The Search for Extraterrestrial Life

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What Makes a Planet Habitable?

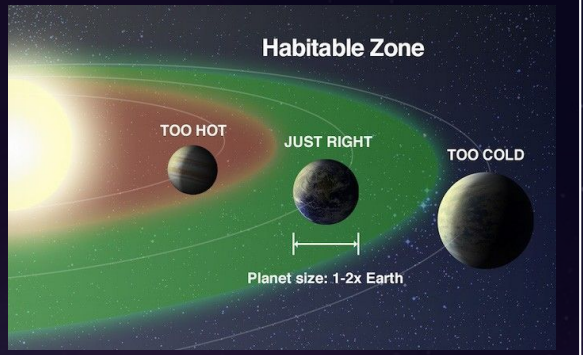

Figure 1: Goldilocks Zone. Retrieved from: https://science.nasa.gov/exoplanets/habitable-zone/

Within the Habitable Zone

- Planet must orbit within the habitable zone
- Distance from star where it's not too hot or too cold
- Distance liquid water can exist
- Too close → water boils
- Too far → water freezes [2]

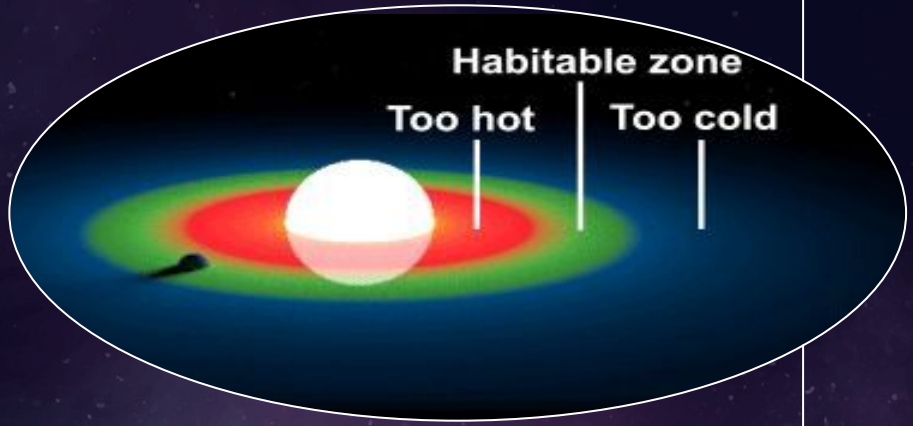

Figure 2: Planet orbiting in the habitable zone. Retrieved from https://centerplanetarysciences.org/astrobiology/habitable-zones/

Liquid Water

- Water is essential for life

1. Acts as a solvent
    - Dissolve a variety of substances
    - Provides a medium where substances can mix and interact efficiently
2. Water supports complex structures like cells and proteins
3. Keeps temperature stable
    - Water has high heat capacity …. Can absorb and store heat without changing temperature too much
    - Helps prevent extreme temp swings that could destroy complex molecules needed for life [7]

Figure 3: Picture of lake. Retrieved from https://www.tripadvisor.ca/Attraction_Review-g154917-d207490-Reviews-Horseshoe_Lake-Jasper_National_Park_Alberta.html

Breathable/Suitable Atmosphere

- **A “breathable” atmosphere on an exoplanet doesn’t just mean “has oxygen”—it’s a combination of chemistry, pressure, temperature, and long-term stability that allows complex life (like us) to survive. What we look for is:**
    - Correct gas composition (Oxygen, Nitrogen, Carbon Dioxide)
    - Enough oxygen (21%) … too little (<10%) = suffocation risk … too much (30%) = highly flammable environment
    - Nitrogen – acts as stable background gas to dilute oxygen
    - Trace gases like carbon dioxide help regulate temperature
    - Non-toxic environment … Carbon monoxide (CO) can be deadly, sulfur dioxide (SO_2) toxic and corrosive, thick methane (CH_4) or ammonia (NH_3) atmospheres are incompatible with human biology (likely to be incompatible with other biology as well) [2]

Figure 4: Astronaut holding helmet. Retrieved from https://www.freepik.com/premium-photo/male-astronaut-taking-his-helmet-off-space-mission-unknown-planet_21872940.htm

Magnetic Field

- Deflects charged particles from stellar wind
- Prevents atmosphere from being stripped away
- Protects surface life from harmful radiation [4]

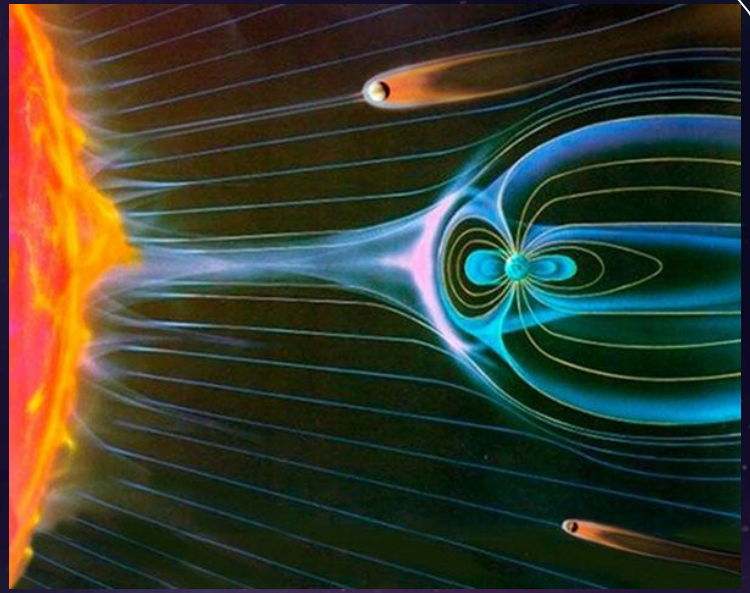

Figure 5: Magnetic field blocking stars solarwinds. Retrieved from https://www.astronomy.com/science/earths-magnetic-field-provides-vital-protection/

Stable Temperature and Climate & Stable Star

- Needed to maintain liquid water
- (As we talked about) Supports life's chemical processes
- **Time for evolution:**
  - Life requires stable conditions over millions or billions of years to grow from simple microorganisms to more complex organisms
  - A planet with wild climate swings would likely kill off emerging life before it could develop
- Stable stars help planets retain atmospheres
- Provide consistent energy and temperature
- Unstable stars:
  - Produce strong flares
  - Can strip atmospheres
  - Can destroy ozone → harmful UV exposure
- Types of unstable stars:
  - Variable (pulsating) stars
  - Young stars still forming
  - Old stars in late life stages [6]

Figure 6: Picture of the sun.. Retrieved from https://science.howstuffworks.com/sun.htm

Suitable Gravity

- Too little gravity:
  - Atmosphere escapes
  - Water may be lost with it or frozen
- Too much gravity:
  - Harmful to humans (blood flow pulled to legs, bone stress)
  - Could pin organisms down
- Life in high gravity:
  - Likely short, compact , with thick skeletons [1]

Figure 7: Flat man laying on the road. Retrieved from https://www.gettyimages.se/search/2/image?phrase=flat%20people&sort=mostpopular&license=rf%2Crm

Orbital Stability

- Orbit should be **nearly circular**
- Smaller planets in the habitable zone can be effected by gravity of giant planets
- If highly elliptical - can pull smaller planets in and out of the habitable zone
- Effects of instability:
    - Wild climate swings [5]

Figure 8: Picture of planets orbiting star. Retrieved from https://www.gettyimages.se/search/2/image?phrase=planet%20orbit%20&sort=mostpopular&license=rf%2Crm

Stable Rotational Axis

- Not required for simple life
- Important for **complex life**
- Provides:
  - Stable, predictable climate
  - Consistent seasons
  - Fewer extreme environmental changes [3]

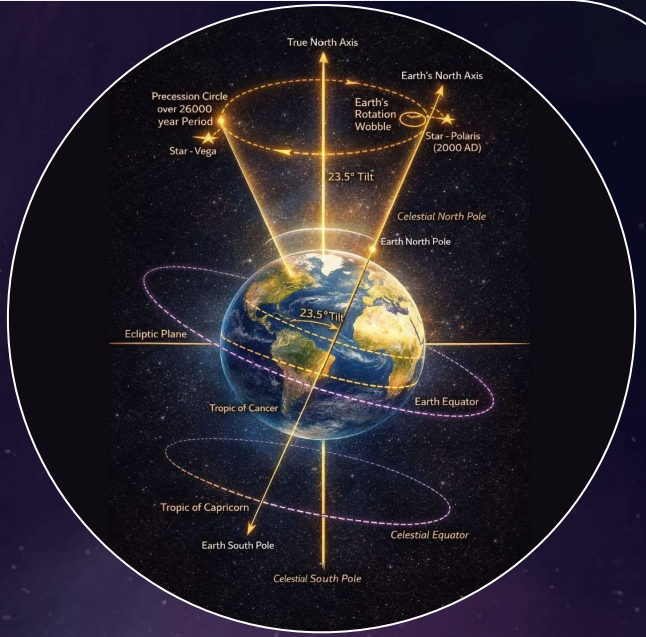

Figure 9: Earth's rotational axis. Retrieved from https://www.facebook.com/groups/FlatEarthDiscuss/posts/1717350656096682/

02

Our Search & The Fingerprints of Life

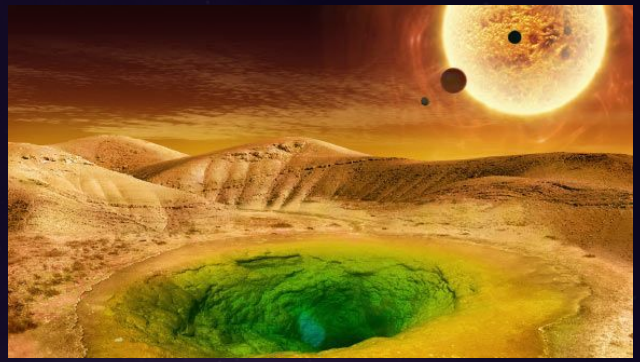

Figure 10: Conception of what the surface of an exoplanet could look like. Retrieved from: https://science.nasa.gov/universe/exoplanets/will-we-know-life-when-we-see-it-nasa-led-group-takes-stock-of-the-science/

We are entering an exciting era in the search for life!

- We have been hypothesizing about extraterrestrial life for centuries. [23]
- Shift from looking for life similar to humanity, to life similar to that found elsewhere on earth
  - Less focused on “little green men”
  - Emphasis on looking for Biosignatures [9]
- Confirmation of existence of exoplanets is fairly recent in comparison

Figure 11: Goofy Alien Retrieved from: https://media.tenor.com/kzFjf_4B1uQAAAAj/squishivt-squishivr.gif

Biosignatures: The Fingerprints of Life

- Something that can only be explained by the existence of life
  - A Particular Atmospheric Composition
  - Surface Characteristics indicative of biological activity
  - Disturbances of Equilibrium [9]
- A good biosignature is reliable, survivable, and detectable [10]

Figure 12: Atmosphere Retrieved from: https://img.tfd.com/wn/EC/6826B-atmosphere.jpg

oxygen-chemical-element-on-the-periodic-table-of-elements.jpg

Strong Signals for life

- Chemical Composition of an Atmosphere contains some of the following compounds
  - Oxygen (O2), Ozone (O3), Methane (CH4), Carbon Dioxide (CO2) [10]
- Current best biosignature: Oxygen
  - Free O2 in an atmosphere is uncommon [10]
  - Oxygen is in Earth's atmosphere due to photosynthesis [10]
  - Opportunities for false positives, context is important [9]

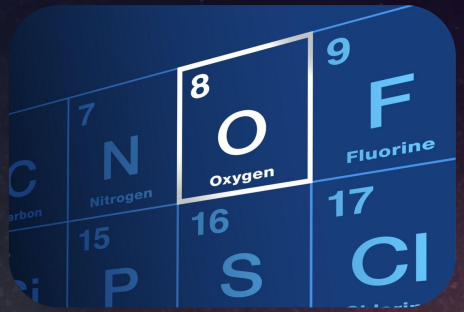

Figure 13: Periodic Table. Retrieved from: oxygen-chemical-element-on-the-periodic-table-of-elements.jpg

Exploring Exoplanets Light Years Away

- We use spectroscopy to determine the composition of a planet's atmosphere
  - Atmosphere absorbs certain wavelengths of light, which we detect [16]
- Transmission and eclipse spectroscopy Method:
  - Compare spectra of planet in front of star, and behind it [16]

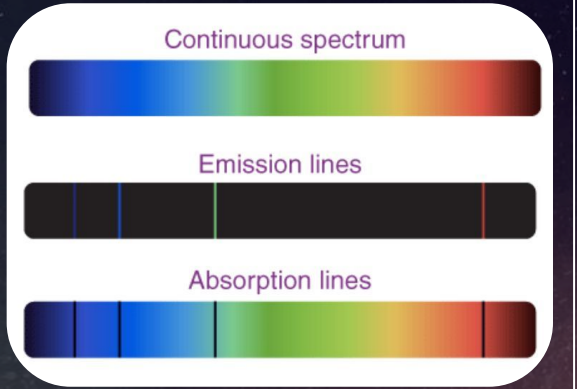

Figure 14: Absorption Spectrum. Retrieved from: https://cdn1.byjus.com/wp-content/uploads/2023/03/Absorption-Spectrum-Updated.png

Transmission and Eclipse Spectroscopy Method

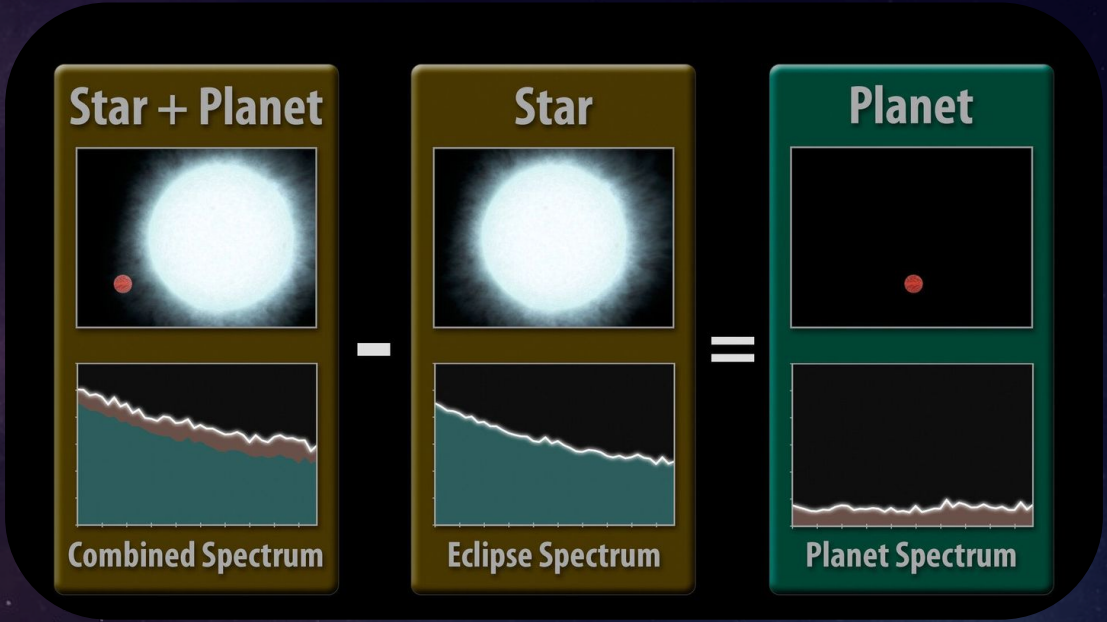

Figure 15: Eclipse Spectroscopy. Retrieved From: https://www.esa.int/ESA_Multimedia/Images/2023/09/Eclipse_spectroscopy

Our Current Search Efforts

- Further investigating discovered exoplanets
- JWST is sensitive enough for spectroscopy of large planets [8]
- The European Space Agency's Ariel mission is specifically intended to inspect exoplanet atmospheres (Launching 2031)[16]

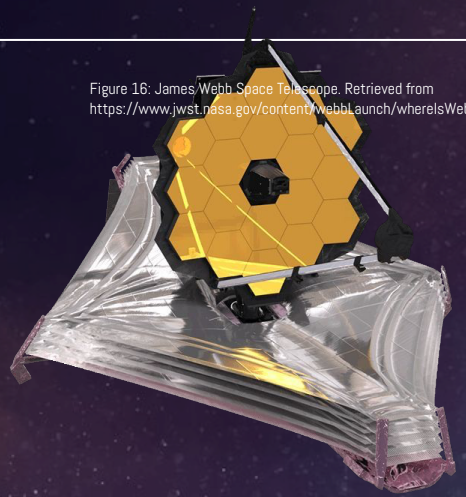

Figure 16: James Webb Space Telescope. Retrieved from https://www.jwst.nasa.gov/content/webbLaunch/whereIsWebb.html

Figure 17: Artist's impression of the Ariel Mission Probe. Retrieved from https://commons.wikimedia.org/w/index.php?curid=150544297

Search for Extraterrestrial Intelligence (SETI)

- Focuses on communicating with or observing intelligent life
- Our earliest searches for life fall in this category
- Many organizations have conducted SETI activities [14]
- Was an official NASA program, ending funding in the 1990s [14]

Figure 18: Earth. Retrieved from: https://www.space.com/54-earth-history-composition-and-atmosphere.html

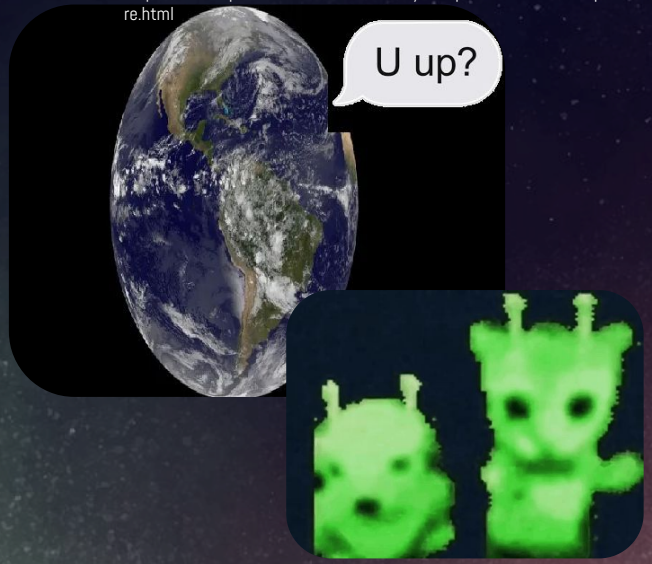

Figure 19: Real Aliens. Retrieved from: https://giphy.com/gifs/catdog-alien-cat-sikabhu-sBffRwz30Z81xIBw4i

03

Top Candidates for Life

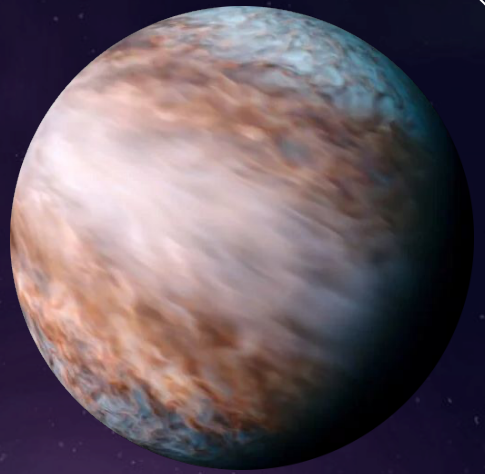

Figure 20: Exoplanet WASP-127b. Retrieved from: https://www.eso.org/public/news/eso2502

How many Exoplanets?

- Exoplanet defined as any planet outside the solar system[17]
- Based on the size of the universe (huge), estimates are anywhere from 100 billion to over 3 trillion exoplanets in the Milky Way.
- How many have we actually observed/discovered?
- How many are actually realistic candidates for life?

- 6,153 Confirmed Exoplanets and counting [20]
- How many are actually realistic candidates for life?
- ~45 are noted as “potentially habitable” for life[18]
- Note: We won’t be covering all 45, but will cover some of the ones that seem to be the promising.

TRAPPIST-1e

Distance: 40 ly[18]
Size: 0.92x Earth radius
Orbital Period: ~6 days
Star Type: Ultra Cool Red Dwarf
Age: ~7.6 billion years

- JWST currently looking at this planet
- Tidally locked [19]
- In the center of TRAPPIST-1's habitable zone[18]
- Atmosphere could potentially be stripped from Host star[19]

- Seems to be a rocky world [19]

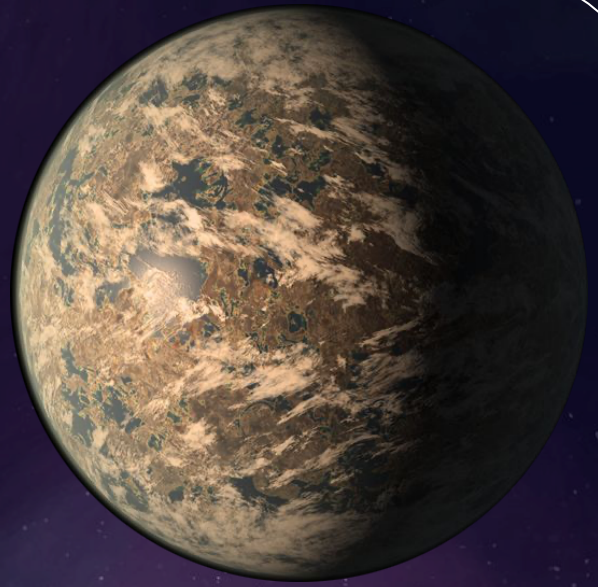

Figure 21: Trappist 1-e. Retrieved from TRAPPIST-1e_artist_impression_2018.png

LHS 1140 b

Distance: 48 ly
Size: 1.7x Earth radius[21]
Orbital Period: ~24 days[21]
Star Type: Quiet/Inactive Red Dwarf
Age: ~5 billion years

- Also tidally locked
- Bullseye ocean possible, since only one side faces the host star at all times
- Potentially nitrogen rich atmosphere
- Likely an ocean planet or ice world[21]
- Estimated that 10-20% of mass is water [21]

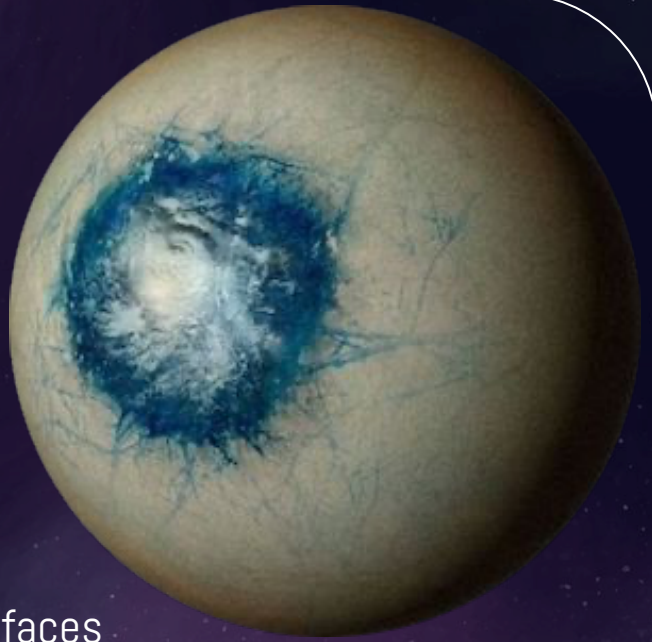

Figure 22: LHS 1140b. Retrieved from LHS-1140-b-water-world-exoplanet-artist-concept-July-8-2024.jpg

Kepler-452b

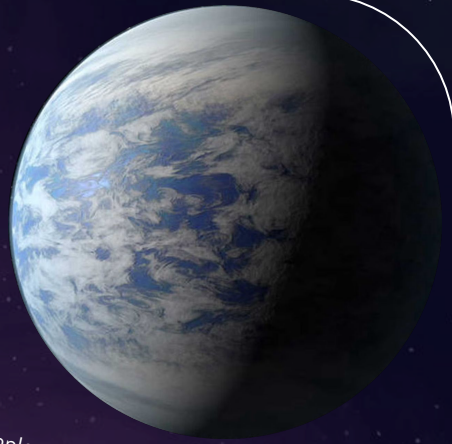

Figure 23: Kepler 452b. Retrieved from https://cdn.discovermagazine.com/assets/image/58182/habitable-exoplanet-xs.jpg

Distance: 1400+ ly
Size: 1.5-1.6x Earth radius
Orbital Period: ~385 days
Star Type: G2 Type star [22]
Age: ~6 billion years[22]

- Distance of 1.042 AU to its Star
- First Earth Sized Exoplanet found in habitable zone of its star
- ~3-5x the mass of earth, so gravitational effect much stronger
- Distance from Earth makes it harder to get a real idea of the planet [22]

Compare and Contrast

- TRAPPIST 1-e is the closest option, but higher chances that any potential life would find it hard to survive for long periods of time due to the host star
- LHS 1140b is the best option for an ocean, and the host star is less active, giving its atmosphere a better chance at survival
- Kepler-452b has the most similar conditions to our Earth, but simply too far away to extract or obtain any information about the planet

Clicker: If we could embark and investigate one of these planets, which would you pick?

A. TRAPPIST 1-e

B. LHS 1140b

C. Kepler-452b

D. REDIRECT MORE MONEY TO THE U.S. MILITARY

Figure 24: Silly Alien Cat. Retrieved from https://i.imgflip.com/a2cda7.jpg

Questions?

Figure 25: Trump playing poker with aliens. Retrieved from

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcSDBfOwu1F3lBxuHlRI