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A2 7 Dune Part I: Charting the Oasis

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Abstract

We set out to begin determining the feasibility of the fictional planet of Dune being habitable. We conclude that it must orbit its parent star at a distance between 122 and 123.4 AU to have a mean temperature of 560 K, as described by the original book.

Introduction

In Frank Herbert's famous science fiction series *Dune* [1], the story is set upon the planet of Arrakis. A desert planet devoid of any surface water and has its own unique biosphere dominated by the life cycle of the sandworms. In this paper, we set out to find Arrakis's distance from its parent star to begin to understand the planet's biosphere.

Arrakis orbits the star α Carinae, commonly known as Canopus. Canopus is an A9 II spectral-type star with a luminosity of 10,700 times that of the Sun ($L_\odot$) and a mass of 9.8 solar masses ($M_\odot$) [2].

We can identify the possible orbital distance of Arrakis from Canopus by calculating the limits of the star's habitable zone. From this, the possible surface temperatures in this region and the likely location of Arrakis can be identified. This can be done by working out a star's solar constant ($S_\odot$). Where the $S_\odot$ is the irradiance per metre squared on the surface of a mathematical sphere that encloses the star at a varying distance, given by the equation:

$$S_\odot = \frac{L}{4\pi r^2} \tag{1}$$

Where $S_\odot$ is equal to the luminosity of the star (L) divided by the surface area of a sphere, with the radial distance (r), which is given in units of watts per meter square.

Calculation

Assuming the Sun's habitable zone is around 0.95 to 2.4 astronomical units (AU) [3], we can work out the $S_\odot$ at these lower and upper bounds. The $S_\odot$ can then be used to find the distance of these bounds around Canopus. Firstly, we find that the $S_\odot$ at the boundaries of the habitable zone are 1508 Wm^{-2} at 0.95 AU and 236 Wm^{-2} at 2.4 AU by applying equation 1. When stated as a ratio of the $S_\odot$ divided by the $S_\odot$ at Earth ($S_\oplus$), the bounds are 1.1 and 0.17, respectively. Secondly, we rearrange equation 1 for the radial distance and expanding out $S_\odot$; giving the following equation:

$$R = \begin{cases} \text{Upper Limit, } \sqrt{\frac{L^*}{0.44}} \\ \text{Lower Limit, } \sqrt{\frac{L^*}{1.2}} \end{cases} \tag{2}$$

Where: R is the radial distance in AU and L^* is $L/L_\odot$. Taking the values calculated above and applying them to Canopus with equation 2, we arrive at the values for the range of the habitable zone as: $122 \leq r(\mathrm{AU}) \leq 312$.

Discussion

From the limits of the habitable zone, we have found an estimate of where Arrakis lies in the Canopus system. But this can be narrowed down further by examining the surface temperature of the planet, which can be calculated using the many-layers model of planetary atmospheres [4]:

$$T = \sqrt[4]{\frac{(n+1)S_{\odot}(1-\alpha)}{4\epsilon_s \sigma}} \tag{3}$$

Where: T is the surface temperature in Kelvin; n represents how powerfully the greenhouse effect is in an atmosphere; for example, on Earth n is given as one; α is the albedo of the planet; ϵ_s is the surface emissivity, which is given as one as it is assumed to be in unity; σ is the Boltzmann constant. This model is used as it allows for consideration of energy being trapped inside a planet's atmosphere, allowing for higher surface temperatures that match those measured in the solar system.

To reduce the outer limit, we can take Arrakis' mean temperature of 286°C (560 K) [5] as the minimum surface temperature. Combining this with equation (3) and an albedo of sand as 0.4 [6], we can calculate the upper limit of where Arrakis is located by raising n until a value equaling the surface temperature exists within the habitable zone. When n = 24, the surface temperature rises to 560 K at 123.4 AU.

This implies that for Arrakis to exist within Canopus' habitable zone with the surface temperatures described in the books, the planet must have a powerful greenhouse effect, as indicated by the value of n. In light of the high ozone content (~ 0.5 %) of Arrakis' atmosphere [5], this result is unsurprising as ozone is a powerful greenhouse gas. Therefore, the limits of Arrakis's distance to Canopus are between 122 and 123.4 AU. For comparison, an Earth analogue, with an albedo of ~ 0.3 [6] and n of 1, in the Canopus planetary system would orbit at 129 AU.

Taking the midpoint of the range at 122.7 AU as the most likely orbital position for Arrakis, the planet will have a solar constant of 1500 Wm^{-2}. It should be noted that a surface temperature of 560 K is too high for human habitability, but this value should be taken as the temperature at the equator. The temperature will decrease at higher latitudes closer to the poles, which is where Frank Herbert chose to set *Dune*.

Conclusions

We find that Arrakis should orbit its star, Canopus, at a distance between $122 \leq r(\mathrm{AU}) \leq 123.4$. This is closer than a planet that is equivalent to Earth. This makes sense as the planet is warmer and is more affected by the greenhouse effect, as described in the books. However, this gives a starting point for considering how terraform the planet for human life.

References

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