A Test of the Copernican Principle

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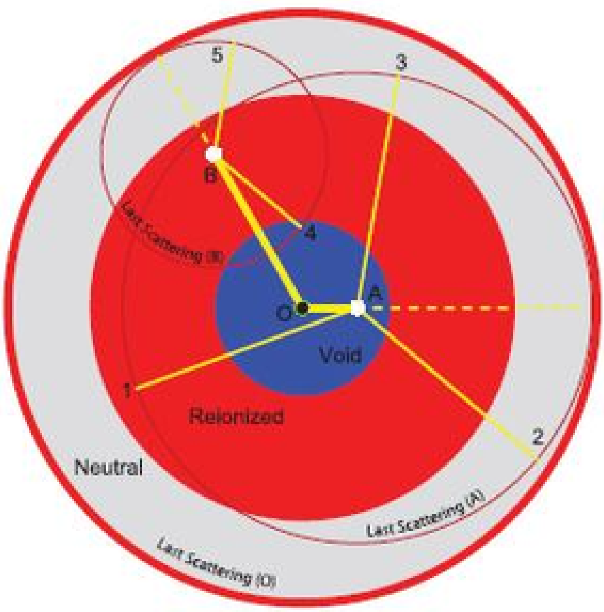

This image shows a cross-section of a void universe with an observer (O) in the center, in violation of the Copernican principle. CMB photons (yellow lines) can scatter off reionized gas, and some may lead to CMB distortions. Credit: Caldwell, R. R. and Stebbins, A. ©2008 APS.

The Copernican principle states that the Earth is not the center of the universe, and that, as observers, we don’t occupy a special place. First stated by Copernicus in the 16th century, today the idea is wholly accepted by scientists, and is an assumed concept in many astronomical theories.

However, as physicists Robert Caldwell of Dartmouth College in

Hanover, New Hampshire, and Albert Stebbins of Fermilab in Batavia, Illinois, point out, the Copernican principle has never been confirmed as a whole. In a recent paper published in *Physical Review Letters* called "A Test of the Copernican Principle," the two researchers set out to prove the 500-year-old principle using observations of the cosmic microwave background (CMB).

"The Copernican principle is a cornerstone of most of astronomy, it is assumed without question, and plays an important role in many statistical tests for the viability of cosmological models," Stebbins told *PhysOrg.com*. "It is also a necessary consequence of the stronger assumption of the Cosmological Principle: namely, that not only do we not live in a special part of the universe, but there are no special parts of the universe – everything is the same everywhere (up to statistical variation).

"It is a very handy principle, since it implies that here and now is the same as there and now, and here and then is the same as there and then. We do not have to look back in time at our current location to see how the universe was in our past – we can just look very far away, and given the large light travel time, we are looking at a distant part of the universe in the distant past. Given the Cosmological Principle, their past is the same as our past."

Cosmic Distortion

When the universe was just 400,000 years old, matter and radiation decoupled and left a remnant radiation that still pervades the entire universe today. By measuring the tiny temperature fluctuations of this CMB radiation, scientists can learn things about the universe such as its shape, size, and rate of expansion. In the latter case, the observations show that the universe is expanding at an ever-accelerating rate, leading scientists to speculate about the existence of dark energy, new laws of gravity, and other possible – and often exotic – theories.

But what if the universe's accelerating expansion is just an illusion? As Caldwell and Stebbins explained, this scenario is entirely plausible if the Copernican principle is loosened a bit. If, instead of the universe being homogenous and isotropic as the Cosmological Principle states, there is rather "a peculiar distribution of matter centered upon our location," then the universe would be centered on a low-density, matter-dominated void. Such a universe would be non-accelerating, and there would be no need for dark energy or other similar theories.

That's why it's important to know if the Copernican principle is correct: it will ensure that CMB observations haven't been misinterpreted to indicate cosmic acceleration when there is none. To test the principle, Caldwell and Stebbins developed a "CMB-distortion test": they looked for deviations of the CMB spectrum from a perfect blackbody as might have been caused by a large, local void. A void or other "non-Copernican structure" would cause ionized gas to move relative to the CMB, and the Doppler-shifted CMB scattered toward us could contain detectable deviations from a blackbody.

"In essence, we use the reionized Universe as a mirror to look at ourselves in CMB light," the researchers explained. "If we see ourselves in the mirror, it is because ours is a privileged location. If we see nothing [i.e. no peculiar distortions] in the mirror, then the Copernican principle is upheld."

The Hubble Bubble

As an initial test, Caldwell and Stebbins focused on a universe model consisting of a simple, spherically symmetric void, which is also known as a "Hubble bubble." This void universe resembles an open (low-density) universe embedded inside a flat (medium-density) universe. The size of the void depends on how gas is distributed throughout the universe. Basically, gas can exist in three zones – neutral, reflection, and Doppler – depending on its redshift. Depending on how these three zones overlap, the void can come in five sizes, from small to "superhorizon," where the void encompasses the entire observable universe.

Using their CMB-distortion test, the researchers calculated that only the smaller void models could lead to the type of distortion associated with a violation of the Copernican principle. Then, by analyzing data for the CMB spectrum, they were able to rule out nearly all of these non-Copernican Hubble bubble void universes – meaning the Copernican principle passed this first test. However, Caldwell and Stebbins also noted that other models – such as those with a higher density or smaller radius – may still exist that evade this test.

The researchers added that this is not the first time that bits of the Copernican principle have been tested, but it is one of the first tests of the remaining radial inhomogeneity on very large scales. Caldwell explained that, in 1995, physicist Jeremy Goodman of Princeton proposed a similar test of spectral distortions. Goodman's implementation resulted in a weaker constraint, or test, of the Copernican principle.

"This [large-scale testing] is not easy to do because, when we look far away, we are looking back in time, and it is difficult to say whether what we see is due to changes with time, which does not violate the Copernican principle, or changes with distance, which does," Stebbins explained. "Thus, it is a hard question to answer, which is why it has not been done."

More Tests

In the future, the scientists plan to further pinpoint the CMB distortions that could be caused by a local non-Copernican structure, and also apply the test to other more general universe models. These tests should be useful in potentially ruling out alternative hypotheses for dark energy, as Caldwell explained. More fundamentally, the tests could either verify the foundation of centuries of astronomical work, or – and the chance is slim – suggest that the Copernican principle may not be as certain as we think.

“If our test of the Copernican principle were to fail, it would probably not be believed, and a variety of other observations would be required to test it,” Stebbins said. “If all these further tests confirmed the large void, then we would have to rethink our ideas about dark energy, or, namely, unthink them.

“I think the scientific community would not be too unhappy with the idea of a large under-dense region – it is not hard to think of ideas of how they might come to be, even in the context of a hot big bang model. What is hard to understand is why we would be so close to the center of one. No doubt someone would come up with an ‘anthropic’ argument for it – but I've thought a bit about that, and don't really think there is a salable anthropic explanation. (By the way, I don't think there is a salable intelligent design reason, either.) In the end, we might have to live with the Walter Cronkite explanation ‘... and that's the way it is .... ’”

More information: Caldwell, R. R. and Stebbins, A. “A Test of the Copernican Principle.” *Physical Review Letters* 100, 191302 (2008).