The Search for Earth-like Planets

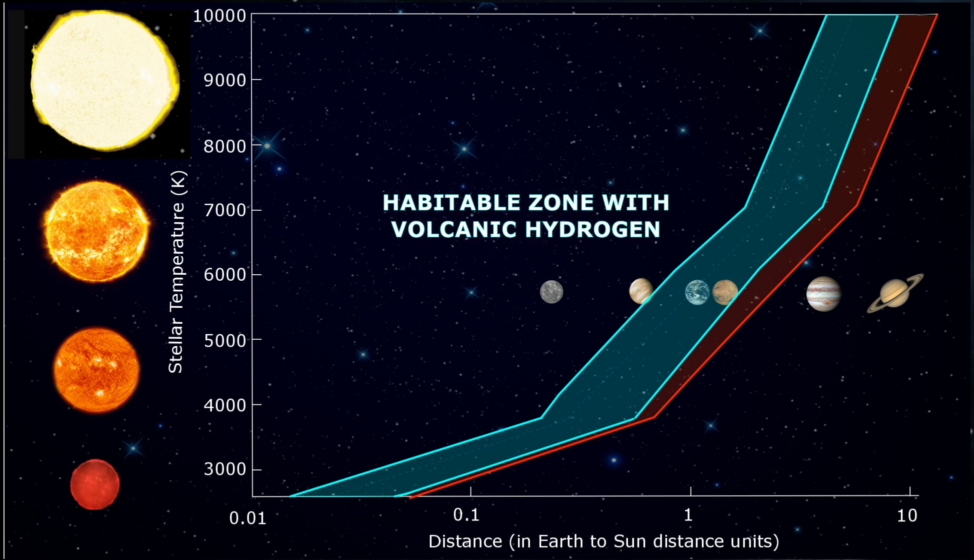
Scott Donald, Kyle Sharpe, Herao Zhang

What Makes an Exoplanet “Earth-like”?

- Is it in the Habitable zone?
- Size?
- Atmosphere?
- Water?
- Orbit and rotation?
- How similar to earth is it required to be?

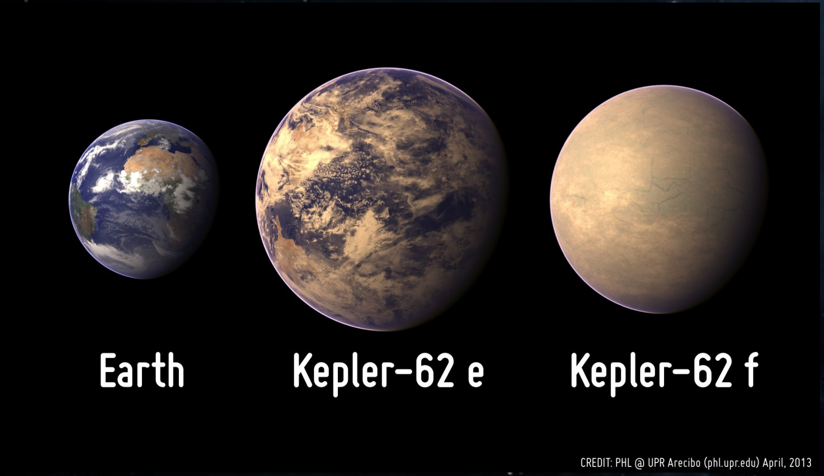
Habitable Zone

- The habitable zone is an area where a planet's orbit falls in the perfect distance from a star.
- This is considered to be close enough to stop ice from covering it, but not so close that it can not support liquid water on its surface.
- It is also considered that earth is in a galactic habitable zone as well, close enough to the center to have heavy elements from stellar explosions, but far enough away to avoid excessive gamma radiation.



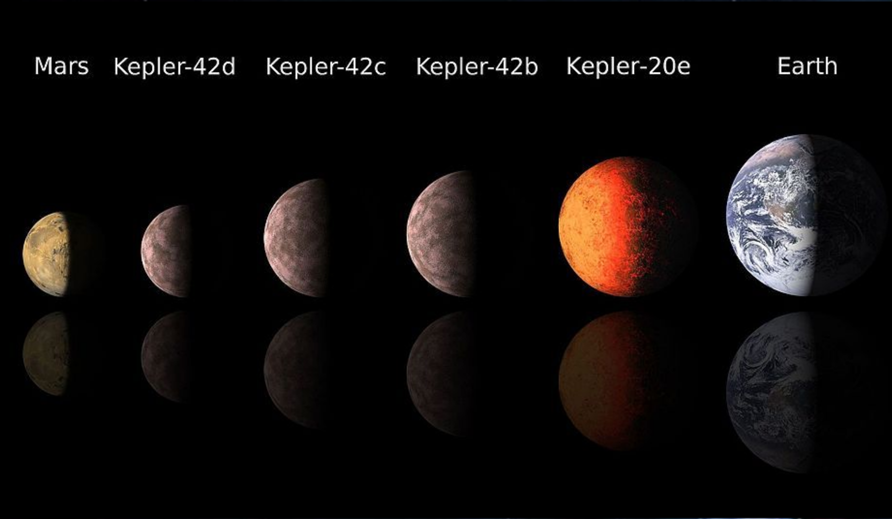
Super-Earth Size Planets

- Are up to approximately 10 times the mass of earth.
- The gravity and plate tectonics on these planets will be intense and cause a thicker atmosphere.
- This suggests the habitable zone for larger planets is pushed farther from their star.
- The intense gravity can also cause too many inhospitable gases from early solar system development to be trapped in their atmosphere.



Sub-Earth Size Planets

- Range from 0.15 - 0.8 times the radius of earth.
- The low gravities of these planets make the development and retention of an atmosphere very difficult.
- This is caused by the escape velocities of particles being too low and they are eventually lost to space.
- With small surface to volume ratio, these planets tend to end up geologically dead, due to lack of volcanic and tectonic activity.

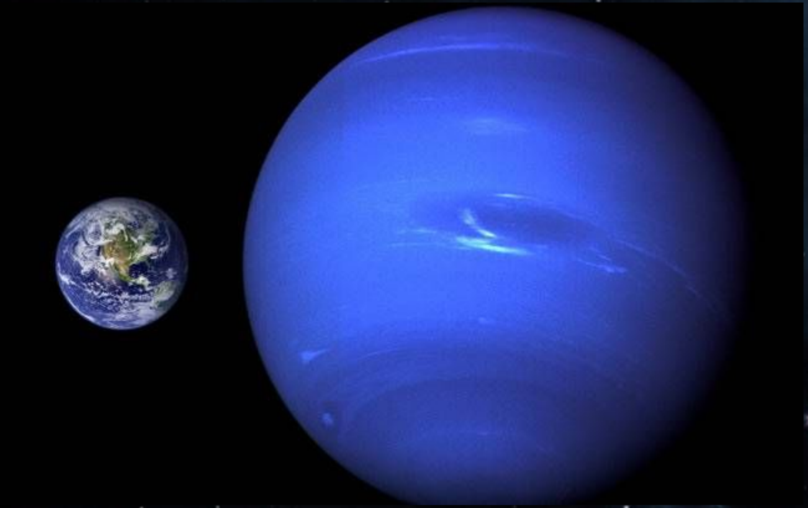


Atmosphere

- Due to eukaryotes developing and evolving processes such as photosynthesis.
- This took the stores of CO_2 that were created by volcanic activity and released oxygen.
- Ocean and land plants developed and pulled CO_2 out of the air.
- A global carbon cycle developed
- This kept surface temperatures in a regular range.
- Allowed earth to retain large volumes of water.

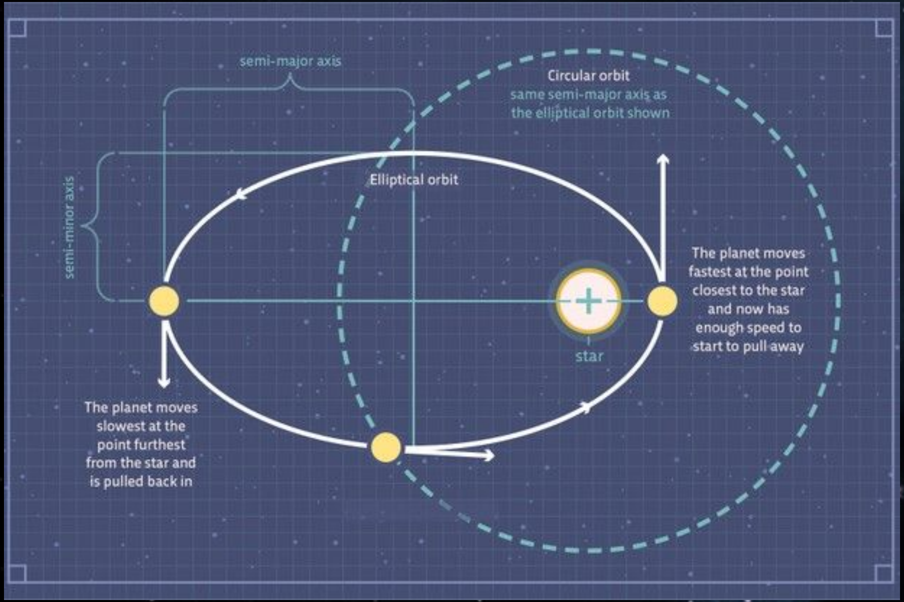
Water

- There are a few types of water retaining planets that may hold or have held life.
- Those such as earth with oceans and sunlight that may develop a carbon cycle.
- Planets like Mars or Venus that possibly had water, but low atmospheric pressures can not retain water on the surface as it becomes a gas at less than 608 Pa.
- Some planets on the farther edge of the habitable zone may be able to have liquid water under a frozen layer. This sub-layer of water is kept liquid by geothermal heat.
- There is no light in these oceans, but life has proven this is not a necessity for existence.



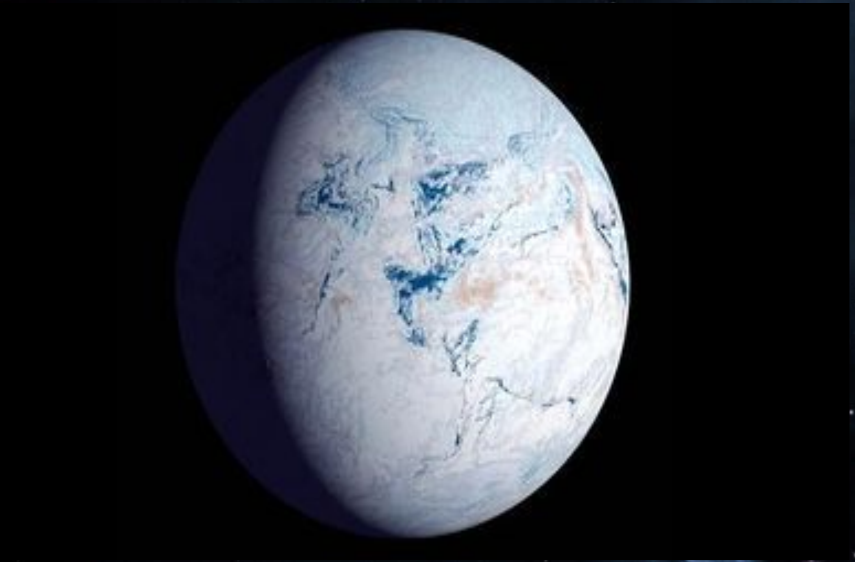
Orbit

- Earth's orbit is nearly circular, which limits it's seasonal changes.
- An elliptical orbit will increase these fluctuations and may put them across the freezing and boiling temperatures of water on the surface.
- The elliptical orbit will cause the planet to spend too much time outside the habitable zone for life to survive.
- Data collected on extrasolar planets shows that 90% of them have a much more elliptical orbit than earth.



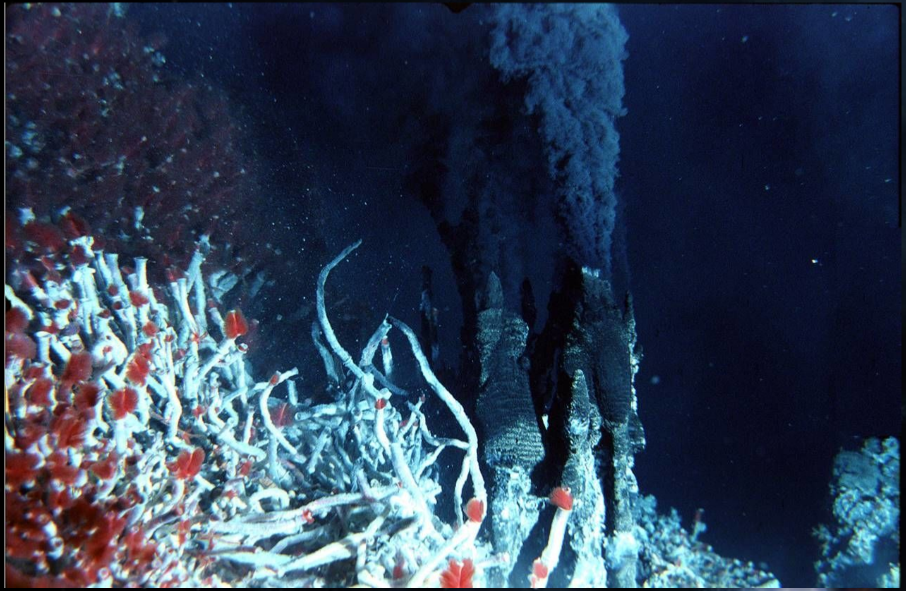
Rotation

- The earth has a tilt rotation of approximately 23 degrees, this allows for the moderate and survivable seasons.
- If the earth had less tilt and the highest intensity radiation only changed within a few degrees of the equator, the heat could not travel to the poles and cold polar weather would dominate the planet.
- The day length could not vary too much in duration either, for example if the days were months or years long, the extreme changes in temperature this would cause, could not harbour life.



How Similar Does the Planet Have to Be?

- Extremophiles living on earth in hydrothermal vents over 100 degrees celsius and acidophiles living in such low pHs, demonstrate just how versatile and adaptable life is.
- The discovery of new life on earth gives hope and expands what we see as the habitable zone.
- We have created the building blocks for life in a laboratory setting, showing that the process is not so unlikely to exist outside our solar system.
- Maybe our view on what life is capable of, is not nearly complete yet.



Earth Similarity Index (ESI) proposed by Schulze Makuch in 2011

- ESI is characterizing how similar a planetary-mass object or natural satellite is to Earth
- Computed with physical parameters: radius, density, escape velocity and surface temperature
- Range from 1 (Earth) to 0 (totally dissimilar to Earth)

x_I can be any planetary property

x_{I0} is the corresponding Earth value

n is the number of properties

w_I is the weighting exponent

$$\mathrm{ESI} = \prod_{i=1}^{n} \left(1 - \left|\frac{x_i - x_{io}}{x_i + x_{io}}\right|\right)^{\frac{w_i}{n}}$$

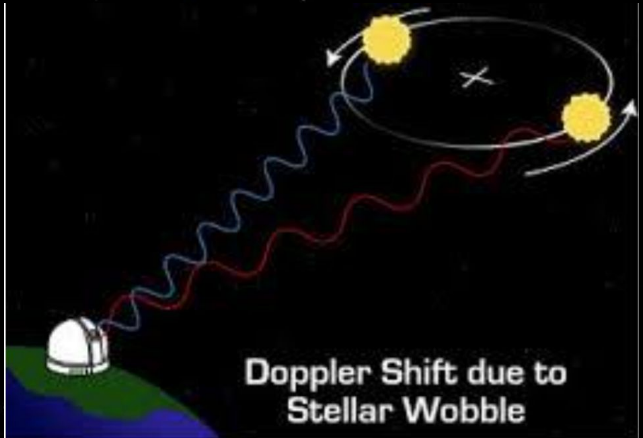
Methods for searching exoplanets

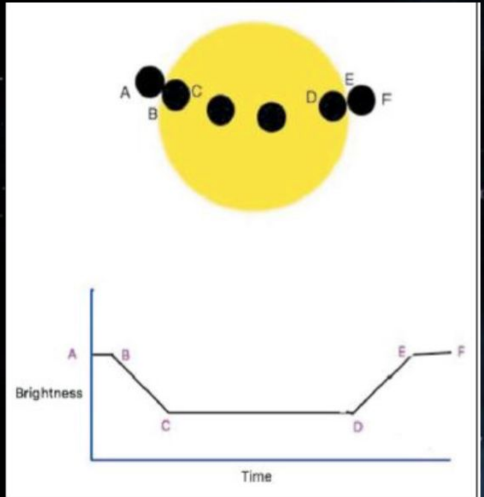
- **Radial Velocity (Doppler Technique)**

  Doppler shift technique is one of the popularly used methods to detect exoplanets and to estimate their physical parameter

- **Transit Technique**

  When the planet passes between a star and an observer, the star's apparent brightness decreases.



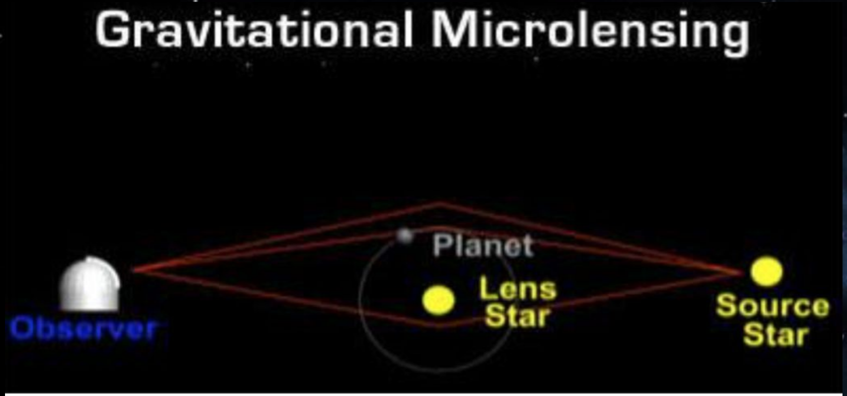


- **Microlensing Technique**

When light from distant star passes near a massive object, it bends. The gravity of the massive object acts like a lens, which results in sudden increase in the brightness.

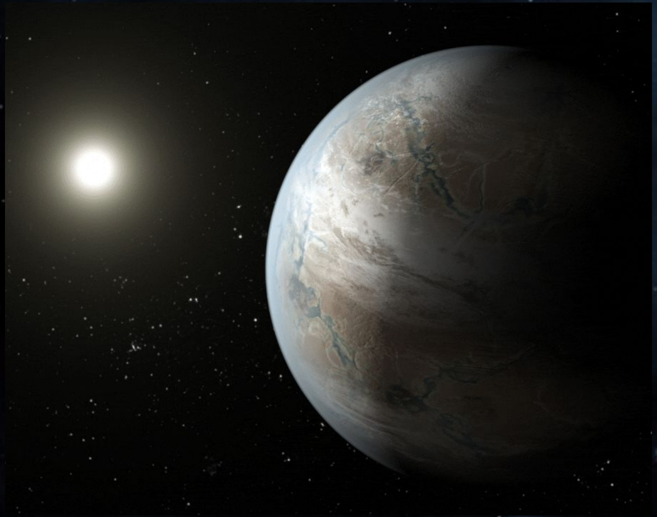
- **Direct Imaging Technique**

This technique is based on direct observation of light from planets. But it has difficulty due to the intense glare of the star when the distance between planet and host star is very close. Recently a few exoplanets have been imaged directly, which are far away from their host stars (distance of 10–30 AU or more) blocking the star light using a Coronagraph.



Methods for Finding Earth-like Planets

- Space telescopes using indirect methods such as light transit photometry dominate the search; land based direct observations are limited to Jupiter sized planets in distant orbits to their stars.
- The search for “Earth-like” planets begins with the more general exoplanet.
- Once an exoplanet is confirmed, the determination of whether it is located in a habitable zone can be made. Data analysis is time consuming and ongoing.

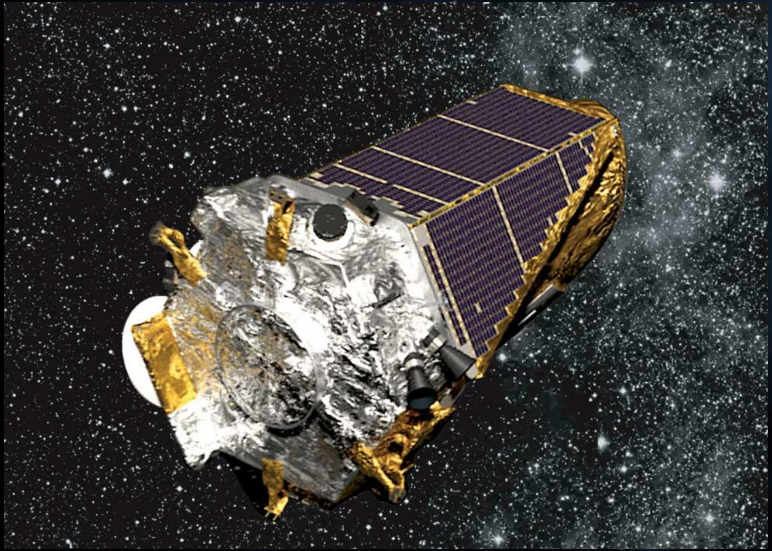


NASA LBTI Ground Based Telescope

- “Large Binocular Telescope Interferometer”
- Funded by NASA, but operated and designed by University of Arizona.
- Utilizes two 8m telescopes to detect exoplanets from Earth.
- Utilizes interferometry, which involves superimposing waves in order to produce higher resolution images.
- Same technology that was used to image the recent black hole, but on much smaller scale.

NASA Kepler Space Telescope

- Launched in 2009. And observed one small patch of the sky for four years, identifying ~150,000 stars and more than 2,000 exoplanets.
- Utilizes transit photometry to indirectly detect distant planets.
- Main mission ended in 2013 with the failure of two reaction wheels. The telescope was renamed K2 and continues to discover exoplanets.
- Vast majority of exoplanets discovered by Kepler Space Telescope.

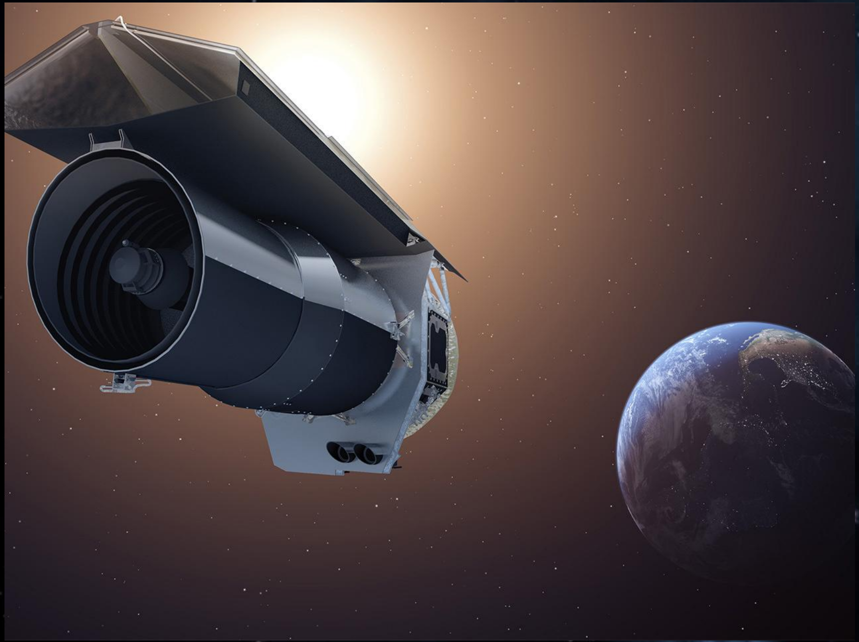


CNES & ESA CoRoT Space Telescope

- “Convection, Rotation, and planetary Transits.”
- Launched in 2006 and continued to function until 2013, well past its nominal lifespan.
- Led by French Space Agency with significant contributions from European Space Agency. As well as Austria, Belgium, Germany, and Brazil.
- Primary method used to detect exoplanets is light transit photometry.
- Named for French landscape painter Jean-Baptiste-Camille Corot.

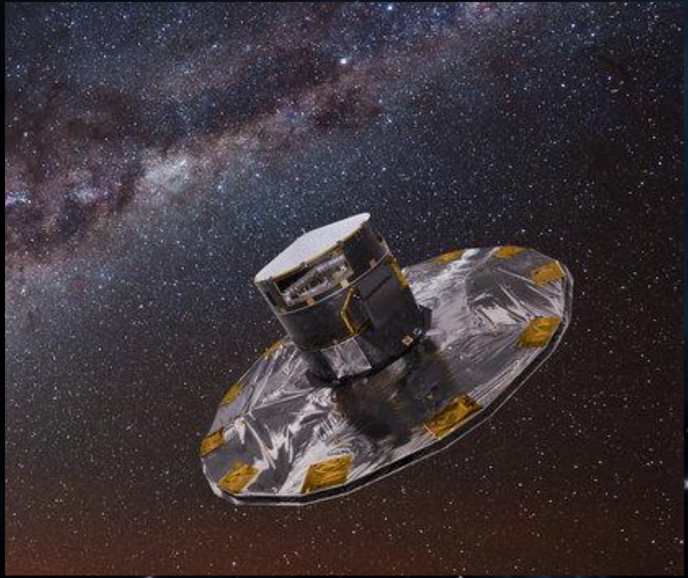
NASA Spitzer Space Telescope

- Launched in 2003, uses infrared to detect distant objects that would be too faint to observe in the visible spectrum.
- First spacecraft to fly in Earth-trailing orbit. This allows for a wider view than Earth-orbiting telescopes such as Hubble.
- Original requirements called for only 2.5 years of operation, but the telescope continues to function in its “Beyond” stage.
- Paved the way for NASA’s future James Webb Space Telescope, which is set to launch in 2021.



ESA GAIA Space Observatory

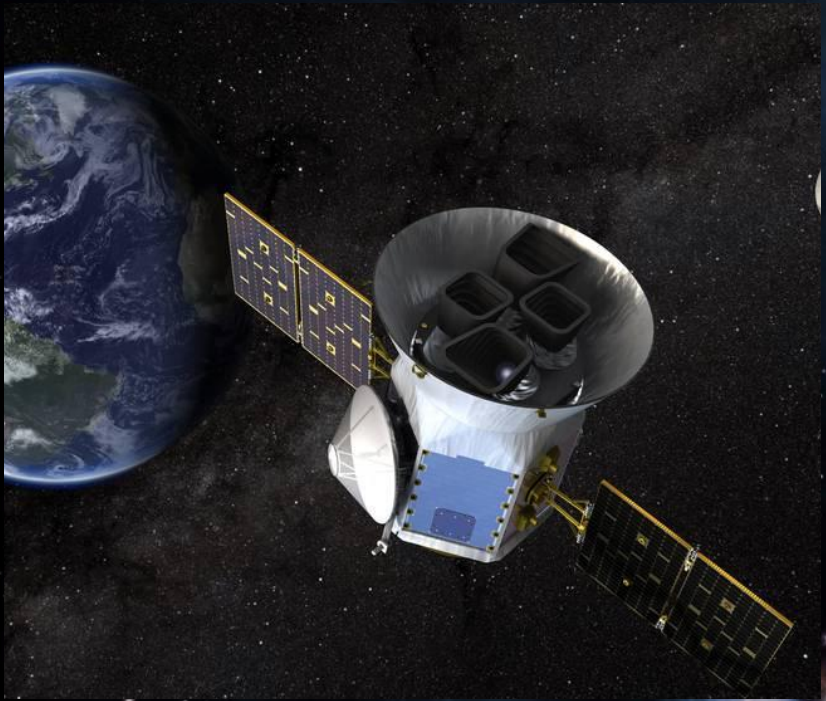
- “Global Astrometric Interferometer for Astrophysics” Acronym stuck after interferometry was excluded from mission plan.
- Original mission was to create a 3D map of Stars in the galaxy
- Recording the motion, lumosity, temperature and composition of stars.
- Exoplanet discovery through light transit method is a side-product of the multitude of observations recorded.



http://sci.esa.int/gaia/58784-exoplanets/

NASA TESS Space Telescope

- “Transiting Exoplanet Survey Satellite”
- Specifically built to discover exoplanets smaller than Neptune, which are the ones that Kepler has trouble detecting.
- Launched in April, 2018, and began its 2 year primary mission in July, 2018.
- Kepler surveyed ~0.25% of night sky, compared to ~85% in TESS mission (400x)
- Stars observed 30x-100x brighter than Kepler, to allow for easier follow-up work.
- As of January 2019, 3 confirmed exoplanets, as well as ~280 potential candidates.



JWST/WEBB Space Telescope

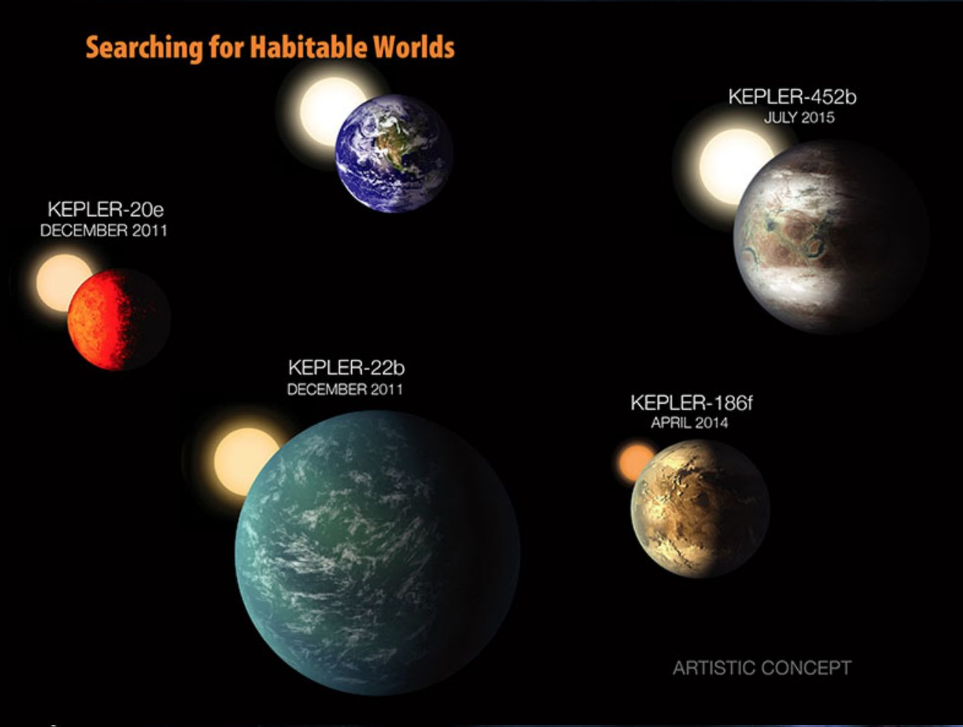
- International collaboration between NASA, ESA, and CSA. Managed by NASA Goddard Space Flight Center.
- “James Webb Space Telescope”
- Unprecedented infrared sensitivity, will be able to look back 13.5 billion years at the formation of early galaxies
- Planned launch in 2021, described as the “successor to Hubble Space Telescope”
- Has a totally sweet 6.5m primary mirror that is made up of 18 separate segments that orient themselves post-launch

Looking Toward the Future: Direct Imaging

- JPL prototype coronagraph or "starshade" meant to block distant star's light so a direct observation can be made of exoplanets.
- Unfurls to the size of a baseball diamond while a telescope tens of thousands of miles away directly captures images of planets orbiting a star.
- Proven effective using land based telescopes, but this will be on a much larger scale.

NASA Kepler mission

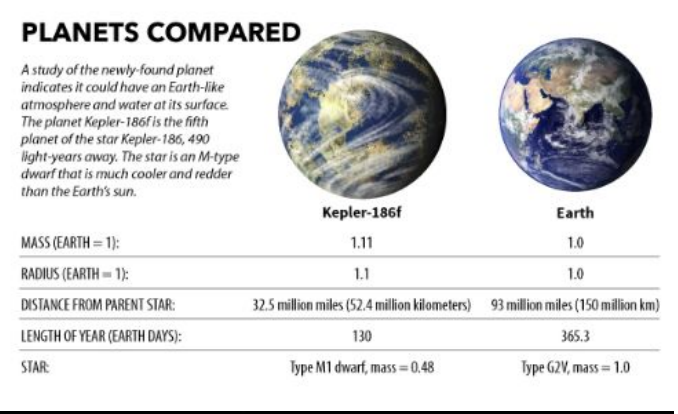
- Kepler-20e orbiting a Sun-like star slightly cooler and smaller than our sun every six days. BUT it is scorching hot and unable to maintain an atmosphere or a liquid water ocean
- Kepler-22b BUT unlikely to have a solid surface.
- Kepler-186f the first Earth-size planet found in the habitable zone of M dwarf
- Kepler-452b the first near-Earth-Size planet in the habitable zone of a star very similar to the sun

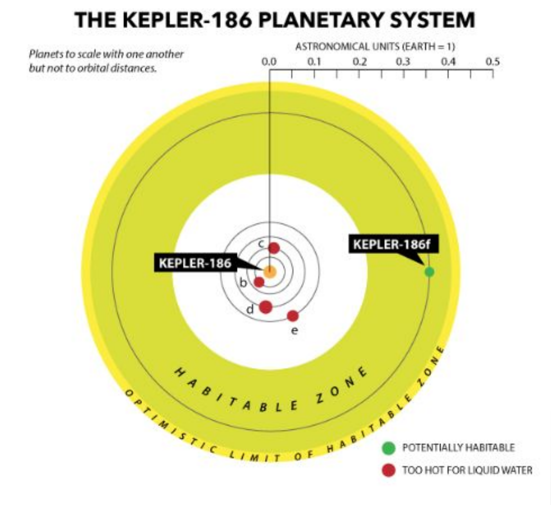


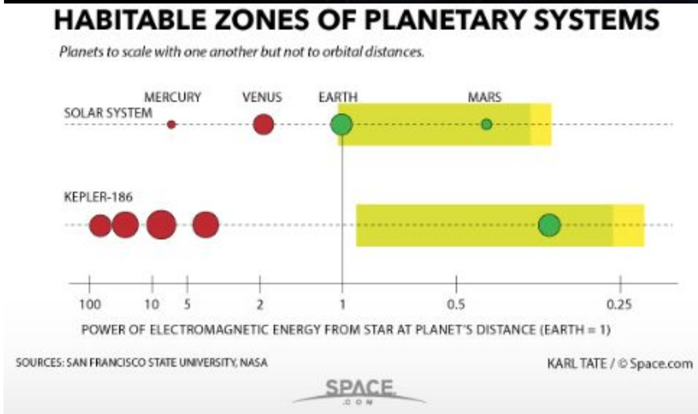
Kepler 186f ‘Earth’s cousin’

Kepler-186 is 500ly from Earth in the constellation Cygnus

- an exoplanet orbiting the red dwarf Kepler-186
- Orbits once every 130-days
- Receives one third the energy from its star that Earth gets from sun







References

1. https://www.nasa.gov/mission_pages/kepler/overview/index.html
2. http://sci.esa.int/corot/
3. https://www.nasa.gov/mission_pages/spitzer/main/index.html
4. http://sci.esa.int/gaia/58784-exoplanets/
5. https://exoplanets.nasa.gov/news/1542/nasas-tess-rounds-up-its-first-planets-snares-far-flung-supernovae/
6. https://jwst.nasa.gov/index.html
7. http://nexsci.caltech.edu/missions/LBTI/
8. https://exoplanets.nasa.gov/resources/1015/flower-power-nasa-reveals-spring-starshade-animation/
9. https://www.nasa.gov/ames/kepler/kepler-186f-the-first-earth-size-planet-in-the-habitable-zone
10. http://www.sci-news.com/astronomy/kepler-62f-186f-exoplanets-stable-climate-regular-seasons-06149.html
11. http://www.sci-news.com/astronomy/kepler-62f-186f-exoplanets-stable-climate-regular-seasons-06149.html
12. http://www.sci-news.com/astronomy/kepler-62f-186f-exoplanets-stable-climate-regular-seasons-06149.html
13. https://arxiv.org/pdf/1801.07101.pdf
14. https://www.youtube.com/watch?v=PxG66QMd4wE
15. https://www.space.com/28312-earth-like-planets-recipe.html
16. https://www.iflscience.com/space/what-makes-one-earth-planet-more-habitable-another/