ANTHROPIC PRINCIPLE IN COSMOLOGY

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Abstract.

A brief explanation of the meaning of the anthropic principle – as a prescription for the attribution of a priori probability weighting – is illustrated by various cosmological and local applications, in which the relevant conclusions are contrasted with those that could be obtained from (less plausible) alternative prescriptions such as the vaguer and less restrictive ubiquity principle, or the more sterile and restrictive autocentric principle.

Introduction.

Having been asked to contribute a discussion of the anthropic principle for a colloquium on cosmology, I would start by recalling that although its original formulation [1] was motivated by a problem of cosmology (Dirac's) and although many of its most interesting subsequent applications (such as the recent evaluation [2] of the dark energy density in the universe) have also been concerned with large scale global effects, the principle for which I introduced the term "anthropic" is not intrinsically cosmological, but just as relevant on small local scales as at a global level. In retrospect I am not sure that my choice of terminology was the most appropriate, but as it has now been widely adopted [3] it is too late to change. Indeed the term "anthropic principle" has become so popular that it has been borrowed to describe ideas (e.g. that the universe was teleologically designed for our kind of life, which is what I would call a "finality principle") that are quite different from, and even contradictory with, what I intended. This presentation will not attempt to deal with the confusion that has arisen from such dissident interpretations, but will be concerned only with developments of my originally intended meaning, which I shall attempt to explain in the next section.

Meaning of the Anthropic principle.

Whenever one wishes to draw general conclusions from observations restricted to a small sample it is essential to know whether the sample should be considered to be biassed, and if so how. The anthropic principle provides guidelines for taking account of the kind of biass that arises from the observer's own particular situation in the world.

Although frequently relevant to purely local applications, the anthropic principle was originally formulated in a cosmological context as a reasonable compromise two successively fashionable extremes. The first of these was what might be described as the autocentric principle, which underlay the pre Copernican dogma to the effect that as terrestrial observers we occupy a privileged position at the center of the universe. The opposite extreme was the more recent precept describable as the cosmological ubiquity principle, but commonly referred to just as the cosmological principle, which would have it that the Universe is much the same everywhere, having no priviledged center, and that our own neighbourhood can be considered as a typical random sample.

To put it more formally, in conventional Bayesian terminology, the a priori probability distribution for our own situation was supposed, according to the autocentric principle, to have been restricted to the region where we actually find ourselves, whereas according to the ubiquity principle it was supposed to have been uniformly extended over the whole of space time. Thus according to the autocentric principle we could infer nothing at all about the rest of the universe from our local observations, whereas according to the ubiquity principle we could immediately infer that the rest of the universe was fairly represented by what we observe here and now.

As a reasonable compromise between these unsatisfactory over simplistic extremes, the anthropic principle would have it that – within the context of whatever theoretical model may be under consideration – the a priori probability distribution for our own situation should be prescribed by an anthropic weighting, meaning that it should be uniformly distributed, not over space time (as the ubiquity principle would require), but over all observers sufficiently comparable with ourselves to be qualifiable as anthropic.

Of course if the qualification "anthropic" were interpreted so narrowly as to include only members of our own human species, then the cosmological implications of the anthropic principle would reduce to those of the scientifically sterile autocentric principle, but it is intended that the term "anthropic" should also include extraterrestrial beings with comparable intellectual capabilities. Thus, unlike the autocentric principle but like the ubiquity principle, the anthropic principle has non trivial implications that can be subjected to empirical verification. The prototype example was provided by the famous debate [4] between Dirac and Dicke about whether the strength of gravitation should decrease in proportion to the expansion of the universe: subsequent work has shown rather conclusively that Dirac's prediction (that it would), which was implicitly based on the cosmological ubiquity principle, must be rejected in favour of Dicke's prediction (that it would not), which was implicitly based on the anthropic principle. (This debate illustrates a common source of misunderstanding in this area, which is that relevant but questionable principles tend to be taken for granted tacitly, and even subconsciously, rather than being made explicit.)

If it were necessary to be more precise, one would need some kind of *microanthropic* principle specifying the notion of anthropic weighting in greater detail, dealing with questions such as whether it should be proportional to the longevity and erudition of the individuals under consideration. (For example should someone like Dirac or Dicke qualify for a higher weighting than a child who dies in infancy before even learning to count?) I have recently shown [5] how this issue provides insights that are useful for the fundamental problem of the interpretation of quantum theory.

The strong anthropic principle.

For the crude qualitative applications of the anthropic principle that have been discussed so far in the scientific literature, the fine details dealt with by the microanthropic principle [5] are in practice unimportant.

There is however a refinement of a rather different kind that plays a significant role in the published literature. This is the distinction between what are known as the "strong" and "weak" versions of the anthropic principle. In the ordinary, widely accepted, "weak" version the relevant (anthropically weighted) a priori probability is supposed to concern only a particular given model of the universe, or a part thereof, with which one may be concerned. In the more controversial "strong" version the relevant anthropic probability distribution is supposed to be extended over an ensemble of cosmological models that are set up with a range of different values of what, in a particular model are usually postulated to be fundamental constants (such as the well known example of the fine structure constant). The observed values of such constants might be thereby explicable if it could be shown that other values were unfavourable to the existence of anthropic observers. However if (as many theoreticians hope) the values of all such constants should turn out to be mathematically derivable from some fundamental physical theory, then the "strong" version of the anthropic principle would not be needed.

A prototype example of the application of this "strong" kind of anthropic reasonning was provided by Fred Hoyle's observation [6] that the triple alpha process that is necessary for the formation (from primordial hydrogen and helium) of the medium and heavy elements of which we are made is extremely sensitive to the values of the coupling constants governing the relevant thermonuclear reactions in large main sequence

stars. This contrasts with the case of the biochemical processes (depending notably on the special properties of water) to which such considerations do not apply, despite the fact that (as discussed by Barrow and Tipler [7]) they are also indispensible for our kind of life: the relevant biochemical properties are not sensitive to the values of any physical coupling parameters but are mathematicaly determined by the quantum mechanical consequences of the special properties of the 3 dimensional rotation group.

Although it does not affect the chemistry of the light and medium weight elements that play the dominant role in ordinary biochemistry, the particular value (approximately 1/137) of the electric coupling parameter that is (appropriately) known as the "fine structure" constant is more significant for the – less biologically relevant – details of heavy element chemistry. Of potentially greater "strong" anthropic relevance, however, is the effect [1] of the "fine structure" constant on the convective instabilities that are probably important for the creation of planets during main sequence star formation

A particularly topical application [2] [8] of the "strong" anthropic principle concerns the recently estimated value of Einstein's cosmological repulsion constant on the supposition that it is identifiable with what is commonly referred to as the "dark energy density" of the universe. If this parameter had been much larger (as might have been naively expected from fundamental physical considerations) then the universe would have already been inflated to such a low density at such an early stage in its life after the big bang that the galactic and stellar structures needed for our life systems would never have been able to condense out at all.

Although far from tautological, but of considerable scientific interest from the point of view of explaining the environment in which we find ourselves, the foregoing examples do not actually provide direct predictions of facts that are not already well established. However the next section will describe examples in which the anthropic principle provides genuine predictions in the form of conclusions that remain unconfirmed and even controversial.

Anthropic prediction.

Although oversimplified expressions of the anthropic principle (such as the version asserting that life only exists where it can survive) reduce to mere tautology, the more complete formulation (prescribing an a priori probability distribution) can provide non-trivial predictions that may be controversial, and that are subject to rational contestation since different from what would be obtained from alternative prescriptions for a priori probability, such as the ubiquity principle that would attribute a priori (but of course not a posteriori) probability even to uninhabited situations.

The example that seems to me most important was provided by the prediction [9] that the occurrence of anthropic observers would be rare, even on environmentally favorable planets such as ours. This prediction was based on the observation that our evolutionary development on Earth has taken a substantial fraction of the time available before our Sun reaches the end of its main sequence (hydrogen burning) life. This would be inexplicable on the basis of the ubiquity principle, which would postulate that the case of our planet was typical and hence that life like ours should be common. On the basis of the anthropic principle it would also be inexplicable if one supposes that biological evolution can procede easily on timescales short compared with those of stellar evolution, but it is just what would be expected if the biological evolution of life like ours depends on

chance events with characteristic timescales long compared with those of stellar evolution.

The (as yet unrefuted) implication that I drew from this (more than twenty years ago) was that the search for extraterrestrial civilisations was unlikely to achieve easy success. I have found however that such conclusions tend to be unpopular in many quarters, presumably because they involve limitations on the extent and more particularly the duration of civilisations such as ours which (in lieu of personal immortality) many people would prefer to think of as everlasting: in the words of Dirac (when refusing to accept Dicke's effectively anthropic reasonning [4]) the assumption to be preferred is "the one that allows the possibility of eternal life".

One of the most remarkable attempts to show that – despite the inexorable action [10] of the entropy principle commonly known as the Second Law of thermodynamics – life could after all continue to exist in the arbitrarily distant future, has been made by Freeman Dyson [11] , whose recent intervention in a related debate [12] provides another striking example of the kind of misunderstanding the anthropic principle was meant to help avoid. However the issue on this occasion is not the very long term future of life in the universe, but the more immediate question of the future of our own terrestrial civilisation in the next few centuries. Apparently under the influence of wishful thinking reminiscent of Dirac's, Dyson has strongly objected to a thesis developed particularly by Leslie [13] (and from a slightly different point of view by Gott [14]) of which a conveniently succinct discussion with a comprehensive review of the relevant litterature was provided by Demaret and Lambert [15]. The rather obvious conclusion in question is that the anthropic principle's attribution of comparable a priori weighting to comparable individuals within our own civilisation makes it unlikely that we are untypical in the sense of having been born at an exceptionally early stage in its history, and hence unlikely that our civilisation will contain a much larger number of people born in the future.

The foregoing reasonning implies that our numbers will either be cut off fairly soon by some (presumably [9] man made, e.g. ecological) catastrophe (the "doomsday" scenario [13]) or else (more "optimistically") will be subject to a gradual (controlled?) decline that must start even sooner but that could be relatively prolonged. Despite the fact that such conclusions can be and have been drawn independently (without recourse to anthropic reasonning) from other considerations of an economic or environmental nature, Dyson persists [12] in denying their validity, thereby implicitly repudiating the anthropic weighting principle on which they are based. Dyson's position seems to be based on what might be called the "autocentric principle" (the extreme opposite to the "ubiquity principle") as referred to above, whereby one attributes a priori probablity only to one's actual position in the universe. A supposition of this commonly (but usually subconsciously) adopted kind makes it legitimate for Dyson to rule out the use of the Bayes rule as something that is redundant (albeit not strictly invalid) because, according to this autocentric principle, no a priori probability measure is attributable to anything inconsistent with what has already been observed. However (quite appart from its failure to face the ecological considerations leading to the same conclusions) Dyson's wishful thinking in this context seems even less intellectually defensible than Dirac's ubiquitism, because the autocentric principle effectively violates Ockham's razor by its sollipsistic introduction of an artificial distinction between "oneself" and other manifestly comparable observers.

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