The Weak Anthropic Principle

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1 Static meets Dynamic

In 1917, Einstein set out to find the solutions, on the cosmological scale, to his equations of general relativity. He fully expected the solution to describe a static Universe, and was dismayed to find that the equations called instead for a dynamic process, an expansion or contraction. Despite his proven genius at seeing past the scientific dead-ends and prejudices of his time, he was so opposed to this notion that rather than accept it, he chose to go back and modify his equations by introducing Λ, known as the *Cosmological Constant*, a term the theory allows but does not call for. Λ has a rather astonishing physical significance; it modifies the force-law of gravitation to read

$$F(r) \propto \frac{1}{r^2} + \Lambda r \tag{1}$$

Einstein hypothized a finely tuned value for this constant to counter, at very large distances, the slow global crunch of gravity. He was thus able to propose a static solution. Unfortunately, it was soon shown to be inherently unstable. Five years later Friedmann found the general homogenous, iso- tropic solutions to Einstein's equations – describing a dynamic Universe – and of course, in 1929, Hubble would publish his results, describing the observed expansion of the visible Universe. Einstein deeply regretted the "blunder" of introducing the Cosmological Constant, and his failure to predict the non-static nature of the Universe. However, the constant would not go away so easily. To quote [Weinberg],

> "To say that a cosmological constant term is unnecessary is not enough; our experience in quantum field theory over the past half-century indicates that any term in the field equation that is not forbidden by some fundamental principle is likely to be present."

It is clear from (1) that the potential for Λ to wreak havoc with the way we expect gravity to function is enormous. Infact, if we cannot simply declare it a spurious term in the equations – something we surely wish we could – Λ must be incredibly tiny for the Universe to behave in a seemly fashion. We should be quite grateful that it *is*, but it is difficult not to ask *why*.

2 Constants of Nature

Other values like Λ exist, such as the fine-structure and gravitation constants, that seem to be fundamental in that we do not know of any more primal attributes of nature from which they can be derived. Particle physicists look at reality on the very smallest scale, and astrophysicists analyze the billion-year-old information that reaches us from space, and as far as we can tell, these values do not vary to any detectable degree. Their status as constants of nature would seem justified.

This notion, that fundamental reality as we see it here is likely to be representative of reality anywhere, is known as the *Cosmological Principle*. It seems to be generally regarded as philosophically attractive, an obvious extension of the Copernican Principle: there should not be anything special about the portion of space where we live; humanity does not occupy a priviliged position in any way.

However, it could surely also be accused of being provincial, and like Einstein's assumptions of a static Universe, perhaps more than a little grounded in prejudice. It is after all an article of faith, and articles of faith tend to evolve. That reality does not appear to crumble at the edges of what we can observe should hardly surprise us: however, take a step back! View the billions of light-years available to our perusal as merely a well-behaved spot in a Universe of unthinkable size and complexity! Why should the full time-frame of the Big Bang/Crunch be more than a tiny, fleeting flare in an *truly* majestic, uncaring eternity? Such a perspective would be truly in the spirit of Copernicus, rather than one where we arbitrarily dismiss what we cannot see as irrelevant.

Of course, at the same time, the Cosmological Principle *does* seem to hold for all space that we are ever likely to reach or even observe directly. Not many decades ago there was every reason to dismiss this kind of fanciful reasoning about what might lie outside the detectable as pointless speculation. But today, the theories that physicists work on could match the wildest construct of the imagination, and so a shift in our perspective seems quite appropriate.

Kindred in spirit to the Copernican world-view is one of the corner-stones of scientific methodology; the immaculately objective observer. Any scientist worth his salt will try hard to minimize external influences on his experiment, and if he cannot rid himself of such bias, he will try to correct his data for it. Let's play with an archetypal lab situation for a moment.

3 Survival of the fittest

Imagine a laboratory, a very large one, in which we have a number of jars. Each jar contains a tiny, potent singularity, a Big Bang waiting to happen. For each such Universe-egg we have chosen randomly, according to some probability distributions known to us, values for the natural constants that will shape the reality of that Universe.

Next, press the 'hatch' button and wait. Depending on the distributions of constants, the different Universes will develop quite differently. Perhaps only a miniscule number will live past the first second. A few might develop matter that forms clumps: galaxies, suns, planets. And if we wait long enough, if there were sufficiently many worlds, and the values we gave out were well- behaved enough, perhaps in one Universe, life might evolve.

If we examine the life-producing jar we will be unsurprised to find that it received very nice values for its constants of nature. There are an astonishing number of things that have to go just right in any Universe that wants to have a shot at producing life, not to mention intelligence, and all those things depend desperately on nature to work just so.

An interesting question now is what the newly evolved little intelligent life-forms in the successful Universe-jar are thinking about. They will be discovering mathematics, astronomy, and biochemstry, and as they investigate the nature of their reality, they will note some of its ludicrously well-behaved properties and they will puzzle over them. They will ask why the value of their cosmological constant should be so incredibly tiny, and wonder at how lucky they are to be living in so life-friendly a place. We, meanwhile, eaves–dropping on our pet life-forms, can only to look at discarded heaps of failed Universes in the corners of our lab, and agree.

There is obviously a difference in perspective here. In the course of asking how their reality works, they are certain to question what is random and what is law, what is constant and what varies, and what levels of reality may exist beyond their means of detection. In any such reasoning, they will be forever handicapped by their subjective perspective, the bias of their own existance. We are in a position to *know* their Universe looks the way it does because it *has* to look that way to produce intelligent life

They lack that perspective. Still, one day, they might come to think these thoughts; to note that the Universe they are in a position to observe necessarily *must* have the properties it does. When they do, they will have discovered – while probably calling it something rather different – the

> *Weak Anthropic Principle (WAP): The observed values of all physical and cosmological quantities are not equally probably but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirement that the Universe be old enough for it to have already done so.*

as defined in [Barrow/Tipler].

This might be seen as mildly anticlimactic. In fact, it is little more than common scientific sense: if we suspect our observations to be subjective, we must attempt to compensate for this bias. There are stronger Anthropic Principles, and we will get to them later. For now, let's see how interesting we can make the WAP. In the simplest vision of the Big Bang Universe, WAP is a little boring. All it seems to do is tell us to be grateful that we were given such nice constants and before we know it, we'll be religious. Luckily, there are alternatives: let us briefly go through some of the more speculative theories physicists are exploring and see if we can not broaden the perspective a little.

4 Inflation, Wormholes and Supersymmetry

One of the really juicy aspects of Cosmology is the way current conditions depend on initial ones; ie how the billion-year-expansion depends on the almost infinite density and heat of the very (very) early Universe. A second or so, after the Big Bang, reality as we know it was manifest much as we know it today. It is when we go to the absolutely earliest times that what we know breaks down, and it is here that many of the fantastic theories pack their punch.

Inflationary Universes qualify as fantastic. The idea is that when the Universe was incredibly young, say 10^{-40} seconds old, and likewise incredibly hot, *phase transitions* occured under very particular circumstances in such a way that for brief, brief moments, gravitation was essentially repulsive, and for those brief periods, the Universe went trough *exponential* expansion.

These theories have a number of attractive properties that explain difficulties with traditional Cosmological models. For our purposes, they make the WAP more interesting because they reduce the visible Universe as we know it to the hugely inflated correspondant of a tiny sub-region of some chaotic initial-value space. Such a vision almost begs to be expanded to encompass other Universes, causally disjoint from ours, similarly inflated but from other conditions: our lab situation recreated.

A favourite of science-fictiction shows are space-time *wormholes*. These are very narrow tunnels, with mouths of sizes around the Planck length, that "provide non-local connectedness within space and time" [Barrow] and thus seem to violate conservation laws (electrons can disappear at one end and appear at the other) and perhaps causality. The relevance to WAP here is on the one hand that an expanded view of the world is warranted, one where our Universe is run through with such little wormholes, possibly connecting us to short-lived sub-Universes, possibly doubling back to connect separate regions.

The second thing that happens is that wormholes seem to "bleed" constants of nature; to give them random jolts. Like the inflationary theories this provides a mechanism for natural selection: the general vision one where conditions can vary on the most fundamental level, and every manner of chaotic reality can exist next-door, and where we must use the WAP to explain why things are so benevolent just here.

Another viable set of theories have been those of superstrings and supersymmetry. These have been the domain of mathematicians as much as physicists and are quite grand in their description of nature. They avoid the quantum-field singularities of zero-extent particles by representing them instead as one-dimensional entities – strings – with some very attractive results. A rather startling implication of this line of thought is the prediction that the fullness of reality has more than the 3+1 dimensions we are comfortable with. When things were very very hot, in the beginning of things, there was more potential and less actual: all the ten or twentyfive dimensions of space were on equal footing, and nature was fundamentally stringy. As things cool down, again after something like 10 −40 seconds, three dimensions come out somehow victorious, and explode outwards in size – perhaps initially through inflation – becoming perceivable by living beings – while the rest remain, microscopic in extent.

One of the exciting consequences of such all-encompassing theories is that the constants of nature that apply in our perceived reality can be suspected to be derivable from essentially more fundamental attributes of fully N-dimensional space. Even if the influence of the microscopic dimensions at this time are, well, microscopic – it means, again, that the fates that selected *this* specific character of nature might have had a lot of choice in the matter: the WAP again becomes meaningful (and perhaps necessary) in explaining why just three dimensions should survive, why they should survive just so, as to produce the constants we observe.

5 Other Anthropic Principles

While the WAP is essentially scientific common sense, it is quite possible to extend it. Turning again to [Barrow/Tipler] for a definition, we have

> *Strong Anthropic Principle (SAP): The Universe must have those properties which allow life to develop within it at some stage in its history.*

Arguments in favour of the SAP derive support either from a Design Argument; that there is a benevolent will, a Designer, behind the observed life-friendly attributes of our Universe, or from the observer-sensitive nature of quantum physics, where intelligent life has a very real role to play in selecting what exists and what does not. But that is for a different essay.

6 Latest News!

Recent efforts to measure the deceleration of the Universe have produced some startling results. Using the Hubble Space Telescope to examine the explosion of extremely distant supernovae, the results seem to indicate that the Universe is not, infact, decelerating at all, but rather accelerating. Needless to say, this is something of a shocker.

Not only does there not seem to be nearly enough mass to pull things back, but there seems to be a counter-graviational force at work. This makes it difficult to avoid casting glances in the direction of the Cosmological Constant. Perhaps more importantly, it should serve as a reminder that simply because a theory has been favoured for half a century does not make it less dependant on fundamental assumptions in the transition from the local to the global.

References

[Weinberg] Steven Weinberg, *The first 3 minutes*

[Barrow/Tipler] John D. Barrow and Frank J. Tipler, *The anthropic cosmological principle*

[Barrow] John D. Barrow, *Theories of Everything*