ALEXANDRE BAGDONAS AND ALEXEI KOJEVNIKOV*

Funny Origins of the Big Bang Theory

ABSTRACT

Popularization of science typically follows the lead of scientific research, conveying to lay audiences ideas and discoveries initially published in professional scientific literature and vetted by the expert community. The physicist George Gamow (1904–1968) did not respect this tradition, but promoted some of his most unorthodox scientific hypotheses as funny stories in his popular writings for nonspecialists and teenagers, sometimes years before he dared to present them to the purview of academic peers in papers submitted to specialized research journals. Gamow's proposal of the Big Bang cosmology—the theory that our universe started out in an explosive manner from a superhot and superdense state with thermonuclear reactions forming matter—was discussed by him initially in a series of nonserious articles and books, starting in 1938. Historians of cosmology recognize Gamow's crucial contribution to the development of the Big Bang theory on the grounds of his subsequent professional publications but have not paid sufficient attention to his popular science writings and their role in changing our conception of the universe.

KEY WORDS: popularization of science, humor, relativistic cosmology, Big Bang theory, relativistic astrophysics, stellar energy, origin of chemical elements, George Gamow

*Alexandre Bagdonas, Department of Mathematics and Physics Education, Universidade Federal de Lavras (Federal University of Lavras), Lavras, Brazil; alexandre.bagdonas@ufla.br; Alexei Kojevnikov, Department of History, University of British Columbia, Vancouver, Canada; a.nikov@ubc.ca

The following abbreviations are used: *AJ*, *The Astrophysical Journal*; GBGP, George and Barbara Gamow Papers, Manuscript Division, Library of Congress, Washington, DC; *EPJH*, *The European Physical Journal H*; *HSNS*, *Historical Studies in the Natural Sciences*; NBLA, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD; *PR*, *The Physical Review*; SCP, Subrahmanyan Chandrasekhar Papers, Joseph Regenstein Library, Special Collections Research Center, University of Chicago; *ZP*, *Zeitschrift für Physik*.

Historical Studies in the Natural Sciences, Vol. 51, Number 1, pps. 87–137. ISSN 1939-1811, electronic ISSN 1939-182X. DOI: https://doi.org/10.1525/hsns.2021.51.1.87.

> [I]f his book has residual merits, these are in its store of anecdotes. They are funny, and their relevance is independent of accuracy, for they did circulate in the profession and have something to tell about it.
>
> —Thomas Kuhn, reviewing George Gamow's *Thirty Years That Shook Physics: The Story of Quantum Theory* (1966)

> His achievements were encumbered by such unconventionality, that it was a credit to the [National] Academy that he was elected at all.
>
> —Karl Hufbauer, "George Gamow," *Biographical Memoirs*[1]

INTRODUCTION

In December 1938, the British *Discovery Magazine: A Monthly Popular Journal of Knowledge* published a short story, "Toy Universe," written by the theoretical physicist George Gamow. It described adventures of a curious "little clerk of a big city bank," C. G. H. Tompkins, in an imaginary world governed by Einstein's general theory of relativity, but of such small dimensions, that the otherwise negligible relativistic effects became perceptible by human senses. The article also popularized some additional concepts that at the time did not belong to the generally accepted knowledge in the field. It described the toy model of our world as a pulsating universe that underwent periodic expansions and contractions, and with the temperature correspondingly changing from very hot to cool, then back into a hot state. The publication launched Gamow's "Mr. Tompkins" saga that continued in several further installments in the same journal and eventually expanded into a series of best-selling books that explained various fields of advanced scientific knowledge to inquisitive teenagers and earned Gamow rewards and recognition as a classic of science popularization. Importantly, "Toy Universe" also marked Gamow's first entry into relativistic cosmology, a field of advanced research in which he had not published before.[2]

1. Thomas Kuhn, "The Turn to Recent Science," *Isis* 58 (1967): 409–19, on 412; Karl Hufbauer, "George Gamow, March 4, 1904–August 19, 1968," *Biographical Memoirs of the Fellows of the National Academy of Sciences* (Washington, DC: NAS, 2009): 1–39, on 3. The title of Gamow's book was a pun on John Reed's *Ten Days That Shook the World*, an American communist's eyewitness account of the 1917 Bolshevik revolution.

2. George Gamow, "Toy Universe," *Discovery Magazine* (Dec 1938): 431–39. The final sequel, George Gamow, *Mr. Tompkins in Paperback* (Cambridge: Cambridge University Press, 1965), united under one cover his two earlier books, *Mr. Tompkins in Wonderland: Or, Stories of C, G,*

As of 1938, Gamow enjoyed a scholarly reputation as one of the top experts in theoretical nuclear physics, at the time the most active and prestigious branch of fundamental research. The general theory of relativity, by contrast, was at the lowest ebb of its popularity, with only a small number of active researchers, but at least it was accepted and respected by scientists who worked in other fields.[3] Its subfield, relativistic cosmology, lacked such a privilege. Though practiced by a handful of university professors, it was often looked down upon by other physicists as too speculative and dubiously scientific. Gamow believed that the use of some speculative hypotheses did not contradict the scientific status of relativistic cosmology, yet decided to promote it and advance some new ideas initially through humorous articles and books written for non-specialists. Only a decade later was he ready to start submitting a series of scholarly papers on this subject to peer-reviewed professional journals.

Gamow's entry into the field of cosmology would eventually become a game changer, but significantly later. He developed a theory that our universe exploded like an enormous, cosmic-scale thermonuclear device out of the initial extremely hot and dense state, and furnished this hypothesis with astronomical data and with calculations of how nuclear reactions could produce matter, stars, and galaxies. The model allowed him and coauthors to explain realistically the origin of chemical elements and predict some new effects, including cosmic background radiation. Bringing methods from the more prestigious nuclear science to bear on the evolution of the universe, essentially merging the two fields together, helped relativistic cosmology look somewhat more respectable in the eyes of the then-hegemonic nuclear physicists. Still, Gamow's students who collaborated on this pathbreaking research could not find good academic jobs, despite the high demand for physicists in 1950s America. And within the cosmological field per se, the explosive scenario was then often ridiculed with the derogatory term "Big Bang" and preferred to a more gradualist alternative, the "Steady State" theory. The attitudes among practicing physicists and astronomers would change eventually, by the mid 1960s, toward the general acceptance of the Big Bang theory as respectable, mainstream cosmology. But by then Gamow had switched his research to other fields and was also effectively marginalized, if not ostracized in the

and H (Cambridge: Cambridge University Press, 1939) and *Mr. Tompkins Explores the Atom* (Cambridge: Cambridge University Press, 1944).

3. Jean Eisenstaedt, "La relativité générale à l'étiage: 1925–1955," *Archive for History of Exact Sciences* 35 (1986): 115–85.

discipline.[4] Retroactively, Gamow received recognition as a pioneer of the Big Bang theory from physicists as well as historians, but standard accounts of the development of his cosmological model rely primarily on his scholarly publications, without paying sufficient attention to texts that he wrote for lay readers. The fact that some pathbreaking scientific ideas originated in a funny, popular format has thus remained generally overlooked and unacknowledged.[5] Although not completely unprecedented in history of science, such a pattern asks for a fuller investigation and reflection.

The present paper explores Gamow's path toward the Big Bang cosmology primarily through the lens of his popular science writings. The first section presents Gamow as a quintessential transnational scientist: his scientific education and professionalization in revolutionary Russia, his itinerant career as a cosmopolitan postdoc in interwar Europe, and his status as an immigrant scientist in New Deal America. We explore Gamow's unique multicultural background for sources of his belief in an expanding universe, his interest in popularization of science, and his specific humorous style of doing and living physics. The second section looks at Gamow's early American years for an understanding of two important transitions: his move from highly prestigious and institutionalized nuclear research to more marginal and less appreciated interdisciplinary fields, nuclear astrophysics and relativistic cosmology; and his turn toward prolific production of popular scientific articles and books at a time circa 1940, when engagement in popularization was uncommon and rarely appreciated among American physicists. The third section explores the transfer of Gamow's ideas on Big Bang cosmology from the popular to the professional genre during the early postwar years and the contributions he made together

4. For accounts of Gamow's cosmology, see John North, *The Measure of the Universe: A History of Modern Cosmology* (Oxford: Clarendon Press, 1965), 228–56; Jacques Merleau-Ponty, *Cosmologie du XX siècle* (Paris: Gallimard, 1965), 370–83; Helge Kragh, "Gamow's Game: The Road to the Hot Big Bang," *Centaurus* 38 (1996): 335–61; Helge Kragh, *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton, NJ: Princeton University Press, 1996); Craig Sean McConnell, *The Big Bang—Steady State Controversy: Cosmology in Public and Scientific Forums* (PhD dissertation, The University of Wisconsin–Madison, 2000); Nasser Zakariya, *A Final Story: Science, Myth, and Beginnings* (Chicago: University of Chicago Press, 2017); and James Peebles, "Discovery of the Hot Big Bang: What Happened in 1948," *EPJH* 39 (2014): 205–23.

5. In addition to the Mr. Tompkins series, the following trilogy is particularly important for the genesis of Gamow's cosmological ideas: George Gamow, *The Birth and Death of the Sun: Stellar Evolution and Subatomic Energy* (New York: Viking Press, 1940); Gamow, *Biography of the Earth: Its Past, Present and Future* (New York: Viking Press, 1941); and Gamow, *The Creation of the Universe* (New York: Viking Press, 1952).

with his collaborators Ralph Alpher and Robert Herman. This brings the story approximately to 1953, when Gamow effectively left the field of cosmology and turned to biological problems of the genetic code, where he also pioneered some fundamental breakthroughs. Finally, the conclusion discusses the role of popularization in the development of fundamental science and the phenomenon of entertaining science from a historically comparative perspective.

WORLD LINE OF A TRANSNATIONAL SCIENTIST

Prankster in Soviet Russia

George (Georgii Antonovich) Gamow was born in 1904 in Odessa, the third largest city of the Russian Empire and its main seaport in the southwestern, Ukrainian part. Since the second half of the nineteenth century, the city also acquired Novorossia University, where Gamow's father received his education. The family's modest noble status and reasonably prosperous, middle-class lifestyle could not survive the troubles of the 1917 revolution. During the ensuing Civil War and Western intervention, power in Odessa changed hands about fourteen times between various factions, until the Bolshevik forces finally established control of the city in 1920. Despite turmoil, Gamow graduated from high school and enrolled in the university, but radical educational reforms enacted by the Commissariat of Enlightenment of the Ukrainian Soviet Republic closed the university's research institute in physics. In 1922, he decided to transfer to the former imperial capital, St. Petersburg, which by then was renamed to Petrograd and in 1924 would be again renamed to Leningrad.[6]

In Leningrad University, Gamow continued to pursue his interests in physics and astronomy and could already have become involved in cosmological research:

> The subject that fascinated me most from my early student days was Einstein's special, and especially general, theory of relativity, and I had quite

6. Gamow's autobiography provides an entertaining, but sometimes unreliable, description of the first half of his life: George Gamow, *My World Line: An Informal Biography* (New York: Viking Press, 1970), which he, much more appropriately, wanted to subtitle *Fragments of Memory*. Later biographers corrected many inaccuracies and added important information: Viktor Ya. Frenkel, "George Gamow: World Line 1904–1933," *Physics-Uspekhi* 37 (1994): 767–89; Hufbauer, "Gamow" (ref. 1); and especially commentaries to the Russian translation of Gamow's autobiography: Yu. I. Lisnevskii, "Dopolnitelnye materialy k biografii uchenogo," in *Moia Mirovaia Liniia: Neformal'naia Avtobiografiia*, G. Gamov (Moscow: Nauka, 1994): 151–230.

> a lot of somewhat uncoordinated knowledge in this field. What I needed most at that time was a strict mathematical foundation . . . It just happened that Professor Alexander Alexandrovich Friedmann of the Mathematics Department announced at that time his course of lectures entitled "Mathematical Foundations of the Theory of Relativity," and so, naturally, I landed on the bench of the classroom for the first of his lectures . . . [Friedmann was] excited about problems of relativistic cosmology and had become the originator of the theory of the expanding universe . . . But he did not live to take part in the development of his brainchild . . . [Friedmann's death in 1925] ruined my plans to continue my work on relativistic cosmology[7]

Einstein's relativity reached its all-time popularity after the 1919 solar eclipse confirmed its astronomical predictions. In Soviet Russia, where the news arrived by the end of 1920, it was also talked about in all intellectual circles. Alexander Friedmann was among those few real experts in general relativity who were rare even among professional physicists and mathematicians. He taught the first advanced university course in Russia on general relativity, to which Gamow referred, and co-authored a textbook on its mathematical apparatus and another book that interpreted the new theory for the philosophically inclined public. Friedmann's most daring contribution came in two short mathematical papers of 1922 and 1924 in which he proposed the first version of a radically new cosmological model that decades later would be labeled the "Big Bang." Friedmann started from a hypothesis that the universe's radius could change with time and managed to find mathematical solutions to Einstein's general equations, an infinite class of them, that satisfied this assumption. The universe in his various scenarios expanded, sometimes from a finite radius but more often from a geometrical point, and sometimes its expansion could reverse into contraction and collapse back into a point, with a possible new rebirth.[8]

Friedmann's proposal contradicted the established cosmological wisdom of the time and initially was not taken seriously. He died untimely in 1925, from an infection, just as the empirical astronomical data were starting to provide

7. Gamow, *My World Line* (ref. 6), 41–45.

8. E. A. Tropp, V. Ya. Frenkel, and A. D. Chernin, *Alexander A. Friedmann: The Man Who Made the Universe Expand* (Cambridge: Cambridge University Press, 1993). For further analysis of his cosmological theory in its cultural context, see Alexei Kojevnikov, "Space-Time, Death-Resurrection, and the Russian Revolution," forthcoming in *Science and Technology in Russia's Great War and Revolution, 1914–1922*, ed. Anthony Heywood and Scott Palmer (Bloomington: Indiana University Press, 2021).

indications that our universe, indeed, may be expanding. We do not know what Gamow thought of cosmological scenarios then, but at least he was familiar with the earliest version of the Big Bang model since his student years, so that fifteen years later, already as an established physicist, he remembered Friedmann's cosmology and started promoting it further in his own writings. Gamow paid final homage to his teacher by dedicating to Friedmann his last popular book, which he was writing at the time of his own death in 1968.[9]

As a graduate student Gamow started working with another professor and switched his attention entirely to quantum theory of the atom, excited about it not in small part because he studied it together with close friends. The previously timid boy was happy to find student company, in which he flourished socially and became an extrovert. The group's core also included Dmitry Ivanenko, a somewhat younger Lev Landau, soon to be joined by Matvey Bronstein, Victor Ambartsumian, and several other, subsequently famous, theoretical physicists and astronomers. The revolutionary Soviet culture of the 1920s encouraged student radicalism and rebelliousness, but unlike their leftist friend Landau, Gamow and Ivanenko showed little interest in politics per se. All three, however, were on the same page as rebels against authorities in the discipline of physics, mocking their teachers and senior colleagues for their old-fashioned scientific views.[10] The students' dismissive attitude was not limited to classical theories and standard textbooks in physics. Gamow snobbishly referred to calculations he did with his graduate adviser on the so-called old quantum theory as "dull." Instead, he and his friends embraced the newest and the most radical quantum mechanics, once the first research papers on it started appearing in German physical journals in late 1925. Feeling no need for advice or encouragement from their teachers, the young punks immediately composed their own papers in the new quantum mechanical language and submitted them to the same German journals.[11]

9. George Gamow, *The Universe in the Making*, unfinished manuscript (GBGP).

10. Gennady E. Gorelik and Viktor Ya. Frenkel, *Matvey Petrovich Bronstein and Soviet Theoretical Physics in the Thirties* (Boston: Birkhauser, 1994); Karl Philip Hall, *Purely Practical Revolutionaries: A History of Stalinist Theoretical Physics* (PhD dissertation, Harvard University, 1999); Alexei Kojevnikov, *Stalin's Great Science: The Times and Adventures of Soviet Physicists* (London: Imperial College Press, 2004); and A. Sardanashvily, *Dmitrii Ivanenko—Superzvezda Sovetskoi Fiziki* (Moscow: URSS, 2010).

11. Gamow, *My World Line* (ref. 6), 45. Their first papers on quantum mechanics: G. Gamow and D. Iwanenko, "Zur Wellentheorie der Materie" *ZP* 39 (1926): 865–68; D. Iwanenko and L. Landau, "Zur Ableitung der Klein–Fockschen Gleichung," *ZP* 40 (1926): 161–62.

Besides physics, the friends also excelled in pranks in and around the profession, some relatively harmless acts, others less so, which occasionally got them into trouble with academic and political authorities. In this company Gamow developed the character and reputation that would follow him for the rest of his life, as an incessant joker who made fun of everything and did not take anyone seriously, including himself. As if he simply could not stop making fun, he often risked good relations with colleagues, teachers, and later even students for the sake of a good joke. Such behavior was appreciated by some of his friends, but irritated others and, over time, undermined his standing in the profession. Gamow's demonstrative attitude toward his own research and even dearest thoughts was also usually half-joking, with the effect that he and his ideas were sometimes taken less seriously than they deserved. Truth-telling was often subordinate to fun: in his popular and autobiographical books, Gamow told many funny stories and historical anecdotes, which although based on some real episodes, were transformed or embellished with fictional details for the sake of making them more entertaining.[12] We thus need to be critically selective when using Gamow's quasi-historical and quasi-biographical writings as sources.

In 1927, the trio of Gamow, Ivanenko, and Landau, sitting at a lunch table, decided to concoct a physics paper on the spot and submit it for publication. They wanted to dedicate it as a birthday present to their friend Irina Sokolskaia, but also to mock the low acceptance criteria of the *Journal of the Russian Physico-Chemical Society*. The latter did publish with the straight face their coffee-table conversation, although without the romantic dedication to the authors' muse. The three graduate students discussed there how to construct a system of basic physical units out of the three fundamental constants, 1/c, G, and h (inverse speed of light, gravitational constant and the Planck constant), and what implication this could have for a future unified theory of relativity, quantum, and gravity, and for the values of mass and charge of the most basic

12. For accounts of his humorous stories and pranks, see George Gamow, interview by Charles Weiner, 25 Apr 1968 (NBLA) http://www.aip.org/history/ohilist/4325.html; Wolfgang Yourgrau, "The Cosmos of George Gamow," *New Scientist* 48 (1970): 38–39; Frederick Reines, ed., *Cosmology, Fusion and Other Matters: George Gamow Memorial Volume* (Boulder: Colorado Associated University Press, 1972); Ralph A. Alpher and Robert C. Herman, interview by Martin Harwit, 11 Aug 1983 (NBLA) http://www.aip.org/history/ohilist/3014_1.html; Eamon Harper, W. C. Parke, and G. D. Anderson, eds., *The George Gamow Symposium* (San Francisco: Astronomical Society of the Pacific, 1997); and Eamon Harper, "In Appreciation George Gamow: Scientific Amateur and Polymath," *Physics in Perspective* 3 (2001): 335–72.

elementary particle. Although initially invented as a joke, the motif of c-G-h physics would subsequently resurface in Bronstein's pioneering quantization of gravitational waves as well as in Gamow's popular books.[13]

In his later recollections, Gamow found it hard to explain how he had developed the habit and talent for writing popular books on science. He did mention, however, that already as a student he liked reading such literature and composed several articles for wider audiences. The Soviet political and public culture elevated popularization of science to heretofore unprecedented importance. Reflecting the Bolsheviks' hopes that the rational scientific worldview would replace religious beliefs in the minds of poorly educated classes, the Soviet promotion of scientific propaganda resembled, by its magnitude and prominence, what many other cultures invest in religious propaganda. Special journals, entire publishing houses, film studios, and many authors worked on popularizing scientific and technical knowledge "for the masses."[14] Professional researchers in the Soviet Union were also required, as part of their job duties, to write about science for the general public. Gamow and his friend Bronstein could both write easily and fluently, and they engaged in such activities with apparent readiness. It certainly did not hurt that authoring popular science literature and textbooks paid well by Soviet standards and allowed young scientists to significantly augment their otherwise meager salaries.[15]

13. Gorelik and Frenkel, *Matvey Bronstein* (ref. 10). For the English translation and modern analysis of the c-G-h paper, see G. Gamov, D. Ivanenko, and L. Landau, "World Constants and Limiting Transition," *Physics of Atomic Nuclei* 65 (2002): 1373–75; L. B. Okun, "Key Problems in Fundamental Physics: On the Article of George Gamow, D. Ivanenko, and L. Landau," *Physics of Atomic Nuclei* 65 (2002): 1370–72.

14. James T. Andrews, *Science for the Masses: The Bolshevik State, Public Science, and the Popular Imagination in Soviet Russia, 1917–1934* (College Station: Texas A&M University Press, 2003); John McCannon, "Technological and Scientific Utopias in Soviet Children's Literature, 1921–1932," *The Journal of Popular Culture* 34 (2001): 153–69.

15. An unpublished fragment of Gamow's autobiography describes his and his wife's bohemian living conditions: "The Radium Institute . . . had plenty of room for the comparatively meagre equipment available for radioactive research. I managed to obtain a spacious office in it and was permitted to put into it both my writing desk and a large sofa which could serve as a double bed. Of course, there was no kitchen, but I had no difficulty in selecting from the Institute's equipment a large electric heater which served a double purpose: to cook some food, whenever it was available . . . and to maintain the temperature of the room above freezing point during the winter months. Thus, considering all the shortages of living space, fuel, and food of that period, our situation was fine and dandy." (GBGP, Box 24, 11–12).

Once Gamow gained some notoriety as a scientist, around 1930, he started writing occasional articles for a wider readership, though not exactly "for the masses."[16] Their genres ranged from a historical review of research literature for physicists, to a report about his field in the journal *Priroda*, intended primarily for scholars in other disciplines, and to articles in the journal *SoReNa* (Socialist Reconstruction and Science), whose main readers were engineers and engineering students. Bronstein authored several books for high school students and teenagers interested in science. Their style of popularization was different, however, from Gamow's later *Mr. Tompkins* series, resembling more the popular history of science rather than the entertaining and funny science fiction. Science popularization was still a serious business in the Soviet Union, and Gamow's joking side remained mainly a feature of the unofficial student culture, rather than of his officially supported publication activities. We can thus conclude that although the three aspects—interest in relativistic cosmology, engagement in science popularization, and fondness for humor and jokes—all had roots in Gamow's cultural upbringing in the Soviet Union, at that time they were still separate and unrelated facets of his activities and would come together only later.

Escape Artist: From Europe to America

In 1928, Gamow received a Soviet stipend to travel to Europe and arrived in Göttingen, the birthplace of quantum mechanics, to work with one of its leaders, Max Born. "Göttingen was a dull little town whose total of entertainment possibilities was represented by two poor movie theatres; and the author, who had hoped for something more on his first trip abroad, had nothing better to do than to take up research," commented Gamow years later. During that short stay he stumbled upon a great original idea on how to transfer the methods of quantum mechanics from the atom to a different class of phenomena, radioactivity and the nucleus, and published an article that made him internationally famous. Gamow wanted to explain why some α-particles could escape from a nucleus whereas other α-particles, even with a much higher energy, were unable to penetrate the nucleus. The answer came from a counterintuitive quantum mechanical effect, the quantum

16. The most complete bibliography of Gamow's publications, including some previously overlooked popular articles from the Soviet period, was compiled by Lisnevskii "Dopolnitelnye Materialy" (ref. 6), 136–50.

tunnelling, according to which an α-particle had a small chance of escaping through the high energy barrier that would have locked a classical particle inside. In his later popular science book, Gamow illustrated the idea with the following analogy: "the decay of the radioactive elements is really a purely quantum-mechanical process in which α-particles 'leak through' the nuclear potential walls, just as an old-fashioned ghost passes through the thick walls of an ancient castle."[17] For calculations, Gamow relied on Erwin Schrödinger's wave mechanics, but needed some help from another young Soviet mathematical physicist who was also visiting Göttingen at the time, Nikolai Kochin. Reportedly, Gamow offered him a co-authorship, which Kochin declined because by his own mathematical standards, the equation he helped to solve was simply too trivial.[18]

The episode reveals some of the features of Gamow's research style that would become recurrent throughout his career. Very quick-witted, he often pioneered pathbreaking ideas by bringing insights from one field of research into another, opening up new avenues of investigation and gathering important low-hanging fruit. But tedious mathematical formalism was not his forte, and he was often sloppy even in relatively simple calculations.[19] Once the new field grew to become more sophisticated and populated with researchers, Gamow often lacked the patience or skills to compete with technically more advanced and disciplined thinkers, and without bringing the larger project to a systematic completion, he could leave it and burst into a different, still undeveloped and exciting area of research. His 1928 paper inaugurated such important new field—applications of quantum mechanics to nuclei—which immediately started gathering followers and, several years later, grew into the advanced discipline of theoretical nuclear physics. Gamow continued this line of investigation for another few years until he

17. Gamow, *Birth and Death* (ref. 5), 64–65.

18. G. Gamow, "Zur Quantentheorie des Atomkerns," *ZP* 51 (1928): 204–12, and "The Quantum Theory of Nuclear Disintegration," *Nature* 122 (1928): 805–06. For an analysis, see Roger H. Stuewer, "Gamow, Alpha Decay, and the Liquid-Drop Model of the Nucleus," in *Gamow Symposium* (ref. 12), 30–43.

19. As recalled by his PhD student, "Gamow was childlike in his enthusiasm for puzzles, games and tricks . . . [he] could not spell; he could not do simple arithmetic. I think it would actually have been impossible for him to find the product of 7×8. But he had the mind that made it possible for him to understand the Universe." Vera C. Rubin, "The Hubble Expansion and the Motion of the Galaxy," in *Gamow Cosmology: Proceedings of the International School of Physics "Enrico Fermi"*, ed. F. Melchiorri and R. Ruffini (Amsterdam: North Holland, 1986), 160–67, on 162.

left it the mid-1930s, after the discovery of the neutron transformed nuclear physics into a mature, most popular, and most competitive branch of fundamental science.

During these years, until the mid-1930s, Gamow lived the peripatetic life of a postdoctoral fellow, subsisting on international fellowships, mostly in various European centers, while periodically returning to the Soviet Union and then quickly looking for another possibility to travel abroad for a research stay or an international conference. He spent some time in Cambridge with Ernest Rutherford and in Copenhagen with Niels Bohr.[20] Bohr's institute attracted visiting young postdocs from various countries, who formed the core of the new international community of quantum physicists and spread its gospel worldwide. There, Gamow entered new friendships, including a long-lasting one with the Hungarian Edward Teller, and found a new community to socialize in. He identified himself more and more as a transnational quantum physicist, a member of the international Copenhagen network, patronized by Bohr. Although not as rebellious as Soviet students, that youthful postdoctoral community was also appreciative of Gamow's humorous lifestyle and science. He found enough willing participants in and grateful spectators of his practical jokes and joking contributions to the otherwise important scientific publications (Fig. 1).

Back in the Soviet Union, Gamow was welcomed as a celebrity. The first among his cohort of young post-revolutionary students, he made a landmark contribution to physics and achieved international recognition. The official party newspaper *Pravda* even published a poem about his achievements, which became a source of further jokes among his friends. Half-seriously and half-playfully, they pushed for Gamow's election to the Soviet Academy of Sciences (he was, indeed, elected, as corresponding member just as he turned 28), and for a new research institute for theoretical physics under his directorship (more senior experimentalists did not let this happen). But he was more interested in travelling abroad, which was becoming harder and

20. After four months in Germany, Gamow went to Copenhagen from August 1928 to May 1929 with a Rask-Ørsted fellowship arranged by Bohr. He returned to Leningrad and received a Rockefeller fellowship that allowed him to stay in Western Europe for 22 months, until August 1931; Gamow, interview (ref. 12) and Hufbauer, "Gamow" (ref. 1). On the transnational community in quantum physics, see Alexei Kojevnikov, *The Copenhagen Network: The Birth of Quantum Mechanics from a Postdoctoral Perspective* (Berlin: Springer, 2020); Heráclio D. Tavares, Alexandre Bagdonas, and Antonio A. P. Videira, "Transnationalism as Scientific Identity: Gleb Wataghin and Brazilian Physics, 1934–1949," *HSNS* 50 (2020): 248–301.

FIG. 1. Having fun in Copenhagen. Landau on a cripple cart, Gamow on his motorcycle, Teller on skiis, playing with Niels Bohr's sons Aage and Ernst in front of Bohr's institute, 1931. *Source:* Courtesy of Niels Bohr Archive, Copenhagen.

harder each year, especially after the Nazis came to power in Germany and the specter of future wars started looming over Europe. Since the end of 1932, Soviet authorities dramatically cut the number of permissions for foreign travel. In his autobiography, Gamow flamboyantly described a couple of his daring attempts to cross the border illegally, which he made together with his wife Lyubov Vokhminzeva, nicknamed Rho. To his own surprise, he obtained official permission for both of them to travel to the Solvay conference in October 1933. He left for Brussels without intention of returning to the USSR, playing his last practical joke on the Soviet authorities and on senior colleagues who vouched for his political loyalty. Gamow's decision offended his friend Landau, who thought the motivation was a materialistic desire to cash in on his international success, and many other Soviet physicists, who blamed on Gamow's defection their fast disappearing chances for attending conferences abroad. Initially, Soviet diplomats permitted Gamow to extend his foreign stay for a year, but as the situation with his non-return dragged on, and international relations continued to worsen, Gamow would be expelled from the Soviet Academy in 1938, together with several other defectors, and had his Soviet citizenship revoked.[21]

The international world of science was already full of refugees from Nazi Germany, desperate even for temporary employment. Gamow's fame made his chances better than most, especially in America, where European theoretical physicists were highly valued. After several months in Paris, Cambridge, and Copenhagen, looking for a long-term job, Gamow decided to move to the USA. He was interested in collaboration with experimental nuclear physicists, especially in Berkeley, but Ernest Lawrence, according to Gamow, "wanted to have a good worker" and not just someone who thinks and talks.[22] George Washington University in Washington, DC, did not have a theoretical physicist and made Gamow an offer. He accepted on condition that the department would hire a second European theorist, his friend Teller, and give them funding to organize annual conferences. Together, they collaborated on a number of investigations in nuclear physics.[23] Their Washington conferences in Theoretical Physics were obviously modelled on the Copenhagen conferences, the meeting spot for the growing community of quantum theorists, with the hope to replicate a similar success in the USA.

The conferences met annually in 1935–1942 and 1946–1947 (Fig. 2). Gamow and Teller planned "no crowds, no formal papers, limiting the number of invited members to about a dozen," so that a small group of theoretical physicists could informally discuss mutually interesting problems and look for solutions.[24] The topic of the first Washington conference in April 1935 was the puzzle of beta-decay, which had also been discussed in Copenhagen a year earlier. Some physicists, including Bohr, were inclined to think that the difficulties could only be resolved by accepting that energy might not conserve in subatomic processes, but in 1930, Wolfgang Pauli proposed a different

21. Gamow, *My World Line* (ref. 6), 74; For the 1989 official rehabilitation of Gamow and others by the Soviet Academy of Sciences, see *Vestnik AN SSSR*, no. 2 (1990): 155–58.

22. Gamow, interview (ref. 12). Lawrence, like some other American physicists, was skeptical of Gamow's "speculative" contributions. "I am glad to hear that you are straightening out all the problems of the stars, but I think when you get things straight you will a short time later find them crooked again, but still it is nice that you are able to make sense of such speculative matters." Lawrence to Gamow, 1 Dec 1939 (GBGP, Gamowian Miscellany, Box 30).

23. George Gamow and Edward Teller, "Selection Rules for the β-Disintegration," *PR* 49 (1936): 895–99; "Some Generalizations of the Transformation Theory," *PR* 51 (1937): 289; "The Rate of Selective Thermonuclear Reactions," *PR* 53 (1938): 608–09; "Energy Production in Red Giants," *PR* 55 (1939): 791.

24. Gamow to Chandrasekhar, 12 Oct 1937, with an invitation to the 1938 conference (SCP).

TABLE 2

The Washington Conferences, 1935–1942*

Date	Topic	Total Sci. Attendance*
19–21 Apr 1935	Nuclear Physics	35
27–29 Apr 1936	Molecular Physics	60
15–20 Feb 1937	Elementary Particles	26
21–23 Mar 1938	Stellar Energy	34
26–28 Jan 1939	Low Temperature	53
21–23 Mar 1940	Interior of the Earth	56
22–24 May 1941	Elementary Particles	33
23–25 Apr 1942	Stellar Evolution & Cosmology	25

FIG. 2. Washington Conferences on Theoretical Physics. *Source:* Schweber, *Nuclear Forces* (ref. 32), 493.

solution, a hypothetical new particle, the neutrino, uncharged and with an almost undetectable mass. In 1934, Enrico Fermi developed this proposal further by suggesting a model of beta-decay as the transformation of a neutron into a proton, electron, and a neutrino. Gamow reviewed in *Nature* these and other attempts, still considering the neutrino hypothesis "rather doubtful."[25]

The immigrant Gamow and his wife arrived in the US on November 6, 1934, on board a steamer from Copenhagen, declared their intention to become American citizens in April 1936, and were naturalized on August 5, 1940. His generally unremarkable FBI surveillance file contains a typical set of contradictory reports. When interviewed by FBI agents, most American colleagues characterized him positively, as an important scientist and a loyal and patriotic citizen, who had come to America "because of his opposition to the Russian regime." "Dr. COMPTON said that he did not believe that GAMOW was particularly anti-communist yet he was extremely reluctant to live under such conditions that were being practiced by the Russians where his freedom of movement and action were restricted." At social gatherings, Gamow frequently told stories about his defection from the USSR, yet some still suspected that his escape "was planned by the Soviets" and that he could be a Russian spy. Another suspicious acquaintance withdrew herself from the circle of one of Gamow's friends citing "moral and social discomfort of being with them. By this I mean that the entire group in general had an entire lack of moral conduct. They had a 'European' attitude towards such things as sex and

25. "The Washington Conference on Theoretical Physics," *Science* 81 (1935): 395; George Gamow, "Modern Ideas of Nuclear Constitution," *Nature* 133 (1934): 744–47.

were most loose in thoughts and actions . . . They seemed to feel that they were forced to be with the American people whom they looked upon as barbarians culturally . . . Both George and Rho Gamow had only contempt for all conventional social and moral attitudes and also for the United States culturally." Another denunciation claimed that Gamow had a scientific collaboration with the Brazilian physicist Mário Schenberg, who after the war became a member of the Communist Party. During the war, Gamow was employed by military agencies in Washington, DC, and subsequently worked as consultant for the nuclear weapons center in Los Alamos. His postwar attitudes seemed to become much more anti-communist and even paranoid: reportedly, he refused to travel abroad out of fear of abduction by the Soviets.[26]

Although it is quite possible that Gamow continued to feel culturally European and socialized mostly with other immigrants, scientifically, he was adapting to American conditions much faster. At the time of his arrival in the mid-1930s, European theoretical and nuclear physics were still perceived in America as superior, although in reality this was no longer the case for the latter. By contrast, American astronomy and astrophysics did not suffer from such an inferiority complex. Within a couple years, Gamow's started combining the existing disciplines into a new hybrid field, nuclear astrophysics. As he rationalized in a later interview, he turned to nuclear theory in 1928 because "everybody was doing atomic and molecular structure, and van der Waals forces, and doublets and triplets and spin and so on—it was too much. I didn't want to get mixed up with all this, so I decided to choose myself a corner where nobody was doing anything." Similarly, once theoretical nuclear physics had become popular in its own right, he felt inclined to move elsewhere and do another "pioneering thing."[27] Gamow's changing research focus would shift consecutively to the problems of stellar energy and stellar evolution, the origin of chemical elements, and eventually to relativistic cosmology.

MR. GAMOW IN WONDERLAND

> "Which is more useful, the Sun or the Moon?" asks Kuzma Prutkov, the renowned Russian philosopher, and after some reflection, he answers himself: "The Moon is the more useful, since it gives us its light during the

26. It seems that even the FBI did not take Gamow too seriously, as a potential security risk. Federal Bureau of Investigation, Gamow's FOI file.

27. Gamow, interview (ref. 12).

> night, when it is dark, whereas the Sun shines only in the daytime, when it is light anyway."[28]

Gamow's Game: Nuclear Stars

The challenge to explain the source of the Sun's energy prompted Gamow to bring nuclear theorists into contact with astronomers and astrophysicists. As a further, unintended consequence, their joint efforts also opened the path toward the later development of the hydrogen bomb. In the 1920s, astronomers started applying theories of relativity and the quanta to describe processes inside stars. Gamow had also made an earlier attempt, together with his friends Bronstein and Landau, to understand stellar energy using Bohr's short-lived hypothesis of statistical conservation of energy.[29] By the mid-1930s, he became convinced that no known physical force other than nuclear could generate enough energy for the shining Sun. Nuclear theory by then had matured to enable a renewed attack on the problem. Gamow discussed the physics of stars with other nuclear physicists, including J. Robert Oppenheimer and a refugee from Germany, Hans Bethe.[30] Between 1937 and 1939, he with coauthors published a dozen articles on stellar theory and "played a catalytic part" in the fundamental discovery of the solar energy cycle, which Teller nicknamed the "Gamow Game":

> Under the influence of Gamow's prodding, a small group of physicists and astronomers met at George Washington University and the Carnegie Institution in Washington in the spring of 1938. We had one of those disorganized discussions that we call a conference, which seem to lead nowhere . . . did little more than pose the problems with some clarity, but the solution followed within the next few months. Hans Bethe, Charles

28. Gamow, *Birth and Death* (ref. 5), 1. Prutkov is a fictional character, a collective penname for a group of authors who wrote satirical essays in mid-19th century Russia.

29. Karl Hufbauer, "Astronomers Take Up the Stellar-Energy Problem, 1917–1920," *Historical Studies in the Physical Sciences* 11 (1981): 277–303; Hufbauer, "Landau's Youthful Sallies into Stellar Theory: Their Origins, Claims, and Receptions," *Historical Studies in the Physical and Biological Sciences* 37 (2007): 337–54; G. Gamow and L. Landau, "Internal Temperature of Stars," *Nature* 132 (1933): 567; Gamow to Bohr, 31 Dec 1932, in *Niels Bohr Collected Works*, vol. 9 (Amsterdam: Elsevier, 1986), 534–38.

30. Gamow and Oppenheimer met a few times at conferences and at Oppenheimer's family ranch in New Mexico. In 1938, Oppenheimer decided to investigate the problem of stellar collapses that resulted in his pathbreaking paper on black holes: Karl Hufbauer, "J. Robert Oppenheimer's Path to Black Holes," in *Reappraising Oppenheimer: Centennial Studies and Reflections*, ed. Cathryn Carson and David A. Hollinger (Berkeley: Office for History of Science and Technology, University of California, 2005), 31–47.

> Critchfield, and Gamow succeeded in determining not only what reactions keep the stars going, but also in reconstructing how stars develop, change their appearance, and finally exhaust their sources of energy. The most remarkable part of this job was done by Bethe, who . . . found that, in addition to the possibility of hydrogen nuclei reacting with each other, one has to consider the reactions between hydrogen and carbon nuclei . . . Gamow had invented a new kind of game for the physicists, and Bethe proved to be the champion at it.[31]

Bethe attended the Washington conferences from 1935 to 1939. Initially he was uninterested in astrophysics and did not plan to participate in 1938, but was persuaded to come by Teller and later described the meeting as the most important conference in his life. He learned about important advances in astrophysics and met Critchfield, a George Washington University graduate student who was working on stellar energy and with whom Bethe started collaborating on the problem.[32] According to Gamow's jocular account, Bethe found the correct cyclical sequence of nuclear reactions thanks in part to his healthy appetite, while riding a train on his return trip from the 1938 Washington conference.[33] The successful solution of the riddle of solar energy enabled the development of nuclear astrophysics, including Gamow's further investigations into what nuclear reactions were possible at various stages and in different types of stars, and his concurrent popular account of the new research field in *The Birth and Death of the Sun* (Figs. 3, 4).

Initially, he thought of writing a scholarly monograph on the Sun's energy and stellar evolution, and in March 1939, sent a letter to the Chicago astronomer and fellow Russian émigré, Otto Struve, inquiring about such possibility.[34] Citing financial constraints of his astronomical series, Struve could

31. Edward Teller, "The Work of Many People," *Science* 121 (1955): 267–75, on 268; Harper, "In Appreciation" (ref. 12); David DeVorkin, "The Changing Place of Red Giant Stars in the Evolutionary Process," *Journal for the History of Astronomy* 37 (2006): 429–69.

32. Hans Bethe, "Influence of Gamow on Early Astrophysics and on Early Accelerators in Nuclear Physics," in *Gamow Symposium* (ref. 12), 45–48; Karl Hufbauer, "Stellar Structure and Evolution, 1924–1939," *Journal for the History of Astronomy* 37 (2006): 203–27; Silvan S. Schweber, *Nuclear Forces: The Making of the Physicist Hans Bethe* (Boston: Harvard University Press, 2012), 345, 493.

33. "Hans Bethe is not the man to miss a good meal simply because of some difficulties with the Sun and, redoubling his efforts, he had the correct answer at the moment when a passing dining-car steward announced the first call for dinner." Gamow, *Birth and Death* (ref. 5), 112.

34. Gamow to Struve, 13 and 20 Mar 1939; Struve to Gamow, 18 Mar 1939 (Struve Papers, NBLA). Pascal Covicci invited Gamow to write a popular book about the Sun for the Viking

FIG. 3. Participants in the 4th Washington Conference on theoretical physics, March 1938. *Source:* Special Collections Research Center, George Washington University Libraries.

only offer a short book with no honorarium or royalties. Gamow then turned to Oxford's Clarendon Press that published his earlier monograph *Constitution of Atomic Nuclei and Radioactivity*, but eventually, probably for pecuniary reasons, settled on writing a popular book for Viking Press. By the standards of the time, this was rather unconventional, as Jane Gregory explained in the case of Fred Hoyle, whose situation as a cosmologist and

Press. Of Gamow's more than twenty books, the majority would be published by the Viking Press or Cambridge University Press. He often offered the same book to more than one publisher: Gamow to Covicci, 21 Mar 1964 (GBGP); Gamow, *My World Line* (ref. 6), 157.

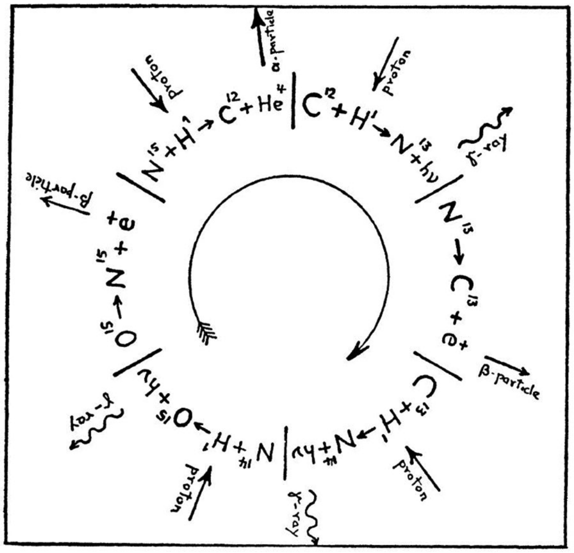

FIG. 4. The Carbon-Nitrogen cycle of nuclear reactions fueling the Sun's energy. *Source:* Gamow, *Birth and Death of the Sun* (ref. 5), 114. Courtesy of Igor Gamow and the George Gamow Memorial Fund.

popularizer in the 1950s UK, and financial motivations to write for general audiences, were similar to Gamow's in the US:

> Popularizing science was a risky activity, especially for a young scientist in a controversial field. According to its critics, popularization demeaned science; and it unduly magnified the work of the popularizer in comparison with that of his colleagues, and gave minority viewpoints undeserved prominence . . . "[Popularization] was frowned on very heavily by the scientific establishment of the day, so it was a tug of war between what one might earn with a young family, and incurring the unpopularity. If you were incomprehensible to the public that was OK, but if there was any appreciation by the public that was regarded as very bad."[35]

Gamow's book, which appeared in 1940, included the most recent developments in nuclear physics and its astrophysical applications: the 1939 discovery of uranium fission by Otto Hahn and Lise Meitner, Weizsäcker's and Bethe's discussions of carbon-nitrogen cycle inside the Sun, and Gamow's

35. Jane Gregory, *Fred Hoyle's Universe* (Oxford: Oxford University Press, 2005), 59. Gregory quotes her interview with Hoyle in 1993.

own, with Teller, theory of nuclear reactions in red giants. In addition to the Sun, it discussed other types of stars and their evolution—red giants, white dwarfs, supernovae—but not black holes, which Gamow consistently ignored. He offered further thoughts on the possibility of harnessing the energy of fission and nuclear explosions, as well as speculations on the distant past and future of the Sun and the solar system, of the universe as a whole, and of the Earth and its climate change. Ostensibly and primarily, the book was written for lay audiences, but Gamow also expected it to be read by his academic peers in lieu of a scientific discussion. He expressed his own, often peculiar opinions on several unresolved controversies and discussed the manuscript in correspondence with other scientists, soliciting their opinions. Unlike nuclear physicists, astronomers did not easily accept Gamow into their own professional domain. This did not discourage him from many repeated attempts at collaboration and from inviting astronomers to the Washington conferences. During this period, Gamow corresponded intensively with several leading astronomers, especially those who worked at Yerkes Observatory: Struve, Gerard Kuiper, and especially Subrahmanyan Chandrasekhar. In his book, Gamow referred with humor to astronomers' misgivings and presented his own unorthodox view of the history of astrophysics and cosmology, all the while warning the reader to not take his jokes too literally.[36]

Violating further academic conventions and the accepted hierarchy between the genres, Gamow continued scientific polemics with astronomers in the popular format.[37] Without much argument, he dismissed the opinion of James Jeans that gaseous nebulae had separated from each other to form protogalaxies before the stars were born. Gamow claimed that his own and Teller's research supported the opposite scenario that stars were formed prior to the galaxies. Not surprisingly, his astronomical opponents disliked such a cavalier style of scientific polemics, preferring debates in professional publications. Others, such as Chandrasekhar and Struve, praised Gamow's popularization while

36. "Though the author cannot conclude this preface with the customary statement that 'all the characters appearing herein are purely imaginary and have no connection with any living person,' it is perhaps best that he warn the reader against giving too great credence to such minutiae in the following pages as the untidiness of Democritus' beard, the rainy weather in Princeton at the time of the construction of the Russell diagram, and the relationship between Dr. Hans Bethe's famous appetite and his rapid solution of the problem of solar reaction." Gamow, *Birth and Death* (ref. 5), viii.

37. On these conventions and the continuous spectrum of intermediate genres between the specialized and the popular, see Stephen Hilgartner, "The Dominant View of Popularization: Conceptual Problems, Political Uses," *Social Studies of Science* 20 (1990): 519–39.

noting a few astronomical mistakes and historical inaccuracies.[38] The English astronomer William H. McCrea called Gamow's book an "irritating piece of brilliant writing . . . because of the impossibility of identifying the reader to whom it is addressed" and because of the mixture of basic knowledge with technically complicated discussions about very recent and still unfinished research. He considered Gamow an "ideal author" for a potential scholarly monograph on the use of nuclear physics in stellar theory, which could be reviewed by astronomers and only then popularized. Gamow did try to write a scholarly book on the topic, but it was hard for him to master the finer astronomical technicalities.[39]

Mr. Tompkins's Universe: Relativistic Cosmology

> Alice laughed. "There's no use trying," she said. "One can't believe impossible things." "I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."[40]

Two months after the 1938 conference, Gamow travelled to Europe where he had two encounters crucial for his subsequent shift to relativistic cosmology. He stopped in Berlin, where he met the nuclear physicist Carl Friedrich von Weizsäcker, who had independently discovered the carbon-nitrogen cycle for solar energy. Weizsäcker learned from Gamow about Bethe's solution of the problem, while Gamow, in return, learned about Weizsäcker's cosmological model that envisioned a violent primordial universe in which nuclear reactions

38. Otto Struve, *AJ* 92, 319; Gerard F. W. Mulders, *Publications of the Astronomical Society of the Pacific* 53 (1941): 56–58; S. Chandrasekhar, "Galactic Evidences for the Time-Scale of the Universe," *Science* 99 (1944): 133–36.

39. "The quasi-historical treatment is definitely misleading . . . since it gives the illusion that each department of the work has been more or less a one-man show." W. H. McCrea, *The Observatory* 64 (1942): 206–07. McCrea's review of Gamow's *Mr. Tompkins* book was, on the contrary, quite positive, mentioning only "one or two lapses" in Professor's lecture about general relativity. McCrea, "'Mr. Tompkins in Wonderland' by G. Gamow," *The Mathematical Gazette* 24 (Feb 1940): 62–63. Gamow discussed his difficulties in writing a technical book and its first three chapters in correspondence with Chandrasekhar in 1940 (SCP). He later published these chapters in George Gamow and C. L. Critchfield, *Theory of Atomic Nucleus and Nuclear Energy-Sources* (Oxford: Clarendon Press, 1949).

40. Lewis Carroll, *Alice in Wonderland*, as cited in George Gamow, "The Negative Proton," *Nature* 135 (1935): 858–61, on 858.

were producing chemical elements.[41] Gamow then proceeded to a conference in Warsaw on "New Theories in Physics," where an encounter with the English physicist Charles Galton Darwin set him on the path of becoming a prolific popular science writer. Upon hearing about Gamow's difficulty in finding a suitable magazine for a short popular science story, Darwin advised him to contact C. P. Snow, the editor of *Discovery, A Monthly Popular Journal of Knowledge*, which endeavoured to build a bridge between the literary and the scientific cultures.[42] In December 1938, Gamow published in Snow's magazine the first adventure of Mr. Tompkins, "Toy Universe," with the model of a relativistic, expanding and contracting universe.

Einstein's relativity was under attack in Nazi Germany, and Weizsäcker did not rely on it in his theory, using instead an alternative, non-relativistic model proposed in 1933 by the British astrophysicist Edward Milne, in which the universe was expanding in the Euclidean flat, static, and infinite space. Gamow certainly preferred cosmology based on general relativity, which he had learned from Friedmann in 1923, and in 1937, taught in his own graduate course "Gravitation and Cosmology" at George Washington University.[43] In early 1938, he wrote "a short, scientifically fantastic story (not a science fiction story) in which [he] tried to explain to the layman the basic ideas of the theory of curvature of space and the expanding universe." He sent it to "more than a dozen" American magazines, but none of them accepted it.[44] Its publication in *Discovery* was very well received, and Gamow started producing sequels at a rate of about one per month, popularizing relativity, quantum mechanics, and cosmology. In March 1939, he collected six stories under one cover and

41. Carl Weizsäcker, interview by Karl Hufbauer, 18 Apr 1978 (NBLA) http://www.aip.org/history/ohilist/4948.html.

42. "Our object, then, is to give readers an interest both in the Sciences and the Humanities by making the work of both as plain as possible. Whether we fail or not remains to be seen. We mean to try." *Discovery: A Monthly Popular Journal of Knowledge*, ed. A. D. Russell, no. 1 (Jan 1920): 3. C. P. Snow would subsequently become famous for his 1959 essay on a related theme, "The Two Cultures."

43. Hufbauer, "Gamow" (ref. 1), 21. Edward Milne, "World-Structure and the Expansion of the Universe," *Zeitschrift für Astrophysik* 6 (1933): 1–35.

44. Preface to the 1965 edition of *Mr. Tompkins in Paperback* (ref. 2). Gamow's term "scientifically fantastic" was the literal translation of the Russian term for science fiction, *nauchnaia fantastika*. The main difference between science fiction in English and the Soviet genre of "scientific fantasy" was that the latter's plots and ideas were not completely imaginary, but usually connected to some real or perceived possibilities of the actual science of the day. The name Tompkins, which Gamow considered funny, was inspired by the name of a graduate student whom Gamow met in 1935. Gamow, interview (ref. 12).

FIG. 5. Mr. Tompkins, the Professor, and the Toy Universe. *Source:* Gamow, *Mr Tompkins in Wonderland* (ref. 2), 4. Courtesy of Igor Gamow and the George Gamow Memorial Fund.

signed the preface to his first popular book, *Mr. Tompkins in Wonderland: or, Stories of c, G, and h*. The three fundamental physical constants, c, G, and h, from his earlier paper with Landau and Ivanenko became the initials of the main character of the series, Mr. C. G. H. Tompkins, a curious bank clerk whose weird dreams were inspired by physics lectures given by the Professor. The "Wonderland" referred to an imagined world in which the values of physics constants could change, an allusion to *Alice in Wonderland*, enjoyed and quoted by Gamow in one of his earlier nuclear physics papers. Like Mr. Tompkins's, Alice's adventures included changing her own dimensions vis-à-vis other objects, only to understand in the end that it was simply her dream.

The first of Mr. Tompkins's dreams happened during the Professor's lecture on general relativity. Feeling confused by its complicated content, Mr. Tompkins dozed off and woke up on a little rock in space. He soon discovered that he had been relocated to a very small planet, together with the Professor, who remained engaged in calculations. The Professor explained that their new universe was curved and much smaller than the "real one," where the rest of humanity lived, and for this reason, was also expanding and contracting at a faster rate (Fig. 5):

> Each universe pulsates between a very small and a very large radius. For the big universe the period is rather large, something like several thousand million years, but our little one has a period of only about two hours. I think we are now observing the state of largest expansion.[45]

A pulsating or "periodic" world was one of the three main classes of cosmological solutions found by Friedmann in 1922, which "unwittingly reminded [him] of the Indian mythology of life's periods."[46] Friedmann perceived such a solution—"the creation of the world from nothing" and its subsequent destruction—as the most likely model of the real universe and estimated its life period as ten billion years. Gamow's "toy universe" added another remarkable feature—its temperature oscillated in counterphase with its size, as explained by the Professor:

> "Do you notice how cold it is? In fact, the thermal radiation filling up the universe, and now distributed over a very large volume, was giving only very little heat to their little planet, and the temperature was at about freezing point. It is lucky for us," said the professor, "that there was originally enough radiation to give some heat even at this stage of expansion. Otherwise it might become so cold that the air around our rock would condense into liquid and we would freeze to death. But the contraction has already begun, and it will soon be warm again . . . [T]he temperature will rise so high that we shall both be dissociated into separate atoms. This is a miniature picture of the end of the big universe—everything will be mixed up into a uniform hot gas sphere, and only with a new expansion will new life begin again."[47]

In later books, Gamow illustrated the process of cosmological expansion with the help of Arthur Eddington's balloon analogy. He also estimated that in the "embryonic stage of the universe," all matter would be squeezed down to the maximum density of an atomic nucleus and contained within an

45. Gamow, "Toy Universe" (ref."2), 438.

46. A. Fridman, *Mir kak prostranstvo i vremia* (Peterburg: Academia, 1923), 122. On cyclic models, see Helge Kragh, "Continual Fascination: The Oscillating Universe in Modern Cosmology," *Science in Context* 22 (2009): 587–612.

47. Gamow, "Toy Universe" (ref. 2), 438. A reviewer objected that the Professor "has been unjustifiably dogmatic about the pulsation of the actual universe; most workers would not agree with his positive assertion that the expansion of the universe must stop after a certain time." McCrea, "Mr. Tompkins" (ref. 39). In later editions of *Mr. Tompkins in Paperback* (ref. 2), the factual error pointed by McCrea, that the Andromeda nebula shows a small blueshift and not a redshift, still remained uncorrected.

astronomically very small volume.[48] The concept of oscillating temperature was inspired by Einstein and Richard C. Tolman. In 1931, after a visit to Pasadena where he had discussions with Tolman and Hubble, Einstein abandoned his earlier static cosmological model and accepted the correctness of Friedmann's. Among various possible scenarios, he preferred the single cycle of expansion followed by contraction back into a point. Tolman was more inclined to interpret this solution as periodic, and he also added thermodynamic considerations, discussing in his 1931 paper on whether the process could be reversible.[49] He argued that "the expansion and contraction of the Einstein model would not be accompanied by an increase in entropy and hence could presumably be repeated over and over again." Tolman discussed several physical models of such a universe: with and without matter, containing only black-body radiation, as well as an equilibrium mixture of radiation and a perfect monatomic gas. For the universe filled with black-body radiation, assuming adiabatic expansion, Tolman derived a formula connecting the temperature and the scale factor of the universe. Gamow's Professor probably got it from Tolman's 1934 book.[50]

As he was inventing further adventures of Mr. Tompkins, Gamow developed some new cosmological ideas on galaxies' formation in an expanding universe. On December 15, 1938, he submitted a preliminary letter to *Nature*, coauthored with Teller, and sent a copy of the manuscript to Tolman and Howard Robertson at Caltech, two of the very few physicists who worked on relativistic cosmology in the 1930s:

48. Arthur S. Eddington, *The Expanding Universe* (Cambridge: Cambridge University Press, 1933), 33. Gamow entertained different estimates for the minimal size of the universe: "only 10 times larger than the orbit of Neptune" (10^8) in *Birth and Death* (ref. 5), 229; "only about eight Sun radii" (10^7) in George Gamow, *One, Two, Three . . . Infinity: Facts & Speculations of Science* (New York: Viking Press, 1947), 332; "3 million miles, i.e., ten times the radius of the orbit of the moon!" (10^6) in Gamow, *Atomic Energy in Cosmic and Human Life: Fifty Years of Radioactivity* (Cambridge: Cambridge University Press, 1946), 85; and "about 9 miles" in *Creation of the Universe* (ref. 5), 51.

49. Richard C. Tolman, "On the Theoretical Requirements for a Periodic Behavior of the Universe," *PR* 38 (1931): 1758–71, on 1761, 1768. On Einstein's model, see C. O'Raifeartaigh and B. McCann, "Einstein's Cosmic Model of 1931 Revisited: An Analysis and Translation of a Forgotten Model of the Universe," *EPJH* 39 (2014): 63–85; Harry Nussbaumer, "Einstein's Conversion from his Static to an Expanding Universe," *EPJH* 39 (2014): 37–62.

50. Richard C. Tolman, *Relativity, Thermodynamics, and Cosmology* (Oxford: Clarendon Press, 1934), equation 171.6 on 428. Ten years later, Tolman's formula with a proper citation appeared in George Gamow, "The Evolution of the Universe," *Nature* 162 (1948): 680–82, on 681.

> I hope you have noticed my recent contribution to the problem of the expanding universe. It is printed in *Discovery* and is entitled "Mr. Tompkins in Wonderland, I. Toy Universe." But [*sic*] writing this fantastic story I became really interested in the recession of nebulae and as the result of discussions about it with Teller we came to a number of interesting results about which I would like to know your opinion.[51]

Gamow's first scholarly entry into relativistic cosmology was rather cautious, taking a back seat to the more empirically grounded, astrophysical problem of the origin of the receding great nebulae observed by Edwin Hubble. In 1929, Hubble had measured a linear relation between galactic redshifts and their distance from the Earth. Einstein and other theoreticians understood his results as the experimental confirmation of the general relativistic model of the expanding universe. Hubble, however, remained for a long time unconvinced by such interpretation, in part, due to his empiricist reservation against extrapolating from the limited observable space to the entire universe as a whole, and also because of the troubling numerical contradiction. The then observable rate of the expansion rendered the total age of the universe about two billion years, a "suspiciously short time scale," which was shorter than many other astronomical and geological estimates, for example, the age of the Earth.[52]

In the main, astrophysical part of their paper, Gamow and Teller formulated conditions for how, despite the expansion according to Hubble, the matter could still condense into galaxies: (1) the velocity of recession of nebulae had to be smaller than the thermal velocity of particles; and (2) the gravitational potential energy had to be larger than kinetic energy. The necessary density of matter had to exceed approximately 600 times the present density of the universe, which happened about one billion years ago, and "the velocity of particles at the moment of formation of nebulae necessary to secure the observed dimensions of nebulae" would require temperatures of several million degrees.[53] Assuming that such high temperatures could only be achieved in stars, they

51. George Gamow and Edward Teller, "The Expanding Universe and the Origin of the Grand Nebulae," *Nature* 143 (1939): 116–17; Gamow to Robertson, 15 Dec 1938 (Robertson Papers, Box 2, Folder 31, California Institute of Technology Archives). He sent the same letter to Tolman.

52. Edwin Hubble, "A Relation Between Distance and Radial Velocity among Extra-galactic Nebulae," *Proceedings of the National Academy of Sciences* 15 (1929): 168–73; Edwin Hubble, *The Realm of the Nebulae* (New Haven, CT: Yale University Press, 1937); Stephen G. Brush, "Cautious Revolutionaries: Maxwell, Planck, Hubble," *American Journal of Physics* 70 (2002): 119–27, on 124.

53. Gamow and Teller, "The Expanding Universe" (ref. 51), 116.

concluded that "the formation of stars took place before the formation of the great nebulae." This brought them, in the subsequently revised, longer version of their paper in *Physical Review*, into further polemics with Jeans, who had defended the opposite theory that galaxies were formed prior to stars: "if we assumed that particles participating in the formation of nebulae were gas molecules, the temperature of the gas must have been around one million degrees. At such temperatures and at densities . . . in nebulae the mass of the radiation would be more than 10^9 times that of matter."[54] Their comparison between the density of matter and the density of radiation in an expanding universe would become more important in the late 1940s for Gamow's model of the hot big bang, where it would lead to the prediction of the cosmic background radiation.

Only "Cosmological Consequences," the last section of their paper, dealt with relativistic cosmology in the proper sense. Gamow's initial, pulsating "toy universe" of 1938 was a finite, closed world with positive curvature. A light ray emitted by Mr. Tompkins would return to the point of emission from the opposite side, thus allowing to see "your hair cut on the back of your head without any mirror, but only milliards of years after you had been to the barber."[55] But more careful estimates allowed Gamow and Teller to reach the opposite conclusion, that the real universe had a negative spatial curvature and was, therefore, infinite, and expanding forever into the future (another class of Friedmann's cosmological scenarios of 1922). In the acknowledgments to their paper, Gamow and Teller "express[ed] thanks to Mr. C. G. H. Tompkins for having suggested the topic of this paper and to H. A. Bethe for valuable discussions."[56] Almost simultaneously, in Mr. Tompkins's sixth dream, his last adventure published in the May 1939 issue of *Discovery*, Gamow popularized this new cosmological conclusion. While explaining the concept of curved space, the

54. James Jeans, "The Expanding Universe and the Origin of the Great Nebulae," *Nature* 143 (1939): 158–59; Gamow and Teller, "On the Origin of the Great Nebulae," *PR* 55 (1939): 654–57, on 656. In 1948, Gamow accepted some of Jeans' criticism by using the latter's more rigorous formula for nebular condensations in George Gamow, "The Evolution of the Universe," *Nature* 162 (1948): 680–82, on 682.

55. Gamow, "Toy Universe" (ref. 2), 437. As he combined short stories into *Mr. Tompkins in Wonderland* in March 1939, Gamow added the "Appendix" with Professor's lectures that motivated Mr. Tompkins's dreams. In the lecture "Curved Space and Gravitation," Professor explained the mathematical concept of curved space and the conditions for universes with positive and negative curvatures.

56. Gamow and Teller, "On the Origin of the Great Nebulae" (ref. 54), 657. They cited Tolman's *Relativity, Thermodynamics, and Cosmology* (ref. 50) and assumed the cosmological constant to be zero.

Professor remarked casually: "It was usually accepted that our universe is finite and closed in itself, but two young physicists have shown, some weeks ago in an article in *Nature*, that the universe is infinite and has a negative curvature." Without any additional argument, Gamow cited the same conclusion in *The Birth and Death of the Sun*: "We shall, therefore, have to be satisfied with the observation that, according to the most recent investigations, our space seems to be infinite and rapidly expanding into infinity. So much the better!"[57]

Gamow's preferred cosmological model thus changed from a finite and pulsating world to the infinite one with only one moment in time, several billion years ago, when the expansion started. This expansion would continue indefinitely and was preceded, Gamow believed, by the infinite contraction and collapse. His argument for the infinite, open universe contradicted the opinion of Hubble and Tolman, who had argued in 1935 that "the observed density-distribution of nebulae in space shows thinning out at greater distances, thus leading to a positive curvature and a closed cosmological model." Gamow and Teller disputed that conclusion as based on an arbitrary assumption that nebulae's luminosity remains the same "even if their ages differ by hundreds of millions of years." In their view, even a "slight decrease of total luminosity with age" could result in a different sign for the curvature of space.[58] Later in 1943, Gamow wrote to Chandrasekhar seeking additional astrophysical help for his position:

> [I]t would be highly desirable to have negative curvature . . . If nebulae were 10% brighter in the past, this would change the age estimate that could be larger and could lead to negative curvature . . . [O]ne simple argument is the loss of stars for surrounding space. Can you tell me what will be the half-life time of an average spiral nebulae if one takes into the account gravitational friction? Can the "evaporation" of stars bring down their number by the amount of 10%, say, in 2 billion years?[59]

57. Gamow, *Mr. Tompkins in Wonderland* (ref. 2), 49; *Discovery Magazine* (May 1939), 233; *Birth and Death* (ref. 5), 229. The "Appendix" (ref. 55) still mentioned both possibilities: the finite and closed, "so-called pulsating worlds," or "infinite saddle-like spaces in permanent state of contraction or expansion," adding that "so far astronomical evidence has definitely shown that our space is expanding, although the question whether this expansion will ever turn into a contraction, and whether the space is finite or infinite in size is not yet definitely settled." In all his subsequent books, until the late *Matter, Earth, and Stars* (Englewood Cliffs, NJ: Prentice-Hall, 1958), 552, Gamow popularized the concept of open, infinitely expanding universe with a negative curvature.

58. Edwin Hubble and Richard C. Tolman, "Two Methods of Investigating the Nature of the Nebular Redshift," *AJ* 82 (1935): 302; Gamow and Teller, "On the Origin" (ref. 54), 657.

59. Gamow to Chandrasekhar, 27 Oct 1943 (SCP).

After his first foray into the field of relativistic cosmology in 1939, Gamow would not publish further scholarly articles in this field until 1946, but he continued elaborating on his ideas in popular writings. With his transition to astrophysical and cosmological topics, Gamow's use of popular science became multifaceted. He was not merely disseminating post-factum the already established knowledge, but used the medium to promote his preferred positions in ongoing scientific controversies, to offer additional arguments in a hope to convince opponents or skeptics, and to convert additional supporters. He was also broadcasting some of his dearest scientific hypotheses prematurely, sometimes several years before he would publish them in research papers. This allowed him to express ideas for which he did not yet have sufficient proofs and possibly to avoid the barrier of peer-reviewing. Gamow's attempt to argue not only to laymen, but at the same time also to physicists and astronomers via popular channels, did not seem to be working, at least initially. The Caltech physicists were not very impressed by Gamow's speculations concerning the expanding universe and the origin of nebulae.[60] It appears that recourse to popular media was not helping Gamow's standing among professional astronomers and cosmologists, but only confirmed the curse of popularizers as formulated by Gregory in the case of Hoyle.

FROM "METAPHYSICAL SPECULATION" TO "UNQUESTIONABLE TRUTH"

> "Enough!" the reader has by now certainly exclaimed. "After all, this book is supposed to be based on certain physical realities. But all this talk of the universe's being formed from a superdense and superhot gas sounds very much like metaphysical speculation!"[61]

60. His first peer-reviewed paper that combined nuclear physics with relativistic cosmology: George Gamow, "Expanding Universe and the Origin of Elements," *PR* 70 (1946): 572–73. Robertson did not reply to Gamow's letter of December 15, 1938. Gamow wrote him again on January 8, 1939, assuming the first letter "was stolen by the spies of some foreign power"; Robertson Papers (ref. 51). In their responses, dated January 16 and February 3, respectively, Robertson and Tolman expressed reservations. Tolman felt it "premature and ad-hoc at the present time to try to explain excess nebular counts at great distances by assuming higher luminosities for the nebulae, say 10^8 years ago." Both advised Gamow to compare his results with Georges Lemaître, "Evolution of the Expanding Universe," *Proceedings of the National Academy of Sciences* 20 (1934): 12–17. In their subsequent paper, Gamow and Teller cited a "similar formula" for the expression of critical density that had been derived by Lemaître, but interpreted differently. Gamow and Teller, "On the Origin" (ref. 54), 655.

61. Gamow, *Birth and Death* (ref. 5), 228.

"Primordial Pressure Cooker": Origins of Chemical Elements

The "alchemical" origin of chemical elements, or the "cooking problem," had its roots in the work by Gamow and friends, with whom in 1929 he went on a skiing adventure in the Alps. In discussions during that trip, Fritz Houtermans and Robert d'Escourt Atkinson reversed Gamow's quantum tunnelling theory of radioactive decay to investigate the opposite process of nuclear synthesis. They found that α-particles were inefficient as projectiles, but bombardment with protons looked more promising. Protons could penetrate the nucleus much easier and interact with it, allowing, in principle, reactions of two types: either the splitting of a heavy nucleus by an incident high-energy proton, or the absorption of the proton resulting in the synthesis of a heavier element. The former option was realized experimentally, on Gamow's advice, in 1932 in Cambridge and later that year also in the Ukrainian Physico-Technical Institute in Kharkov.[62] The latter option could potentially take place in the hot and dense interior of the Sun as the fusion of hydrogen into helium and subsequent, step-by-step production of progressively heavier elements. Atkinson and Houtermans joyfully titled their paper "How to cook a helium nucleus in a potential pot?" but, complained Gamow, "the title was changed to a more conventional one by the magazine's editor, who had no sense of humor."[63] As Gamow admitted many years later, several calculational mistakes cancelled each other out, thus making the final result meaningful. The conclusion was encouraging, but in a rather limited sense: "only the lightest elements are easily transformed by proton-bombardment under the conditions governing in the interior of stars."[64]

The 1932 discovery of the neutron added further possible nuclear reactions to the list and, importantly, a much more efficient projectile. In April 1935, participants at the first Washington conference discussed the problem of radioactive beta-decay, which Gamow thought could also provide a mechanism for the creation of heavier elements in stars. He proposed that more complex

62. Ibid., 74–76. Gamow's discussions with Rutherford encouraged the latter's students John Cockroft and Ernest Walton to construct an accelerator of high–energy protons in Cavendish Laboratory and to successfully produce the nuclear splitting of lithium into helium. See Schweber, *Nuclear Forces* (ref. 32), 343; John Cockcroft, "Nobel Lecture" (1951).

63. Gamow, *My World Line* (ref. 6), 70–73. R. D. E. Atkinson and Friedrich Georg Houtermans, "Zur Frage der Aufbaumöglichkeit der Elemente in Sternen," *ZP* 54 (1929): 656–65; Kragh, *Cosmology and Controversy* (ref. 4), 85–86; Hufbauer, "Gamow" (ref. 1), 18.

64. George Gamow, "Nuclear Transformations and the Origin of the Chemical Elements," *The Ohio Journal of Science* 35 (1935): 406–13, on 409.

nuclei could be produced through the capture of a neutron and the latter's subsequent transformation into a proton, with an emission of a β-particle. Later that year he published his first paper on the origin of chemical elements, hoping that this hypothesis would lead to "a complete explanation of the relative abundance of different elements in the universe."[65]

During his 1938 European trip, Gamow held discussions with Weizsäcker regarding the two related problems, the stellar energy and the origin of elements. Weizsäcker likewise came to the conclusion that nuclear reactions in the stars could lead to the creation of the lightest elements, but not those beyond oxygen. He further calculated that the nuclear synthesis of heavy chemical elements required such high densities and temperatures (on the order of 10^{11} K) that did not exist inside normal stars nor, generally, in the present state of the universe. In an article published in June 1938, Weizsäcker argued that heavy elements originated during an earlier, much more violent era of the universe, when huge conglomerations of matter, probably consisting of hydrogen, collapsed under the force of gravity. Nuclear reactions in that extremely dense state could destroy huge stars and provide remaining fragments with velocities of the order of 10 percent velocity of light, close to the velocities of receding nebulae.[66] Weizsäcker's model used classical space-time, not even special relativity, but Gamow, upon his return to the USA, combined Weizsäcker's argument with relativistic cosmology. He was involved in writing *The Birth and Death of the Sun*, which concerned mostly nuclear reactions, solar energy, and the evolution of different types of stars, but in the last chapter Gamow introduced the Hubble recession of distant galaxies, the concept of a relativistic, expanding universe, and conditions that were conducive to nucleosynthesis:

> The story begins with space uniformly filled with an unbelievably hot and dense gas, in which the processes of the nuclear transformation of the various elements went on as easily as an egg is cooked in boiling water. In this "prehistoric" kitchen of the universe, the proportions of the different chemical elements were established . . . To this early epoch also belongs the formation of the long-lived radioactive elements, which even at the present time have not yet quite decayed. Under the action of the tremendous pressure of this hot compressed gas, the universe began to expand, the density and the temperature of matter slowly declining . . . [67]

65. Ibid., 413. See also Gamow, *Birth and Death* (ref. 5), 84.

66. Carl Weizsäcker, "Über Elementumwandlungen im Innern der Sterne, II," *Physikalische Zeitschrift* 39 (1938): 633–46, on 644; Weizsäcker, interview (ref. 41).

67. Gamow, *Birth and Death* (ref. 5), 230.

At that juncture, Gamow could not yet offer any detailed calculations, and admitted, half-jokingly, that the picture looked too hypothetical, but added: "There is, however, a good physical reality that strongly supports, if it does not actually prove the truth of these seemingly metaphysical speculations about the very first stages of the development of our universe." His first argument relied on the present existence of radioactive elements uranium and thorium. Had the universe been much older than a few billion years, Gamow reasoned, these elements would have already decayed completely and could no longer be found in nature. He considered it important and not accidental that independent estimates for the oldest objects based on various sets of data and disciplines (astronomical, geological, radioactive) all converged on approximately several billion years.[68] The contradiction that bothered Hubble, that the then available astronomical measurements of galactic expansion pointed toward the cosmological era being even shorter than the geological age of the Earth, did not worry Gamow too much. He believed that the measurements would eventually be corrected or explained away. Gamow's second suggestive argument relied on Weizsäcker's:

> The recent investigations of the young German physicist Carl von Weizsäcker have definitely proved that the formation of such heavy elements as uranium and thorium could have taken place only under the physical conditions of enormously high densities and temperatures . . . As such extreme conditions could not be found even in the central regions of the hottest stars, we are forced to look for them in the early superdense and superhot stages of the universe.[69]

Two years later, the cosmological "cooking problem" made its first appearance in Gamow's scholarly publication, but by that time his main hypothesis had changed significantly, mostly due to the novel concept of uranium fission. The early stage of the universe, Gamow came to believe, was not a superhot gas, but a superdensely packed nuclear matter, essentially one giant nucleus

68. Ibid., 227–28. In his popular books, Gamow provided various, gradually improving estimates for the age of the world: radioactive elements and redshift-distance relation in *Birth and Death* (ref. 5), 228; ages of the earth, the oceans, and the moon in *Biography of the Earth* (ref. 5), 1–9; estimated ages of various astronomical objects in *Atomic Energy* (ref. 48), 75–80, and in *One, Two, Three . . . Infinity* (ref. 48), 328; and the final and most complete set of estimates in the first chapter of *Creation of the Universe* (ref. 5), 20.

69. Gamow, *Birth and Death* (ref. 5), 228.Chandrasekhar expressed a similar attitude toward the contradictory estimates regarding the age of the universe: S. Chandrasekhar, "Galactic Evidences for the Time-Scale of the Universe," *Science* 99 (1944): 133–36.

that came about when all previously existing atoms were crushed into each other by the cosmological contraction, so that individual atoms could no longer survive, electrons were pressed into the nuclei until the resulting neutron conglomerate resisted any further compression and stopped the universe from collapsing completely into a point. In April 1941, he wrote to Robertson about his attempts to investigate the origin of chemical elements by "extrapolating the expansion backwards to find the densities and temperatures at the beginning of the expansion." He was looking for advice, whether "any law of pressure dependence on density" or a cosmological constant could prevent contraction into a mathematical singularity.[70]

Gamow reported to Chandrasekhar that he was working "on [the] expanding universe trying to adjust the initial conditions (minimum radius of the universe) to explain the origin of chemical elements. It is a mess of a thing!" He mentioned that in the early universe, "the matter represented just one giant nucleus (Lemaître primeval atom), which later broke into smaller pieces when the expansion started." Gamow no longer considered the nuclear synthesis of heavier elements from lighter ones (*Aufbau*) but saw the origin of elements in the splitting of the giant primeval nuclear matter into much smaller parts (*Abbau*). He conceded that "such breakdown fission-process would be of course very difficult to calculate," and was still looking for "some better way of attacking the problem."[71] Just at the time when many of his colleagues in nuclear physics became fully engaged with the classified project of turning uranium fission into an atomic bomb based on the Frisch-Peierls scenario, Gamow, who was not admitted into the Manhattan Project, was imagining a similar fission-like process in the early universe.[72] But cosmological fission would have to be more complex than the then known fission of the uranium nucleus into two halves.

Gamow and Chandrasekhar corresponded and collaborated intensively in 1941; they also met in Washington, DC, in January and in Chicago in March to discuss stellar theory, relativistic cosmology, and the URCA process

70. George Gamow, "Concerning the Origin of the Chemical Elements," *Journal of the Washington Academy of Sciences* 32 (1942): 353–55. Gamow to Robertson, 17 Apr 1941; Robertson to Gamow, 21 Apr 1941, Robertson Papers (ref. 51).

71. Gamow to Chandrasekhar, 9 May 1941 (SCP).

72. Gamow did not get clearance for the Manhattan Project during the war, but, starting 1943, he worked as a consultant for the Navy, in cooperation with Einstein. His famous 1948 "alphabetical" paper on the origin of chemical elements (see ref. 85) was supported by the US Navy Bureau of Ordnance.

proposed by Gamow and Mário Schenberg.[73] In December that year, Chandrasekhar, in collaboration with Louis R. Henrich, published his own paper on the origin of elements. The thermodynamic approach allowed them to avoid any specific hypotheses about the state of matter and nuclear reactions. Assuming the condition of thermal equilibrium, they calculated relative abundancies of different chemical elements and compared those with the empirical data—terrestrial, meteoritic, and astrochemical—compiled by the Swiss-Norwegian geochemist Victor Goldschmidt. The resulting theoretical estimates were in good agreement with the observed distribution for lighter elements, but not the heavier ones. For the latter, Chandrasekhar and Henrich needed to postulate a separate equilibrium and a different, earlier cosmological epoch. Relativistic cosmology appeared only cautiously, as "purely exploratory," at the end of their paper, where they allowed themselves to speculate that the origin of chemical elements could be linked with the "original expansion and cooling" of the universe or with "another (possibly related) suggestion . . . that it might have arisen from the loss of energy by neutrino emission in the manner contemplated by Gamow and Schoenberg."[74]

In April 1942, Chandrasekhar reported his and Henrich's results at the eighth Washington conference dedicated to "The Problems of Stellar Evolution and Cosmology." Gamow agreed with the need to explain theoretically the observed abundancies of chemical elements, but his review emphasized the failure of Chandrasekhar's approach to do so:

> Discussion centered mainly around the possibility that the heavy elements originated at still higher temperature and density and that their relative proportions were later "frozen up" in the process of expansion. This discussion led to the conclusion that the "freezing up" process could hardly take place since, in the presence of free neutrons, heavy elements would be transformed into light ones (through the "neutron evaporation"), even at much lower temperatures. It seems, therefore, more plausible that the elements originated in a process of explosive character, which took place at the "beginning of time" and resulted in the present expansion of the universe.[75]

73. G. Gamow and M. Schoenberg, "Neutrino Theory of Stellar Collapse," *PR* 59 (1941): 539–47. Schenberg came to the US on two Guggenheim Fellowships to work with Gamow in 1940 and with Chandrasekhar in 1941. URCA stands for Ultra Rapid Catastrophe, but was also the name of a casino in Rio de Janeiro, where Gamow and Schenberg squandered a lot of money.

74. S. Chandrasekhar and Louis R. Henrich, "An Attempt to Interpret the Relative Abundances of the Elements and their Isotopes," *AJ* 95 (1942): 288–98, on 298.

75. George Gamow and J. A. Fleming, "The Eighth Annual Washington Conference of Theoretical Physics," *Science* 95 (1942): 579–81, on 579. Gamow had used chemical abundancies

Gamow later characterized the difficulty as the "heavy elements catastrophe," an allusion to the famous "ultraviolet catastrophe" in the early quantum theory. Since the binding energy in the first approximation depends linearly on the atomic weight, thermodynamic equilibrium predicted an exponential decrease in the abundance of progressively heavier elements. The empirical data showed such a decrease only for the first half of the periodic table, and an approximate constancy for the elements with atomic numbers above 50.[76]

In December 1942, Gamow published a graph illustrating this distribution. He was completely convinced that heavy elements could not be produced in existing stars or "in any other part of the present state of the universe." The remaining two alternatives, he thought, were their production in an earlier cosmological era when thermodynamic equilibrium allowed for much higher temperatures and densities, or fission, the "non-equilibrium, breaking-up process of the original bulk of nuclear matter caused by a rapid expansion in the early evolutionary stages."[77] The "equilibrium approach" of Chandrasekhar and Henrich described the observed distribution of the lighter elements, but not the heavier ones. The fission-like process could better account for the heavy elements part of the graph, but not for the presence of lighter elements. Gamow hoped that more complex fission, including multiple splitting into three and more parts, could possibly explain the entire distribution.

In 1943, Gamow informed Chandrasekhar about his plan to write "a lengthy article on the general evolution of the universe (chemical elements, stars, stellar systems, etc.)," but his difficult calculations did not progress well.[78] By the mid-1940s their collaboration fell apart, mostly due to disagreements over astrophysics. Alpher and Herman, Gamow's postwar

---

already in *Birth and Death* (ref. 5), 180, but for the discussion of stellar evolution rather than cosmology. He, Alpher, and Herman, would include Goldschmidt's and Harry Brown's empirical data on the distribution of chemical elements in most of their cosmological publications from 1948 to 1953.

76. The term "heavy elements catastrophe" appeared in Ralph Alpher and Robert Herman, "Theory of the Origin and Relative Abundance Distribution of the Elements," *Reviews of Modern Physics* 22 (1950): 153–12, on 168. They later attributed the name to Gamow. Alpher and Herman, *Genesis of the Big Bang* (Oxford: Oxford University Press, 2001), 68.

77. Gamow, "Concerning" (ref. 70), 354. He also discussed this graph in Gamow, "Expanding Universe" (ref. 60), and in *Creation of the Universe* (ref. 5), 51. Several years later Hoyle offered a correction and explained that elements heavier than iron can also be produced in supernova explosions.

78. Gamow to Chandrasekhar, 27 Oct 1943 (SCP).

collaborators, had no contact with Chandrasekhar and did not appreciate the latter's influence on the development of Gamow's cosmological ideas in the early 1940s.[79] Gamow continued to believe in the cosmological fission approach at least until 1946, when he presented it in his popular book, *Atomic Energy in Cosmic and Human Life: Fifty Years of Radioactivity*.[80] That very year, however, he switched from fission back to the fusion model.

The genre of popular books allowed Gamow to present his cosmological ideas in a state of gestation, when they still looked too speculative and imprecise to be published in physical or astrophysical journals. Even Teller, Gamow's friend and close collaborator in the 1930s, and an expert on nuclear reactions, decided to stay away from Gamow's cosmological exercises:

> Gamow was deeply interested in the origin of the universe. You know the universe is coming apart. You can calculate that about ten billion years ago things were on top of each other. What do you mean by each other? In how small a volume? How did that happen? Gamow speculated and speculated—and predicted that radiation emitted at that time should be noticeable even today. The radiation was found. I took relatively little part in that. It was for me, at that time, a little bit too speculative.[81]

But through hybridization with nuclear physics, then the most prestigious field of science, Gamow could hope to make relativistic cosmology more acceptable to other physicists and astronomers. The problem of the origin and relative abundance of various chemical elements, highly legitimate from the nuclear science perspective, was not finding an acceptable solution in astrophysics. Gamow came to the conclusion that conditions and reactions in regular stars were insufficient to produce heavy elements, and searching for an explanation, he turned away from the interior of stars to the primordial cosmological oven, initiating the transfer of methods and approaches of nuclear physics to the analysis of the early state of the universe.

79. Reportedly, Gamow told Alpher that their cosmological articles would not be accepted by Chandrasekhar for publication in the *Astrophysical Journal*. They thus sent their papers to physics journals. Alpher and Herman, interview (ref. 12); Victor S. Alpher, "Ralph A. Alpher, Robert C. Herman, and the Cosmic Microwave Background Radiation," *Physics in Perspective* 14 (2012): 300–34, on 304–05.

80. Gamow, *Atomic Energy* (ref. 48), 86.

81. Edward Teller, "Some Personal Memories about George Gamow," *Gamow Symposium* (ref. 12), 124–26.

$\alpha\beta\gamma$ "Ylem": Creation of the Universe

Starting in 1946, relativistic expansion acquired a much more central role in Gamow's cosmology. Chemical elements were not simply created at the early stage of the universe, but dynamically influenced by the very process of its expansion. The latter happened so quickly that lighter elements formed earlier and in different conditions than the heavier ones, which accounted for the absence of thermodynamic equilibrium between them. Instead of fission, Gamow returned to thermonuclear fusion, which he had considered in 1935 but abandoned in 1941. Assuming an extremely hot and dense soup of neutrons in the beginning of expansion, Gamow envisioned that the reactions of neutron-capture and beta-decay could form all elements in progression. After reviewing again and dismissing the equilibrium approach, he suggested this new process as a better alternative for explaining the origin of elements and the observational data on their relative abundance.[82]

The physical background of this picture resembles a thermonuclear bomb of cosmological dimensions, with many of the same nuclear reactions and with the need to consider them in the dynamics of explosion rather than in equilibrium. It is hardly accidental that Gamow's switch chronologically coincided with his friend Teller's transition from the atomic bomb to inventing scenarios for possible hydrogen bombs. Gamow's personal relation with Teller would soon draw him, too, to Los Alamos, to take part in the development of thermonuclear weapons. Though he was officially employed there for only one year, he retained connections as a consultant and continued to participate in discussions.[83] In a drawing from 1950, Gamow included photographic insets of Stanisław Ulam, Teller, and himself working on the H-bomb, and of Oppenheimer, who objected to this project (Fig. 6). By the late 1940s Gamow became much more openly anti-communist and driven by the Cold War mentality into committed involvement in the bomb work. He was making sure, however, that his published papers on cosmological nucleosynthesis did not include any explicit references to thermonuclear weapons.

82. Gamow, "Expanding Universe" (ref. 60), 574.

83. "Evidently he was eager to assist Teller in his effort to promote the construction of the fusion bomb." Harper, "In Appreciation" (ref. 12), 359. "A number of years ago, an article in a national magazine described my contribution to the development of the hydrogen bomb as that of bringing Edward Teller to this country; there is, of course, a shaker of salt in that statement." Gamow, *My World Line* (ref. 6), 134. On further connections between cosmology and thermonuclear weapons, see Zakariya, *Final Story* (ref. 4), chap. 6 and 7.

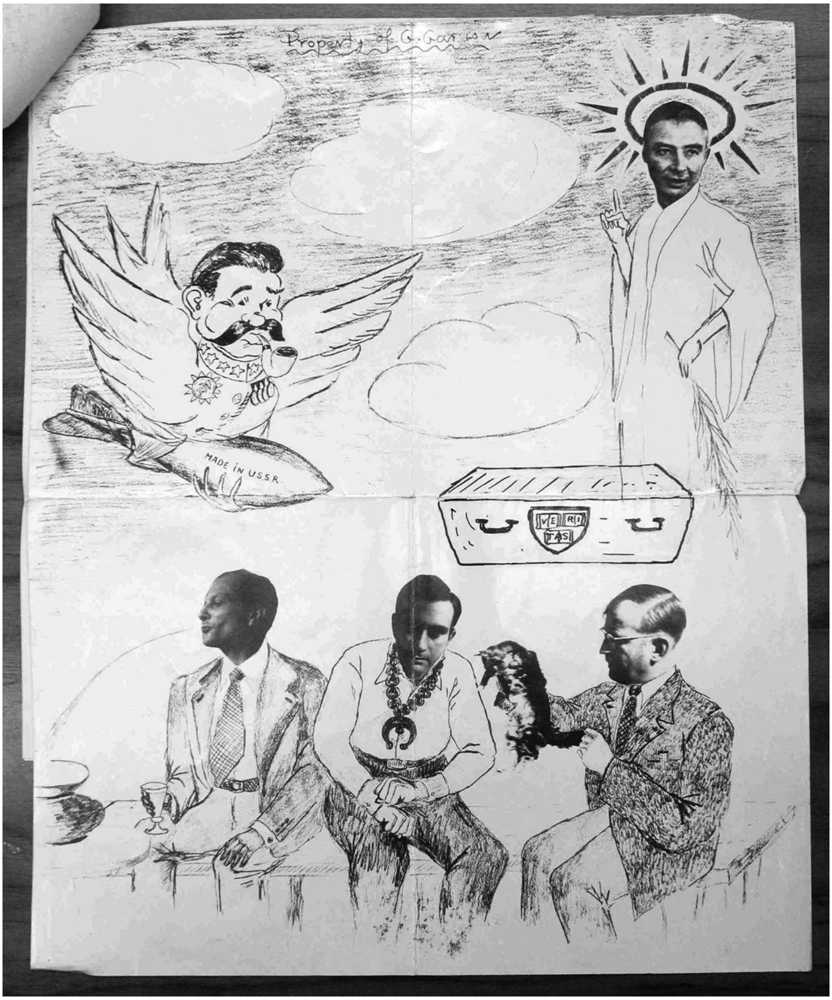

FIG. 6. Gamow's explanations on the drawing: "A drawing made by G. Gamow (with photographic insets) which was hanging in his office in the Los Alamos Scientific Laboratory during the dispute about the political necessity of developing an H-bomb and during the early stages of its development, after President Truman said: 'Yes, go ahead.' Top left is Comrade Stalin, carrying the A-bomb made in the U.S.S.R. Top right is Dr Robert Oppenheimer, who was objecting to the H-bomb project on the basis that it is extremely difficult (actually it took less than two years) and that it will induce the U.S.S.R. to do the same (actually the Russians worked on the H-bomb at the very time this discussion was taking place). The coffin with the Harvard University coat-of-arms belongs to Dr James B. Conant, who said that the H-bomb will be built only over his dead body. On the bench below are doctors Stanislaw Ulam, Edward Teller, and George Gamow, demonstrating their proposals for making H-bombs. The symbolism of these devices cannot be explained because AEC classified them as 'SECRET'." *Source:* GBGP, box 29. Courtesy of Igor Gamow and the George Gamow Memorial Fund.

Deprived of earlier collaborators, Gamow found two younger ones: Ralph A. Alpher and Robert C. Herman. Both worked on classified projects at the Applied Physics Laboratory in Maryland, where Gamow was also employed as a consultant. In early 1946, Alpher became Gamow's doctoral student at George Washington University. Alpher's and Herman's parents were immigrants from Russia, and they both shared some cultural habits with Gamow, including a penchant for practical jokes and meeting informally as bars to hold discussions and work together. It was Alpher who unearthed from the dictionaries the long-forgotten English word "Ylem" to describe the superhot and superdense primordial gas at the beginning of cosmological expansion.[84]

In 1948, as Alpher was finishing his dissertation, Gamow decided to submit a joint paper with their results to the *Physical Review*. He added Hans Bethe as the third co-author, "in absentia," simply because their names would then read as the first three letters of the Greek alphabet. Alpher was not very fond of the idea, while Herman reportedly rejected Gamow's proposals to take the pseudonym "Delter" to complete the joke. The article, published on April 1, 1948, became known as the "alphabetical," or "$\alpha\beta\gamma$" paper. Bethe apparently appreciated the prank, but he did not accept Gamow's invitations to collaborate further on cosmological topics.[85] Gamow, Alpher, and Herman proceeded writing together and separately a dozen more articles on the thermonuclear synthesis of elements in the early universe, which included the prediction of the cosmic background radiation with the present temperature of single digits.[86] Gamow summarized their results for wider audiences in *Scientific American*:

> [U]nder the tremendous temperatures and densities prevailing in the universe during the stage of its maximum contraction, primordial matter must have consisted entirely of free neutrons and protons moving much too fast to stick together and form stable nuclei. As the universe started to expand, this

84. Alpher and Herman, *Genesis of the Big Bang* (ref. 76), 70–75; Alpher and Herman, interview (ref. 12).

85. R. A. Alpher, H. Bethe, and G. Gamow, "The Origin of Chemical Elements," *PR* 73 (1948): 803–04. Gamow enjoyed telling the story of the alphabetical article, somewhat variably, in many of his books. He mentioned the "neutron capture theory of the origin of elements recently developed by Alpher, Bethe, Gamow and Delter" in George Gamow, "On Relativistic Cosmogony," *Reviews of Modern Physics* 21 (1949): 367–73, on 369, and insinuated that "[w]hen the theory went temporarily on the rocks, Dr. Bethe seriously considered changing his name to Zacharias." Gamow, *Creation of the Universe* (ref. 5), 65.

86. Peebles, "Discovery" (ref. 4), 206, presented the timeline of these publications and their various estimates for the background radiation.

> primordial gas began to cool. When its temperature dropped to about one billion degrees, particle condensation began. The growth of heavier nuclei was achieved by adding free neutrons to already existing lighter nuclei . . . According to our calculations, the formation of elements must have started five minutes after the maximum compression of the universe. It was fully accomplished, in all essentials, about 30 minutes later. By that time the density of matter had dropped below the minimum necessary for nuclear-building processes. All the elements were created in that critical 30 minutes, and their relative abundance in the universe has remained essentially constant throughout the three billion years of subsequent expansion.[87]

Alpher's doctoral defense in April 1948 attracted public interest and drew a crowd of spectators (Fig. 7). The professional community still did not pay much attention to their cosmological project: "discounting self-citations, the cluster of papers published between 1948 and 1950 by Gamow's group received an average of fewer than three citations per year in the US physics literature over the next 15 years."[88] Among the reasons for such neglect, besides the generally low number of papers on relativistic cosmology, its continuing unpopularity, and Gamow's own idiosyncrasies and propensity to damage relations with colleagues, was the rivalry with an appealing contender, the Steady State theory developed by Hoyle, Hermann Bondi, and Thomas Gold. Instead of cosmological expansion, it explained the observed redshifts by the hypothesis of constant creation of matter in the universe, which was eternal and did not require a beginning. Hoyle was a popularizer of science, too, and in a radio program for BBC in 1949 invented the term "Big Bang" to mock Gamow's and Lemaître's theories of the universe: "I cannot see any good reason for preferring the big bang . . . an irrational process that cannot be described in scientific terms [nor] challenged by an appeal to observation."[89] The name stuck and was eventually accepted by those whom it was supposed to ridicule. Hoyle's Steady State theory would be rejected by the mainstream community by the late 1960s, but he remained unconvinced and continued to oppose the Big Bang cosmology until his death in 2001.

87. George Gamow, "Galaxies in Flight," *Scientific American* (Jul 1948): 21–24, on 24.

88. David Kaiser, "Whose Mass is it Anyway? Particle Cosmology and the Objects of Theory," *Social Studies of Science* 36 (2006): 533–64, on 540.

89. Fred Hoyle, *The Nature of the Universe* (Oxford: Blackwell, 1950); Helge Kragh, "Naming the Big Bang," *HSNS* 44 (2014): 3–36. On the rivalry between the Big Bang and Steady State theories in the 1950s, see Kragh, *Cosmology and Controversy* (ref. 4) and McConnell, *The Big Bang–Steady State* (ref. 4).

FIG. 7. A 1948 Herblock Cartoon, © The Herb Block Foundation. This cartoon, published in the *Washington Post* (April 16, 1948), "was inspired by a statement in Alpher's dissertation to the effect that the period of nucleosynthesis in the early universe lasted about 5 minutes." Ralph Alpher and Robert C. Herman, "George Gamow and the Big Bang Model," in *Gamow Symposium* (ref. 12), 58.

Gamow did not like the name "Big Bang" and avoided using it (at least until it became common in the 1960s). In 1952, he published *The Creation of the Universe*, the third part of his popular trilogy. Earlier volumes, *The Birth and Death of the Sun* and *Biography of the Earth*, dealt with the Sun among other stars and with the Earth among other planets. The new book was dedicated entirely to what he called cosmogony, or "the theory of the origin of the world." Understanding that his views were not attracting much support from colleagues, Gamow presented himself as one of those who "believe[d] that the present state of the universe resulted from a continuous evolutionary process, which started in a highly compressed homogeneous material a few billion years ago—the hypothesis of 'beginning'."[90] Though writing for non-specialists, Gamow continued using the popular format to engage in scientific debates, as he had done earlier. He compiled data from various disciplines to argue that they all, independently, pointed that the universe was not much older than several billion years. He presented astronomical arguments and Hubble's data to justify the theory of expanding universe, and further speculated that the energy of cosmological expansion came from preceding contraction:

> The Big Squeeze which took place in the early history of our universe was the result of a collapse which took place at a still earlier era, and . . . the present expansion is simply an "elastic" rebound which started as soon as the maximum permissible squeezing density was reached . . . Thus nothing can be said about the pre-squeeze era of the universe, the era which may properly be called "St. Augustine's era," since it was St. Augustine of Hippo who first raised the question at to "what God was doing before He made heaven and earth."[91]

Gamow explained and reviewed several theories of elements formation: Chandrasekhar's "frozen equilibrium," his earlier "primeval atom," and his now preferred "Ylem" theory. He dismissed the rival Steady State theory of the origin of elements, comparing it to "the request of an inexperienced housewife who wanted three electric ovens for cooking a dinner: one for the turkey, one for the potatoes, and one for the pie. Such an assumption of heterogeneous cooking conditions, adjusted to give the correct amounts of light, medium-weight, and heavy elements, would completely destroy the simple picture of atom-making by introducing a complicated array of specially designed 'cooking facilities'."[92]

The text also included a public relations effort to protect the image of his cosmology from political and ideological connotations. The name "Big Bang" was not used at all, most likely to avoid allusions to thermonuclear weapons.[93] The atomic bomb and the Manhattan Project were mentioned twice, but neither the hydrogen bomb, which was then still under

90. Gamow, *Creation of the Universe* (ref. 5), 4–5. *Biography of the Earth* (ref. 5) emerged from discussions between geophysicists and physicists during the sixth Washington conference. Edward Teller and M. A. Tuve, "The Sixth Washington Conference on Theoretical Physics," *Science* 91 (1940): 621–23.

91. Ibid., 29–30, and a similar description in Gamow, *One, Two, Three . . . Infinity* (ref. 48), 331.

92. Ibid., 52.

93. David Kaiser, "The Other Evolution Wars," *American Scientist* 95 (2007): 518–25, on 521.

development in Los Alamos, nor the fact that it relied on some of the same reactions of nuclear synthesis that Gamow ascribed to the early universe, were mentioned at all. Instead, Gamow used the word "evolution" inside the text and "creation of the universe" on the cover, which brought religious connotations that he also tried to dispel, not least because the hypothesis of cosmological "beginning" was often assumed by its critics to constitute a version of religiously motivated "creation science." The most explicit such attacks were coming from the Soviet Union, directed especially against Jeans and Eddington, who were, indeed, connecting cosmological popularization with explicitly religious lessons. To Gamow, this ideological critique presented an opportunity to play Cold War rhetoric: he simplified the main cosmological debate as the dichotomy between the "beginning" of the universe in time and its "steady state" eternal existence. Proponents of the latter were illustrated with an example of a Soviet astronomer who "was apparently forced by the philosophy of dialectical materialism to accept this hypothesis." Among the pioneers of the former, Gamow emphasized the American astronomer Hubble. He also mentioned Lemaître and Friedmann, but not as prominently as in his earlier writings.

Almost to the day, in November 1951, when Gamow signed the preface to *The Creation of the Universe*, Pope Pius XII delivered an address before the Pontifical Academy of Sciences in the Vatican on "The Proof of the Existence of God in the Light of Modern Natural Science," in which he approvingly cited some conclusions of the theory of expanding universe as confirming Christian beliefs. Gamow responded with his impeccable sense of irony in his next scholarly article in *Physical Review*, quoting the papal phrases verbatim as the source of infallible confirmation:

> It can be considered now as an unquestionable truth that "*from one to ten thousand million years ago, the matter of the (known) spiral nebulae was compressed into a relatively restricted space, at the time the cosmic processes had their beginning*" and that during this stage "*the density, pressure, and temperature of matter must have reached absolutely enormous proportions*" since "*only under such conditions can we explain the formation of heavy nuclei and their relative frequency in the period system of elements.*"[94]

In the second edition of *The Creation of the Universe* in August 1952, Gamow responded to some reviewers' objections with a qualifying note that

94. George Gamow, "The Role of Turbulence in the Evolution of the Universe," *PR* 86 (1952): 251. Verbatim quotes from the Pope's address emphasized by Gamow.

"creation" is understood "not in the sense of 'making something out of nothing,' but rather as 'making something shapely out of shapelessness,' as, for example, in the phrase 'the latest creation of Parisian fashion'." The word "creation" still remained on the title and helped sales. Gamow hoped that his book would "constitute an adequate survey of the subject for scientists in various fields, and at the same time be of service to laymen interested in the problems of modern cosmology."[95] It did become a conclusive summary of his mature cosmology, including an estimate of what would later be called the cosmic background radiation. A year later, in 1953, he shifted his main efforts from cosmology to the problem of genetic code. To Wolfgang Yourgrau's question of why he was moving to biological topics, Gamow responded by quoting Chekhov: "When a little bird was asked why its songs were so short, it replied that it had so many songs to sing and would like to sing them all—before the end."[96]

CONCLUSIONS: COSMOLOGICAL METAPHYSICS, HUMOR AND ESTRANGEMENT

In his imaginative study of scientific popularization, Nasser Zakariya distinguished four genres of universalizing the vision of the universe—historical, picaresque, scaled, and foundationalist—and showed how popularizers used them interchangeably as tools for cosmological synthesis. He observed that Gamow's

> cosmological books were written in a staggered rhythm with his technical papers . . . At times Gamow appears to have published ideas first in a popular or generalist venue and later in a technical one . . . Throughout the 1940s and 1950s, Gamow popularized his universal historical research well before many aspects of it achieved significant consensus.[97]

Our analysis in the preceding sections substantiates and significantly strengthens these remarks. Like many scientists, Gamow sometimes felt the need to rhetorically separate and contrast the two sides of his productivity,

95. Gamow, *Creation of the Universe* (ref. 5), 5.

96. Yourgrau, "The Cosmos of George Gamow" (ref. 12), 39.

97. Nasser Zakariya, "Four Genres of Synthesis: Gamow, Relative Laity, and Explosive Universes," chap. 2 from "Towards a Final Story: Time, Myth, and the Origins of the Universe" (PhD thesis, Harvard University, 2010); Zakariya, "Making Knowledge Whole: Genres of Synthesis and Grammar of Ignorance" *HSNS* 42 (2012): 432–75, on 453.

popular and scientific.[98] In actual practice, however, he habitually mixed these genres and did not respect their distinctions. He used popular media to advance original scientific proposals, including those that seemed too speculative or premature for peer-reviewed publications. In books for teenagers, he conducted polemics with academic colleagues and hoped that they would take such arguments into scholarly consideration. In his professional articles, he used pranks, humor, and fictional or non-scientific actors (Bethe, Mr. Tompkins, Delter, Pius XII). Gamow's case, like the comparable case of Hoyle, provides strong support to the arguments of those who have criticized the "culturally dominant view of the popularization of science" as "rooted in the idealized notion of pure, genuine scientific knowledge against which popularized knowledge is contrasted," and the two-stage model, according to which the development of real scientific knowledge necessarily precedes its popularization and simplification.[99] It goes without saying that the popular and the scientific do not have a strictly defined boundary, but represent a continuous range of genres, media, and texts with variously imagined audiences. Gamow's publications were scattered across different parts of this spectrum, from those aiming at narrow specialists to general readers, as well as the intermediate, borderline genres.

As historians of cosmology, we do not have to remain bound by these genre restrictions either. By following Gamow's research ideas through his non-academic writings, we not only find that his involvement with relativistic cosmology started significantly earlier and was represented more fully in his popular books than in peer-reviewed articles, but also the distinction between Gamow's flexibly changing hypotheses and long-lasting commitments. In his careful analysis of Gamow's scientific publications, Helge Kragh traced the scientist's path toward the hot Big Bang model of the early universe. He characterized Gamow's approach as "factual" and "pragmatic" in the American sense, but a more appropriate description would be

98. "Do I enjoy writing books on popular science? Yes, I do. Do I consider it my major vocation? No, I do not. My major interest is to attack and to solve the problems of nature, be they physical, astronomical, or biological. But to 'get going' in scientific research one needs an inspiration, an idea. And good and exciting ideas do not occur every day. When I do not have any new ideas to work on, I write a book." Gamow, *My World Line* (ref. 6), 161.

99. Hilgartner, "The Dominant View" (ref. 37), 519; Jane Gregory, "The Popularization and Excommunication of Fred Hoyle's 'Life from Space' Theory," *Public Understanding of Science* 12 (2003): 25–46.

"playful," which is quite opposite to "pragmatic."[100] Gamow's attitude to many of his ideas was relatively light-hearted and open to easy reversals, as recalled, for example, by Teller:

> I liked to get up late. At the crack of dawn—I mean at nine-thirty in the morning—Geo would call me almost every day with a recent idea and that idea was simply wrong. Almost always! Geo Gamow had the wonderful property that he did not mind being wrong. He did not do it for the prestige. He did it for fun. He did it for love. And when his idea was not wrong it was not only right, it was right and new.[101]

Yet to some other ideas, Gamow was attached firmly, one is tempted to say "metaphysically," in particular to the vision that our universe underwent a catastrophic collapse followed by an expansion. He was willing to entertain a variety of different approaches and scenarios: he initially preferred a closed universe but later switched to an open, infinite one; considered various possible nuclear reactions; envisioned a thermonuclear synthesis of chemical elements, then switched to a fission-like model, only to return to the hot, thermonuclear explosion in the end; abandoned a periodic, oscillating universe in favor of the scenario in which the catastrophe happened only once. Yet his popular books reveal his persistent belief that, prior to the current expansion, the universe had been contracting and collapsed into a super-dense state, even if no information about that pre-singularity could have survived today. A historically more justified name for his cosmological worldview would thus be the "Big Squeeze,"[102] the idea whose roots go back to Gamow's early years of studying with Friedmann.

The transnational and transdisciplinary nature of Gamow's case makes it more unique and revealing, compared to many other scientists-popularizers. He transgressed boundaries not only between genres of scientific writing, but also of countries, cultures, languages, disciplines, scholarly communities, and perhaps most dangerously, the boundary between a joke and real life. His constant migrations contributed to his essential, multifaceted marginalization. Even growing up in his native country, he felt alienated, at least politically,

100. Helge Kragh, "Gamow's Game" (ref. 4); Kragh, "George Gamow and the 'Factual Approach' to Relativistic Cosmology," in *The Universe of General Relativity*, ed. Anne J. Kox and Jean Eisenstadt (Boston: Birkhauser, 2005): 175–88; Kragh, *Cosmology and Controversy* (ref. 4), 135.

101. Edward Teller, "Some Personal Memories" (ref. 81), 125.

102. George Gamow, "Modern Cosmology," *Scientific American* (Mar 1954): 55–63; Gamow, *Creation of the Universe* (ref. 5), 30.

because of post-revolutionary changes. And even in disciplines he helped create, nuclear theory or nuclear astrophysics, he did not stay long, but left of his own volition, so that his role remained "catalytic" rather than central. Studies of scientific personae have revealed several strategies scientists developed to cope with the essential contradictions of their status during the Cold War: for some, ultimate seriousness and internal agony, and for others, a "physics is fun" posture as a way to enjoy their high privileges while staying aloof from existential responsibilities.[103] Gamow certainly leaned toward the latter option, but refusing to take things seriously served a different function for him. Gamow's tenacious clinging to his incessant sense of humor reflected a fundamental sense of estrangement, a desire to be in the center of attention, and at the very same time, his inability to fully overcome alienation, which resulted partly from his own jokes. Ultimately, his jocular persona could not save him from succumbing to alcoholism.

History of science knows of other cultural precedents when fundamental breakthroughs in knowledge occurred in the form of funny and entertaining popularization. It happened during the eighteenth-century Enlightenment, in Parisian salons where savants amused the aristocratic public. It also happened in the Soviet Union, where ideas of space travel by means of rocket propulsion spread primarily through science fiction and books for schoolchildren.[104] In both cases, specific social conditions made the scientific community less insular and more open to the inclusion of wider audiences. Gamow internalized the values of popularization in his early Soviet days, but he excelled in this activity in the 1940–50s US, when the American scientific community felt confident in its own self-sufficiency and relatively untroubled by pressures from below. Gamow's books were extremely successful best sellers among general readers and teenagers, yet they did not gain him much appreciation and respect among academic peers, at least contemporaneously.

103. Paul Forman, "Social Niche and Self-Image of the American Physicist," in *The Restructuring of Physical Sciences in Europe and the United States 1845–1960*, ed. Michelangelo De Maria, Mario Grilli, and Fabio Sebastiani (Singapore: World Scientific, 1989), 98–104; Jessica Wang, "Physics, Emotion, and the Scientific Self: Merle Tuve's Cold War," *HSNS* 42 (2012): 341–88.

104. Geoffrey Sutton, *Science for a Polite Society: Gender, Culture, and the Demonstration of Enlightenment* (Boulder, CO: Westview Press, 1995); Asif Siddiqi, *The Red Rockets' Glare: Spaceflight and the Russian Imagination, 1857–1957* (Cambridge: Cambridge University Press, 2010).

"It is possible, but regrettable, that Gamow's fun-loving and irrepressible approach to physics led some scientists not to take seriously his work, and perhaps our work too because of our close identification with him," commiserated Alpher and Herman decades later.[105] Indeed, Gamow's idiosyncratic style often damaged his reputation and did not seem to have helped convert his colleagues. Sufficiently marginalized, after 1953 he shifted his research to the problem of genetic code. Alpher and Herman, not having found university positions, continued their professional careers as applied scientists. Their prediction of the cosmic radiation was generally ignored.[106] Gamow felt offended by not being invited to the 1958 Solvay Conference, dedicated to "The Structure and Evolution of the Universe."[107] He and Hoyle continued their scientific duels in the popular media. Gamow mocked his opponents' insistence on stability in the universe as parochially British and imperialist, because "it has ever been the policy of Great Britain to maintain the status quo in Europe."[108] Even after the accidental discovery of microwave background radiation in 1964, Gamow remained frustrated by the lack of recognition and urged Alpher and Herman to write a joint article about their prediction to set the historical record straight.

Yet his popularization efforts seem to have paid off in the next generation. Gamow's ideas found a much more welcoming reception among younger American readers, students who grew up with and became inspired into science by his books.[109] Allan Sandage recalled that during the 1950s he probably read five or six times "the wonderful book by Gamow called *The Creation of the*

105. Ralph Alpher and Robert Herman, "Reflections on Early Work on 'Big Bang' Cosmology," *Physics Today* (Aug 1988), 24–34, on 24–25.

106. Hoyle recalled Gamow telling him about the background radiation when they met personally in 1956. He was familiar with A. McKellar's 1941 estimate of the intergalactic temperature but missed the chance to relate theory and observation. Stephen G. Brush, "Prediction and Theory Evaluation: Cosmic Microwaves and the Revival of the Big Bang," *Perspectives on Science* 1 (1993): 565–602, on 579; Gregory, *Fred Hoyle's Universe* (ref. 35), 106.

107. Gamow, *My World Line* (ref. 6), 128.

108. Gamow, *My World Line* (ref. 6), 127, quoting Teller; Gamow, *Mr. Tompkins in Paperback* (ref. 2), 63–64; Gamow to Arno Penzias, 29 Sep 1963 (GBGP).

109. Interviews with some thirty physicists and astronomers who worked in cosmology starting in the 1950s revealed that for British students, such inspiration typically came from reading books by Jeans, Eddington, and Hoyle, whereas Gamow was mostly influential in the USA. For example, Marc Davis, Margaret Geller, and John Hucra read Gamow at young age and later worked together on extragalactic astronomy and cosmology. Alan P. Lightman and Roberta Brawer, *Origins: The Lives and Worlds of Modern Cosmologists* (Cambridge: Harvard University Press, 1990), on 343, 372, 379.

Universe." Upon completing his PhD on stellar evolution in 1953, he worked with Hubble and continued observations with the 200-inch telescope at Mount Palomar. He empirically justified Gamow's criticism of the estimated age of the universe based on the assumption of constant luminosity, which resolved what had been considered a major difficulty for the Big Bang cosmology.[110] Explaining his own initiation into science, Steven Weinberg recalled that "theoretical physics, at least as Gamow portrayed it, had an element of the paradoxical, the counter-intuitive, to it; I felt that if I could understand theoretical physics, I could understand anything." In 1977, Weinberg published his highly influential summary of the Big Bang cosmology, *The First Three Minutes*, and has remained an active spokesman on the public understanding of science ever since.[111] As a graduate student at the University of Chicago, Carl Sagan was inspired by Gamow's books to spend his summer working with Gamow at the University of Colorado and went on to become the most important science popularizer of his own generation.[112]

The acceptance of the Big Bang theory as our mainstream conception of the origin of the universe is usually credited to new astronomical observations in the 1960s: quasars, radio-astronomy, and especially microwave background radiation. But besides an improved empirical base, the popularity of cosmology also drew from social and cultural changes that affected criteria of legitimacy and acceptability in fundamental science. The launch of Sputnik in 1957 ushered in the Space Age and replaced the atomic bomb as the new chief symbol of scientific progress. Student protests and critiques of science for its excessive militarization made the scientific community less insular and more susceptible to popular demands.[113] And the work of popularizers such as Gamow and Hoyle influenced a new, up-and-coming generation of scientists, providing them with inspiring visions and new problems for research. Together, these developments made it possible for relativistic cosmology to

110. Allan Sandage, "Beginnings of Observational Cosmology in Hubble's Time: Historical Overview," in *The Hubble Deep Field*, ed. Mario Livio, S. Michael Fall, and Piero Madau (Cambridge: Cambridge University Press, (1998), 1–32; Peter Susalla, *From Philosophy to 'Science': A Cultural and Disciplinary History of Cosmology in the Twentieth Century* (PhD thesis, The University of Wisconsin–Madison, 2013).

111. Lightman and Brawer, *Origins* (ref. 109), 452; Zakariya, *Final Story* (ref. 4), 289; Steven Weinberg, *The First Three Minutes: A Modern View of the Origin of the Universe* (New York: Basic Books, 1977).

112. Keay Davidson, *Carl Sagan: A Life* (New York: John Wiley & Sons, 1999), 82.

113. David Kaiser, *How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival* (New York: Norton, 2011).

shake off its image as a metaphysical and speculative field and achieve the status of legitimate and prestigious science in its own right.

ACKNOWLEDGEMENTS

The authors would like to dedicate this paper to the memory of Karl G. Hufbauer (1937–2020), whose works and invaluable advice inspired our investigation. We are grateful to David DeVorkin, Igor Gamow, Jane Gregory, Thiago Hartz, David Kaiser, Lino Machado, Climerio Silva, Domingos Soares, Heráclio Tavares, Antonio Augusta Videira, Jessica Wang, and Nasser Zakariya for criticism and helpful suggestions. Our archival explorations were supported by grants-in-aid from the Maurice A. Biot Fund, the Caltech Archives, and the Center for History of Physics, American Institute of Physics. A grant from FAPESP (São Paulo Research Foundation), process 2013/02218-3, made possible Alexandre Bagdonas's research stay in Vancouver.