THE OCCURRENCE OF PLANETS IN THE ABIOGENESIS ZONE. Marcos Jusino[1,2] and Abel Méndez[2], [1]Department of Physics, University of Puerto Rico at Mayaguez, Mayagüez, PR (marcos.jusino1@upr.edu). [2]Planetary Habitability Laboratory, University of Puerto Rico at Arecibo, Arecibo, PR (abel.mendez@upr.edu).

Introduction: Precursor molecules to the building blocks of life such as ribonucleotides, amino acids and lipids could have been produced in an early, prebiotic Earth in which ultraviolet radiation induced the activation energy required to trigger photochemical reactions. Accordingly to the "Primordial Soup theory", these reactions are to occur in the presence of surface liquid water, to which the positioning of the planet inside the conservative Habitable Zone is vital (see Figure 1).

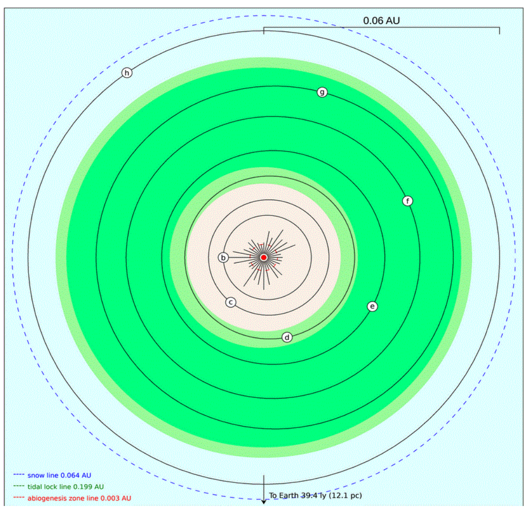

Figure 1: Plot of the orbits of the planets around TRAPPIST-1 and the habitable zone (green shades). (PHL, UPR Arecibo)

The Abiogenesis Zone, as defined by Rimmer *et al.* [1], is the zone in which a yield of 50% for the photochemical products is obtained, adopting the current UV activity as representative of the UV activity during the stellar lifetime and assuming a young Earth atmosphere. Rimmer *et al.* [1] portrayed this by modeling the UV detachment of electrons from anions in solution, such as H_2S and SO_2 in the presence of HCN to produce HS^- and SO_3^{-2} for the latter, in representation of past works involving reactions to form the pyrimidine nucleotide RNA precursors [2, 3].

Details for the Abiogenesis Zone. This zone approximately ranges in UV radiation from 200nm to 280nm, since this is the critical wavelength range for photochemical reactions as proved by Todd *et al.* [4]. A weakly reduced atmosphere with a plausible composition of N_2, O_2, H_2 and CO_2, as speculated to have had existed in prebiotic times between 3.8 and 3.5 Ga [5], is essential for the photochemical reactions to occur, since UV radiation at its critical wavelength range is weakened in present-day Earth's atmosphere.

Calculations done in our project suggest that there is a proportional relation between the mass and effective temperature of the star and the exterior limit of their Abiogenesis Zone. The lower the mass of the star, the smaller the radius of the zone's exterior limit should be, and vice versa (see Figure 2). This also suggests an inverse relation between the positioning of the Habitable Zone and the Abiogenesis Zone.

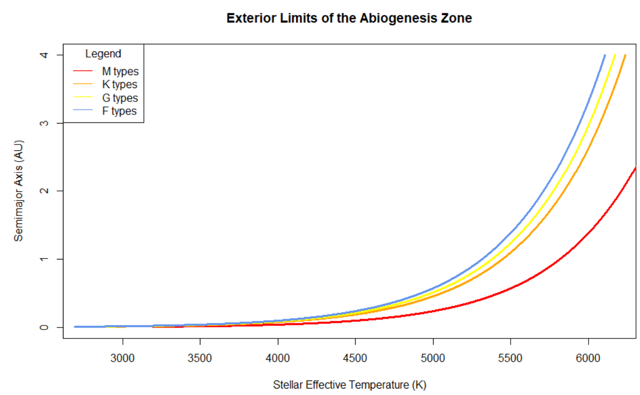

Figure 2: Relation between the size of the Abiogenesis Zone and the stellar temperature of main-sequence star type.

Lingam and Loeb [6] proved that planets orbiting around stars type M-dwarfs cannot sustain Earth-like biospheres because they do not receive enough photons in the photosynthetically acting range of 400-750nm, unless they are active enough for flares to compensate. However, since only a 20% of M-dwarfs are active [1], and flares give rise to other positive and negative effects [6], we do not consider them in our project.

Known Planets in the Abiogenesis Zone: When applying our estimates of the Abiogenesis Zone to our catalog of Potentially Habitable Exoplanets Catalog we found eight candidates: Kepler-452 b ($R_E = 1.63$), τ Cet e ($R_E = \sim 1.8$), Kepler-1638 b ($R_E = 1.87$), Kepler-1606 b ($R_E = 2.07$), Kepler-1090 b ($R_E = 2.25$), Kepler-22 b ($R_E = 2.38$), Kepler-1552 b ($R_E = 2.47$), and Kepler-1632 b ($R_E = 2.47$). Although all of these eight exoplanets are inside both the Habitability Zone and the Abiogenesis Zone, they are all warm superterrans (i.e. Super-Earths or Mini-Neptunes), and less likely to support life. A large planetary radius might suggest the presence of a thick gaseous atmosphere, deep oceans, or both. Thus, these planets are less likely to be of rocky composition.

Kasting [5] showed that the presence of the Carbon cycle in a planet is key to its habitability since it acts as a temperature regulatory system to preserve liquid water on its surface - specially the silicates weathering component. Vast amounts of water oceans in a planet create obstacles (ice VII) between the planetary surface and the water, and gaseous planets imply high temperatures and high pressures, significantly decreasing the chances of liquid water on its surface; both cases interrupt the Carbon cycle [7].

Alibert [7] calculated the maximum planetary radius that would make a planet inhabitable. For planets in the Super-Earth mass range (1 to 12 Earth masses), the maximum radius that a planet, with composition similar to that of Earth, can have varies between 1.7 to 2.2 Earth radii. Our best choices for candidates would theoretically be Kepler-452 b ($R_E = 1.63$) and τ Cet e (R_E = ~1.8) because of their lowest planetary radius from our sample. (see Figure 3 and Figure 4)

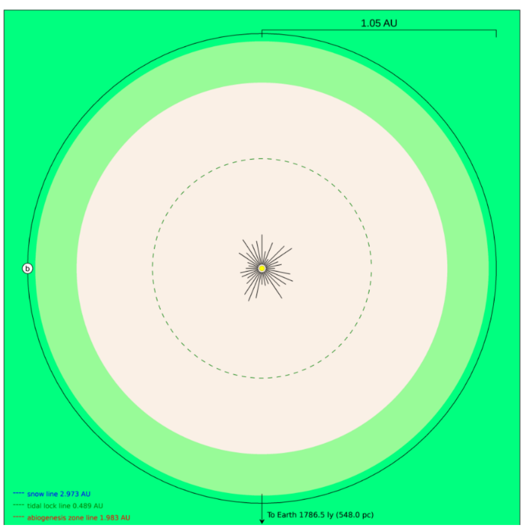

Figure 3: Plot of Kepler-452 b, an exoplanet around Kepler-452. (PHL, UPR Arecibo)

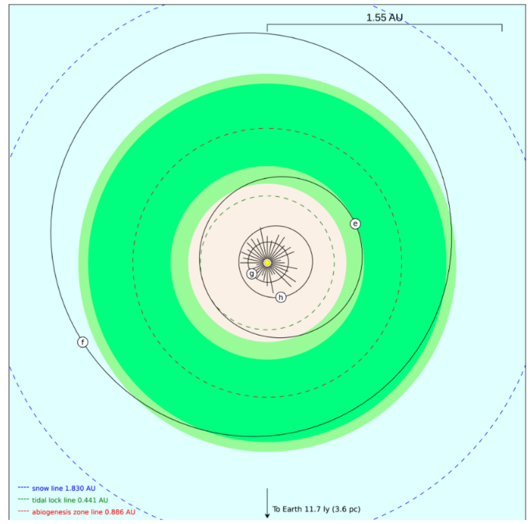

Figure 4: Plot of τ Cet e, an exoplanet around τ Cet. (PHL, UPR Arecibo)

When applying our estimates of the Abiogenesis Zone to our very own Solar System, we find its exterior limit to be at 2.02 AU. According to the Habitable Zone calculator [8, 9], the inner limit of our Habitable Zone is located at 0.95 AU and its external limit is located at 1.68 AU. This suggests that both an early Earth (with a reduced atmosphere) and an early Mars (in which surface liquid water was present) could have also hosted these photochemical reactions and thus synthetized key precursor molecules to the building blocks of life.

Conclusion: The Abiogenesis Zone is the zone in which a yield of 50% for the photochemical product is obtained, adopting the current UV activity as representative of the UV activity during the stellar lifetime and assuming a young Earth atmosphere [1]. Although there are eight small exoplanets in both zones, none of them are very good candidates due to their size, except for maybe Kepler-452 b and τ Cet e. So far, not a single Earth-sized planet has been discovered to be in both the Habitable Zone and the Abiogenesis Zone.

References: [1] Rimmer P. B. *et al.* (2018) *Sci. Adv.*, **4**. [2] Patel B. H. *et al.* (2015) *Nat. Chem.*, **7**, 301-307. [3] Xu J. *et al.* (2018) *Chem. Commun.*, **54**, 5566-5569. [4] Todd Z. R. *et al.* (2018) *Chem. Commun.*, **54**, 1121-1124. [5] Kasting J. F. (1993) *Science*, **259**, 920-926. [6] Lingam M. and Loeb A. (2019) *Monthly Notices of the Royal Astronomical Society*, **000**, 1-4. [7] Alibert Y. (2013) *Astronomy & Astrophysics*, **561**. [8] Kopparapu *et al*. (2013) *Astrophysical Journal*, **765**, 131. [9] Kopparapu *et al.* (2014), *Astrophysical Journal Letters*, **787**, L29.