The Anthropic Principle and Cosmic Inflation

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Some scientists and commentators have argued that our universe is ‘fine tuned’ for life. Our most basic physical laws and constants seem just the right value for life on earth to evolve. The Anthropic Principle was devised to explain this apparent design in terms of our privileged role as observers. In this essay, the author examines the adequacy of the Anthropic Principle and its implications for the latest developments in cosmology. His discussion turns on how inflation theory and the idea of the multiverse may burst the bubble of the proponents of special design.

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1. Introduction

It appears our universe is 'fine tuned' for life. With just a minor variation in some physical laws and constants, life, it seems, would be rendered impossible. In this essay, I will look at some of these key features and explore their significance for cosmology. I will examine what the Anthropic Principle has to say about our role as observers and the kind of universe we should expect to see. I will also explore the implications of modern cosmology and, in particular, inflation theory for the notion that the universe is built with our evolution in mind.

Some scientists and commentators have argued that there are many apparently incidental features about the universe that cannot differ from what we observe without it being impossible for life on earth to germinate and survive.

Such apparent 'fine-tuning' includes the following:[1]

- If the strong nuclear force were 2% stronger, atoms would not have formed out of quarks. If it was 5% weaker, all atoms other than hydrogen would not have formed. This would have prevented the emergence of hydrogen-burning stars and deprived living things of hydrogen-based water.
- If electromagnetic forces were marginally different, stars would not have produced the amount of carbon needed to allow life to evolve.
- If space was not three-dimensional, planetary orbits would not be stable, making the evolution of life extraordinarily unlikely.
- Gravity is some 10^{40} times weaker than the electrical forces. If the strength of gravity were only 100 times stronger than it is, the universe would not have existed long enough for stars and planets to form.
- If the cosmological constant (dark energy) were an order or magnitude larger, galaxies would unlikely form.

The Anthropic Principle illuminates how we should deal with this apparent sensitivity of the cosmic constants to change. It is to this that I will now turn.

[1] See, for example [Craig 1990; Davies 2004]

2. The Anthropic Principle

The term *Anthropic Principle* was coined by an Australian physicist, Brandon Carter, in his [1974] article[2] that first appeared in *Confrontation of Cosmological Theories with Observational Data*. In it, Carter countenanced against overreaction to the Copernican Principle. This principle postulates that we do not occupy a privileged central position in the universe. Copernicus' challenge in the 16th century to the Ptolemaic view that our earth is stationary at the centre of the universe has been repeated in kind throughout the following centuries. Subsequent scientific advancements have revealed that the earth's geology, astronomy and cosmology occupies but a tiny corner of the universe in space and that our history is fleetingly short as judged against cosmic time. In the middle of the 19th century, Charles Darwin completed the dethronement of the human race by showing how our evolution and the evolution of all life on this planet is the result of blind physical forces.

Carter wanted to redress the balance by suggesting how our evolution and place in the universe limits the kinds of universe we can observe. His point with his Anthropic Principle was to show how the conditions we observe may be typical for any kind of observer but not typical for the entire universe.

He expressed this as his *weak* Anthropic Principle: 'our location in the universe is necessarily privileged to the extent of being compatible with our existence as observers.'[3] Using this principle, he predicted in retrospect the observed value of the cosmological constant to fall within a narrow band suitable for stars to form. Anthropic reasoning suggests that we should epistemically favour explanations in which our location as observers in space and time are unremarkable. The apparent 'fine-tuning' effects listed in the introduction above are then just anthropic effects of the kinds of observers we are.

Some advocates have put the case for a stronger version of the Anthropic Principle.[4] On these renditions of this stronger version, proponents have argued that the weak version entails that the conditions in the *entire* universe are compatible with the evolution of observers or even that such conditions are necessary. These stronger conclusions are unwarranted extrapolations from and misinterpretations of the weak Anthropic Principle.

Carter's weak version is not saying that the universe was intentionally set up for life to exist or that life is some kind of goal of the universe's existence. *Contra* the strong version, the evolution of life is not a *necessary* product of the universe. Such teleological hypotheses result from confused readings of the weak Anthropic Principle. The weak version is not saying that the reality of our existence in some way restricts the range of universes that could possibly exist, thereby ruling out as impossible those that could not support life. What it is saying is that given that observers exist, this restricts the range of observed universes to those that support the evolution of life.

The Anthropic Principle suggests that the universe we observe may be but a tiny part of a very much bigger universe in which the physical conditions and laws are different in other locations compared with those in our own locality. Inflation theory in modern cosmology lends a theoretical underpinning and experimental support to this idea.

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[2] To remove the bias towards the male gender and the human species, the principle is also later referred to as the *Biophilic Principle*.

[3] [Carter 1974: 291]

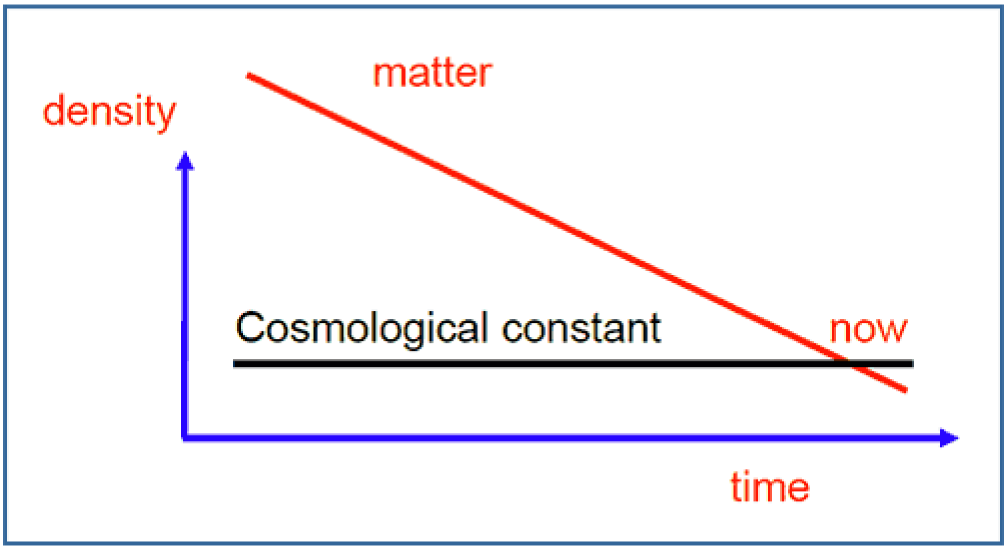
[4] For a comprehensive review and argument, see [Barrow and Tipler 1986]

3. Inflation Theory and the Multiverse

One way to express this notion of many different local domains, each with their own physical laws and constants is with the idea of the multiverse.[5] The idea of the multiverse is not a wild philosophical fancy on the part of some cosmologists, arrived at after a heavy night of drinking. It arises from the cosmologists' models of the constituents of the universe. One of those constituents is dark energy.

Dark energy is the energy of the vacuum; of empty space. It works in opposition to the pulling effects of gravity. The observed expansion of our universe is occurring at an accelerating rate as a result of the action of dark energy. This accelerating expansion is a natural consequence of the fact that the density of dark energy stays constant with time while the density of matter declines as the universe expands. It is this constancy that leads modern cosmologists to identify dark energy with Einstein's cosmological constant. The history of the universe has passed the point at which the density of matter is greater than the density of dark energy. The effects of dark energy compared with that of matter have now tipped in dark energy's favour.

Diagram 1 – Evolution of density of matter and dark energy[6]



The density of dark energy is observed to be 6 x 10^{-27} kg m^{-3}. However, this value is much smaller than the density expected from quantum mechanical calculations by many orders of magnitude. Using quantum mechanics and Einstein's mass–energy equivalence ($e = mc^2$), physicists calculate an expected Planck scale vacuum density of 10^{100} kg m^{-3}. By this reckoning, the masses of elementary particles turn out also to be much lower than expected. It is the solution to these two problems that led physicists to the possibility of the multiverse.

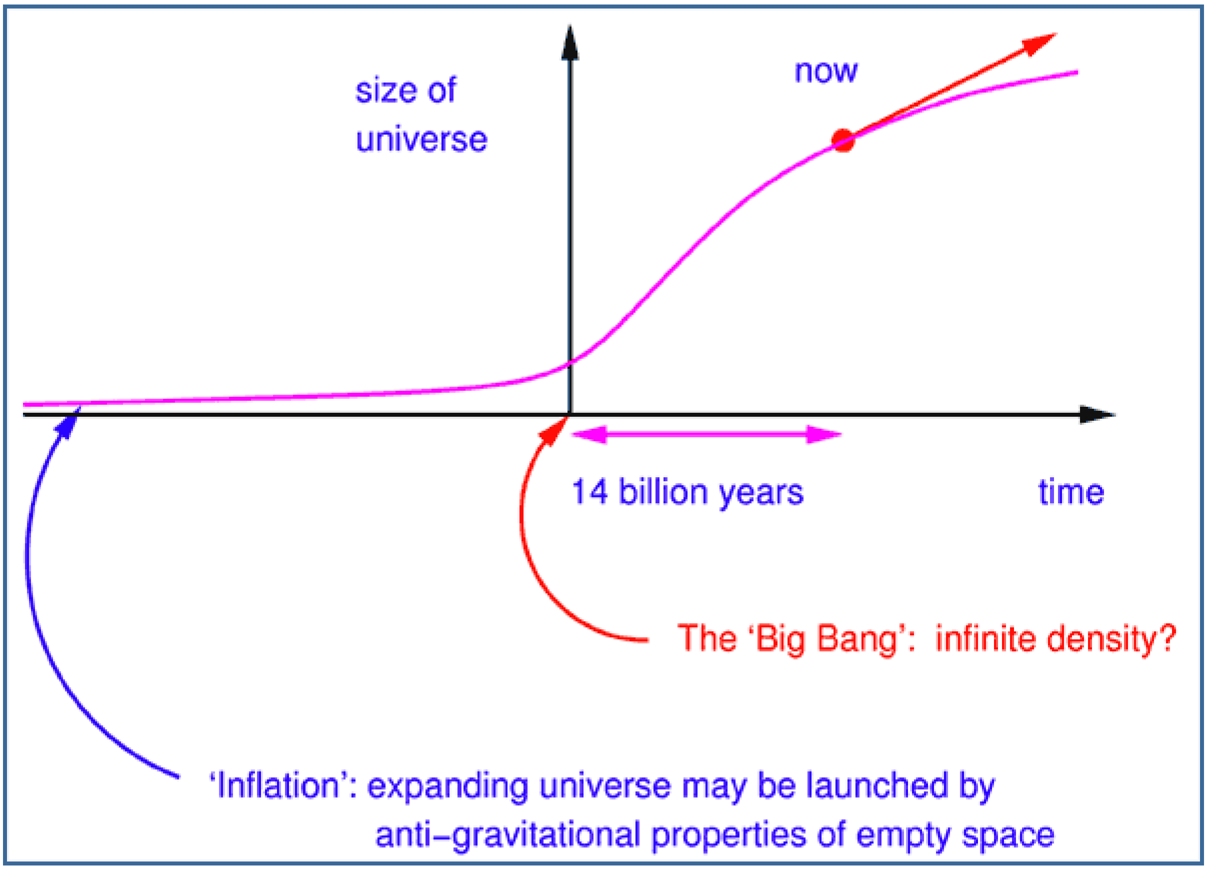
[5] Some theorists use the term 'bubble universe' or 'pocket universe'.

[6] All diagrams sourced from Slides for The Anthropic Principle in Cosmology.pdf, Alasdair Richmond, University of Edinburgh.

Physicists proposed an early period of inflation just after the birth of the universe to solve another problem in cosmology; the horizon problem. The temperature of the cosmic microwave background (CMB) is highly uniform (varying by only 1 part in 100,000), yet regions of the CMB were so far apart during the time of the early universe that even light was not fast enough to travel from one such region to the other. This apparent lack of causal connectedness between regions is solved by positing an early period of rapid inflation in which the regions were in causal contact prior to the period of inflation. After the initial inflationary period, it is thought, the vacuum energy dissipates and drops to the much lower level observed today.

As it turned out, inflation theory also accounted very accurately for the quantitative irregularities in the CMB and for the seeds of structure in the early universe that led to the large scale structure we see today. Taking account of inflation, the universe turns out much older than cosmologists thought. The universe did not arise from a singularity 13.7 billion years in the past, as was supposed. The universe was accelerating exponentially prior to this time; prior to what was thought to be the big bang. The puzzle now is to work out how the vacuum energy density can change with time.

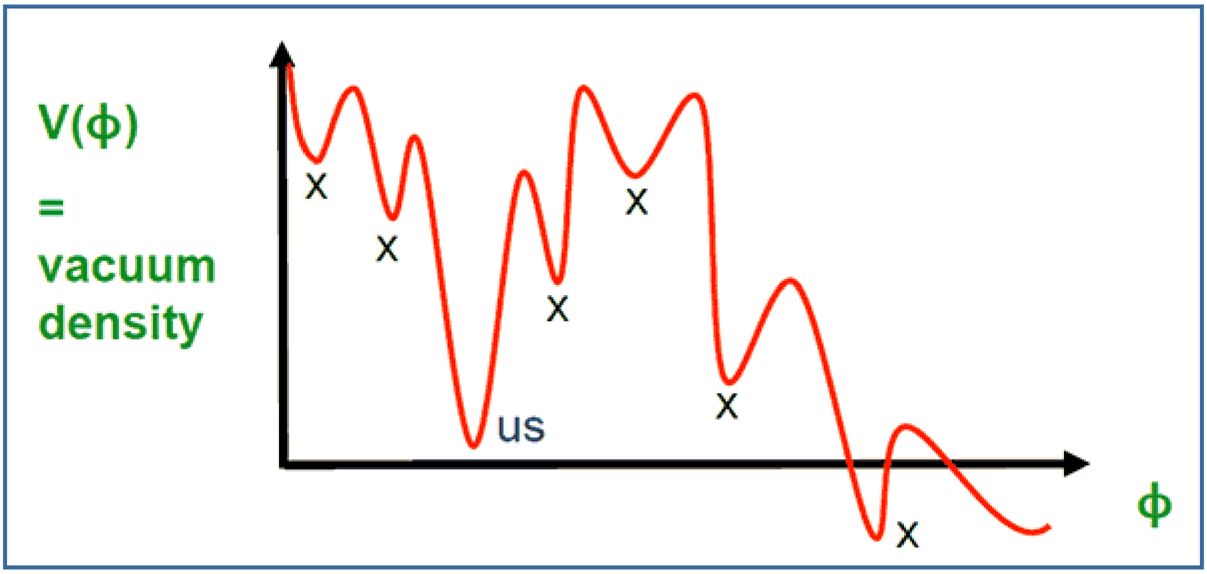
Diagram 2 – History of the expansion of the universe



The most promising answer to the puzzle borrows from Peter Higgs work in the 1960s on the Higgs field. Just as the Higgs field allows for different energy levels for the vacuum energy, a newly proposed inflaton field allows the vacuum density to change dynamically.

The thing with inflation is that it arises spontaneously from random quantum fluctuations in the vacuum. This process of blowing up a small region of space can happen many times in many different places. It is this blowing up of a very small quantum region into a massive bubble that gives us a new universe. Each of these bubbles is physically isolated from the others and has its own physical laws and constants. Each has its own value for the minimum vacuum energy density, the Vacuum State. In most bubbles, the value would be extremely high. However, quite independently of cosmological considerations, physicists using string theory calculate the number of possible minimum values for the energy density to be in the order of 10^{500}. Some of these minimum values approach zero.

Diagram 3 – Possible minimum values of vacuum density and our universe



Our universe is a universe with just such a low value for the vacuum density. In 1987, Steven Weinberg (the author of the Standard Model of elementary particles) used the anthropic argument to show why we don't live in a universe with a large vacuum density. He pointed out that if the vacuum density is not less than a specific threshold value, gravity will not sufficiently counteract the inflationary force to form the universe's large scale structures (i.e. galaxy structures).

Cosmologists cannot test inflation theory by directly conducting experiments in other universes as these are forever beyond our reach. However, they are able to test the consequences of the theory. In 1979, the Soviet physicist, Alexei Starobinsky, realized that the early inflationary period did not only modulate the density of matter in the young universe. He saw that it also modulated the gravitational field. From this realisation, he predicted the existence of relic gravitational waves left over from the early inflationary period. However, these gravitational waves are not easy to detect. How can they be detected? Starobinsky predicted that these gravitational waves will leave their imprint in the form of B-mode polarisation of light on the last scattering surface (the CMB) some 380,000 years after the end of the period of inflation.

For years, cosmologists have been searching for gravitational waves. On March 17th 2014, the BICEP2 research team, using the telescope mounted at the South Pole, announced that they had detected relic gravitational waves.[7] The results are currently being debated as measurements from the Plank satellite indicate that polarisation from dust in our own Milky Way galaxy may be muddying the results. We will need to wait for confirmation. These are indeed very exciting times.

In this essay, I considered the view that our universe has been fine-tuned for life to evolve. Carter's Anthropic Principle shows us how the fact that we are able to observe the universe constrains the kinds of universe we could observe. Even so, some scientists misconstrued the Anthropic Principle to construct elaborate teleological theories. I then explored how the application of quantum mechanics and string theory to the evolution of the early universe provides evidential support for the notion of a period of hyper-inflation. Tantalizingly, the theory underpinning inflation entails that we live in a multiverse in which the conditions for the evolution of life vary from region to region. In this way, we have come back full circle to the Anthropic Principle and a testable empirical theory that answers the question of why we find the universe the way it is.

[7] For the latest BICEP2 research results, refer to http://bicepkeck.org/

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