(AST251H S) Project 3: Assessing If A Planet Actively Hosts Life

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1 Introduction

In this paper, we aim to assess two extraterrestrial messages received on Earth as well as the corresponding additional information we have about the exoplanets from which the messages are believed to have been sent in order to determine the likelihood of the sources being extraterrestrial intelligent lifeforms. First, we assess the transmission from Planet 1 (P1) to determine whether it is a potential sign of intelligence. Then, we further assess the known properties of P1 to determine whether it actually hosts life. Lastly, if we conclude that P1 potentially hosts life, we speculate the biochemistry of these life forms. If not, we seek alternative explanations to account for the patterns seen in P1's atmosphere and surface. We repeat the same steps of analysis for Planet 3 (P3).

2 Planet 1 (P1)

(Q1) The transmission believed to have been received from P1's solar system is a continuous narrowband microwave signal, which lasted a short duration before stopping. A narrowband signal is a signal that corresponds to a narrow range of wavelengths, or has a "small fractional bandwidth" (Hagen 2009, 3). In contrast to broadband signals, which require higher transmission power to overcome noise, narrowband signals are easier to detect and transmit since they have less noise (Browne 2018). However, narrowband signals contain less information than broadband signals, and are usually communicated over shorter distances (Browne 2018), which perhaps explains the short duration of this signal. Most importantly, broadband signals are largely produced by natural astrophysical phenomena, whereas narrowband signals, like radio frequency interference (RFI) signals on Earth, tend to be artificially produced (Brzycki et al. 2020, 2). This indicates that the transmission likely originated from an extraterrestrial intelligent life form.

To decode the signal, we convert the binary system of 1s and 0s (with the given most probable aspect ratio) into an image using software that maps 1s to black squares and 0s to white squares. Figure 1 depicts this image. Since we believe that the message contains a literal image (according to `yaktubay_p1.pdf`), we rule out the possibility of it depicting something abstract such as a mathematical equation or a number system. Instead, we find that the image on Figure 1 likens a theoretical spacecraft called *Bussard ramjet*, which is depicted on Figure 2. The Bussard ramjet is a spaceship that produces thrust through the fusion of interstellar particles and can theoretically travel at speeds close to the speed of light of the order of years (Semay and Silvestre-Brac 2004, 75). However, with our current technologies, physical constraints pose an obstacle to the Bussard ramjet's actualization (76). Yet, the similarities between the Bussard ramjet's design and the received transmission are hard to miss. In the signal, we see a structure that contains small parts sandwiched between large plates, the most astounding similarity being the zig-zag pattern (circled in red) that likens the electron beam guns (circled in red) on Figure 2. Hence, we conclude that the message from P1 represents evidence of an intelligent sender, and signifies a high-tech spacecraft indicative of the sender's superior technological knowledge.

(Q2) Evidence suggests that P1 actively hosts life. 25.8% of P1's atmosphere consists of O_2, indicating that the rate of O_2 production is higher than the rate of O_2 removal (Schwieterman et al. 2018, 673). On Earth, O_2 is predominantly produced by biotic processes such as photosynthesis and the burial of organic matter, and removed by processes such as chemical reactions with reduced volcanic gases (673). On P1, O_2 levels vary periodically and fully out of synch with CO_2 levels, which could be due to varying photosynthesis activity that seasonally increases the rates of CO_2 removal and, at the same time, O_2 production. Further, high O_2 levels could potentially be due to abiotic processes such as photolysis (UV rays breaking down H_2O and CO_2 to produce O_2) (674). However, such abiotic processes would have their own spectral signatures such as the absence of atmospheric H_2O and N_2, and the presence of CO (678). As P1's atmosphere consists of 21.3% H_2O, 39.6% N_2, and shows no signs of CO, abiotic O_2 production through photolysis is unlikely. Further, the photolytic production of O_2 requires high stellar luminosities, a requirement unmet by P1's K-type host star with luminosity $0.125L_{\odot}$. Moreover, the presence of N_2O (2.27×10^{-5}%) is a strong biosignature as we observe no signs of its abiotic production. Specifically, most abiotic production of N_2O generates more nitrogen oxide in the process than N_2O (676), and yet, nitrogen oxide is undetected in P1's atmosphere. Further, studies show that many stellar environments in general lack signs of abiotic N_2O production (676). Lastly, P1 contains 0.215% CH_3Cl, which is predominantly produced biotically on Earth, especially through anthropogenic industrial processes (677). Although CH_3Cl can also be produced by volcanic activity, its biotic production seems more likely given the discussed evidence. Hence, we conclude that P1 hosts life.

The remaining information on P1 is inconsequential to our conclusion. A mass of 3.4 Earth masses and the given surface maps suggest that P1 is a terrestrial Super-Earth that contains both land and liquid surfaces (likely water as per atmospheric composition) - an Earth-like planet suitable for life. The host star, being a $0.595M_\odot$ K-type star with luminosity $0.125L_\odot$, is "the best of all worlds" (NASA 2021) in terms of hosting life. The atmospheric pressure of 1.6 atm is similar to the Earth's atmospheric pressure (1 atm), not affecting our results. Moreover, assuming that the radial velocity of the host star is measured edge-on, the sinusoidal velocity curve suggests a circular orbit, which is more suitable for life than elliptical ones due to low seasonal climate variance (Linsenmeier et al. 2015, 55). Then, the periodically varying levels of N_2O, CH_3Cl, H_2O, and N_2 in the atmosphere could be due to P1's atmospheric regulation systems that we have no information on.

(Q3) Given the high levels of H_2O in P1's atmosphere (21.3%), we can say that this form of life uses H_2O as its solvent to break down carbon molecules (Cockell 2018, 758). Further, O_2 levels (25.8%), as a waste product of photosynthesis, indicate that this life form evolved to use "water as a source of electrons" (758) much like Earth-like life forms. In general, the presence of atmospheric spectra that exhibits organic carbon-based biosignatures, such as methyl chloride (CH_3Cl) in this case, indicate the existence of a carbon-based life form (759). Hence, the biochemistry of life on P1 depends on carbon and water just like Earth-like life forms.

3 Planet 3 (P3)

(Q1) The transmission believed to have been received from P3's solar system is a continuous broadband microwave signal. The signal has a periodic pattern that repeats itself as nine 1s followed by five 0s, which is depicted on Figure 3. Although a repeating pattern potentially signifies an intelligent source, there are a few things that might suggest otherwise. First, unlike narrowband transmissions, broadband transmissions must overcome noise to carry detectable information, which requires a significant amount of power (Browne 2018). Further, broadband transmissions can carry more information than narrowband transmissions (Browne 2018). Attempting to position ourselves within a non-human intelligent life form's perspective, there must be a reason that motivates the exhaustion of incredible amounts of power to transmit a broadband signal across astronomical distances. One reason could be that the intelligent life form wants to communicate an amount of information they cannot communicate given the carrying capacity of narrowband signals. However, our signal merely contains a series of repeating and identical patterns that could have been communicated with a narrowband signal as well; the signal has no attributes, such as slightly unique differences in each pattern, that conclusively support an intelligent origin. Further, not only are broadband signals abundant in the universe (Brzcki et al. 2020, 2), but *periodic* broadband signals are as well. For example, we know that solar and stellar flares cause period pulsations that can be detected here on Earth (Kashapova et al. 2020, 1). These pulsations can definitely be in the microwave portion of the EM spectrum like in our case, because stars emit a wide range of wavelengths including microwaves (Gudel 2016, 743). Therefore, given the logical inconsistencies of exhausting so much power to communicate a non-varying pattern and the abundance of periodic signals in the universe, we conclude that the message does not represent evidence of an intelligent sender.

(Q2) Evidence indicates that life does **not** actively exist on P3. P3's atmosphere consists of 17.6% N_2, 56.8% CO_2, and 25.6% H_2O. First, although significant levels of atmospheric O_2 and O_3 are commonly cited as strong biosignatures, evidence of low levels of O_2 in the Earth's atmosphere during the early Proterozoic (Pilcher 2003, 472) suggests that the absence of O_2 in P3's atmosphere is inconsequential to our assessment. However, when the available atmospheric evidence is taken into account, the absence of atmospheric O_2 likely indicates the absence of life itself. Specifically, the absence of O_2 and CH_4 and the abundance of CO_2 and H_2O, which are the products of chemical reactions between O_2 and CH_4, indicate that P3 lacks biotic mechanisms, such as photosynthesis (O_2 production) and the decay of organic waste (CH_4 production), that produce enough O_2 and CH_4 to offset equilibrium (Krissansen-Totton et al. 2018, 1). Further, N_2 in P3's atmosphere is not necessarily a biosignature as most of the nitrogen on Earth originates from its composite materials, which have been releasing N_2 into the atmosphere for billions of years (Matthews 2019). Thus, although N_2 is a requirement for exoplanet habitability for life-like-us (McKay 2014, 12628), it is not a conclusive biosignature.

The remaining information on P3 is inconsequential to our conclusion as it mostly indicates the potential habitability of P3, rather than the active existence of life. For example, with P3's orbital period (320 days as evident from radial velocity graph), the host star's mass (0.932 $M_\odot$), and the host star's luminosity (0.755 $L_\odot$), we estimate the planetary equilibrium temperature to be around $251K$, which is similar to Earth's equilibrium temperature of $254K$ (Mendez and Rivera-Valentin 2017, 4). This means that, just like Earth, due to greenhouse effects from high levels of

H_2O and CO_2, P3 sits between a range of surface temperatures at which liquid water can exist. Water could also exist in liquid form due to the high atmospheric pressure of 16.5 atm despite our calculated equilibrium temperature. Such speculations are further supported by the blue-ish liquid regions of P3 on its surface map. Other factors such as the type-G host star and planetary mass (0.4 Earth masses) indicate potential habitability, as our own Sun is a type-G star and P3 is a terrestrial planet (as per the surface map that depicts land) larger than Mars but smaller than Venus. Moreover, the varying levels of gas abundance in the atmosphere could be due to the rotation of the planet, which could vary the levels of atmospheric gases depending on factors such as cloud cover. Overall, none of these factors change our conclusion that P3 does not currently host life. Instead, they point to a *potential* for life.

(Q3) In the case of P3, the abundance of CO_2 is a false positive. For example, animals and human activity on Earth produce large quantities CO_2 through respiration, manure usage, and industrial processes (Phillipe 2015, 10; Keeling 2016, 174). However, volcanic activity on Earth is a significant abiotic source of CO_2 production as well (Gerlach 2011, 201). Therefore, the existence of CO_2 on its own is not a conclusive biosignature as it could be due to, say, volcanic activity on P3. Rather, the co-existence of CO_2 with CH_4 and the absence of CO could be a strong biosignature due to methane replenishment (NASA 2018). Further, although P3's surface map depicts Earth-like land and liquid masses, there seems to be no signs of vegetation (green color), unlike the surface map of P1. Lastly, as mentioned, atmospheric N_2 and H_2O are not biosignatures, but signs of habitability.

4 Figures

Figure 1: P1 narrowband microwave transmission converted from binary representation of 1s and 0s to an image with the most likely aspect ratio. 1s were mapped to black squares, 0s were mapped to white squares. The software used to create this image can be found here.

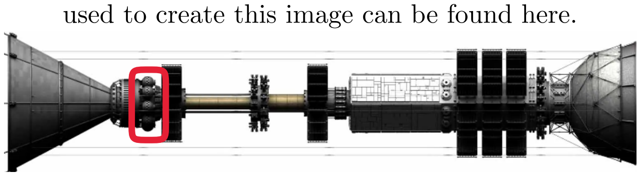

Figure 2: Artist's depiction of a *Bussard ramjet*. Image by Nick Stevens.

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1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1
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0 0 0 0

Figure 3: P3 broadband microwave transmission in its binary form of 1s and 0s.

5 Calculations

To calculate the estimated equilibrium temperature of P3, we must first calculate the orbital semi-major axis a. According to Kepler's third law and assuming that stellar mass is much larger than planetary mass, we have $a \approx \left[\frac{P^2 G M_s}{4\pi^2}\right]^{1/3}$, where P is P3's orbital period (roughly 320 days $\approx 2.765 \times 10^7$ seconds according to stellar radial velocity graph), $G = 6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$ is the gravitational constant, and $M_s = 0.932 M_\odot$ is the host star's mass. Plugging these values in, we get $a \approx 1.34 \times 10^{11} m$. Further, since P1's atmospheric composition is an Earth-like atmosphere consisting of N_2, CO_2, and H_2O (Schwieterman et al. 2018, 672), we can estimate P3's bond albedo as the Earth's, which is 0.3. Then, not considering atmospheric effects, planetary equilibrium temperature is $T_{eq} \approx \left[(1-A)\frac{L_s}{16\sigma\pi a^2}\right]^{1/4}$, where $A = 0.3$ is the bond albedo, $L_s = 0.755 L_\odot$ is the host star's luminosity, $\sigma = 5.67 \times 10^{-8} W m^{-2} K^{-1}$ is the Stefan-Boltzmann constant, and $a \approx 1.34 \times 10^{11} m$ is the orbital semi-major axis. Hence, we get $T_{eq} \approx 251 K$.

Bibliography

Astrobiology at NASA. 2018. “Detecting Life’s Influence on Planetary Atmospheres.” https://astrobiology.nasa.gov/news/detecting-lifes-influence-on-planetary-atmospheres/.

Browne, Jack. 2018. "Comparing Narrowband and Wideband Channels." https://www.mwrf.com/technologies/systems/article/21848973/comparing-narrowband-and-wideband-channels.

Brzycki, Bryan, Andrew P. V. Siemion, Steve Croft, Daniel Czech, David DeBoer, Julia DeMarines, Jamie Drew, et al. 2020. “Narrow-Band Signal Localization for SETI on Noisy Synthetic Spectrogram Data.” *Publications of the Astronomical Society of the Pacific* 132 (1017): 1–12. https://doi.org/10.1088/1538-3873/abaaf7.

Cockell, Charles S. 2018. “Using Exoplanets to Test the Universality of Biology.” *Nature Astronomy* 2 (10): 758–59. https://doi.org/10.1038/s41550-018-0586-x.

Gerlach, Terry. 2011. “Volcanic Versus Anthropogenic Carbon Dioxide.” *Eos* 92 (24): 201–2. https://doi.org/10.1029/2011EO240001.

Güdel, Manuel. 1994. “Quiescent Microwave Emission from Late-Type Stars.” *International Astronomical Union Colloquium* 142: 743–751. https://doi.org/10.1017/S0252921100078052.

Hagen, Jon B. 2009. *Radio-Frequency Electronics: Circuits and Applications*. Second edition. Cambridge: Cambridge University Press.

Kashapova, L. K., E. G. Kupriyanova, Z. Xu, H. A. S. Reid, and D. Y. Kolotkov. 2020. “The Origin of Quasi-Periodicities During Circular Ribbon Flares.” *Astronomy and Astrophysics* 642: 1-11. https://doi.org/10.1051/0004-6361/201833947.

Keeling, Charles D. 1972. “Industrial Production of Carbon Dioxide from Fossil Fuels and Limestone.” *Tellus* 25 (2): 174-98. https://doi.org/10.3402/tellusa.v25i2.9652.

Krissansen-Totton, Joshua, Stephanie Olson, and David C. Catling. 2018. “Disequilibrium Biosignatures over Earth History and Implications for Detecting Exoplanet Life.” Science Advances 4 (1): 1–13. https://doi.org/10.1126/sciadv.aao5747.

Linsenmeier, Manuel, Salvatore Pascale, and Valerio Lucarini. 2015. “Climate of Earth-Like Planets with High Obliquity and Eccentric Orbits: Implications for Habitability Conditions.” *Planetary and Space Science* 105: 43–59. https://doi.org/10.1016/j.pss.2014.11.003.

Matthews, Robert. 2019. “What Does the Nitrogen in the Air Come From?” https://www.sciencefocus.com/planet-earth/where-does-the-nitrogen-in-the-air-come-from/.

McKay, Christopher P. 2014. “Requirements and Limits for Life in the Context of Exoplanets.” *Proceedings of the National Academy of Sciences - PNAS* 111 (35): 12628–33. https://doi.org/10.1073/pnas.1304212111.

Mendez, Abel, and Edgard G. Rivera-Valentin. 2017. “The Equilibrium Temperature of Planets in Elliptical Orbits.” *Astrophysical Journal Letters* 837 (1): 1–6. https://doi.org/10.3847/2041-8213/aa5f13.

NASA. 2021. “The Search for Life.” https://exoplanets.nasa.gov/search-for-life/habitable-zone/#:~:text=The%20K%20stars%2C%20especially%20the,your%20chances%20of%20finding%20life.%22.

Philippe, F.-X., and B. Nicks. 2015. “Review on Greenhouse Gas Emissions from Pig Houses: Production of Carbon Dioxide, Methane and Nitrous Oxide by Animals and Manure.” *Agriculture, Ecosystems & Environment* 199: 10–25. https://doi.org/10.1016/j.agee.2014.08.015.

Pilcher, Carl B. 2003. “Biosignatures of Early Earths.” *Astrobiology* 3 (3): 471–86. https://doi.org/10.1089/153110703322610582.

Schwieterman, Edward W., Nancy Y. Kiang, Mary N. Parenteau, Chester E. Harman, Shiladitya DasSarma, Theresa M. Fisher, Giada N. Arney, et al. 2018. “Exoplanet Biosignatures: A Review of Remotely Detectable Signs of Life.” *Astrobiology* 18 (6): 663–708. https://doi.org/10.1089/ast.2017.1729.

Semay, Claude, and Bernard Silvestre-Brac. 2005. “The Equation of Motion of an Interstellar Bussard Ramjet.” *European Journal of Physics* 26 (1): 75–83. https://doi.org/10.1088/0143-0807/26/1/009.