Investigating Habitability in the Kepler-47 Binary System

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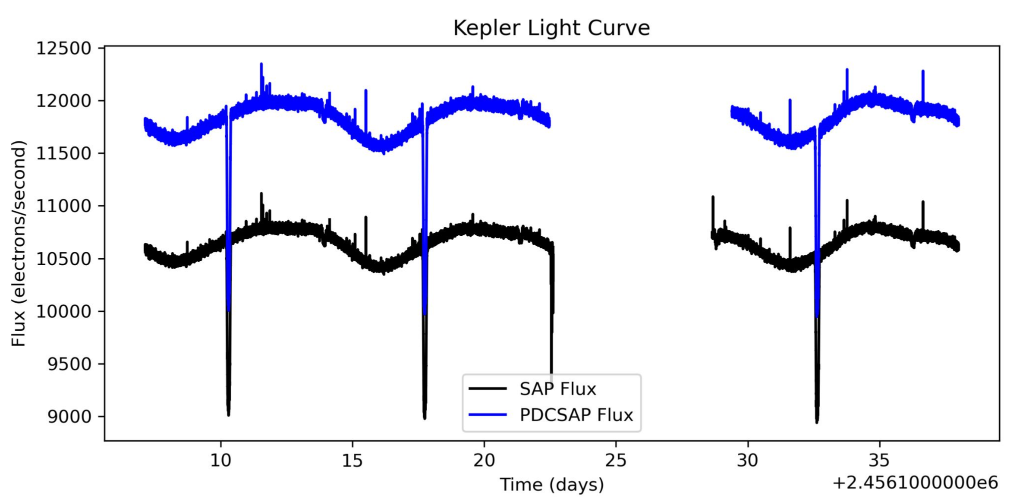
The Kepler-47 System

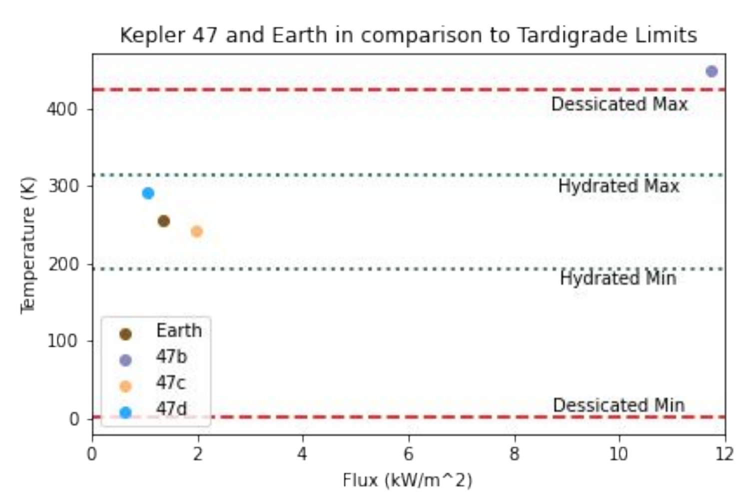
The Kepler-47 system is a binary star system with three planets orbiting the stars. The planets, 47b, 47c, and 47d, are all circumbinary, i.e. they orbit both stars in the system. The main star, Kepler-47A, is a G-type star, with a radius of 0.96 $R_\odot$ and a mass of 1.04 $M_\odot$, which is pretty similar to the Sun. The smaller star, 47B, is a red dwarf that is about one-third the size and mass of the Sun. 47c, the light curve for which is shown below, is a gas giant that orbits in the system's habitable zone[1] The habitable zone of a binary system is more complicated to compute than a habitable zone for a single star system because there are two stars of different luminosities and temperatures, and because as the stars orbit each other the habitable zone moves as well.

The light curve for Kepler-47c, shown below, is generated from data collected by Kepler archived on MAST[6]. The PDCSAP flux, specifically, is the flux corrected for instrumental variations.



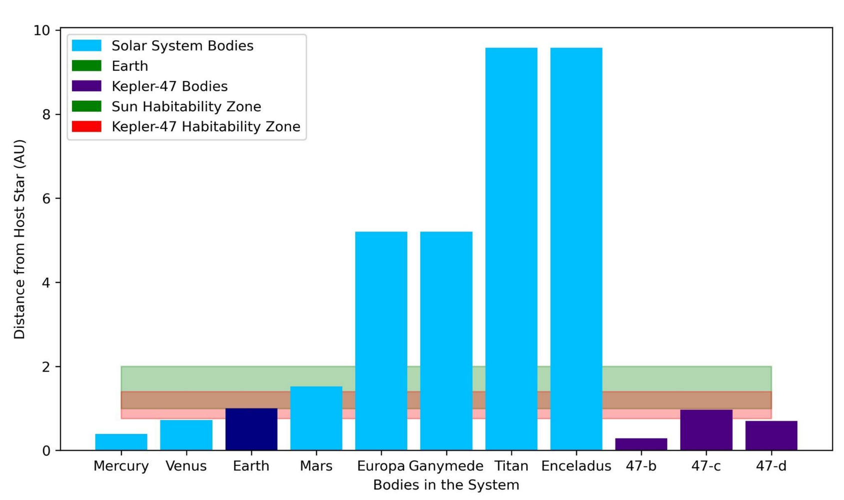
Temperature and Radiation Concerning Life

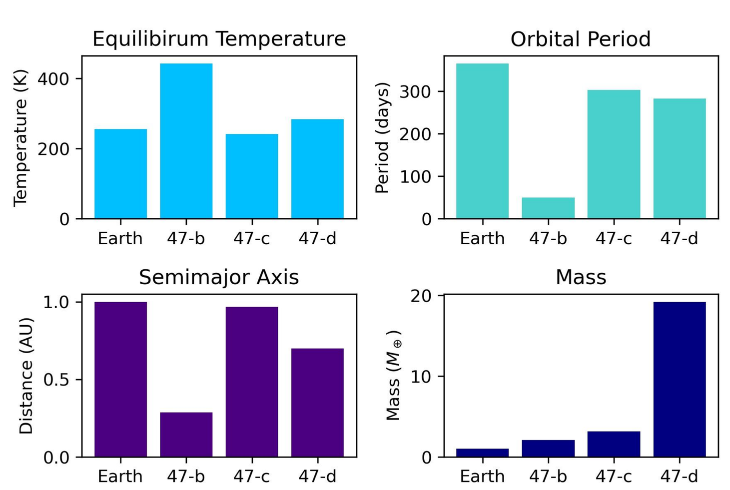
This graph shows the effective temperature bounds that can sustain Tardigrade life, with a minimum of 1.15 deg K (-272 deg C) to 423.15 deg K (150 deg C)[2]. Tardigrades can survive these extreme temperatures in a desiccated form called a Tun. Tardigrades can survive hydrated (and active) at temperatures of 193.15 deg K (-80 deg C) to 314.15 deg K (41 deg C)[3]. Tardigrades can survive at the bottom of the ocean to the vacuum of space and can withstand up to 6200 Grays of absorbed radiation[2], which is not comparable to the flux received by the planets graphed here. Earth is known to sustain Tardigrade life and is in a similar location (Temperature and Flux wise) to both Kepler-47c and 47d. Kepler-47b has an effective temperature greater than Tardigrades can survive. This graph supports the fact that Kepler-47c is in the habitable zone, and that Kepler-47d is potentially within that zone as well[1]. This graph is an extremely non-conservative model that fails to take into account numerous qualifications required for life, yet can give us a look at one facet of potential habitability.



Solar System vs. Kepler-47

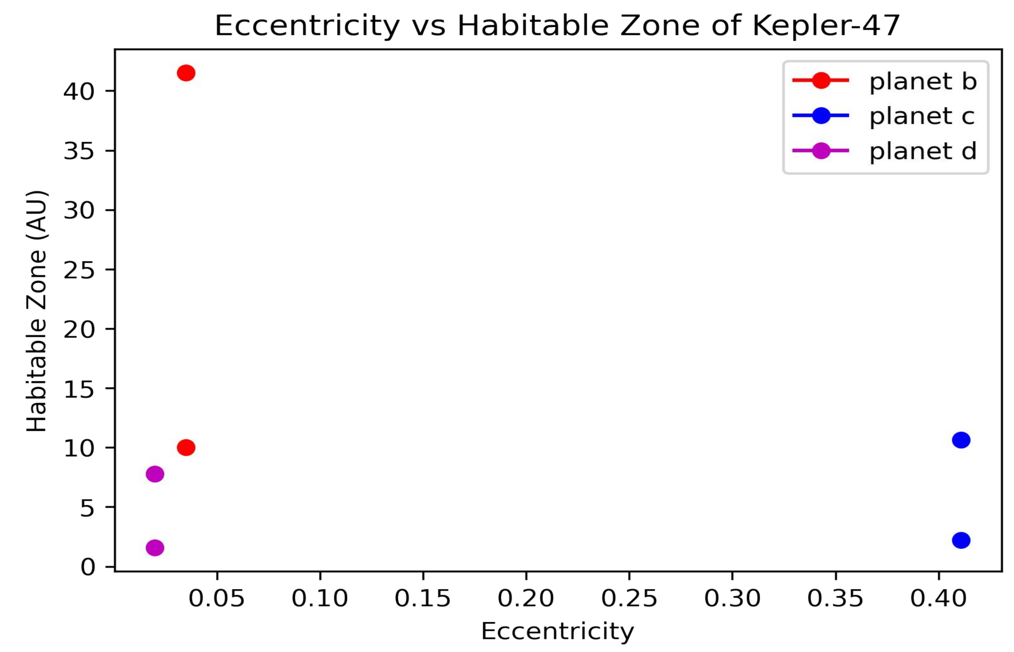
The figures below show the differing characteristics of our Solar System and the Kepler-47 system. In our Solar System, there are two planets that are in the habitable zone, Earth and Mars. However, Earth is the only planet that has liquid water. Looking at comparisons between the Earth and the Kepler planets, 47c is the most similar to Earth. The Earth has an equilibrium temperature of 255 K, while 47c has a temperature of 241 K. The Earth is 1 AU from the Sun while 47c is about 0.96 AU away from its host stars. Kepler-47c is slightly bigger that the Earth, estimated to be about 3.17 Earth masses.





Habitability of a Planet in a Binary System

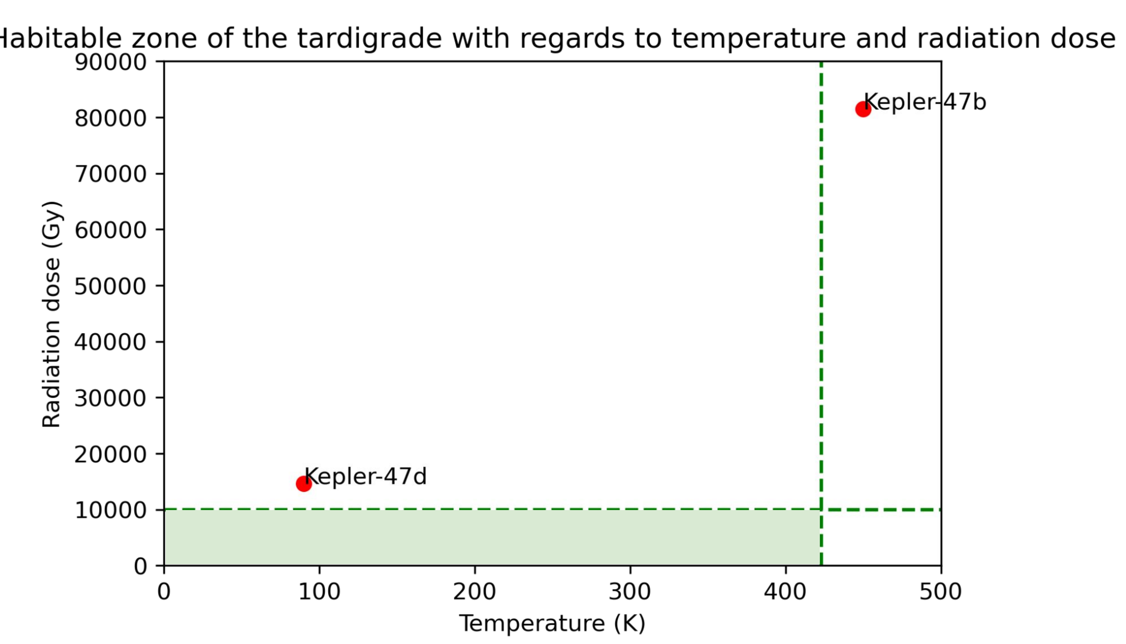
Using the data from Kepler-47[4], we computed the planets' habitable zone or distance away from the host binary that the planet can have in order to retain liquid water on its surface. We obtained this equation from [5], which takes in both Kepler-47's stars luminosity, mass, eccentricity and semi-major axis, as well as the planets' semi-major axis and eccentricity. The output is fairly straightforward: it returned the inner and outer zone of each planet. We then plot its eccentricity versus habitable zone.



The plot showed each planet's inner and outer zone. If the planets lies within these values, it then can retain liquid water on the surface. From [4], planet 47b, planet 47c, and planet 47d have semi-major axis of 0.2954 AU, 0.989 AU, and 0.6992 AU respectively. Planet 47b lied outside of its habitable zone, so water might not be able to retain on its surface. On the other hand, planet 47c and 47d stayed within its habitable zone, which indicated that both planets can have liquid water on its surface.

Further insights related to temperature and radiation

The versatility of the tardigrade makes it a great candidate to measure the habitability of exoplanets from a less human-biased perspective.



Based on the tardigrade criteria for temperature and radiation intake, the habitable zone is defined by the green zone on the graph. Both Kepler-47b and Kepler-47d do not pass this habitability test (data for other Kepler-47 planets was not available). However, these results are based on very conservative assumptions. The yearly radiation levels for both planets are measured at their respective atmospheres, and are thus overestimates of the values at the surface. Temperature is assumed to be constant around the entire planet, whereas the side facing away from both suns should be slightly cooler. Finally, this graph does not take into account the possibility for life to form and develop under the surface of the planets. If Kepler-47b or Kepler-47d possessed an underground system, this environment would be substantially cooler than at the surface and be protected of radiation by the ground. Based on the conservatism of these assumptions, it is fair to assume that Kepler-47d is most likely in the habitable zone with regards to these criteria.

In conclusion, this graph most importantly illustrates the limitations faced by astrobiologists when defining habitability. Available data is limited and biased, and so is our understanding and knowledge of life.

Conclusions w.r.t. habitability

Using the data from Kepler-47c, we were able to make direct comparisons to Earth. While the temperature on Kepler-47c is significantly colder than many places on Earth, it still is well within what we see in some parts of the world. The Kepler planets orbit a G-type and M-type star; we also orbit a G-type star. M-type stars are extremely common, but they are extremely dim. This explains the luminosity of each of the host stars, with one host star having 84% of the luminosity of the sun and one having a mere 1%. Varying mass of a planet could affect the surface gravity which can alter mean surface temperature. Varying radius mainly affects the difference in pole to equator surface temperature. Habitability is affected by this in that temperature can greatly affect the ability to not only survive, but also thrive. A key factor is that radiation is affected by temperature; emitted at a rate proportional to the fourth power of the temperature. In addition, temperature affects the ability for liquid water to exist, a key component in habitability.

Although liquid water is capable of existing on Kepler 47c, that is not enough to consider it habitable. Radiation, fluxuations in seasons, atmosphere, or surface temperature all have a massive impact on habitability. Habitability being summed up to the existence of liquid water neglects the factors that fully encompass habitability. Furthermore, the chaotic nature of a binary system makes these factors very difficult to account for when analyzing habitability – as the stars' mutual orbits change, the temperature, radiation, etc. on circumbinary planets vastly changes on short timescales – life would have to be highly evolved to the chaos. Additionally the radiation on Kepler-47b and d is too high for even tardigrades to exist, thus making it impossible for humans to survive, so it's likely that Kepler-47c is also too radioactive. The atmospheres are that of a gas giant, something a human would not be able to survive.

In conclusion, it is vital to consider all aspects of habitability and the full scope of the planet must be taken into consideration prior to labeling it habitable. With our current definition of life and our limited habitability variables, we do not think any of the Kepler planets are habitable.

The Way Forward

Increased resolving power of instrumentation, and continued support and funding of observational astronomy will allow us to investigate habitability more thoroughly as well as detect, investigate, and classify increasing numbers of exoplanets, exomoons, exo-atmospheres and protoplanetary disks. Pioneering areas of instrumentation research include starlight suppression, wavefront control and detection sensitivity. A priority area of the 2021 astronomy decadal review was "Pathways to Habitable Worlds".The decadal has a profound impact on astronomical instrument and program funding in the United States.

Large ground based observatories such as ELT, and TMT are planned. Nancy Roman recommended by the 2010 decadal is under development with a 2027 planned launch date, and JWST is now launched. Other space based missions such as Luvoir, Starshade Rendezvous, HabEx, Origins and the Exo-Earth Interferometer are possible future projects. It is hypothesized that JWST will be able to see atmosphere's on exoplanets and may confirm a first exomoon. The way forward may include exomoons like exomoon candidate Kepler-1625b-i. Oceans on Europa and Enceladus in our own solar system could someday be places we find alien life. With telescopes, like TESS in service and JWST data on the way, our chances of finding exomoons are improving. In November 2021 NASA announced the 5,000 confirmed exoplanet. Studying exoplanet atmospheres and looking for signs of life will be one of JWST's missions.

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