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# ANTHROPIC EXPLANATIONS IN COSMOLOGY

In the last century cosmology has ceased to be a dormant branch of speculative philosophy and has become a vibrant part of physics, constantly invigorated by new empirical inputs from a legion of new terrestrial and outer space detectors. Nevertheless cosmology continues to be relevant to our philosophical world view, and some conceptual and methodological issues arising in cosmology are in need of epistemological analysis. In particular, in the last decades extraordinary claims have been repeatedly voiced for an alleged new type of scientific reasoning and explanation, based on a so-called “anthropic principle”. “The anthropic principle is a remarkable device. It eschews the normal methods of science as they have been practiced for centuries, and instead elevates humanity's existence to the status of a principle of understanding” [Greenstein 1988, p. 47]. Steven Weinberg has taken it seriously at some stage, while many physicists and philosophers of science dismiss it out of hand. The whole issue deserves a detailed critical analysis. Let us begin with a historical survey.

## History of the anthropic principle

After Herman Weyl’s remark of 1919 on the dimensionless numbers in physics, several eminent British physicists engaged in numerological or aprioristic speculations in the 1920's and 1930's (see Barrow 1990). Arthur Eddington (1923) calculated the number of protons and electrons in the universe (Eddington's number, N) and found it to be around $10^{79}$. He noticed the coincidence between $N^{1/2}$ and the ratio of the electromagnetic to gravitational forces between a proton and an electron: $e^2/Gm_em_p \approx N^{1/2} \approx 10^{39}$. He also tried to explain the value of the fine structure constant $\alpha = e^2/\hbar c$ through numerological reasonings which were obscure and unconvincing to other physicists. In his relentless but sloppy search for ratios and numerical coincidences, Klee (2002) sees Eddington “attempting to extract numerological revenge on behalf of

Pythagoras.” In the 1930s Edward Milne developed a “kinematic theory of relativity”, based on philosophical ideas, such as the cosmological principle. He advocated the idea that the “constants” of physics, like the gravitational constant *G*, changed over the life of the universe. These predictions proved unfounded, as did the kinematic theory of relativity.

After a most distinguished career in quantum mechanics, Paul Dirac came under the spell of Eddington and Milne and in 1937 became also involved in numerology. As already mentioned, it was well known that the ratio of the electrostatic attraction between the proton and the electron in the hydrogen atom to the gravitational force between the same two particles is about $10^{39}$. Dirac found other combinations of fundamental constants with a somehow similar value. If we take as unit of time the time it takes light to travel a distance equal to the classical electron diameter, then the current age of the universe (estimated at that time to be just about two billion years) is about $6\times10^{39}$ of those units. So, again the order of magnitude $10^{39}$! Dirac suggested that this coincidence should be explained by looking for some link between the fundamental constants and the age of the universe. Since the age of the universe increases with time, the fundamental constants of physics also have to change in time, in order to keep that relation. Specifically, the value of the gravitational constant *G* would decrease with time. Later data from our solar system, from space probes and from the binary pulsar discovered by Hulse and Taylor in 1974 allow us to exclude that *G* is weakening at even a hundredth of the rate assumed by Dirac.

The scientific community soon became sick of these speculations. Already in 1931 Beck, Hans Bethe and Riezler spoofed Eddigton’s numerology in a parody they managed to get published in *Naturwissenschaften*. It was a curious precursor of Alan Sokal’s 1996 ‘hoax’ paper. In 1937 Herbert Dingle denounced in *Nature* the whole speculative approach: “This combination of paralysis of the reason with intoxication of the fancy is shown, if possible, even more strongly in Prof. Dirac's letter in *Nature* … in which he, too, appears victim of the great ‘Universe’-mania … Milne and Dirac … plunge headlong into an ocean of ‘principles’ of their own making … The criterion for distinguishing sense from nonsense has to a large extent been lost…”

In 1961 Robert Dicke published in *Nature* a short paper entitled “Dirac's cosmology and Mach's principle”. Dicke rejected Dirac's speculation about the change of *G* in time and found a simpler explanation in the selection effect (on possible values of the constants) of the fact that we, humans, are here. So the Hubble time *T* elapsed since the big bang (the age of the universe) “is not a ‘random choice’ from a wide range of possible choices, but is limited by the criteria for the existence of physicists.” So the values of *T* are constrained by the requirement “that the universe, hence galaxy, shall have aged sufficiently for there to exist elements other than hydrogen. It is well known that carbon is required to make physicists.” Dirac published a short reply to Dicke, saying that Dicke's analysis was sound, but that he (Dirac) preferred his own argument because it allowed for the possibility that planets “could exist indefinitely in the future and life need never end.” Dicke was a practical man, more interested in observation than in speculation. After his 1961 paper, he did not dwell on that piece of anthropic reasoning nor did he show any further interest in the matter.

The carbon of which Dicke spoke is produced by nuclear fusion of helium inside red giant stars. This process takes several billion years (in small or medium-size stars) or a few million years (in large stars), after which period the star can explode as a supernova, scattering the newly formed elements throughout space, where they can eventually become part of a planet, on which life could evolve. So, in order to be able to produce carbon-based life, the universe must be at least several million years old. On the other hand it can not be too old (older, let us say, than $10^{12}$ years), because if it was, all the stellar processes would have already concluded and there would be no life-sustaining radiation energy around. This is the reason for the coincidence remarked by Dirac, and there is no need to go to the length of postulating a variable gravitational constant. In any case, the “prediction” is extremely vague, and the range of time that allows carbon atoms or planets to exist extremely broad: from a few million to a trillion years.

In 1973 C. B. Collins and Steven Hawking noticed that only a narrow range of initial conditions (out of all the possible values of the physical constants) could give rise to the observed isotropy of the actual universe. They found this result unsatisfactory, because current theory did not offer any explanation for the fact that the universe turned out this way rather than another. Collins and Hawking reasoned along anthropic lines to discuss the flatness problem. Starting with the assumption that galaxies and stars are necessary for life, they argued that a universe beginning with too much gravitational energy would recollapse before it could form stars, and a universe with too little of it would never allow gravitational condensation of galaxies and stars. (Notice that they were talking of galaxies, and the assumption that galaxies are indicators of life does no real work in the argument). Thus, out of many different possible initial values of Ω (the ratio of the actual average density of the universe to the critical density), only in a universe where the initial value of Ω was almost precisely 1 could we have existed. This would explain why Ω is so near to 1.

In 1974 Brandon Carter published "Large Number Coincidences and the Anthropic Principle in Cosmology", in which he presented his ideas, previously exposed in oral form. In this article Carter baptized the type of reasoning already present in Dicke's paper as the *anthropic principle*. He distinguished two versions of it, the weak and the strong. The weak anthropic principle says that "what we can expect to observe must be restricted by the conditions necessary for our presence as observers". This true but trivial version is very different from the strong anthropic principle, which says that "the universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage". Others have formulated the strong anthropic principle as saying that it is a law of nature that life or intelligent life has to evolve.

In 1979 Bernard Carr and Martin Rees pointed to many alleged "cosmic coincidences", numerical relations among physical magnitudes that, if allowed to change (keeping everything else in the theoretical structure constant), would make carbon-based life impossible. Carr (1982) and others began to speak of a fine tuning of the physical constants to make life possible.

All these speculative developments culminated in 1986 in the book of John Barrow and Frank Tipler, *The Anthropic Cosmological Principle*. This 700 page book exhaustively traced the history of teleological ideas and cataloged the alleged applications of the anthropic principle to lots of coincidences and contingencies in the initial conditions of the universe and in the fundamental constants of physics. For example, the strength of the fundamental forces of nature (gravitation, electromagnetism, weak and strong interaction) as given by their corresponding fine structure constants (dimensionless numbers which are ratios of fundamental constants, like $c, h, G, e, m_p, m_e$) is found to be so well proportioned and fine tuned, that any tinkering with their values or ratios would make life impossible. Other speculations, for example on (and against) extraterrestrial intelligence, were also extensively dealt with. The scientific reception of the book was rather negative. In his review in *Nature* (1986), astrophysicist William Press even wrote that "there is some fundamental intellectual dishonesty here, some snake oil to be peddled". Nevertheless the book popularized the "anthropic" talk. The anthropic principle made its way into the popular science literature and even popped out (in a loose and redundant way) in some serious technical papers.

Some outstanding physicists like John A. Wheeler, Hawking and Weinberg have at some stage appealed to the anthropic principle as a desperate way out of their difficulties. Rees has been promoting the anthropic principle in a continuous stream of popular science books. In 1990 Shaposhnikov and Tkachev tried to estimate the mass of the Higgs boson by anthropic considerations. From 1987 on Weinberg has tried to find an anthropic bound to the cosmological constant. More recently, he has become more skeptical: "This sort of reasoning is called anthropic, and it has a bad name among physicists. Although I have used such arguments myself in some of my own work on the problem of the vacuum energy, I am not that fond of anthropic reasoning." (Weinberg 2001, p. 173). In 1998 Hawking and Neil Turok used the Hawking-Hartle wave function for the universe, coupled with the anthropic principle, as a way of achieving an open universe in a broadly inflationary scenario (without false vacuum). Shortly thereafter, the new distance measurements of type Ia supernovae seemed to favor a flat universe again, and at least Turok does not wish to appeal to the anthropic principle any longer. Still in 2003 Leonard Susskind invoked the anthropic principle as a desperate way out of the huge multiplicity of solutions plaguing string theory. Most physicists are appalled at the introduction of these loose ways of reasoning in science. As commented by Peter Mittelstaedt in 2000, the anthropic principle is not a problem in philosophy of science, but in psychology of science: how could competent physicists take such a thing seriously?

## Cosmic coincidences and fine tuning

As we saw, the numerological speculations of Eddington, Milne and Dirac were at the origin of the anthropic thinking. Numerology is the resort to obscure and far-fetched explanations for numerical coincidences. As a matter of fact, and as documented by Klee (2002), the authors in the anthropic tradition have had a rather sloppy and cavalier way of seeing astonishing coincidences in numbers different by several (even by six) orders of magnitude. If we look for broad numerical coincidences, we will find them everywhere. The number of neurons in our brain seems to be of the same order of magnitude as the number of stars in our galaxy, about $10^{11}$. And so what? The numerologist would be tempted to look for hidden designs behind this harmless coincidence.

Let us consider the following six fundamental physical constants: the gravitational constant, the speed of light, Planck's constant, the electric charge of the electron and the proton, the rest mass of the proton, and the rest mass of the electron ($G, c, h, e, m_p, m_e$). Let us consider a 6-dimensional space, each of whose 6 coordinates coincides with the set of all possible values of one of those 6 fundamental physical constants. Each vector or point of this space represents a possible combination of values for the six physical constants considered, or, if you prefer, each point represents a (logically) possible universe. In most of these possible universes there would have been no galaxies, no long lasting main sequence stars, no life, no intelligence, no scientists. Only in a small subset of the set of all possible universes can all these things exist. So, if we already know that there are scientists, or humans, or rabbits, or stones, we can infer from this item of information that the actual universe is a point of the restricted subset which allows for the existence of such things. This inference rule has been called the (weak) anthropic principle.

The anthropic speculations often focus on the fact that most points in the possibility space would represent universes unfit for life, on the many coincidences which are necessary for life to arise and on the alleged evidence of fine tuning provided by these coincidences. For example, if the charge of the proton had been (in absolute value) different from the charge of the electron, no stable objects could have formed. Every two atoms would repel each other, every star, planet or organism would explode. “If we modify the value of one of the fundamental constants, something invariably goes wrong, leading to a universe that is inhospitable to life as we know it” (Gribbin & Rees 1989).

Carr and Rees (1979) reviewed the many “anthropic coincidences”, the many cases where the values of constants are in the narrow ranges compatible with life. They concluded that “nature does exhibit remarkable coincidences and these do warrant some explanation. … The anthropic explanation is the only candidate and the discovery of every extra anthropic coincidence increases the *post hoc* evidence for it."

Carr and others continued to elaborate the idea and they began to speak of fine tuning. For example, it is well known that the density of the universe is very close to the critical density, which would make the space flat, marking the frontier between an open and a closed spacetime. Now the actual density deviates from the critical density by at most an order of magnitude (a factor of ten). In the past the deviation was much smaller: it was only one part in $10^{16}$ one second after the Big Bang, and still smaller before. These are the type of densities which allow the universe to expand at the adequate rate for the formation of chemical elements like carbon and the evolution of life.

There is no known physical reason why the initial expansion rate should have been what it was, so one is led to speculate why this should be. One suggestion is that we could not be here if things were otherwise. On the one hand, if the expansion rate were slightly too low, the universe would recollapse before life had time to arise; on the other hand, if the expansion rate were slightly too high, life could not arise either because galaxies could not have formed amid the general expansion (Carr 1982).

All this talk of coincidences and fine tuning is rather muddled and careless. As pointed out by Ernan McMullin (93), the large-number coincidences have nothing to do with the "fine tuning" of the constants, and this has nothing to do with the laws. The same applies to the alleged improbability of the actual world. No one wants to buy a lottery ticket with the number 5555555. It seems very improbable that such a number will win. As a matter of fact, that number is no less probable than any other, let us say 3405175, which looks less peculiar. A repetition of draws would erase any surprising coincidences in the long run, but in a single draw any result (however full of coincidences) is as likely as any other. Already Rémi Hakim (1989) rejected as lacking any foundation the sense of "probability" used in talk of multiple universes and arguments of fine tuning: "The notion of probability issues from (and implies) the real possibility of repeating the same random experiment a large number of times in an independent way. However the choice of universe is, for us, not only impossible to repeat, but even to realize at a single time".

The universe (as far as we can know it) is something unique ('uni-verse' and 'uni-que' come from the same root 'uni', one). We can learn a posteriori how the universe is, but it makes no sense to speculate on how it should be on the basis of a priori statistical considerations. This is the reason why John Leslie's (1989) firing squad argument is flawed. He compared our existence to the survival of a sentenced man, because each of the guns in his execution squad misfires. Has someone (God?) tinkered with the guns beforehand? Of course, there have been lots of firing squads and seldom have all the guns misfired. There is a grim statistics of firing squads. But the universe is a unique historical fact. There are no statistics of universes. Besides, the components of the firing squad are people with the intention of shooting, but there are no intentions in the fabric of the universe. At least in usual language, fine tuning implies intentionality and multiplicity of cases. The question of fine tuning does not arise in unintentional one-element sets.

## The weak anthropic principle

Brandon Carter (1974) introduced the weak anthropic principle with the words: "what we can expect to observe must be restricted to the conditions necessary for our presence as observers." Barrow and Tipler (1986) formulate the same principle in this way: "The observed values of all physical and cosmological quantities are not equally probable, 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." Roberto Torretti (1994) expressed perplexity at the usage of the probability notions by Barrow and Tipler: "What does it mean to say that 'the observed values of all the physical … quantities are not equally probable'? … In fact, any correctly observed value, just because of having been observed, has probability 1."

In a nutshell: The fact that we exist implies that the universe satisfies all the necessary conditions for our existence. Or, in probabilistic garments: The conditional probability of the real universe being in the restricted region of the possible-universes space where life is possible, given the fact that we exist, is different (and much higher) than the absolute probability would be in an a priori probability distribution which did not take into account the fact that such things as people and rabbits actually exist.

Gale (1986) stressed that the weak anthropic principle, “even if acceptable, … appears *so* weak as to be meaningless. At first glance, it looks either trivial, or tautological or transcendental, or all three at once.” Nevertheless, he thought it could function as a heuristic device. Earman (1987), after careful examination, concluded that in the weak anthropic principle “it is hard to find anything stronger than a tautology”.

The (weak) anthropic principle is a valid rule of inference, but it is not a physical (or non-physical) explanation of anything. If the physical constants being what they are is a necessary condition for the existence of humans (or cockroaches), and there are humans (and cockroaches), then, we can conclude, the physical constants are what they are, ie they are in the limited region of the possibility space which make humans and cockroaches possible. This is not a principle of physics, but an application of a trivial theorem of logic: whenever *A* is a necessary condition for *B* and *B* obtains, *A* must also obtain. This is just an equivalent reformulation of the good old inference rule of *modus ponens*: from (if *A* then *B*) and *A* you can infer *B*. Remember that ‘if A then B’ is equivalent to ‘*B* is a necessary condition of *A*’.

So-called anthropic reasonings are very often just indirect reasonings (by *reductio ad absurdum*), in which, knowing already that *A*, we prove that *B* by showing that if not *B* then not *A*. So, if we already know (as we do) that there are people, or stones, and that if protons and electrons had different electrical charges, there would be neither people nor stones, we can conclude that protons and electrons have to have the same electric charge (in absolute value). This type of reasoning is again an application of another old inference rule, *modus tollens*.

Far from representing any breakthrough in scientific reasoning, the (weak) anthropic principle is just the restatement of an elementary rule of logic, already known in the Middle Ages and even by the ancient Stoics. It is valid with the barren and trivial validity of tautologies. It only allows us to infer what we already knew (that the constants have the values we know they have), but it does not allow us to explain anything. Neither does it lead to any new prediction.

## No predictions from the anthropic principle

It is usually agreed that the anthropic principle has never led to any genuine scientific prediction (i.e. to any prediction of something previously unknown). So, for example, Carr and Rees at the end of their 1979 sympathetic review, aknowledge that the anthropic principle "is entirely *post hoc*: it has not yet been used to predict any feature of the Universe." Nevertheless Barrow and Tipler (1986, p. 252-253) pretended that there was one case of anthropic prediction: Fred Hoyle's prediction in 1953 of an excited state of the carbon isotope $^{12}C$ at 7.6 MeV above the ground state. This contention was rejected in several reviews of the book. So, Helge Kragh (1987):

> Barrow and Tipler claim that Fred Hoyle's remarkable 1953 prediction of the resonance energy level of $^{12}C$ was based on the anthropic principle. What Hoyle showed was that only if there exists a certain carbon resonance can astrophysical theory be consistent with the present existence of carbon … But Hoyle's prediction is not anthropic since it does not refer to the existence of human beings but only to carbon atoms …

Barrow and Tipler's pretension was acritically accepted by some later writers, like Yuri Balashov (1991): "Many authors argue that the anthropic principle … is absolutely incapable of predicting anything new. One must remember, however, that in 1953 Hoyle *predicted*, based on what we now call anthropic arguments, the *unknown* excited resonance level in $^{12}C$." Some popular science books have made the view notorious, even if the comments often went in opposite directions. So, in connection with the resonances between helium, beryllium and carbon, Gribbin and Rees (1989) write: "This combination of coincidences, just right for resonance in carbon-12, just wrong in oxygen-16, is indeed remarkable. There is no better evidence to support the argument that the universe has been designed for our benefit - tailor-made for man". On the contrary, Greenstein (1988) comments: "Those resonances really are coincidences. They are genuinely remarkable strokes of luck. The anthropic principle provides no explanation for anything, and no amount of anthropic reasoning can explain these coincidences."

According to our actual understanding of nucleosynthesis, most of the atomic nuclei of hydrogen (protons, H), deuterium ($^{2}H$), helium ($^{3}He$ and $^{4}He$) and the isotope lithium-7 ($^{7}Li$) were formed shortly after the big bang. The rest of the atomic nuclei were cooked later in the core of red giant stars. Hydrogen and helium continue to be by far the most abundant nuclei. After hydrogen and helium, carbon and oxygen (in the form of the isotopes $^{12}C$ and $^{16}O$) are the two most abundant nuclei in the visible universe.

In his classic 1954 paper "On nuclear reactions occurring in very hot stars: The synthesis of elements from carbon to nickel", Hoyle gave the first satisfactory account of the production of carbon, oxygen and neon in the interior of red giant stars. It was already well understood that main sequence stars burn hydrogen into helium. Once the hydrogen supply is exhausted, they leave the main sequence, expand dramatically, become red giant stars and begin to burn helium. The burning or fusing of helium to produce first carbon and then oxygen and neon, was still not understood. Once carbon was available, oxygen could be formed by fusing carbon with helium and neon could then be formed by fusing oxygen with helium. The main difficulty laid in the production of carbon from helium in the first place. Edwin Salpeter suggested originally that the fusion of three "alpha particles" ($^{4}He$ nuclei) to $^{12}C$ would occur by a simultaneous collision.

$$3\ ^{4}He \rightarrow\ ^{12}C + \gamma$$

Calculations showed that the three-collisions were too rare and the burning rate of helium would be too slow. Taking into account that two-collisions were much more frequent than three-collisions, Salpeter then made the further suggestion that helium burning occurred in a two-step process: first two helium nuclei collided to form the isotope beryllium-8 and then this beryllium nucleus collided with an helium nucleus to form carbon.

$$2\ ^{4}He \rightarrow\ ^{8}Be$$

$$^{4}He +\ ^{8}Be \rightarrow\ ^{12}C + \gamma$$

The problem is that $^{8}Be$ is highly unstable, it bursts apart in $10^{-15}$ s, making the encounter with an helium nucleus too improbable. If it nevertheless happened, it would have to be due to the existence of a certain resonance in $^{12}C$. Hoyle accurately calculated the resonance, an excited state of the $^{12}C$ nucleus at about 7.6 MeV above the ground state. Subsequently this resonance was experimentally detected in the exact predicted energy range, to the astonishment of the scientists (Cook, Fowler and others) who performed the experiment. Hoyle's calculation is considered a tour de force of modern astrophysics. Hoyle was able to derive the properties of the excited energy levels of $^{12}C$ and $^{16}O$ from the astronomical facts then known, like the cosmic abundances of carbon and oxygen. In the whole 1954 paper by Hoyle there is of course no reference to the still unborn anthropic principle, but neither is there any reference to humans or life or observers. Taking the known facts of astronomy and chemistry into account to formulate a bright hypothesis that solves a previous puzzle and gets confirmed by experiment is an example of the standard scientific method at its best. It has nothing to do with humans or with any specifically anthropic way of reasoning.

The anthropic authors have often underlined the very precise fine tuning needed for the famous resonant excited energy level of $^{12}C$ at 7.644 MeV, which is "just" (in fact, 277.3 keV) above the sum of the combined energies of a $^{8}Be$ and a $^{4}He$ nucleus. Mario Livio and his fellow astrophysicists Hollowell, Weiss and Truran have run systematic computer simulations of the consequences for carbon production in stars of increasing or decreasing that value of 7.644 MeV. In 1989 they published their results in *Nature*. By lowering the level of 7.644 MeV by 60 keV, the production of carbon was four times higher than normal. "It appears that carbon production is not strongly favored by nature, because a small reduction in the energy difference would lead to a relatively much greater increase in carbon abundance …" An increase of 60 keV would not significantly alter the level of carbon production. So carbon abundances like the observed or still higher are compatible with a window (of the resonant excited energy level of $^{12}C$) of 120 keV, equivalent to a temperature window of 1.39 billion K. As Klee (2002) asks: "How can a temperature window *that* wide within which the resonant energies can fall count as a case of 'fine tuning' that results in energy levels that are 'just barely' resonant?"

## Misnomer

"Anthropic principle" is a complete misnomer. First of all, and as already remarked by Mc Mullin (1993) and acknowledged even by Rees (2001), it is not a principle at all. More importantly, it does not deserve the adjective "anthropic" (relative to humans), as there is nothing specifically human or about humans in the type of reasoning it refers to. It could also have been called the rabbit principle or the cockroach principle. There cannot be rabbits or cockroaches without heavy chemical elements having been formed in the interior of massive stars and scattered around in supernova explosions. But there are rabbits and cockroaches. So (we can conclude by the rabbit principle or the cockroach principle) the fundamental physical constants must be in the narrow margin that allows for heavy chemical elements to be formed in stars and scattered in supernova explosions. Perhaps we should rather talk about the beetle principle, for, as observed (tongue in cheek) by Haldane, God loves beetles above anything else, as shown by the many species of beetles (more than 300,000) He created. Neither is there anything specific about life or living organisms in the principle. It could also be called the washing machine principle, or the limestone principle. Of course, there could not be any washing machines or limestones without heavy chemical elements having been produced in the interior of massive stars and scattered around in supernova explosions.

That the weak anthropic principle has no more to do with humans than with beetles or uranium atoms was soon recognized. According to Earman (1987), the motivation force of the weak anthropic principle "does not derive from any consideration about Man, Consciousness, or Observership. The weak anthropic principle, as used by Dicke and Carter, is in fact nothing but a corollary of a truism of confirmation theory. Nor does the application of the corollary have to rely on life or minds, for the selection function is served just as well by the existence of stars and planetary systems supporting a carbon-based chemistry but not life forms." Helge Kragh (1987) remarks that "in virtually all the examples of the (weak) Anthropic principle mentioned by Barrow and Tipler the existence of human beings, or even life, is in fact irrelevant. Most of the so-called anthropic arguments can be reduced to standard scientific arguments of the retroductive form in which it is asked which constraints have to be put on nature in order to make it consistent with current theory and observation." The same point was raised by Wilson 1991 and McMullin (1994).

The anthropic authors frequently switch between carbon atoms and human consciousness (or observership), as if they were somehow equivalent, or at least as if the first was a precondition of the second. So Alexander Vilenkin talks about consciousness, but only to say that galaxies are good tracers of life and consciousness and to confine his arguments to galaxies. In general, either heavy chemical elements or galaxies are all that is needed for "anthropic" arguments. Only in the very particular version of Wheeler's participatory anthropic principle does consciousness or observership as such play any role. For the rest, it is just carbon atoms what we are talking about. Besides, in traditional religious thought, observers, minds or intelligences need not be made out of carbon or other heavy chemical elements. God(s), angels and other alleged spiritual beings were supposed to be minds and to be observing and even watching us all the time.

## Privileged position

Carter (1974) wrote: “We must be prepared to take account of the fact that our location in the universe is *necessarily* privileged to the extent of being compatible with our existence as observers”. But *any* position is privileged to the extent of being compatible with the existence of whatever exists at that position. Such an alleged privilege is so universal as to constitute no privilege at all.

The special conditions of temperature which prevailed at the very early time when the universe was a quark soup made for a privileged position for the quark soup. Indeed as soon as the universe expanded and cooled, the conditions were not right any more, and the quark soup lost its privileged position and disappeared, transformed into something else. Black holes are also privileged in the sense of having very special conditions in their corner of the world. Anything is privileged when it is in a cosmic position which satisfies the conditions for its existence.

Aerobic creatures (like us) are privileged because they are in an oxygen-filled medium like the earth's atmosphere, while anaerobes like the bacteria in the guts of mammals are privileged due to the lack of oxygen in their environment. The sulfate-reducing bacteria *Thiopneutes* require sulfur for their respiration and are quickly poisoned by exposure to oxygen. So there is little wonder that they enjoy the privilege of living in media rich in sulfates and lacking free oxygen, like certain muds or soils of geothermal regions. Even neutrons bound in atomic nuclei and neutron stars are in a privileged situation, which allows them to exist. Free neutrons decay into protons and electrons in about ten minutes.

Carter (1983) pretended to react “against exaggerated subservience to the ‘Copernican principle’”. He called Copernican principle “the assumption that our own situation in the Universe is not in any way privileged, but is typically representative in a Universe that is entirely homogeneous apart from minor local fluctuations”. He identified the modern version of the Copernican principle with the “perfect cosmological principle” of Hermann Bondi and Thomas Gold.

The "cosmological principle" is the name some people give to the assumption that the universe is spatially homogeneous and isotropic, i.e., that the 3-dimensional slices (hypersurfaces) of constant time of the 4-dimensional spacetime are symmetric. This assumption is necessary for the application of the FRW metric, which is the component of the standard big bang model that allows us to solve Einstein's field equations. (As is well known, the non linear equations of general relativity cannot be solved in general, but only in some extremely simple cases, like the Schwarzschild or the FRW metrics.) The so-called perfect cosmological principle also postulates the temporal symmetry and homogeneity and is thus incompatible with the big bang model, which represents a dynamically evolving universe. It is the basis of the steady state model.

In the day-dreaming world of anthropic speculation, nothing is what it appears. The anthropic principle is not anthropic and the Copernican principle is not Copernican. Actually Copernicus never defended anything like the perfect cosmological principle, not even the cosmological principle. He did not think that the positions of the Sun and the Earth were homogenous. He just thought that the "honorific" central position was reserved for the Sun, not the Earth. His point was that the Earth was not at the center, but was a planet circling the central Sun. McMullin (1993) comments that Carter

> begins from what he calls the "Copernican principle" to the effect that the cosmic abode of man is in *no* way privileged. (Copernicus would, I suspect, be astonished to have this taken to be an inference from his theory!) By "privileged", he does not mean to have an honorific status or advantage attached, rather that the human abode has *no* special features associated with it that would mark it off from any other part of the cosmos. He calls it a "dogma" of earlier cosmologists. In the face of it, it is *obviously* false, since the Earth is a planet, has an atmosphere, and has many other features that *do* mark it off from empty space, for example. What he seems to have in mind is the much more limited claim that the earth, the human abode, is not "privileged" … in its overall spatial or temporal *location*. … The reference to humans here (rather than, say, to beetles) comes only from the expectations engendered by religious or philosophical traditions that led people to expect that the human abode *would* be privileged in its cosmic location, privileged in the proper sense of being at the center and not just of being different.

### Bayesian argument

Carter (1983), Garret & Cole (1992) and others have pointed out that the weak anthropic principle can be viewed as an application of Bayes' theorem.

The Bayesian approach to inductive inference is based on the assignment of prior probabilities to competing hypotheses (using the principle of maximum entropy or otherwise), and the reassignment of posterior probabilities, once new data are available, as a function of the likelihood of those data, assuming the truth of the different hypotheses. The hypothesis which gives the maximum probability to the data is favored.

The posterior probability of the hypothesis $H$ in view of the new data $D$ and the background knowledge $K$, $P(H|D \wedge K)$, is given by Bayes' theorem in terms of the prior probability $P(H|K)$ (assigned using the maximum entropy principle) and the likelihoods $P(D|H \wedge K)$ and $P(D|K)$:

$$P(H|D \wedge K) = \frac{P(H|K) \cdot P(D|H \wedge K)}{P(D|K)}$$

From here follows the inference principle:

$$P(D|H \wedge K) > P(D|K) \Rightarrow P(H|D \wedge K) > P(H|K)$$

which says that the likelihood of the data, given the hypothesis, gives support to the hypothesis.

Now, if we take the hypothesis to be $R$ (that the values of the constants and parameters of the standard cosmological model are in the restricted range that allows – via the formation of stars and planets and heavy chemical elements – for the evolution of carbon-based life), the datum to be $L$ (that there is carbon-based life on Earth) and the background knowledge to be $M$ (the standard cosmological model), then we can reformulate the last formula as:

$$P(L|R \wedge M) > P(L|M) \Rightarrow P(R|L \wedge M) > P(R|M)$$

The likelihood of there being carbon-based life, assuming the standard cosmological model with its constants and parameters in the narrowly restricted range which allows for the evolution of life, is much greater than the likelihood of finding carbon-based life, assuming only the standard model without any specific values for the parameters (because most combinations of the values of its parameters preclude the evolution of carbon-based life). So we can conclude that the posterior probability of the parameter values being in the life-producing zone, given the datum that there is life, is much greater than its prior probability. And this can be considered to be another version of the weak anthropic principle.

The argument is formally correct. What is a little odd is to consider the standard cosmological model as background knowledge and the fact that there is life as a *new* datum. The Bayesian rule is a rule of inference, not a principle of explanation. But even as an inference principle couched in Bayesian terms, the argument only leads to already known results, and remains conspicuously sterile.

## Difference between inference and explanation

We don't need to assume that all syntactically correct why questions make sense. How many hairs do I have on my head now? Why that many? Why is today Tuesday? Why is water $H_2O$? Why does the Earth have only one natural satellite? Why does the Sun have nine planets? Why is there anything? As remarked by Sylvain Bromberger (1992), "Why questions, unlike other wh-questions [what, how, when, where, ...], can be obscure ... It is the obscurity of not knowing what, if anything, controls whether it has an answer at all. ... I don't know why there are nine large planets. I don't know whether there is an answer to that why-question. ... I don't know whether there being only nine planets isn't simply a brute fact".

Perhaps the values of the fundamental constants of physics are brute facts. Perhaps there is nothing to explain about them. Or perhaps there is an explanation, but we do not know whether we will ever find it. That explanation could only be provided by some sort of overarching theory, which would allow us to deduce such values from more general principles, instead of measuring them empirically. The existence of such a theory is just a hope. Anyway, the fact that we exist does not explain why the constants of physics and the parameters of the standard cosmological model have the values they have. Our life and existence do not explain the initial conditions of the universe or the value of the fine structure constants. The alleged anthropic explanation follows a pattern to which the following “explanations” also belong:

Why is it raining? Because I have opened my umbrella. Why did I get the bacterial infection? Because I am taking antibiotics. Why did he commit a crime? Because he is now in prison. Why did they get married in the first place? Because they later got divorced. Why did he smoke? Because he later gave up smoking. Why did he die yesterday? Because he was alive one week ago. Humankind developed the linguistic ability, because I am writing today. Writing was invented, because I am writing today. There is still hydrogen left in the sun's core because I am writing today. There is something rather than nothing, because I am writing here today. My grandmother did not die a virgin, because I am writing today.

Why is there oxygen in the Earth's atmosphere? Because we humans breathe oxygen. Of course this “anthropic explanation” is no explanation at all. The oxygen in the atmosphere antedates our arrival on Earth by two billion years. On the contrary, that the atmosphere contains oxygen is a precondition of the existence of aerobic creatures like us. Philip Gasper (1991, in a context independent of any concern for the anthropic principle) gave this as a text-book example of derivation without explanation: “For instance, from the laws of biology together with the fact that there are mammals on the earth, we can deduce that there is oxygen in the atmosphere. We clearly have not explained the presence of oxygen in this way ...”

In whatever account of explanation, the *explanans* contains initial conditions which are temporally prior (or at most simultaneous) to the facts to be explained (*explanandum*). The only point that all people who talk about causes and explanations agree on is that you cannot explain a cause by its effects. You cannot explain the initial conditions of the universe fifteen billion years ago by our existence now. Carr and Rees (1979) remarked: “From a physical point of view, the anthropic “explanation” of the various coincidences in nature is unsatisfactory, in three respects. First, it is entirely *post hoc*: it has not yet been used to predict any feature of the Universe ... Second, the concept is based on what may be an unduly anthropocentric concept of the observer. ... Third, the anthropic principle does not explain the exact values of the various coupling constants and mass-ratios, only their order of magnitude." Gale (1981) gave this analysis of Dicke's initial reasoning: "In general arbitrariness has been eliminated by showing that a phenomenon can be predicted or that a theory can be deduced from some more fundamental premise. Dicke's technique is quite different. Deductive or predictive logic proceeds from a fundamental assumption to a derived result: the future is deduced from the past. The temporal flow of Dicke's argument is in the opposite direction. He cites a present condition (man's existence) as the explanation of a phenomenon grounded in the past (the age of the universe)."

The blunder of anthropic explanations is so obvious that it does not even escape sympathetic theologians. Commenting Collins and Hawking's (1973) explanation, "... the isotropy of the universe is a consequence of our existence", William Craig (1988) wrote "literally taken, such an answer would require some form of backward causation whereby the conditions of the early universe were brought about by us acting as efficient causes merely by our observing the heavens". And Richard Swinburne (1990) added: "The suggestion might seem to be that our existence is in some way the *cause* of the laws of nature and boundary conditions being the way they are (because if they were not that way we wouldn't be able to observe them). That suggestion is nonsense. The laws of nature and boundary conditions cause our existence; we do not cause theirs."

## Anthropocentrism and design

According to the Jewish, Christian and Islamic religious tradition the world was made by God for the sake of man, and man was made for singing the praises of God. Everything, from the nightly skies to the minute bugs, bears witness to God's precise craftsmanship and intelligent design. God designed an anthropocentric universe, in which the Earth, humans' abode, occupied center stage, surrounded by the atmosphere, the seven skies (of the sun, the moon and the five known planets) and the sphere of the fixed stars, above which God and the rest of the heavenly Court dwelt. God and the angels were always looking down at us, humans, watching us, caring about us. The world was like a theater and we were the protagonists of the cosmic drama.

All these tenets are deeply alien to modern science. The whole history of the Scientific Revolution has been the story of the continuous and increasing abdication by man of any anthropocentric pretensions to occupy a privileged cosmic position in a universe designed for him. This epic story is well known. Copernicus demoted the Earth from the center of the cosmos to a mere planet circling the sun. Bruno demoted the sun to just one more among myriads of similar stars. Still in 1920 most astronomers doubted the existence of any galaxies outside our own Milky Way, as shown in the public confrontation between Shapley and Curtis at the Washington meeting of the National Academy of Science that year. Since then, we have become aware that not only our sun is just one unimpressive star among many billions of other stars of our galaxy, but that also our own galaxy is just one among many billions of other galaxies. The isotropy inferred from the cosmic background radiation is the most radical denial of any local anthropocentrism. And, as emphasized by cosmologist Joel Primack (1993), the fact that most of the matter in the universe seems to be dark matter, matter of a different kind of the usual one we are acquainted with, “is the ultimate Copernican revolution. … Not only will the Earth no longer be the center of the universe, it won't even be made of the same sort of stuff”. Even Weinberg (2001, p. 46) rejects emphatically any form of anthropocentrism: “Nothing that scientists have discovered suggests to me that human beings have any special place in the laws of physics or in the initial conditions of the universe.” And teleology has disappeared from modern biology.

Against this background it is surprising that some authors have tried to reopen the debate on cosmic design and anthropocentrism under the banner of the (strong) anthropic principle. Their popular writings have often led to rather muddled misrepresentations of modern science results.

## The strong anthropic principle

The weak anthropic principle is a tautological inference rule. The strong anthropic principle, on the contrary, is a substantial metaphysical assertion, committing its upholders to a thoroughly anthropocentric view of the universe. The whole cosmic evolution is seen as a gigantic plot to produce people (or life). Some hint of it was already in Dyson (1971): “As we … identify the many accidents of physics and astronomy that have worked together to our benefit, it almost seems as if the Universe must in some sense have known that we are coming”. Its name and its first formulation are due to Carter (1974): “the Universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage”. In Barrow and Tipler's (1986) words: “The Universe must have those properties which allow life to develop within it at some stage in its history”. According to Greenstein (1988): “The weak principle states that *humanity can exist only in a habitable environment* [i.e., humanity can exist only where it can exist]. But the strong Anthropic principle goes further. It states that *a habitable environment must exist*. It states that ... a planet must be found wrapped in gasses of precisely the composition required by humans”. Remark the unconditional “must” in all three formulations. The universe *must* be fit for human life. Human life is not a welcome chance result of cosmic evolution, but instead its aim and ultimate reason. In the last author's words: “Life obeys the laws of physics – this much is a truism. What is new ... is that ... the reverse seems also to be true – that the laws of physics conform themselves to life. ... How did it come to pass that against all odds the cosmos succeeded in bringing forth life? It had to. It had to in order to exist”.

The strong anthropic principle is an acknowledgedly metaphysical speculation, with no base whatsoever in logic or physics. No deduction from it can be considered a scientific explanation of anything.

Even Carter (1974) conceded: “It is of course always philosophically possible – as a last resort, when no stronger physical argument is available” to take resource to the anthropic principle. “I would personally be happier with explanations of the values of the fundamental coupling constants etc. based on a deeper mathematical structure (in which they would no longer be fundamental but would be derived)”. Carr and Rees (1979, at the end of their sympathetic review) declared: “The anthropic principle ... may never aspire to being much more than a philosophical curiosity. One day, we may have a more physical explanation for some of the relationships discussed here that now seem genuine coincidences. For example, the coincidence $\alpha_G = (m_e / m_w)$, which is essential for nucleogenesis, may eventually be subsumed as a consequence of some presently unformulated unified physical theory”. Alan Guth (1990) commented: “... the anthropic principle kind of rubs me the wrong way. ... Obviously, there are some anthropic statements you can make that are true. If we weren't here, then we wouldn't be here. ... I find it hard to believe that anybody would ever use the anthropic principle if he had a better explanation for something. ... the physical constants are determined by physical laws that we can't understand now. ... I don't think the laws were contrived in order to allow life to exist". Kane, Perry and Zytkow (2000), in a paper significantly entitled "The beginning of the end of the anthropic principle", argue that the success of the string theory program would preclude any anthropic considerations. Murray Gell-Mann (1994) has written that the strong Anthropic principle "would supposedly apply to the dynamics of the elementary particles and the initial condition of the universe, somehow shaping those fundamental laws so as to produce human beings. That idea seems to me so ridiculous as to merit no further discussion." Weinberg (2001, p. 238) has asserted that this type of anthropic reasoning "just amounts to an assertion that the laws of nature are what they are so that we can exist, without further explanation. This seems to me to be little more than mystical mumbo jumbo."

The most desirable epistemic situation would be that the values of the fundamental constants of physics that we now put by hand (through experimental measurement) could one day be derived from some fundamental physical theory. In the mean time (and this mean time can last forever) they have to be accepted as brute facts.

Biologists have not been less severe on the strong anthropic principle than physicists. John Maynard Smith (1996) commented: "How can this curious claim be understood? The simplest interpretation is that the Universe was designed by a creator who intended that intelligent life should evolve. This interpretation lies outside science. ... as biologists, we are unhappy with the anthropic principle because, faced with a need for historical explanation, it seems to be a cop-out". In biology we explain, for example, the historical origin of the eukaryotes by the symbiotic theory, that is supported by empirical evidence, like the presence of specific DNA and a bacteria-like translating machinery in the mitochondria of the eukaryotic cells. "It would be unsatisfactory to argue that, because eukaryotes are in fact here, the many accidents, however unlikely, needed to give rise to them must have happened."

## Religion in disguise

As the strong anthropic principle cannot be justified in terms of physics, some authors have given it a theological interpretation: the Universe must produce life, because God created it with that intention. The fact of our existence would allegedly explain why the physical constants have the (life-compatible) values they have only if complemented by the assumption that either there is a personal omnipotent God intent on producing humans or all the possible worlds do in fact exist. “The conditions in our universe really do seem to be uniquely suitable for life forms like ourselves … But the question remains - *is* the universe tailor-made for man? Or is it … more a case that there is a whole variety of universes to “choose” from, and that by our existence we have selected, off the peg as it were, the one that happens to fit?” (Gribbin & Rees 1989).

The metaphysical speculations on the strong anthropic principle have trickled down through popular science books into the hands of theologians and moralists. So the moral philosopher Derek Parfit began his 1993 Harvard course on ethics and metaphysics with the words: “Modern physics tells us that either God exists (and wants to produce humans) or all possible worlds actually exist (and so this one, fit for us).” In published words of Parfit (1992): “Of these different global possibilities, one must obtain, and only one can obtain. … That is why, rather than believing that the Big Bang merely happened to be right for life, we should believe either in God or many worlds.”

Reviewing Barrow and Tipler’s book, Helge Kragh (1987) commented: “Under the cover of the authority of science and hundreds of references Barrow and Tipler … contribute to a questionable … mystification of the social and spiritual consequences of modern science. This kind of escapistic physics, also cultivated by authors like Wheeler, … and Dyson, appeals to the religious instinct of man in a scientific age.” He also underlines “the speculative, quasi-religious nature of this kind of science writing”. William Press (1986) in his review of the same book in *Nature* made unusually harsh remarks: “The authors badly want to be the founding doctrinal theorists of a ‘new’ resurgence of teleological belief in science.” Their “end is nothing less than the fusion of matters of science with matters of individual faith and belief… It has taken us a long way to separate these matters… We should not lightly allow them to become once again jumbled, least of all by a book … whose extra-scientific agenda most of us will, ultimately, wish to reject” … “There is some fundamental intellectual dishonesty here, some snake oil to be peddled. The authors … do not always play fair with their readers. …

There is too a distressing amount of what seems to be mathematical flim-flam, that is, quotations of precise results in a manner designed to mislead less-mathematical readers and cause them to jump to the author's desired (usually non-mathematical) conclusion."

Several theologians and moralists, like Swinburne, Craig or Parfit, have heard the talk about fine tuning of initial conditions, and infer that we are confronted with a choice between only two alternatives: either God exists and is keen on producing humans, or many (all possible) worlds exist, and our existence has the selection effect of picking up one of the few compatible with life. Some theologians use the obvious difficulties of the many worlds hypothesis as grist for their own theistic mill. "We appear then to be confronted with two alternatives: posit either a cosmic Designer or an exhaustively random, infinite number of other worlds. Faced with these options, is not theism just as rational a choice as multiple worlds?" (Craig 1988).

Some cosmologists of strong religious convictions are ready to go to still greater lengths than the theologians in defense of their faith. Frank Tipler (a Tulane University physicist and co-author with Barrow of the classical book on the anthropic principle), later went on to make propaganda for the Christian doctrine of resurrection in the TV program *Soul* (1992), in which he predicted that life will take over the whole physical universe in the future, and resurrection of all the dead people in mind and body will take place, via a gigantic processing of information under the pushing will of God. "What I mean by resurrection is exactly the same thing as is taught in our churches" - said Tipler in the program. Life is information processing and the future supercomputer will run the complete brain-program of everyone who ever lived. A background voice summarizes the message: "Theology has become a branch of physics." In 1994 Tipler published a large book, *The Physics of Immortality*, in which he pretended to "prove" that all creatures who ever lived will be resurrected at the end of time. Its reception in the scientific press was unanimously devastating. All reviewers coincided that the book is a hoax.

Well, theology has not yet quite become a branch of physics. Neither has the anthropic principle. It has not even become a part of theology. The traditional theological idea pictures God as an absolute and omnipotent monarch, who can directly satisfy any of His desires. The "anthropic" view would demote God to the ceremonial role of a mere constitutional monarch, who has to work within the limits of a constitution (the laws of physics and the standard model of cosmology) that He is unable to change, His power reduced to the fixing of some specific details. It is as if He was unable to create people straight away, but had to go the long and roundabout way of tinkering with the values of the fundamental constants and fine tuning them, so that after many billions of years in some insignificant speck of the universe His wish could finally be fulfilled. Such a God would not resemble the God of the Bible. Little wonder that some theologians (Craig 1988) are less than enthusiastic about the anthropic principle.

## Participatory anthropic principle

Wheeler (1977) took a hint from a version of the Copenhagen interpretation of quantum mechanics implying that the quantum characteristics of the observed system are created by the act of observation. He asked: “Is the architecture of existence such that only through ‘observership’ does the universe have a way to come into being?” He did not advocate this line of thought. “It is too frail a reed to stand either advocacy or criticism.” But, as remarked by Earman (87), “excessive caution is not one of the faults of anthropic theorists”. Barrow (1982) and Barrow and Tipler (1986) elevated the speculation on the alleged observer-dependency of the universe to the status of a principle, the participatory anthropic principle: “Observers are necessary to bring the universe into being”.

Other authors were more critical. So Gale (1981): “With his hypothesis Wheeler has carried the anthropic principle far beyond the domain of the logic of explanation; he has crossed the threshold of metaphysics: Few scientists or philosophers of science would be comfortable with his vision”. And in 1986 he added:

> Wheeler … has incorporated the strongest possible teleology and anthropocentrism into his cosmos. Wheeler takes the ensemble view, and adds a further bit of spice from quantum mechanics. … Observed events become actual only in the very event of being observed. Although this proposition … has roots going back to Bishop Berkeley, … Wheeler, however, goes even further than these ontologies by coupling together the three notions of quantum reality, ensemble universe, and anthropic principle. According to his view, that universe comes into existence which,

> through the participation of intelligent observers, can come into existence via the act of observation itself. On this view, the observer and the observed are linked together in a self-excited loop of self-causation. … Here a creation drama rather than a salvation drama would be the focus of history and evolution, but still of totally central focus would be the human (or other) intelligence which would serve as the reason for it all.

Earman (1987) uncovered a crucial misunderstanding in Wheeler's participatory anthropic speculation: "even if one opts for a dualistic Process 1 - Process 2 [Copenhagen-style] interpretation of QM, with conscious observers playing a central role in the former, it does not follow that without conscious observers the world would not have being, existence, reality, or actuality, but only that certain kind of changes would not take place in it. After a Process 1 [reduction or collapse by observation] change the world is no more real or actual than before; and the QM state after measurement contains just as many (though different) unactualized possibilities as before." It is difficult not to subscribe to Earman's conclusion: "Failing to find any firm ground in physics for PAP, … my concern is with attempts to wrap PAP in the cloth of scientific respectability. These attempts amount to no more than hand waving. As a scientific principle, the participatory anthropic principle has a peculiarly apt acronym."

## Many worlds

Some authors adhere to the strong anthropic principle, but reject religious explanations based on the will of God. They try to square the circle by appealing to a plurality of universes. It is doubtful that the trick works.

At the end of his classic 1974 paper, Carter wrote:

> It is of course always philosophically possible – as a last resort, when no stronger physical argument is available – to promote a *prediction* based on the strong anthropic principle to the status of an *explanation* by thinking in terms of a "world ensemble". By this I mean an ensemble of universes characterized by all conceivable combinations of initial conditions and fundamental constants.

He offered a "world ensemble explanation of the weakness of the gravitational constant". (A stronger *G* would be incompatible with planets and so with observers). Then he tried to relate his idea of many universes to Everett's interpretation of quantum mechanics:

> Although the idea that there may exist many universes, of which only one can be known to us, may at first sight seem philosophically undesirable, it does not really go very much further than the Everett doctrine (...) to which one is virtually forced by the internal logic of quantum theory. According to the Everett doctrine the Universe, or more precisely the state vector of the Universe, has many branches of which only one can be known to any well-defined observer (although all are equally "real"). This doctrine would fit very naturally with the world ensemble philosophy that I have tried to describe.

There are several confusions here. As pointed out by McMullin (1993), not only is there no warrant whatsoever for the many-universe concept, but

> Carter cites the Everett "branching worlds" model in quantum theory "to which one is virtually forced by the internal logic of quantum theory". But one is *not* virtually forced to it; indeed, it has found little support among quantum theorists. But more important, Everett's branching worlds do not provide the range of alternative initial conditions or alternative physical laws that this version of an anthropic explanation of the initial parameter constraint would require.

The assumption of infinitely many universes and the application of the anthropic principle to "select" one suitable for life is supposed to explain the "cosmic coincidences" that allow carbon atoms to be available for life and ultimately for humans to exist. One philosopher convinced by this line of argument is the neo-Platonist Leslie, who has devoted an entire book (1989) and several articles to the defense of this position. His most recent stand (2000) tends to build on an assumed metaphysical principle (another one!) of "ethical requiredness" that is supposed to be creatively effective. The other convinced philosopher is Nick Bostrom (2002), whose anthropic reasoning emphasizes the observation selection effects. Of course statisticians have to be careful in the selection of their samples and mindful of distortions introduced in their data by unintended selection effects of their procedures. If you catch fish in a pond with a net that only retains fish larger than 15 cm, you cannot conclude that all or most of the fish in the pond are larger than 15 cm. Your result is merely an artifact of your sampling method and it doesn't need to reflect the actual situation in the pond. But it is difficult to follow Bostrom and Leslie when they try to apply statistical considerations to the one and only universe available to empirical science.

Roger White (2000) argues that even if the hypothesis of there being many universes increases the probability that some universe wil be life-permitting, it does not increase the probability that *our* universe is life-permitting. The hypothesis is that the initial conditions and constants of each universe are chosen randomly and independently of the other universes. The choices are like independent rolls of a die. So, the appeal to many worlds does nothing to explain why this one allows for the existence of life.

## Multiverses galore

Authors fond of many universes talk about them in a variety of incompatible ways. The totality of the many universes accepted by an author forms the multiverse for that author. There are at least as many multiverses as authors talking about them; in fact, there are more, as some authors have several multiverses to offer. Let us recall the main proposals for multiple universes. The first was due to a philosopher; the rest to physicists.

(1) David Lewis (1986) put forward an impressive and tightly argued theory of the plurality of worlds, called modal realism. Possible worlds and possible individuals occupy the whole logical space. “There are so many other worlds, in fact, that absolutely every way that a world could possibly be is a way that some world is.” (p. 2). All possible worlds and possible individuals exist in a full and concrete sense, in the same sense in which we and our own “worldmates” exist. Our actual world is just one world among uncountably many, the world where we happen to be, but it is no more real or concrete than other worlds, which are possible for us but actual for their inhabitants (if any). Nevertheless there are no spatiotemporal or causal relations of any kind between worlds. Each world is isolated. Only of (logically) impossible worlds and impossible individuals can we say that they do not exist.

Lewis thought he could define the modal notions of necessity, possibility, predetermination, supervenience, counterfactuals and natural properties by quantification over possible worlds and possible individuals. For example, necessity is truth at all possible worlds; possibility amounts to existential quantification over the worlds. He called his theory of modal realism "a philosopher's paradise" and was ready to pay the price for it: an overblown ontology. But one philosopher's paradise is another philosopher's nightmare. He himself complained of "the incredulous stare" often meeting the exposition of his ideas. But even if, for the sake of argument, we accepted such other worlds, totally isolated from ours, how could we say anything about them? Lewis insisted that we can gain information about other worlds by relying on "our abundant modal knowledge". He thought obvious that there are uncountable infinities of donkeys. We have "necessary knowledge that there are donkeys at some worlds – even talking donkeys, donkeys with dragons as worldmates …" (p. 112).

If the condition for the existence of a possible world is just the logical consistency of its description, why not let consistency do the work instead, as in mathematics? Lewis compared his acceptance of many worlds with the acceptance in mathematics of many sets. Both are useful and allow for a simple theory. But, as Cantor remarked, mathematics is the realm of freedom. Physics and metaphysics are not. Lewis denied that possible worlds are just mathematical structures. He wanted them to be concrete and physical, like ours.

His ontological flamboyance notwithstanding, Lewis gave a sober assessment of the pretences at explanation of other multiversalists. "There may indeed be a sense in which modal realism makes us more comfortable with the arbitrary, brute facts of the world … but I insist that they remain arbitrary and they remain unexplained." (p. 128). "Of course, any inhabitant of a world will find that his world is a habitable one. That is only to be expected. It does not cry out for further explanation." And he did not see any merit in so-called anthropic explanations:

> It's all very well to invoke the anthropic principle when the remarkable habitability of our world seems to cry out for explanation. But I do not think that this invoking of the anthropic principle is *itself* an explanation. … It is not an explanation because it gives no information about the causal or nomological ways of our world. It tells us nothing about how any event was caused; it does nothing to subsume laws under still more unified and general laws. (p. 132-133)

(2) George Ellis and G. Brundrit (1979) suggested the existence of many unconnected domains beyond each other's horizon and inside an open infinite

FRW universe. This is the most modest of the proposals and it might be plausible, even if the conclusions drawn by the authors rely on a misleading argument about the infinite (more on this later).

(3) Wheeler (1977) suggested an oscillatory or cyclic universe. (It has nothing to do with Wheeler's participatory anthropic principle). An infinite sequence of alternatively crunching and expanding universes goes on for ever. Each big crunch "rebounds" in a new big bang. The successive universes are reborn with entirely new initial conditions. So all (?) Big bang models are realized and (no wonder) a few of them are hospitable to life. There are obvious difficulties with this proposal. If the expansion rate of a cycle is sufficiently great (if the universe of that cycle is open or flat), the recollapse and crunch will not take place. The universe will continue to expand forever and the cyclic scenario will destroy itself. Besides and more fundamentally, as pointed by Earman (1987), a causal curve approaching a big bang singularity cannot be continuously extended through the singularity. Ian Hacking (1987) contended that the alleged cosmic fine tuning does not allow inference to a cyclical ensemble of universes that come into being one after the other with no memory of previous universes being carried into subsequent ones. In this last case, the argument would be as fallacious as assuming that a good poker hand is evidence that a long series of poor hands has been previously dealt. Hacking calls it "the inverse gambler's fallacy."

(4) Everett's (1957) many-worlds interpretation of quantum mechanics. Actually, this proposal has nothing to do with the alleged cosmological multiverse needed in connection with the anthropic principle. Everett's many worlds of QM correspond to the various states (vectors) in a superposition of states. They are introduced in order to avoid the reduction or collapse of the wave function at the act of measurement. The many worlds of inflation and other cosmological contexts have nothing to do with them. It is an obvious mistake to confuse one with the other. This confusion (already present in Carter) has been denounced by McMullin, Peter Mittelstaedt and others. Earman (1987) uncovered a crucial flaw:

> Anthropic theorists are not above some double dealing. ... they appeal to the Everett many-world interpretation of QM to generate an actual ensemble of worlds; but recall that the main motivation for this interpretation was to avoid process 1 [the reduction of a superposition to an eigenstate of the observable being measured] changes altogether,

whether such changes are induced by conscious observers or otherwise. This fact is conveniently ignored when it does not suit.

The confusion of Everett's many worlds with the alleged cosmological multiverse is too much even for a staunch advocate of many universes like Rees. Indeed there are different scenarios for the many universes. "However one of them, at most, can be correct. Quite possibly none is: there are alternative theories that would lead to just one universe" [Rees 2001, p. 171].

(5) Vilenkin (1983) and Andre Linde (1986) proposed a different kind of multiverse, based on quantum cosmology (a speculative offshoot of quantum mechanics) and the inflationary universe scenario. According to them, quantum fluctuations in nothing (where "nothing" means not only the absence of matter, but also of space and time) produce a multiplicity (infinity) of nucleations, each of which leads to a different eternally inflating superuniverse. Each of these superuniverses is totally (spatially, causally, informationally) disconnected from the others. Each superuniverse of eternal inflation produces a never-ending series of different bubble-universes, but all of them are parts of the same spacetime (even if cosmic time is only well defined inside a single bubble), and you can define hypersurfaces cutting across universes. Our observable universe is just a region of our bubble universe, a particular region flattened by inflation (always according to this eternal inflation scenario). Vilenkin applies the anthropic principle very crucially in his quantum cosmology to constrain the immense set of initial conditions. The probabilities are weighted by the probability of producing observers or civilizations. But he considers galaxies as good tracers of observers and civilizations, and so restricts his attention just to the conditions for galaxy formation. So the anthropic principle is here a galactic principle.

Eternal inflation seems to be almost unavoidable in the inflationary scenario. The false vacuum energy does not get exhausted with the inflationary bubble, because the expansion of the bubble proceeds more rapidly than the decay of the false vacuum. If there is inflation (a big if), then it is plausible that eternal inflation obtains. The inflationary superuniverse goes on inflating forever (outside our bubble). Notice that if you accept both quantum cosmology and eternal inflation, you get an infinity of infinities of bubble universes.

(6) Lee Smolin (1997) proposed a highly speculative evolutionary cosmological model: whenever a black hole is formed, processes deep inside it might trigger the creation of another universe into a space disjoint from our own.

The so created "baby-universe" inherits some of the properties of its parent-universe, including the capacity to produce new black holes and so to spawn new generations of universes without end.

(7) There are still other conjectures that suggest a multiplicity of universes. For instance, Lisa Randall and Raman Sundrum (1999) think of multiple universes as branes, four-dimensional subspaces of an assumed five-dimensional spacetime. The branes are separated in extra dimensional space and there is no contact between them.

(8) Max Tegmark (2003) is the ultimate multiversalist, a true believer in all kinds of proposed multiverses and oblivious of the warnings of their mutual incompatibility: "The key question is not whether the multiverse exists but rather how many levels it has." To all the previous proposals, he adds a new "Platonic" level of multiple universes, so that the whole physical (?) multiverse gets final symmetry and closure. This level IV encompasses just any thinkable structure, because anything thinkable is physically realized:

> Why was only one of the many mathematical structures singled out to describe the universe? A fundamental asymmetry appears to be built into the very heart of reality. As a way out of this conundrum, I have suggested that complete mathematical symmetry holds; that all mathematical structures exist physically as well. Every mathematical structure corresponds to a parallel universe. The elements of this multiverse do not reside in the same space but exist outside of space and time. Most of them are probably devoid of observers. This hypothesis can be viewed as a form of radical Platonism, asserting that the mathematical structures in Plato's realm of ideas … exist in a physical sense. Level IV brings closure to the hierarchy of multiverses, because any self-consistent fundamental physical theory can be phrased as some kind of mathematical structure. [p. 40].

There is nothing wrong with grand speculations with no connection to empirical reality, but they should not be confused with empirical science. Empirical science is rooted in mistrust of mere reason and insistence on empirical checks. Some scientists forget it at their own risk. Rees (2001) writes: "The multiverse concept is already part of empirical science: we may already have intimations of other universes …" The cover of the May 2003 issue of *Scientific American* asserts: "Infinite Earths in Parallel Universes Really Exist"; in the interior, the title and banner of Max Tegmark's paper reads: "Parallel Universes: Not just a staple of science fiction, other universes are a direct implication of cosmological observations."

The hypothesis that all possible worlds exist is as difficult to understand as it is to accept. The set of all possible worlds is not at all defined with independence from our conceptual schemes and models. If we keep a certain model (with its underlying theories and mathematics) fixed, the set of the combinations of admissible values for its free parameters gives us the set of all possible worlds (relative to that model). It changes every time we introduce a new cosmological model (and we are introducing them all the time). Of course, one could propose to consider the set of all possible worlds relative to all possible models formulated in all possible languages on the basis of all possible mathematics and all possible underlying theories, but such consideration would produce more dizziness than enlightment.

In any case, there seems not to be the slightest reason for accepting an infinite (or finite, for that matter) plurality of universes different from and unconnected with the one we inhabit. Of course, they are not impossible. But neither are impossible the bizarre mythological worlds. Even supporters of the anthropic principle, like Carr (1982), are skeptical here: "Both the 'many worlds' and 'many cycles' explanations for the anthropic principle are rather bizarre and I would not recommend that either be taken too seriously." Lightman (1991) speaks about being "uncomfortable with postulating different universes. We inhabit just our one universe, and arguments that must go outside of that universe in order to explain it may have also gone outside science."

## Infinity does not imply realization of all possibilities

A whole family of anthropic explanations proceeds from the assumption that all physically possible universes are somehow realized in an ensemble of actually existing universes. This ensemble would allegedly guarantee the existence of at least a universe hospitable to life, like ours. "In an infinite ensemble, the existence of some universes that are seemingly fine-tuned to harbor life would occasion no surprise." (Rees 2001, p.xvii). Of course, in that case, and as stressed by Wilson (1993), it would be the ensemble (rather than the anthropic principle) that would carry the weight of the explanation. Unfortunately the effort is wasted, as the premise remains arbitrary and the logical reasoning is flawed. Let us elaborate this last point.

A frequent confusion in the anthropic literature is the notion that an infinity of objects characterized by certain numbers or properties implies the existence among them of objects with any combination of those numbers or characteristics. Ellis and Grundrit (1979) asserted that in an infinite collection of universes every possible universe has to be realized and even that it has to be repeated an infinity of times. The multiverse would "contain infinitely many planets with histories almost exactly like Earth's, with infinitely many beings named G.W. Leibniz, for instance." The same contention was repeated by Leslie (1989). Despite its trivial falsity, this idea keeps recurring in the anthropic and multiversalist literature to this day, as the two following quotes show:

> If the universe were literally infinite, then anything, however improbable, could happen. Indeed, it could happen infinitely often, leading to replicas of our Earth, even infinitely many of them. But these clones would be located far beyond our own galaxy … (Rees 2001, p. 29)
>
> Is there a copy of you reading this article? A person who is not you but who lives on a planet called Earth, … ? The life of this person has been identical to yours in every respect … The idea of such an alter ego … merely [assumes] that space is infinite (or at least sufficiently large) in size and almost uniformly filled with matter, as observation indicate. In infinite space, even the most unlikely events must take place somewhere. There are infinitely many other inhabited planets, including not just one but infinitely many that have people with the same appearance, name and memories as you … [The] universes of your other selves … are the most straightforward example of parallel universes. Each universe is merely a small part of a larger 'multiverse'. [Tegmark 2003, pp. 31-32].

This suggestion is mistaken. An infinity does not imply at all that *any* arrangement is present or repeated. For example, think of the trivial case of an infinite set of binary sequences $s_n$ with the $i$-th member $x_i = 1$ if $i \neq n$, and $x_i = 0$ if $i = n$:

$s_1$ = 0111111111111111111...

$s_2$ = 1011111111111111111...

$s_3$ = 1101111111111111111...

$s_4$ = 11101111111111111...

$s_5$ = 11110111111111111...

And so on. As $n$ ranges over all natural numbers, we get an infinity of different binary sequences that are almost everywhere = 1, but differ in the place where they are = 0. This set of binary sequences is infinite, but most binary sequences you can think of (for example, any containing two or more 0's, such as 1010101010...) are not in it. And no sequence is repeated.

Of course there are much simpler counterexamples. The infinite set of the even numbers does not contain any of the odd numbers. The infinite set of the numbers greater than a trillion does not contain any of the numbers up to one trillion. In general, all infinite sets contain proper infinite subsets. This property was famously used by Dedekind to define infinity. The same happens with uncountable domains, like the n-dimensional Euclidean spaces. Any interval of the real line is an infinite set of real numbers, but does not contain all real numbers; most of them remain outside. Any straight line in the plane is an infinite set of points of the plane, but does not include all points of the plane.

If every possible world is characterized by a finite sequence of numbers (including quantum numbers, as in Tegmark 2003), then every possible world can be coded or represented by a different natural number (via a Gödel numbering of all sequences). So, the assumption that all possible worlds are realized in an infinite universe is equivalent to the assertion that any infinite set of numbers contains all numbers (or at least all Gödel numbers of the sequences), which is obviously false.

Some anthropic authors are aware of these difficulties. Barrow and Tipler (1986, p. 24), discussing the alleged infinite repetition of everything in an infinite universe, remarked that “the infinity alone is not a sufficient condition for this to occur; it must be an exhaustively random infinity in order to include all possibilities”. Following this observation, some authors speak of there being an “exhaustive infinity” of universes. Of course, from the assumed existence of an exhaustive infinity of universes you can tautologically infer that every possibility is realized, by definition (if it was not, the infinity would not be exhaustive). Other authors consider the universe a statistical thermodynamic system in equilibrium satisfying the ergodicity hypothesis or take at face value some far-fetched scenarios of inflationary cosmology. But in these cases infinity alone no longer carries the weight of the argument, it is just another among many unchecked assumptions being piled up in this line of reasoning.

## Conclusions

In its weak version, the anthropic principle is a mere tautology, which does not allow us to explain anything or to predict anything that we did not already know. In its strong version, it is a gratuitous speculation, only sustained by previous religious faith. The attempt to secularize it by an appeal to an infinity of universes unconnected by principle with our own ends in failure. In McMullin's (1994) words, "the weak Anthropic principle is trivial ... and the strong Anthropic principle is indefensible." Alleged anthropic explanations do not explain anything and are not needed in cosmology. And if someone still intends to revive the corpse of anthropocentrism, he will need stronger medicine than just the anthropic principle itself.

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[1] I thank Jeremy Butterfield, Carl Hoefer and Terry Jones for useful comments.

## REFERENCES

Agazzi, E. & A. Cordero (ed.): 1991. *Philosophy and the Origin and Evolution of the Universe*. Dordrecht-Boston-London: Kluwer Academic Publishers.

Balashov, Yuri. 1991. Resource Letter AP-1: The Anthropic Principle. *American Journal of Physics,* **59**: 1069-76.

Barrow, John. 1990. The mysterious lore of large numbers. In Bertotti, Balbinot, Bergia & Messina 1990, p. 67-93.

Barrow, John & Frank Tipler. 1986. *The Anthropic Cosmological Principle*. Clarendon Press. Oxford.

Barrow, John, H. Sandvik & J. Magueijo. 2001. Anthropic Reasons for Non-zero Flatness and Lambda. *Astro-ph*/0110497 (22 Oct 2001), submitted to *Physical Review D*.

Beck, G., H. Bethe & W. Riezler. Bemerkung zur Quantentheorie der Nullpunktstemperatur. *Naturwissenschaften*, **19**: 39.

Bertola, F. & U. Curi (eds.). 1993. *The Anthropic Principle*. Cambridge University Press.

Bertotti, Balbinot, Bergia & Messina (ed.). 1990. *Modern Cosmology in Retrospect*. Cambridge University Press.

Bostrom, Nick. 2002 *Anthropic Bias: Observation Selection Effects in Science and Philosophy*. New York: Routledge.

Boyd, Richard & Gasper & Trout (ed.). 1991. *The Philosophy of Science*. Cambridge (Mass.): MIT Press.

Bromberger, Sylvain. 1992. *On What We Know We Don't Know*. The University of Chicago Press.

Carr, Bernard. 1982. On the origin, evolution and purpose of the physical universe. *The Irish Astronomical* Journal, **15**: 237-253.

Carr, Bernard & Martin Rees. 1979. The anthropic principle and the structure of the physical world. *Nature*, **278**: 605-612.

Carter, Brandon. 1974. Large number coincidences and the anthropic principle in cosmology. In Longair (1974), p. 291-298.

Carter, Brandon. 1983. The anthropic principle and its implications for biological evolution. *Philosophical Transactions of the Royal Society of London*, **A 130**: 347-363.

Collins, C. and Stephen Hawking. 1973. Why is the universe isotropic? *Astrophysical Journal*, vol. 180, p. 317-34.

Craig, William. 1988. Barrow and Tipler on the anthropic principle vs. divine design. *British Journal for the Philosophy of Science*, **38**: 389-395.

Dicke, Robert: 1961. Dirac's cosmology and Mach's principle. *Nature*, **192**: 440-441.

Dingle, Herbert. 1937. Modern Aristotelianism. *Nature*, **139**: 784-786.

Dingle, Herbert. 1937a. Deductive and inductive methods in science: A reply. *Nature*, **139**: 1011-1012.

Dirac, Paul. 1937. The cosmological constants (Letter to the Editor). *Nature*, **139**: 323.

Dirac, Paul. 1938. New basis for cosmology. *Proceedings of the Royal Astronomical Society of London*, **A 165**: 199.

Dowrick, N. & N. McDougall. 1988. Axions and the anthropic principle. *Physical Review,* **D 38**: 3619-3624.

Earman, John. 1987. The SAP also rises: A critical examination of the anthropic principle. *American Philosophical Quarterly*, **24**: 307-317.

Earman, John & Jesús Mosterín. 1999. A Critical look at inflationary cosmology. *Philosophy of Science*, **66**: 1-50.

Eddington, Arthur. 1923. *The Mathematical Theory of Relativity*. Cambridge University Press.

Ellis, George. 1991. Major themes in the relation between philosophy and cosmology. *Mem. Soc. Astronomica Italiana*, **62**: 553-605.

Ellis, George & G. Brundrit. 1979. Life in the infinite universe. *Quarterly Journal of the Royal Astronomical Society*, **20**: 37-41.

Everett, Hugh. 1957. Relative state formulation of Quantum Mechanics,. *Reviews of Modern Physics*, **29**: 454-462.

Gale, George. 1981. The anthopic principle. *Scientific American*, **245** (June): 154-171.

Gale, George. 1986. Whither cosmology: anthropic, anthopocentric, teleological? En N. Rescher (ed.): *Current Issues in Teleology*, Lanham, Md.: University Press of America, p. 102-110.

Gell-Mann, Murray. 1994. *The Quark and the Jaguar: Adventures in the simple and the Complex*. Little, Brown and Co.

Gott III, J. Richard. 1993. Implications of the Copernican priciple for our future prospects. *Nature*, **363**: 315-319.

Greenstein, George. 1988. *The Symbiotic Universe*. New York: William Morrow.

Gribbin, John & Martin Rees. 1989. *Cosmic Coincidences: Dark Matter, Mankind, and Anthropic Cosmology*. New York: Bantam Books.

Hacking, Ian. 1987. The inverse gambler's fallacy: The argument from design: The anthropic principle applied to Wheeler universes. *Mind*, **96**: 331-340.

Hakim, Rémi. 1989. The special status of cosmology in science. In F. W. Meyerstein (ed.), *Foundations of Big Bang Cosmology*, Singapore-London: World Scientific, pp. 85-139.

Hall, P. J. 1983. Anthropic explanations in cosmology. *Quaterly Journal of the Royal Astronomical Society*, **24**: 443-447.

Hawking, Stephen & Neil Turok. 1998. Open inflation without false vacua. *Phys. Lett.,* **B 451**: 25.

Hoyle, Fred. 1954. On nuclear reactions occurring in very hot stars. *Astrophysical Journal*, Suppl, **1**: 121-146.

Kane, G., M. Perry and A. Zytkow. 2000. The beginning of the end of the anthropic principle. *Astro-ph*/0001197.

Kanitscheider, Bernulf. 1993. Anthropic arguments – Are they really explanations? In Bertola, F. & U. Curi (1993), pp. 171-181.

Kirschenmann, Peter. 1992. Does the anthropic principle live up to scientific standards? *The Annals of the Japan Association for Philosophy of Science*, **8**: 69-96.

Klee, Robert. 2002. The revenge of Pythagoras: How a mathematical sharp practice undermines the contemporary design argument in astrophysical cosmology. *British Journal for Philosophy of Science*, **53**: pp. 331-354.

Knobe, Joshua, K. Olum & A. Vilenkin. 2003. Philosophical implications of inflationary cosmology. *Arxiv.org/abs/physics*/0302071.

Kragh, Helge. 1987. Review of Barrow and Tipler’s *The Anthropic Cosmological Principle. Centaurus,* **30**: 191-194.

Leslie, John. 1989. *Universes*. London-New York: Routledge.

Leslie, John (ed.). 1990. *Physical Cosmology and Philosophy*. New York: Macmillan.

Leslie, John. 2000. Our Place in the Cosmos. *Philosophy*, **75**: 5-24.

Lewis, David. 1986. *On the Plurality of Worlds*. Oxford: Basil Blackwell.

Lightman, Alan & Roberta Brawer. 1990. *Origins. The Lives and Worlds of Modern Cosmologists*. Cambridge (Mass.): Harvard University Press.

Lightman, Alan. 1991. *Ancient Light. Our changing view of the universe*. Cambridge (Mass.): Harvard University Press.

Linde, Andrei. 1986. Eternal chaotic inflation. *Modern Physics Letters*, **A 1**: 81.

Linde, Andrei. 2003. Inflation, quantum cosmology and the anthropic principle. In Barrow, Davies & Harper (ed.), *Science and Ultimate Reality: From Quantum to Cosmos*, Cambridge University Press.

Livio, Mario, D. Hollowell, A. Weiss & J. W. Truran. 1989. The anthropic significance of the existence of an excited state of $^{12}C$. *Nature*, 340: pp. 281-284.

Longair, Malcolm (ed.). 1974. *Confrontation of Cosmological Theories with Observational Data*. International Astronomical Union.

Martel, H., P. R. Shapiro & S. Weinberg. 1998. Likely values of the cosmological constant. *Astrophysical. Journal*, **492**: p. 29.

Maynard Smith, John & E. Szathmáry. 1996. On the likelihood of habitable worlds. *Nature*, **384**: 107.

McMullin, Ernan. 1993. Indifference principle and anthropic principle in cosmology. *Studies in the History and Philosophy of Science*, **24**: 359-389.

McMullin, Ernan. 1994. Fine-tuning the universe? In M. Shale & G. Shields (ed.), *Science, Technology, and Religious Ideas*, Lanham: University Press of America.

Mosterín, Jesús. 1996. Philosophy and cosmology. In *Spanish Studies in the Philosophy of Science* (ed. by G. Munévar), Kluwer Academic Pubishers, Dordrecht-Boston-London, pp. 57-89.

Mosterín, Jesús. 2000. The anthropic principle in cosmology: A critical review. *Acta Institutionis Philosophiae et Aestheticae* (Tokyo, Japan), **18**: 111-139.

Mosterín, Jesús. 2002. Examen del principio antrópico en cosmología. *Diálogos*, 79: pp. 203-236.

Mosterín, Jesús & Roberto Torretti. 2002. *Diccionario de Lógica y Filosofía de la Ciencia*. Madrid: Alianza Editorial.

Parfit, Derek. 1992. Why does the universe exist?. *Times Literary Supplement*, 3 July.

Press, William. 1986. A place for teleology? *Nature*, **320**: 315-316.

Primack, Joel. 1993. Quote in *Time*, Jan 18.

Randall, Lisa & Raman Sundrum. 1999. Large mass from a small extra dimension, *Physical Review Letters*, **83**: 3370-3373.

Randall, Lisa & Raman Sundrum. 1999. An alternative to compactification, *Physical Review Letters*, **83**: 4690-4693.

Rees, Martin. 2001. *Our Cosmic Habitat*. Princeton Universsity Press.

Shaposhnikov, M. & I. Tkachev. 1990. Higgs boson mass and the anthropic principle. *Modern Physics Letters*, **A 5**: 1659-1661.

Smith, Quentin. 1985. The anthropic principle and many-worlds cosmologies. *Australasian Journal of Philosophy*, **72**: 371-382.

Smith, Quentin. 1994. Anthropic explanations in cosmology. *Australasian Journal of Philosophy*, **72**: 371-382.

Smolin, Lee. 1997. *The Life of the Cosmos*. Oxford University Press.

Susskind, Leonard. 2003. The anthropic landscape in string theory. *arXiv:hep-th*/0302219.

Swinburne, Richard. 1990. Argument from the fine tuning of the universe. In Leslie 1990, pp. 154-173.

Tegmark, Max. 2003. Parallel universes. In Barrow, Davies & Harper (eds.), *Science and Ultimate Reality: From Quantum to Cosmos*, Cambridge University Press.

Tegmark, Max. Parallel universes. *Scientific American* (May 2003), pp. 30-41.

Tipler, Frank. 1989. The anthropic principle: A primer for philosophers. *PSA 1988*, vol 2, pp. 27-48. The Philosophy of Science Association.

Tipler, Frank. 1994. *The Physics of Immortality.* New York: Doubleday.

Torretti, Roberto. 1994. El 'observador' en la física del siglo XX. In F. J. Ramos (ed.), *Hacer: Pensar*. Editorial de la Universidad de Puerto Rico. Vilenkin, Alexander. 1983. Birth of inflationary universes. *Physical Review*, **D 27**: 2848-1855.

Weinberg, Steven. 1987. Anthropic bounds on the cosmological constant. *Physical Review Letters*, **59**: 2607-2610.

Weinberg, Steven. 2000. A priori probability distribtion of the cosmological constant. *ArXiv:Astro-ph*/0002387.

Weinberg, Steven. 2001. *Facing Up*. Harvard University Press.

Wheeler, John. 1974. Beyond the end of time. In Rees, Ruffini & Wheeler (ed.), *Black Holes, Gravitational Waves and Cosmology*, Gordon and Breach.

Wheeler, John. 1977. Genesis and observership. In J. Butts & J. Hintikka (ed.), *Foundational Problems in the Special Sciences*, Dordrecht: Reidel, pp. 3-33.

Wheeler, John. 1980. Beyond the black hole. In H. Woolf (ed.), *Some Strangeness in the Proportion*, Reading (Mass.): Addison-Wesley, pp. 341-375.

White, Roger. 2000. Fine-tuning and multiple universes. *Noûs*, **34** (2): pp. 260-276.

Williams, George. 1992. *Natural Selection: Domains, Levels, and Challenges.* New York: Oxford University Press.

Wilson, Patrick. 1991. What is the explanandum of the anthropic principle? *American Philosophical Quaterly*, **28**: 167-173.

Wilson, Patrick. 1994. Carter on anthropic principle predictions. *The British Journal for Philosophy of Science,* **45**: 241-253.