

RESOURCE LETTER

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This is one of a series of Resource Letters on different topics intended to guide college physicists, astronomers, and other scientists to some of the literature and other teaching aids that may help improve course contents in specified fields. No Resource Letter is meant to be exhaustive and complete; in time there may be more than one letter on some of the main subjects of interest. Comments on these materials as well as suggestions for future topics will be welcomed. Please send such communications to Professor Roger H. Stuewer, Editor, AAPT Resource Letters, School of Physics and Astronomy, 116 Church Street SE, University of Minnesota, Minneapolis, MN 55455.

Resource Letter AP-1: The anthropic principle

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This Resource Letter provides a guide to the literature on the anthropic principle. The letter E after an item indicates elementary level or material of general interest to persons becoming informed in the field. The letter I, for intermediate level, indicates material of somewhat more specialized nature. The annotation A indicates rather specialized or advanced material.

We have found a strange foot-print on the shores of the unknown. We have devised profound theories, one after another, to account for its origin. At last, we have succeeded in reconstructing the creature that made the foot-print. And Lo! it is our own.

Sir Arthur Eddington

I. INTRODUCTION

That we observe around us not some arbitrary state of affairs but one that is compatible with our existence seems rather trivial. However, in recent times, a whole family of nontrivial connotations of this statement became widely known as variations of the "anthropic cosmological principle" (AP). The term was coined in 1973 by Brandon Carter in his famous talk at the special IAU Symposium devoted to the 500th anniversary of Nicolas Copernicus.

1. "Large Numbers Coincidences and the Anthropic Principle in Cosmology," B. Carter, in *Confrontation of Cosmological Theories With Observation Data*, edited by M. Longair (Reidel, Dordrecht, 1974), pp. 291–298. Reprinted in Ref. 26. (1)

AP was proposed as a counterbalance to the unwarranted extension of the Copernican principle that we do not occupy a privileged place in the Universe to its extreme dogmatic version that our place cannot be privileged in *any* sense. The latter is obviously untrue since our mere existence as complex physicochemical creatures requires certain conditions that are met only in particular sites in the Universe and at some definite stages in its physical history. As an example, the temperatures suitable for life are available in a narrow range of distances from a typical star, like our Sun. That is why life cannot exist *anywhere*. On the other hand, the Universe as a whole is in the process of irreversible evolution. Because of that, for any form of life

to emerge a succession of necessary preceding events has to take place. That is why life cannot originate at *any* time.

This observation was taken into account by Robert Dicke in his early presentation of AP arguments intended to attack Dirac's explanation of a mysterious "large numbers" coincidence between the age of the Universe $T_u \sim 10^{10}$ years expressed in atomic units $\tau = e^2/m_e c^3$, $T = T_u/\tau \sim 10^{40}$, and the inverse gravitational coupling constant $\alpha_G^{-1} = hc/Gm_p^2 \sim 10^{40}$.

2. "Dirac's Cosmology and Mach's Principle," R. H. Dicke, *Nature* **192**, 440–441 (1961). Reprinted in Ref. 26. (1)

Dirac assumed in 1937 that all such coincidences are in fact exact equalities. So from $T = \alpha_G^{-1}$ it follows that some fundamental constants of nature must vary with time. According to Dicke, the exotic assumption of changing constants is superfluous if proper attention is paid to specificity of the cosmological epoch for which this coincidence is valid. From simple estimates, it follows that only at this epoch are the conditions available necessary for the existence of physicists (namely, the presence of heavy elements produced in the interior of stars at final stages of their evolution and a sufficient amount of radiation-supplying stars). No wonder we live at this particular epoch and witness the above-mentioned coincidence; at earlier or much later epochs we could not be present, and numerical values of constants that would in this case exhibit no coincidence would remain *unwitnessed*. Moreover, we are not recommended to try to explain "large numbers" coincidence otherwise, say, in Dirac's manner. Any such attempt may result in a false explanation owing to the overlooking of the *weak* AP. As Carter's formulation says, "our location in the Universe is necessarily privileged to the extent of being compatible with our existence as observers."

The weak AP may be considered as a sort of explanation

of the exceptionality of a cosmological epoch suitable for life provided its emergence is possible sometime, i.e., is compatible with the laws of nature and general trend of cosmic evolution. The *strong* AP goes further, pointing to specificity of the Universe itself in which we happen to live. The extraordinary "fine tuning" of the physical constants and some other parameters turns out to be a necessary condition for stable existence of the main building units of our orderly world (nuclei, atoms, stars, etc.) in the sense that even a small variation of one of the former would cause the abrupt destruction of either the latter themselves or their birthplaces in the evolutionary chain. In light of such a radical instability, the successful passing of the Universe through all the "traps" from baryogenesis to the formation of galaxies and finally to the appearance of life and consciousness is *a priori* improbable. However, life and consciousness being on hand, the appropriate conditions, i.e., "fine tuning" of fundamental parameters, were insured with great accuracy. That is what Carter's strong AP actually states: "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."

Since its first exposition, AP became a matter of overall interest which culminated with the comprehensive study by J. D. Barrow and F. J. Tipler comprising virtually every aspect of the entire problem up to 1986.

3. **The Anthropic Cosmological Principle**, J. D. Barrow and F. J. Tipler (Clarendon, Oxford, 1986). (E,1)

The above three items are classics in the discussions of AP that are under way in the leading physical, biological, philosophical, science-popular, religious, and theological literature. An AP-related bibliography amounts to over 400 entries, a full hundred of them being reviews of Barrow and Tipler's encyclopedic book.

It must be stressed that the whole "anthropic case," from its very beginning, was rather controversial. Different views were proposed of every aspect of AP. In the chorus of opinions and commentaries the critical and skeptical voices are of considerable intensity. The most debatable questions concern the scientific value and epistemic status of AP: Is it a genuine explanation endowed with predictive and heuristic power (and, if yes, what does it actually explain), or just a philosophical toy agreeable to humanitarian consciousness but rather futile as a scientific tool? However, the criticisms, as well as explicit and implicit rebuttals thereof, are sometimes based on misconceptions. That can be partly explained by the fact that AP is not a strict and unambiguous statement but rather a wide spectrum of formulations, definitions, attitudes, and interpretations. It is the problem of interpretation that leads mostly to discord and misunderstanding. Unanimity is not attained even as to *what* in anthropic problems is to be interpreted and *where* to draw a borderline between different formulations of AP (besides the weak AP of Dicke and Carter and Carter's strong AP there are two other "canonical" formulations—Wheeler's participatory AP and Tipler's final AP, as well as some marginal versions). That is why AP cannot be treated in a wholesale and unspecified way. The most widespread objections to, as well as diverse arguments in favor of "AP on the whole" seem, in fact, to pertain to the particular versions thereof.

This Resource Letter provides a guide to the literature on AP in various fields of inquiry. The survey of relevant journals, conference proceedings, and books (Secs. II–IV) is followed by the bibliography relating to current research

topics organized into several sections. Section V covers scientific and, partly, philosophical prehistory of modern anthropic reasoning. In fact, it is quite natural that a concept like AP seems to be deeply rooted in the entire human intellectual enterprise. Besides immediate scientific predecessors of present-day anthropic arguments this concerns some *Leitmotiven* in the history of philosophy, theology, and culture in general. Section VI deals with AP at work; it contains the original expositions of different versions of AP and their applications to particular problems in physics, astronomy, and cosmology. In Sec. VII we present epistemological and methodological aspects of AP that are widely discussed by physicists themselves, not only by philosophers of science. This is probably because the problems raised by AP are related to the burning foundational and conceptual issues of physics and cosmology, such as the interpretation of quantum mechanics, the problem of initial conditions in cosmology, or the concept of the plurality of worlds. So it might be useful for any specialist to become closer acquainted with these matters while reading about AP. Those interested in these and similar questions are recommended also to consult related Resource Letters on Cosmology [Am. J. Phys. **44** (3), (1976)], Cosmology and particle physics [Am. J. Phys. **56** (6), (1988)] and Extraterrestrial civilizations [Am. J. Phys. **57** (1), (1989)].

The coverage of articles in this Resource Letter is concentrated primarily on recent publications that appeared after Barrow and Tipler's book (Ref. 3) which itself, besides its other merits, may serve as a guide to earlier publications. Only particularly important works up to 1986 are surveyed here. Along with research papers, we included some essay and feature reviews of the above-mentioned book. These reviews are interesting in themselves since they discuss the most debatable details of the entire problem.

My main task is to help an interested reader to become oriented in the vast interdisciplinary bulk of literature on AP and to elaborate his or her personal view of this vital issue. It is perhaps worth adding that in the most comprehensive works on AP the discussion of fundamental problems is sometimes combined with a considerable portion of good humor—so necessary in treating the ultimate questions of science and human existence. And AP seems to deal with both.

II. JOURNALS

The papers on AP appeared in various physical, astronomical, multidisciplinary, and philosophical journals. We selected those which address AP in not just an incidental manner. The major scientific journals grouped by frequency of appearance of AP-related articles are: Nature. Q. J. R. Astron. Soc.; Phys. Lett. B; Am. J. Phys.; Sky Telescope; J. Phys. A; Observatory; Nuovo Cimento B; Sov. Phys. Usp.; Am. Sci.; Phys. Lett. A; Mod. Phys. Lett.; Rev. Mod. Phys.

There are not many important philosophy and history of science journals which have published several papers on AP. The majority of methodological discussions of AP are found in monographs and the following journals: Am. Philos. Q.; Int. Philos. Q.; Mind; Br. J. Philos. Sci.; Zygon.

III. CONFERENCE PROCEEDINGS

To date only two conferences seem to have taken place which were dedicated entirely to AP.

4. **The Anthropic Principle**, edited by F. Bertola and U. Curi (Cambridge U.P., Cambridge, 1991). Proceedings of the first meeting attended by all leading experts on AP (Venice, November 1988). (E,I)
 5. **Anthropic Principle in the Structure of Scientific World Pattern**, Abstracts of the Seminar held in Leningrad, USSR, November 1989, edited by A. A. Grib (Leningrad State University, Leningrad, 1989). In Russian. See also Ref. 55. (E)
- However, AP was extensively debated at meetings on broader topics, such as cosmology in general, viewed from physical, philosophical, and even theological standpoints.
6. **Cosmos and Creation—The Physicist's View**, Proceedings of the 1982 Conference of the Science and Religion Forum, Guildford, Ir. Astron. J. 15 (3), 223–262 (1982). (E)
 7. **The Constants of Physics**, Philos. Trans. R. Soc. London Ser. A 310, 209–363 (1983). A discussion organized by W. H. McCrea, M. J. Rees, and S. Weinberg. Published also as a book by the Royal Society of London (1983). (I)
 8. **Origin and Early History of the Universe**, Proceedings of the 26th Liège Intern. Astron. Coll., July 1986, edited by J. Demaret (University of Liège, Liège, 1987). (I)
 9. **Physics, Philosophy and Theology: A Common Quest for Understanding**, edited by R. J. Russell, W. R. Stoeger, and G. V. Coyne (Vatican Observatory, Vatican City State, 1988). Proceedings of the workshop at Castel Gandolfo. (E)
 10. **Origin and Evolution of the Universe: Evidence for Design**, edited by J. Robson (McGill-Queens U.P., Montreal, 1988). (E)
 11. **The Origin of the Universe**, Proceedings of the Conference held in Fort Collins, Colorado, September 1988, edited by R. F. Kitchener (work in progress). (E)

IV. BOOKS

Though AP is a relatively new field, specialized books have already been written about it. Besides Ref. 3, there are:

12. **Das Anthropische Prinzip: Der Mensch im Fadenkreuz der Naturgesetze**, R. Breuer (Meyster, Wien, 1981). A lively account of the early applications of AP, from geophysics to astrophysics. Contains a brief historical overview and raises interesting conceptual issues of cosmology. Foreword by R. Kippenhahn. (E)
13. **The Accidental Universe**, P. C. W. Davies (Cambridge U.P., Cambridge, 1982). A very readable account of preinflationary cosmology; provides a good physical basis for recognizing anthropic coincidences in nature. (E)
14. **Big Bang, Big Bounce: How Particles and Fields Drive Cosmic Evolution**, I. L. Rozental (Springer, Berlin, 1988). Brings together microphysics and cosmology in an attempt to understand the variety of fine tunings necessary for the existence of "bound states" —nuclei, atoms, stars, and galaxies. The author, however, prefers the term "expediency principle" to "more speculative AP." (E)
15. **The Symbiotic Universe: Life and Mind in the Cosmos**, G. Greenstein (Morrow, New York, 1988). A popular exposition of the AP followed by far-reaching extrapolations of its most extreme versions concerning the supposed intimate relations between life, mind, and cosmos. (E)
16. **Universes**, J. Leslie (Routledge, London and New York, 1989). Professor of philosophy with a profound knowledge of modern cosmology discusses, in the form of an intellectual adventure, the alleged evidence of anthropic fine tunings. Skillfully written. Recommended to anyone interested in the subject. (E)

It is quite different difficult not to express an opinion on AP while writing a book on cosmology. For that reason, many authors of such books devote special chapters or sections to AP.

17. **Masks of the Universe**, E. R. Harrison (Collier Macmillan, New York and London, 1985). (E)
18. **Cosmic Understanding**, M. K. Munitz (Princeton U.P., Princeton, 1986). A deep insight into conceptual foundations of cosmology. (E)
19. **Particle Physics and Inflationary Cosmology**, A. D. Linde (Gordon and Breach, New York, 1990). The final chapter discusses applications of AP to inflationary scenarios and quantum cosmology. (I,A)

Today we witness a strong tendency to bridge a gap between the sciences and humanities, or, so to say, to endow natural sciences with a "human dimension." Cosmology and especially AP contribute greatly to this process. During the last decade many scientists turned to cultural implications of modern science.

20. **The Self-Organizing Universe**, E. Jantsch (Pergamon, Oxford, 1980). A new evolutionary understanding based on the ideas of self-organization can compete with anthropic explanations of the Universe's intricate features. (I)
 21. **God and the New Physics**, P. Davies (Dent & Sons, London, 1983). Discusses theistic implications of modern physics. Chapter 12 deals with AP. (E)
 22. **The Intelligent Universe**, F. Hoyle (Holt, Rinehart and Winston, New York, 1984). A prominent astrophysicist defends his view of the origin of life. Evolution "under cosmic control" versus AP as an "opportunistic Darwinian explanation." Beautifully illustrated. (E)
 23. **The New Story of Science: Mind and the Universe**, R. M. Augros and G. N. Stanciu (Gateway, Chicago, 1985). Science, mind, and human values. Participatory AP defended. Foreword by Sir J. Eccles. (E)
 24. **The World Within the World**, J. D. Barrow (Clarendon, Oxford, 1988). A coauthor of "The Anthropic Cosmological Principle" reflects on the origin and status of natural laws. (E)
 25. **Beyond the Big Bang: Quantum Cosmologies and God**, W. B. Drees (Open Court, La Salle, IL, 1990). An author, equally well at home in physics and theology, discusses in Chap. 4 current formulations of AP. (E,I)
- Finally, there is a book of readings that contains reprints of original AP-related papers of Carter (Ref. 1), Dicke (Ref. 2), Pagels (Ref. 93), along with classical cosmological works by G. Gamow, H. Bondi, and other eminent scientists.
26. **Physical Cosmology and Philosophy**, edited by J. Leslie (Macmillan, New York, 1989). (E,I)

V. HISTORICAL BACKGROUND TO THE MODERN ANTHROPIC PRINCIPLES

A. Review works

The most comprehensive account of scientific, philosophical, and cultural prehistory of AP is contained in Chaps. 2 and 3 of Ref. 3. In addition, some recent papers may be useful for a reader with special interests in history and philosophy of science.

27. "Aristotle, Teleology and Modern Science," L. B. Grant and M. A. B. Deakin, *Search* 17, 263–266 (1986). It is argued that Aristotle's *telos* is compatible with modern science. AP serves as an illustration. (E)
28. "Nietzsches Idee des Zyklischen Universums vor dem Hintergrund der Heutigen Physikalischen Kosmologie," B. Kanitscheider, in *Kant und Nietzsche—Vorspiel einer Künftigen Weltauslegung*, edited by J. Albertz (Freie Akademie, Wiesbaden, 1988), pp. 133–155. Parallels between Nietzsche's idea of cyclic cosmos and modern concept of multiple universes which is an indispensable part of strong anthropic explanations. (E)
29. "Anthropic Web of the Universe: Atom and Ātman," P. Gradinarov, *Philos. East West* 39 (1), 27–45 (1989). AP and ancient Indian thought. (I)
30. "Anthropic Principle: History and Present Status," V. V. Kazuyutinsky and Y. V. Balashov, *Priroda (Nature)* N1, 23–32 (1989). A. R. Wallace and K. E. Tsiolkovsky as predecessors of anthropic reasoning. In Russian (E)

B. Early anthropiclike arguments in physics and astronomy

The inferences from the existence of human observers to the conditions which made it possible aimed at explaining the observed features of the environment were exploited long before modern AP.

31. "On Certain Questions of the Theory of Gases," L. Boltzmann, *Nature* **51**, 413–415 (1895). Boltzmann in fact used an anthropic argument in his famous fluctuation hypothesis: We observe rather improbable, disequilibrium states of the cosmos simply because the far more probable, equilibrium state could not contain its observers. (E)
32. "The Arrow of Time," P. Davies, *Sky Telescope* **72** (3), 339–342 (1986) argues that Boltzmann's application of AP is not so impressive as today's, since there is no need for the whole orderly cosmos in the fluctuation hypothesis. A small fragment comprising Earth and surrounded by chaos would do as well. Certainly this by no means diminishes Boltzmann's merits. (E)
33. *Man's Place in the Universe*, A. R. Wallace (McClure, Phillips, New York, 1903). A famous coauthor of Darwin's discovery anticipated in the last chapter of his book almost all versions of modern AP. (E)
34. "On Nuclear Reactions Occurring in Very Hot Stars," F. Hoyle, *Astrophys. J. Suppl.* **1**, 121–146 (1954). In 1953 Hoyle made an anthropic prediction of an excited state—"level of life"—of ^{12}C at 7.6 MeV needed for carbon production in the interior of stars. (A)
35. "The Anthropic Significance of the Existence of an Excited State of ^{12}C ," M. Livio, D. Hollowell, A. Weiss, and J. M. Truran, *Nature* **340**, 281–283 (1989). Hoyle's prediction made specific by recent computer simulation. (I)
- For more early anthropic arguments see Ref. 3, Chap. 3.

C. Dimensionality of space

The number of spatial dimensions may be considered as one of the fundamental physical parameters. Why does physical space have three dimensions? This question made sense in 1917, thanks to P. Ehrenfest, who showed that $N > 3$ is incompatible with the existence of dynamically stable structures such as planetary systems or classical atoms. No wonder we do not observe $N > 3$.

36. "In What Way Does It Become Manifest in the Fundamental Laws of Physics That Space Has Three Dimensions," P. Ehrenfest, *Proc. Amsterdam Acad.* **20**, 200–214 (1917). (I)

Why do we not observe $N < 3$? In 1955 G. Whitrow suggested additional biological arguments rendering $N = 2$, not to mention $N = 1$, impossible.

37. "Why Physical Space Has Three Dimensions," G. J. Whitrow, *Br. J. Philos. Sci.* **6**, 13–31 (1955). (E)

Ehrenfest's analysis has been corroborated within the frameworks of general relativity (Ref. 38) and quantum mechanics of atoms (Ref. 39).

38. "Schwarzschild Field in N Dimensions and the Dimensionality of Space Problem," F. R. Tangherlini, *Nuovo Cimento* **27** (3), 636–651 (1963). (A)

39. "On the Existence of Atoms in N-Dimensional Space," L. Gurevich and V. Mostepanenko, *Phys. Lett. A* **35** (3), 201–202 (1971). (I)

More detailed exposition of this story can be found in Ref. 3, Sec. 4.8.

D. Fundamental constants and "large numbers" coincidences

Modern AP appeared in the context of coincidences of "large numbers" (Ref. 2), i.e., enormous dimensionless combinations of fundamental physical constants and certain cosmological parameters. In 1919, H. Weyl first noticed that the ratio of the classical electron radius $r_e = e^2/m_e c^2$ to its gravitational radius $r_{G_e} = Gm_e/c^2$, $r_e/r_{G_e} = e^2/Gm_e^2 \sim 10^{40}$ coincide by the order of magnitude with the ratio of the radius of the Universe in the De Sitter model $R \sim 10^{27}$ cm to r_e , $R/r_e \sim 10^{40}$.

40. "Eine Neue Erweiterung der Relativitätstheorie," H. Weyl, *Ann. Phys.* **59**, 101–133 (1919). (I)

The first to recognize the full significance of large

numbers and the need to explain their coincidences was A. S. Eddington.

41. *Relativity Theory of Protons and Electrons*, A. S. Eddington (Macmillan, New York, 1936). (I)

Eddington devoted many years to attempts to derive all dimensionless combinations of constants of orders 10^{40} and 10^{80} in a purely deductive way, without recourse to experiments. This was broadly regarded as unconnected to ordinary scientific discourse. Eddington's "fundamentalism" thus aroused intensive criticism and was later outstripped by Dirac's large numbers hypothesis.

42. "The Cosmological Constants," P. A. M. Dirac, *Nature* **139**, 323 (1937). (E)

43. "Cosmological Models and the Large Numbers Hypothesis," P. A. M. Dirac, *Proc. R. Soc. Lond. Ser. A* **338**, 439–446 (1974). (I)

Dirac's aim was to explain numerous large numbers coincidences by relating them to T or T^2 , $T \sim 10^{40}$ being the dimensionless age of the Universe in the standard model. Dirac's hypothesis was much debated and developed further.

44. "The Fundamental Constants and Their Time Variation," F. Dyson, in *Aspects of Quantum Theory*, edited by A. Salam and E. Wigner (Cambridge U. P., Cambridge, 1972), pp. 213–236, is a good review of such attempts. See also Ref. 3, Secs. 4.4 and 4.5. (I)

Finally, it was R. H. Dicke who put forward an alternative explanation of some coincidences based on the weak AP (Ref. 2).

VI. MAJOR VERSIONS OF ANTHROPIC PRINCIPLES AND THEIR APPLICATIONS

A. General accounts

There are a great many popular expositions of the main idea of AP.

45. "Energy in the Universe," F. J. Dyson, *Sci. Am.* **225** (3), 51–59 (1971). "As we look out into the Universe and 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." (E)

46. "Cosmology: Man's Place in the Universe," V. Trimble, *Am. Sci.* **65** (1), 76–86 (1977). (E)

47. "Do We Live in the Simplest Possible Interesting World?" E. J. Squires, *Eur. J. Phys.* **2** (1), 55–57 (1981). (I)

48. "The Anthropic Principle," G. Gale, *Sci. Am.* **245** (6), 114–122 (1981). A philosopher's outlook. (E)

49. "Redefining the Cosmos," H. T. Simmons, *Mosaic* **13** (2), 16–22 (1982). Surveys all key versions of AP up to 1982. (E)

50. "A Universe in Our Own Image," A. Finkbeiner, *Sky Telescope* **68** (2), 107–111 (1984). A freelance writer interested in cosmology defends Wheeler's participatory AP (Sec. VI F below). See, however, a commentary by K. Winkler on p. 110. (E)

51. "Are We the Center of the Universe?" G. Kane, *Michigan Q. Rev.* **24** (2), 277–287 (1985). A particle physicist's contribution to the special issue on "Science and the Human Image." (E)

52. "The Anthropic Universe," M. Rees, *New Sci.* **115**, 44–47 (1987). A careful analysis of premises backing popular anthropic arguments. (E)

53. "Le Principe Cosmologique Anthropique," J. Demaret, *Rev. Questions Sci.* **159** (1–2), 109–144 (1988). (I)

54. "Black Holes, Galactic Evolution and Cosmic Coincidences," M. Rees, *Interdisc. Sci. Rev.* **14** (2), 148–161 (1989). A popular account of recent cosmological achievements, including AP. (E)

55. "Multifaced Anthropic Principle," Yu. V. Balashov, *Comments Astrophys.* **15** (1), 19–28 (1990). An analytical survey of basic versions of AP (except FAP) related to the 1989 Leningrad Seminar (Ref. 5). (E)

B. Anthropic principle and the structure of the physical world

Although the anthropic coincidences on which the existence of complex structures critically depends are numer-

ous, not all basic features of our world are determined by them. Gross sizes and time scales of galaxies, stars, planets, and even the objects of the immediate environment are sometimes due to the balance of competing forces of nature. It is important to demarcate anthropic factors from nonanthropic ones. Otherwise we could be led astray in our efforts to explain the fundamental properties of the Universe.

56. "The Anthropic Principle and the Structure of the Physical World," B. J. Carr and M. J. Rees, *Nature* **278**, 605–612 (1979). The most complete review of anthropic and nonanthropic structural aspects of the Universe. (I)
57. "The Anthropic Principle," B. J. Carr, *Acta Cosmol.* **11**, 143–151 (1982). (I)
58. "Dependence of Macrophysical Phenomena on the Values of Fundamental Constants," W. H. Press and A. P. Lightman, in Ref. 7, pp. 323–335. (I)
- See also Ref. 3, Chap. 5 and Ref. 13.

C. Anthropic bounds on physical parameters

To see AP at work one should address the original works in which various anthropic constraints on the fundamental parameters of physics and cosmology are imposed. For instance, the numerical value of the fine structure constant $\alpha_e = e^2/\hbar c \sim 1/137$ is, in this sense, not arbitrary; it is closely connected to the fact that there exist intelligent observers who actually observe this particular value. This can be shown in many independent ways. Consider the lifetime of a proton in the modern gauge unified theories which can be expressed as $t_p \sim \alpha_e^2 \exp(1/\alpha_e) h/m_p c^2$. The lifetime t_p cannot be less than the age of the Universe $T_u \sim 10^{10}$ yr, argues I. L. Rosental (Refs. 14 and 59), which gives $\alpha_e < 1/80$. An equally stringent lower limit on α_e also exists. For grand unification to be possible, the mass of the X -boson $m_X \sim m_p \exp(1/4\alpha_e)$ must not exceed Planck's limit $m_{Pl} \sim (hc/G)^{1/2}$. (The anthropic significance of grand unification comes from the consequent cosmological baryon asymmetry needed to make physicists in the course of evolution.) This leads to $\alpha_e > 1/170$.

However, it must be noted that the force of the above argument based on the early models unifying strong and electroweak interactions has been put into doubt by the experimental failure to see proton decays at the level predicted by the simple models.

59. "Physical Laws and the Numerical Values of Fundamental Constants," I. L. Rosental, *Sov. Phys. Usp.* **23** (6), 296–305 (1980). (I)
60. "Axions and the Anthropic Principle," N. Dowrick and N. A. McDougall, *Phys. Rev. D* **38** (12), 3619–3624 (1988). Anthropic constraint on the axion density. (A)
61. "Has a Possible Change of the Values of the Physical Constants a Role in Biological Evolution?" H. J. Kreuzer, M. Gies, G. L. Malli and J. Ladik, *J. Phys. A* **18** (9), 1571–1577 (1985). Studies the impact of the variation of α_e on the biologically significant chemical properties of heavy elements. (A)
62. "Cognizable Worlds: The Anthropic Principle and the Fundamental Constants of Nature," G. Greenstein and A. Kropf, *Am. J. Phys.* **57** (8), 746–749 (1989). Suggests rather moderate anthropic constraints on e , m_p/m_e , and G proceeding from atomic, molecular and stellar prerequisites of life. (I)
63. "Extended Chaotic Inflation and Spatial Variations of the Gravitational Constant," A. D. Linde, *Phys. Lett. B* **238** (2–4), 160–165 (1990). Variations of effective G may be limited by anthropic considerations in the inflationary model based on Brans–Dicke theory of gravity. (A)

Several papers deal with anthropic bounds on the cosmological constant Λ whose observable proximity to zero

remains one of the greatest riddles of present-day cosmology.

64. "Anthropic Bound on the Cosmological Constant," S. Weinberg, *Phys. Rev. Lett.* **59**, 2607–2610 (1987). (A)
65. "The Cosmological Constant Problem," S. Weinberg, *Rev. Mod. Phys.* **61** (1), 1–23 (1989). (A)
66. "Life After Inflation and the Cosmological Constant Problem," A. D. Linde, *Phys. Lett. B* **227** (3–4), 352–358 (1989). (I)
67. "Upper Bound on the Cosmological Constant for a Recollapsing, Closed Universe," F. R. Tangherlini, *Nuovo Cimento B* **103** (3), 311–317 (1989). (I)

D. Anthropic principle and initial conditions of the evolutionary Universe

Cosmology is rather specific with respect to "local physics" because it deals with the unique object which includes all that exists. For that reason, a physical description of the Universe differs from that of a local system. The present structure of the Universe, as of any other system, is the consequence of not only dynamical laws of evolution but also of particular initial conditions. But in the cosmological case the problem of their origin is no less important than the question of the origin of the laws of nature themselves: Why were the initial conditions just those that have led to the cosmological picture observed today, and not others? The fact that "the cosmological picture observed today" includes observers makes the problem of initial conditions in cosmology fit for anthropic approach.

68. "Why is the Universe Isotropic?" C. B. Collins and S. W. Hawking, *Astrophys. J.* **180** (2), 317–334 (1973). Observers can exist only in the asymptotically isotropic Universe. The initial conditions leading to an isotropic state in the future are of zero measure on the set of all possible ones. "The fact that we have observed the Universe to be isotropic is therefore only a consequence of our existence." (A)
69. "The Isotropy of the Universe," J. D. Barrow, *Q. J. R. Astron. Soc.* **23** (3), 344–357 (1982). The conclusion of Collins and Hawking put into doubt. More on that in Ref. 3 Sec. 6.11. (A)
70. "Birth of the Closed Universe and the Anthropogenic Principle," Y. B. Zel'dovich, *Sov. Astron. Lett.* **7**, 322–324 (1981). Quantum creation of the Universe with actually observed characteristics is due to the anthropic selection of small initial perturbations of metric. (I)
71. "The Big Band Cosmology—Enigmas and Nostrums," R. H. Dicke and P. J. E. Peebles, in *General Relativity: An Einstein Centenary Survey*, edited by S. W. Hawking and W. Israel (Cambridge U.P., Cambridge, 1979), pp. 504–517. The relevance of AP to the unsolved problems of standard cosmology. Some of them were actually solved later in a nonanthropic way. (I)
72. "Cosmological Transitions with the Alteration of Metric Signature," A. D. Sakharov, *Sov. Phys. JETP* **60**, 214 (1984). The hypothesis of different metric signatures in different places of the Universe. AP may help to understand why we observe the particular (+ + + -) signature. (A)

E. Anthropic principle and multiple universes

Though anthropic constraints on the properties of the Universe taken by themselves make it clear why we cannot observe other properties, incompatible with our existence, they do not explain why these remarkable features of our world take place altogether. However, if one postulates an infinite plurality of worlds endowed with all possible physical arrangements (various values of constants, various numbers of spatial dimensions, various evolutionary dynamics), then there will certainly be some favorably organized universes in this set able to create intelligent life and thereby *realize* themselves at some stage. We apparently find ourselves in one of such "cognizable worlds." The con-

cept of multiple universes (small- u) is implied in all correct anthropic explanations. And what about physical realization of the ancient idea about the plurality of worlds? In physics there are some hypotheses potentially suitable for this role. In 1973 Carter referred, in this connection, to the many-worlds interpretation of quantum mechanics. Later, especially after the advent of inflationary and quantum-creation-*ex-nihilo* cosmologies, some other possibilities for multiple universes appeared. Their status is discussed in many papers.

73. "Life in the Infinite Universe," G. F. R. Ellis and G. B. Brundrit, Q. J. R. Astron. Soc. **20** (1), 37–41 (1979). In a low-density, homogeneous, open and infinite Universe there can be infinitely many causally disjoint fragments in which all possible conditions might actually be realized. (I)

74. "The Epoch of Observational Cosmology," T. Rothman and G. F. R. Ellis, Observatory **107**, 24–29 (1987). (I)

75. "The Anthropic Principle in a Unique Universe," M. A. B. Deakin, G. J. Troup, and L. B. Grant, Phys. Lett. A **96** (1), 5–6 (1983). A critical paper. Argues that multiple universes are not only unnecessary in the anthropic context, but "lead as well to considerable difficulties." (E)

Multiple universes can neighbor with each other not only in space (or superspace), but also in time. Such is the case in Wheeler's model of the oscillatory Universe in which the cycles of expansion and recollapse follow one another successively, the basic physical features being "re-processed" in each cycle. Sooner or later the "inhabitable" cycle comes.

76. Gravitation, C. W. Misner, K. S. Thorne, and J. A. Wheeler (Scott Foresman, San Francisco, 1973). Chap. 44 (reprinted in Ref. 26) of this remarkable monograph expounds the idea of "self-reprocessing Universe." (E)

The application of AP to Wheeler's model was criticized by I. Hacking who associated such an application with a popular fallacy in probabilistic inference.

77. "The Inverse Gambler's Fallacy: The Argument From Design. The Anthropic Principle Applied to Wheeler Universes," I. Hacking, Mind **96**, 331–340 (1987). (E)

However, Hacking's criticism was cogently refuted in Refs. 78–80.

78. "On Hacking's Criticism of the Wheeler Anthropic Principle," M. A. B. Whitaker, Mind **97**, 259–264 (1988). (E)

79. "The Inverse Gambler's Fallacy and Cosmology—A Reply to Hacking," P. J. McGrath, Mind **97**, 265–269 (1988). (E)

80. "No Inverse Gambler's Fallacy in Cosmology," J. Leslie, Mind **97**, 269–272 (1988). (E)

References 81–82 are catalogs of all known models of multiple universes and their potential anthropic implications.

81. "Cosmological Fecundity: Theories of Multiple Universes," G. Gale, in Ref. 26, pp. 189–206. (E)

82. "Multiple Universes," J. Leslie, in Ref. 11. (E)

References 83 and 84 contain the philosophical analysis of the many-worlds context of AP.

83. "The Anthropic Principle and Many-Worlds Cosmologies," Q. Smith, Australas. J. Philos. **63** (3), 336–348 (1985). (E)

84. "World Ensemble Explanations," Q. Smith, Pacific Philos. Q. **67**, 73 (1986). (E)

F. Participatory anthropic principle

The above-mentioned applications of AP consist in "cutting out" a particular "sector" of physical reality (an entire universe from the world ensemble, as in the case of the strong AP, or a small spatial fragment or temporal epoch of the single Universe, as in the original weak AP of Dicke and Carter) with which a subject could in principle be correlated as observer. The key concept here is *correlation*, not

some casual dependence. With the help of the former, the presence of certain features in our "sector" may be explained. But this rather moderate version of AP by no means implies the absence of other "sterile" and, hence, "unobservable" "sectors" of physical reality.

However, there exists a far more radical interpretation of AP which may be traced to certain early treatments of quantum mechanics implying that quantum characteristics are created in the act of observation and do not possess an independent existence. J. A. Wheeler extrapolated these ideas to "participatory AP": The observer is no less necessary for the creation of the Universe, than the Universe is for his own creation. In other words, the observer, emerging at a later stage of evolutionary history, fulfills a reduction imparting, via "feedback" relations, the status of reality to that very Universe in which he already exists. All the other "possible worlds," where the phenomenon of observation solely capable of turning possibility into reality (in this extended Copenhagen sense) is not foreseen, do not exist in a strict ontological sense.

85. "Genesis and Observership," J. A. Wheeler, in *Foundational Problems in the Special Sciences*, edited by J. Butts and J. Hintikka (Reidel, Dordrecht, 1977), pp. 3–33. (E)

86. "Beyond the Black Hole," J. A. Wheeler, in *Some Strangeness in the Proportion*, edited by H. Woolf (Addison-Wesley, Reading, MA, 1980), pp. 341–363. (E)

87. "World as System Self-Synthesized by Quantum Networking," J. A. Wheeler, IBM J. Res. Dev. **32**, 4–15 (1988). (E)

G. Final anthropic principle

Finally, there is an AP put forward by F. J. Tipler: "Intelligent information-processing must come into existence in the Universe, and, once it comes into existence, it will never die out" (Ref. 3, p. 23). The reason to postulate final AP is the following. If the creation of consciousness is necessarily implied in the universal order, then it is hard to reconcile oneself with the perspective of its future destruction, which seems to be inevitable in standard cosmologies. More reasonable would be to assume that nature is not that indifferent to the future fate of consciousness and provides conditions to its eternal existence, however not necessarily in the original human form. This assumption imposes further restrictions on the physical structure of our world. These are based on information theory and computer theory.

88. "Cosmological Limits on Computation," F. J. Tipler, Int. J. Theor. Phys. **25** (6), 617–661 (1986). (A)

89. "The Omega Point Theory: A Model of an Evolving God," F. J. Tipler, in Ref. 9, pp. 313–331. (E)

The perspectives of eternal survival in the evolutionary Universe were discussed, among others, by F. Dyson and A. Linde.

90. "Time Without End: Physics and Biology in an Open Universe," F. J. Dyson, Rev. Mod. Phys. **51**, 447–460 (1979). (I)

91. "Life After Inflation," A. D. Linde, Phys. Lett. B **211** (1–2), 29–31 (1988). (A)

VII. SCIENTIFIC STATUS OF ANTHROPIC PRINCIPLE

AP is both pluralistic and controversial. It is easy to see the difference between moderate, weak, and strong, versions of AP and radical and rather speculative participatory and final APs. However, all formulations of AP are periodically brought under critical fire. Is AP an explana-

tion, a speculation, or a tautology? If it is an explanation, *what* does it explain and *how* must we use it most effectively?

A. Criticisms of particular formulations of anthropic principle

Almost every detail of anthropic reasoning has been thoroughly criticized in the literature. This certainly does not mean that the critics were always right. It might be useful for a reader to put his or her adherence to AP on trial, by reading some samples of this criticism.

92. "Anthropic Explanations in Cosmology," P. J. Hall, Q. J. R. Astron. Soc. 24, 443–447 (1983). (I)
93. "A Cozy Cosmology," H. R. Pagels, Sciences 25 (2), 34–38 (1985). The most caustic objections against AP on the whole. Reprinted in Ref. 26. (E)
94. "Compatibility of the Universe to Complex Order: Paradigms and Speculations," R. D. Meisner, J. Br. Interplanet. Soc. 39 (3), 121–126 (1986). (E)
95. "A Place for Teleology," W. H. Press, Nature 320, 315–316 (1986). A critical review of Barrow and Tipler's book (Ref. 3): "The authors badly want to be the founding doctrinal theorists of a new resurgence of teleological belief in science." (E)
96. "The SAP Also Rises: A Critical Examination of the Anthropic Principle," J. Earman, Am. Philos. Q. 27, 307–317 (1987). One of the most comprehensive studies of what AP is and what it is not. (I)
97. "The Anthropic Cosmological Principle," by J. Barrow and F. Tipler," H. Kragh, Centaurus 30 (2), 191–194 (1987). Expresses the opinion that there is nothing "anthropic" in AP. (E)
98. "Ho-Hum Cosmology," D. Merope, Sky Telescope 77 (1), 6 (1989). In a short letter the author asserts that the weak AP is a mere tautology, while the strong AP is nontrue. This is a rather popular view among the opponents of AP. (E)
99. "On the Epistemological Status of Cosmology—Anthropic Principle, Cosmological Numbers and the Subject of Cosmology," R. Wahsner, Ann. Phys. (Leipzig) 46 (6), 453–461 (1989). "Cosmology destroys the fundamental on which it lies as a natural-scientific discipline if it introduces subjectivistic principles," such as AP. (E)

B. Epistemic nature of anthropic principle

However, a more balanced analysis discovers real merits in AP, which, of course, must not be exaggerated. In its moderate versions AP is not an alternative cosmological theory but an additional consideration which must necessarily be taken into account in scientific reasoning from experience to theory. This capacity brings AP close to the so-called "Bayesian inferences to the best explanation." Any fundamental theory has to allow for AP in the entire balance of arguments pro and con for some alleged explanation of the delicate fine tunings on which the structure of our world hinges.

100. "Cosmological Principles II," E. R. Harrison, Comm. Astrophys. Sp. Phys. 6 (2), 29–35 (1974). Places AP among other cosmological principles. (I)
101. "Understanding the Fundamental Constants," B. Carter, in *Atomic Physics and Fundamental Constants*, edited by J. H. Saunders and A. H. Wapstra (Plenum, New York, 1976), Vol. 5, pp. 650–654. (I)
102. "Breaking the Laws," M. Berry, Nature 300, 133–134 (1982). A review of Ref. 13. Suggests an interesting idea that the evolution towards structural stability may be "virtually irresistible" not only in biology, but also in physics. (E)
103. "The Anthropic Principle and its Implications for Biological Evolution," B. Carter, in Ref. 7, pp. 347–363. Bayesian nature of AP clarified and its potentialities demonstrated in the context of evolutionary models in biology. (I)
104. "Explanation in Physical Cosmology," B. Kanitscheider, Erkennt-

nis 22 (1–3), 253–263 (1985). Anthropic arguments as "blanks" for future dynamical explanations. (E)

105. "Essay Review on 'The Anthropic Cosmological Principle,' by J. D. Barrow and F. J. Tipler," G. F. R. Ellis, Gen. Rel. Grav. 20 (5), 497–511 (1988). AP and the foundational problems of cosmology. (E)
106. "The Anthropic Principle: A Primer for Philosophers," F. J. Tipler, in *Proceedings of the 1988 Biennial Meeting of the Philosophy of Science Association*, edited by A. Fine and J. Leplin (Philosophy of Science Association, East Lansing, 1989), Vol. 2, pp. 27–48. A very readable interpretation of the meaning of anthropic principles, with a particular emphasis on the final AP. (E)
107. "Why There is Something—The Anthropic Principle and Improbable Events," J. Katz, Dialogue (Can. Philos. Rev.) 27 (1), 111 (1988). AP and probabilistic reasoning. (I)
108. "Patterns of Explanation in Cosmology," J. D. Barrow, in Ref. 4, pp. 1–15. The essential place of the weak AP within the factors that must be taken into account in understanding observations. (E)

C. Can there be anthropic predictions?

One of the most debatable questions concerns AP's ability to make predictions of unknown facts and properties of nature. Many authors argue that AP is *post hoc*, i.e., it at best explains the already known values of constants, but 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 (Ref. 34). In Ref. 103 Carter also made a biologically relevant prediction that the past bioevolution on Earth involved no more than two improbable steps (Carter's ideas were developed further in Ref. 3, Sec. 8.7).

109. "Anthropic Principle Arguments Against Steady-State Cosmological Theories," F. J. Tipler, Observatory 102, 36–39 (1982). Tipler's arguments concern all types of static and steady-state cosmologies that were proposed in the past and would, perhaps, be suggested in the future. (I)
110. "New Twist for Anthropic Principle," J. Maddox, Nature 307, 409 (1984). An account of Carter's work (Ref. 103). (E)
111. "Probabilistic Phase Transitions and the Anthropic Principle," J. Leslie, in Ref. 8, pp. 439–444. Suggests what the adherents of AP might predict within the framework of chaotic inflationary cosmological scenarios. (E)
112. "Life and the Sun's Lifetime," M. Livio and A. Kopelman, Nature 343, 25 (1990). Carter's results (Ref. 103) specified. (I)
113. "Risking the World's End," J. Leslie, Can. Nucl. Soc. Bull. 10 (3), 1–6 (1989). Carter's ideas (Ref. 103) extrapolated to the future fate of mankind. The so-called Doomsday Argument based on considerations similar to those used in anthropic reasoning suggests that the risks of ending all human life are usually severely underestimated. (E)
114. "A Comment on Dynamical Coupling Constants and the Anthropic Principle," V. A. Rubakov and M. E. Shaposhnikov, Mod. Phys. Lett. A 4 (2), 107–109 (1989). This is an interesting turn in the anthropic reasoning. In the modern quantum cosmological models it is possible to estimate probabilities of the birth of universes with different dynamical coupling constants in certain simple cases. Together with the fact that AP independently cuts out "anthropic windows" in the space of coupling constants, this enables one to predict that the probability of appearance of the "observable/inhabitable" Universe is maximal near the boundary of the "window." Consequently, our own Universe most probably possesses such "marginal" characteristics. This conjecture is not empty and may be exposed to test, by inquiring whether the familiar coupling constants in fact lie near the boundaries of "anthropic regions." (A)
115. "Higgs Boson Mass and the Anthropic Principle," M. E. Shaposhnikov and I. I. Tkachev, Mod. Phys. Lett. A 5 (21), 1659–1662 (1990). Similar anthropic prediction, according to which the mass of the Higgs boson should be equal to 45 GeV provided the electroweak scenario of baryogenesis is correct. (A)
116. "The Elusive Anthropic Principle," M. Abramowicz and G. Ellis,

Nature 337, 411–412 (1989). A conference report (see Ref. 4). Briefly summarizes D. Sciama's talk in which some possibilities for anthropic predictions are outlined. (E)

D. Anthropic principle and the search for extraterrestrial intelligence (SETI)

Chap. 9 of Ref. 3 is devoted to the relations between AP and SETI. An argument against the existence of extraterrestrial life based on the possibility of space travel is proposed. There are several other intersections between AP and SETI.

117. "Natural Selection of Stellar Civilizations by the Limit of Growth," M. D. Papagiannis, Q. J. R. Astron. Soc. 25 (3), 309–318 (1984). (I)
118. "Anthropic Principle: Probability and the Possibility of Extraterrestrial Life," P. J. Hall, J. Br. Interplanet. Soc. 39 (3), 138–139 (1986). (I)
119. "Fermi Paradox and Alternative Strategies for SETI Programs: The Anthropic Principle and the Search for Close Solar Analogs," M. Fracassini, L. E. Fracassini, and A. L. Pasinetti, Astrophys. Space Sci. 146 (2), 321–331 (1988). AP could account for the failure of SETI. It also "suggests the search for strict solar analogs as a primary target for SETI strategies." (I)

See also the related Resource Letter on Extraterrestrial civilizations [Am. J. Phys. 57 (1), (1989)].

VIII. PHILOSOPHICAL AND CULTURAL ISSUES OF ANTHROPIC PRINCIPLE

A. Philosophical implications

These are many. For the most part, philosophical papers on AP try to put the latter into the framework of classical or modern ideas.

120. "Is Philosophy Relevant to Cosmology?" E. McMullin, Am Philos. Q. 18 (3), 177–189 (1981). Reprinted in Ref. 26. (E)
121. "Kantian Epistemology as an Alternative to Heroic Astronomy," W. I. McLaughlin, Vistas Astron. 28 (4), 611–639 (1985). An astronomer's attempt to put AP into the context of Kant's theory of knowledge. (I)
122. "Some Metaphysical Perplexities in Contemporary Physics," G. Gale, Intern. Philos. Q. 26 (4), 393–402 (1986). AP, bootstrap theory of hadrons and EPR paradox in quantum mechanics as manifestations of conceptual crisis in physics. (E)
123. "Metaphysical Presuppositions of the Anthropic Principle," J. Schneider, in Ref. 8, p. 445. This is only a half-page abstract. AP from the viewpoint of "transcendental schematism" of I. Kant and "transcendental semiotics" of K. Appel. (E)
124. "The Anthropic Principle," J. Rosen, Am. J. Phys. 53 (4), 335–339 (1985). (E)
125. "The Anthropic Principle II," J. Rosen, Am. J. Phys. 56 (5), 415–419 (1988). In these two papers AP is considered as a step to an overall holistic understanding of the Universe. (E)
126. "Philosophical Problems of Cosmology," J. J. C. Smart, Rev. Int. Philos. 41, 112–116 (1987). Draws a demarcation between legitimate and illegitimate uses of AP, the latter being "back to front," i. e., incorrect, as explanations. (E)

B. Anthropic principle and the teleological problem

It is known that biological systems exhibit purposeful behavior. In physics the situation is different: Teleology is usually treated here as an alien and undesirable element. On the other hand, anthropic fine tunings may be looked upon as manifestations of purpose in inanimate nature. This leads straightforwardly to teleological and, hence theistic conclusions. However, one may suggest that the facts of fine tuning are indications of yet undiscovered inherent order which could, in principle, be explained dynamically

in the future theory. The varieties of teleological reasoning, with relevance to AP, are studied in several papers.

127. "A Revised Design: Teleology and Big Questions in Contemporary Cosmology," G. Gale, Biol. Philos. 2 (4), 475–491 (1987). A feature review of Ref. 3. Stresses the difference between "epistemological" and "ontological" teleology. (E)
128. "The Anthropic Principle and Teleological Interpretations of Nature," J. M. Zycinski, Rev. Metaphys. 41 (2), 317–333 (1987). Correct versions of AP are "quasiteleological" arguments suggesting *as if* certain phenomena evolve toward some goal while implying at the same time that this goal may really not exist. (E)
129. "Barrow and Tipler's Anthropic Cosmological Principle," F. W. Hallberg, Zygon 23 (2), 139–157 (1988). Critically examines "nine speculative premises" of Tipler's final AP. (E)
130. "Gaia and the Anthropic Principles," P. B. Fellgett, Q. J. R. Astron. Soc. 29 (1), 85 (1988). Parallels of AP and J. Lovelock's hypothesis of Gaia which considers Earth's biosphere as a single living being regulating its state by means of feedbacks with nonliving environment. (E)

C. Theistic inferences

The proponents of strict theistic interpretations of the anthropic problem, reminiscent of classical design arguments, are mostly among theologians and religious thinkers.

131. "Anthropic Answers and the Existence of God," P. Forrest, Proc. Russ. Soc. 7, 1–13 (1982) (I)
 132. "New Life for the Teleological Argument," L. S. Betty and B. Cordell, Int. Philos. Q. 27 (4), 409–435 (1987). (E)
 133. "The Design Argument, Cosmic Fine Tuning and the Anthropic Principle," J. J. Davis, Int. J. Philos. Religion 22 (3), 139–150 (1987). (I)
 134. "Barrow and Tipler on the Anthropic Principle vs. Divine Design," W. L. Craig, Br. J. Philos. Sci. 39 (3), 389–395 (1988). Multiple universes and divine design as competing interpretations of anthropic fine tunings. (E)
 135. "The Anthropic Principle—A Theistic Inference from Contemporary Cosmology," G. N. Schlesinger, Tradition 23 (3), 1 (1988). (E)
- F. J. Tipler used his final AP to bridge a gap between scientific cosmology and Judeo-Christian-Islamic religious tradition:
136. "The Omega Point as Eschaton: Answers to Pannenberg's Questions for Scientists," F. J. Tipler, Zygon 24 (2), 217–253 (1989). (E)
 137. "Theological Appropriation of Scientific Understanding: Response to Hefner, Wicken, Eaves, and Tipler," W. Pannenberg, Zygon 24 (2), 255–271 (1989). Theologian Pannenberg's response to Ref. 136. (E)

D. Miscellaneous papers

138. "Information, Cosmology, and Life," G. H. A. Cole, Spec. Sci. Technol. 9 (4), 259–263 (1986). (E)
139. "Anthropic Universe," E. F. Mallove, in *Quickening Universe: Cosmic Evolution and Human Destiny*, (St. Martin's, New York, 1987), pp. 49–60. (E)
140. "What You See is What You Beget' Theory," T. Rothman, Discover 8 (5), 90–99 (1987). (E)
141. "How to Draw Conclusions From A Fine-Tuned Cosmos," J. Leslie, in Ref. 9, pp. 297–311. (E)
142. "Physics, Philosophy, and Myth," M. B. Hesse, in Ref. 9, pp. 185–202. (E)

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