NASA SPACE APPS CHALLENGE, 2023

Project StarPath

Planet Asterion

Local Event: Mahendragarh, India

Habitable Exoplanets: Creating Worlds Beyond Our Own

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PLANETARY MASS & SATELLITE

Exoplanets may be classified broadly based on their masses, which are traditionally compared with those of the planets in our own solar system. The divisions are, in decreasing order of mass:

- Gas giant
- Neptunian
- Super-Earth
- Terrestrial

Of these, gas giants and neptunian planets have extremely high masses and no solid terrestrial surfaces which prevent human habitation. Their atmospheres are very dense and cyclonic, similar to Jupiter in our system. Due to this, we can confidently exclude these categories from consideration and instead focus on the remaining two. As per the NASA Exoplanet Catalog, of the 5523 confirmed exoplanets discovered, 1674 are super-Earths while only 199 are terrestrial. Though this may be influenced by the technological levels of previous generation telescopes, it fits in with a trend of higher-mass planets in foreign star systems. Due to this, the existence of a planet similar to the one hypotheses by us is greater with a super-Earth (mass up to 10 times that of earth). For sustaining human life, a higher planetary mass than M_E has many advantages over a lower fractional value.

- Better interior heating, leading to a longer lifespan of the planet's core; tectonic plate activity
- Stronger magnetic field which blocks harmful solar radiation
- A thicker atmosphere is retained due to higher surface gravity

For human settlement on the planet however, the load on the body must be taken into account. Astronauts and experimental test pilots regularly experience high g-loads during training and on the job, but this is only for relatively short intervals of time and cannot be a benchmark for long term habitation. It is found that we can live under gravitational acceleration of up to 1.5 g (max.) for sustained periods.

After taking these factors into consideration, the mass of our planet was fixed to be 1.35 M_E ($\approx$0.0042 M_J), which is found to be relatively common and consistent with super-Earth findings. Proportionally, the mean surface gravity will be 1.35 g.

No	Exoplanet's Name	Radius (Rjup)	Mass (Mjup)	Semi Major Axis (AU)	Eccentricity	Orbital Period (days)				
1	AU Mic d	0.0898	0.0032	0.0847	0.001	12.7381				
2	CD Cet b	0.1284	0.0124	0.0185	0	2.2907		AVG MASS (Mjup)		
3	CoRoT-24 b	0.33	0.018	0.056	0	5.1134		0.01460505051	≈	0.0146
4	EPIC 201170410 b	0.0934	0.0036	0.0349	0	6.7987				
5	EPIC 201238110 b	0.167	0.0149	0.1346	0	28.1656				
6	EPIC 201757695 b	0.081	0.0022	0.0296	0	2.0478				
7	EPIC 201833600 c	0.089	0.0031	0.0416	0	3.9615				
8	EPIC 201841433 b	0.093	0.0036	0.035	0	4.1698				
9	EPIC 205950854 c	0.117	0.0082	0.0623	0	8.0507				
10	EPIC 206024342 b	0.152	0.0136	0.0521	0	4.5076				
11	EPIC 206032309 b	0.09	0.0032	0.0239	0	2.8781				
12	EPIC 206042996 b	0.145	0.013	0.049	0	5.2971				
13	EPIC 206215704 b	0.08	0.0021	0.025	0	2.2537				
14	EPIC 211939692.01	0.232	0.0202	0.1875	0.16	26.8549				
15	EPIC 211939692.02	0.232	0.0202	0.2428	0.06	39.553				
16	EPIC 212297394 b	0.118	0.0084	0.0319	0	2.2894				
17	EPIC 212424622 b	0.194	0.0171	0.1397	0	18.0983				
18	EPIC 212499991 b	0.143	0.0129	0.2025	0	34.885				
19	EPIC 212587672 b	0.1	0.0046	0.1185	0	15.2841				
20	EPIC 212737443 b	0.231	0.0291	0.098	0.2	13.603				
21	EPIC 212737443 c	0.24	0.0303	0.28	0	65.55				
22	GJ 15A b	0.1199	0.0095	0.072	0.094	11.4407				
23	GJ 160.2 b	0.1526	0.0245	0.079	0.02	9.7471				
24	GJ 163 b	0.162	0.0311	0.06	0.02	8.6312				
25	GJ 163 c	0.1516	0.0239	0.124	0.03	25.637				
26	GJ 163 f	0.1474	0.0214	0.326	0.04	109.5				
27	GJ 176 b	0.1533	0.025	0.066	0.08	8.7748				

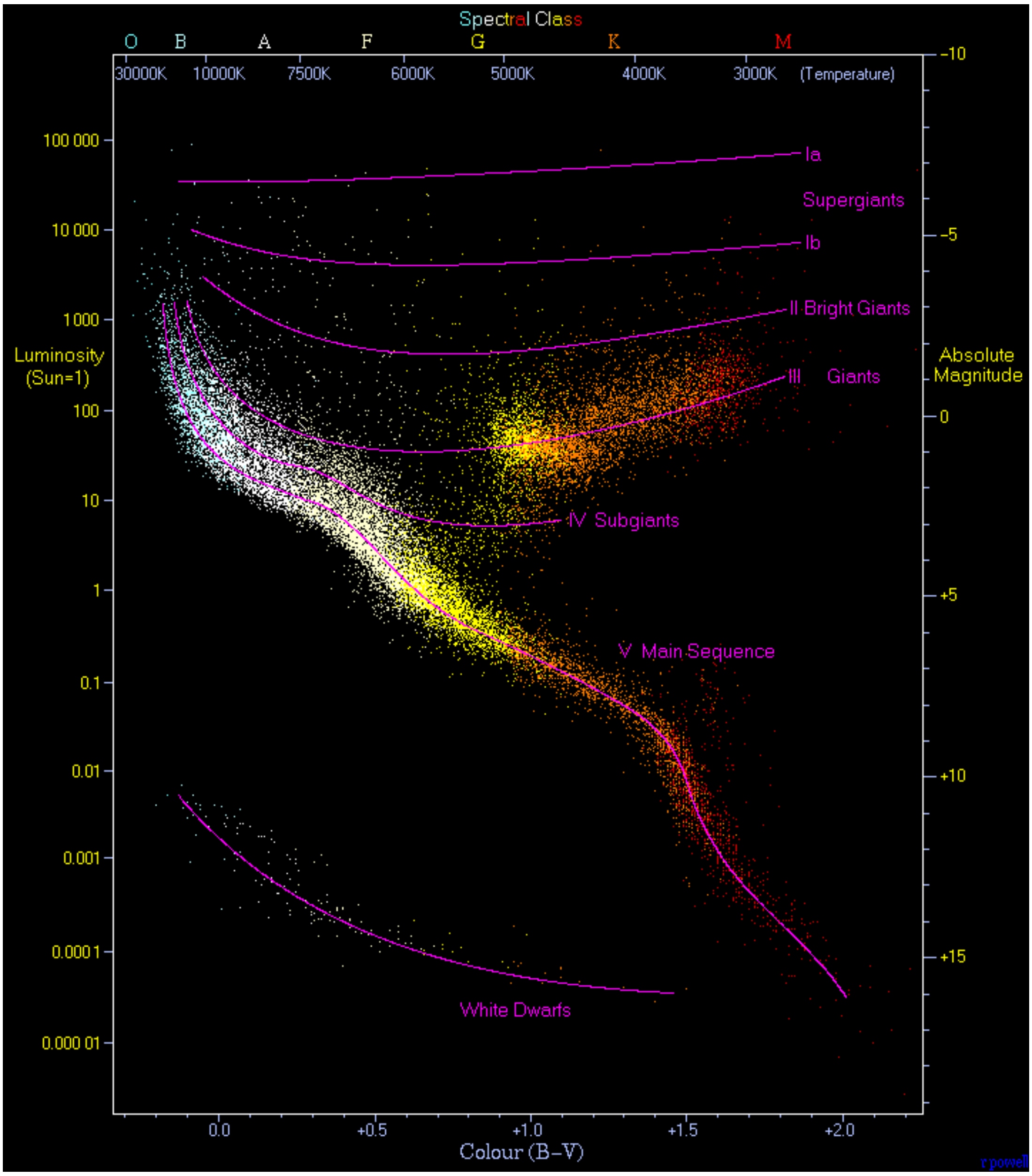
[Above: The dataset collected from ExoKyoto; Data points credit: Kyoto University, http://www.exoplanetkyoto.org/?lang=en]

We accessed the open source ExoKyoto database which classifies exoplanets on a large scale and selected the first 100 planets (excluding Earth itself) which were included under the super-Earths category. We found that the average mass in this dataset was ~0.0146 Jupiter-masses (M_J). The percentage of planets with our specified mass of 1.35 M_E was calculated to be 11%.

Natural satellite:

The planet has a moon with 5% of the planetary mass, i.e., 0.0675 M_E. This is extremely helpful as it supports the formation of tides in surface water bodies and magma cycling underneath the crust, promoting ideal conditions for life to form.

HOST STAR CHARACTERISTICS



[Above: A Hertzsprung–Russell diagram, plotting luminosity against star colour; Credit: Richard Powell]

All stars in the universe are classified based on their temperature and luminosity (which depend on mass), and the categories are marked from hottest to coolest as:

- O
- B
- A
- F
- G
- K
- M

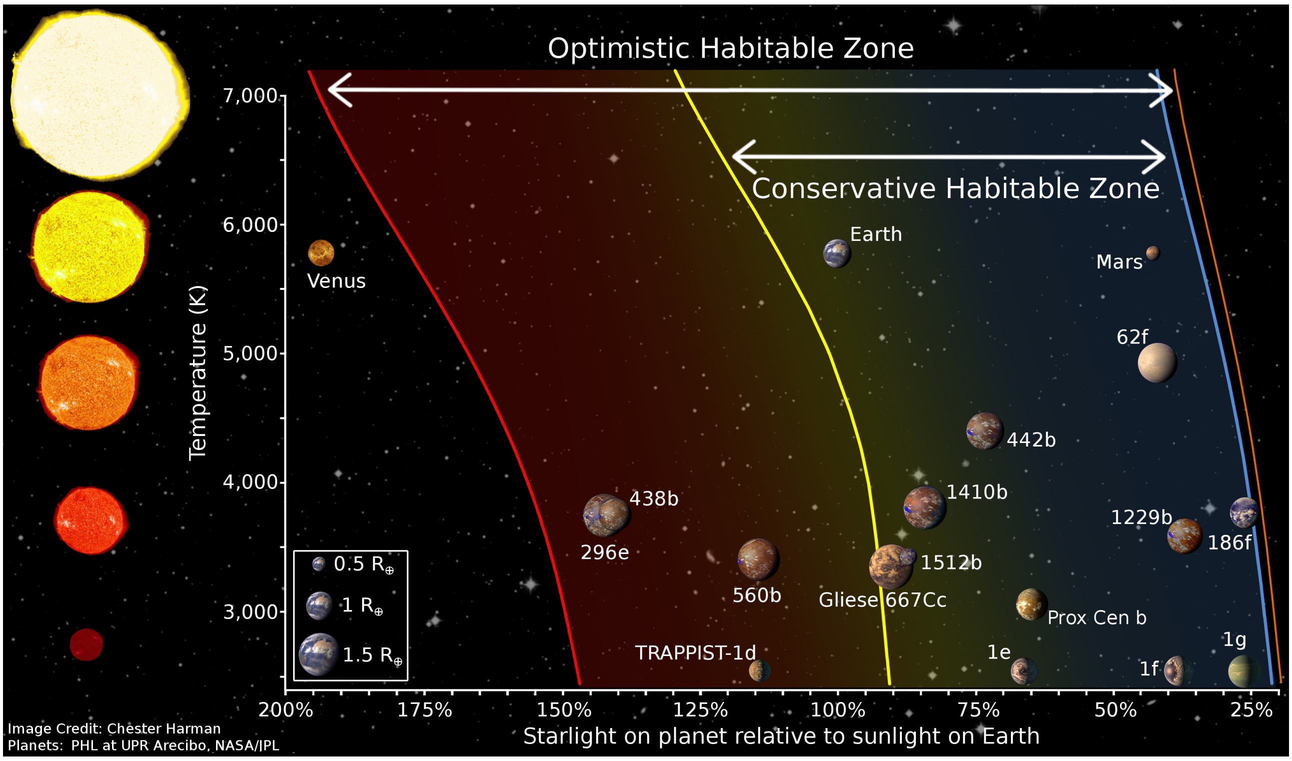
The most common stars in the galaxy are the M-type red dwarfs. These have lifespans of over 100 billion years, which is suitable for the formation of a habitable planet. However, as they are small and dim, their habitable zones are very close to the star: this exposes an orbiting planets to extremely high levels of solar surface phenomena, X-rays, UV-rays, etc. This is enough to completely sterilise and eradicate earth-like life present on the planet's surface and does not make it viable for human settlement. Furthermore, closely-orbiting planets may become tidally locked, leading to early water loss.

The Sun (Sol), is a G-type or yellow-dwarf star in the middle of its lifespan.Though its system is the only one known to support life, it may not be the most suitable host type when designing an ideal planet, since they are both rarer and short-lived (approx. 10 billion years) which might not give time for life to mature on other exoplanets. In addition, young G stars were observed to have a very fast rotation which causes it to emit high levels of radiation and spew solar matter towards surrounding planets.

Stars larger than the Sun (O, B, A, F types) have even shorter lifespans and are highly unstable due to their fast fusion rate and high mass, which results in violent star-deaths in the form of supernovae, annihilation any and all orbiting stars in their habitable belt.

This leaves us with the last category: the K-type stars, better known as orange dwarfs. They are less luminous and slightly cooler than the Sun; they burn steadily for a much longer time. The temperature of these stars is around 3500-5000 kelvins. Their stellar activity is much more stable and benign. Due to this, they provide a balance between the smaller M- and larger G-type stars, making them the best host star environment for habitable planets. The K-type star provides a stable source of energy and warmth and so, they are called 'Goldilocks Stars'. This is why we have chosen it as the host star for our planetary system.

HABITABLE/ GOLDILOCKS ZONE



[Above: Graph showing different ranges of habitable zones. Credit: Chester Harman; NASA/JPL]

The concept of the Habitable Zone, often fondly referred to as "the Goldilocks zone," represents a celestial sweet spot within the void of outer space. It's a region encircling a star's orbit where conditions are just right—neither scorching hot nor frigidly cold—for the presence of liquid water, that precious essence of life shared by all known organisms, including us, *Homo sapiens*. In our quest for survival and the search for habitable dwellings beyond Earth, our first and foremost mission is to pinpoint planets residing within this revered Goldilocks Zone. These celestial realms offer us a compelling promise of potentially stimulating the delicate seeds of life, creating harmony between our species and the universe itself.

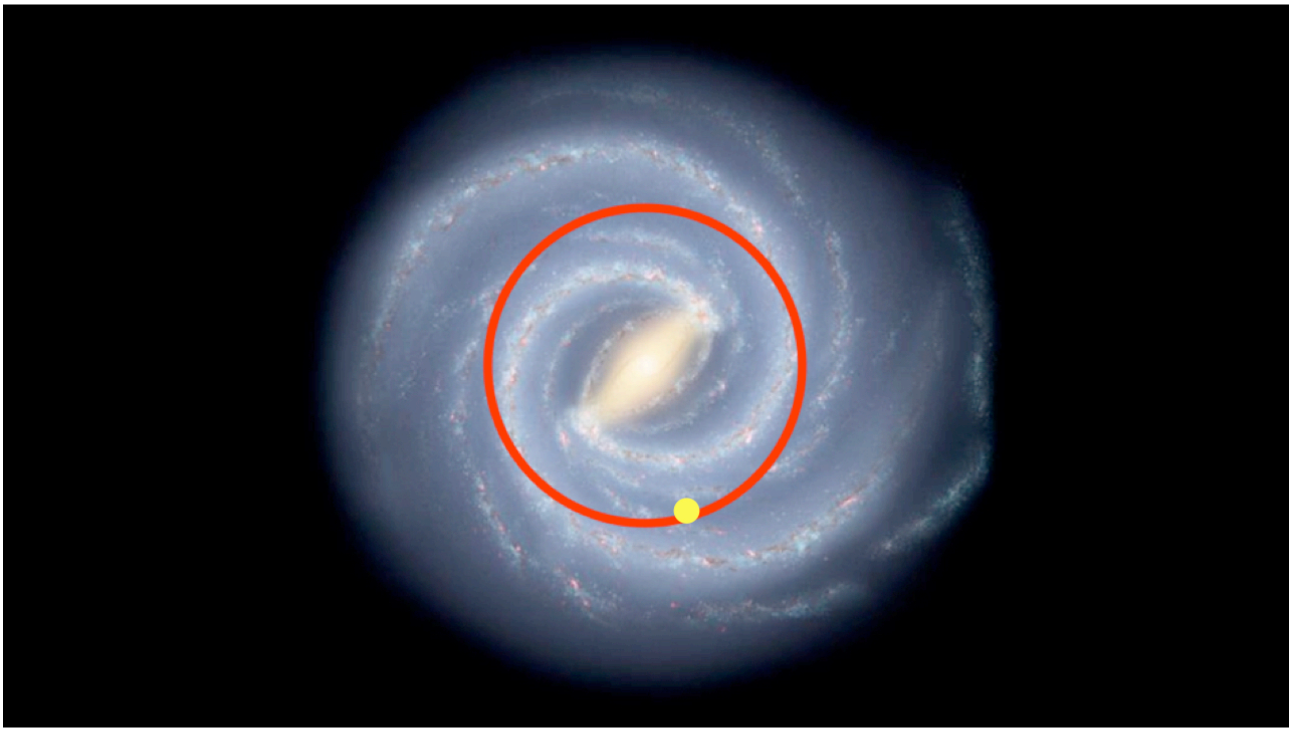
• **Spectral Type of the Host Star:** The type and sub-class of the host star are crucially significant. Spectral types indicate a temperature sequence, ranging from hotter to cooler stars (The K dwarf stars are Ideal for our search of habitable zones as they tend to have a long lifespan, which would allow enough time for the development of complex organisms. It also tends to give out weaker amounts of radiation.). A star's temperature directly influences the traits of its Goldilocks Zone, affecting the quantity and distribution of radiation received by planets within that zone.
The simplified equations provide a starting point for understanding the Goldilocks Zone, it's important to recognise that multiple complex factors must be considered for a more accurate estimate of a planet's potential habitability.
• **Atmospheric Composition:** The gases in a planet's atmosphere are equally important in temperature regulation. Variations in atmospheric composition can impact the planet's ability to retain solar energy and, in turn, influence its overall temperature.

The Binary Star Systems:

Binary star systems are characterised by the presence of two stars held together by gravity, orbiting each other. Planets that exist within such systems are categorised as either S-type or P-type. S-type planets orbit a single star, while P-type planets orbit both stars. Depending on specific conditions, Earth-sized planets can be situated within the habitable zone (HZ) of the primary star.

However, it's crucial to note that the radiation emitted by the secondary star can influence the boundaries of the binary system's HZ. Additionally, gravitational interactions with the secondary star can impact a planet's orbit and temperature. Unstable and eccentric orbits, as well as fluctuating temperature, are a major setback in the habitability of an exoplanet. Due to these reasons, we have not chosen a binary system, but instead opted for a classic single star system.

GALACTIC HABITABLE ZONE



[Above: A representation of an orbit in the habitable zone of the Milky Way galaxy. Image credit: NASA/JPL-Caltech/R. Hurt; Diagram credit: Hugh Ross]

The Milky Way is a remarkable vast spiral galaxy, one among the billions of galaxies that occupy the observable universe. The star system of our Sun (Sol) stands as the singular known star system in the universe where life, as we know it, has been observed to thrive. This incredible feat is mostly attributed to the notion of the Galactic Habitable Zone (GHZ), a region within a galaxy where life is most likely to develop.

The GHZ is a region that balances several crucial factors for the emergence and upkeep of life. It lies neither too close to the galactic centre, nor too far away. This careful positioning is paramount because both extremes present problematic challenges to the prospect of life.

If a planetary system were to be situated too near the centre of the Milky Way, life as we know it could not be maintained. This hazardous zone is exposed to and bombarded with cosmic hazards, which include extreme emissions of gamma rays, cosmic rays, and X-rays. Supernova explosions and meteor/planetary debris are also dominant, as the gravitational pull from the densely packed stars in this central cluster sends matter hurtling toward any possible planetary systems.

Hydrogen and helium are the primordial elements of which stars are formed. Other elements like iron, oxygen, etc. are formed in the cores of stars due to stellar fusion activity. Hence, in astronomy and astrophysics, all elements other than hydrogen and helium are referred to as

metals. These are crucial ingredients for the development of planetary systems, as they play a fundamental role in the formation of planets and, ultimately, the emergence of life.
In the extreme outer regions of the Milky Way, the scarcity of said metals and heavy elements hampers the creation of rocky planets on which life is possible within stellar systems.

Furthermore, the spiral arms of the Milky Way, while visually captivating, can be treacherous for potential life-bearing planetary systems. The presence of numerous stars and other celestial bodies within the spiral arms poses threats that include gravitational disruption, radiation, and potential collisions with other objects.

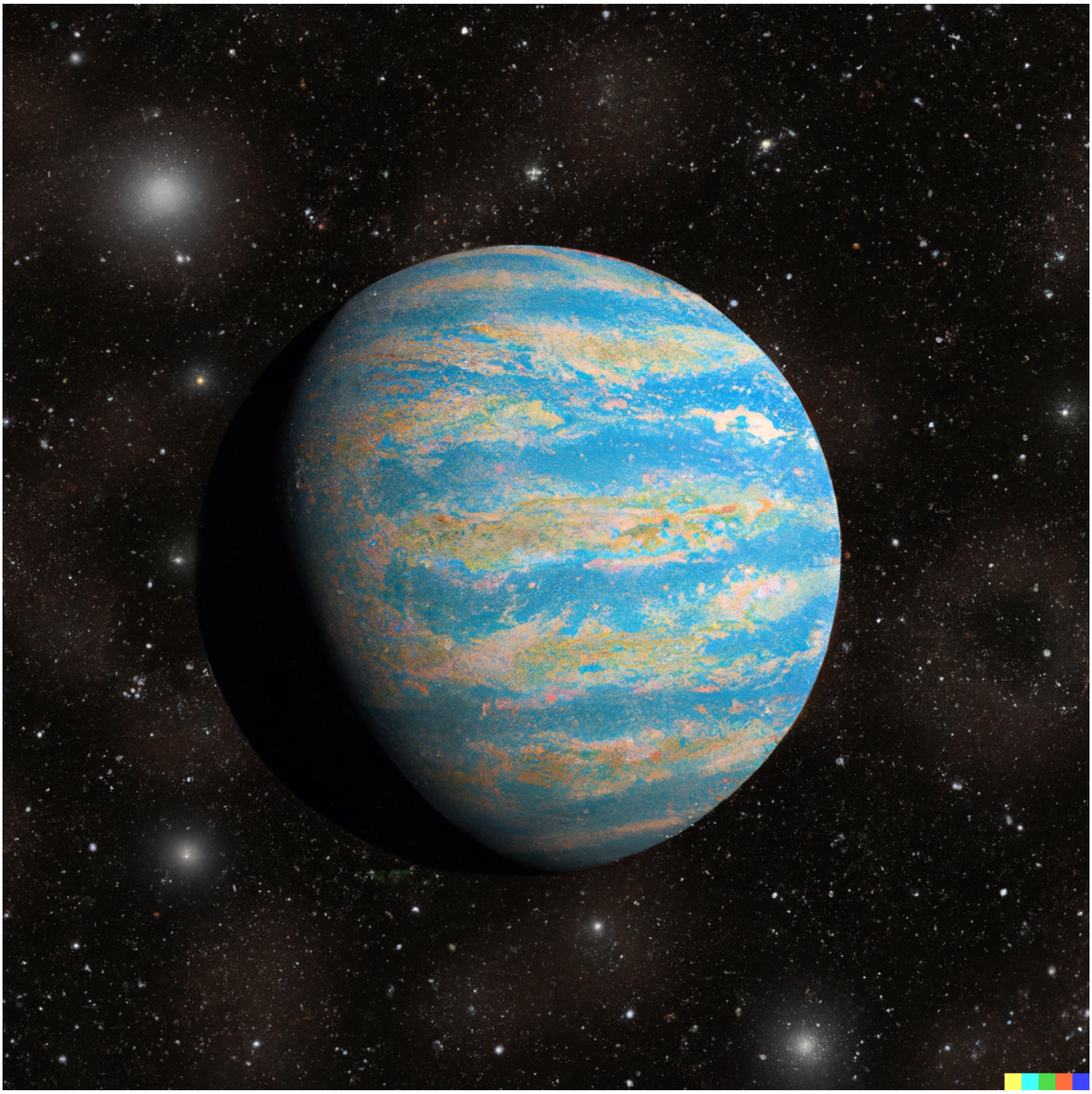
Taking all these factors into account, the optimal location within the Milky Way's GHZ for a habitable planetary system to form lies in the region between the outer boundary and the galactic centre, strategically set between two spiral arms.

In light of these considerations, we have chosen to locate our planetary system in the outer boundary of the GHZ, precisely between the Perseus arm and the Scutum-Centaurus arm of the Milky Way Galaxy. These two arms are among the most prominent and stable spiral arms within the galaxy. Our planetary system is positioned approximately 29,352 light-years from the galactic centre, which is home to the supermassive black hole known as Sagittarius A*, and it is located at a distance of 2,352 light-years from our own Solar System. A sufficiently advanced humanity which has perhaps mastered cryogenic sleep for long duration spaceflight might be able to travel to this star system to colonise it.

The system orbits the galactic centre in a circular path, maintaining a velocity of approximately 180 kilometres per second (648,000 miles per hour). This trajectory is carefully selected to minimise any contact with the potentially unsafe regions associated with the spiral arms, ensuring the safety and stability of our planetary system.

ASTERION: OUR EXOPLANET

As our planet contains large bodies of liquid water, we wanted to choose a name symbolising the eternal relationship between life and water. 'Asterion' is a river god in Greek mythology, and the name translates to 'starry'. In many ways, rivers are the paths of water. Therefore, the name of our exoplanet being Asterion is directly linked to our team name, Project StarPath.



[Above: An original AI render of the exoplanet Asterion]

A SPECULATIVE JOURNEY OF THE DISCOVERY OF EXOPLANET ASTERION IN THE FUTURE BY NASA'S HABITABLE WORLDS OBSERVATORY (HWO)

Context:

The search for another pale blue dot culminated with the discovery of planet Asterion by NASA's Habitable Worlds Observatory (HWO). The most remarkable out of the initial discoveries was the presence of water, that is, roughly 80% of the planet is covered in water bodies. Another striking feature was the presence of vegetation, which indicated that the planet was not a barren water world. These promising signs and subsequent findings by exoplanetary probes led to Asterion being declared as the ideal exoplanet for human colonisation.

Overview:

The exoplanet Asterion has a larger mass (1.35 ME) when compared to Earth and as a result exerts a gravitational acceleration of roughly 1.35 g-forces on its inhabitants. Human beings are capable of adjusting to this level of g-force for sustained periods. There is only a very slight tilt of 8° in the axis of the planet and therefore there are no noticeable seasonal variations in the different regions of the planet. The column of atmosphere is marginally thicker and denser than the Earth's. This could result in a shorter and stockier built for the human colonisers over a large period of time as the human population increases. The atmospheric composition is similar to that of our home planet, with 25% oxygen, 70% nitrogen, 3% carbon dioxide and the remaining 2% argon, krypton, neon, water vapour and other gases. This makes the air readily breathable and suitable for carbon-based life forms. Average temperature of the planet is or 293.15 K with maximum recorded temperature of 330 K and the lowest being 177 K.

Geographic features and life forms:

The oceans of Asterion cover a vast expanse, almost the entirety of the region between 40º N and 40º S latitudes. There are a few large islands in this belt which are extremely fertile due to its volcanic origin. These islands are rich in sulphur along with large deposits of aluminium, iron, diamonds, gold, nickel, lead, zinc and copper. The presence of volcanic ash in the soil is hugely beneficial for cultivation of the land. Moreover, the presence of shallow-sea hot springs from molten rock in the sea bed makes the ocean rich in metallic elements and many more making it the perfect cauldron to create life. The deep oceans are also rich in marine creatures of a higher evolutionary order which makes fishing a viable activity. The soil is suited for the cultivation of crops like maize, potatoes, peas etc., which will ensure that there is sufficient food for the human settlers.
The presence of volcanoes also indicates plate tectonics which is belied by the presence of fold mountains. Mountain ranges are mostly concentrated in the Northern hemisphere. The Southern hemisphere contains vast tracts of plains. There is more volcanic activity in the Northern hemisphere, therefore human beings settling on the numerous islands is the most logical step.

Vegetation varies with change in latitude and can be differentiated into biomes, primarily rainforest, plains and tundra. There are many avian and mammal species which reside in the

rainforests, six-legged horse-like beasts and horned hounds in the plains and tundra which can be domesticated gradually upon the arrival of the human colonisers and used for our benefit. As the air is thicker due to higher gravity, there are several large flying organisms which feed on the reef-organisms of the equatorial oceans. There are a lot of marshes and swamps in the regions where the land meets the ocean. There is a network of rivers in the Northern Hemisphere, originating from the ice caps in the poles and draining out into the ocean which provides fresh water which is useful in many ways for the human beings settled on it. The flood plains provide the apt composition of nutrients and the exact type of soil required for the cultivation of wheat, rice and other staple cereals and pulses.
The presence of rivers in the Northern Hemisphere also makes it apt for harnessing energy in the form of hydel power. This could be used to meet the energy demands of the people. There is a possibility of setting up wind farms in the Southern Hemisphere, on the vast tracts of land, to harness the wind energy. In addition to this, huge reserves of coal have been found in the marshy regions which can be used as an additional source of energy by the human beings settled on the planet.

The similar conditions to our home planet, Earth, makes Asterion an ideal exoplanet for human colonisation and settlement.

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