

The Curvature of the Universe and Supporting Evidence

As technology has advanced, it has become possible to measure and observe more and more of the universe. Many of our observations are based on line of sight and geometry. Most people think of geometry as things on a flat plane, otherwise known as Euclidean geometry, but what if the universe was differently shaped? Math changes dramatically when leaving a flat surface, for instance the Pythagorean theorem, a theorem so elementary it is literally taught in elementary schools, becomes invalid. In order to know what mathematical rules apply, we need to know the curvature of the universe. Is the universe flat? To answer this question bluntly, yes, yes it is.

One of the biggest lasting effects of and evidence for the Big Bang is the Cosmic Microwave Background. This is the electromagnetic radiation left over from the Big Bang and the oldest light in the universe. By observing the Cosmic Background Radiation we can get a glimpse of what the universe was like before the formation of stars and planets that warp space around it. At this point in time mass-energy was incredibly evenly distributed, with only the smallest variationsⁱ. To learn more about the curvature of the universe the best source of data is the Cosmic Background Radiation.

How can we observe the curvature of the universe if the light we are observing is also in this universe, surely everything would appear linear to an observer in the same space? There are slight temperature differences in the Cosmic Background Radiation measured by the Cosmic Background Explorer. This satellite also detected anisotropies. Anisotropy is used to describe a direction-dependent attributeⁱⁱ. By being able to detect these anisotropies the Cosmic Background Explorer provided scientists with the data needed to measure the geometry of the universe.

The oscillations in the Cosmic Microwave Background were caused by the conditions of the early universe. By observing the nature of these oscillations, along with a lot of very complex math (far too complex for this report to attempt to explain), it is possible to calculate the cosmological curvature. Data from three space missions, the Cosmic Background Explorer, the Wilkinson Microwave

Anisotropy Probe, and the Planck Space Observatory was used to confirm that the curvature of the universe is $0.000 \pm 0.005^{\text{iii}}$. This is consistent with a flat universe.

Alright, the universe is flat, we can now use euclidean geometry. But many other incredible discoveries arose from this. A flat universe should expand at a decelerating rate, but we know for a fact that ours is expanding at an accelerated rate. Using the rate of expansion and the knowledge that the universe is flat, the average density of the universe can be calculated. This value does not match the sum of visible and dark matter in the universe^{iv}. This means that there must be something else in it that had yet to be discovered. This is called dark energy. This discovery could change not just which math rules we apply to the universe, but also our understanding of what it is made of.

Science still doesn't really know what dark matter is, now theres even more to discover. Its a bit of a relief that the universe follows euclidean geometry, but also a small bit concerning that we only just proved this conclusively a few years ago. It is also astounding that all this could be learned just from observing the Cosmic Microwave Background. Man, science is crazy.

- i Bhattacharjee, Y. (2009). In the Afterglow Of the Big Bang. *Science*, 327(5961), 26-29. doi:10.1126/science.327.5961.26
- ii Hogan, C. J. (1990). Experimental triumph. *Nature*, 344(6262), 107-108. doi:10.1038/344107a0
- iii Hogan, C. J. (1990). Experimental triumph. *Nature*, 344(6262), 107-108. doi:10.1038/344107a0
- iv Turner, M. S. (2003). Dark Energy: Just What Theorists Ordered. *Physics Today*, 56(4), 10-11. doi:10.1063/1.1580026