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A3 2 Mr Blue Sky

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Abstract

In this paper we outline what makes the sky appear blue and what changes would need to be made to the Sun in order to create a vastly different coloured sky. We found that a solar system similar to ours could have a sky dominated by any given colour in the visible spectrum. Assuming the size of the star was comparable to our Sun, a surface temperature between 4,140 K and 7,245 K would cover the entire visible electromagnetic spectrum from Red to Violet.

Introduction

The colour of the sky is a very familiar sight, however why is it a specific shade of blue and does it have to be? We will investigate the possibility of having an array of different colours instead and what that would mean for the Earth, Sun or any scenarios comparable to our solar system. This paper details the possible appearances for an earth-like planet's sky and what factors could impact that.

Theory

The observed colour of the sky is not an intrinsic property of itself as a physical object, but is caused by light bouncing off particles in the Earth's atmosphere. This is part of an effect called Rayleigh scattering [1] and causes shorter wavelengths of light to be scattered to a greater proportion and hence the sky appears predominantly blue as it is scattered more than the other wavelengths of light emitted from the sun. It can also be noted that both the thickness and composition of the atmosphere affects the amount of scattering as well as the light's angle of penetration [2]. This is seen at sunset and sunrise where the shallow angle causes light to travel further distances through the atmosphere and allows light of greater wavelengths the ability to scatter more and is thus seen in greater intensity in these scenarios. This same effect can also be caused by a denser atmosphere as particles collide more often or the opposite effect can be seen if the atmosphere was composed of heavier gasses since they refract light to a lesser degree. Atmospheric composition also affects the perceived colour as Mie Scattering [3] causes elastic scattering that is not as wavelength dependent as light refracts off particles that have a diameter similar to or larger than the wavelength of the incident light. Dust and water in the air are the main causes for this effect. The intensity of light caused by scattering as a general rule is seen in equation (1) which can then be expanded to account for atmospheric properties where ρ is density in kg/m^3 and d is atmospheric thickness in m.

$$I \propto \frac{l}{\lambda^4} \tag{1}$$

$$I \propto \frac{\rho d}{\lambda^4} \tag{2}$$

The Sun emits light across a wide range of the electromagnetic spectrum however the peak wavelength is governed by the surface temperature in accordance with Wein's law [1].

$$\lambda_{max} = \frac{b}{T} \tag{3}$$

Where λ_{max} is the wavelength the sun emits the most light, b is Wein's constant and T is the surface temperature of the Sun. Therefore using the surface temperature of the sun according to the Stefan Boltzmann law (4) and rearranging it as follows, we can estimate the surface temperature of any star and hence the corresponding peak wavelength that will be most visible.

$$L = 4\pi R^2 \sigma T^4 \tag{4}$$

$$T = (\frac{L}{4\pi R^2 \sigma})^{-4} \tag{5}$$

Results

We first must look at what values our current solar system produces to understand the physics at work before considering any hypothetical alternatives. Using equation (5) we can obtain that the sun has a surface temperature of $5,779$ K by putting in values for $L_\odot$ and $R_\odot$ of 3.846×10^{26} W and 6.957×10^{8} m as well as a Stefan-Boltzmann constant of $\sigma = 5.670 \times 10^{-8}$ $\mathrm{Wm^{-2}K^{-1}}$. Using this value for surface temperature, we can apply this to Wein's displacement law (3), taking b as 2.898×10^{-3}, and we obtain a value of 5.015×10^{-7} m or 501.5 nm. In more common terms, this represents a light blue or cyan colour [4] which can be seen experimentally by going outside. Now consider an apocalyptic looking scenario where the sky has a deep red hue corresponding to 700 nm peak wavelength, what changes would the Sun have to go through? Firstly rearranging equation (3) to find temperature, we see the surface of the sun would need to be 4,140 K. This means the sun would need to have either a 95% larger radius or have a luminosity only 26% of its existing value, making it far less energetic. This can be found using the Stefan Boltzmann law or simply the following luminosity temperature relation.

Red tinted skies like this would seem obvious if the host star was a Red Giant however the values we have calculate indicate this same observed colour can be seen on the planet while orbiting a main sequence star. This is because "Red Giants" typically burn with a surface temperature of 2,500 K and size of over 100 $R_\odot$ [5] which is significantly different to our calculations.

Conclusion

These values of $4,140$ K for red light and $7,245$ K for violet light, while giving dramatically different results, are not hugely different to the values of our current sun. This means that having a completely different colour atmosphere is entirely possible in many scenarios where a planet is placed around just a slightly different main sequence star. Due to the abundance of Sun-like stars we predict exist, we can therefore thoroughly conclude that every possible colour sky is achievable and likely out there somewhere in the universe.

References

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