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A revolution is brewing: observations of TRAPPIST-1 exoplanetary system fosters a new biomarker

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ABSTRACT

The recent discovery of seven potentially habitable Earth-size planets around the ultra-cool star TRAPPIST-1 has further fueled the hunt for extraterrestrial life. Current methods focus on closely monitoring the host star to look for biomarkers in the transmission signature of exoplanet's atmosphere. However, the outcome of these methods remain uncertain and difficult to disentangle with abiotic alternatives. Recent exoplanet direct imaging observations by THIRSTY, an ultra-high contrast coronagraph located in La Trappe (France), lead us to propose a universal and unambiguous habitability criterion which we directly demonstrate for the TRAPPIST-1 system. Within this new framework, we find that TRAPPIST-1g possesses the first unambiguously habitable environment in our galaxy, with a liquid water percentage that could be as large as $\sim$ 90 %. Our calculations hinge on a new set of biomarkers, CO_2 and $C_xH_{2(x+1)}O$ (liquid and gaseous), that could cover up to $\sim$ 10 % of the planetary surface and atmosphere. THIRSTY and TRAPPIST recent observations accompanied by our new, unbiased habitability criterion may quench our thirst for the search for extraterrestrial life. However, the search for intelligence must continue within and beyond our Solar System.

1. Introduction

The question of whether or not there is life in the Universe has arisen since the very first appearance of intelligent life on the Earth. It is a question that has inspired the imagination of scientists, artists, and philosophers, culminating in the landmark philosophical paper by Beck (1971). Although attempts to find (and indeed, even define) life and intelligent life on Earth (De Garde 1916; Stout 2006) and elsewhere have thus far met with limited success, with the discovery of thousands of planets outside our Solar System, we are now poised to make great progress in this arena.

The difficult question of what is required for life to exist in the Universe can be split up into smaller, yet still challenging, outstanding questions as summarized in the Drake equation, also referred to as Drake's Gold Alien Location Equation [Drake's Gold ALE].

One of the key questions that has arisen in recent times is the boundaries of the Habitable Zone, classically defined as the range of orbital distances in a stellar system where surface liquid water could be stable (Kasting et al. 1993). It is, however, seldom addressed how this concept might become obsolete in exoplanetary worlds where the priorities for living a good life are different than getting liquid water everywhere and at all times (Kim Kardashian, *personal communication*). A groundbreaking paper to that respect is the study by Kane and Zelsiz (2014) which demonstrated that the existing concepts about the Habitable Zone completely overlooked the risk posed by Zombie attacks.

We propose to take this line of research a step further by questioning the very concept of biomarkers. Most studies on biomarkers chose to focus on oxygen and methane. The former is not a good choice because abiotic oxygen might arise as result of photodissociation of water molecules (Wordsworth and Pierrehumbert 2014); the latter is not a good choice because the controversial discovery of methane on Mars is still so difficult to understand that a new paper on methane is not desirable (Zahnle et al. 2011).

We propose instead a new biomarker completely overlooked in previous studies: beer. We argue this bio-marker is universal: everyone drinks beer and, contrary to wine and vodka, non-alcoholic beer does exist (Light 1988). Another robust piece of evidence is that beer is cheaper than water and sodas in most parts of the Earth (Carney 2013).

Furthermore, perhaps the only common ground amongst nations on Earth is that all make their own beer, promoting beer as the most universal and thus reliable biomarker to trace life on Earth, and by extension elsewhere in the universe. Last but not least, beer is known for its property to generate more liquid than what was ingested (Bladder 1601), making it superior to liquid water to that respect.

Like all possible alcoholic beverages, beer needs to be drunk responsibly; nevertheless, it is the human stupidity which is responsible for most beer-driven catastrophies[1]. Unfortunately, a world devoid of beer will still be prone to the worst tendencies for racism, misogyny and homophobia. Sadly, stupidity might even be a better biomarker than beer; measuring this quantity remotely is however impossible, which has the fortunate consequence that ALE-iens might still want to visit us humans, and thus benefit from favorable in-situ biomarkers such as love (Valentine 1999), heavy-metal music (Cannibal and Corpse 1990), and food (Ramsay et al. 1925). Despite their desirable qualities, the latter biomarkers are not as easily detectable and abundant as beer (Kingfisher and Cobra 2001), which remains by far the perfect biomarker in the Universe.

The technological leap forward that has been propulsed by modern astronomy now enables us to directly image planets in which the beer biomarker might not only be in gaseous phase but also in stable liquid phase at the surface. The breathtaking

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[1] The best known exemple is the London Beer Flood that happened on 17 October 1814 and caused the death of 8 people.

Fig. 1. *Direct imaging (right panel) of a beer planet using the ground-based coronagraph THIRSTY (Telescope HIgh-Resolution for Systems Transiting Yeast). This planet named THIRSTY-1664b orbits the 1664th host star detected by the THIRSTY instrument. North is up. The higher terrains seen in the northern hemisphere are informally called Sierra Nevada (note that all names are informal). The shape of craters (e.g. the giant Chimay crater) might indicate the presence of liquid beer, or at least beerthermalism. The dark plains in the southern hemisphere, named Ale Planitia, may be an evidence of ancient resurfacing by beer-volcanoes (akin to the seas on the Moon). The detached layers that can be distinguished close to the northern and southern polar regions could be related to the formation of high-altitude beer clouds. By comparison, an image of the Moon (not to scale) is shown on the left pannel.*

Figure 1, obtained recently with the ground-based coronagraph THIRSTY (Telescope of HIgh-Resolution for Systems Transiting Yeast)[2], features a direct imaging of a putative beer planet in which either liquid beer (Beer 2016) or beervolcanism (De Beer 1962) could have shaped the surface of the planet. The famous THIRSTY image also features a detached layer likely to be high-altitude clouds (Bohren 1987) made of liquid beer droplets (Beer et al. 2009). Such breakthrough imaging opens new perspectives not only on the importance of beer as a biomarker, but also on the concept of "Ha-beer-table Zone" i.e. the range of orbital distances to the stellar object in which liquid beer is stable in vast areas across the surface of the planet (Beer et al. 2008), stellar variability throughout geological ages being accounted for (Beer et al. 2006).

2. A quantitative assessment of the Ha-beer-table Zone

The Ha-beer-table Zone has remained thus far a theoretical concept seldom discussed quantitatively in the literature. In this section, we gather all the existing criteria for the stability of liquid beer and plot, for the first time, the Ha-beer-table Zone diagram. It is a groundbreaking result, whose applications to the terrestrial environment were also validated by the authors themselves through *in-situ* immersion in a beer jacuzzi.

2.1. Ha-beer-table Zone criteria

Several distinct criteria can be listed to help define the Ha-Beer-Table Zone.

The Homer Simpson criterion (Hintz 1997): The surface temperature of the planet shall remain between 10 and 20 degrees Celsius (283 and 293 Kelvins), which is the optimal temperature to conserve beer.

The Perrier-San Pellegrino criterion (Badoit et al. 1953) To maintain one's beer carbonated, one needs to pressurize it. Therefore, any computation of the Ha-beer-table Zone shall account for the pressurization of beers of various levels of carbonation. For various kinds of beers, Table 1 summarizes the CO_2 partial pressure needed to pressurize the beer.

Table 1. CO_2 volumes for various types of beers and associated CO_2 partial pressures (in bar). Adapted from the chart from Principles of Brewing Science. 1 volume of CO_2 corresponds to ~0.045 moles (= 2g) of CO_2 per liter of beer.

Type of beer	CO_2 volume	P_{CO_2}(10°C)	P_{CO_2}(20°C)
British Style Ales	1.7	0.75	1.3
Porter, Stout	2.0	1.0	1.7
Belgian Ales	2.2	1.2	1.9
American Ales and Lager	2.5	1.6	2.3
Fruit Lambic	3.7	2.8	3.8
German Wheat Beer	3.9	3.0	4.0

Table 2. Alcohol/ethanol partial pressures (in millibars) for drinks with various volumes of alcohol.

Alcohol by volume	molar concentration	$P_{C_2H_6O}$(10°C)	$P_{C_2H_6O}$(20°C)
3°	0.009	0.36	0.72
5°	0.016	0.64	1.3
7°	0.023	0.92	1.8
9°	0.030	1.2	2.4
11°	0.037	1.5	3.0
13°	0.044	1.8	3.5

The Clausius-Clapeyron-Henry-Budweiser criterion (Bud et al. 1971): For each type of beer, the partial pressure of ethanol $P_{C_2H_6O}$ will be different in the atmosphere, and a function of both temperature and concentration of alcohol $[C_2H_6O]_l$ in the beer ocean (see Table 2):

$$P_{C_2H_6O} = \frac{[C_2H_6O]_l}{H_{C_2H_6O}(T)}, \tag{1}$$

with $H_{C_2H_6O}(T)$ the Henry Weinhard's constant.

In summary, the three previous criteria tell us that atmospheres of beer planets should be composed of 0.7-4.0 bars of CO_2, as well as 0.-3.5 millibars[3] of ethanol.

The Sunburn criterion (Tan and Siebert 2004): UV photons are extremely harmful for the fermenting ability of yeasts (Tanner and Byerley 1934), and therefore could significantly spoil the taste of the beer. Depending on the amount of CO_2 (e.g. the level of carbonation) in the ocean of beer, a planet could have two different ways to be self protected from UV radiation and therefore to keep a good taste:

1. A low carbonated beer planet must have a significant ozone layer that is very efficient to absorb UV light.
2. A highly carbonated beer planet is expected to form a complete foam cover that should naturally protect the precious beer from UV radiation.

In any case, it has been shown, using the Beer-Lambert law (Beer 1852), that UV light should not penetrate deeper than few tens of meters in beer oceans (Cockell 2000). This also tells us that, even though it might be tempting to drink surface liquid beer when reaching (after a long journey) a distant beer planet, make no mistake, the best ale lies meters below.

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[2] the project was initiated more than 40 years ago by Beer et al. (1971).

[3] The 0 millibar case should be disregarded here, since we definitely do not want to lose our time to look for alcohol-free beer exoplanets.

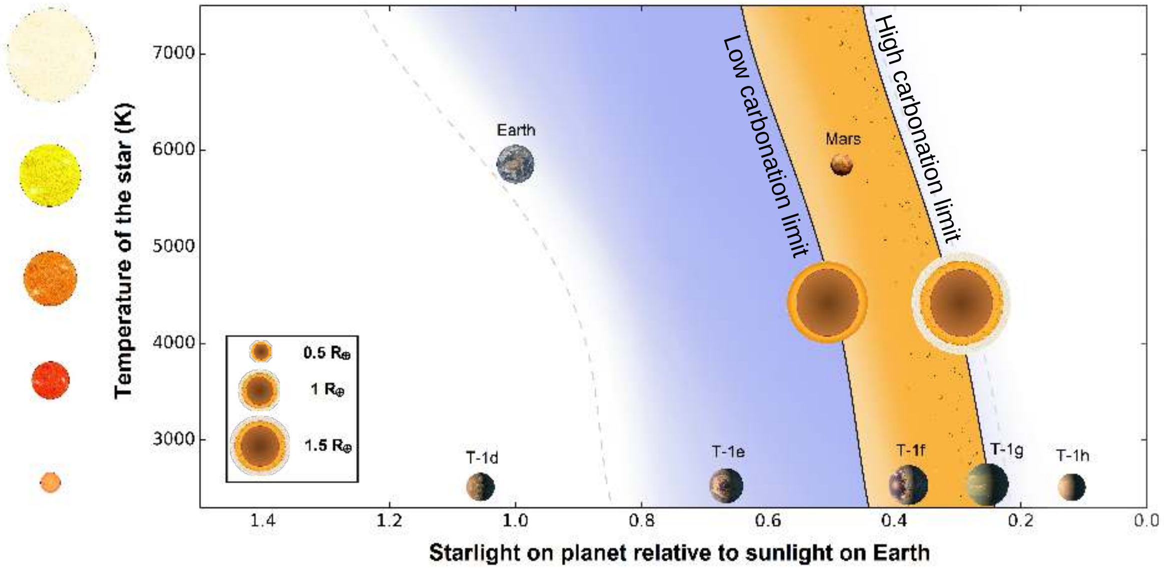

Fig. 2. *Diagram showing the radial extent of the Ha-beer-table Zone as a function of stellar temperature. As a comparison, dashed lines corresponds to the traditional limit of the old-fashioned Habitable Zone (Kopparapu et al. 2013).*

2.2. Inner and outer edges of the Ha-beer-table Zone - Low and high carbonation limits

Following the previous criteria, the inner edge of the Ha-beer-table Zone is set at the orbital distance for which a low-carbonated (P_{CO_2} = 0.7 bar), alcohol-free beer planet has a surface temperature of 20°C.

The outer edge of the Ha-beer-table Zone is set at the orbital distance for which a highly-carbonated (P_{CO_2} = 4 bars) beer planet with a high volume of alcohol (arbitrarily fixed at 11° in the present study; $P_{C_2H_6O}$= 2 millibar) has a surface temperature of 10°C.

There are three good reasons to preferentially hunt planets near the outer edge of the Ha-beer-table Zone:

1. Such planets are expected to maintain high surface pressures (up to 4 bars of CO_2) that tend to homogenize the temperature of the ocean of beer and thus favor its conservation. This is of high importance on tidally locked beer planets.
2. Such planets would 1) receive fewer UV flux and 2) form a thick layer of foam because they are expected to be highly carbonated. These two effects combined favor the protection of the beer.
3. A trivial and highly reasonable argument is clearly to look for planets where the degree of alcohol is higher.

2.3. Ha-beer-table Zone diagram

Using the DML (Draught Micro-Labrewatory) 3-D Full Global Climate Model[4] designed to simulate the climate of any kind of planets around any kind of stars, we computed both the inner and outer edges of the Ha-beer-table Zone, for various types of stars and various orbital distances. Our results are summarized on Figure 2. Implications of these results are discussed in section 3.

2.4. Going further

The climate of beer planets is not trivial to assess because of the many possible retroactions related to the beer surface properties.

As a first example, even weak tidal waves (induced by the star or close-in planets) could sufficiently shake the beer ocean so that a very thick layer of foam forms at its surface. This material is known to be both very porous and bright, and it is very likely that it will impact the diurnal surface temperatures and the cycles of beer condensation and sublimation. It is a challenging task to evaluate how long such a foam can subsist on the beer planet's surface with a changing thermal inertia. The stronger the waves, the thicker the foam and the longer it will remain on the surface. Further studies should also consider in detail how the presence of a thick layer of foam could affect the tidal dissipation of a beer planet and thus calculations of its orbital evolution.

In any case, significant progress could be made by laboratory experiments of:

- mechanical properties of foam for various kind of beers.
- reflexion spectrum of foam. This might be of importance around cool stars like TRAPPIST-1 as previously shown by Joshi and Haberle (2012).
- absorption spectra of ethanol-carbon dioxide mixtures for multiple sets of temperature and pressure.

Such measurements could be made extremely difficult because in-situ ingestion of alcohol by experimenters would significantly increase the size of the error bars.

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[4] The model includes a generalized radiative transfer designed for cocktails of beer atmospheres, and takes into account various processes such as the radiative effect of beer clouds and the surface albedo of foam.

3. Ha-beer-tability in the Solar System and beyond

3.1. Beer Planets in the Solar System

An unexpected corollary of the groundbreaking diagram in Figure 2 is that Mars is located in the Ha-Beer-Table Zone. It might explain the recent bursts of methane detected by the Curiosity rover (Webster et al. 2015), although further work is needed to confirm this possibility.

Fortunately, the presence of an underground yeast-rich ocean of beer on Mars might be tested by future missions of exploration on Mars like Mars 2020 or Exomars 2020.

3.2. TRAPPIST-1 is the first system in the Ha-beer-table Zone

After Mars, Kepler-62f, Kepler-1229b, Kepler-186f, GJ581d, TRAPPIST-1f and g are indeed the first planets in the Ha-beer-table Zone. However, preliminary 3-D climate simulations of TRAPPIST-1f - assuming a synchronous rotation - show that even though mean surface temperatures of 10-20°C could be achieved, the surface temperature is expected to reach locally temperatures as high as 40°C and as low as -10°C, giving the surface liquid beer an unpleasant taste. TRAPPIST-1g could be a well carbonated, alcohol-rich planet, as supported by 1) the Time Transit Variation (TTV[5]) analysis of the planet (Gillon et al. 2017) and 2) the fact that TRAPPIST-1 planets are today in a near-resonant chain, suggesting that the planets could have formed far from their star (beyond the beer-line) and migrated afterward to their current position. TRAPPIST-1g is therefore the best known candidate for ha-beer-tability outside our Solar System and 100% of James Webb Space Telescope (JWST)[6] observing time should be dedicated to characterizing the atmosphere of this potentially ha-beer-table planet.

Although we know from history that giving a name to a planet increases the probability that it does not exist (e.g. Vogt et al. (2010)), we cannot help but propose 7 names that should be adopted in the future for the 7 wonders of the TRAPPIST-1 system:

- **TRAPPIST-1b as *Achel the brown.***
- **TRAPPIST-1c as *Isid'or the amber.***
- **TRAPPIST-1d as *Trappe the blond.***
- **TRAPPIST-1e as *Chimay la bleue.***
- **TRAPPIST-1f as *Chimay la rouge.***
- **TRAPPIST-1g as *Chimay the gold-i-locked.***
- **TRAPPIST-1h as *Chimay la blanche.***

3.3. Beeruptions and implications

We examined the consequences of tidal heating for TRAPPIST-1 planets. Following Peale et al. 1979 one can predict the heating, and eventual extreme beervolcanism due to forced eccentricities. Assuming an Io-like rigidity $\mu = 6.5 \cdot 10^{11}$ dynes cm^{-2}, and a tidal heating factor $Q \sim 100$, we calculate that *Chimay la rouge* and *the gold-i-locked* - the two potentially habeertable planets of TRAPPIST-1 system - could experience reccurent beeruptions. If these events occur during transits, they could transiently and significantly increase the transit depth of the two planets. Even though preliminar analysis using Kepler/K2 data did not show any sign of beervolcanism activity (Luger et al. 2017), such detection could be attempted by rigorous follow-up observations of TRAPPIST-1 light curve.

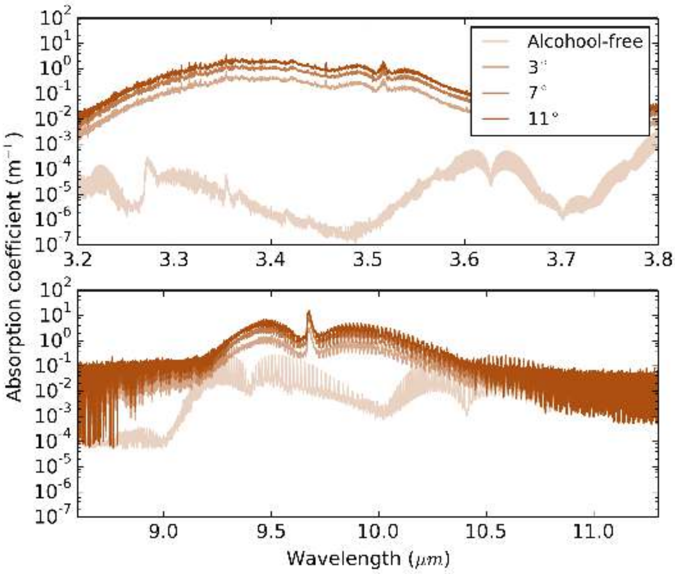

Fig. 3. *Synthetic infrared absorption spectrum of a beer planet, at P = 1 bar and T = 293K, for beer planets at several degrees of alcohol, and compared with a pure* CO_2 *(alcohol-free) atmosphere. Alcohol vapor and byproducts cause a significant rise of opacity from 3 to 4 microns, and from 8.5 to 10.5 microns. Our calculations use the HITRAN database (Rothman et al. 2013). Lack of data for ethanol forced us to use absorption lines of an excellent proxi: methanol (Harrison et al. 2012). We take therefore this opportunity to encourage the HITRAN consortium to set up absorption lines of ethanol. In any case, we looked for interesting spectral features at 1664 cm*$^{-1}$ *but did not find any.*

4. Beer: one biomarker to rule them all

A few bars of CO_2, a few millibars of alcohol, a cover of foam or an ozone layer; that's all you need to build the atmosphere of a beer planet. We computed the synthetic[7] spectrum of such atmosphere (see Figure 3) and found many interesting features that could be used to identify remotely beer exoplanets:

- Ethanol/methanol are very strong absorbents around 3-to-4 and 8.5-to-10.5 microns. Even light beer oceans are expected to generate atmosphere extremely opaque in the regions where ethanol and methanol absorb. Ethanol (in particular when associated to a gas like CO_2) is in fact a powerful greenhouse. This plays an important role in the calculation of the edges of the Ha-beer-table Zone (see Figure 2).
- Simultaneous measurements of 1) a strong CO_2 absorption (in particular around 2.8, 4.3 and 15 microns) and 2) a strong ethanol absorption (around 3.5 and 9.5 microns) would be an excellent biomarker to detect beer planets. In fact, given the high opacities of ethanol and carbon dioxide in their respective domains of absorption, it would be easy (assuming low flattening by beer clouds in the spectra) to characterize the presence and volume of alcohol of an ocean of beer on TRAPPIST-1 planets using JWST.
- Quantifying precisely these absorptions could not only reveal the existence of a beer planet, but also tell us the degree of alcohol in it. The link might not be straightforward though, because the amount of ethanol in the upper atmosphere might be limited by the saturation. This could bias

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[5] not to be confused with Time Turbidity Variation.

[6] even between two transits.

[7] Note that, although the spectrum is called "synthetic", the beer should be preferentially organic.

the measurement of the degree of alcohol in the beer planet. Such processes could be addressed in future studies.

- At any rate, an ethanol mixing ratio higher than few percents would indicate the presence of rhum/vodka/... at the surface of the planet. These scenarios are out of the scope of this paper but should be addressed as a high-priority science goal.

5. Concluding remarks

In this study, we calculated the boundaries of the so called Ha-beer-table Zone. We showed that planetary ha-beer-tability is critically dependent on the carbonation level of a potential beer ocean, as well as its degree of alcohol. From this definition, we derived a new combination of biomarkers that should be used in the future - in particular with JWST through transit spectroscopy - to detect and characterize beer planets.

We know that Earth-like planets, Jupiler-like planets... are common in our galaxy and by extension in the Universe. Following the discoveries of the TRAPPIST-1 planets, and given the large extent of the Ha-beer-table zone as calculated in our study, beer planets should also be extremely common in our galactic neighborhood.

More generally, our work raises the question of how extraterrestrial life would evolve on beer planets. At first sight, beer should be a solvent at least as good as water for life to emerge (Miller 1953). However, we are worried about what form would take natural selection on such planets and if drunk living organisms would really be able to evolve in what we - humans - call the intelligent life paradigm. If beer planets are really common, this is an alternative scenario that should be assessed to solve the Fermi paradox.

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