When is a prediction anthropic?

Fred Hoyle and the 7.65 MeV carbon resonance

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Abstract: The case of Fred Hoyle's prediction of a resonance state in carbon-12, unknown in 1953 when it was predicted, is often mentioned as an example of anthropic prediction. An investigation of the historical circumstances of the prediction and its subsequent experimental confirmation shows that Hoyle and his contemporaries did not associate the level in the carbon nucleus with life at all. Only in the 1980s, after the emergence of the anthropic principle, did it become common to see Hoyle's prediction as anthropically significant. At about the same time mythical accounts of the prediction and its history began to abound. Not only has the anthropic myth no basis in historical fact, it is also doubtful if the excited levels in carbon-12 and other atomic nuclei can be used as an argument for the predictive power of the anthropic principle, such as has been done by several physicists and philosophers.

1. Introduction

In the early months of 1953 the British astrophysicist and cosmologist Fred Hoyle famously predicted the existence of an excited state in the carbon-12 atomic nucleus, arguing that such a state was necessary for the production of carbon in the stars. The prediction was quickly confirmed and recognized as a breakthrough in the understanding of stellar nucleogenesis. When the Royal Swedish Academy of Sciences awarded the prestigious Crafoord Prize of 1997 to Hoyle for his pioneering contributions to astrophysics, it mentioned specifically his prediction of the carbon energy level as "perhaps his most important single contribution within the field."[1]

In spite of its importance, Hoyle's prediction has never been investigated from a historical perspective, nor has its relationship to the later anthropic principle, often taken for granted, been examined in any depth. This paper is primarily a critical historical analysis of how Hoyle arrived at his prediction and the role it played in astrophysics in the 1950s. I am particularly concerned with the alleged anthropic nature of the prediction and how Hoyle himself looked upon the question. While the paper is basically a contribution to the history of astrophysics, an attempt to get history right, it is more than that. The subject is of considerable philosophical interest and has several times been discussed within the context of philosophy of science.[2] I shall argue that the proper philosophical significance of the case of the carbon-12 resonance can only be appreciated if its complex history is taken into account. In the last section I discuss in a more general way the possible anthropic significance of Hoyle's remarkable prediction.

2. The anthropic claim

Ever since Brandon Carter announced the anthropic principle in a lecture at Cracow in 1973, it has been discussed whether the controversial principle (in one of its several versions) belongs to science or philosophy.[3] It is generally agreed that the anthropic principle, to be of any scientific value, must result in predictions of more or less the same kind as known from ordinary scientific theories, preferably in precise predictions of phenomena that are not known to exist at the time of the prediction. Among the very few anthropic predictions – and possibly the only one – that belongs to this category, Fred

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[1] http://crafoordprize.se. The prize for 1997, which apart from the honour included half a million USD, was shared between Hoyle and Edwin Salpeter.

[2] See, e.g., Leslie 1994, Klee 2002, Walker and Ćirković 2003, and Mosterin 2004.

[3] Carter 1974.

Hoyle's prediction in 1953 of a definite resonance state in carbon-12 is the one that most frequently have appeared in the anthropic literature.

To summarize this well known case, in 1953 Hoyle realized that to make enough carbon inside the stars, there had to exist a resonance state of the carbon-12 nucleus at 7.68 MeV, which at the time was not known experimentally. Although Hoyle's theoretical arguments were at first met with scepticism, at least according to some sources, experiments made at the California Institute of Technology (Caltech) soon confirmed the predicted resonance. Hoyle had apparently shown that an unknown property of the carbon nucleus, a manifestation of the precise strength of the nuclear forces, follows from the undeniable existence of carbon-based life. We exist, consequently there must be a 7.68 MeV carbon-12 resonance! The story of how Hoyle made the famous and alleged anthropic prediction has been told numerous times, in many cases as evidence of the predictive power of anthropic arguments. "Hoyle was rigorously applying what would later become known as the anthropic principle," one can read. "This was the first and only time that a scientist had made a prediction using the anthropic principle and had been proved right."[4] Statements like this abound, both in published sources and, not least, on the internet.

To my knowledge, the first time that the case of the carbon resonance appeared explicitly in an anthropic context was in an influential article by Bernard Carr and Martin Rees of 1979, in which the two scientists discussed and summarized all the arguments for the anthropic principle known at the time.[5] Ten years later, Rees, now in a popular book written jointly with the astrophysicist and science writer John Gribbin, gave a much more detailed account of the case and its anthropic nature. As the two authors noted, most anthropic arguments are made with the benefit of hindsight, the predictions being really

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4 Singh 2004, p. 395.

5 Carr and Rees 1979. Apparently Carr and Rees did not consider the 7.65 MeV resonance level a proper case of anthropic prediction, for they concluded that the anthropic principle "is entirely *post hoc*: it has not yet been used to predict any feature of the Universe" (p. 612).

postdictions. “But Hoyle's prediction is different, in a class of its own,” they said, “It is a genuine scientific prediction, tested and confirmed by *subsequent* experiments.”[6] They elaborated:

> Hoyle said, in effect, “since we exist, then carbon must have an energy level at 7.6 MeV.” Then the experiments were carried out and the energy level was measured. As far as we know, this is the only genuine anthropic principle prediction; all the rest are “predictions” that *might* have been made in advance of the observations, if anyone had had the genius to make them, but that were never in fact made in that way. … There is no better evidence to support the argument that the Universe has been designed for our benefit – tailor-made for man.[7]

We find what is basically the same argument, spelled out in considerable details, in *The Anthropic Cosmological Principle*, the encyclopedic and influential work published by John Barrow and Frank Tipler in 1986. The two authors referred to “Hoyle's anthropic prediction” not only in connection with the carbon resonance with also with regard to the energy levels of oxygen-16: “Hoyle realized that this remarkable chain of coincidences – the unusual stability of beryllium, the existence of an advantageous resonance level in C^{12} and the non-existence of a disadvantageous level in O^{16} – were necessary, and remarkably fine-tuned, conditions for our own existence and indeed the existence of any carbon-based life in the Universe.”[8] Using the past tense, readers of the book inevitably get the impression that Hoyle's anthropic insight went back to his work in 1952-54, whereas in reality, as we shall see, it dates from a much later period. Barrow was among the first scientists to explicitly describe Hoyle's prediction as anthropic, such as he did in a paper

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[6] Gribbin and Rees 1989, p. 247.

[7] Note the ambiguous ”in effect”, followed by an invented quotation. Gribbin and Rees do not claim that this is what Hoyle actually said or thought, but they freely reconstruct what they think his prediction was effectively about.

[8] Barrow and Tipler 1986, p. 253.

of 1981, although at that time he did not claim that the prediction was actually anthropically motivated.[9]

A good story which is told many times easily becomes self-perpetuating. It tends to live a life of its own, such as has been the case with the claim of Hoyle's anthropic prediction. In an early bibliography of anthropic literature, the philosopher Yuri Balashov repeated the myth: "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."[10] The claim reappears in the more recent literature, both scientific and popular, in much the same form as when it was first told in the 1980s. Thus, to the prominent theoretical cosmologist Andrei Linde, "the existence and properties of this [carbon] resonance was one of the first successful predictions based on the anthropic principle."[11] Also Brandon Carter, the inventor of the anthropic principle, came to believe that the prediction qualifies as anthropic. In 2006 he said: "A prototype example of the application of this 'strong' kind of anthropic reasoning was provided by Fred Hoyle's observation that the triple alpha process … is extremely sensitive to the values of the coupling constants governing the relevant thermonuclear reactions in large main sequence stars."[12]

What may be called the "anthropic myth" exists in two versions. According to one of them, exemplified by the quotations from Balashov and from Barrow and Tipler, Hoyle was originally motivated by considerations of life to make the prediction. The other version, illustrated by the quotations from Linde and Carter, reconstructs Hoyle's argument as *de facto* anthropic, without making a historical claim.

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[9] Barrow 1981, p. 414.
[10] Balashov 1991, p. 1072.
[11] Linde 2007, p. 144.
[12] Carter 2006, p. 176. The strong anthropic principle exists in several versions, but can be boiled down to the statement that the universe must have have those properties that allow (intelligent) life to develop within it at some stage in its history. The weak form of the anthropic principle is the almost (but only almost) trivial statement that the observed properties of the universe must be consistent with observers.

As one might expect, the story is an element in many of the obituaries, biographies and commemorative articles which have come out after Hoyle's death in 2001. "Hoyle had anticipated the anthropic principle by arguing that because we are here, this C^{12} excited state must exist," says one of the obituaries.[13] On the occasion of the fifty-year's anniversary of the 1953 prediction, *The Guardian* included an article on how Hoyle originally presented his deduction of a 7.65 MeV state to the American nuclear experimentalist and later Nobel laureate William Fowler. "The state had to exist, reasoned Hoyle, because life existed and life was based on carbon." The sceptical Fowler found it outrageous: "What compounded Fowler's amazement was the manner of Hoyle's prediction. He had predicted the 7.65 MeV energy state of carbon-12 using an anthropic argument: it had to exist because, if it didn't, neither could human beings. To Fowler, such flaky logic smacked of religion rather than science. To this day, Hoyle is the only person to have made a successful prediction from an anthropic argument in advance of an experiment."[14]

Many more examples could be provided, but the quoted ones will suffice to illustrate the widespread belief or myth that Hoyle's prediction of the early 1950s was an early example of anthropic reasoning or an anticipation of the anthropic principle *avant le mot*. The problem with the belief is not the predictive nature of Hoyle's argument, but its supposed anthropic nature.

3. From alpha to carbon

From a historical point of view, the problem of explaining the formation of chemical elements is closely related to the the problem of energy production in the stars, such as considered by Hans Bethe in his pathbreaking and eventually Nobel-rewarded theory of 1939. In Bethe's theory of the CNO (carbon-nitrogen-oxygen) cycle, carbon played a crucial role as a catalytic agent, but Bethe merely assumed the existence of carbon rather

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[13] Clayton 2001, p. 1570. For biographies, see below.
[14] Chown 2003 (online version).

than accounting for its genesis. Although his theory was mainly concerned with energy production, and not with nucleosynthesis, he did discuss what he called triple collisions of alpha particles, including the direct formation of carbon-12 by the collision of three alpha particles: $3\ ^{4}He \rightarrow\ ^{12}C$. However, he found that the yield of carbon would be negligible unless the temperature was $T \sim 10^{9}$ K, much higher than the 2×10^{7} K of the interior of the Sun and similar stars. Bethe concluded that "there is no way in which nuclei heavier than helium can be produced permanently in the interior of stars under present conditions." [15] Yet, somehow carbon, oxygen and the other elements had come into existence. How?

While the production of heavier elements was not part of Bethe's astrophysical work, it was of crucial importance to the cosmological research programme initiated by George Gamow in 1946 and developed in collaboration with Ralph Alpher and Robert Herman in particular. The essence of the Gamow approach to cosmology was the big bang assumption of an early, hot and compact universe in which the elements had been formed by neutron capture and other nuclear processes within the first few hours of the cosmic expansion. However, it turned out that only the formation of the lightest elements, the hydrogen and helium isotopes, could be explained in this way. The problem, known as the "mass gap problem", was the non-existence of nuclei of atomic weights 5 and 8 which were needed as "bridges" between helium and carbon. Gamow and his associates tried hard to solve or circumvent the mass gap problem, but their efforts were met with no success. The problem was studied in detail by Enrico Fermi and his Chicago colleague Anthony Turkevich, but after many ingenious suggestions they, too, were "left with the sad conclusion that this theory [Gamow's] is incapable of explaining the way in which the elements have been formed." [16] In regard of Hoyle's later prediction it is of some interest to note that at one stage Fermi and Turkevich considered the process

[15] Bethe 1939, p. 446. The "present conditions" Bethe referred to were the pressure and temperature in the interior of main sequence stars.

[16] Fermi 1949, p. 720. On the mass gap problem in Gamow's big bang theory of the universe, see Kragh 1996, pp. 128-132. Although the work of Fermi and Turkevich was never published, it was

$$^3H + {}^4He \rightarrow {}^7Li + \gamma$$

They found that "a resonance would have to be at about 400 keV or closer in order to convert any appreciable amount of the material into Li^7."[17] Unfortunately no such resonance had been found experimentally and for this reason the attempt to bridge the gap at mass 5 was abandoned.

By the early years of the 1950s it seemed impossible that carbon and the other heavy elements could have been produced cosmologically in the early universe, and it seemed equally impossible that they could be produced in ordinary stars. In a work of 1951 the Estonian-Irish astronomer Ernst Öpik suggested that what was not possible in ordinary main sequence stars might be realized in red giant stars.[18] In the late phase of such a star the contracting core reaches a temperature of about 4×10^8 K, and Öpik showed that at this temperature nearly all helium would convert into carbon by a triple alpha process, thus circumventing the mass gap problem. However, Öpik's paper made almost no impact at all and was initially unknown even to astrophysicists working in the same research area.

One of those astrophysicists was Edwin Salpeter, an Austrian-born theorist who had worked with Bethe on problems of quantum mechanics and in the summer of 1951 spent some time with William Fowler and his group at the Kellog Radiation Laboratory of the California Institute of Technology. In his first work on nuclear astrophysics Salpeter

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known from summary accounts given by Gamow and his coworkers. See in particular Alpher and Herman 1950, pp. 193-202.

17 Alpher and Herman 1950, p. 196.

18 Öpik 1951.

argued, much like Öpik but in greater detail, that in red giant stars at $T > 10^8$ K three alpha particles would fuse into carbon.[19] This would happen in two reactions

$$^4\mathrm{He} + {}^4\mathrm{He} + Q \rightarrow {}^8\mathrm{Be} + \gamma \qquad (Q = 95\ \mathrm{keV})$$

$$^4\mathrm{He} + {}^8\mathrm{Be} \rightarrow {}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma + Q \qquad (Q = 7.4\ \mathrm{MeV})$$

For the rate of energy production ε of the triple alpha process, expressed in units of erg/g/sec, he found for temperatures $T \sim 2 \times 10^8$ K

$$\varepsilon = 10^3 \left(\frac{\rho}{2.5\times10^4}\right)^2 \left(\frac{T}{2\times10^8 K}\right)^{18} X_\alpha^3$$

where ρ is the density in g/cm^3 and X_α is the concentration by weight of helium.

Measurements made at Los Alamos and the Kellogg Radiation Laboratory a few years earlier had shown that beryllium-8, although unstable, is only so by a slight amount, namely about 95 keV. The Los Alamos physicist Arthur Hemmendinger obtained 103 ± 10 keV for the disintegration energy of beryllium-8 into two alpha particles, while Fowler and his collaborators reported 89 ± 5 keV.[20] Salpeter reasoned that the ground state of the nucleus provided a resonance level at a low excitation energy for a pair of alpha particles. Thus, at the high temperature in a red giant, there will be a fraction of the alpha particles that have thermal energies high enough to form beryllium-8 nuclei. Although these have a half-life of only 10^{-16} seconds, at a temperature in the vicinity of 2×10^8 K beryllium-8 will be continuously present. According to Salpeter's estimate, the result would be an equilibrium ratio of beryllium-8 to helium-4 of about 10^{-10}. Under these conditions

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19 Salpeter 1952, submitted 2 October 1951. See also the recollections in Salpeter 2002, especially pp. 8-10. The Salpeter triple alpha process was first reported in the 23 February 1952 issue of *Nature* (Bondi and Salpeter 1952).

20 Hemmendinger 1949. Tollestrup, Fowler, and Lauritzen 1949.

beryllium-8 could absorb another alpha particle and form carbon-12. Salpeter also considered (as Öpik had done) the further formation of elements, such as

$$^{12}C + {}^{4}He \rightarrow {}^{16}O + \gamma + Q_1 \qquad (Q_1 = 7.1 \text{ MeV})$$

$$^{16}O + {}^{4}He \rightarrow {}^{20}Ne + \gamma + Q_2 \qquad (Q_2 = 4.7 \text{ MeV})$$

Taking into account the resonance effects due to the ground state of beryllium-8, Salpeter's rate equation indicated a rate for helium burning considerably greater than the one calculated by Öpik (which he did not know about at the time). In his brief paper published in the *Astrophysical Journal* in 1952, Salpeter noted that the calculated rate might depend on the position of resonance levels in carbon-12. If an appropriate resonance level existed, the production rate could be larger than the estimated one by a factor of 1000. But he did not follow up on the remark. Fifty years later Salpeter reflected that "I did not have the chutzpah (or guts) to do anything about it." The calculation made in 1951, he said (evidently with hindsight), "would lead to most of the helium being converted to oxygen and neon instead of carbon, but I just did not have the guts to think of resonance levels that had not been found yet!"[21]

4. Prediction and confirmation

Fred Hoyle had the chutzpah that Salpeter admittedly lacked. Contrary to Salpeter, Hoyle had for long been interested in nuclear astrophysics and the processes in the interior of the stars that generated the chemical elements. In an important paper of 1946 he examined the formation of heavier elements up to about the middle of the periodic system, concluding that the most abundant of these elements would be grouped about iron.[22] As to the lighter elements he assumed with Bethe that carbon-12 was formed by three helium nuclei. In this

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[21] Salpeter 2002, p. 9. "Chutzpah" is a Jewish-English word meaning "audacity" or "nerve."
[22] Hoyle 1946.

long and complex paper he did not deal with the details of the nuclear reactions but merely established the general framework for element formation.

In the fall of 1952 Hoyle was invited to spend the first three months of 1953 at Caltech. Having arrived in Pasadena he decided to follow up on Salpeter's work by taking a fresh look at the triple alpha process generating carbon. One reason for his dissatisfaction with Salpeter's calculations may have been his conviction that helium burning in red giants should start at temperatures just above 10^8 K rather than at 2×10^8 K such as assumed by Salpeter. Greatly interested in all aspects of stellar evolution, Hoyle was aware of a recent work by Allan Sandage and Martin Schwarzschild on stellar models with gravitationally contracting cores.[23] According to one of the models by Sandage and Schwarzschild, the central temperature might be as low as 1.1×10^8 K, which Hoyle saw as a problem for Salpeter's reaction rate equation. Much later, Hoyle recalled about his reconsideration of the triple alpha process:

> Salpeter's publication of the 3α process freed me to take a fresh look at the carbon production problem. I found difficulty in generating enough carbon, because the carbon kept slipping away into oxygen as it was produced. A theoretically possible way around this difficulty was greatly to speed-up the carbon synthesis by a rather precisely-tuned resonance which would need to be about 7.65 MeV [originally 7.68 MeV] above ground-level in the ^{12}C nucleus.[24]

That is, Hoyle realized that to get an appreciable fraction of the original helium transformed into carbon-12 the ^{8}Be$(\alpha,\gamma)^{12}$C process had to proceed resonantly at an energy level of about 7.68 MeV or 0.31 MeV above the sum of the masses of beryllium-8 and

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[23] Sandage and Schwarzshild 1952, who referred to Salpeter's work on p. 475. See also Hoyle and Schwarzschild 1955, especially p. 31. For the works by astronomers and physicists on stellar structure and evolution in the period, see Tassoul and Tassoul 2004, pp. 143-155.

[24] Hoyle 1986, p. 449. For accounts of Hoyle's work on stellar nucleosynthesis, see Arnett 2005 and Mitton 2005, pp. 197-222.

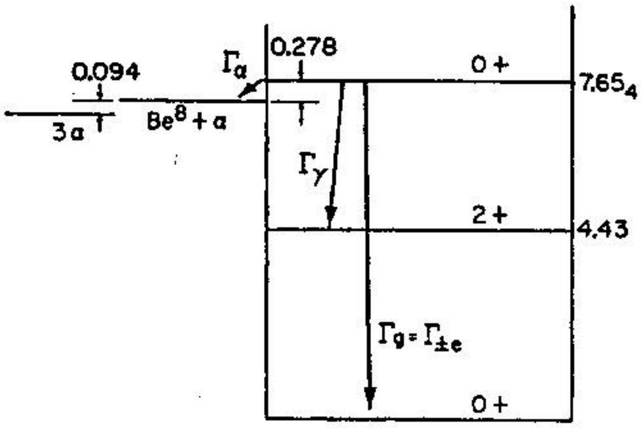

Figure 1. Some of the energy levels in carbon-12, expressed in MeV, compared with the energies of 3α and (^{8}Be + α). From Salpeter 1957, p. 517.

helium-4. The predicted state was about 3.2 MeV above the first excited state of carbon-12, which was known experimentally (Figure 1). "Assuming … that the Be^8 + α reaction through this level is not forbidden by strict selection rules, the resonance contribution from it quite overwhelms not only the nonresonance yield but also the resonance contributions from other levels"[25]

With the new hypothesized resonance the carbon yield would increase by a factor of about 10^7 compared to that of the Salpeter process. Moreover, Hoyle also realized that the enormous enhancement of the triple alpha process by means of the resonance was not enough to secure a sufficient net yield of carbon-12. Because, if the produced carbon-12 were consumed by other reactions, and especially by the $^{12}C(\alpha,\gamma)^{16}O$ process, nothing would have been gained. By comparing the reaction rates of the two processes he found that the latter must occur through a known nonresonant level at 7.10 MeV above the ground state of oxygen-16, slightly less than what corresponds to the combined masses of carbon-12 and the alpha particle. Because the 7.10 MeV level is just below (^{12}C + α) = 7.16 MeV, resonance cannot occur.

[25] Hoyle 1954, p. 130.

In this way Hoyle was able to explain how most of the carbon produced in the core of a giant star will still be present when the star explodes as a supernova and spreads its material into interstellar space. In his account of the theory, as first presented in a paper of 1954, Hoyle concluded that the theory was able to reproduce roughly the abundance ratios between carbon-12, oxygen-16 and neon-20, but only if there existed a carbon resonance level at about 7.7 MeV. For the ratios he deduced

$$^{12}C : {}^{16}O \sim 1 : 3 \text{ and } {}^{16}O : {}^{20}Ne \sim 1 : 1,$$

in good agreement with astrospectroscopic estimates. Thus, with Hoyle's new insight the steps in the triple alpha reaction could be written

$$^{4}He + {}^{4}He + Q_1 \rightarrow {}^{8}Be + \gamma$$

$$^{4}He + {}^{8}Be + Q_2 \rightarrow {}^{12}C^*$$

$$^{12}C^* \rightarrow {}^{12}C + 2\gamma + Q_3$$

where $Q_1 \sim 95$ keV, $Q_2 \sim 0.31$ MeV and $Q_3 \sim 7.68$ MeV. The net result was

$$^{4}He + {}^{4}He + {}^{4}He \rightarrow {}^{12}C + 2\gamma + 7.28 \text{ MeV}$$

Hoyle did not rush to announce his prediction, which was only communicated to the community of physicists after it had been confirmed experimentally. The announcement took place at the meeting of the American Physical Society in Albuquerque in early September 1953, five months after Hoyle had left Caltech for a stay at Princeton University. In the brief abstract Hoyle and his three coauthors said that the observed cosmic abundance ratio of He : C : O could be reproduced "if the reaction $Be^8(\alpha,\gamma)C^{12}$ has a resonance state near 0.31 MeV, corresponding to a level at 7.68 MeV in C^{12}."[26] A fuller account of the reactions only appeared in Hoyle's more extensive paper in the *Astrophysical Journal* of 1954, in which the prediction was not given much emphasis.

Since Hoyle had his office in the Kellogg Laboratory and knew Fowler from earlier travels and meetings it was natural for him to approach Fowler and the other Kellogg experimentalists with regard to having his prediction confirmed. The encounter between the British theorist and the American experimentalists has been told in various versions. Fowler recalled:

> I was very sceptical that this steady state cosmologist, this theorist, should ask questions about the carbon-12 nucleus. … Here was this funny little man who thought that we should stop all this important work that we were doing otherwise and look for this [resonance] state, and we gave him the brushoff. Get away from us, young fellow, you bother us.[27]

Fowler's recollection may be more colourful than accurate. In any case, it does not agree with the memory of Hoyle according to whom his request to Fowler merely resulted in "a long technical discussion of whether the experimental methods used thus far might have missed the state I was looking for."[28] Fowler and his team quickly took an interest in what

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26 Hoyle, Dunbar, Wenzel, and Whaling 1953. This first presentation was actually the work of the Kellogg experimentalists and not Hoyle, who at the time had left Pasadena and was back in Cambridge. According to the recollections of Ward Whaling, "We wrote to him [Hoyle] and said, 'We're going to publish a paper and we'd like you to put your name on it, too.' … And he acceeded, since the experiment – he didn't get in and turn and twist the knobs and read the counters, but it was his idea, his concept, that led us to do it in the first place." Interview with Ward Whaling by Shelley Erwin, April-May 1999, California Institute of Technology Archives. Available online as http://resolver.caltech.edu/CaltechOH:OH_Whaling_W.

27 Interview with W. Fowler by Charles Weiner, American Institute of Physics, February 1973, as quoted in Kragh 1996, p. 299. In his Nobel Lecture of 1983 Fowler gave a less dramatic account of the meeting between Hoyle and the Kellogg physicists (Fowler 1984).

28 Hoyle 1994, p. 264. Hoyle further recalled that it took "about ten days" to verify the prediction. On the other hand, in 2004 Whaling recalled that the experiment took three months (Mitton 2005,

Hoyle told them and prepared looking for the missing resonance. One reason may have been that the prediction of a 7.68 resonance level, although unconfirmed at the time, was not completely unexpected.

As early as 1940, two physicists at Cornell University had reported an energy level in carbon-12 at 7.62 MeV based on measurements of the range of alpha particles from the reaction $^{14}N(d,\alpha)^{12}C$, where d denotes a deuteron.[29] However, later and more precise measurements of the same deuteron-nitrogen reaction, made by R. Malm and W. Buechner at the Massachusetts Institute of Technology, failed to confirm a level about this energy.[30] On the other hand, some studies of nuclear processes seemed to provide evidence for a level in the area 7.0-7.5 MeV, which was included as a possibility in some of the level diagrams published by the Kellogg Radiation Laboratory in the early 1950s (Figure 2).[31] What matters is that by 1952 there was conflicting evidence in regard to the question of a carbon-12 state in the vicinity of 7.5 MeV, not far from the state that Hoyle needed. Hoyle was undoubtedly aware of the possibility of such a resonance, which may have stimulated his decision to examine the triple alpha process more closely. Thus, it is not quite true that the 7.68 MeV excited state was "contrary to all the then-known evidence," such as the standard story has it.[32]

It has been suggested that Hoyle did not really predict a new energy level, but rather "predicted that the newly expunged level would be real," as stated by David

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p. 209). And Charles Barnes, a nuclear physicists who worked at the Kellogg Laboratory at the time, told in 2002 that the experimental confirmation took "literally just a few weeks" (Gregory 2005, p. 64). Evidently one has to be careful with scientists' recollections!

29 Holloway and Moore 1940.

30 Malm and Buechner 1951.

31 Hornyak, Lauritsen, Morrison, and Fowler 1950, p. 325. Britten 1952. Ajzenberg and Lauritsen 1952, p. 355. For more references to pre-1953 works on the energy levels of carbon-12, see Cook, Fowler, Lauritsen, and Lauritsen 1957.

32 Scerri 2007, p. 257. Eric Scerri, a philosopher and historian of the chemical sciences, conveys the anthropic myth: "Hoyle had reasoned that the resonant state of carbon had to exist since beings like us are made largely by carbon and are able to pose the questions as to the formation of the element carbon" (p. 323).

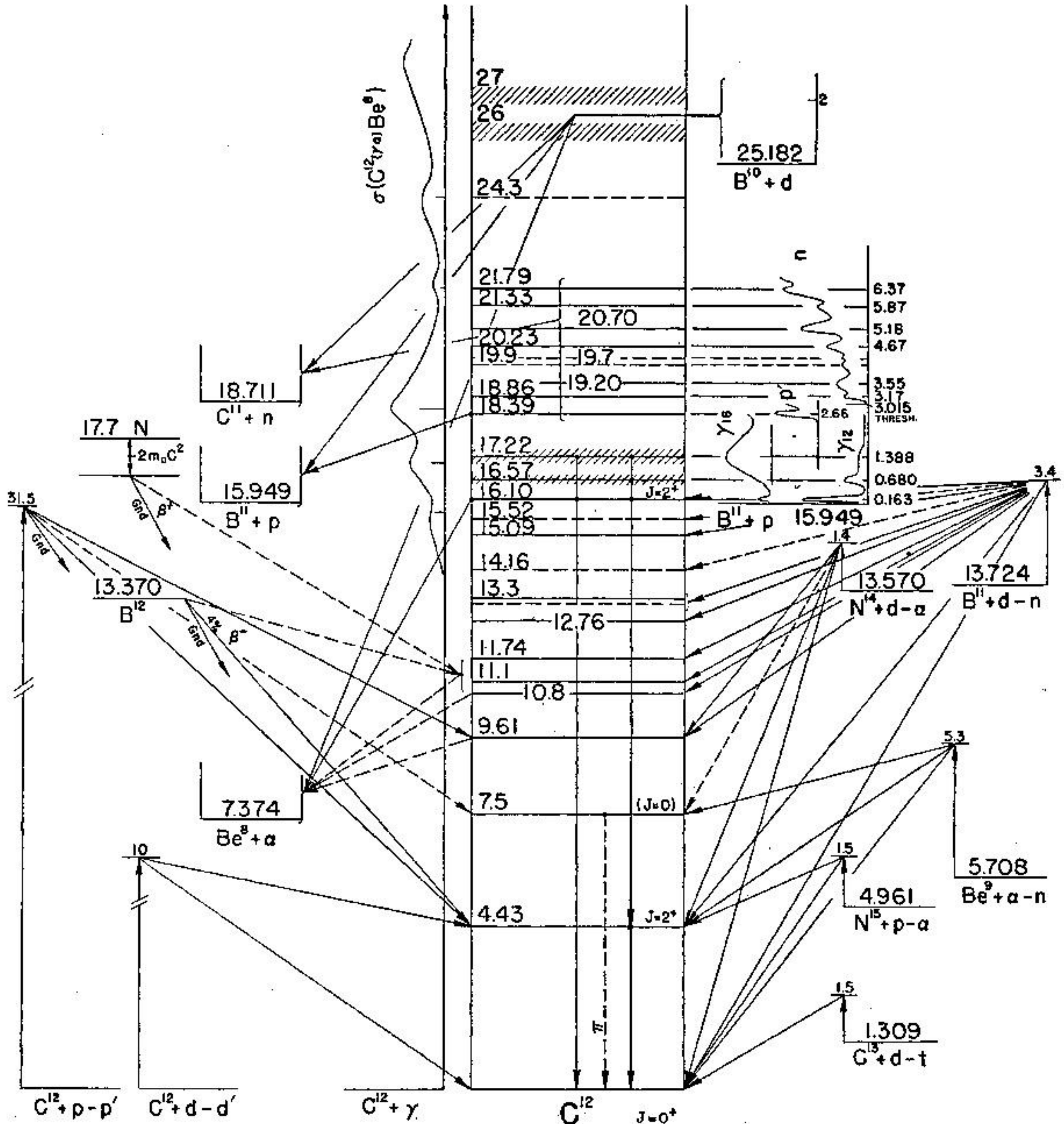

Figure 2. Energy levels of carbon-12, as reported in Ajzenberg and Lauritsen 1952, p. 355. Notice the level at 7.5 MeV above the ground state.

Arnett, an American astrophysicist.[33] Yet, even though there was unconfirmed evidence of one or more resonances in the range 7.0-7.5 MeV, Hoyle's prediction did not depend on this evidence. Moreover, none of the experimentally suggested levels had energy higher than 7.5 MeV. Contrary to the uncertain and conflicting experimental evidence, Hoyle's prediction of the 7.68 level was sharp and definite.

Ward Whaling had come to Caltech in 1949, and by 1952 he had joined the Kellogg group as a nuclear physicist specializing in the determination of energy levels in the lighter elements. Level diagrams were a specialty at the laboratory, where they were worked out by Thomas Lauritsen and others. Whaling recalled how Hoyle addressed him and his group with respect to the question of a carbon-12 resonance of the proper energy. At the time the group consisted of Whaling, William Wenzel, Ralph Pixley, and an Australian visitor by the name Noel Dunbar.

> So we looked at Tommy's [Thomas Lauritsen's] level diagrams, and you could see that at one point somebody had penciled in a level there, but then other people had tried to see it, and then Tommy had erased it; it seemed no to exist. And its energy wasn't exactly where it needed to be, anyway, for Hoyle's purposes. It was close by – like 7.4, or something like that, instead of 7.6. But the idea immediately occurred: 'Well, let's look and see if we can see such a state in carbon-12.' … We decided to look at it by bombarding nitrogen-14 with deuterons and looking at the alpha particle. The reaction goes to carbon-12 plus an alpha particle. And by looking at the energy of the alpha particles, we should find high-energy alpha particles that leave carbon-12 in its ground state. And groups of alphas of lower energy, because some of the energy was left in the carbon-12 residual nucleus. So we decided we would try that.[34]

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33 Arnett 2005, p. 22, who referred to the work of Malm and Buechner as the one which showed the non-existence of earlier reported lines of about 7 MeV.

34 Whaling interview, http://resolver.caltech.edu/CaltechOH:OH_Whaling_W.

Apart from being communicated at the September 1953 meeting of the American Physical Society, the work of Whaling and his collaborators was published in early November in *Physical Review*, this time without Hoyle as a coauthor.[35] The reaction examined by the Kellogg physicists, that is $^{14}N(d,\alpha)^{12}C$, was the same that had been been studied more than twenty years earlier by Holloway and Moore, except that Whaling and his group measured the spectrum of the alpha particles by means of a double-focusing magnetic spectrometer, a method far superior to the old one based on the range-energy relationship of alpha particles. They found a value for the carbon resonance of 7.68 ± 0.03 MeV with a width less than 25 keV, in excellent agreement with Hoyle's calculations. These calculations were based on astrophysical considerations, but at the time astrophysics was of no great interest to the Kellogg physicists who merely expressed their indebtedness "to Professor Hoyle for pointing out to us the astrophysical significance of this level." What this significance was they did not say.

Further experiments reported by Fowler and his group of nuclear physicists narrowed down the carbon-12 resonance level to 7.653 ± 0.008 MeV and showed that the spin and parity state of the level was most likely 0^+. (The ground state is also 0^+, while the first excited level of energy 4.43 MeV is a 2^+ state.) For the disintegration energy of beryllium-8 decaying into two alpha particles they obtained 93.7 ± 0.9 keV. These results were found by producing the resonance state in the beta decay of boron-12 to three alpha particles.[36] The data found by the Kellogg physicists and other groups were in full agreement with Hoyle's theory.

By the time Hoyle made his prediction he was not only busy with nucleosynthesis in the stars, he was also working on the steady-state cosmological theory that he, together with Bondi and Tommy Gold, had introduced in 1948. Indeed, he was at the time best known as a cosmologist and advocate of a controversial theory of the universe based on

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35 Dunbar, Pixley, Wenzel, and Whaling 1953. See also Spear 2002.
36 Cook, Fowler, Lauritsen, and Lauritsen 1957.

the hypothesis of continuous creation of matter. By its very nature, the steady-state theory was restricted to stellar processes when it came to explaining the building up of elements, and for this reason it was important to demonstrate that all the elements could in fact be produced without assuming a hot primordial state of the universe. Although Hoyle's work in nucleosynthesis thus had a connection to his favoured cosmological model, it was not motivated by this model or otherwise closely related to cosmology. In his papers on the synthesis of carbon and other elements Hoyle was careful not to mention the cosmological debate. This was also the case when he joined forces with Fowler, Margaret Burbidge and Geoffrey Burbidge and in 1957 published the comprehensive and soon famous work on stellar nucleosynthesis known as the B^2HF theory.[37] Although this theory was not directly associated with steady-state cosmology, indirectly it weakened Gamow's big bang alternative and, consequently, added support to the steady-state view of the universe. To Bondi, the B^2HF theory was a "tremendous triumph" for the steady-state conception of the universe.[38]

Hoyle's argument that there must exist a resonance state in carbon-12 at an energy of about 7.7 MeV was a brilliant prediction based on astrophysical reasoning and one that deservedly occupies a prominent place in the history of astrophysics. But was it an anthropic prediction?

5. Hoyle on cosmic fine tuning

In his biography of Fred Hoyle, Simon Mitton notes that "A certain amount of folklore now surrounds the experiment [of Whaling et al.] and Hoyle's role." While this is certainly correct, unfortunately Mitton adds to the folklore in his account of how Hoyle motivated his interest in the resonance to his colleagues at Caltech:

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[37] Burbidge, Burbidge, Fowler, and Hoyle 1957.
[38] Bondi 1966, p. 400. See also Kragh 1996.

> After studying Salpeter's paper in the Astrophysical Journal, Hoyle was not prepared to let the matter rest. … Fred said to his associates, "Since we are surrounded by carbon in the natural world and we ourselves are carbon-based life, the stars must have discovered a highly effective way of making it, and I am going to look for it."[39]

Another biographer of Hoyle, Jane Gregory, tells what is basically the same story. Referring to Hoyle's thoughts in 1953, she says: "Hoyle thought that since human beings exist to ask such questions about the universe – and they exist in their particular biological form because carbon exists in plenty – then the universe must be one in which carbon is readily made."[40] However, there is no documentary evidence at all (at least none that I know of) that Hoyle expressed himself in this or some similar anthropic way, nor that he originally thought along such a line. The two works, both well researched and solidly documented, repeat the anthropic myth.

Whether or not Hoyle himself came to believe that he had found evidence for anthropic fine-tuning in 1953, he did not originally see it in that way. Hoyle *might* have reasoned something like this: Since life is known to exist, and life as we know it is carbon based, … there must exist a 7.68 MeV resonance. This is what many sources, including the two mentioned biographies, claim or at least indicate. In that case his reasoning would have counted as an anthropic prediction. But this was not the way Hoyle argued in 1953. In his autobiography of 1994, entitled *Home Is Where the Wind Blows*, Hoyle said that the prediction caused him to contemplate the question of whether the existence of life might be due to coincidences in nuclear physics. Perhaps, he said, "life would perforce exist only where the nuclear adjustments happened to be favorable, removing the need for arbitrary coincidences, just as one finds in the modern formulation of the weak anthropic

[39] Simon 2005, p. 206. For a more florid folklore account, see Chown 1999.
[40] Gregory 2005, p. 63.

principle."[41] We are not told when he began thinking along these lines, but as mentioned there is no evidence to suggest that such anthropic-like thoughts motivated his prediction. Instead of speculating of what he might have thought, it is more fruitful to look at how Hoyle expressed himself in his published works relating to the prediction and the anthropic principle.

In the early publications on the carbon resonance neither Hoyle nor others mentioned it as a case of fine-tuning, nor did they refer to the existence of life in the universe. A lecture given in 1957 in the University Church, Cambridge, on the relationship between science and religion might have provided an opportunity for Hoyle to make the connection, but in fact he did not. Hoyle discussed the possibility that "the laws of nuclear physics are designed to promote the origin of the complex atoms, so it may well emerge … that the laws seem as if they have also been deliberately designed to promote the origin of life." He went on to say: "Life demands highly special physical conditions if it is to flourish. Hence if life is part of a deliberate plan so must the origin of the physical conditions be."[42] Although Hoyle found the hypothesis of specially designed fine-tuning appealing, he did not clearly support it. What is more, he did not refer to his earlier calculation of the carbon-12 resonance as a case in point.

As far as I know, Hoyle first referred to life in connection with the nuclear processes generating carbon and oxygen in a book of 1965, where he offered an account of the delicate balance of the energy levels in beryllium-8, carbon-12 and oxygen-16. "The whole balance of the elements carbon and oxygen is critical not only for the chemistry of living organisms but for the distribution of the planets," Hoyle said. He continued:

[41] Hoyle 1994, p. 266. Hoyle spoke of the prediction as "an early application of what is known nowadays as the anthropic principle" (p. 256).

[42] Hoyle 1957, p. 65. Another contribution to the lecture series was given by Charles Pantin, a British zoologist who is sometimes mentioned as an early advocate of anthropic reasoning and the the idea of multiple universes (e.g., Barrow and Tipler 1986, p. 250).

> If carbon were more abundant than oxygen it would be inevitable, I think, that a big graphite planet would lie nearest to the sun. …Had there not been a favorably placed resonance in the C^{12} nucleus, the rate of carbon production would be so slow that very little carbon would exist in the world; the opposite to the graphite planet situation. … When we examine the O^{16} nucleus we see that a level exists very close to the sum of the rest masses of C^{12} and an α–particle, but fortunately the level is *below*, so that an actual resonance can never occur. I say fortunately, because if there was little carbon in the world compared to oxygen, it is likely that living creatures would never have developed."[43]

In a textbook published ten years later he repeated the comment, adding the speculation that the balance between the electromagnetic and nuclear forces (and hence the energy levels) might "vary from one region of the universe to other, very distant regions."[44] In that case, life as we know it would only form in some cosmic regions, evidently in our own and possibly only in ours. In neither of the publications did Hoyle connect his work of 1953 with anthropic considerations, either in the sense that he singled out intelligent life or suggested that his early work was anthropically motivated.

Latest by 1980 Hoyle was aware of the anthropic principle, such as expounded in the Carr-Rees article in *Nature*. Apparently he now conceived his prediction of 1953 as related to anthropic reasoning. "Is the positioning of the level at 7.65 MeV in ^{12}C an accident?" he asked. "Is it an accident that the 7.12 MeV level of ^{16}O lies just below the sum of the rest masses of ^{12}C and ^{4}He? Without these circumstances together, the cosmic ratio of C to O would not be appropriate to life, which demands approximately equal abundances for these two crucial elements."[45] By the early 1980s Hoyle was occasionally

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[43] Hoyle 1965, p. 147. Elsewhere in the small volume Hoyle referred to "bubble universes," a kind of multiverse associated with steady-state cosmology (p. 131).
[44] Hoyle 1975, p. 402.
[45] Hoyle 1980, pp. 54-55. Hoyle also mentioned a few other instances of fine-tuning, referring to Carr and Rees 1979 for "a fuller compilation of these 'anthropic' issues."

associating his prediction of the 7.65 MeV level with the anthropic principle, but not in any explicit sense. For example, in 1982 he spoke of the energy levels of carbon-12 and oxygen-16 as a "put-up job." "A common sense interpretation of the facts suggests," he said, "that a superintellect has monkeyed with physics, as well as chemistry and biology, and that there are no blind forces worth speaking about in nature."[46] He did not specifically refer to life, whether human or not.

Although Hoyle was at that time intensely occupied with the nature and origin of life, he did not endorse the anthropic principle in any of its ordinary meanings and neither did he find it to be of much use for cosmology. As he saw it, the significance of the principle lied elsewhere. In an address at the first Venice Conference on Cosmology and Philosophy in 1987, he gave a review of his ideas of the relations between cosmology and biology, emphasizing that the key problem was how to explain the origin of life. According to Hoyle's reasoning, it was extremely implausible that life on Earth could have occurred by chance, which "seems to me [to] be the essence of the *anthropic principle*." As to this principle, he turned it upside down:

> Until we understand it [the origin of life], much, I believe, will remain to be discovered about cosmology, for surely the occurrence of life is the largest problem of which we are aware. It is not so much that the Universe must be consistent with us as that we must be consistent with the Universe. The anthropic principle has the problem inverted, in my opinion.[47]

Surely, this is a version of the anthropic principle quite different from the one formulated by Carter and subsequently developed by a host of other physicists, cosmologists and philosophers. At the following Venice conference, dedicated to the anthropic principle and taking place in 1989, Hoyle apparently adopted the strong principle, but it was in a

[46] Hoyle 1982, p. 16 and slightly differently in Davies 1982, p. 118.
[47] Hoyle 1991, p. 518.

version quite different from the usual one, namely as a predictive property. "If our existence leads to a potentially falsifiable prediction in the sense of Popper," Hoyle said, "then I take it that the anthropic principle is being employed in its strong mode."[48] He might have referred to his early prediction of the carbon-12 resonance as an example, but did not. Instead he derived a prediction from "the immense biochemical complexity of life" concerning the spectrum of the microwave background, which he considered "an example of a prediction from the strong anthropic principle relating the basic issue of the origin of life to the basic form of cosmology."[49] This basic form of cosmology was the steady-state theory of the universe, which according to Hoyle was in harmony with and indeed favoured by anthropic considerations.

Given that the standard view was and presumably still is that the anthropic principle rules out the steady-state universe and its basis in the perfect cosmological principle,[50] Hoyle's argument at the second Venice conference underlines the unorthodox nature of his conception of the anthropic principle. The general argument that the existence of life in the universe can be understood on the basis of the anthropic principle in conjunction with the steady-state theory (rather than big bang cosmology) also appeared in the book *Life on Mars?* that Hoyle wrote with his long-time collaborator and former student Chandra Wickramasinghe. However, Hoyle now referred to the weak and strong forms of the anthropic principle in versions that were more in line with those adopted by most other authors. He suggested that the strong version was of little or no scientific value – it might be nothing but "a semantic substitute for teleology." On the other hand, he and

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48 Hoyle 1993, p. 85. Popperian falsifiability is not a methodological virtue commonly associated with the anthropic principle. While Hoyle avoided connecting his 1953 prediction with the anthropic principle, at the same conference the French astrophysicist Hubert Reeves drew the connection. Maintaining that the anthropic principle could result in predictions made from *a posteriori* considerations, he mentioned Hoyle's prediction as an example. Reeves 1993, p. 68.

49 Ibid., p. 88.

50 What is sometimes known as the Davies-Tipler argument is an alleged refutation of cosmological theories with an infinite past, including the steady-state theory, on the basis of the strong anthropic principle. See Davies 1978 and Barrow and Tipler 1986, pp. 601-608.

Wickramasinghe considered the weak anthropic principle – that "the universe must be consistent with the existence of life, and in particular with the existence of human life" – to be both testable and scientifically valuable. They explicitly described Hoyle's early prediction as a deduction from the anthropic principle:

> The weak anthropic principle serves to remove otherwise inexplicable cosmic coincidences by the circumstance of our own existence. One of the present writers [Hoyle] was involved in an early application of the weak anthropic principle. … It was shown in 1952-53 that to understand how carbon and oxygen could be produced in approximately equal abindances, as they are in living systems, it was necessary for the nucleus of ^{12}C to possess an excited state close to 7.65 MeV above ground level. No such state was known at the time of this deduction but a state at almost exactly the predicted excitation was found shortly thereafter. So one could say that this was an example of using the weak anthropic principle in order to deduce the way the world must be, although the concept of the anthropic principle had not been explicitly formulated at that time.[51]

So Hoyle finally came to the conclusion that his 1953 prediction was a case of anthropic reasoning, or rather that it could be understood as anthropic in a *post factum* sense. But it took him about forty years, and he never suggested that his motivations for the predictions were related to the existence of life in the universe.

6. A case of anthropic prediction?

I have demonstrated that Hoyle's famous prediction of the 7.65 MeV resonance state was not originally thought of in terms of anthropic fine-tuning, neither by Hoyle himself nor

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[51] Hoyle and Wickramasinghe 1999, pp. 89-90. The article, which first appeared as a preprint in 1991, was also published as a chapter in Hoyle and Wickramasinghe, *Life on Mars? A Case for a Cosmic Heritage* (Bristol: Clinical Press, 1997).

by other researchers involved in stellar nucleosynthesis. The early literature related to the anthropic principle did not refer to the prediction of 1953 as an example of anthropic reasoning, although it would have been tempting to use the case in the controversy that started evolving at the time. Proponents of the anthropic principle were painfully aware of its lack of predictivity, yet they ignored the one case that would soon be regarded as an exception. For example, in 1982 Carr emphasized how much more impressive it would be "if the Anthropic Principle could be used to *predict* a coincidence," regretting that "so far this has not been done."[52] Like all astrophysicists, Carr was aware of Hoyle's prediction, and yet he did not think of it as anthropic. As mentioned, nor did Carr and Rees in their paper of 1979.

To further illustrate the point, consider an important paper that the Princeton physicist Robert Dicke published in 1961 and which is generally regarded as one of the main sources for the anthropic principle. Dicke discussed how "the biological requirements to be met during the epoch of man" constrained cosmological knowledge, and in this context he mentioned that heavier elements must have been produced in the stars. "It is well known that carbon is required to make physicists," as he phrased it.[53] Had Dicke seen Hoyle's mechanism of carbon generation as connected to human life, it would have been natural to refer to the prediction. Again, Dicke did not make the connection.

Only from about 1984 was the case *reconstructed* to be an anthropic prediction and it became common to associate Hoyle's reasoning with the existence of life in the universe. Apparently Hoyle came to share this view. It was also only from this time that the case became well known outside the small community of nuclear astrophysicists, which undoubtedly reflects the increasing popularity of the anthropic principle. Taken together,

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[52] Carr 1982, p. 251, reprinted in Leslie 1990, pp. 134-153.
[53] Dicke 1961, p. 440, reprinted in Leslie 1990, pp. 121-124.

the two brief papers of 1953 that originally announced the prediction were cited 8 times between 1953 and 1981, whereas they received 62 citations in the period 1982-2009.[54]

There is no generally agreed definition of what constitutes an anthropic prediction, a concept which is used in diverse and loose ways. In a paper of 1994, John Leslie defined anthropic predictions as "predictions *encouraged* by the anthropic principle, even if not dictated by it," adding that such predictions might well be made before Carter formulated and named the principle.[55] This is a reasonable definition, but it is much less reasonable to exemplify it by Hoyle's "two dramatically successful anthropic predictions" of the carbon-12 resonance and the nonresonant state in oxygen-16. Apart from the fact that Hoyle's use of the nonresonant 7.1 MeV level in oxygen was not a prediction – since the level was known at the time – by Leslie's definition Hoyle must have been encouraged by anthropic considerations to make his prediction. Leslie maintains that "'anthropic' considerations did influence him," quoting from Hoyle that "we can exist only in the portions of the universe where those levels happen to be correctly placed."[56] But this is a quotation from 1965, twelve years after the prediction! Only if Hoyle had said something along this line in 1953 (which he did not), might it be taken as evidence that he was anthropically encouraged. Unfortunately, this kind of careless use of historical sources is not exceptional among philosophers, scientists and science writers.

I shall here take "anthropic prediction" to mean that if a property or phenomenon of nature is (i) inferred from or inspired by the existence of (intelligent) life in the universe, and if (ii) the property or phenomenon is unknown at the time of prediction, then it qualifies as an anthropic prediction. If the second condition is not employed, a great variety of inferences will have to be accepted as anthropic. The same is the case with the

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[54] According to ISI Web of Science. The two papers are Dunbar, Pixley, Wenzel, and Whaling 1953 and Hoyle, Dunbar, Wenzel, and Whaling 1953. Given that the latter paper has received only 41 citations over more than half a century it is hardly correct to call it a "much-cited paper" (Scerri 2007, p. 323).

[55] Leslie 1994, p. 120.

[56] Ibid., p. 126. The quotation is from Hoyle 1965, p. 159.

second condition: it is not enough that a prediction can be reconstructed as relating to the existence of life, the relation must actually enter the prediction. If it can be shown that advanced life depends crucially upon a predicted property, but this played no role in the prediction, one should not speak of an anthropic prediction, but rather of an anthropically relevant or significant property.

For example, in 1931 Paul Dirac predicted the existence of positrons, and much later these particles turned out to play an important part in the early universe; it can assumedly be argued that had positrons not existed, neither would we. It is obviously unreasonable to call Dirac's prediction anthropic for this reason alone. As we have seen, Hoyle's prediction was novel but not based in considerations of life. Although the existence of the resonance state may be said to be anthropically significant (like Dirac's prediction may in principle be said to be), the prediction was no more anthropic than Dirac's prediction of the positron.

While there is no doubt that Hoyle's prediction was not initially conceived as anthropic, it may still be argued that it nonetheless was anthropic. One may argue, contrary to what I have suggested, that Hoyle's own motivations and the entire history of the case are irrelevant for deciding whether or not it is anthropic in nature. Although such a position is foreign to a historian's mind (and therefore to mine), for the sake of argument I shall grant it as legitimate. According to this line of thought, what matters is solely if the predicted state is actually a necessary condition for the existence of intelligent life. If the answer is yes, the prediction was anthropic, irrespective of what Hoyle and contemporary scientists thought.

More recent investigations of the energy levels in carbon and oxygen have to some extent been inspired by considerations of this sort, that is, they have been attempts to establish how finely tuned for life the levels really are. Are they *really* of anthropic significance? Of course, Hoyle's prediction refers only to the existence of carbon atoms, not to human beings. Had humans or other intelligent life forms not evolved, it would not have changed the prediction a iota (– but then, of course, the prediction would not have been made!). For this reason, it has sometimes been objected that it cannot possibly be anthropic in any strict sense. However, this is hardly a valid objection since it is generally acknowledged that the term "anthropic principle" is a misnomer: it does not refer specifically to humans, but is a selection principle that requires the universe and its history to be consistent with the conditions that are necessary for our existence as observers. Ten years after having introduced the anthropic principle, Carter regretted having suggested the term, which he now preferred to call the "self-selection principle."[57]

In a series of "experiments" in the form of computer calculations Mario Livio and his colleagues D. Hollowell, A. Weiss and J. W. Truran investigated in 1989 how changes in the carbon-12 resonance would affect the production of carbon in the stars. Using updated values for Hoyle's 0^+ resonance (7.644 MeV) and its place above the sum of the energies of beryllium-8 and helium-4 (277 keV), they tested the consequences of a hypothetical change in the energy difference. Livio and his collaborators reported that, in the case of helium burning in the core of a massive star some twenty times as heavy as the Sun, the difference between the two energies could be increased by 60 keV without destroying the consistency with the observed abundance of carbon and oxygen. If the 7.644 level were lowered by 60 keV, it turned out that the yield of carbon would increase markedly.

Relating their results to the anthropic principle, Livio and colleagues pointed out that the 60 keV shift represents a significant fraction of the energy difference between the 7.644 level and the (^{8}Be + α) energy. Hence their conclusion: "Thus, we believe that at least some formulations of the strong anthropic principle, which is based on the necessity of having the 0^+ level exactly where it is, is weakened significantly by our results."[58] In

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57 Carter 1983.

58 Livio, Hollowell, Weiss, and Truran 1989. For a sharper anti-anthropic conclusion based on the calculations of Livio et al., see Klee 2002. And for a critique of Klee's arguments, see Walker and Ćirković 2003. It is noteworthy that while Livio et al. and also Carter related the case of the carbon-

agreement with this conclusion, Steven Weinberg has observed that what affects carbon production in the stars is not the Hoyle resonance level of about 7.65 MeV, but the energy difference of roughly 0.25 MeV between the excited state and the state of the (^{8}Be + α) system at rest. "This energy misses being too high for the production of carbon by a fractional amount of 0.05 MeV/0.25 MeV, or 20 percent, which is not such a close call after all."[59]

Later and more sophisticated calculations in the same tradition, but focusing on slight variations in the strong interactions keeping the nucleons together, have led to results that to some extent differ from those of Livio and his collaborators. In a series of works Heinz Oberhummer and colleagues have calculated the sensitivity of the location of the resonance level to the strength of the nucleon-nucleon interaction, finding that even a small change in the strength (about 0.5%) will make carbon-based life impossible.[60] The helium in the stars will be transformed into either carbon or oxygen, but not into both elements. This and similar work has strengthened the case for fine-tuning somewhat, yet without unambiguously confirming the anthropic significance of the Hoyle resonance level. It is presumably a matter of taste how finely tuned for life a coincidence has to be in order to qualify as anthropic. As Livio and colleagues remarked, the implications for evaluating the anthropic principle "are not entirely free from subjective feelings."

Rather than focusing on the degree of fine-tuning, one may deny the anthropic nature of Hoyle's prediction by arguing that it has nothing to do with the existence of life. This is what Lee Smolin, an outspoken critic of the anthropic principle, has done. As he argues, the fact that we and other living beings are crucially made of carbon compounds is

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12 resonance to the strong anthropic principle, in the 1990s Hoyle saw it as an example of the weak form of the principle.

[59] Weinberg 2001, p. 237. The essay on "A designer universe?" was first published in *The New York Review of Books*, 21 October 1999, 46-48. Weinberg 2007 confirms that he does not consider the Hoyle resonance as evidence for anthropic fine tuning.

[60] Oberhummer, Pichler, and Csótó 1998. Oberhummer, Csótó, and Schlattl 2000. Schlattl et al. 2004. For still later and more precise investigations of the triple alpha process, see Fynbo et al. 2005.

unnecessary for the argument, which is really nothing but a deduction from observed facts and the known laws of physics.[61] In the anthropic version – not to confuse with Hoyle's authentic version – the argument starts with the observation that life can only exist if carbon is plentiful in the universe. But this observation is redundant, it plays no role in the logic that leads to the prediction. Let us imagine, says Smolin, the counterfactual scenario that Hoyle's prediction had been falsified rather than verified by experiments. In that case, would we have concluded that carbon is not essential to life? Surely not, we might conclude that there was something wrong with our model of the triple alpha process, that carbon was not necessarily produced in stars alone, or even that our knowledge of stellar composition and the laws of nuclear physics needed to be reconsidered. The carbon-life connection would never be questioned.

7. Conclusion

Fred Hoyle's prediction of the 7.65 MeV resonance state in carbon-12 was a remarkable inference from astrophysics to nuclear structure, the first of its kind, and it had a dramatic effect on the subsequent development of stellar nucleosynthesis and other branches of astrophysics. In following the history of the event I have pointed out that the existence of an excited state in this region was already suggested by some experiments, but that Hoyle's prediction nonetheless counts as a novel prediction of a nuclear phenomenon. Contrary to the folklore version of the prediction story, Hoyle did not originally connect it with the existence of life. The popular association with the anthropic principle is of later date and has no basis in historical fact, something many authors seem to be unaware of or just do not care about. The anthropic myth, which I have called it, is widely considered a story that ought to be true, even if it is not – and it isn't. Not only did the case not figure in the anthropic literature until the early 1980s, Hoyle did also not conceive it as anthropic until about that time.

[61] Smolin 2007, p. 340-341. For further philosophically based critique of the anthropic carbon-12 claim, see Mosterin 2004.

I conclude that from a historical point of view it is misleading to label the prediction of the 7.65 MeV state anthropic or to use it as an example of the predictive power of the anthropic principle. Whether the principle has such power remains a contested issue, but this general and difficult question is beyond the scope of the present paper. Admitting that there is a certain arbitrariness in the notion of anthropic prediction, I have argued that it can best be understood in a historical sense. Even if Hoyle's prediction is considered from an ahistorical point of view, there are reasons to doubt its anthropic nature.

References

Ajzenberg, Fay and Thomas Lauritsen (1952). "Energy levels of light nuclei. IV," *Reviews of Modern Physics* 24, 321-402.

Alpher, Ralph and Robert Herman (1950). "Theory of the origin and relative abundance distribution of the elements," *Reviews of Modern Physics* 22, 153-212.

Arnett, David (2005). "Sir Fred Hoyle and the theory of the synthesis of the elements," pp. 9-24 in Douglas Gough, ed., *The Scientific Legacy of Fred Hoyle*. Cambridge: Cambridge University Press.

Balashov, Yuri (1991). "Resource letter AP-1: The anthropic principle," *American Journal of Physics* 59, 1069-1076.

Barrow, John D. (1981). "The lore of large numbers: Some historical background to the anthropic principle," *Quarterly Journal of the Royal Astronomical Society* 22, 388-420.

Barrow, John D. and Frank J. Tipler (1986). *The Anthropic Cosmological Principle*. Cambridge: Cambridge University Press.

Bethe, Hans (1939). "Energy production in stars," *Physical Review* 55, 434-456.

Bondi, Hermann (1966). "Some philosophical problems in cosmology," pp. 393-400 in C. A. Mace. ed., *British Philosophy in the Mid-Century*. London: Allen and Unwin.

Bondi, Hermann and Edwin E. Salpeter (1952). "Thermonuclear reactions and astrophysics," *Nature* 169, 304-305.

Britten, Roy (1952). "The scattering of 31.5-MeV protons from several elements," *Physical Review* 88, 283-294.

Burbidge, E. Margaret, Geoffrey R. Burbidge, William A. Fowler, and Fred Hoyle (1957). "Synthesis of the elements in the stars," *Reviews of Modern Physics* 29, 547-650.

Carr, Bernard J. (1982). "On the origin, evolution and purpose of the physical universe," *Irish Astronomical Journal* 15, 237-253.

Carr, Bernard J. and 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," pp. 291-298 in Malcolm S. Longair, ed., *Confrontation of Cosmological Theories with Observational Data*. Dordrecht: Reidel.

Carter, Brandon (1983). "The anthropic principle and its implications for biological evolution," *Philosophical Transactions of the Royal Society* A 310, 347-1983.

Carter, Brandon (2006). "Anthropic principle in cosmology," pp. 173-180 in Jean Claude Pecker and Jayant V. Narlikar, eds., *Current Issues in Cosmology*. Cambridge: Cambridge University Press. (ArXiv:gr-qc/060617).

Clayton, Donald C. (2001). "Fred Hoyle, 1915-2001," *Bulletin of the American Astronomical Society* 33, 1570-1572.

Cook, Charles W., William A. Fowler, Charles C. Lauritsen, and Thomas Lauritsen (1957). "B^{12}, C^{12}, and the red giants," *Physical Review* 107, 508-515.

Chown, Marcus (1999). *The Magic Furnace*. London: Jonathan Cape.

Chown, Marcus (2003). "Open minds reap rewards," *The Guardian*, 13 March.

Davies, Paul C. W. (1978). "Cosmic heresy?" *Nature* 273, 336-337.

Davies, Paul C. W. (1982). *The Accidental Universe*. Cambridge: Cambridge University Press.

Dicke, Robert H. (1961). "Dirac's cosmology and Mach's principle," *Nature* 192, 440-441.

Dunbar, D. Noel F., Ralph E. Pixley, William A. Wenzel, and Ward Whaling (1953). "The 7.68-MeV state in C^{12}," *Physical Review* 92, 649-650.

Fermi, Enrico (1949). "Teorie sulle origine degli elemente," pp. 707-720 in *Collected Papers*, Vol. 2. Rome: University of Chicago Press.

Fowler, William A. (1984). "The quest for the origin of the elements," *Science* 226, 922-935.

Fynbo, Hans O. U. et al. (2005). "Revised rates for the stellar triple-α process from measurements of ^{12}C nuclear resonances," *Nature* 433, 136-139.

Gregory, Jane (2005). *Fred Hoyle's Universe*. Oxford: Oxford University Press.

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

Hemmendinger, Arthur (1949). "Erratum: Disintegration of Be^8," *Physical Review* 75, 1267.

Holloway, M. G. and B. L. Moore (1940). "The disintegration of N^{14} and N^{15} by deuterons," *Physical Review* 58, 847-860.

Hornyak, W. F., Thomas Lauritsen, Philip Morrison, and William A. Fowler (1950). "Energy levels of light nuclei. III," *Reviews of Modern Physics* 22, 291-372.

Hoyle, Fred (1946). "The synthesis of the elements from hydrogen," *Monthly Notices of the Royal Astronomical Society* 106, 343-383.

Hoyle, Fred (1954). "On nuclear reactions occurring in very hot stars. I: The synthesis of elements from carbon to nickel," *Astrophysical Journal, Supplement Series* 1, 121-146.

Hoyle, Fred (1957). [No title], pp. 55-66 in N. F. Mott et al., *Religion and the Scientists*. London: SCM Press.

Hoyle, Fred (1965). *Galaxies, Nuclei, and Quasars*. New York: Harper & Row.

Hoyle, Fred (1975). *Astronomy and Cosmology: A Modern Course*. San Francisco: W. H. Freeman and Company.

Hoyle, Fred (1980). *Steady-State Cosmology Re-visited*. Cardiff: University College Cardiff Press.

Hoyle, Fred (1982). "The universe: Past and present reflections," *Annual Review of Astronomy and Astrophysics* 20, 1-35.

Hoyle, Fred (1986). "Personal comments on the history of nuclear astrophysics," *Quarterly Journal of the Royal Astronomical Society* 27, 445-453.

Hoyle, Fred (1991). "Some remarks on cosmology and biology," *Memorie della Societa Astronomica Italiana* 62, 513-518.

Hoyle, Fred (1993). "The anthropic and perfect cosmological principles: Similarities and differences," pp. 85-89 in Francesco Bertola and Umberto Curi, eds., *The Anthropic Principle*. Cambridge: Cambridge University Press.

Hoyle, Fred (1994). *Home Is Where the Wind Blows: Chapters From a Cosmologist's Life*. Mill Valley, California: University Science Books.

Hoyle, Fred, D. Noel F. Dunbar, William A. Wenzel, and Ward Whaling (1953). "A state in C^{12} predicted from astrophysical evidence," *Physical Review* 92, 1095.

Hoyle, Fred and Martin Schwarzschild (1955). "On the evolution of type II stars," *Astrophysical Journal*, *Supplement* 2, 1-40.

Hoyle, Fred and N. Chandra Wickramasinghe (1999). "The universe and life: Deductions from the weak anthropic principle," *Astrophysics and Space Science* 268, 89-102.

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

Kragh, Helge (1996). *Cosmology and Controversy. The Historical Development of Two Theories of the Universe*. Princeton: Princeton University Press.

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

Leslie, John (1994). “Anthropic prediction,” *Philosophia* 23, 117-144.

Linde, Andrei (2007). “The inflationary universe,” pp. 127-150 in Bernard Carr, ed., *Universe or Multiverse?* Cambridge: Cambridge University Press.

Livio, Mario, D. Hollowell, A. Weiss, and J. W. Truran (1989). “The anthropic significance of the existence of an excited state of ^{12}C,” *Nature* 340, 281-284.

Mitton, Simon (2005). *Fred Hoyle: A Life in Science*. London: Aurum Press.

Mosterin, Jesús (2004). “Anthropic explanations in cosmology,” pp. 441-471 in Petr Hájek, Luis Valdés-Villanueva, and Dag Westerståhl, eds., *Proceedings of the 12th International Congress of Logic, Methodology and Philosophy of Science*. Amsterdam: North-Holland. (http://philsci-archive.pitt.edu/archive/00001658/)

Oberhummer, Heinz, Rudolf Pichler, and Attila Csótó (1998). “The triple-alpha process and its anthropic significance,” pp. 119-123 in Nikos Prantzos and Sotiris Harrissopulos, eds., *Nuclei in the Cosmos, V*. Paris: Editions Frontières.

Oberhummer, Heinz, Attila Csótó, and Helmut Schlattl (2000). “Fine-tuning carbon-based life in the universe by the triple-alpha process in red giants,” pp. 197-206 in V. Burdyuzha and G. Khozin, eds., *The Future of the Universe and the Future of Our Civilization*. Singapore: World Scientific.

Öpik, Ernst (1951). “Stellar models with variable composition. II: Sequences of models with energy generation proportional to the fifteenth power of temperature,” *Proceedings of the Royal Irish Academy A* 54, 49-77.

Reeves, Hubert (1993). “The growth of complexity in an expanding universe,” pp. 67-84 in Francesco Bertola and Umberto Curi, eds., *The Anthropic Principle*. Cambridge: Cambridge University Press.

Salpeter, Edwin E. (1952). “Nuclear reactions in stars without hydrogen,” *Astrophysical Journal* 115, 326-328.

Salpeter, Edwin E. (2002). “A generalist looks back,” *Annual Review of Astronomy and Astrophysics* 40, 1-25.

Sandage, Allan R. and Martin Schwarzschild (1952). "Inhomogeneous stellar models. II. Models with exhausted cores in gravitational contraction," *Astrophysical Journal* 116, 463-476.

Scerri, Eric R. (2007). *The Periodic Table: Its Story and Significance*. Oxford: Oxford University Press.

Schlattl, Helmut et al. (2004). "Sensitivity of the C and O production on the 3α rate," *Astrophysics and Space Science* 291, 27-33.

Singh, Simon (2004). *Big Bang*. London: Fourth Estate.

Smolin, Lee (2007). "Scientific alternatives to the anthropic principle," pp. 323-366 in Bernard Carr, ed., *Universe or Multiverse?* Cambridge: Cambridge University Press.

Spear, R. (2002). "The most important experiment ever performed by an Australian physicist," *The Physicist* 39, 35-41.

Tassoul, Jean-Louis and Monique Tassoul (2004). *A Concise History of Solar and Stellar Physics*. Princeton: Princeton University Press.

Tollestrup, Alvin V., William A. Fowler, and Charles C. Lauritzen (1949). "Energy release in beryllium and lithium reactions with protons," *Physical Review* 76, 428-430.

Walker, Mark and Milan Ćirković (2003). "Anthropic reasoning and the contemporary design argument in astrophysics: A reply to Robert Klee," http://philsci-archive.pitt.edu/archive/00001443/.

Weinberg, Steven (2001). *Facing Up: Science and Its Cultural Adversaries*. Cambridge, Mass.: Harvard University Press.

Weinberg, Steven (2007). "Living in the multiverse," pp. 29-42 in Bernard Carr, ed., *Universe or Multiverse?* Cambridge: Cambridge University Press.

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