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Author for correspondence:
Manasvi Lingam,
Email: mlingam@fit.edu

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A brief history of the term 'habitable zone' in the 19th century

Manasvi Lingam

Department of Aerospace, Physics and Space Science, Florida Institute of Technology, Melbourne, FL 32901, USA

Abstract

The appellation 'habitable zone' in astrobiology in sooth evinces an overlooked and winding history that can be traced back to the 19th century. This paper sketches how this term from geography was generalized to encompass planetary habitability. The people involved in this narrative are numerous, but the bulk of their musings were rather nebulous. Yet, during this period appear the first true insights, although sadly this saga is not altogether sans blights.

Introduction

In modern parlance, the circumstellar habitable zone (denoted by HZ hereafter) is conventionally understood to encapsulate the area around a host star (or stars) where liquid water can theoretically exist on the surface of a terrestrial planet endowed with an appropriate atmospheric composition (e.g. Kasting 2010; Lingam and Loeb 2019). To quote one specific example of many, Méndez *et al.* (2020) recently defined the HZ as follows:

> …the circumstellar region around a star where a terrestrial planet with a suitable atmosphere could host liquid water on its surface.

The HZ paradigm has a long and labyrinthine history, further compounded by the fact that many of the early researchers in astrobiology opted to use alternative terminology instead. It is worth explicating this matter in greater detail by focusing on a select few instances. In the 1950s and 1960s, the astrophysicist Su-Shu Huang (1915–1977) authored a number of crucial papers in which the appellation 'habitable zone' was employed in its modern sense (Huang 1959*a*, 1959*b*, 1960). During roughly the same period, however, other publications utilized terms such as the 'ecosphere' (Strughold 1953, 1955; Dole 1964; Shklovskii and Sagan 1966) and 'liquid water belt' (Shapley 1953, 1959; Strughold 1956).

In the 1960s and 1970s, among the first quantitative estimates for the inner and outer edges of the HZ for solar-type stars via numerical climate models were presented. Most of these studies arrived at inner limits close to present-day bounds (cf. Zsom *et al.* 2013), but the outer edge was determined to be approximately 1 AU – a result that stands in contrast to modern formulations, which have yielded estimates of $\gtrsim 1.5$ AU (e.g. Zsom 2015; Ramirez 2018). Hence, the publications of this era, when viewed collectively (Budyko 1969; Ingersoll 1969; Sellers 1969; Rasool and de Bergh 1970), implied that the HZs of stars were very narrow and that planets with temperate climates ought to be correspondingly rare (Levenson 2015).

The best-known examples from the above epoch are the two important papers by Michael Hart from the 1970s that also recognized that stellar luminosity grows with time and the HZ migrates outwards accordingly (Hart 1978, 1979), thereby necessitating the introduction of the continuously habitable zone (CHZ) – the region around a star where clement conditions can be sustained over geological timescales. The width of the 4.6 Gyr CHZ for a Sun-like star as per Hart's modelling was only about 0.06 AU (Hart 1978). The discrepancy compared to subsequent treatments arose from a combination of inaccurate parametrization of the stabilizing carbonate-silicate cycle thereafter elucidated in Walker *et al.* (1981), insufficient precision in the radiative transfer modelling, and not taking certain poorly constrained environmental parameters (at that time) fully into account (Schneider and Thompson 1980; Kasting 2010; Levenson 2015).

It is necessary to appreciate at this juncture that the concept of the HZ is much older than the exact expression 'habitable zone' itself (e.g. Gonzalez 2005). In the renowned *Philosophiæ Naturalis Principia Mathematica*, Sir Isaac Newton (1643–1727) asserted that orbits associated with Mercury and Saturn would lead to the vaporization and freezing of Earth's liquid water, respectively (Newton 1687). The following sentences, in particular, merit reproduction[1]:

[1]The English translation of the relevant sentences can be found in p. 18 of the translation by Ian Bruce: http://www.17centurymaths.com/contents/newton/book3s1.pdf.

> Our water, if the earth were located in the orbit of Saturn, would be frozen, if in the orbit of Mercury it would depart at once into vapours. For the light of the sun, to which the heat is proportional, is seven times denser in the orbit of Mercury than with us: and with a thermometer I have found that with a seven-fold increase in the heat of the summer sun, water boils off.

Several studies in the 19th century opted to use 'temperate zone' in lieu of the HZ, of which the best known is arguably *Of the Plurality of Worlds* (1853) by the polymath William Whewell (1794–1866). In the treatise, Whewell (1855, p. 316) contended that:

> The Earth's Orbit is the Temperate Zone of the Solar System. In that Zone only is the play of Hot and Cold, of Moist and Dry, possible.

Quite intriguingly, the appellation 'temperate zone' has witnessed a renaissance of sorts in modern times (e.g. Tasker 2017), partly since it apparently avoids the pitfalls of conflating the two distinct notions of the HZ and habitability (Tasker *et al.* 2017).

If we restrict ourselves to the terminology 'habitable zone' *sensu stricto*, the earliest mention of this expression has been attributed to Edward Walter Maunder (1851–1928) based on research by Lorenz (2019, 2020), as revealed by these lines (Maunder 1913, p. 149):

> Round our Sun there is but a narrow zone in which a habitable world may circle; in this zone there is room for but few worlds, and we actually know of three alone, the Earth, the Moon and Venus.

It is the objective of this study to illuminate a small subset of the earliest explicit allusions to the 'habitable zone' and analyse in what respects they are similar to, or divergent from, the modern formulation of the HZ. It is evident that this endeavour ought *not* be regarded as definitive because, indubitably, there are myriad writings all the way up to the 19th and 20th centuries, both in English and otherwise, that remain marginalized and inaccessible for a variety of causes.

The HZ in the 19th century

Prior to embarking on the historical voyage to comprehend the metamorphosis of the HZ paradigm, a brief detour into the statistics of Earth-sized planets is warranted for reasons that will become apparent shortly hereafter.

Number of Earth-sized planets in the HZ

In our Solar System, upon examining the number of roughly Earth-sized planets that have clement temperatures amenable to the sustenance of liquid water, we would end up with a sample size of one – to wit, the Earth. Now, if we were to take a considerable leap of faith, and loosely apply the Principle of Mediocrity (also known as the Copernican Principle), we may conjecture that the mean number of roughly Earth-sized rocky planets in the HZs of stars (often denoted by $\eta_\oplus$) would be around unity – namely, $\eta_\oplus \sim 1$ in mathematical terms. However, the latent subtleties underpinning the Principle of Mediocrity are such that it cannot and ought not be invoked and deployed *tout court*, viz., without appropriate qualifications (Ćirković and Balbi 2020).

Several studies have attempted to gauge $\eta_\oplus$ for different spectral types, but the results vary by about an order of magnitude (Kaltenegger 2017), which is primarily a consequence of variations in the statistical techniques and the definition of $\eta_\oplus$ itself. Although the magnitude and the meaning of η continue to be debated, statistical analyses indicate that $\eta_\oplus \approx 0.3$ is feasible (Dressing and Charbonneau 2015; Zink and Hansen 2019), and that $\eta_\oplus \lesssim 0.9$ is realizable under optimal circumstances (Bryson *et al.* 2021); in contrast, it bears mentioning that more conservative estimates have been recently expounded by the likes of Pascucci *et al.* (2019) and Kunimoto and Matthews (2020). Thus, on the basis of the available data, our initial 'guesstimate' of $\eta_\oplus \sim 1$ might not be altogether unreasonable for certain spectral types; if this relation is approximately correct, the Principle of Mediocrity would constitute a useful heuristic *prima facie*.

We will now proceed to delineate a select few of the writings prior to Maunder (1913) that employed the appellation 'habitable zone' explicitly in the 19th century.

Explicit references to the HZ

In the period leading to the *fin de siècle* and even afterwards, the expression 'habitable zone' typically carried a rather divergent connotation compared to its present-day counterpart. The chief reason is that 'habitable zone' referred to the regions of the Earth's surface that were especially conducive and clement for humans; in other words, this phrase was almost exclusively utilized in a geographical context. This tendency was prevalent in not just English writings but also other European languages such as *zona abitabile* in Italian (e.g. Hugues 1884, p. 73), *zone habitable* in French (e.g. de Saint-Martin 1875, pp. 114–115), *zona habitable* in Spanish (e.g. Vilanova y Piera 1874, p. 106) and *bewohnbare Zone* in German (e.g. Günther 1879, p. 298). If we look further beyond into the mists of time (i.e. 18th century and earlier), the 'habitable zone' preserves its geographical connotations (e.g. Wyvill 1672; Raleigh 1677; Walsh 1743; Tiraboschi 1783).

Two key examples suffice to illustrate and underscore the preceding point. Camille Flammarion (1842–1925) – who published *La pluralite des mondes habites* (1862), a well-known early treatise on extraterrestrial life (Crowe 1986) – authored a French science fiction novel entitled *La Fin du monde* (1894). In this novel, Flammarion (1894, p. 240) wrote:

> As the habitable zone became more and more restricted to the equator, the population had still further diminished, as had also the mean length of human life, and the day came when only a few hundred millions remained, scattered in groups along the equator, and maintaining life only by the artifices of a laborious and scientific industry.

The second instance that we wish to highlight will seem quite unexpected at first sight: the famous *De La Démocratie en Amérique* published during 1835–1840 by the French historian and philosopher Alexis de Tocqueville (1805–1859). In this multivolume undertaking, De Tocqueville (1849, p. 467) opined that:

> Above its northern frontiers the icy regions of the poles extend; and a few degrees below its southern confines lies the burning climate of the equator. The Anglo-Americans are therefore placed in the most temperate and habitable zone of the continent.

Now, let us direct our attention to what may very well be the first modern, or semi-modern at the minimum, exposition of the HZ that originated in the closing decades of the 19th century. The monograph in question is *World-life: Or, Comparative Geology* (1883), a wide-ranging exploration of astronomy, planetary

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science, physics and geography by the United States geologist and biologist Alexander Winchell (1824–1891), which was reviewed favourably by contemporary scientists such as George Darwin (Darwin 1884). In this book, when discussing planetary habitability, Winchell (1883, p. 507) contended that:

> The earth, then, so far as we can reason, is in the middle of the habitable zone of the solar system, if our own natures are assumed as the criterion of habitability. On either side, the rigour of the physical conditions seems to proclaim our system a voiceless and lifeless desert.

The above quote illustrates that Winchell's conception of the HZ was markedly different from those of his contemporaries and much closer to that of our own era. Moreover, his emphasis on '*our own natures*' to gauge the boundaries of habitability is partly compatible with the modern formulation of the HZ. In fact, Earth-centric limits for habitability have been invoked to delineate the limits of the 'complex life habitable zone' (Schwieterman *et al.* 2019); see also Ramirez (2020) and Lingam (2020) for cognate analyses. Winchell's tome comprises a number of other notable statements about habitability, such as the hypothesis that tenuous or non-existent atmospheres would make the likes of the Moon, Mars and Mercury inhospitable to life (Winchell 1883, pp. 500–508). This study additionally contained some perspicacious musings on extrasolar planetary systems that warrant reproduction (Winchell 1883, p. 507):

> But there are other suns and other planetary systems, and other worlds which possess the conditions for habitability. When we look on the hosts of stars, and consider that if only one habitable planet wanders about each sun, we understand that the number of habitable worlds is countless.

Thus, if one sought to interpret the above lines very broadly and through a modern prism *ex post facto*, it might be asserted that Winchell was subscribing to the optimistic scenario with $\eta_{\oplus} \sim 1$, which is perhaps not too far removed from reality, as remarked at the beginning of Section ?? 'The HZ in the 19th century'. Among the other striking aspects of this book is the notion that one can study the geology of other worlds to comprehend Earth's geological evolution and *vice versa*, which was termed 'comparative geology' and 'astrogeology' (Winchell 1883, p. vii); the reader may consult Léveillé (2010) for a historical account of this topic.

All of the preceding facets must, however, be tempered by the sober realization that Winchell's writings, especially in the social sciences, were imbued with racist overtones and undertones (Livingstone 2008, 2010; Keevak 2011), of which the most unequivocal is probably *Preadamites, or a Demonstration of the Existence of Men Before Adam* (1880), a publication that continues to be adduced by white supremacists[2].

Conclusion

It is not an exaggeration to aver that state-of-the-art delineations of the HZ constitute one of the cornerstones of the burgeoning area of exoplanets (Kasting *et al.* 1993; Kopparapu *et al.* 2013, 2014; Ramirez *et al.* 2019). Notwithstanding the critiques levelled against this concept (Moore *et al.* 2017; Tasker *et al.* 2017), the HZ is arguably endowed with at least two major advantages: it has the merit of being simple (while concomitantly retaining complexity to an extent) and it functions as a pragmatic and efficient tool in guiding the detection and characterization of exoplanets that may harbour biospheres and their observable signatures. Other benefits accruing from the demarcation and usage of the HZ have been adumbrated in Ramirez (2018). It goes without saying, naturally, that habitability and the HZ are two broad frameworks with only a modest overlap and should not be conflated with each other (e.g. Cockell *et al.* 2016; Lingam and Loeb 2021).

In light of these considerations, it is worth fathoming how this term came to be employed in the multidisciplinary domain of astrobiology. This short paper traces the historical development of the expression 'habitable zone' and shows that it belonged exclusively to the realm of geographical allusions for the majority of the 19th century and earlier epochs. However, as this century hearkened to a close, the first truly modern glimmerings of the HZ paradigm appeared in the prescient treatise by Winchell (1883). Although certain claims in this monograph have proven to be incorrect, some of its prominent predictions – such as the definition of the HZ and the prevalence of Earth-sized planets in the HZ – stand up quite well to scrutiny even today; the same, however, does not hold true for some of Winchell's other contemporaneous writings.

Even though it may be tempting to shrug off the endeavour of tracing the shrouded origins of the HZ as scientifically irrelevant or merely a curio or trifle, an in-depth awareness of the convoluted historical process underlying the genesis and transmutation of the HZ can better inform us about the bygone roots of astrobiology and engender a deeper cognizance and appreciation of where the field might be headed in the turbulent 21st century[3].

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Conflict of interest. The author has no conflicts of interest to declare concerning this manuscript.

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[2]https://record.umich.edu/articles/u-m-remove-little-winchell-names-campus-facilities/.

[3]A thorough acquaintance with history of science widens our horizons, facilitates the retrieval of forgotten accomplishments, and permits the expansion of our current corpus of knowledge (e.g. Chang 2017).

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