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Infinite Worlds

The e-magazine of the

Exoplanets Division
of the
Asteroids and Remote Planets Section

The late Professor Stephen Hawking

Life elsewhere

Special issue 2024 April

Life elsewhere

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The book 'Astrobiology - Understanding Life in the Universe' by Charles S. Cockell, Professor of Astrobiology at the University of Edinburgh is a must read if you are interested in this subject. On the companion website can be found;

- slide sets for each chapter
- exam questions
- the Astrobiology Periodic Table

Is not easy to define 'life' but in his book Chrles S. Cockell quotes NASA scientist Gerald Joyce - life is "a self-sustained chemical system capable of undergoing Darwinian evolution".

Life on other planets may be vastly different to life on Earth and require quite different conditions for its existence so it will be hard to search for something we may not recognise as lifeforms.

Contents

1.0 Habitability

The Habitable Zone is the orbital region around a star in which an Earth-Like planet can possess water on its surface and possibly support life. Liquid water is essential to life on Earth and so the definition of a Habitable Zone is based on the hypothesis that extra-terrestrial life would share this requirement. Although more than 5000 exoplanets have been discovered the number of Earth-like planets can be counted on the fingers of one hand. Such an exoplanet is often referred to as Earth II.

Many factors affect exoplanet habitability as shown in Figure 1.1.

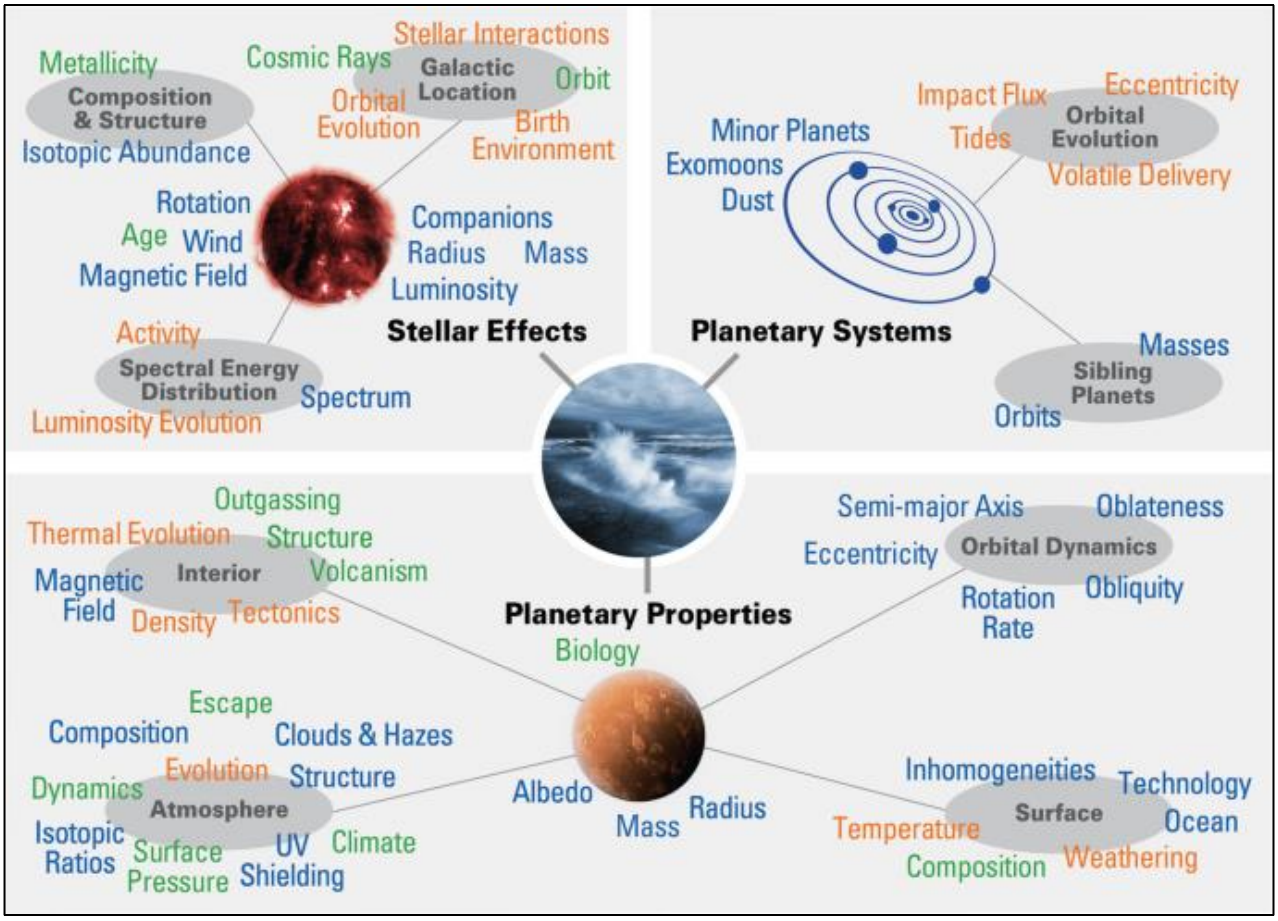


Figure 1.1. The many factors affecting exoplanet habitability from a paper by Meadows and Barnes

Figure 1.2 shows the Habitable Zone (HZ) for various classes of stars

- Hot; planets interior to the HZ are too close to their host star. For the Solar System this would be where Mercury and Venus reside
- Warm; in the HZ as we understand it and where Earth lives

- Cold; exterior to the HZ where Mars and beyond are found

Planets to the left of the dotted line will be tidally locked, always presenting the same face too their host star (as does the Moon to Earth). Life, as we know it, might find it difficult to survive on planets in the Habitable Zone around Red Dwarfs (K and M type stars) due to both tidal locking and highly active host stars.

For the Solar System the Habitable Zone will move outwards as our Sun warms up and Mars will perhaps become more able to support life and the Earth less so – perhaps in 300 to 450 million years' time (man-made climate change not included).

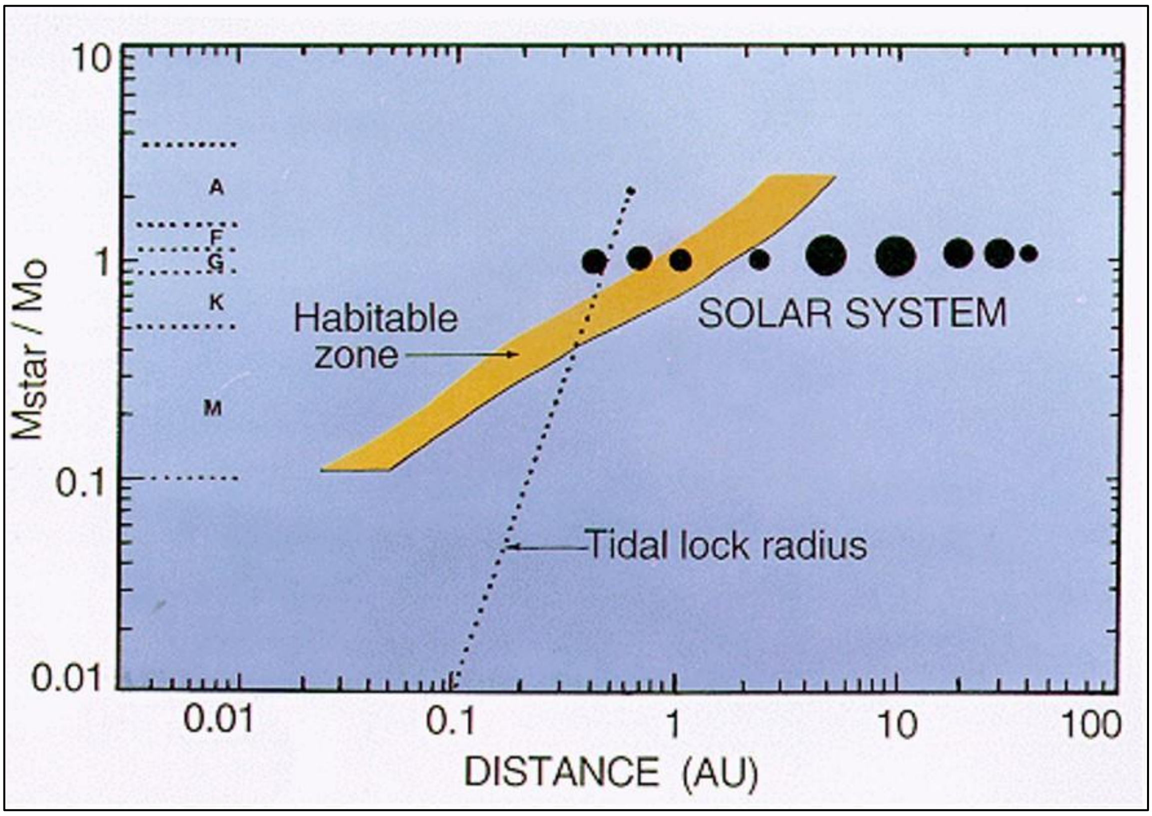


Figure 1.2. Habitable Zones Credit David Darling

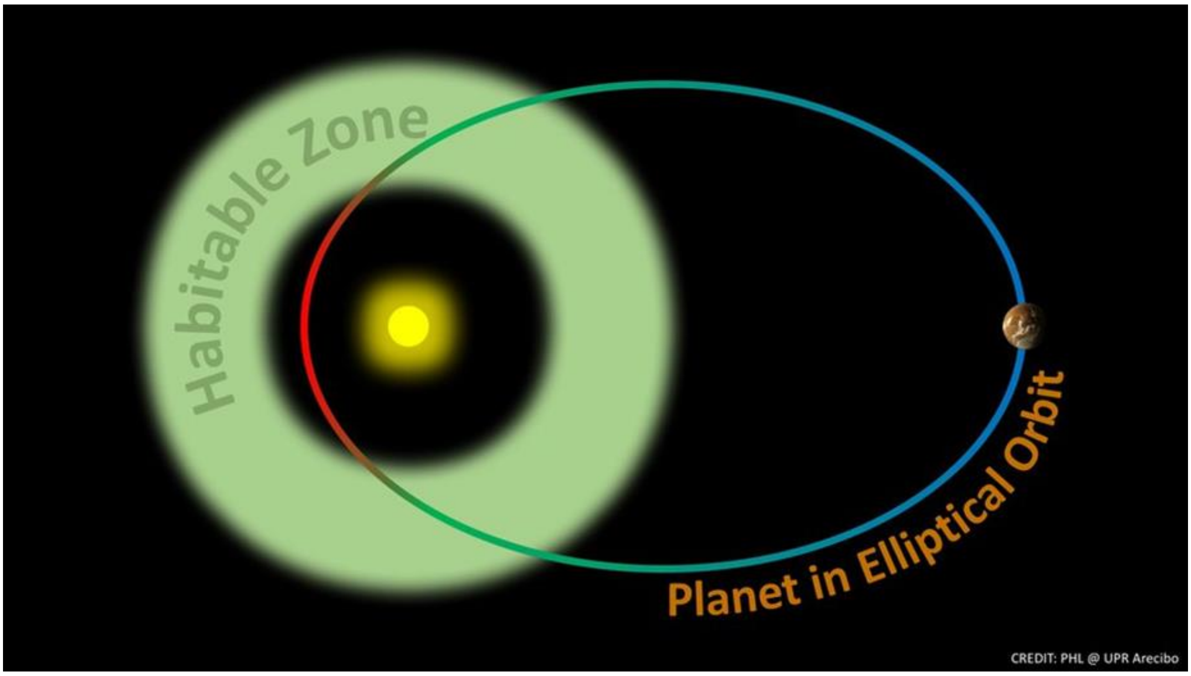


Figure 1.3. Eccentric orbit

A planet on an eccentric orbit, as shown in Figure 1.3, may spend only part of its time in the Habitable Zone and thus make it a little more difficult for life to flourish there.

Habitable Zones also exist on a Galactic and Universal scale

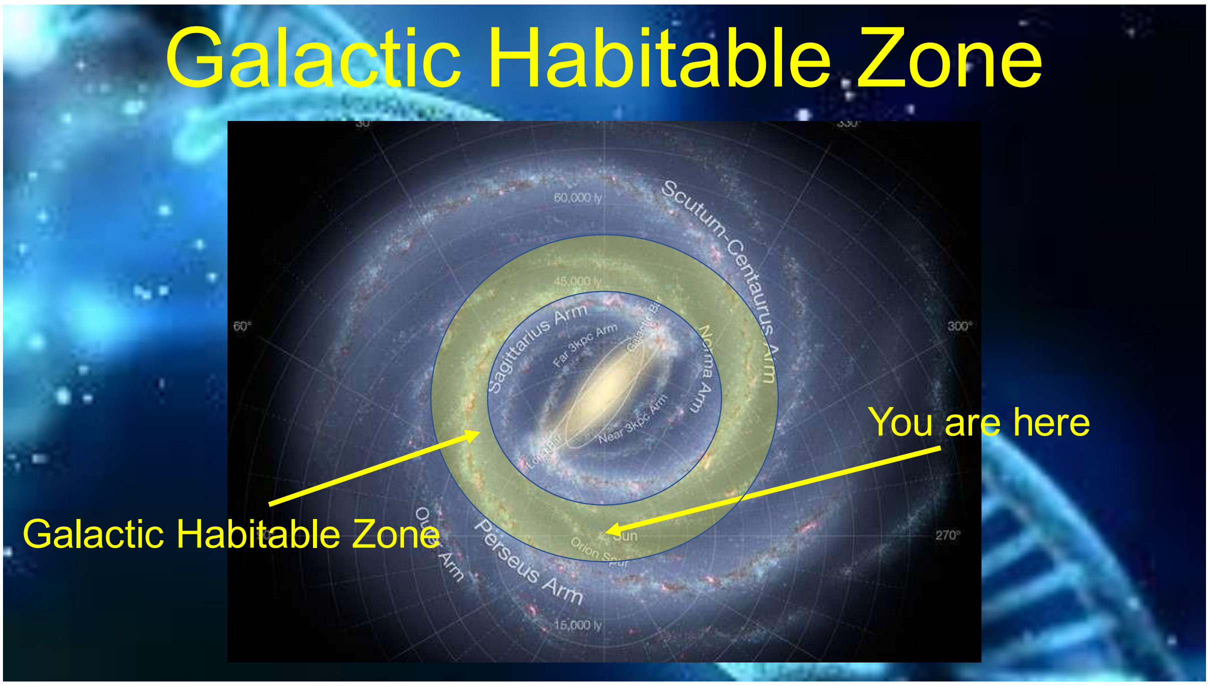


Figure 1.4. Galactic Habitable Zone

The Galactic Habitable Zone, Figure 1.4, extends from 23000 to 29000 light years from the centre of our galaxy and is composed of stars that formed between 8 and 4 billion years ago. The width of the zone is controlled by two factors;

- the inner limit is set by increasing threats to complex life from transient sources of ionising radiation including supernovae and gamma ray bursters
- the outer limit is imposed by galactic chemical evolution specifically the lack of heavier elements such as carbon

Globular clusters can be ruled out as they are quite densely packed with old stars so planetary systems might suffer from gravitational disturbances and the heavier elements will be lacking.

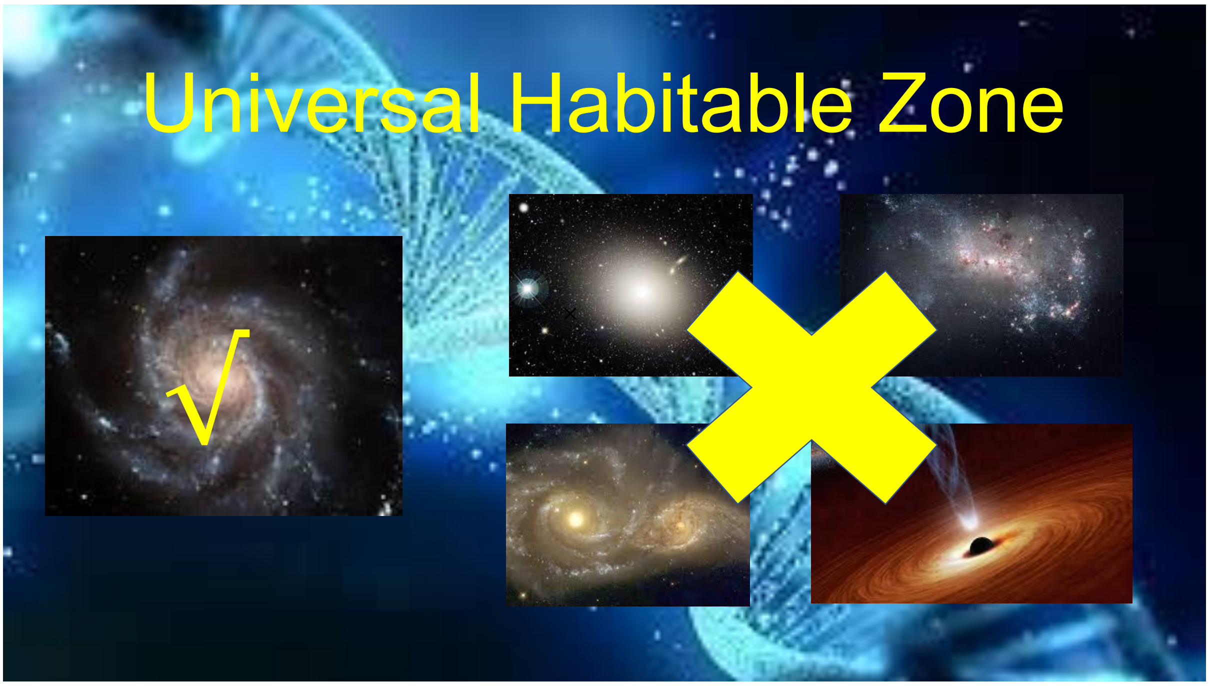


Figure 1.5. Universal Habitable Zones

Irregular and colliding galaxies and those with active nuclei, as shown on the right of Figure 1.5, may be too violent for life to exist due to supernovae, excessive radiation or gravitational influences. Spiral galaxies such as our own are more likely to harbour life but with the previously mentioned restrictions as to distance from the centre.

One theory suggests that there are multiple universes where conditions may or may not be suitable for life to exist.

For more information on stellar Habitable Zones and to calculate same for a particular star system visit The Habitable Zone Gallery, the Habitable Zone Calculator. or the Circumstellar Habitable Zone Simulator Habitability defines whether or not an exoplanet might support life so it is worth turning to the subject of astrobiology.

2.0 Astrobiology

The science of astrobiology seeks to answer the following questions;

- how did life originate and diversify?
- how does life co-evolve with a planet?
- are we alone or does life exist beyond Earth?
- what is the future of life on Earth?

A recipe; Life = Ingredients +oven + cooking time where Ingredients are;

- carbon most likely – can form complex molecules
- oxygen, Magnesium
- water to carry nutrients in and waste out

Oven (Environment)

- terrestrial planet at the right temperature in the habitable zone
- magnetic field to deflect charged particles and help retain atmosphere
- Sun like star (high mass stars die before life can develop, low mass stars are prone to flares
- free from extinction events
- stable thermal environment

Cooking time

- 4 to 8 billion years

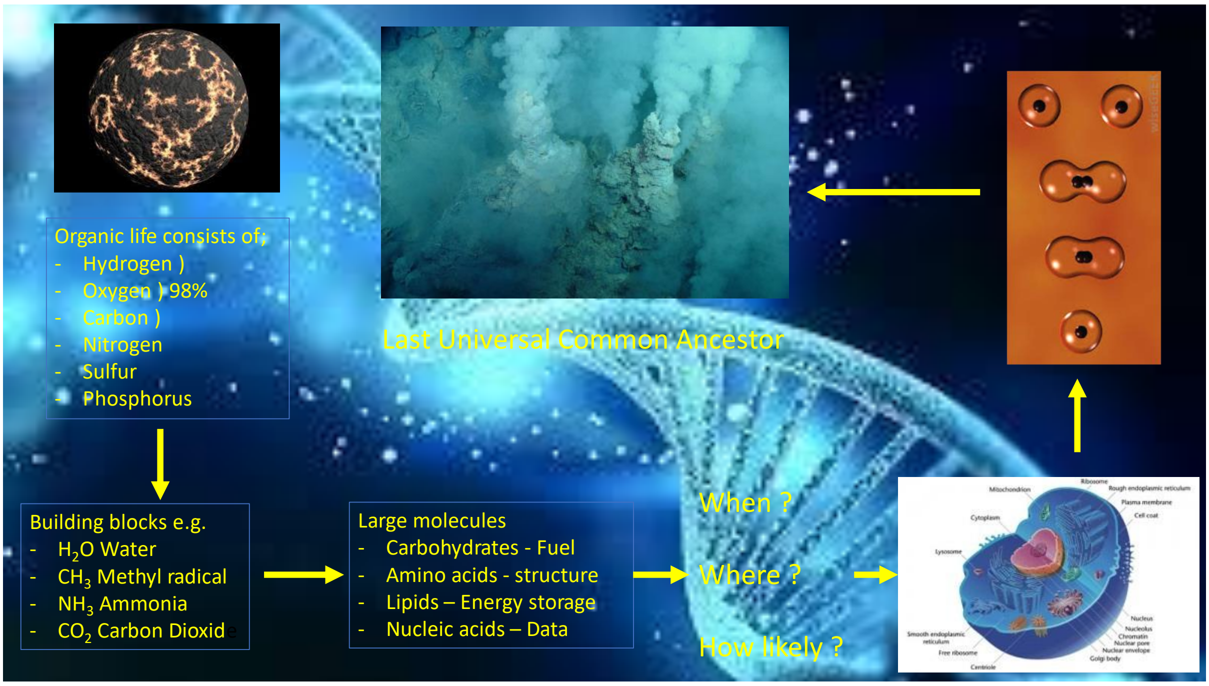


Figure 2.2. Evolution of life on Earth

Figure 2.2 shows how life evolved on Earth from several key elements to a multi-celled Last Universal Common Ancestor. The Earth was formed 4.5 billion years ago and the first life appeared approximately 750 million years after that.

Starting at the top left of the figure and moving in an anti-clockwise direction;

- Hydrogen Carbon and Oxygen make up 98% of the atoms in the human body
- 99 of organic life is made up of the above six elements which combine to form a small number of building blocks
- These building blocks combine to form four groups of large molecules
    - Carbohydrates – the fuel for cellular operations
    - Amino acids – the building blocks for proteins
    - Lipids – which store energy
    - Nucleic acids – which carry out information, communications and memory functions

Such building blocks were formed on the early Earth but how we got from them to self-sustaining, self-replicating cells is not yet fully understood and is the largest gap in our understanding of life's origins. Our Last Universal Common Ancestor emerged 3.5 to 3.8 billion years ago and most likely lived around deep-sea hydrothermal vents.

To achieve a stable thermal environment mentioned above requires;

- near circular orbit
- stable axial tilt
- not tidally locked – planetary rotation necessary to avoid excessive hemispheric heating and cooling
- high heat capacity i.e. oceans – to minimise temperature changes
- stable atmosphere e.g. oxygen levels not varying
- single rather than multi-star system which could lead to an unstable orbit

As to the future of life on Earth there is much discussion on the part Artificial Intelligence (AI) will play – will we rule it, will it rule us or will we learn to live together.

3.0 Is there life elsewhere in the Solar System?

3.1 Planets

Although it is known that early Mars was wetter, warmer and more habitable than today's freeze-dried desert world. The planet had seasonal weather similar to Earth's, with alternating wet and dry seasons, according to mud patterns discovered by NASA's Curiosity rover. These seasonal cycles may have helped form some of the more complex building blocks for life, such as RNA and basic proteins but researchers have yet to find direct proof that life ever graced its surface.

Although life as we know it is almost certainly impossible in the harsh conditions on the surface of Venus, it's possible that it could survive in the Venusian atmosphere. Although Venus' lower atmosphere contains toxic clouds of sulfuric acid, at higher levels the conditions are much less deadly.

3.2 Moons

Life might exist on certain of the moons of Jupiter and Saturn. ESA's JUICE (Jupiter Icy Moons Explorer) mission to Ganymede, Europa and Calisto may give us some clues. Is due to arrive at Jupiter in July 2031 The Cassini spacecraft found water, methane, carbon dioxide and complex organic molecules in plumes emanating from the moon's surface

4.0 Are we alone?

4.1 How many civilisations? - the Drake Equation. Earth is nothing special we are told and, if that is the case, then maybe life, as we know it, is also nothing special. So, the question is ‘Are we alone or is the universe teeming with life?’

Frank Drake produced is now famous equation in an attempt to estimate the number of advanced civilisations in our galaxy;

N = R* x fp x ne x fl x fi x fc x L where with some estimates;

R* = average rate of star formation in our galaxy = 1/year
fp = fraction of stars which have planets = 0.2 to 0.5
ne = average number of planets per star that has planets which can support life = 1 to 5
fl = the fraction of such planets which develop life = 1
fi = the fraction of such planets on which intelligent, civilised life has developed = 1
fc = the fraction of such civilisations which have developed communications = 0.1 to 0.2
L = the length of time for which these civilisations have transmitted detectable signals = 1000 to 100,000,000 years

The answer is somewhere between 20 to 50,000,000 in the Milky Way alone so the situation is perhaps best summed up as the late Sir Patrick Moore was fond of saying ‘We just don’t know’.

4.2 How many habitable planets?

Habitable for humans that is as the possible requirements for intelligent alien life are unknown.

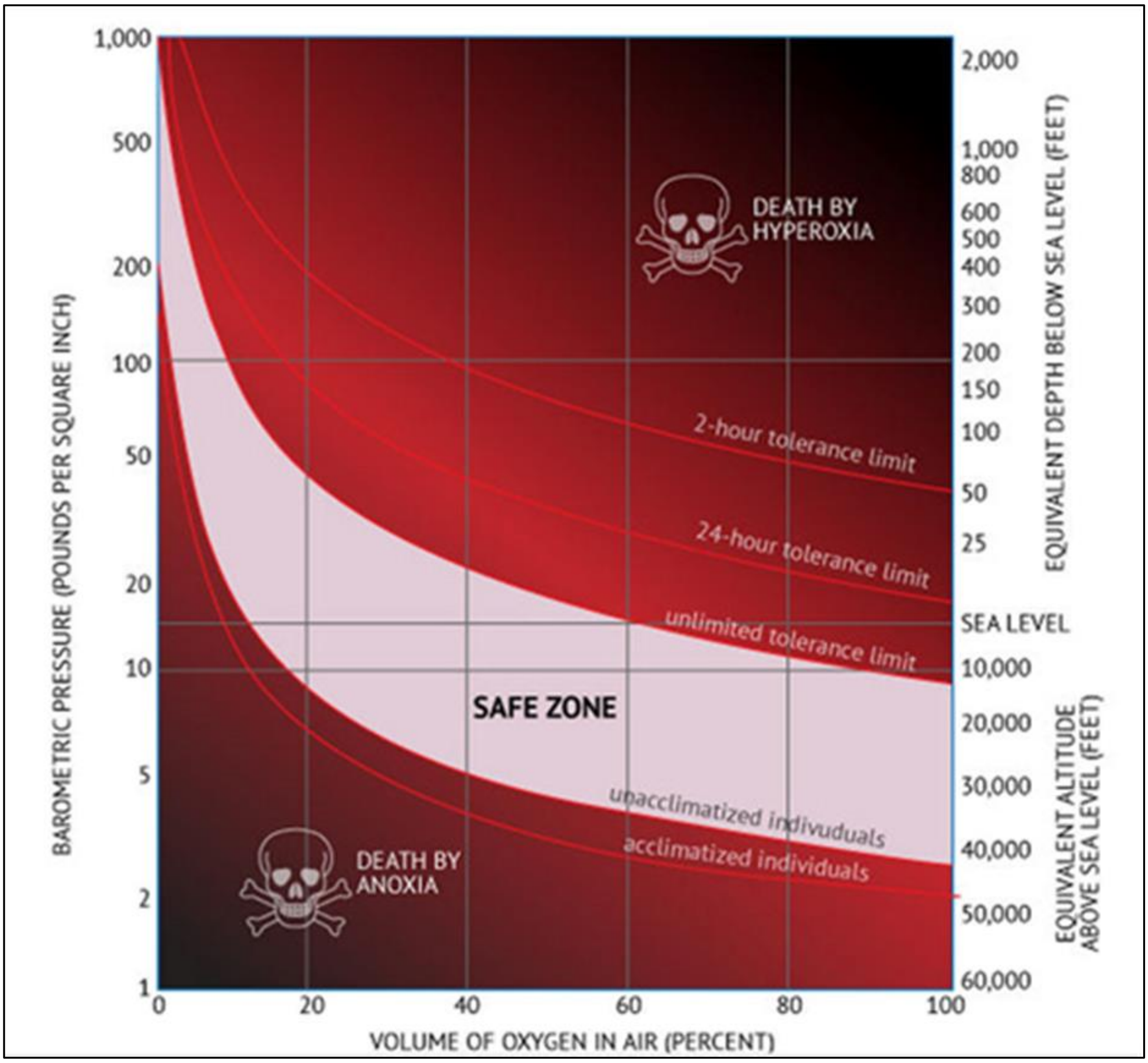


Figure 4.1. Oxygen vs atmospheric pressure Credit MPR News

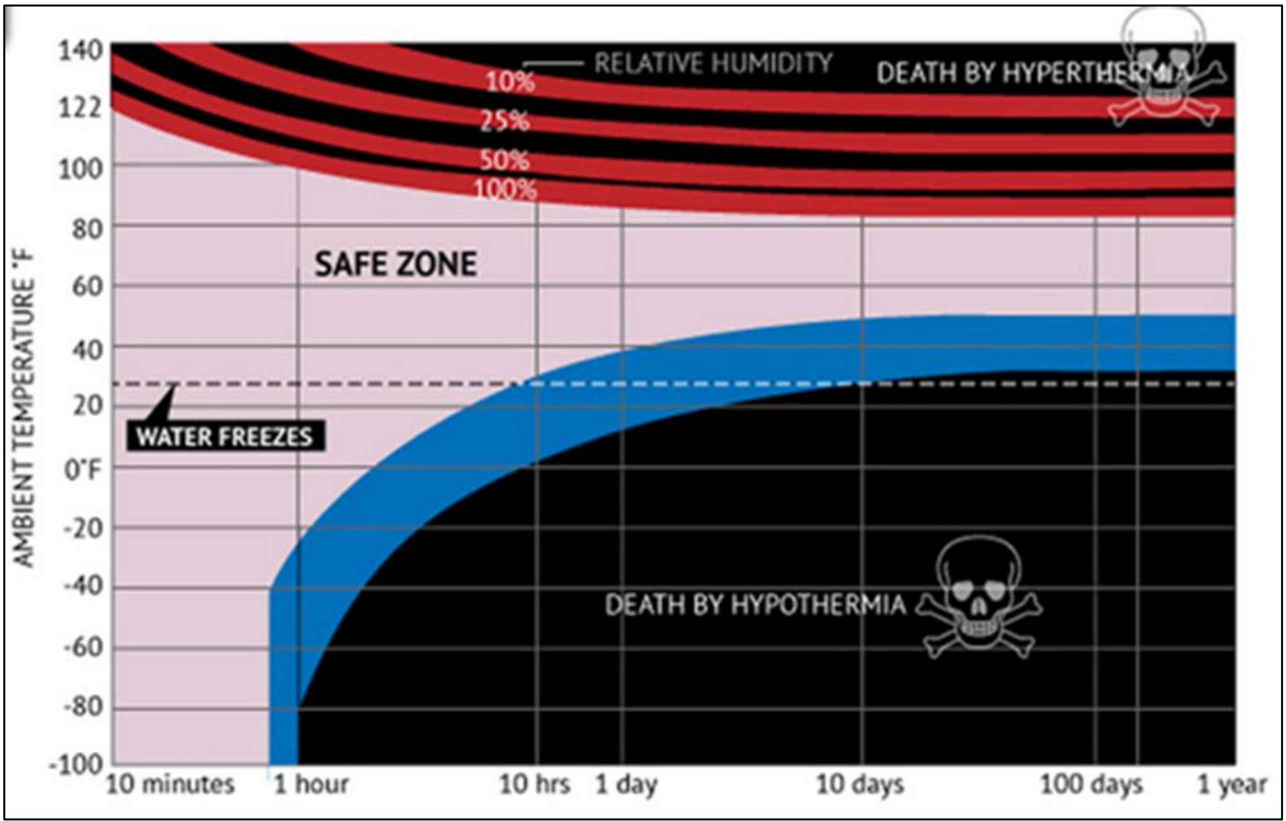


Figure 4.2. Temperature vs duration Credit MPR News

Figures 4.1 and 4.2 show the oxygen levels and temperature necessary for humans to exist. Other forms of life can exist far outside these restrictions and so may extraterrestrial life.

There are various lists of potentially habitable exoplanet;

- https://en.wikipedia.org/wiki/List_of_potentially_habitable_exoplanets - 61 of which 3 orbit Sun-like G-type stars
- https://phl.upr.edu/hwc/data - 70 of which 4 orbit Sun like G-type stars

Based on Kepler space telescope data there could be as many as 11 billion Earth sized planets orbiting in the habitable zones of Sun-like stars.

4.3 The search for life beyond Earth

A subject once not taken seriously is now very much mainstream.

There have been, and are, numerous attempts to contact and detect extra-terrestrial life e.g;

- the golden record on Voyagers 1 and 2 (1977)

- the plaque on Pioneers 10 and 11 (1973)
- the Arecibo message (1974)
- Teen Age Message (TAM) sent form the Yevpatoria 70m dish located in the Crimea
- Cosmic Calls 1 and 2 interstellar radio messages (1999 and 2003)
- Project Ozma by Frank Drake using the Green Bank radio telescope (1960)
- Soviet scientists searched for ET radio signals (1960s)
- Ohio State SETI program – the Wow signal but not detected again (1977)
- SERENDIP, Berkeley University SETI Research Center (1979 on going)
- Oak Ridge Observatory Suitcase SETI (1983 to 1985)
- META and BETA (1985 to 1999)
- NASA Microwave Observing Program (MOP) (1992 to 1993)
- Project Phoenix (MOP resurrected under Jill Tarter) (1995 to 2004)
- SETI Allen Telescope Array (SETI@home) (2007 to 2020)
- Breakthrough Listen based at Berkeley University (2015 on going)

Two current areas of research are detecting biosignatures and technosignatures.

Biosignatures include atmospheric and surface (vegetation) time related changes. A paper 'Exoplanet Biosignatures - A Review of Remotely Detectable Signs of Life' by Schwieterman and others reviews advances in assessing biosignature plausibility, including novel methods for determining chemical disequilibrium from remotely obtainable data and assessment tools.

Potential atmospheric (gaseous) biosignatures are;

- Oxygen (O_2) and Ozone (O_3)
    - Oxygen is produced by photosynthesis
    - Ozone is the result of oxygen molecules being broken apart by ultraviolet light and then recombining – indicates the presence of Oxygen
- Methane (CH_4)
    - Waste product produced by e.g. cows, sheep, goats; decaying organic material; microorganisms. termites, rice agriculture

Nitrous Oxide (N_2O)

- Decaying plant matter produces Nitrogen in this form

Sulfur-bearing gases e.g. dimethyl sulphide (CH3SCH3 or DMS)

Methyl chloride or chloromethane (CH3CL)

Potential because some of them can be produced abiotically (non-living means) as well as biotically (living means)

A technosignature is any measurable property or effect that provides scientific evidence of past or present technology. Technosignatures are analogous to biosignatures, which signal the presence of life, whether such life is intelligent or not.

On 26-28 September 2018 NASA hosted the Technosignatures Workshop at the Lunar and Planetary Institute in Houston, Texas, to learn more about the current field and state of the art for technosignatures searches and what role NASA could possibly play in the future in these searches.

4.4 Is anyone out there?

What if no-one is out there?

The Fermi Paradox

If there are billions of stars with planets around them intelligent civilizations should have developed on some of those planets

We would expect that perhaps by now we would have been visited by alien intelligences

Why have we not found any extraterrestrial intelligences?

Why have they not visited Earth?

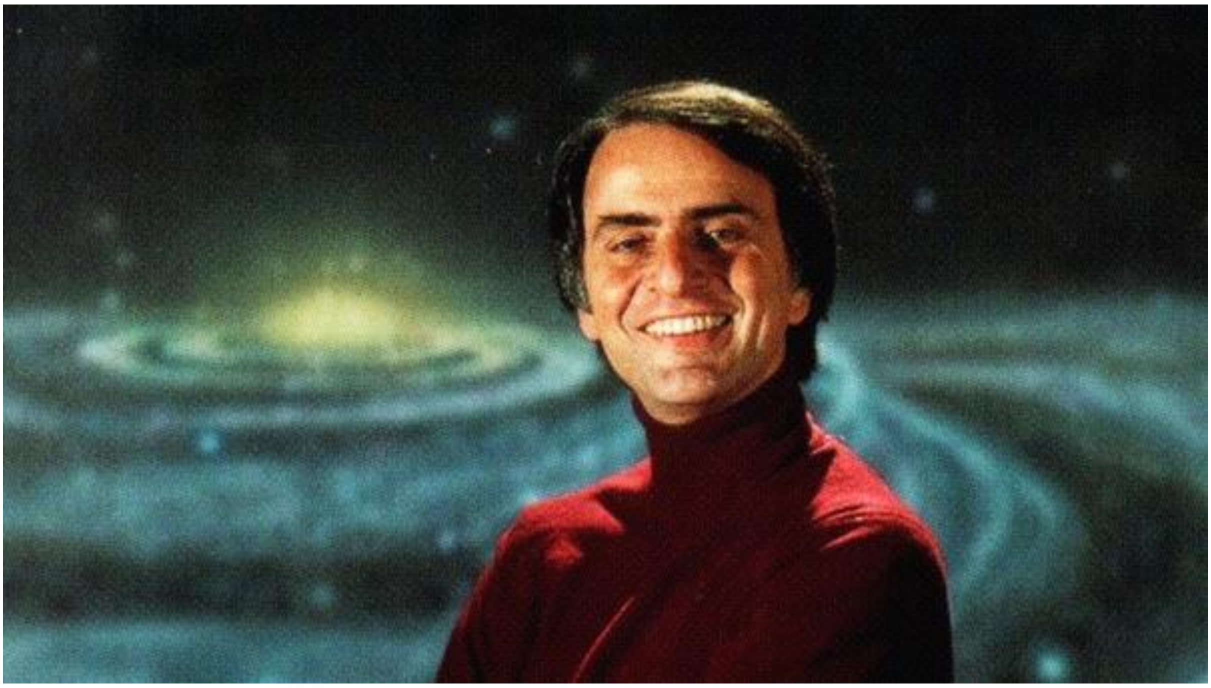
What if someone is out there?

Should we communicate or not?

How would we communicate?

Who should communicate?

Would they be welcoming?



The late Carl Sagan stated ‘The universe is a pretty big place. If it’s just us, seems like an awful waste of space’

The search continues……….

5.0 Resources

5.1 Books

The Goldilocks Enigma – Why is the Universe Just Right for Life by Paul Davies
Homo Deus – A brief History of Tomorrow by Yuval Noah Harari
How to build a habitable planet – The Story of Earth from the Big Bang to Humankind by Charles H. Langmuir and Wally Broecker
If the Universe is teeming with life where is everybody? Fifty solutions to the Fermi’s Paradox and the problems of extraterrestrial life by Stephen Webb
The great silence – The Science and Philosophy of Fermi’s Paradox by Milan M. Ćirković
Extraterrestrials – Where are They? Edited by Ben Zuckerman and Michael H. Hart
The Impact of Discovering Life Beyond Earth by Steven J. Dick
The Hunt for Alien Life – A Wider Perspective by Peter Linde
Astrobiology -Understanding Life in the Universe by Charles S. Cockell

The Contact Paradox by Keith Cooper

How to Find a Habitable Planet by James Kasting

5.2 Websites

Astrobiology

Coursera https://www.coursera.org/

- Astrobiology and the search for extra-terrestrial life

- Astrobiology: Exploring other worlds

- Emergence of life

European Astrobiology Institute http://europeanastrobiology.eu/

Heidelberg Initiative for the Origins of Life (HIFOL)

IAU online courses in astrobiology http://astrobiovideo.com/en/search#en

NASA https://www.nasa.gov/

– Astrobiology at NASA https://astrobiology.nasa.gov/

– NASA Astrobiology Institute https://nai.nasa.gov/

The Virtual Planetary Laboratory

UK Centre For Astrobiology https://www.astrobiology.ac.uk/

IAU online courses in astrobiology http://astrobiovideo.com/en/search#en

Habitability

Habitable Zone Gallery http://www.hzgallery.org/

Planetary Habitability Laboratory http://phl.upr.edu/home

– Habitable Exoplanets Catalogue http://phl.upr.edu/projects/habitable-exoplanets-catalog

The search for life beyond Earth

Center for Astrophysics Harvard and Smithsonian – Does life exist outside of the Solar System; https://www.cfa.harvard.edu/big-questions/does-life-exist-outside-solar-system

NASA Exoplanet Exploration; https://exoplanets.nasa.gov/search-for-life/are-we-alone/

Berkeley SETI Research Center https://seti.berkeley.edu/

– Breakthrough Listen https://seti.berkeley.edu/listen/

– SERENDIP https://seti.berkeley.edu/SERENDIP.html

– Astropulse http://setiathome.berkeley.edu/ap_info.php

Breakthrough Initiatives https://breakthroughinitiatives.org/

– Breakthrough Listen http://breakthroughinitiatives.org/initiative/1

– Breakthrough Message http://breakthroughinitiatives.org/initiative/2

– Breakthrough Watch http://breakthroughinitiatives.org/initiative/4

– Breakthrough Starshot http://breakthroughinitiatives.org/initiative/3

Planetary Society http://www.planetary.org/

– SETI http://www.planetary.org/explore/projects/seti/

– Optical SETI (OSETI) http://www.planetary.org/explore/projects/seti/optical-seti.html

– SETI Institute https://www.seti.org/

- SETI Post-Detection Hub; https://seti.wp.st-andrews.ac.uk/

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