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Earth & Space

Climatic Changes for Earths in Sun-like Stellar Binaries

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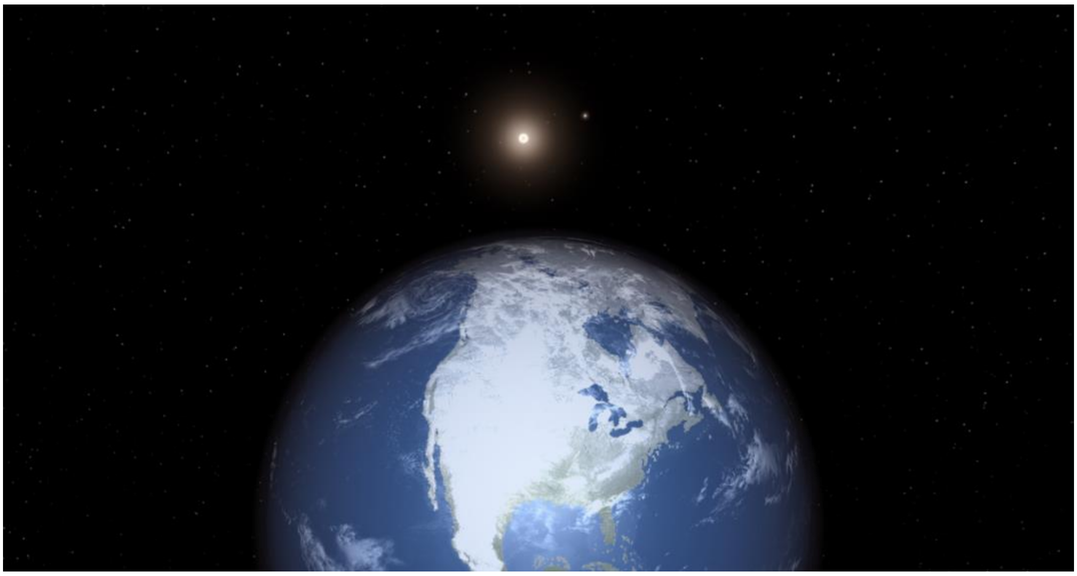
ABSTRACT

Climate cycles are influenced by the changes in a planet's axial tilt or obliquity. Stellar binary companions can alter a planet's obliquity quite substantially through gravitational tugs. The climate on an Earth twin orbiting Alpha Centauri B is especially vulnerable to large changes in obliquity, and a large moon doesn't help. Telescopes could soon identify the spin and tilt of nearby planets.



An Earth twin orbiting Alpha Cen B.
Image credits: Made by Billy Quarles using Universe Sandbox

The mild oscillation of Earth's axial tilt, or obliquity, over time is less than a few degrees and is one of the reasons that complex lifeforms prospered on our planet. Will this be true if the giant planets are replaced by a Sun-like star? Alpha Centauri is a binary star system that allows us to test this notion using computer simulations. It is close enough so that we could verify our results in a human lifetime via small probes propelled using light sails. Our Moon largely prevents Earth's obliquity from changing very much by speeding up the rotation of our spin axis. This contrasts with Mars with its puny moons, where we know large obliquity changes occurred in the past and have dramatically limited the prospects for life. Mars' climatic demise stems from the gravitational tug-of-war on its spin axis from the giant planets, terrestrial planets, and the Sun. As a result, Mars occasionally sits upright, which causes its atmosphere to thin out due to the extreme growth of the polar caps. Earth and Mars represent a dichotomy among the terrestrial planets. The climates on each world are significantly different due to the changes in obliquity over time, among other factors. Our study addresses how the spin axis of an Earth-like planet orbiting one of the stars in Alpha Centauri responds to the periodic gravitational tugs of the other star and a few nearby planets.

We used supercomputers to first simulate the obliquity of a moonless planet orbiting Alpha

Centauri B (the less massive star) over millions of years. We considered many different scenarios or the starting planetary obliquity and varied how fast it spins. We found that the changes in tilt were like the Earth's only if the rotation speed of the spin axis is nearly identical to the rotation speed of the orbit. Otherwise, the obliquity would change by tens of degrees after ~20,000 years. This is like how the Earth's obliquity changes without the Moon, so would a large Moon like ours help? No, this would not help at all and would increase the obliquity oscillations to a level like Mars.

Does this mean that Earth-like planets are doomed to have inhospitable climates? No, other scenarios can mitigate the gravitational influence of the other star on an Earth-like planet's spin. Here are four options that we tried. (1) A much larger tilt changes how fast the spin axis rotates and the timescale for gravitational interactions, where a backward rotation would be ideal because it would lower the net tug from the other star. (2) The planet could orbit at a larger distance around the other star Alpha Cen A (the more massive star) because the brightness of each star in Alpha Centauri is different, and the region where liquid water could exist occurs a larger distance. A larger orbit changes the timescale of gravitational interactions and reduces the magnitude of obliquity changes. (3) Having additional terrestrial planet neighbors, like those in the solar system, can also shift the timescale of gravitational interactions and thereby lower the obliquity oscillations. (4) Growing up in a stellar binary that is more widely separated or less eccentric that Alpha Centauri could also ensure a mild obliquity oscillation like the Earth's. We found option (4) as the best considering the typical orbital and stellar properties of Sun-like binaries. Stars slightly less massive than the Sun and binaries that are more widely separated are more commonly found in our galaxy. Nearly 90% of these binaries could then host an Earth-like planet and allow for an Earth-like obliquity oscillation.

Many processes affect a planet's climate and its changes over time, such as plate tectonics, weathering cycles, and atmospheric dynamics. However, studying these processes on exoplanets is just beyond our reach and may become more tangible in the next few decades. Current technological efforts can detect planets orbiting within binary star systems, characterize their orbits, and even determine a planet's density. Our study lies at the current frontier because planetary spin is the next thing to measure, and next-generation direct imaging will be the technology to do it. Teasing out the oscillations in brightness from a planet from the reflections of intermittent cloud cover or polar caps is like a firefly acting as a signal lamp next to a lighthouse.