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Naming the Big Bang

ABSTRACT

The standard model of modern cosmology is known as the hot big bang, a name that refers to the initial state of the universe some fourteen billion years ago. The name Big Bang introduced by Fred Hoyle in 1949 is one of the most successful scientific neologisms ever. How did the name originate and how was it received by physicists and astronomers in the period leading up to the hot big bang consensus model in the late 1960s? How did it reflect the meanings of the origin of the universe, a concept that predates the name by nearly two decades? Contrary to what is often assumed, the name was not an instant success—it took more than twenty years before Big Bang became a household word in the scientific community. When it happened, it was used with different connotations, as is still the case. Moreover, it was used earlier and more frequently in popular than in scientific contexts, and not always relating to cosmology. It turns out that Hoyle's celebrated name has a richer and more surprising history than commonly assumed and also that the literature on modern cosmology and its history includes many common mistakes and errors. An etymological approach centering on the name Big Bang provides supplementary insight to the historical understanding of the emergence of modern cosmology.

KEY WORDS: big bang, cosmology, universe, Fred Hoyle, George Gamow, scientific names, bibliometrics, etymology

What's in a name? That which we call a rose
By any other name would smell as sweet;
Romeo and Juliet (Act II, Scene 2)

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To avoid an inordinate amount of quotation marks I have chosen to capitalize Big Bang when referring to it as a name. I keep to big bang in other contexts, such as the big bang theory of the universe.

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INTRODUCTION: NAMES AND HISTORIES

"Words are like harpoons," the famous astrophysicist and cosmologist Fred Hoyle said in a 1995 interview. "Once they go in, they are very hard to pull out."[1] He was referring to the term Big Bang, which he had coined nearly half a century earlier for the initial state of the universe without believing that there had been such an initial state. The name had indeed stuck like a harpoon, and that in spite of many people's dissatisfaction with such an undignified label for the grandest and most mysterious event in the history of the universe, the ultimate beginning of everything. Two years earlier the astronomy magazine *Sky and Telescope* had run a competition to rename the big bang theory of the universe.[2] The panel of judges, consisting of astronomer Carl Sagan, television broadcaster Hugh Downs, and science writer Timothy Ferris, mulled over 13,099 suggestions from forty-one countries, only to decide that none of them were worthy of supplanting the misleading and "inappropriately bellicose" name Big Bang. The name had stuck, and it still sticks.

Some names in science are eponymous labels honoring great scientists, while others associate a concept or an object with a particular meaning that another name would not signal. Because names sometimes carry with them epistemic connotations and mental images, they make more than just a linguistic difference. An apt name may help set the frame of mind with which scientists view an object or a concept. (Consider Lavoisier's "oxygen" versus Priestley's "dephlogisticated air.") When a name catches on, it is not only an indication of its popularity but also, in many cases, of the concept associated with the name. Names may also help in making a concept more popular and widely recognized simply because they are apt. Contrary to names for objects such as elementary particles, chemical elements, comets, and extrasolar planets, the names of most theories or concepts, such as the Big Bang or Heisenberg's uncertainty principle, have no official status. They are not decided by committees but just happen to be adopted by the relevant scientific communities.

A case in point is "relativity theory," which was not coined by the originator of the theory but by Max Planck in 1906. Einstein preferred "relativity

1. John Horgan, "The Return of the Maverick," *Scientific American* 272, no. 3 (1995): 46–48.

2. Timothy Ferris, "Needed: A Better Name for the Big Bang," *Sky and Telescope* 86, no. 2 (1993): 4–5; Cheryl J. Beatty and Richard T. Fienberg, "Participatory Cosmology: The Big Bang Challenge," *Sky and Telescope* 87, no. 3 (1994): 20–22. According to Beatty and Fienberg, the competition was widely but mistakenly viewed in the press as an attempt at political correctness and to eliminate sexist language from astronomy.

principle" and only adopted Planck's name around 1915. When Einstein's theory became controversial in the public arena, where it was sometimes conflated with relativism, some physicists suggested renaming it "invariance theory," a name first proposed by the mathematician Felix Klein in 1910. The proposal fell on deaf ears, perhaps because of the term's similarity to the well-established mathematical "invariant theory" going back to the 1850s. In a letter of 1921 Einstein agreed that relativity theory was in some respects a misnomer, yet it "would only give rise to confusion if after such a long time the generally accepted name were now changed."[3] It is not the aim of this essay to discuss the meanings and histories of scientific names in general, but it is worth pointing out that Hoyle's Big Bang is not an exceptional case. There are many other invented names that have in common with this term that they are considered catchy and, in part for this reason, have made a difference in how scientists and the public think about nature.

The name and concept of "black hole" illustrates how a good name can conjure up a mental image that emphasizes the important properties of a physical concept, while other names tend to produce mental blocks that hinder recognition of these properties.[4] In the 1950s physicists recognized that the so-called Schwarzschild space-time singularity created by the gravitational collapse of a massive star was really a horizon surrounding the center of the imploding star. With the recognition of the importance of the horizon a better name was needed for what was traditionally referred to as a "collapsed star" or, among Soviet physicists, a "frozen star." John Wheeler responded to the need when he coined the name black hole in a talk to the American Association for the Advancement of Science on December 29, 1967.[5] Apart from being catchy, Wheeler's name carried with it a different mental picture of the gravitational collapse that corresponded to the modern viewpoint of black hole physics. The name was quickly adopted by physicists and astronomers as well as the general public.

3. Einstein to Eberhard Zschimmer, 30 Sep 1921, document 250, in Diana K. Buchwald et al., eds., *The Collected Papers of Albert Einstein*, vol. 12 (Princeton, NJ: Princeton University Press, 2009), 294–95; Albert Fölsing, *Albert Einstein* (New York: Penguin Books, 1997), 208–10.

4. Werner Israel, "Dark Stars: The Evolution of an Idea," in *Three Hundred Years of Gravitation*, ed. Stephen Hawking and Werner Israel (Cambridge: Cambridge University Press, 1987), 199–276; Kip S. Thorne, *Black Holes and Time Warps: Einstein's Outrageous Legacy* (New York: Norton, 1994), 254–57.

5. John A. Wheeler, "Our Universe: The Known and the Unknown," *American Scientist* 56, no. 1 (1968): 1–20, reprinted in John A. Wheeler, *At Home in the Universe* (Woodbury, NY: AIP Press, 1994), 47–70. The name black hole had been used a few times for astronomical objects before Wheeler canonized it.

The momentous idea that the universe came into being in a kind of explosive act some finite time ago has for more than forty years been known as the big bang theory. The idea dates from 1931, and although Hoyle coined the name in 1949 it took more than twenty years until Big Bang became a household word in the scientific community. When it happened, it was either used as a general label for the explosive birth of the universe or given more precise, but rather different meanings. By focusing on the etymology of Big Bang—how physicists, astronomers, and the lay public spoke of what became the big bang universe—we can obtain some additional insight in the historical development of modern cosmology. We also use the opportunity to correct some widely held misconceptions regarding the etymology as well as the history and substance of the cosmological theories in the period.

THE ORIGIN OF THE UNIVERSE: EARLY IDEAS

Until 1931, the origin of the universe in a physical sense was not part of the new cosmology based on Einstein's relativistic field equations of 1917. In the few cases where a finite-age universe turned up in the literature, it was either as a philosophical speculation, a mathematical possibility, or in the context of the old discussion of a cosmic heat death caused by the global increase of entropy. Arthur Eddington considered the possibility of a cosmic beginning in a zero-entropy state but dismissed it from both a philosophical and a scientific point of view. "As a scientist I simply do not believe that the Universe began with a bang," he said, thus inventing half of the Big Bang term.[6] He never came to terms with the idea of a universe with a beginning in time.

According to a recent paper, the Russian physicist Alexander Friedmann "deserves to be called the father of Big Bang cosmology."[7] The claim rests on a 1922 paper in which he demonstrated for the first time that Einstein's

6. Arthur S. Eddington, *The Nature of the Physical World* (Cambridge: Cambridge University Press, 1928), 85. For the historical development of early relativistic cosmology, see Pierre Kerzberg, *The Invented Universe: The Einstein–De Sitter Controversy (1916–17) and the Rise of Relativistic Cosmology* (Oxford: Clarendon Press, 1989); John D. North, *The Measure of the Universe: A History of Modern Cosmology* (New York: Dover, 1990); Helge Kragh, *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton, NJ: Princeton University Press, 1996); and Harry Nussbaumer and Lydia Bieri, *Discovering the Expanding Universe* (Cambridge: Cambridge University Press, 2009).

7. Ari Belenkiy, "Alexander Friedmann and the Origins of Modern Cosmology," *Physics Today* 65, no. 10 (2012): 38–43, on 38.

cosmological equations had dynamical solutions corresponding to, for example, an expanding universe. In this destined-to-be-famous paper Friedmann even wrote about "the time since the creation of the world," namely, the time that had passed since the universe was concentrated in a point or singularity of zero volume.[8] However, although his paper included singular solutions ($R = 0$ at $t = 0$), it was in a mathematical sense only and without Friedmann paying more attention to these solutions than to other solutions. In fact, his paper was basically mathematical, with no references to either astronomical measurements or physical properties of the universe. In particular, he did not refer to the nebular redshifts discovered a decade earlier.

Curiously, none other than George Gamow, perhaps more than anyone the true father of the exploding universe, credited Friedmann with having introduced this kind of cosmological model. Gamow, who in his youth had studied under Friedmann at the University of Petrograd, wrote as follows: "According to Friedmann's original theory of the expanding universe, it must have started with a 'singular state' at which the density and temperature of matter were practically infinite."[9] This is, however, Gamow reading his own theory into the one of his former teacher. Friedmann's theory of 1922 had nothing to say about the density, temperature, or material composition of the early universe.

In a brief letter to *Nature* of May 9, 1931, the Belgian physicist and astronomer Georges Lemaître suggested that the universe had come into being in an explosive act governed by the laws of thermodynamics and quantum mechanics. "We could conceive the beginning of the universe in the form of a unique atom," he wrote, likening the original state to a huge atomic nucleus that would decay or explode by a "super-radioactive process" and thereby initiate the cosmic expansion.[10] Lemaître's model was of the singular type earlier considered by

8. Alexander Friedmann, "Über die Krümmung des Raumes," *Zeitschrift für Physik* 10 (1922): 377–86, on 380; Eduard A. Tropp, Viktor Ya. Frenkel, and Arthur D. Chernin, *Alexander A. Friedmann: The Man Who Made the Universe Expand* (Cambridge: Cambridge University Press, 1993).

9. George Gamow, *My World Line: An Informal Autobiography* (New York: Viking Press, 1970), 141; Arthur D. Chernin, "George Gamow and the Big Bang," *Space Science Reviews* 74 (1995): 447–54.

10. Georges Lemaître, "The Beginning of the World from the Point of View of Quantum Theory," *Nature* 127 (1931): 706, reprinted in Georges Lemaître, *The Primeval Atom: A Hypothesis of the Origin of the Universe* (New York: Van Nostrand, 1950), 17–19. For historical analysis, see Helge Kragh and Dominique Lambert, "The Context of Discovery: Lemaître and the Origin of the Primeval-Atom Universe," *Annals of Science* 64 (2007): 445–70. See also Dominique Lambert, *Un Atome d'Univers: La Vie et l'Oeuvre de Georges Lemaître* (Brussels: Éditions Racine,

Friedmann, but the Belgian cosmologist was careful to adopt a physical rather than mathematical point of view. According to his thinking there was no initial zero-volume singularity corresponding to an infinite density, but instead everything began in a material proto-universe of a density of the order of an atomic nucleus and a size comparable to the solar system. This primordial atom or nucleus was changeless and completely undifferentiated, devoid of physical qualities and without a measure of time. Although it was inaccessible to science, Lemaître stressed that it was physically real. As to the origin of the primordial body he was silent, but there is little doubt that Lemaître, who was a Catholic priest, believed it was created by God.

To describe in words the original state of the universe, Lemaître had to take recourse to metaphorical terminology. In his note to *Nature* he spoke of an "original quantum" and a "unique atom," while in later publications his preferred name was the "primeval atom." His only book on the subject, a collection of articles published in 1946, was entitled *L'Hypothèse de l'Atome Primitif* and translated into English in 1950 as *The Primeval Atom*. On some later occasions he used for the primeval atom the image of a base nucleus without surrounding electrons, "nearly an isotope of a neutron."[11] At a meeting in London in 1931 he also used another metaphor, now referring to the "fireworks theory" of cosmic evolution.[12] He realized of course that the apt metaphor was flawed, as fireworks explode into the surrounding space whereas there was no space into which the primeval atom-universe could expand.

In his publications on cosmology Lemaître usually referred to his theory by these two names, primeval atom and fireworks. He never used the term Big Bang, nor did he use "cosmic egg," of which there are several later references, always without indication of a source. The term first may have appeared in John D. Bernal's *Science in History* of 1954, which included a brief section on the controversy between evolution and steady state theories in cosmology. According to Bernal: "Lemaître in 1927 made the drastic assumption that all the matter in the universe was packed into one atom, a kind of cosmic egg,

2000); and Rodney D. Holder and Simon Mitton, eds., *Georges Lemaître: Life, Science and Legacy* (Berlin: Springer, 2013).

11. Lemaître, *Primeval Atom* (ref. 10), 142.

12. Meeting on the occasion of the centenary of the British Association for the Advancement of Science, the session on "The Question of the Relation of the Physical Universe to Life and Mind," *Nature* 128 (1931): 700–22, on 705.

which burst in the first and greatest atomic explosion, not four thousand but four thousand million years ago."[13] In 1962 astronomers Otto Struve and Velta Zebergs mentioned "something G. Lemaître has described as the 'primeval egg' of the universe" and which "is related to what astronomers have called the 'big-bang' theory of cosmology."[14] Although it is possible that Lemaître used the phrase informally in conversations, the egg metaphor does not appear in his written works and is probably apocryphal. It has later been used or reinvented by a few cosmologists to characterize the state of nonsingular turning points in cyclic models of the universe.[15]

Most astronomers and physicists either ignored Lemaître's theory of the beginning of the universe or dismissed it as a speculative scenario unsupported by facts. It was considered "a clever *jeu d'esprit*," as one critic called it.[16] On the other hand, the primeval atom hypothesis was received with much interest in newspapers and popular science magazines. In 1932 *Popular Science* included a paper dramatically entitled "Blast of Giant Atom Created Our Universe" in which the Harvard astronomer Donald Menzel described Lemaître's theory in some detail. The essence of the theory—that "the whole universe was born in the flash of a cosmic sky rocket"— was described by the use of images relating to explosions and fireworks.[17]

13. John D. Bernal, *Science in History* (London: Watts, 1954), 541. See also John Pfeiffer, *The Changing Universe: The Story of the New Astronomy* (London: Victor Gollancz, 1956), 225–28. The misdating of the primeval atom hypothesis to 1927 rather than 1931 is common in the literature. One example among many is Simon Singh, *Big Bang* (London: Fourth Estate, 2004), 158, and another is the *Oxford English Dictionary* (online edition of 2012, entry: big bang). In 1927 Lemaître published a pioneering theory of the expanding universe, but this theory, subsequently known as the Lemaître-Eddington model, was not of the big bang type and did not describe a universe of a definite age. For details, see Kragh and Lambert, "Context of Discovery" (ref. 10).

14. Otto Struve and Velta Zebergs, *Astronomy of the 20th Century* (New York: Macmillan, 1962), 472. According to one source, "Lemaître called his theory the 'hypothesis of the primeval atom' and described it as 'the Cosmic Egg exploding at the moment of the creation'." B. G. Sidhart and Joseph Rhawn, "Different Routes to Multiverses and an Infinite Universe," *Journal of Cosmology* 4 (2010): 641–54, on 642. See also Virginia Trimble, "The First Explosions," in *Cosmic Explosions: Tenth Astrophysical Conference*, ed. Stephen S. Holt and William W. Zhang (College Park, MD: American Institute of Physics, 2000), 3–21, on 4.

15. Mark Israelit and Nathan Rosen, "A Singularity-Free Cosmological Model in General Relativity," *Astrophysical Journal* 342 (1989): 627–34.

16. Ernest W. Barnes, *Scientific Theory and Religion: The World Described by Science and Its Spiritual Interpretation* (Cambridge: Cambridge University Press, 1933), 408.

17. Donald H. Menzel, "Blast of Giant Atom Created Our Universe," *Popular Science* 105 (1932): 28–29.

A BIG BANG UNIVERSE WITHOUT A NAME

The Russian-American nuclear physicist George Gamow, at George Washington University in Washington, D.C., is as strong a candidate for paternity of the idea of a big bang as Lemaître, even though he came to the idea many years later and by following a very different approach. This approach to what he called "factual cosmology" focused on how the chemical elements were formed, which according to Gamow's hypothesis had occurred in nuclear processes during a brief period of time in the hot and dense early universe.[18] As early as 1940, in his popular book *The Birth and Death of the Sun*, he suggested that the naturally occurring radioactive elements had been formed shortly after "the creation of the universe from the primordial superdense gas."[19] Six years later he combined the idea with the Friedmann equations of the expanding universe, and over the next few years he developed it in collaboration with his assistants Ralph Alpher and Robert Herman.

What I shall for simplicity (and in agreement with the Matthew effect) call the Gamow theory or model of the early universe presupposed an initial state of highly compressed and very hot nuclear matter, at first taken to consist of neutrons only but subsequently to be revised to a mixture of neutrons and protons in the ratio of approximately 5:1. Another important insight was that in the earliest phase of the expanding universe, when the temperature was exceedingly high, it was dominated by electromagnetic radiation rather than matter. Gamow and his two associates sometimes referred to the primordial soup of

18. Helge Kragh, "George Gamow and the 'Factual Approach' to Relativistic Cosmology," in *The Universe of General Relativity*, ed. Anne J. Kox and Jean Eisenstadt (Boston: Birkhäuser, 2005), 175–88. Other literature on Gamow includes: Eamon Harper, "George Gamow: Scientific Amateur and Polymath," *Physics in Perspective* 3 (2001): 335–72; Eamon Harper, W. C. Parke, and G. D. Anderson, eds., *The George Gamow Symposium* (San Francisco: Astronomical Society of the Pacific, 1997); Kragh, *Cosmology and Controversy* (ref. 6), 101–41; Frederick Reines, ed., *Cosmology, Fusion and Other Matters: George Gamow Memorial Volume* (Boulder: Colorado Associated University Press, 1972). For an interesting perspective on Gamow's style of science, see Nasser Zakariya, "Making Knowledge Whole: Genres of Synthesis and Grammars of Ignorance," *HSNS* 42, no. 5 (2012): 432–75.

19. George Gamow, *The Birth and Death of the Sun* (New York: Viking Press, 1940), 201. A similar picture appeared in the cosmological scenario of Carl Friedrich von Weizsäcker, according to whom the density of the early hot universe was of the same order as the density of an atomic nucleus. Carl F. von Weizsäcker, "Über Elementumwandlungen im Innern der Sterne, II," *Physikalische Zeitschrift* 39 (1938): 633–46. Later German authors referred to Weizsäcker's view of the origin of the universe as an *Urexplosion* (primordial explosion). See, e. g., Hans Kienle, "Das Alter der Sterne und die Expansion der Welt," *Naturwissenschaften* 130 (1943): 149–50.

photons and nuclear particles as "ylem," an ancient word for the original matter of the world that was first suggested by Alpher in a paper of 1948. Gamow quickly appropriated the term and used it frequently in his writings as if he had coined it himself, but it was rarely used by other physicists.

Although Gamow's theory was well known in the early 1950s, it was accepted only by a small minority of physicists (and, remarkably, by no astronomers). Between ten and fifteen nuclear physicists contributed to aspects of the theory, but only a few of them considered it in the context of cosmology.[20] I am not aware of a single astronomer who endorsed Gamow's theory of the early expanding universe. Nor was any particular word or phrase associated with the theory—people used a variety of names for it, none of which can be characterized as catchy. Hoyle's Big Bang was occasionally used in the period 1950–65, but the term did not refer specifically to Gamow's theory but most often to finite-age models in general. Another name was the "$\alpha\beta\gamma$ theory," a reference to an important 1948 paper nominally written by Alpher, Hans Bethe, and Gamow. (Meant as a joke, Gamow added Bethe as an author—without his knowledge—to create an alphabetic authorship.) In a popular book of 1952 with the then provocative title *The Creation of the Universe*, Gamow gave a full account of his theory without using the term Big Bang. On the other hand, he coined the name "big squeeze" for the collapsing universe that might be imagined to have preceded the present expansion. Interestingly, Gamow sometimes referred to the big squeeze in ways that were almost indistinguishable from what Hoyle called the Big Bang. He thus spoke of "the Big Squeeze which took place in the early history of our universe" and took the date of the big squeeze to be equal to the age of the universe.[21]

Given that Gamow's universe was in fact of the big bang type, it is understandable that some authors have mistakenly believed that he was the originator of the name. The Swedish physicist Hannes Alfvén, a Nobel Prize winner of 1970 and a sharp critic of what he considered the myth of the big bang, was perhaps the first to convey the mistake, to which he added another one. In

20. Kragh, *Cosmology and Controversy* (ref. 6), 137–41.

21. George Gamow, *The Creation of the Universe* (New York: Viking Press, 1951), 36. In later literature the names "big squeeze" or "big crunch" were mostly used for the ultimate end of the universe in the far future, should the gravitational contraction overpower the force of expansion. Such a scenario presupposes that our universe is closed, which Gamow denied. His universe was spatially infinite. In some of his work from about 1950 he imagined a cosmic one-cycle process where the universe evolved from infinite rarefaction over a superdense state toward a new state of infinite rarefaction, but he realized that the idea was speculative.

a book of 1966 expounding his own alternative of a so-called plasma universe, he wrote: "Gamow introduced a number of suggestive terms, among them 'ylem' for the dense primeval clump of matter and 'big bang' for the explosion itself." Again, in a widely read book by Timothy Ferris: "Gamow . . . authored the modern approach to Lemaître's expanding-universe cosmology, for which he coined the term 'Big Bang theory'."[22] The truth is that Gamow resented the name Big Bang, which he only used once, in a popular article of 1961 where he equated the big bang theory with "evolutionary cosmology."[23] Although the Gamow theory of the universe presupposed an initial state, it had nothing to say about the origin of the universe in an absolute sense. Gamow as well as Alpher and Herman stressed that it was a theory of the *evolution* of the early universe, not of its creation.

In a 1968 interview Charles Weiner mentioned to Gamow that in the popular mind his name and the big bang were almost synonymous. Gamow agreed, but was not pleased. "I don't like the word 'big bang'," he said. "I don't call it 'big bang,' because it is a kind of cliché. This was invented, I think, by steady-state cosmologists—'big bang' and also the 'fire ball' they call it, which has nothing to do with it—it's not fire ball at all. Nothing to do with the fire ball of atomic bomb."[24] Gamow was of course aware of the name Hoyle had proposed for the kind of theory that contrasted so strongly with Hoyle's own steady state theory. In the late 1950s radio-astronomical measurements made by Martin Ryle and his group in Cambridge seemed to contradict the steady state theory, which Ryle strongly disliked. In part as a result of their disagreements about the interpretation of the radio data, the relationship between the two distinguished astronomers evolved into a major feud between them. The controversy caused Barbara Gamow, the wife of George Gamow, to describe in the form of a poem an imagined discussion between Ryle and Hoyle.[25] In two of the verses Hoyle speaks to Ryle:

22. Hannes Alfvén, *Worlds-Antiworlds: Antimatter in Cosmology* (San Francisco: W. H. Freeman, 1966), 15; Timothy Ferris, *The Red Limit: The Search for the Edge of the Universe* (New York: William Morrow, 1977), 77. The same mistake appears in P. James E. Peebles, "Impact of Lemaître's Ideas on Modern Cosmology," in *The Big Bang and Georges Lemaître*, ed. André Berger (Dordrecht, Neth.: Reidel, 1984), 23–30, on 26. See also Simon Mitton, *Fred Hoyle: A Life in Science* (London: Aurum, 2005), 129, who wrongly says that Gamow promoted the name big bang.

23. George Gamow, "Gravity," *Scientific American* 204, no. 3 (1961): 94–106, on 104.

24. Interview with George Gamow by Charles Weiner, 25 Apr 1968, Niels Bohr Library & Archives, American Institute of Physics, www.aip.org/history/ohilist/4325.html (accessed 1 Mar 2013).

25. Ibid. Another piece of poetry, relating to the Hoyle-Ryle clash, was due to U.S. columnist Art Buchwald: "Said Ryle to Hoyle / 'Please do not boil / The World began with a bang' / Said

Said Hoyle, "You quote
Lemaître, I note,
And Gamow. Well, forget them!
That errant gang
And their Big Bang –
Why aid them and abet them?
You see, my friend,
It has no end
And there was no beginning
And Bondi, Gold,
And I will hold
Until our hair is thinning!"

HOYLE'S BIG BANG—NOT A BIG DEAL

The steady state theory of the universe was proposed in 1948 in two different versions, the one by Hoyle and the other by his friends and Cambridge colleagues Hermann Bondi and Tommy Gold.[26] According to this theory, although the universe was expanding, on a large scale it had always looked the same and would remain so. To make the constant average density of matter agree with the expansion, Hoyle and his two colleagues introduced the radical hypothesis of a continual and spontaneous creation of matter throughout space, although at a rate so small that it would not be directly detectable. Having no beginning and no end in time, obviously the Hoyle-Bondi-Gold universe was in strong contrast to the finite-age evolution theories of, for example, Lemaître and Gamow. The postulated creation of cosmic matter, generally assumed to be in the form of hydrogen atoms, was controversial and often seen as the characteristic feature of the theory. For this reason the steady state theory was sometimes described as the new "creation theory."[27] In the later literature creation cosmology would typically refer to the big bang theory.

Hoyle to Ryle / 'Well boil my bile / Your theory doesn't hang'." *New York Herald Tribune*, Feb 1961, as quoted in Jane Gregory, *Fred Hoyle's Universe* (Oxford: Oxford University Press, 2005), 131.

26. On the origin and development of the steady state theory, see Kragh, *Cosmology and Controversy* (ref. 6), and Yuri Balashov, "Uniformitarianism in Cosmology: Background and Philosophical Implications of the Steady-State Theory," *Studies in History and Philosophy of Science* 25 (1994): 933–58.

27. Fred Hoyle, "Continuous Creation," *The Listener* 41 (1949): 567–68; George C. McVittie, "The Cosmological Problem," *Science News* 21 (1951): 61–75.

On March 28, 1949, Hoyle gave a twenty-minute talk on the new cosmological theory to BBC's Third Programme mainly aimed at highbrow listeners. Less than two weeks later the text was reproduced in full in *The Listener*, the widely sold BBC magazine.[28] Having described the essence of the steady state theory, he contrasted it to theories based on "the hypothesis that all the matter of the universe was created in one big bang at a particular time in the remote past."[29] This is the origin of the cosmological term Big Bang, which Hoyle mentioned three times. At the end of his talk, Hoyle made it clear that he found this kind of theory unacceptable on both scientific and philosophical grounds, in particular because the big bang creation process was "irrational" and outside science. "I cannot see any good reason for preferring the big bang idea," he concluded. "Indeed it seems to *me* to be in the philosophical sense a distinctly unsatisfactory notion, since it puts the *basic* assumption out of sight where it can never be challenged by a direct appeal to observation."[30]

Later the same year Hoyle was again approached by the BBC, this time to give a series of five broadcasts on *The Nature of the Universe*. Hoyle accepted and his radio talks were on the air in January and February 1950. Half a year later the Third Programme broadcasts were repeated with only superficial changes on BBC's more popular Home Service program.[31] The successful broadcasts were printed verbatim in *The Listener* and within a few months they appeared in book form, published in England by Blackwell and in the United States by Harper and Brothers. The books followed the original scripts closely, with the American edition differing from the British only by minor changes and by incorporating the notes in the text.

Hoyle referred twice to the Big Bang in the British edition of *The Nature of the Universe*, and in ways which were not clearly derisive. He first characterized the big bang idea as the belief that "the Universe started its life a finite time ago in a single huge explosion, and that the present expansion is a relic of the

28. Mitton, *Fred Hoyle* (ref. 22), 125–35; Gregory, *Hoyle's Universe* (ref. 25), 46–53; Fred Hoyle, *Home Is Where the Wind Blows: Chapters from a Cosmologist's Life* (Mill Valley, CA: University Science Books, 1994). Hoyle's original typescript is in the Cambridge University Library and can be found online at www.joh.cam.ac.uk/library/special_collections/hoyle/exhibition/radio/ (accessed 1 Mar 2013).

29. Hoyle, "Continuous Creation" (ref. 27), 568.

30. The emphasis on "me" and "basic" appears in the typescript (ref. 28), where the words are underlined, but not in the published version (ref. 27).

31. Hoyle's BBC broadcasts attracted attention also in the United States. See "According to Hoyle," *Time* 56, no. 11 (1950), 84–91, where Big Bang was not mentioned.

violence of this explosion." This idea he found to be "unsatisfactory even before detailed examination showed that it leads to serious difficulties."[32] A few pages later Hoyle referred again to those theories that assumed all the matter in the universe "to have appeared at one instant of time, the whole creation process taking the form of one big bang." This kind of creation was "very much queerer than continuous creation," he said, but he did not describe it as "irrational" as he had done in his 1949 broadcast and as he also did in the American edition.[33] When the book was republished in 1960, Hoyle included the somewhat stronger wording of the American edition. There were many critical responses to the BBC broadcasts and the book that followed, but very few of them paid attention to the name for the exploding universe that Hoyle had so casually invented.[34]

There are in the literature some misconceptions about Hoyle's BBC addresses, including Gamow's possible role in them. According to one account, Hoyle "jokingly referred to Gamow's theory of the creation of the universe as the 'Big Bang'."[35] In fact, Hoyle did not mention Gamow or his theory at all, and when he referred to Lemaître, which he did once, it was not to his primeval-atom hypothesis but to his 1927 theory of the expanding universe. In a symposium on the history of cosmology held in Bologna in 1988, Alpher and Herman, who were Gamow's closest associates in the years around 1950, reported: "According to Gamow, Hoyle first used this phrase [Big Bang] in a pejorative sense during a BBC radio debate with Gamow."[36] Or, as Alpher

32. F. Hoyle, *The Nature of the Universe* (Oxford: Blackwell, 1950), 102.

33. Ibid., 105, and on 124 in the U.S. edition.

34. I know of only two exceptions. A book review in *Science* mentioned Hoyle's dislike of the "big bang idea." Kirtley F. Mather, "Current Science Reading," *Science* 113 (1951): 427–29. A similar reference appeared in an editorial comment in *Popular Science* 159, no. 8 (1951): 78, which promoted Hoyle's book by printing a chapter from it. Whereas the name Big Bang aroused little interest among either scientists or the general public, Hoyle's critical comments on religion in the last part of his book gave rise to a heated debate. This issue is discussed in Gregory, *Hoyle's Universe* (ref. 25), and in Craig S. McConnell, "The BBC, the Victoria Institute, and the Theological Context for the Big Bang–Steady State Debate," *Science & Christian Belief* 18 (2006): 151–68. In this debate, which was largely restricted to Great Britain, Hoyle's name for the exploding universe played no role.

35. Somak Raychaudhury, "And Gamow Said, Let There be a Hot Universe," *Resonance* 10 (2004): 32–43, on 37. Likewise, in David Kaiser, "The Other Evolution Wars," *American Scientist* 95 (2007): 518–25, on 520: "Hoyle himself coined the term 'big bang' to describe Gamow's program during these radio lectures; it was meant to sound childish and dismissive."

36. Ralph Alpher and Robert Herman, "Early Work on 'Big-Bang' Cosmology and the Cosmic Background Radiation," in *Modern Cosmology in Retrospect*, ed. Bruno Bertotti et al. (Cambridge: Cambridge University Press, 1990), 129–58, on 135. In a slightly different formulation

put it five years earlier, in an interview by Martin Harwit: "There were those radio debates on BBC between Hoyle, on the one hand; and I think Gamow participated in some of those debates."[37] There never was such a radio debate between the two cosmologists! Perhaps Alpher and Herman misunderstood something Gamow had told him, or perhaps the fun-loving Gamow just told the story as one of his perpetual jokes.

It is possible that Gamow felt Hoyle's Big Bang to be a pejorative or even mocking phrase, but there is no documentation that either Gamow, Lemaître, or other protagonists of explosion cosmologies at the time felt offended by the term, or that they paid attention to it at all. In his works of 1949 and 1950 Hoyle certainly dismissed the idea of a sudden origin of the universe, but he did not describe it in ridiculing or mocking terms. In any case, with the later success of the big bang theory it became common to see Hoyle's neologism as an attempt to make the idea of an explosion universe, and Gamow's version of it in particular, sound ridiculous. This is not how Hoyle saw it. At the time he seems to have considered it just an apt but innocent phrase for a theory he was opposed to, and he later insisted that he had not thought of it in a derogatory sense. In a 1989 interview, Alan Lightman asked him if he was really the source of the name. Hoyle answered:

> Well, I don't know whether that's correct, but nobody has challenged it, and I would have thought that if it were incorrect somebody would have said so. I was constantly striving over the radio—where I had no visual aids, nothing except the spoken word—for visual images. And that seemed to be one way of distinguishing between the steady-state and the explosive big bang. And so that was the language I used.[38]

As a broadcaster Hoyle needed word pictures to get across technical and conceptual points, and Big Bang was one of them. When he had to explain the expansion of the universe, he made extensive use of the inflating-balloon image that had first been introduced by Eddington in 1931 to illustrate a positively

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the same story was reported in Ralph Alpher and Robert Herman, "Cosmochemistry and the Early Universe," in Harper, Parke, and Anderson, *Gamow Symposium* (ref. 18), 49–70, on 63.

37. Interview with Ralph Alpher and Robert Herman by Martin Harwit, 12 Aug 1983, Niels Bohr Library & Archives, American Institute of Physics, www.aip.org/history/ohilist/3014_2.html (accessed 1 Mar 2013).

38. Alan Lightman and Roberta Brawer, *Origins: The Lives and Worlds of Modern Cosmologists* (Cambridge, MA: Harvard University Press, 1990), 60; interview with Fred Hoyle of 15 Aug 1989, Niels Bohr Library & Archives, American Institute of Physics, www.aip.org/history/ohilist/34366.html (accessed 1 Mar 2013). See also Horgan, "Return of the Maverick" (ref. 1).

curved space with increasing radius.[39] Likewise, to illustrate the slow rate of matter creation in the steady state theory, Hoyle appealed to pictures familiar to all Britons. In his first BBC broadcast he explained that it would take about a billion years until a new atom was created in "a volume equal to a pint of milk bottle." And the next year he said about the creation rate that it was "no more than the creation of one atom in the course of about a year in a volume equal to St. Paul's Cathedral."[40] The standard view, to be found in numerous books and articles, is the one reported in a popular book by the Nobel laureate astrophysicist George Smoot and his coauthor, science writer Keay Davidson: "Hoyle had meant the term [Big Bang] to be derogatory, but it was so compelling, so stirring of the imagination, that it stuck, but without the negative overtones."[41] As we shall see, it took twenty years until the term was seen as compelling and stirring of the imagination.

NONCOSMOLOGICAL CONTEXTS

Given that a "bang" often refers to an ordinary explosion, one should not be too surprised to read of big bangs also in noncosmological contexts. In fact, although Hoyle coined the term in the cosmological meaning it is used today, he was not the first scientist to speak of a big bang. In the 1920s meteorologists and atmospheric physicists studied large explosions to learn more about the propagation of sound waves and the constitution of the upper part of the atmosphere. "Methods of producing the 'Big Bang' . . . may not be the most effective for the purpose," we read in a note of 1924 apparently written by a meteorologist.[42] Two years later the leading British geophysicist Francis Whipple similarly stressed the advantage of frequent smaller explosions as compared with "the occasional 'big bang'."[43] The first scientific paper with

39. Arthur S. Eddington, "The Expansion of the Universe," *Monthly Notices of the Royal Astronomical Society* 91 (1931): 412–16.

40. Hoyle, "Continuous Creation" (ref. 27), 568, and Hoyle, *Nature of the Universe* (ref. 32), 106. Realizing that American readers might not be familiar with St. Paul's Cathedral, in the American edition Hoyle referred instead to "a moderate-sized skyscraper." Analogies apart, the predicted rate of matter creation was 10^{-43} gram per cube centimeter per second.

41. George Smoot and Keay Davidson, *Wrinkles in Time* (New York: William Morris, 1994), 68.

42. P. J. Ryle, "Study of Explosions," *Nature* 114 (1924): 123.

43. Francis J. W. Whipple, "Audibility of Explosions and the Constitution of the Upper Atmosphere," *Nature* 118 (1926): 309–13.

Big Bang in its title was a meteorological analysis of the winds caused by a five-thousand-ton TNT explosion that occurred in the spring of 1947 on the island of Helgoland.[44] The paper was received by the *Journal of Meteorology* two months before Hoyle coined his memorable phrase. The few meteorological references to "big bang" did not carry with them a specific technical meaning. It was just a bang caused by a big explosion.

Eight years later, at the height of the controversy over the steady state universe, we again have Big Bang in a headline, but also in this case without any connection to cosmology. What was called the big bang in the weekly magazine *The Economist* was a reference to the atomic bomb, and more specifically to the British plan of testing a hydrogen bomb.[45] The Cold War nuclear weapons race was also the context in which the eminent British-American theoretical physicist Freeman Dyson made a noncosmological reference to the big bang. Referring to the difference between the fission bombs and the thermonuclear fusion bombs, in an article in *Foreign Affairs* he noted that "it is relatively much cheaper to make a big bang than a small one."[46] The use of Big Bang as a referent to massively destructive weapons, such as nuclear bombs, was fairly common in the period of the Cold War. "After the technological revolution in the twentieth century, God is on the side of the big bang," one paper said, and it was not referring to God as the creator of the universe.[47] According to David Kaiser, when the phrase Big Bang appeared in American newspapers during the 1940s and 1950s, in the large majority of cases it referred to nuclear weapons and not to the origin of the universe.[48]

We find the same connotation in John Osborne's play *Look Back in Anger*, which was first performed in 1956 and three years later turned into a movie with Richard Burton in the role as Jimmy Porter, a young disaffected man of working-class origin. Jimmy says: "If the big bang does come, and we all get killed off, it won't be in aid of the old-fashioned, grand design. It will just be . . . as pointless and inglorious as stepping in front of a bus" (Act III, Scene

44. E. F. Cox et al., "Upper-Atmosphere Temperatures from Helgoland Big Bang," *Journal of Meteorology* 6 (1949): 300–11. See also "Weltkriegsrelikte: Der Tag, an dem Helgoland der Megabombe Trotzte," *Spiegel Online*, 13 Feb 2007 (accessed 10 Mar 2013).

45. "The Big Bang," *The Economist*, 2 Feb 1957, 365.

46. Freeman J. Dyson, "The Future Development of Nuclear Weapons," *Foreign Affairs* 38 (1959): 457–64.

47. Hanson W. Baldwin, "The New Face of War," *Bulletin of Atomic Scientists* 12, no. 5 (1956): 153–58. See also "Artillery Size Atomic Bomb," *Science News Letter* 60, no. 13 (1951): 195, and Barry Schneider, "Big Bangs from Little Bombs," *Bulletin of Atomic Scientists* 31, no. 5 (1975): 24–29.

48. Kaiser, "Evolution Wars" (ref. 35).

1). Although Osborne did not have cosmology in mind, and most likely was unaware of Hoyle's earlier coining of Big Bang, during the Cold War it was not unnatural to associate the new atomic bombs with the hypothesis of an exploding universe. As early as April 16, 1948 the *Washington Post* included an article reporting on Alpher's doctoral dissertation on element formation in the early universe. Headlined "World Began in 5 Minutes, New Theory," the article was accompanied by a cartoon in which Herbert Lawrence Block ("Herblock") presented an evil-looking atomic bomb contemplating if five minutes would be enough to destroy the world.[49] Also *Science News Letter* of April 24, 1948, included a reference to the atomic bomb in its account of Alpher's new creation theory of the universe, which it summarized as follows:

> At the very beginning of everything, the universe had infinite density concentrated in a single zero point. Then just 300 seconds—five minutes—after the start of everything, there was a rapid expansion and cooling of the primordial matter. The neutrons—those are the particles that trigger the atomic bomb—started decaying into protons and building up the heavier chemical elements. . . . This act of creation of the chemical elements took the surprisingly short time of an hour. (The Bible story said something about six days for the act of creation.)[50]

It can be argued that big bang cosmology resonated with the atomic age, whereas steady state cosmology had no such association, and that this was a contributing reason for the popularity of big bang theories in the United States in particular. There probably was some kind of link in the public mind, as illustrated by a 1950 article in the *Observer* according to which "The present popular interest in cosmology seems to have a connection with the atomic bomb."[51] On the other hand, the connection is invisible in the scientific literature where theories of the big bang type were far from popular. In fact, in the period from 1954 to 1964 they were largely absent in the physical and astronomical literature, whereas they appeared fairly frequently in the popular literature.

49. The cartoon is reproduced in Ralph Alpher and Robert Herman, "Reflections on Early Work on 'Big Bang' Cosmology," *Physics Today* 41, no. 8 (1988): 24–34.

50. "Early Stages of the Universe," *Science News Letter* 53, no. 17 (1948): 259. See also Zakariya, "Making Knowledge Whole" (ref. 18), who refers to links between "the Gamow-Alpher-Herman cosmogonic program and the wider atomic bomb project."

51. "Uncertain Cosmos," *The Observer*, 30 Jul 1950, as quoted in Gregory, *Hoyle's Universe* (ref. 25), 73.

A CATCHY NAME THAT DIDN'T CATCH ON

The cosmological controversy in the 1950s is often misunderstood to be simply between the steady state theory and the big bang theory, or even personalized to be a fight between Hoyle and Gamow. We have an early example of this dramatized version in a comment in *Popular Science* of March 1962:

> In one corner you have burly, pun-making Russian-American physicist George Gamow. He says the universe did have a beginning and that beginning was a very big bang. About 10 million years ago all the atoms that now make up the uncountable stars were concentrated into one point, a superheavy glob. This glob exploded suddenly, throwing matter throughout the vastness of space. . . . In the other corner you have piano-playing, novel-writing, baggy-tweeded English astronomer Fred Hoyle. His side says that there was no instant creation. The universe is in a steady state. Hydrogen atoms—the simplest form of ordinary matter—are always being generated throughout space. They always were and always will be.[52]

Although in the American popular press the cosmological controversy was usually put in the context of Hoyle versus Gamow, this is largely a misrepresentation. The Gamow-Alpher-Herman theory of the early universe played very little role in the predominantly British debate and Hoyle rarely referred to it. The only time that Hoyle and Gamow engaged in a kind of direct confrontation was in 1956, when both scientists argued their case in companion articles in a special issue of *Scientific American*.[53] What the steady state theory challenged was not specifically physical big bang conceptions of either Gamow's or Lemaître's type, but more generally the class of evolution theories based on the Friedmann equations, and especially those with a singular

52. Martin Mann, "The March of Science: Big-Bang Up, Steady-State Down," *Popular Science* 180, no. 3 (1962): 29. Another presentation of the cosmological debate as a fight between Hoyle and Gamow, including the term Big Bang, appeared in Martin Gardner, *Relativity for the Million* (New York: Pocket Books, 1962). For a much more sober and informative contemporary account, see Neal H. Deunk, "A Controversy in Contemporary Cosmology," *School Science and Mathematics* 62, no. 7 (1962): 487–502.

53. George Gamow, "The Evolutionary Universe," *Scientific American* 192, no. 9 (1956): 136–54, and Fred Hoyle, "The Steady-State Universe," ibid., 157–66; Gregory, *Hoyle's Universe* (ref. 25), 92–93. Both articles were included in Gerald Piel et al., eds., *The Universe* (New York: Simon and Schuster, 1957). During Hoyle's stay in California in 1956 he met with Gamow, with whom he discussed cosmological issues, including the formation of elements and the possible existence of a microwave background. See Fred Hoyle, "The Big Bang in Cosmology," *New Scientist* 92 (1981): 521–27.

beginning or what Hoyle and Bondi called source-point models.[54] Gamow's theory belonged to this class, but the majority of astronomers and physicists considered it a dead end, primarily because it was unable to account for the formation of elements heavier than helium. As mentioned, between 1953 and 1965 there was almost no scientific interest in the Gamow big bang theory.

Characteristically, when the BBC arranged a radio symposium on modern cosmology in 1959, with the participation of Bondi, William Bonnor, Raymond Lyttleton, and Gerald Whitrow (who served as a moderator), none of the speakers referred to Gamow's theory or Lemaître's primeval atom hypothesis.[55] While Bondi and Lyttleton argued for different versions of the steady state theory, Bonnor defended the relativistic evolution theories in the form of an oscillating universe. None of them mentioned the term Big Bang. When Hoyle contrasted the steady state theory and the source-point models he would typically single out the Einstein–de Sitter model as representative of the latter class. This model, proposed by Einstein and the Dutch astronomer Willem de Sitter in 1932, was of the big bang type insofar that it was expanding from a definite origin at $R = 0$ for $t = 0$, but there was no physical explosion or big bang built into the model.

A related misunderstanding is that after Hoyle had introduced the Big Bang, "the catchy phrase . . . caught on, in both camps."[56] In fact, the phrase only appeared insignificantly in the scientific literature until the 1970s. The number of references to the cosmological Big Bang before the discovery in 1965 of the cosmic microwave background seems to have been restricted to just a few dozen, of which most appeared in the popular literature, especially in the United States.[57] Hoyle often compared the steady state theory with

54. Hermann Bondi, *Cosmology* (Cambridge: Cambridge University Press, 1952), 117–20; Fred Hoyle, "Observational Tests in Cosmology," *Proceedings of the Physical Society* 77 (1961): 1–16.

55. The radio symposium was broadcast towards the end of 1959 and the following year transformed into a book: Hermann Bondi et al., *Rival Theories of Cosmology: A Symposium and Discussion of Modern Theories of the Structure of the Universe* (London: Oxford University Press, 1960).

56. Werner Marx and Lutz Bornmann, "How Accurately Does Thomas Kuhn's Model of Paradigm Change Describe the Transition from the Static View of the Universe to the Big Bang Theory in Cosmology?," *Scientometrics* 84 (2010): 441–64.

57. The *Web of Knowledge* lists no papers in the period 1950–65 with "big bang" in their titles (http://wokinfo.com). Nor does the very extensive SAO/NASA Astrophysics Data System reveal astronomical literature with abstracts including the term (http://adsabs.harvard.edu/). The *Scopus* database starts only in 1960 and lists no big bang titles before 1966 (www.scopus.com). Nonetheless, there were several papers, notes, and books in which the term appeared. I have counted thirty-four sources that mention the name before 1965, and it is likely that there are several more.

cosmologies of the big bang type, but until 1965 he did not use the term he had invented.

The first time the term appeared in a research publication may have been in a paper of early 1957 by William Fowler, a nuclear physicist at Caltech's Kellogg Laboratory and a future Nobel laureate. Fowler was well acquainted with Hoyle, who had stayed at Caltech in 1953 and again in 1956, working on the theory of element formation in the stars. Together with Hoyle and Margaret and Geoffrey Burbidge, Fowler developed in 1956–57 a comprehensive and soon famous theory of stellar nucleosynthesis known colloquially as the B²HF theory. In his paper in *Scientific Monthly* Fowler also considered the alternative favored by Gamow, namely that the elements had been formed in the very early hot universe. In this connection he mentioned the postulate of "a primordial 'big bang' in which all the matter of our universe was ejected with high velocity from a common region."[58] He most likely had come to the name by his close contact with Hoyle.

Another of Hoyle's collaborators was the English astronomer Raymond Lyttleton, who in the 1940s had worked with Hoyle on the problem of how stars accrete interstellar matter. Lyttleton much preferred the steady state theory over the evolutionary theories of the kind proposed by Lemaître and Gamow. In a popular book of 1956 based on a series of programs in the Television Series of the BBC he referred to "the 'big bang' hypothesis," which he compared unfavorably to the steady state theory of Hoyle, Bondi and Gold.[59] Three years later, in a review of the radio astronomer Bernard Lovell's *The Individual and the Universe*, a published version of the BBC Reith Lectures of 1958, Lyttleton expressed his dissatisfaction with Lovell's sympathetic account of "the 'big-bang' exploding super-atom hypothesis," which to his mind was nothing but metaphysics.[60] Among the British supporters of the steady state model was also William McCrea, an authority in cosmology and relativity physics at the Royal Holloway College, University of London. In a talk given to a 1962 summer school on radio astronomy he briefly referred to

Of these sources, twenty-three are of a popular or general nature while seven are scientific contributions and four are philosophical studies. The national distribution is the U.S. (24), Great Britain (8), Germany (1), and Australia (1).

58. William A. Fowler, "Formation of the Elements," *Scientific Monthly* 84 (1957): 84–100, on 89.

59. Raymond A. Lyttleton, *The Modern Universe* (London: Hodder & Stoughton, 1956), 197.

60. Raymond A. Lyttleton, "Man and the Universe," *Nature* 183 (1959): 1624–25. Lovell did not use the term Big Bang in his book.

Big Bang as a name for the class of evolutionary theories that assumed a singular initial state.[61]

At a 1961 conference in Santa Barbara, California, the German astronomer and leading cosmologist Otto Heckmann, of the University of Bonn, advocated a model in which the whole universe was slowly rotating. The advantage of this model, he thought, was that the initial state of infinite density, the singular big bang, could then be avoided. Heckmann argued that it would be "incorrect to conclude from the Hubble law that there must have been a 'big bang' in the strict sense."[62] He apparently associated the term with the singularity of infinite density at $t = 0$, not with the explosion of Lemaître's extended primeval atom. Lemaître, who attended the conference, agreed that the initial singularity was an idealization and maintained his belief in a primeval atom as the original state of the world. The following year 28-year-old Steven Weinberg published a paper on the cosmological role of neutrinos in which he referred to the "big bang theory," undoubtedly the first time the name appeared in *Physical Review*.[63] As he mentioned in a footnote, his investigation of neutrinos in big bang cosmologies was indebted to a personal communication from Hoyle.

The question of the origin of the universe was further discussed by George McVittie, an eminent British astronomer and cosmologist who in 1952 went to the United States, where he became director of the University of Illinois Observatory. Favoring an empiricist attitude to cosmology, McVittie was not only a staunch opponent of the steady state theory, he also disliked theories that included a sudden beginning of the universe. In a critical and careful book review essay of 1961 he objected to the idea of a big bang as apparently justified by the Friedmann equations. Some of the solutions to these equations led in a formal sense to the consequence that at $t = 0$ all matter in the universe was concentrated at a single mathematical point, but was this proof of a big bang? Not according to McVittie:

> It is said that certain models of the universe deduced from general relativity involve an initial "nuclear explosion" or a "big bang" which initiates the start

61. William H. McCrea, "Cosmological Theories: A Survey," in *Radio Astronomy Today*, ed. H. P. Palmer, R. D. Davies, and M. I. Large (Manchester: Manchester University Press, 1963), 206–21, on 216. McCrea's important contributions to steady state cosmology are described in Kragh, *Cosmology and Controversy* (ref. 6).

62. Otto Heckmann, "On the Possible Influence of a General Rotation on the Expansion of the Universe," *Astronomical Journal* 66 (1961): 599–603, on 603.

63. Steven Weinberg, "Universal Neutrino Degeneracy," *Physical Review* 128 (1962): 1457–73.

> of the expansion. . . . General relativity predicts no nuclear explosion, big bang, or instantaneous creation, for that matter, as the cause of the start of the expansion at that moment. Such notions have been woven round the predictions of general relativity by imaginative writers.[64]

McVittie did not identify the imaginative writers, but he most likely had Gamow and Lemaître in mind. In a later paper, written at a time when the hot big bang had become the standard model, he amplified his critique of the physical big bang and its wide use in "semi-popular expositions of cosmology." He thought the term was "loaded with inappropriate connotations" such as an exploding bomb, and for this and other reasons "it is unfortunate that the term 'big bang', so casually introduced by Hoyle, has acquired the vogue which it has achieved."[65]

Not unlike McVittie, the British physicist and cosmologist William Bonnor, at the Queen Elizabeth College, University of London, was as critical of the steady state theory as he was of big bang theories. He suspected that both classes of theories violated established standards of science. In a popular book completed in the summer of 1963, he included a section headlined "The Big Bang" in which he discussed "The start of the expansion [that] is colloquially referred to as the 'big bang'." The subsequent section was entitled "Was There Really a Big Bang?", a question he answered with a resounding no. Bonnor rejected the idea of a big bang, in part for philosophical reasons and in part because "neither the fusion-bomb theory of Gamow nor the primeval fission-bomb of Lemaître is successful in accounting for the origin and abundance of the heavy elements."[66] He much favored an eternally cyclic model in which the universe oscillated smoothly between states of high but not infinitely high mass density.

64. George C. McVittie, "Rationalism versus Empiricism in Cosmology," *Science* 133 (1961): 1231–36, on 1232. On McVittie, see William H. McCrea, "George Cunliffe McVittie (1904–88), OBE, FRSE, Pupil of Whittaker and Eddington: Pioneer of Modern Cosmology," *Vistas in Astronomy* 33 (1990): 43–58, and José Sanchez-Ron, "George McVittie, the Uncompromising Empiricist," in Kox and Eistenstadt, *Universe of General Relativity* (ref. 18), 189–222.

65. George C. McVittie, "Distance and Large Redshifts," *Quarterly Journal of the Royal Astronomical Society* 15 (1974): 246–63, on 260.

66. William B. Bonnor, *The Mystery of the Expanding Universe* (New York: Macmillan, 1964), on 112 and 115. The American mathematics and science writer Martin Gardner may have been the first to use Big Bang in a book chapter headline ("Big Bang or Steady State?"). Contrary to most other writers at the time, he referred to the term without putting it in quotation marks. Gardner, *Relativity for the Million* (ref. 52), 167–79.

Astronomers and physicists were not the only ones to make sporadic use of Big Bang before 1965. Norwood Russell Hanson, a distinguished philosopher of science at Yale University, apparently liked the term, which he used repeatedly in an analysis of the concept of creation in the two competing world systems.[67] Moreover, he coined his own word for supporters of the "Disneyoid picture" of the exploding early universe—"Big Bangers." According to Russell Hanson, the difference between the Big Bangers and the Continual Creators was basically of a semantic nature, rooted in different meanings given to words such as creation and universe. To his mind, neither of the two world systems was satisfactory from a philosophical point of view.

MICROWAVES AND THE BIG BANG

The mid-1960s was a watershed in the history of modern cosmology. While big bang theories of the universe had been proposed earlier, it was only in 1965 that the theory changed its status from outsider to mainstream theory.[68] With improved data for the distribution of radio sources and the new quasars, and particularly with the discovery of the cosmic microwave background, steady state cosmology was largely abandoned and left the cosmological scene to the now victorious hot big bang theory. By the end of the decade, this theory, consisting of a large class of models sharing the assumption of a hot and dense beginning of the universe, had become a standard theory accepted by a large majority of physicists and astronomers.

The decisive turn in the status of the big bang occurred with the recognition in the spring of 1965 that an unexplained microwave radiation at wavelength 7.3 cm found by Arno Penzias and Robert Wilson the year before could be

67. Norwood Russell Hanson, "Some Philosophical Aspects of Contemporary Cosmologies," in *Philosophy of Science: The Delaware Seminar*, vol. 2, ed. Bernard H. Baumrin (New York: Interscience, 1963), 465–82. On the term "big banger," see Charles E. Carson, "Among the New Words," *American Speech* 85, no. 4 (2010): 450–60. Russell Hanson seriously misrepresented the steady state theory by stating that it shared with the big bang theory the view that "our universe, in its very early youth, was considerably different in constitution and appearance from what it is now" (on 467). The first reference in the philosophical literature to Big Bang may have been due to John Hospers, a politician and professor of philosophy at the University of Southern California. John Hospers, *An Introduction to Philosophical Analysis* (New York: Prentice Hall, 1953), 350.

68. Stephen G. Brush, "Prediction and Theory Evaluation: Cosmic Microwaves and the Revival of the Big Bang," *Perspectives on Science* 1 (1993): 245–78; Kragh, *Cosmology and Controversy* (ref. 6), 318–80.

understood as a fossil of the exploding universe. Although such a cosmic background radiation had been predicted by Alpher and Herman as early as 1948, it was independent work by Robert Dicke and James Peebles at Princeton University that led to the conclusion that the Penzias-Wilson radiation was a relic from the primordial decoupling of matter and radiation caused by the early cooling of the expanding universe.[69]

Peebles and his Princeton associates did not use the term Big Bang in their seminal paper in the *Astrophysical Journal* of July 1965, but instead referred to the "primordial fireball," a name that Wheeler had suggested.[70] With this term they did not refer to the origin of the universe, but to the state at which matter ceased being in thermal equilibrium with radiation and the universe thus became transparent to photons. In other words, they referred to the origin of the cosmic background radiation. Only the following year, when calculating the formation of helium in the early universe, did Peebles use the name Big Bang and on this occasion he also referred for the first time to the earlier work of Gamow, Alpher, and Herman. He only used the name once, apparently identifying it with Gamow's "theory of the formation of the elements in the early, highly contracted Universe."[71] Big Bang had become part of the cosmologists' vocabulary, but in the decade following the discovery of the microwave background it was not widely used. The *Web of Knowledge* lists only 11 scientific papers in the period 1960–70 with the name in their titles, followed by 23 papers in the period 1971–75 (Fig. 1). According to the SAO/NASA database, the numbers for the two periods are 9 and 30, respectively, and *Scopus* lists 3 and 13 papers in the physical sciences with Big Bang in their article titles.

While the discovery of the cosmic microwave background was generally seen as convincing evidence for the big bang, Hoyle and a few other physicists and astronomers disagreed. Ted Bastian, a physicist at Cambridge University,

69. P. James E. Peebles, Lyman A. Page, and R. Bruce Partridge, *Finding the Big Bang* (Cambridge: Cambridge University Press, 2009). On the Alpher-Herman prediction see also Ralph A. Alpher and Robert Herman, *Genesis of the Big Bang* (New York: Oxford University Press, 2001), 116–23.

70. Robert H. Dicke, P. James E. Peebles, Peter G. Roll, and David T. Wilkinson, "Cosmic Black-Body Radiation," *Astrophysical Journal* 142 (1965): 414–19. For Wheeler as the originator of "primordial fireball," see Peebles, Page, and Partridge, *Finding the Big Bang* (ref. 69), 199. The term "fireball" was at the time associated with nuclear weapons, where the fireball forms shortly after the detonation, but neither Peebles nor other cosmologists referred to the analogy.

71. P. James E. Peebles, "Primordial Helium Abundance and the Primordial Fireball, II," *Astrophysical Journal* 146 (1966): 542–52.

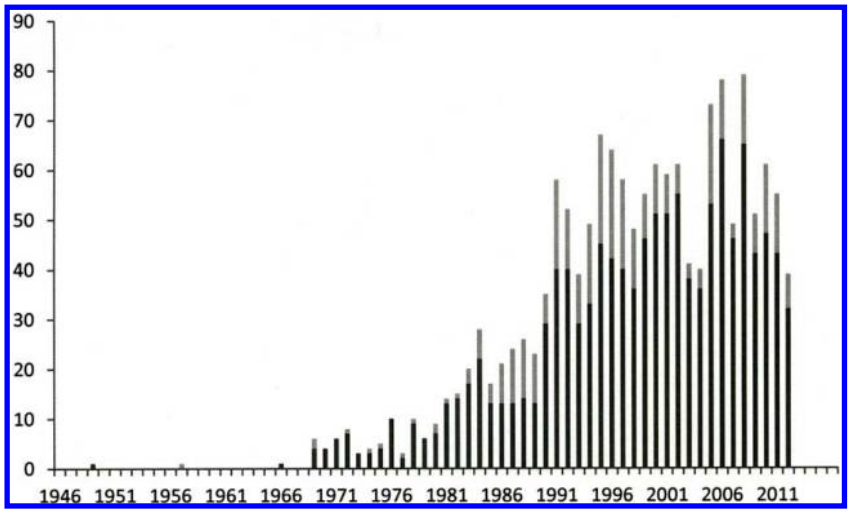

FIG. 1. *Web of Knowledge* data showing the number of science papers (black) with "big bang" appearing in their title (accessed Dec 2012). Total number = 1,205. The corresponding number in the SAO/NASA database (astronomy and physics) is 1,837 or, including arxiv e-prints, 1,960. The lighter gray extensions of the upward lines refer to papers in the humanities, arts, and social sciences. *Source*: See ref. 57.

criticized "the simple realism that is exhibited by some opponents of the steady state theory," accusing them of assuming "that the big bang is adequately modelled by the explosion of a shrapnel shell."[72] Nonetheless, as the British-American astrophysicist George Burbidge noted with dismay in a paper of 1971, "the big bang bandwagon has gained momentum."[73] This was clearly the case, but the name Big Bang lagged somewhat behind the bandwagon. Possibly the first research paper referring to Big Bang in its title, in March 1966 Stephen Hawking and Roger Tayler of Cambridge University examined the synthesis of helium in anisotropic models of the early universe. They took the big bang theory to mean that "the universe had a singular origin with high

72. Ted Bastian, "For and Against the Steady State," *New Scientist* 27 (1965): 164.

73. Geoffrey R. Burbidge, "Was There Really a Big Bang?" *Nature* 233 (1971): 36–40, on 40. At the time Burbidge preferred an agnostic view, but he eventually came to the conclusion that the big bang theory was wrong. In the 1990s he joined forces with Hoyle and his longtime collaborator Jayant Narlikar in developing the so-called quasi steady state cosmological model (QSSC). Whereas the QSSC universe is eternal, there are periodic creations of matter in what the three authors described with the oxymoron "little big bangs." Fred Hoyle, Geoffrey Burbidge, and Jayant V. Narlikar, "A Quasi-Steady State Cosmological Model with Creation of Matter," *Astrophysical Journal* 410 (1993): 437–57.

temperature and density."[74] McCrea, the former advocate of and contributor to the steady state theory, identified Big Bang with a cosmic space-time singularity such as required by the so-called Penrose-Hawking singularity theorem.[75] This was a meaning different from the one held by Peebles, Fowler, and several other cosmologists, who associated Big Bang with the formation of atomic nuclei in the early universe.

According to the Penrose-Hawking theorem there must be at least one singularity in cosmological models based on classical general relativity. In an important paper of 1970 Hawking and Roger Penrose referred to the Big Bang in the meaning of a space-time singularity, speaking for instance of "an initial (e.g. 'big bang' type) singularity."[76] The singularity theorem did not necessarily imply a beginning of the universe in a state of infinite density, since it was generally believed that at exceedingly high energies general relativity would have to be replaced with an unknown theory of quantum gravity. Charles Misner at the University of Maryland, College Park, tended to identify big bang cosmology with the view that "the Universe has evolved from an earlier state in which conditions were so extreme that the presently known laws of physics were inadequate."[77]

A NEW COSMOLOGICAL PARADIGM

The discovery of the cosmic background radiation, and with it the revival of the big bang universe, was widely reported in American newspapers and popular science magazines. As early as May 21, 1965—before the discovery had been published in the *Astrophysical Journal*—the *New York Times* included on its front page Walter Sullivan's report on the heavenly signals and their implications for the big bang universe. "The idea of a universe born 'from nothing' raises philosophical as well as scientific problems," Sullivan informed the readers.[78] Reports in other newspapers and journals, including *Scientific*

74. Stephen W. Hawking and Roger J. Tayler, "Helium Production in an Anisotropic Big-Bang Cosmology," *Nature* 209 (1966): 1278–79.

75. William H. McCrea, "A Philosophy for Big-Bang Cosmology," *Nature* 228 (1970): 21–24.

76. Stephen W. Hawking and Roger Penrose, "The Singularities of Gravitational Collapse and Cosmology," *Proceedings of the Royal Society of London A* 314 (1970): 529–48, on 530.

77. Charles W. Misner, "Absolute Zero of Time," *Physical Review* 186 (1969): 1328–33.

78. Walter Sullivan, "Signals Imply a 'Big Bang' Universe," *New York Times*, 21 May 1965. For more references to journals and popular magazines, see Brush, "Prediction and Theory Evaluation" (ref. 68).

American, *Sky and Telescope*, and *Newsweek*, followed over the next few months. Most of the articles highlighted the novelty of the amazing picture of a big bang universe, although C. P. Gilmore wrote in *Popular Science* about "Lemaître's 'big bang' theory."[79] Another article, appearing in *Science News Letter* in June 1965, explained: "The 'big bang' theory holds that some 12 or more billion years ago all matter in the universe was in one place and was spewed outward in every direction by a gigantic explosion."[80]

Apart from dealing with the new cosmic background radiation, many of the articles also dealt with the recently discovered and at the time still mysterious quasars. For example, this was the theme in an article in *Popular Mechanics* that repeated the explosion analogy to be found in almost all popular expositions: "The big bang theory postulates that the universe began with a huge explosion of an original mass."[81] At about the same time the cosmological big bang picture appeared—probably for the first time—in a commercial context, an advertisement from the Eastman Kodak Company. "Quasars are receding at nearly the speed of light," the advertisement said. "They must be out by the 'shock wave' from the original big bang of creation" (*Science* 149, 17 Sep 1965, 1320).

As illustrated by a paper in *Sky and Telescope* written by Thornton Page, an astronomer at Wesleyan University, Connecticut, the connection between quasars and big bang cosmology appeared in popular journals even before the announcement of the discovery of the cosmic microwave background. In early 1965 Page referred several times to the Big Bang—"the explosion that started the expansion of the universe"—which he related to Lemaître's primeval atom and Gamow's theory of element formation. Moreover, he pointed out that the distribution and distances of the quasars "may tell us whether the Big-Bang or the Steady-State cosmology is correct."[82] Indeed, by 1966 analyses of quasar data provided additional evidence that the steady state theory could not be correct. Hoyle tried to evade the conclusion by a drastic modification of the steady state theory, incorporating features of the big bang picture in it:

79. C. P. Gilmore, "They're Solving the World's Greatest Mystery," *Popular Science* 187, no. 11 (1965): 102–05, 200–03. The big bang theory was also ascribed to Lemaître in "Bigger 'Big Bang'," *Newsweek*, 27 Feb 1961, 65.

80. "'Big Bang' Theory Upheld," *Science News Letter* 87, no. 26 (1965): 403.

81. John F. Pearson, "At the Edge of Space," *Popular Mechanics* 124, no. 3 (1965): 94–97, 232–38.

82. Thornton Page, "The Evolution of Galaxies," *Sky and Telescope* 29, nos. 1–2 (1965): 4–7, 81–84. On the cosmological significance of quasars and their role in the final phase of the steady state theory, see Kragh, *Cosmology and Controversy* (ref. 6), 331–38.

"Perhaps the quasars are an indication that the universe has lots of little bangs instead of one big bang, little bangs that are nevertheless far more violent than the gentle processes of the steady-state theory."[83] The phrase "little bangs" introduced by Hoyle came to be widely used, both in astrophysics and in high energy physics experiments simulating the conditions of the very early universe.

By the early 1970s the hot big bang theory had acquired a nearly paradigmatic status. An opinion survey of predominantly American astronomers conducted in 1959 showed 33 percent to agree that "the universe started with a 'big bang' several billion years ago." In a later poll of 1980 the figure had increased to 69 percent.[84] At the same time cosmology experienced a strong quantitative growth. Whereas the annual number of scientific articles on cosmology had on average been about 30 in the period 1950–62, between 1962 and 1972 the number increased from 50 to 250.[85] Still, compared with other fields of physics and astronomy, cosmology remained a small and loosely organized science.

Another indication of cosmology's growing maturity as a scientific discipline is the emergence of textbooks on the now standard theory of the universe. Before 1970 there had been very few textbooks on cosmology, and most of them, such as Bondi's influential *Cosmology* of 1952, presented the readers with widely different models of the universe. Peebles' *Physical Cosmology* from 1971, the first textbook with this title, was based on a graduate course he gave in Princeton two years earlier. The term Big Bang appeared frequently in the book, although not as frequently as "primeval fireball," a term he used to designate the cosmic background radiation, either now or at the time of matter-radiation decoupling. Thus, Peebles spoke of the present microwave background at

83. Fred Hoyle, *Galaxies, Nuclei, and Quasars* (New York: Harper & Row, 1965), 56. As far as I know, this was the first time Hoyle referred to the Big Bang after 1950.

84. "Discuss Origin of Universe," *Science News Letter* 76, no. 2 (1959): 22; Brush, "Prediction and Theory Evaluation" (ref. 68), 587; C. M. Copp, "Relativistic Cosmology, I. Paradigm Commitment and Rationality," *Astronomy Quarterly* 4 (1982): 103–16. Had the 1980 survey been restricted to astronomers active in cosmological research, it would undoubtedly have shown an even greater approval of big bang cosmology.

85. For bibliometric illustrations of the growth of cosmology, see David Kaiser, "Whose Mass Is It Anyway? Particle Cosmology and the Objects of Theory," *Social Studies of Science* 36 (2006): 533–64, and Marx and Bornmann, "Thomas Kuhn's Model" (ref. 56). However, the growth is in some respect illusory, as the number of publications in the physical and astronomical sciences as a whole grew even more rapidly. While cosmology in 1950 made up 0.4 percent of the physics research papers listed in *Physics Abstracts*, in 1970 the percentage had shrunk to a little less than 0.3 percent. See Michael P. Ryan and L. C. Shepley, "Resource Letter RC-1: Cosmology," *American Journal of Physics* 44 (1976): 223–30.

temperature 2.7 K as the primeval fireball—a very cold fireball, then—and he described the consensus model of the universe as the "Big Bang Fireball picture."[86] Dennis Sciama's more elementary *Modern Cosmology* from the same year identified the Big Bang with the concept originally introduced by Gamow and his group: "The idea that the early dense stages of the Universe were hot enough to enable thermonuclear reactions to occur . . . has come to be known as the α-β-γ theory . . . or as the hot big bang theory."[87]

While the two mentioned textbooks made frequent use of the term Big Bang, Steven Weinberg—who had used the term as early as 1962—largely avoided it in his advanced text *Gravitation and Cosmology* from 1972. Speaking instead of the "standard model," only once did he refer to the "big-bang Friedmann model."[88] Yet another important book from the early period, Yakov Zel'dovich and Igor Novikov's encyclopedic *Relativistic Astrophysics*, avoided the term altogether. The two Russian authors based their exposition on what they called the Friedmann theory of a singular beginning of the universe, referring throughout to the "theory of the hot Universe" as an alternative to the hot big bang theory. With the hot universe they meant the original state of "a Universe filled with material that is dominated by photons."[89] Finally, in their massive textbook *Gravitation* of 1973, Charles Misner, Kip Thorne, and Wheeler included a book-length chapter on modern cosmology. The three authors referred a few times to the "standard hot big-bang model," using the term Big Bang as a name for a model rather than an event at the beginning of the cosmic expansion.[90]

86. P. James E. Peebles, *Physical Cosmology* (Princeton, NJ: Princeton University Press, 1971), 194 and 240.

87. Dennis Sciama, *Modern Cosmology* (Cambridge: Cambridge University Press, 1971), 156.

88. Steven Weinberg, *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity* (New York: Wiley, 1972), 611. In his later and much extended textbook on cosmology, Peebles adopted Weinberg's "standard model" as a less misleading term than "big bang model." As he pointed out, and as several other cosmologists have called attention to, Big Bang is a misnomer. This is not only because it alludes to a noisy explosion in space but also because the big bang, if taken to be a creation event or the event when the universe started expanding, is outside the standard models of cosmology and physics. P. James E. Peebles, *Principles of Physical Cosmology* (Princeton, NJ: Princeton University Press, 1993), 6.

89. Yakov B. Zel'dovich and Igor D. Novikov, *Relativistic Astrophysics, II: The Structure and Evolution of the Universe* (Chicago: University of Chicago Press, 1983), xxv. The book was a revised and enlarged version of the Russian original of 1975, translated by Leslie Fishbone and edited by Gary Steigman.

90. Charles W. Misner, Kip S. Thorne, and John A. Wheeler, *Gravitation* (San Francisco: W. H. Freeman, 1973), 763.

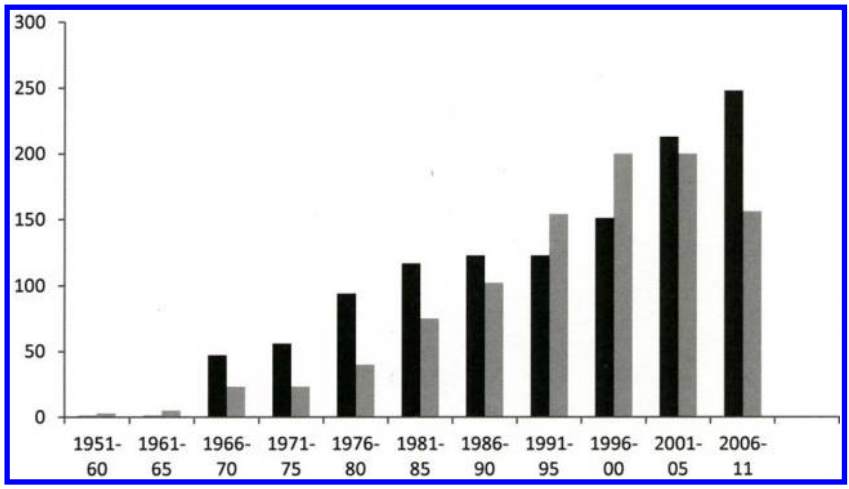

FIG. 2. Number of articles or notes 1951–2011 in *Nature* (black) and *Science* (gray) with references to big bang. Not all the references are to cosmology, but the large majority is. *Source*: The data from *Science* are retrieved from http://www.sciencemag.org/content/by/year and those from *Nature* from http://www.nature.com/nature/index.html.

PROLIFERATIONS

In the last quarter of the twentieth century cosmology was completely dominated by versions of the hot big bang. The few dissenting voices were scarcely taken seriously. Hoyle's old name was now commonly used, although the number of scientific papers referring to Big Bang remained low until about 1990, after which it increased (Fig. 1). Until the end of 2012 the *Web of Knowledge* lists a total of 4,548 science papers with Big Bang as their topic, with only 198 of them published before 1990. *Scopus* includes 4,077 papers from 1960–2012 with Big Bang in title, abstract, or key words, of which 3,673 are in the physical sciences. The corresponding figures for 1960–89 are 422 and 404, respectively. Another way of illustrating the popularity of the Big Bang term is to search for the term in the databases of journals such as *Nature* and *Science* (the result of which is shown in Fig. 2).

To evaluate such bibliometric data one has to take into account the general growth in cosmology publications. Between 1980 and 2000 the number of articles on cosmology grew steadily from about 400 per year to a little more than 2,000 per year.[91] Moreover, one also has to take into account the possibility

91. Marx and Bornmann, "Thomas Kuhn's Model" (ref. 56).

that the drastic rise in papers referring to Big Bang about 1990 is apparent only, to some extent a reflection of the design of the database. That this may be the case is suggested by Fig. 2, where there is no indication of a sharp difference before and after 1990. Indeed, the *Web of Knowledge* only began to include terms from abstracts after that year, which automatically results in a larger number of articles mentioning Big Bang. There is little doubt that a major reason why 96 percent of the hits refer to the period after 1990 is due to this change in the database design. Searching for the term only in the title field, as shown in Fig. 1, provides a more robust measure. The title data suggest that Big Bang became more popular about 1990, but also that there was no drastic increase in the use of the term. In considering the near absence of the term Big Bang until the late 1960s one should furthermore keep in mind that models of cosmology did not generally attract much interest among physicists and astronomers in this early period. On the other hand, until the early 1960s the debate over the steady state theory versus relativistic evolution theories was highly visible, and one would expect the term to appear in this context more often than it did.

Probably as a result of the popularity of the name in cosmology, and of cosmology's wide public appeal, Big Bang began to appear in many other contexts, both within and without the sciences. Thus, about 500 papers referring to Big Bang have been published in the humanities and the social sciences. The number of articles in this category with the name in their titles is about 200 (Fig. 1).

In some cases the phrase Big Bang is used in a general sense to characterize a sudden, comprehensive, and drastic change rather than one which occurs incrementally and over long spans of time. The Tunguska event in 1908 has been described as Siberia's big bang, and biologists sometimes speak of the sudden appearance of life forms in the Cambrian era almost 600 million years ago as biology's big bang.[92] Such uses of the term in the biological literature may allude explicitly to cosmology, as in a paper entitled "Origin of Genes: 'Big Bang' or Continuous Creation?"[93] Similar metaphorical kinds of usage are quite common also in other areas, not least in economic and financial studies. The jumps of Poland and Hungary to market economies in the early 1990s

92. Vera Rich, "The 70-Year-Old Mystery of Siberia's Big Bang," *Nature* 274 (1978): 207; Jeffrey Levinton, "The Big Bang of Animal Evolution," *Scientific American* 267, no. 11 (1992): 84–91.

93. Paul K. Keese and Adrian Gibbs, "Origins of Genes: 'Big Bang' or Continuous Creation?" *Proceedings of the National Academy of Sciences* 89 (1992): 9489–93. See also Eugene V. Koonin, "The Biological Big Bang Model for the Major Transitions in Evolution," *Biology Direct* 2 (2007): 1–17.

were described as economic big bangs. The Big Bang metaphor has been used extensively in discussions of how to transform centrally planned economies into market-oriented ones, as in the cases of China and Eastern Europe. As one author explains, "A big-bang or shock therapy approach implements various reforms . . . quickly, in a concentrated time frame, whereas a gradualist approach spreads various reforms over an extended period."[94]

Finally, the label Big Bang is today used in a variety of commercial, cultural, and artistic contexts that have only the name in common with the original cosmological meaning of the term. Numerous music albums, television series, films, comics, sport events, and commercial products of any kind carry the name that Hoyle casually coined in 1949. The Rolling Stones' album of 2005, *A Bigger Bang*, is one example, the popular American television sitcom *Big Bang Theory* is another. A Google search for "big bang" gives 167 million results, while the search on Google Scholar gives 231,000 results (the combination "big bang" and "universe" reduces the hits to 28.6 million and 124,000, respectively). Although it took a long time for Big Bang to become catchy, it definitely has become so.

CONCLUSIONS

An apt name for an object, phenomenon, or concept may help to bring it recognition and visibility, or to associate it with certain mental images that other names do not convey. Big Bang is one such name that today is almost synonymous with modern cosmology, but the success of the name is of relatively modern date. Far from being an instant success, for a long time the now ubiquitous name was ignored by most physicists and astronomers, including Hoyle himself. It was used earlier and more frequently in popular than in scientific publications, and more in the United States than in England. Only in the 1970s did Big Bang begin to be commonly used in cosmology, and it took more than another decade until it really caught on and came into wide use also outside the small field of physical cosmology.

Although an examination of the use and nonuse of Big Bang adds some flavor to the history, for instance by highlighting the role of the popular literature, it does not challenge the prevailing historiography of cosmology.

94. Shang-Jin Wei, "Gradualism versus Big Bang: Speed and Sustainability of Reforms," *Canadian Journal of Economics* 30 (1997): 1234–47, on 1234.

It supplements it rather than changes it. One might imagine that the Big Bang label helped make the idea of a finite-age universe popular and in this way contributed to the victory of this class of models in the mid-1960s. But this is not what happened. The wide acceptance of the label occurred post hoc, only after observations had provided convincing evidence that we live in a big bang universe. In other words, there is no reason to assume that Hoyle's name had a causal effect on the development of cosmology in the period.

Apart from pointing out that Big Bang can be found in scientific contexts even before Hoyle introduced it, this paper has called attention to several misunderstandings concerning the origin and early history of the phrase. One of them is that the term was due to Gamow, or that Gamow promoted it in order to support his favored conception of the early universe. In fact, Gamow disliked the term and only used it once. Another popular misconception is that Hoyle coined the term to mock or disparage theories with a definite origin of the universe, such as Gamow's. Although one cannot rule it out, this often-repeated view lacks convincing evidence. Had Hoyle intended the term in this way, he would presumably have used it frequently during the cosmological controversy, which he did not. Between 1950 and 1965 he did not refer to Big Bang at all. Moreover, there is no indication that the term was perceived as mocking in the 1950s.

Names usually have several connotations and meanings, such as was the case with Big Bang in the early period and such as is still the case. It is not a well-defined concept and never has been. When physicists and astronomers spoke of big bang cosmology in the 1960s, it was basically in two different ways. According to one view, the Big Bang was a cosmic space-time singularity in the strict sense, an absolute beginning corresponding to an unphysical point of infinite density. This was the meaning that Hoyle called attention to when naming the "irrational" big bang event. On the other hand, it was more common to associate the initial event and the events following it with a physical state of the kind imagined by Gamow or Lemaître, a primordial high-density and high-temperature universe made up of radiation and nuclear particles in a state of rapid expansion. A few physicists identified the Big Bang with a state so early and exotic that it could not be understood in terms of the known laws of physics.

These are images still found today, both among cosmologists and in the general public. In part because Big Bang invites images of a primordial event in the form of a gargantuan explosion, it is widely agreed that the term, although vivid, is a misnomer and that it causes more confusion than clarity. It certainly

does in the teaching of science, where studies consistently show that students tend to associate the Big Bang with an explosion of preexisting matter into empty space.[95] And no wonder, for the explosion metaphor is still routinely used in the popular literature, much as it was in the past. It is one of those metaphors that convey a false picture but is nevertheless, for lack of a more appropriate metaphor, unavoidable. Perhaps Big Bang is a misnomer, but as Hoyle commented, it is one of those catchy harpoon-like words that is very hard to pull out once it has gone in.

ACKNOWLEDGMENTS

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95. Lena Hansson and Andreas Redfors, "Swedish Upper Secondary Students' Views of the Origin and Development of the Universe," *Research in Science Education* 36 (2006): 355–79; Edward E. Prather, Timothy F. Slater, and Erika G. Offerdahl, "Hints of a Fundamental Misconception in Cosmology," *Astronomy Education Review* 1, no. 2 (2003): n.p. (http://aer.aas.org/).