June 30). What is the habitable zone? Phys.org. Retrieved April 26, 2022, from https://phys.org/news/2015-06-habitable-zone.html

Cassan, A., Kubas, D., Beaulieu, JP. et al. One or more bound planets per Milky Way star from microlensing observations. Nature 481, 167–169 (2012). https://doi.org/10.1038/nature10684

Color-Shifting Stars: The Radial-Velocity Method. (n.d.). The Planetary Society. https://www.planetary.org/articles/color-shifting-stars-the-radial-velocity-method

Exoplanet host stars. Department of Physics and Astronomy. (n.d.). Retrieved April 26, 2022, from https://www.physics.uu.se/research/astronomy-and-space-physics/research/planets/exoplanet-hosts/

Geoffrey Marcy, R. Paul Butler, Debra Fischer, Steven Vogt, Jason T. Wright, Chris G. Tinney, & Hugh R. A. Jones (2005). Observed Properties of Exoplanets: Masses, Orbits, and Metallicities. Progress of Theoretical Physics Supplement, 158, 24–42.

Johns, D., Marti, C., Huff, M., McCann, J., Wittenmyer, R. A., Horner, J., & Wright, D. J. (2018). Revised Exoplanet Radii and Habitability Using Gaia Data Release 2. The Astrophysical Journal Supplement Series, 239(1), 14. https://doi.org/10.3847/1538-4365/aae5fb

References: The Sequel

MAP.ORG - Interactive Sky Map. SKY. (n.d.). Retrieved April 26, 2022, from http://www.wikisky.org/

Marcy, G., Butler, R. P., Fischer, D., Vogt, S., Wright, J. T., Tinney, C. G., & Jones, H. R. (2005). Observed properties of exoplanets: Masses, orbits, and metallicities. Progress of Theoretical Physics Supplement, 158, 24–42. https://doi.org/10.1143/ptps.158.24

Mugrauer, M., Neuhäuser, R., & Mazeh, T. (2007). The multiplicity of exoplanet host stars. Spectroscopic confirmation of the companions GJ 3021 B and HD 27442 B, one new planet host triple-star system, and global statistics. \aap, 469(2), 755-770.

Nancy Grace Roman Space Telescope. (2016). Nasa.gov. https://roman.gsfc.nasa.gov/exoplanets_direct_imaging.html

NASA. (n.d.). Astronomers find planet hotter than most stars. NASA. Retrieved April 26, 2022, from https://www.jpl.nasa.gov/news/astronomers-find-planet-hotter-than-most-stars

NASA. (n.d.). What's A transit? – exoplanet exploration: Planets beyond our solar system. NASA. Retrieved April 26, 2022, from https://exoplanets.nasa.gov

References: The Finale

NASA. (n.d.). Radial velocity - exoplanet exploration: Planets beyond our solar system. NASA. Retrieved April 26, 2022, from https://exoplanets.nasa.gov/resources/2285/radial-velocity/

Wang, J. (n.d.). Orbit movies. Exoplanet Orbit Movies. Retrieved April 26, 2022, from https://jasonwang.space/orbits.html

Wang, J., & Fischer, D. A. (2014). Revealing a universal planet–metallicity correlation for planets of different sizes around solar-type stars. The Astronomical Journal, 149(1), 14. https://doi.org/10.1088/0004-6256/149/1/14