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How can dust make planets more suitable for life?

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Abstract

Have you read *His Dark Materials* or seen its movie adaptation *The Golden Compass*? In the imaginary world created by the author Philip Pullman, dust was the most important thing – the material which connected it to ours.

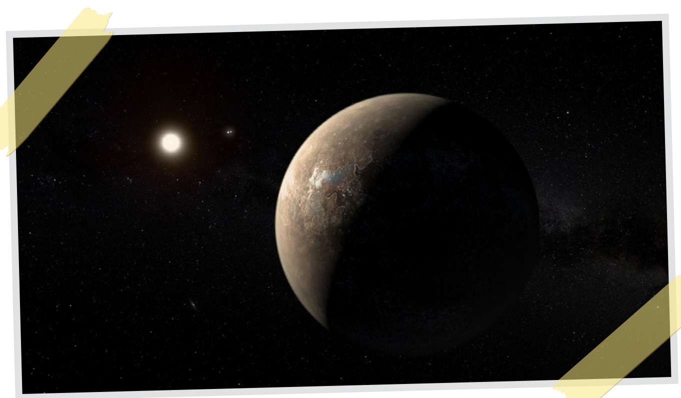
It turns out that even in real life, dust is important to worlds outside of Earth! Especially if we are trying to find out if they are habitable. We learned that dust can cool the hot surface and warm the climate of a planet, making it more suitable for life. On the other hand, larger amounts of dust can make it hard to look for such planets. And actually, if a planet does host life, dust might hide the signs of it!

Introduction

Have you ever dreamed of going into outer space? There are millions of planets outside our Solar System; we call them *exoplanets*. Finding life (or conditions suitable for life) on a different planet is a key goal for many space missions. But what does 'suitable' mean? We believe the planet has to be warm enough to have liquid water on its surface. After all, water is absolutely vital for life on Earth.

Planets get their warmth from the star they *orbit*. On Earth, we get our warmth from the Sun – a *yellow dwarf* star. But most stars in our galaxy are *red dwarfs*, which are much smaller and cooler than our Sun. The only chance for a planet orbiting a red dwarf to be warm and suitable for life (or *habitable*) is for it to be very close to the star. But then gravity 'locks' the planet to that star – it always has the same side facing it. (We also call these types of planets *tidally-locked*.) They have a warm *dayside* and a dark side which can get pretty cold.

This is where airborne *dust* can come to the rescue. Dust is found on dry land surfaces that are not solid rock and it can be picked up by winds. So the more dry land there is, the more dust there should be – both on the surface and in the planet's atmosphere. Airborne dust deflects starlight stopping it from reaching the planet's surface. This cools down the planet. On the other hand, dust can prevent warmth from the surface escaping into space (aka the *greenhouse effect*). Which effect would prevail on a tidally-locked planet? What about a non-locked one?



This is what we imagine *Proxima b* looks like - a tidally-locked planet, orbiting Proxima Centauri - the closest star to the Sun.

(Image: European Southern Observatory)

Methods

We considered two types of planets:

1. A tidally-locked planet orbiting a red dwarf. We used the properties of a planet called *Proxima Centauri b* (or *Proxima b* for short).

2. A non-tidally locked planet orbiting a yellow dwarf, with planetary properties taken from Earth.

We used a *climate model* created for Earth but applied it to an exoplanet. This model already takes into account dust particles and their movement in order to understand the climate of Earth's desert areas. It includes many atmospheric parameters (such as surface pressure, the concentration of oxygen, methane, etc.). It also includes information about the planet's surface and other properties (such as how fast it rotates, its radius, how much light it receives, etc).

For both types of planets, we ran the model with different percentages of land cover. The more land there is, the more dust there could be, but the less water.

Furthermore, for each planet and climate we conducted two simulations:

- One without dust
- One with dust particles.

This allows us to assess the effects of dust.

This is how we envision the surface of a tidally-locked exoplanet (such as *Proxima b*) within the habitable zone of a red dwarf star. Even though we do not know anything about the planetary surface, based on the star's size and color this is what the sky might well look like from the planet's surface.

(Image: University of Exeter, Engine House VFX and We The Curious)

For the curious: There are different sizes of dust particles. The planetary winds can lift the larger particles but then quickly return them to the surface, so they don't travel far. However, when these large particles impact the surface, they help lift the smaller dust particles into the atmosphere. These are not that heavy, so they travel further and stay in the atmosphere for longer.

Results

After running our model, we found that:

- Starlight reaches a **small area of tidally-locked planets** - the dayside. (Fig. 1a)
- Starlight reaches a **greater area of non-locked planets** – the most at the equator and the least at the poles. (Fig. 1b)

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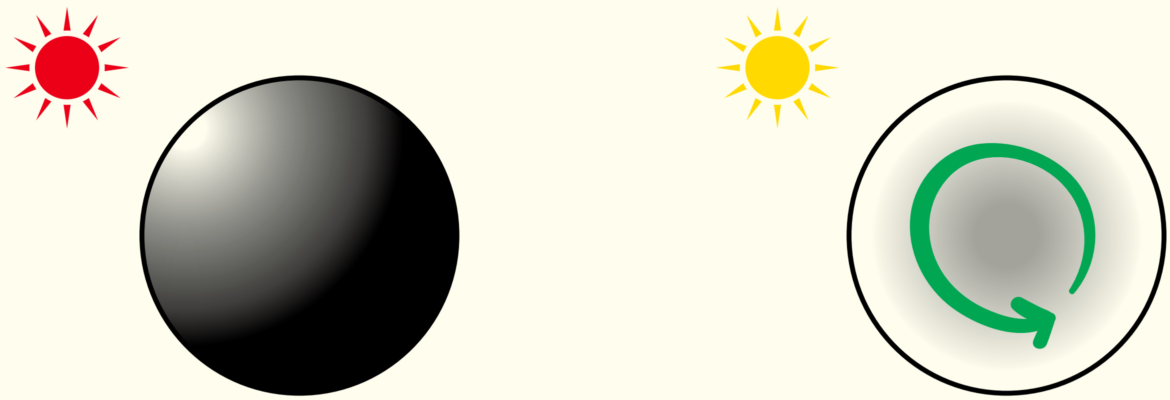
- The winds on the dayside of the locked planet, however, **spread the dust** to the dark side.
- The winds on the non-locked planet have a **difficult time spreading dust** to the poles.
- Thus, dust **cools down non-locked planets** because its particles deflect the starlight and this cancels out the greenhouse effect of dust.
- On the other hand, **on the dayside of locked planets**, dust deflects the radiation coming from the star. The cooling effect wins over the heating effect.
- **On the dark side of locked planets**, there is no radiation from the star (and thus no deflection), so the heating effect wins over the cooling effect.
- Our model also suggests that dust can postpone the water loss of a planet. This can increase the time it remains habitable.



1a. Tidally-locked planet **1b. Non-tidally locked plant**

Figure 1:
The amount of illumination each planet received on its surface.

What is the main difference between the two planets?

Discussion

Our results strongly suggest that airborne dust can greatly widen the *habitable zone* on tidally-locked planets – that is, even planets further from the star could support life. Dust first cools the dayside, which otherwise can get pretty hot. Second, it warms the dark side, which otherwise could get really cold.

What's more, dust can postpone the water loss of a planet. When its atmosphere gets too hot and humid, the water in the oceans can evaporate. The more water is lost over time, the more land is exposed. But as we said, the more land there is, the more dust and thus the cooler the dayside gets. So it's very possible that dust may actually delay the point when planets lose their oceans and are no longer suitable for life.

On the downside, dust could make it harder for us to find possible habitable (or inhabited!) planets. When we search for the possibility of life on another planet, we look for gases such as oxygen, methane and ozone. We call these molecules *biomarkers* because they suggest that some life processes may be taking place. But the more dust is in the atmosphere, the more hidden these gases are. So we might think a planet is uninhabitable because it lacks these gases when in fact they are just hidden by dust. This is another reason we believe that future studies concerning possible habitable planets should always take airborne dust into account.

Conclusion

Our planet Earth is an amazing system! The Sun has kept Earth warm enough for billions of years, which has made life possible. But then, living organisms are also helping shape Earth's climate through biochemical *feedbacks*.

The universe is a pretty enormous place, so chances are there are other planets like ours. Imagine how wonderful it would be if dust turned out to be the key to them, just as Lyra Belacqua – the heroine of Philip Pullman's *His Dark Materials* trilogy – discovered.

Glossary of Key Terms

Biomarkers – molecules such as oxygen, methane and ozone which may be the result of a life process (e.g. respiration). When we look for life on another planet, we actually look for these biomarker molecules.

Climate model – a scientific model is a computer program that uses our knowledge of natural processes to predict outcomes, make hypotheses and explain phenomena. (Meteorologists use weather models to forecast the weather; climate scientists use climate models to predict changes in the climate in the long run.)

Dayside – the side of a planet that is always facing its primary star.

Dust – small particles of solid matter, often coming from ground-down rock. With diameters of 1/1000 of a mm (or 1/25000 of an inch), they are much smaller than sand particles on a beach. They can actually be similar to smoke. (Winds pick up dust from the land surface and spread it around.)

Exoplanet – a planet outside the Solar System.

Feedback (or climate change feedback) – biochemical processes (such as bacterial respiration) which have helped shape Earth's climate over millions of years. Human activities (such as releasing CO_2 into the atmosphere through fossil fuel burning) are also important feedbacks currently changing Earth's climate.

Gravity – the force by which a planet (or another body) draws objects toward itself. (The force of gravity keeps all the planets in the Solar System orbiting around the Sun.)

Greenhouse effect – trapping heat on the surface of a planet.

Habitable planet – a planet is habitable if it can maintain an environment suitable for life.

Habitable zone – the distance from a star in which a planet could have liquid water on its surface and possibly support life.

Locked (tidally-locked) planet – a planet (or another astronomical body) which always has the same face toward the object it orbits. (The Moon is tidally locked to Earth.)

Orbit – to move in a circle around another body (e.g. Earth orbits the Sun.)

Proxima Centauri b – a planet orbiting the red dwarf Proxima Centauri (the closest star to the Sun).

Red dwarf – small faint stars with lower temperature (than the Sun).

Yellow dwarf – stars of medium size which shine in bright yellow; the Sun is a yellow dwarf.

Check your understanding

1. What are some differences between a yellow dwarf and a red dwarf? And what examples do we give here?
2. Why are we interested in tidally-locked planets?
3. What effect does dust have on the dayside of a tidally-locked planet? What about the dark side?
4. How does dust postpone the water loss of a planet?
5. What are some examples of climate change feedback?

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