Phys. Perspect. 14 (2012) 300–334

1422-6944/12/030300-35
DOI 10.1007/s00016-012-0088-7

Physics in Perspective

Ralph A. Alpher, Robert C. Herman, and the Cosmic Microwave Background Radiation

Victor S. Alpher*

Much of the literature on the history of the prediction and discovery of the Cosmic Microwave Background Radiation (CMBR) is incorrect in some respects. I focus on the early history of the CMBR, from its prediction in 1948 to its measurement in 1964, basing my discussion on the published literature, the private papers of Ralph A. Alpher, and interviews with several of the major figures involved in the prediction and measurement of the CMBR. I show that the early prediction of the CMBR continues to be widely misunderstood.

Key words: Ralph A. Alpher; Robert C. Herman; George Gamow; Hans A. Bethe; Luis J. Boya; Subramanyan Chandrasekhar; Robert H. Dicke; Andrei G. Doroshkevich; Martin O. Harwit; Fred Hoyle; Harold I. Ewen; John C. Mather; Igor D. Novikov; P. James E. Peebles; Anro A. Penzias; Edward M. Purcell; George F. Smoot; Rashid Sunyaev; Merle A. Tuve; Steven Weinberg; Robert W. Wilson; Yakov B. Zel'dovich; George Washington University; Johns Hopkins University Applied Physics Laboratory; Department of Terrestrial Magnetism; Carnegie Institution; Princeton University; National Bureau of Standards; Naval Research Laboratory; U.S. Navy Bureau of Ordnance; Philosophical Society of Washington; Washington Academy of Sciences; Washington Conferences on Theoretical Physics; General Electric Corporate Research and Development Center; General Motors Research Laboratory; Union College; University of Texas at Austin; Nobel Prize in Physics; Dicke radiometer; Cosmic Microwave Background Radiation; Cosmic Microwave Background Explorer; steady-state cosmology; big bang cosmology; ylem; bolometer.

* Victor S. Alpher, son of Ralph A. Alpher, received his Ph.D. degree in clinical and experimental psychology at Vanderbilt University in 1985 and was on the full-time faculty of the University of Texas–Houston Health Science Center from 1986 to 1988; he also conducted a private consulting practice in Houston in neuropsychology and gerontology. He received his Diplomate in Clinical Psychology from the American Board of Professional Psychology in 1995.

"We take the origin of modern cosmology to be Einstein's general theory of relativity."

Ralph A. Alpher and Robert C. Herman[1]

"But it really was a terrifically simple idea."

Ralph A. Alpher, referring to the prediction of the Cosmic Microwave Background Radiation[2]

Introduction

Ralph A. Alpher and Robert C. Herman's prediction and calculation of the Cosmic Microwave Background Radiation (CMBR) in 1948,[3] this "terrifically simple idea," eluded detection for sixteen years. Its currently accepted value of 2.*725* degrees kelvin (°K) from data gathered by the U.S. National Aeronautics and Space Administration (NASA) Cosmic Microwave Background Explorer (COBE) is so precise that a plot of the CMBR displays a nearly perfect blackbody spectrum.

Competition is the norm in science, as when Evgeny M. Lifshitz published a solution to an astrophysical problem in 1946 on which Alpher was writing a dissertation,[4] but perhaps the best known race to a discovery was the one to determine the structure of DNA.[5] Although there was no real race to detect the CMBR, its observation became crucial in differentiating between two competing cosmological theories, the steady-state and big bang theories, with enormous significance for science, philosophy, and theology.

Arno A. Penzias and Robert W. Wilson each shared one-third of the Nobel Prize in Physics for 1978 for their discovery of the CMBR in 1964, and John C. Mather and George F. Smoot shared the Nobel Prize in Physics for 2006 for their measurement of the CMBR with NASA's COBE launched in 1989. Based on the published literature, the private papers of Ralph A. Alpher, and interviews with several of the major figures involved, I focus particularly on the critical period 1948–1964 and offer a new perspective on the long voyage from Alpher and Herman's prediction of the CMBR to Penzias and Wilson's discovery and measurement of it.

Gamow, Alpher, Herman, and Chandrasekhar

By the middle of the twentieth century, George Gamow, his student Ralph A. Alpher, and their colleague Robert C. Herman were considered to be the major proponents of what Fred Hoyle in 1949 pejoratively termed the big bang theory of the early universe.* Gamow, however, initially resisted Alpher and Herman's prediction of the CMBR. As Alpher stated in a letter of August 25, 1997:

---

* Fred Hoyle used the term "big bang" in an early 1949 BBC radio broadcast that was published in April 1949 in a BBC radio listener's magazine; see website <http://www.joh.cam.ac.uk/library/special_collections/hoyle/exhibition/radio/> retrieved January 10, 2012. Alpher stated erroneously that Hoyle coined the term in a BBC radio debate with Gamow; see Alpher, "Cosmochemistry" (ref. 4), p. 63.

Gamow's contribution to the prediction was to express strongly his reservations about its validity and meaning for three years after we first published [it in late 1948]. Then he came around and published several papers in which he recognized the existence of such radiation on theoretical grounds but went about calculating its properties erroneously. This really screwed up the literature for some years."[6]

George Antonovich Gamow was born in Odessa, Ukraine, on March 4, 1904, and immigrated to the United States in 1934 where he accepted a professorship at The George Washington University (GWU) in Washington, D.C. The following year he arranged a professorship there for his friend Edward Teller, and the two then joined Merle A. Tuve at the Department of Terrestrial Magnetism (DTM) of the Carnegie Institution of Washington to found the Washington Conferences on Theoretical Physics, which Gamow modeled after the Solvay Conferences in Brussels, Belgium,[7] the seventh one of which he had attended in October 1933.

Gamow's graduate student, Ralph Asher Alpher, was born in Washington, D.C., on February 3, 1921, graduated from Theodore Roosevelt High School in 1937 at age 16 (figure 1),* and received his Bachelor's degree at GWU in 1943, his Master's degree in

Fig. 1. Ralph A. Alpher in 1937 at age 16. *Credit*: Alpher Papers.

* Unless otherwise stated, the photographs in my paper are from the personal files of the Estate of Ralph A. Alpher, Victor S. Alpher, Executor; hereafter Alpher Papers.

1945, and his Ph.D. degree on May 26, 1948.[8] Six months earlier, in the middle of November 1947, he attended the tenth and last Washington Conference on Theoretical Physics on the topic of "Gravitation and Electromagnetism" (figure 2). He attained all of his degrees at night; by day he worked as a physicist at the DTM on contract to the Bureau of Ordnance of the U.S. Department of the Navy from 1940 to 1944 and then at The Johns Hopkins University Applied Physics Laboratory (JHUAPL) until 1955. His colleague, Robert C. Herman, was born in New York on August 29, 1914, received his Bachelor's degree at the City College of New York (CCNY) in 1935 and his Ph.D. degree, which was awarded by a committee chaired by Howard P. Robertson, at Princeton University in 1940. He then spent one year as a Research Associate at the University of Pennsylvania and another year as an Instructor in Physics at CCNY before joining the JHUAPL as a physicist in 1942. Alpher and Herman began collaborating on cosmological problems at the JHUAPL in 1948.

Alpher's Ph.D. thesis was a theoretical treatise on the formation of the elements in an initially hot, expanding universe, based on a nonequilibrium model. Subramanyan Chandrasekhar at the University of Chicago and Yerkes Observatory in Geneva, Wisconsin, was then developing an opposing theory based on an equilibrium model. The main venue of publication for this steady-state theory, championed by Fred Hoyle, was *The Astrophysical Journal*, of which Chandrasekhar was Associate Managing Editor. Gamow therefore expected to have difficulty in publishing in *The Astrophysical Journal*, so he, Alpher, and Herman published primarily in physics journals, which may have significantly hampered the acceptance of their work and big bang theory, and of Alpher and Herman's persistent attempts to convince astrophysicists to measure their predicted CMBR.

In working with Gamow (figure 3), Alpher and Herman thus took some professional risk on this account, and also because Gamow's legendary ebullience led some physicists to think that he did not take his work seriously. A famous case in point was the so-called $\alpha\beta\gamma$ paper, in which Alpher announced his findings on nucleosynthesis and the origin of the elements,[9] prior to the publication of his dissertation under his name alone.[10] By having his name linked to the much more prominent names of Hans Bethe and George Gamow, some were led to think that Alpher was a fictitious physicist, much like the fictitious French mathematician Nicolas Bourbaki.[11]

Alpher recalled Gamow's decision about where to publish his dissertation in an interview with astronomer-historian Martin O. Harwit in 1983.

> **Alpher:** [Then] he [Gamow] told me – and I can't remember exactly whether he had spoken to Chandrasekhar or whether he assumed it; but whichever it was, we decided not to send it to *Astrophysical Journal* because he didn't think Chandrasekhar would publish it.
>
> **Harwit:** Okay, let me ask you about that because in 1946 Chandra was not editor; he was associate managing editor, and it was [Otto] Struve who was

Fig. 2. Participants at the Washington Conference on Theoretical Physics, November 1947, with those who are mentioned in the text in **boldface**. *Front row, left to right*: Herman Weyl, **Edward Teller**, Martin Schwarzschild, Chartles L. Critchfield, John A. Wheeler, Richard Feynman, J. Robert Oppenheimer, Julian Schwinger, Gregory Breit, Horace W. Babcock, **Howard P. Robertson**, Leopold Infeld; *Back row, left to right*: Scott E. Forbush, Walter D. Whitehead, Jr., Norman P. Heydenburg, Ugo Fano, David R. Inglis, Philip H. Abelson, **George Gamow**, **Merle A. Tuve**, John L. Osborne, Richard B. Roberts, **Ralph A. Alpher**, Benjamin D. Van Evera. *Credit*: Alpher Papers.

Fig. 3. George Gamow (1904-1968) in middle age. *Credit*: Alpher Papers.

managing editor of *The Astrophysical Journal*. Would Chandrasekhar still have had that sort of influence, do you think? Or….

Alpher: Well, he specifically mentioned Chandrasekhar…. As far as Struve is concerned, the only time I ever heard Gamow say anything about Struve was that he was a rather stern, formal person…. By the way, you know, Chandra had done some work in this area and there was some interaction between Gamow and Chandrasekhar, and I have in my files, I guess, a letter from Chandrasekhar, or some comment. Gamow sent him a reprint and Chandra sent back a rather formal reply, you know, expressing interest, but not approval or disapproval of what we were doing.

Harwit: Well, there was this paper in 1942 by Chandrasekhar and Henrich.[12]

Alpher: Henrich, oh yes. We referred to that…. Bob and I went through that paper in minute detail when we did our review in *Reviews of Modern Physics*.[13]

Harwit: Do you think on that score Chandrasekhar would in any case have been the person who would have been asked to judge your papers by Struve since they both were at Yerkes.

Alpher: It didn't occur to me at the time, but clearly that would have been the case, and I think there is certainly more of a suggestion in that paper of Chandra and Henrich that one has to look at an early universe to make elements, so there may have been an element, excuse the use of the word, bothering Gamow about maybe, you know, he and Chandra were pursuing the same idea, except maybe George had arrived there first, and had made an explicit statement, where Chandrasekhar was certainly steering in that direction.[14]

By repeatedly publishing in physics journals, Alpher, Herman, and Gamow may have influenced relegating the nascent field of cosmology to physics rather than to astrophysics. Alpher touched on this when his interview turned to a paper that Gamow had published in 1942.[15]

Alpher: [My] feeling at the time was that Chandra would have something to do with its publication, and that George didn't want to subject himself to being rejected. And so he felt more comfortable with the physics community.

Harwit: It's certainly true that at that time there were not very many cosmological papers published in *The Astrophysical Journal*.[16]

Chandrasekhar was Associate Managing Editor of *The Astrophysical Journal* until 1952, after which he became Managing Editor, which increased his influence on publications in cosmology, especially after 1963 when its subheading, *An International Review of Spectroscopy and Astronomical Physics*, was dropped.

The CMBR: Prediction and Measurement

The CMBR was "measured" a number of times prior to 1964 when Penzias and Wilson found that they could not eliminate all known sources of extraneous noise in their radio antenna at Bell Labs in Holmdel, New Jersey,[17] an observation that they did not interpret cosmologically. Historian Helge Kragh has discussed the issue of "discovery without interpretation" and has argued that observation without interpretation is not discovery: "I find it reasonable to speak at least of proto-physical cosmology in the 1930s and a mature physical cosmology about 1950, in the works by Gamow and his associates."[18] He also proposed that a rational cosmology began with Albert Einstein's cosmological model in 1917. Historian Stephen G. Brush has given an insightful account of the rise of the big bang theory,[19] and astronomer-historian Virginia Trimble has presented a historical account of the unrecognized measurements of the CMBR,[20] in which she notes the importance of the informal, unpublished record. Alpher and Herman also cover this aspect of the CMBR history in their 2001 book, *Genesis of the Big*

Bang.[21] I will later consider such informal, unpublished records regarding their efforts to have the CMBR measured after 1948.

Robert H. Dicke and his colleagues at Princeton University published an interpretation of Penzias and Wilson's observation of the CMBR in 1965,[22] but they did not mention Alpher and Herman's prediction of it in 1948;[23] they in fact were the first to predict specifically that the traces of a hot, dense early expanding universe could be measured in degrees Kelvin, and to calculate how it evolved to its present temperature.

Two weeks after the famous $\alpha\beta\gamma$ paper appeared in the *Physical Review*,[24] Gamow wrote to Bethe on April 15, 1948, joking that by inviting him to sit on Alpher's dissertation-defense committee, he would be unable to speak against it. "Ain't that smart!"[25] Moreover, GWU would pay his travel expenses to Washington for further discussions. The $\alpha\beta\gamma$ paper, published as it was on April 1, 1948, April Fool's Day, under the names of three authors, did not look like Alpher's doctoral dissertation. Moreover, though Alpher had intimated in it that there should be relict radiation from the initial expansion of the universe, he did not include that prediction in it or in his second paper, which was based on his dissertation, and which he published under his name alone on December 1, 1948.[26]

Two weeks later, on December 15, 1948, Alpher and Herman published the first ever calculated prediction of the relict radiation from the big bang.[27] This was the first of seven papers they published through 1956 on the CMBR and nucleosynthesis in the early universe. Alpher discussed the situation in the late 1940s in his interview with Harwit.

> **Alpher:** Well, what we did at the time was the following. We personally did nothing, obviously, because, you know, I was not an observational type,* and while Bob [Herman] has done some experimental work, it never occurred to either of us to pursue that ourselves. However, we were in the Washington area, and during the next year, or year and a half, we gave … God knows how many colloquia … in the area because there was a lot of publicity about my thesis,** and this sort of rubbed off afterwards on other things that we did. In other words, each time something was published in the next year and a half – we had a significant number of things come out – there seemed to be newspaper publicity

* While Alpher always considered himself to be a theoretical physicist, when he was working at the General Electric Research and Development Center after 1955 he was involved in experimental work with Donald White, including experimental observations of the effects of blast pressures on various objects using a shock tube. Alpher also conducted a good deal of applied research during World War II, including observing torpedo runs in Puget Sound, and taking a voyage on the *U.S.S. Massachusetts* from Norfolk, Virginia, to New York to measure the effects on the ship's magnetic signature of firing its 16-inch guns, the pounding of waves on its hull, and the like, so that these effects could be countered by degaussing.

** Alpher's thesis defense was moved to a large hall at GWU to accommodate the more than 300 people and reporters in attendance.

about it, and it became known in the Washington area community, certainly. We gave talks at NRL [the Naval Research Laboratory], the National Bureau of Standards; and there were people there – one person I knew in particular named [Alvin G.] McNish who was from the Central Radio Propagation Laboratory. They were getting involved in radio astronomy as well, and we talked about this background temperature calculation, went through it probably on the blackboard, I probably even have some lecture notes, I don't know; and *nobody suggested the measurement* [my italics]. In fact people then were talking about the fact that the limiting sensitivity was rather higher than 5°K, that you simply couldn't say anything.[28]

The next day, Harwit, Alpher, and Herman discussed the difficulty in distinguishing the background radiation from stellar radiation.

Harwit: I was just wondering whether you overlooked the fact that the starlight should always occur at much higher frequencies than the background radiation, because you only talk about densities, usually? It's a minor matter, but I'm just wondering what your thinking might have been at the time.

Alpher: Trying to think back, I think maybe at that time we were thinking in terms of energy densities, and certainly the starlight would have provided double the energy density, in effect, locally. We may have been misled by the fact that we probably were thinking about measuring the stuff with a bolometer, which would have given an energy density measurement rather than a spectral frequency measurement.

Herman: I think what you are saying is correct.

Alpher: So in that sense, we may have misled ourselves, on the other hand, many years later Penzias said that if you take a bolometer and put a piece of paper over it, you could have looked at the stuff, and you know, I say, "Great, where were you in 1948?

Harwit: I see. You discussed this with him.

Alpher: Oh yes, sure.

....

Alpher: Or if we had said the peak lies at such-and-such wavelength, or had we said something other than that it was a background temperature – a blackbody temperature of 5^{o} – it could have made a difference.

Harwit: Let me look at another sociological factor that also comes in here, and ask you whether that played a role. Well, actually it's two factors. Just about the time that you were working on this, [Herman] Bondi, [Thomas] Gold, [Fred] Hoyle in Britain were suggesting a steady-state universe. Did that detract from the evolutionary cosmology that you were talking about and divert attention from the work you were doing?

Alpher: Yes, indeed.

....

Herman: Well, I think the simple straightforward answer is absolutely as Alpher just said, and as a matter of fact, throughout that period for quite some time there was the opposition of these two views. As I recall, whenever we lectured individually, separately, or together, we always presented these views of an evolutionary universe in the "big bang" sense, and also the steady-state point of view. And as time went on, and certain observational evidence came into being, we pointed out, for example, the galactic, i.e. radio source, counts of [Martin] Ryle, and so forth. And I think we presented to the best of our ability a balanced picture.

Alpher: We certainly always tried. In the early days there was a severe criticism of the age of the universe from the evolutionary model. It was much too short. The Hubble constant was way out of what [it should be] then, at least if you believe the evolutionary model.

Harwit: In fact, that's what led to the steady-state universe being proposed.

Alpher: Exactly.

Herman: Yes, indeed.

Harwit: The stars seem to be older than the universe, with the Hubble constant that was accepted....

Alpher: And that's a very difficult thing to deal with, other than to make pious statements that probably Hubble's constant is not known with sufficient certainty. And I think that was a fair statement then. It may still be a fair statement. Within a factor of 2, there's a good deal of argument.

Harwit: And I guess even down to the popular level, as I remember it at least, there was a sort of an enjoyment by amateur astronomers that among the professionals there was this controversy that...

Alpher: Yes indeed.

Harwit: ...excited people to hear. I think it was usually put in the context of Hoyle versus Gamow. Is that your recollection?

Alpher: Oh, yes.

Harwit: …at the cutting edge of this.

Alpher: Yes, indeed.

Herman: Exactly.

Alpher: There were radio debates on the BBC between Hoyle, on the one hand; and I think Gamow participated in some of those debates. In the early '50s, I think that's when the words "big bang" were first introduced." [Hoyle coined this term in early 1949 but there was no BBC debate on it.]

Harwit: Who introduced that?

Alpher: As far as we know it was Hoyle. T.E. [Edward R. (Ted)] Harrison at the University of Massachusetts researched this question and concluded that Hoyle used the phrase pejoratively and first.

Herman: In a pejorative sense.

Harwit: Oh really?

Alpher: Instead of referring to what we were doing as an evolutionary model, he referred to it pejoratively as a big bang.

Herman: Well, this is our impression, that it was pejorative.[29]

Later, Harwit discussed their work with the jovial, ebullient Gamow.

Herman: So, you see, I've seen Gamow at large social gatherings, in fact, specifically at a time when he was considering all these matters about the genetic code, and he'd be tanked up. He would be lying on the floor with pieces of paper and drawing diagrams in a loud, high pitched voice. He was a megalomaniac – he was! But he was brilliant, creative and did many beautiful things. In spite of that there were people who were just put off by George. So that may be an element in how Alpher and I might have been viewed.

Harwit: Are you saying that the scientific community which always prides itself on objectivity has guilt by association?

Alpher: I think there is some element of that in what Bob has said.

Herman: I might not put it that strongly; I do want to be careful, but I think that there are elements of this kind.[30]

Alpher and Herman clearly disagreed about Penzias's attitude toward their work. Later in the interview, Herman commented on Penzias's idea. Herman felt that Penzias had not given Alpher and Herman their due, even though Alpher had spent seven or eight hours with Penzias bringing him "up to speed" on the previous history of cosmology.* Herman pointed out that neither Penzias nor Wilson were cosmologists.

> **Herman:** In fact, he's argued with us about certain things, and has minimized what we've done vis-à-vis Gamow; implied that we were not very bright – all you had to do was put a piece of paper in front of it [a bolometer].
>
> …………………………..
>
> **Alpher:** Well, I heard the remark from Penzias. I don't know that it was derogatory, it was a kind of a science thing, "How come you guys didn't push hard enough to get the [CMBR measured]?"[31]

We see that in predicting the 5°K CMBR Alpher (figure 4) and Herman (figure 5) were at times up against themselves, Gamow, Hoyle, and others in the physics community.

For three years, from 1948 to 1951, Gamow did not consistently support Alpher and Herman's efforts: His opposition to their prediction of the CMBR on theoretical grounds is ironic since, even today it is often cited as being the work of "Gamow and colleagues." Moreover, for reasons that Alpher and Herman never understood, Gamow began to publish his own estimates of the CMBR, which were usually mathematically inconsistent, and in which he did not cite Alpher and Herman's work and hence tended to detract from it. They never challenged him directly on this, however, owing to their respect and admiration for the man they called "Geo" or "Joe."

In 1950 Alpher and Herman predicted the very high value of 28°K for the CMBR, but as they explained in their 2001 book,[32] this figure was based on an erroneous value for the matter density in the universe that Albert Behr had published but then retracted in 1951 after his estimate of the Hubble constant could not be replicated.[33]

Trimble recalled an encounter with Gamow that reflected his ambivalence, inebriation, or perplexing humor toward Alpher and Herman's prediction of the CMBR. In 1967, at the Third Texas Symposium on Relativistic Astrophysics, she asked Gamow about his thoughts on the CMBR, to which he remarked, evidently alluding to Alpher and Herman's value of 5°K, "Well I lost a nickel and you found one. Who's to say it's the same nickel?"[34] Still, at about the same time, Gamow

---

* Alpher met with Penzias in New Jersey for more than a day prior to his Nobel Lecture, trying to acquaint him with the history and publications concerning the CMBR going back to 1948. Penzias, however, did not cite Alpher and Herman's earliest work and incorrectly cited the $\alpha\beta\gamma$ paper as being published in 1949. Shortly after returning to Schenectady, Alpher suffered a heart infarct at age 57. I recall this well, having visited him there in Ellis Hospital. As a gentleman and scholar, he felt obligated to accept Penzias's invitation to discuss the CMBR, but I believe he was unaware of the tremendous stress this put on him. On January 11, 2012, James Comly recalled in a conversation with me how visibly devastated and discouraged Alpher was at this time.

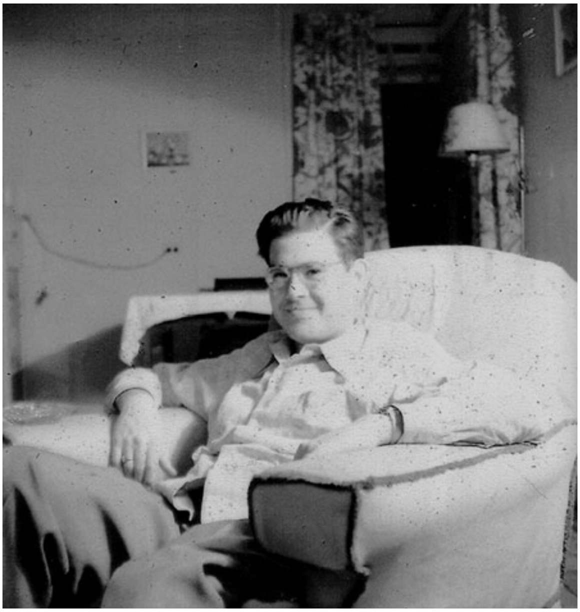


Fig. 4. Ralph A. Alpher in the fall of 1947. *Credit*: Alpher Papers.

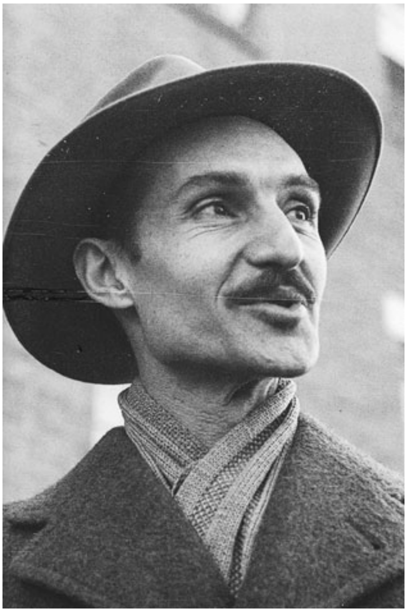


Fig. 5. Robert C. Herman as photographed by Ralph A. Alpher in 1948. *Credit*: Alpher Papers.

published a supportive paper with Alpher and Herman in the *Proceedings of the National Academy of Sciences*.[35] Much later, in 1983, Alpher told the following story about Gamow and Hoyle in a talk to science writers at a meeting of the American Physical Society.

> Now I just learned by reading a recent paper of Fred Hoyle that he claims that he too had been aware of the Adams-McKellar work,[36] because he had been worrying about interstellar molecules, and according to Hoyle, in 1956 he and Gamow had arrived together in a large white Cadillac, which George had just bought (he was then consulting at General Dynamics) and I guess Hoyle was on a visit to Cal Tech, and during this discussion Hoyle tried to argue with Gamow that there was no relict radiation on the grounds that Gamow had just published a paper in a Danish Royal Academy [*sic*] in 1956 in which in a very crude way he had calculated this blackbody radiation and had got 6 Kelvin.[37] And to be sure, as Hoyle pointed out, this was inconsistent with [the] Adams-McKellar data. These remarks which Hoyle recalls or says he recalls were apparently never published.[38]

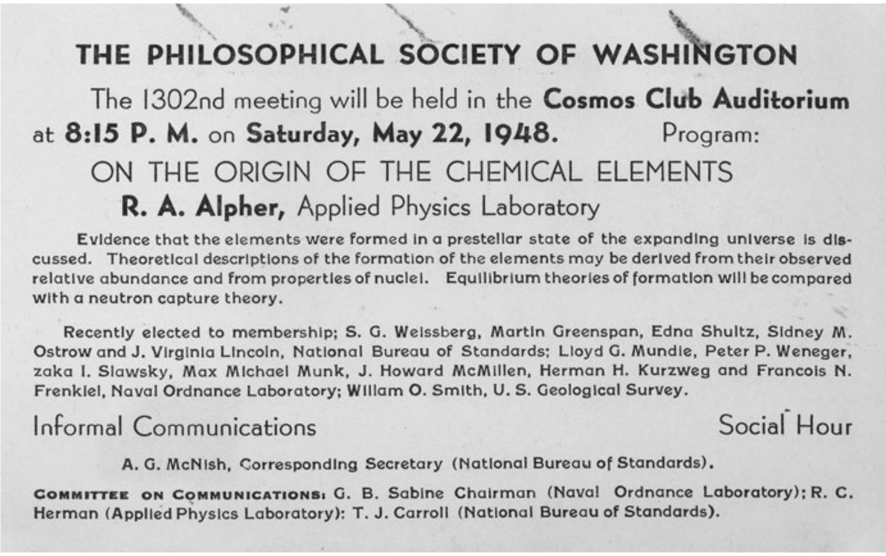
Had Hoyle's remarks been published, Alpher and Herman would have received the credit they deserved for predicting the CMBR in 1948, eight years earlier. It would be many years before spectrographic work, such as Adams's and McKellar's, would be interpreted retrospectively as an early detection of the CMBR.

The Philosophical Society of Washington

Alpher's statement in his interview with Harwit that he and Herman did "nothing" to promote the measurement of the CMBR is not borne out by the many talks and colloquia they gave at professional meetings, first in the Mid-Atlantic region, and later nationally and internationally.[39] Alpher documented eighteen colloquia he gave between February 17, 1950, to the Physics Department of the University of Virginia and April 22, 1955, at a Symposium on Digital Computers in Astrophysical Research at the Franklin Institute in Philadelphia, and he and Herman spoke at meetings of the American Physical Society and of the Philosophical Society of Washington. Alpher also gave a talk on the "Origin of the Elements" at a conference in 1952 at Yerkes Observatory at which Chandrasekhar was present. By then Alpher's 1948 dissertation on nucleosynthesis in the early expanding universe had garnered him a great deal of attention.

Gamow, Alpher, and Herman were elected to membership in the Philosophical Society of Washington on December 6, 1947, four months prior to the publication of the $\alpha\beta\gamma$ paper, and Alpher was elected to the related Washington Academy of Sciences in 1952. He regularly attended meetings of the Philosophical Society, where the lively scientific scene in Washington was on display, as indicated by a partial list of speakers and topics between October 11, 1947, and May 22, 1948.[40]

Thus, in October 1947, Edward U. Condon, Director of the National Bureau of Standards (NBS), reviewed the current state of knowledge on nonelectromagnetic forces influencing the interactions of electrons, protons, and neutrons, and astronomer Robley C. Williams of the University of Michigan reviewed recent developments in electron microscopy. In November 1947, Defoe C. Ginnings and Andrew I. Dahl of the NBS gave talks on temperature measurement in large-velocity, high-temperature gas streams; Jerome B. Green of the Naval Ordnance Laboratory (NOL) reviewed the history of the measurement of atomic spectra and urged further research on it; and Alvin G. McNish of the NBS argued that the origin of cosmic rays could only be in interstellar space. In December 1947, Green reviewed the history of the measurement of atomic spectra and urged that they be studied in the infrared. In January 1948, McNish talked on radio echoes from meteor trails, and on May 22, 1948, Alpher, six weeks after the appearance of the $\alpha\beta\gamma$ paper and just days before he defended his dissertation, gave a talk on "The Origin of the Chemical Elements" (figure 6), which merited nearly a full-column abstract, about three times as long as usual.


THE PHILOSOPHICAL SOCIETY OF WASHINGTON

The 1302nd meeting will be held in the **Cosmos Club Auditorium** at **8:15 P. M.** on **Saturday, May 22, 1948.** Program:

ON THE ORIGIN OF THE CHEMICAL ELEMENTS

R. A. Alpher, Applied Physics Laboratory

Evidence that the elements were formed in a prestellar state of the expanding universe is discussed. Theoretical descriptions of the formation of the elements may be derived from their observed relative abundance and from properties of nuclei. Equilibrium theories of formation will be compared with a neutron capture theory.

Recently elected to membership; S. G. Weissberg, Martin Greenspan, Edna Shultz, Sidney M. Ostrow and J. Virginia Lincoln, National Bureau of Standards; Lloyd G. Mundie, Peter P. Weneger, zaka I. Slawsky, Max Michael Munk, J. Howard McMillen, Herman H. Kurzweg and Francois N. Frenkiel, Naval Ordnance Laboratory; William O. Smith, U. S. Geological Survey.

Informal Communications Social Hour

A. G. McNish, Corresponding Secretary (National Bureau of Standards).

COMMITTEE ON COMMUNICATIONS: G. B. Sabine Chairman (Naval Ordnance Laboratory); R. C. Herman (Applied Physics Laboratory); T. J. Carroll (National Bureau of Standards).

Fig. 6. The announcement on a 3 × 5 inch card of Ralph A. Alpher's talk, "On the Origin of the Chemical Elements," at a meeting of the Philosophical Society of Washington at the Cosmos Club in Washington on the evening of Saturday, May 22, 1948. Note that Alvin G. McNish of the National Bureau of Standards was the Corresponding Secretary, and that Robert C. Herman was a member of the Committee on Communications. *Credit*: Alpher Papers.

Radio Astronomy

Prior to and during the war, both Alpher and Herman had strong ties to the Naval research community.[41] Alpher was employed by the Office of Scientific Research and Development beginning in August 1940, was a contract employee of the Bureau of Ordnance through its Section T from 1940 through 1944, and was officially employed by the JHUAPL on August 1, 1944, to work on the development of magnetic-influence torpedo exploders. He was likely present at the Naval Research Laboratory (NRL) during discussions about the great advances taking place in radio communications and radar. Herman, who had been at the JHUAPL since 1942, served as liaison to the U.S. Navy on the development of the proximity fuse.[42]

After the war, the Naval Observatory and the NRL were at the forefront of the development of radio astronomy. In 1951, the largest accurately configured radio telescope with a 50-foot parabolic antenna was installed on top of NRL Building 43 in Washington, D.C.,[43] and John P. Hagan and his colleagues began using it to look at the absorption of 21-centimeter radiation by interstellar hydrogen.[44] Alpher recalled discussing with Alvin G. McNish at a physics meeting at the NBS whether he thought the CMBR could be measured.[45]

In 1946 Merle A. Tuve (figure 7), Director of Section T at the DTM, was one of the first to leave the JHUAPL after the war to return to the DTM as its Director to

Fig. 7. Merle A. Tuve (1901-1982) ca. 1946. *Credit*: Carnegie Institution of Washington.

establish a program in radio astronomy. Seven years later, in 1953, he became head of a subpanel on radio astronomy of the new National Science Foundation (NSF) and advocated increased support for this field,[46] which in 1957 led to the establishment of the National Radio Astronomy Observatory in Green Bank, West Virginia. In 1966, when James B. Comly joined Alpher at the General Electric Corporate Research and Development Center (GECRDC), they discovered that they had a close personal link: Comly was married to Tuve's daughter Lucy, who also was a researcher there. Comly then asked Alpher to become H.K. Liu's Chief of Staff in the GECRDC's Energy Sciences branch, so Alpher then reported to Comly through Liu.[47]

A landmark conference on radio astronomy that was sponsored by the NSF, the California Institute of Technology, and the DTM was held in Washington, D.C., from January 4-6, 1954,[48] where astonomers and physicists from the United States, Canada, England, Australia, and the Netherlands gave talks. It then became clear that the United States was behind other countries in the development of radio astronomy and that a major effort would be required to bring the United States up to speed in the field.

In 1951 Edward M. Purcell and Harold I. Ewen had reported their momentous observation of the 21-centimeter line of hydrogen in the interstellar radio spectrum, commenting that: "Extrapolation of radio temperature data for somewhat lower frequencies suggests that the background radiation temperature near the 21-cm. line is not more than 10°K."[49] By 1960, J.A. Giordmaine, a graduate student of Charles Townes at Columbia University, in discussing the current limitations of radio astronomy, concluded that:

> At wavelengths shorter than 3 cm crystal noise temperatures as well as atmospheric absorption rise rapidly. Indeed apart from the sun, the moon, and Venus, no discrete sources have been detected at wavelengths between 3 cm and the optical infrared region.[50]

Most astronomers at the time considered interstellar sources of radiation as interference, not as sources of information about interstellar space.

A great conceptual barrier existed between the spectral analysis of interstellar objects and the notion of a pervasive relict radiation from the expansion of the universe. Giordmaine, for example, noted:

> Thermal emission from planetary nebulae also appears to be a source of detectable radiation. In 1958 Drake and Ewen reported detection of 3.75 cm radiation associated with NGC 7293 and NGC 6853, the Helix and Dumbbell nebulae respectively. Although this observation has not yet been corroborated at nearby wavelengths, it appears that cm wavelength observations will become a useful and independent tool in the study of the planetaries, for many of which the optical estimates of electron density are not of high precision.[51]

The basic instrument for measurements in radio astronomy was the microwave radiometer that Robert H. Dicke had invented in 1946.[52] Three years later, Joseph Weber, who had used Dicke radiometers in his radar work for the U.S. Navy, approached Gamow at GWU looking for a doctoral thesis topic.[53] Gamow, who was then still opposed to Alpher and Herman's prediction of the CMBR, said that he had no good problems in mind, so Weber went to Catholic University in Washington to do his dissertation on a noncosmological topic—another of the many missed opportunities to measure the CMBR.

Soviet astronomers also were using Dicke radiometers in the late 1940s and built radio telescopes in the Crimea, on the Volga River near Zimenki, primarily to measure radio waves in the ionosphere, not in interstellar space.[54] Why did they not try to measure the CMBR? Historian Stephen G. Brush, aware of a 1993 paper by theoretical physicist Luis J. Boya at the University of Zaragosa, Spain,[55] sent a copy of Boya's paper to Alpher, asking him to comment on it. In response, Alpher and Herman wrote a letter to Boya on April 13, 1995,[56] which is one of their last joint statements on measuring the CMBR and directly expresses their feelings about this albatross that had been hanging over their heads during much of their careers.* Alpher and Herman wrote:

> We do not apologize for not having managed to convince observational astronomers to look for the background radiation in the late 1940s or early 1950s. Be assured that we tried to do so with appropriate scientists at the Naval Research Laboratory, at the Central Radio Propagation Laboratory of the National Bureau of Standards, at CalTech, and other places. Moreover, we gave several invited papers in 1950 and 1951 before the American Physical Society in which we proposed that someone should attempt to make the necessary measurements. Some recent authors have suggested that it should have been possible. There are many instances in the history of science in which theoretical predictions have preceded observational verification, where it has been argued that the observations could have been made much earlier. It is no surprise given the clarity of hindsight that some argue that measurements of the cosmic microwave background radiation should have been possible in the early 1950s, despite the comments of radio astronomers of the period. You may not have be [*sic*] aware that there were several observations of the radiation, starting in the early 1940s and continuing into the mid 1950s, where, unfortunately, the origin of the radiation was a complete mystery.[57]

They asked Boya, as a respected theoretical physicist, to "rectify the situation with a note to the journal in which your paper was published." Among other things, their letter to Boya shows how keenly they were aware of attempts to measure the CMBR prior the crucial year of 1964.

---

* On receiving the Draper Medal of the National Academy of Sciences in 1993, Alpher and Herman were asked to make a formal statement about the award. I remember Herman's response: "This shows that if you wait long enough, something good will happen."

Penzias and Wilson's Measurement of the CMBR

Martin Harwit conducted illuminating interviews in 1984–1985 with P. James E. Peebles, David T. Wilkinson, and Robert H. Dicke relating to Penzias and Wilson's measurement of the CMBR in 1964.[58] Regarding the possibility of measuring the CMBR with Dicke's 1946 radiometer, Wilkinson noted the need for a cold load, which Penzias and Wilson used, and to account for "insertion losses," the energy absorbed by the equipment, which for measurements below 5°K could obliterate an interpretable observation. Also discussed was the problem of finding an absolute measurement against which to measure the 2.725°K relict blackbody radiation in the infrared region. Dicke suggested that his radiometer could have done so, but Harwit reminded him that Purcell, his mentor at the MIT Rad Lab, believed that it could not. Peebles had studied under Dicke at Princeton and was a postdoc there at the time of Penzias and Wilson's measurement in 1964.

> **Peebles:** He [Dicke] said so many times, "Consider the universe as it is today, you can trace back to the universe as it was yesterday, and the day before. But in the conventional big bang, you run into the day zero where things stop…. Wouldn't it be fun if someone looked for this." So he persuaded Dave Wilkinson and Peter Roll to start thinking about … to start first looking in the literature for other measurements that might be relevant, and second to start building an apparatus. And he just said to me, "Why don't you go and think about the theory." I don't quite remember his words.
>
> **Harwit:** Did you start out by thinking about it or going to the library?
>
> **Peebles:** No, I started out by thinking about it. I was never strong on the literature. Still am not strong on the literature; I have to have something pointed out to me, often, before I'll recognize that someone else could have done something. It's so much more fun to think things through on your own than it is to read someone else's paper….[59]

Prior to the publication of Penzias and Wilson's paper, Peebles gave a colloquium at the JHUAPL during which he reported Dicke's prediction of a 10°K CMBR. Bernard Burke, a radio astronomer at MIT, heard about Peebles's talk and then contacted Penzias and Wilson, who in turn contacted Dicke and his group at Princeton. Neither Penzias and Wilson nor Dicke, however, cited Alpher and Herman's earlier predictions of a relict CMBR in their landmark papers in *The Astrophysical Journal.* While Dicke and his colleagues did provide a cosmological context for Penzias and Wilson's observation, their interpretation of it considered only a static or oscillating universe, and not the competing big bang theory advocated by Alpher and Herman and Gamow. Wilson recently commented that he was surprised by the rapid acceptance of their observation of the CMBR.

> It probably helped that the steady-state theory was failing to fit observations and Bell Labs had a reputation for doing good science…. More often, paradigm changes of that magnitude are resisted much more by established scientists.[60]

Alpher and Herman's predictions were not noticed, although they had published them in the major physics journals at the time. It is even possible that Dicke measured the CMBR without realizing or remembering it, as Purcell noted in an interview with Katherine R. Sopka in 1977.

> **Purcell:** By the end of the [Massachusetts Institute of Technology] Radiation Lab, in '46 even, Dicke had measured the absorption of water vapor in the atmosphere; working with [Robert] Beringer he had measured the oxygen absorption at six millimeters; and he had observed a partial eclipse of the sun with a K-band radiometer. And, in fact, he had made a measurement of the sky temperature which set a non-trivial upper limit on the density of what we now know as the isotropic microwave background radiation, although I believe Dicke himself later forgot that he had done that.
>
> **Sopka:** This was done at the Radiation Lab?
>
> **Purcell:** At the Radiation Lab. That was measured from the roof of the Radiation Lab, yes. You see, toward the end of the war we had made a terrible mistake, and my group had contributed to it or I contributed to it certainly. Namely, we had picked the wavelengths to settle on for K-band almost on top of a water vapor absorption line. This turned out to be fatal to the use of K-band for long-distance radar (for which it wasn't very good anyway). We were greatly chagrined as a matter of fact – it should have been possible to predict this by using some data that were already contained in a paper by [J.H.] Van Vleck. When we began to suspect that we were having trouble with water vapor, Dicke used his radiometer to measure the water vapor absorption line. This led, of course, directly into microwave spectroscopy, was indeed microwave spectroscopy. And the techniques developed during the war provided almost the basis for the explosive development of microwave spectroscopy after the war.
>
> …………………………..
>
> It provided us with the tools, not merely the hardware, but with a basic understanding, which for most of us, certainly for me, came absolutely for the first time of what you have to do to detect a signal in noise.[61]

In the aftermath of Penzias and Wilson's measurement of the CMBR, Alpher and Herman recalled that in early 1965 the Editor of the *Physical Review* asked Herman to referee a paper by Peebles on the CMBR. Herman called in Alpher to help; they both thought the paper was well written, but were disappointed that there was no recognition of their previous work in the field. They therefore provided relevant citations and returned their report over Herman's signature. Now, while the names of referees of papers submitted to the *Physical Review* are anonymous, they recognized Peebles as the author of the paper by its wording and style, and he in turn recognized them as the referees. Subsequently, they received a second draft of the paper for refereeing.

> **Alpher:** So we wrote back a second letter, and said that he still had not, in our view, absorbed what had already been done, and the paper still suffered in that respect, [so] we recommended that it not be published in that form.
>
> **Herman:** It was redundant with what had already been published.
>
> **Alpher:** Okay, then we heard no more after that until the appearance of the papers [by Dicke *et al.,* and by Penzias and Wilson] in the July 1965 issue of *The Astrophysical Journal* with the observation and with the Princeton group's explanation of the background radiation.
>
> **Harwit:** And no reference to your work?
>
> **Alpher:** And still no reference to our work. There was a reference to our…. He did refer to the fact that you [Herman], Gamow and I had discussed an early hot, dense universe, but that was about it….
>
> **Herman:** Well, he didn't state that we had made the calculations and predicted 5°K.
>
> **Alpher:** Precisely. Even in a later paper, which Peebles published in *The Astrophysical Journal* on the background radiation, made very limited reference to our work, if any.[62]

Peebles recalled much later that he gave a colloquium on cosmology at the JHUAPL on February 19, 1965, and only much later learned that Alpher and Herman had made their prediction of the CMBR while working at the JHUAPL over sixteen years earlier.

> Our ignorance in 1964 about the literature of this subject is legendary in the cosmology community, and legends beguile. I see the effect in Bob Dicke's comment (unpublished, dated 1975):
> "There is one unfortunate and embarrassing aspect of our work on the fire-ball radiation. We failed to make an adequate literature search and missed the more important papers of Gamow, Alpher and Herman. I must take the major blame for this, for the others in our group were too young to know these old papers. In ancient times I had heard Gamow talk at Princeton, but I had remembered his model universe as cold and initially filled only with neutrons."[63]

Peebles continued:

> I think Bob [Dicke] apologized too much. I have the greater share of blame for poor homework: Bob was careful to stand back and let younger people in his group get on with research on their own. Our paper Dicke and Peebles (1965)[64]

Fig. 8. Ralph A. Alpher at the JHUAPL in the late 1940s. *Credit*: Alpher Papers.

> did not give proper references to earlier work on the hot big bang, but we remedied that pretty quickly.* I believe the citations are normal and proper in Dicke *et al.* (1965) [which gives the hot big bang interpretation of Penzias and Wilson's measurement].[65]

My father (figure 8) stated many times to me that Dicke was in the audience in a colloquium he had given on the CMBR and the formation of the elements, and that he and Herman remained perplexed about the lack of citation of their work in Dicke and his colleagues' paper. If they were alive today, they would strongly disagree with Peebles that Dicke's references were adequate. Peebles has called it a "myth" that Dicke, he, Roll, and Wilkinson "did not refer to earlier work" in their 1965 paper,[66] and he then listed three early references in it, none of which, however, are to Alpher and Herman's 1948 paper,[67] an omission he did not remember as signifying "more than a lack of careful reading" when writing what was, after all, a "brief paper."[68] I still think, however, that Alpher and Herman would be perplexed by Peebles's account of the crucial period 1948–1965. And oddly enough, in the glossary of their 2009 book, Peebles, Page, and Partridge define "ylem" as "Alpher's name for the state of the early universe,"[69] which is incorrect. It is a Middle English word that Alpher suggested for the "stuff" from

* Alpher and Herman had provided all of the references to Peebles in their referee's report.

which the elements comprising the universe were made. It also has corresponding Old French and Medieval Latin equivalents. They are correct, however, in saying that Alpher brought the word to the discussion;[70] it appears in a well-known photograph of a bottle of Cointreau with YLEM pasted across the label.*

Alpher and Herman's Work on the CMBR after 1955

In 1955 Ralph Alpher accepted a position at the General Electric Corporate Research and Development Center (GECRDC) in Niskayuna, New York, a position that allowed him to devote his time to research, and to support his wife and two children. Other offers, such as one from the Glenn L. Martin Corporation,[71] would have allowed him considerably less freedom. In 1956 Herman accepted an offer at the General Motors Research Laboratory in Detroit, Michigan, so after 1955 their productive team was separated geographically.

Much of Alpher's work at the GECRDC was classified, but he also published on cosmology in internal Technical Monographs, and with Herman in the open literature. They also spoke almost daily over the telephone, cutting their costs after 1967 by using WATS (the Wide Area Telephone Service). Alpher retired from General Electric in 1986 and accepted a professorship in physics at Union College in Schenectady, New York, after which he and Herman continued to collaborate and publish articles and chapters of books, and to give talks and colloquia. They summarized their work in a long 1975 paper in connection with their receiving the Magellanic Premium of the American Philosophical Society,[72] which enabled them to calculate the CMBR to be 2.728 ± 0.0004°K. Herman attributed Gamow's earlier and different results to Gamow's propensity to use approximations in his calculations.[73]

Contrary to what is often said, that Alpher and Herman "gave up" on cosmology after leaving the JHUAPL, there is plenty of evidence that this was not the case. Moreover, before and after they left, my father's files reveal that while only 5 percent of the research funds at the JHUAPL could be dedicated to basic science after Merle Tuve left as its director in 1946, a good deal of research on cosmic rays was still being done there by James Van Allen and his High Altitude Research Group, and my father was a member of his group, which within the lab was called "The Five Percenters." Van Allen recalled:

* As I can attest from many games of Scrabble with my father, he had a vast English vocabulary. In July 2007, the original bottle of "Ylem" was in Room 111 of the National Air and Space Museum of the Smithsonian Institution in Washington, D.C. A photograph of Gamow, Alpher, and Herman surrounds it, which appears to show the centrality of Gamow, and which in 1948 may have seemed appropriate, but it also seems to lend substance to them being referred to as "Gamow and colleagues." Eaman Harper presented a reproduction of the "Ylem" bottle to Alpher and Herman in 1996; see Harper, Parke, and Anderson, *Gamow Symposium* (ref. 4), p. 691. This bottle is now in the Estate of Ralph A. Alpher, Victor S. Alpher, Executor.

> This early work with high-altitude rockets [including leftover German V-2s, and the Aerobee created at the JHUAPL] laid the foundation, both technically and scientifically, for the competence of U.S. laboratories to pursue scientific research with satellites and deep space missions to the Moon and planets beginning in [the International Geophysical Year] 1958.[74]

At the GECRDC, Alpher had a similar opportunity to pursue research in cosmology. He discussed the methods and results of interferometry, which were important in radio astronomy, in considerable technical detail in an early technical document. He and his colleague Donald White had first used interferometry in studying shock waves incident on two-dimensional objects,[75] basic research that was part of the "re-entry" mission under Tony Nerad.[76] In 1961 Alpher also discussed the use of masers for measuring background radiation; calculations showed that while masers could be cooled to liquid nitrogen temperatures, this would reduce the amplitude and increase the frequency of relaxation oscillations beyond the range needed to measure the predicted CMBR. While earlier he did not think that microwave diagnostics and optical interferomentry would be improved at higher frequencies, by 1961 he was more sanguine, feeling that the development of an infrared interferometer as an adjunct to current optical interferometry would "bring one into contact with the upper limit of present microwave diagnostic techniques."[77] In January 1962 he and Peter Cannon discussed the use of the Mössbauer effect to increase the accuracy of temperature measurements, which might be applicable to measuring the CMBR.[78]

In July 1963 Alpher wrote two documents that are of particular interest to measuring the CMBR.[79] In the first one, he recommended that the "background radiation" could be measured in a nonrecoverable space probe, as well as the "integrated output of all radiation sources in the universe."[80] In the second one, he goes goes on to say that:

> This writer has spent some time in surveying the kinds of cosmological experiments one might conceivably do from deep space probes. At present the basic cosmological experiments appear to be those which would provide information to help in distinguishing between the various currently proposed cosmological models, viz: the homogeneous isotropic steady-state universe; the homogeneous isotropic evolutionary universe; the homogeneous isotropic universe in which the "constants of nature," and in particular the gravitational "constant" may vary in space, time, or both; and the anisotropic universe, steady-state or evolutionary.[81]

Alpher then discussed in detail both direct and indirect methods for distinguishing among these models. C. Guy Suits, who was in charge of General Electric Corporate Research and Development, valued the pursuit of such basic research, whose outcomes might not be directly related to GE's profitability.[82]

Alpher recommended other projects at the GECRDC that reflected his broad theoretical knowledge and its links to observation, but at the same time he kept current in cosmology and astrophysics and related instrumentation. On the cover of one of his 1963 papers he penned a reference to Robert J. Gould and Geoffrey R. Burbidge's 1963 article on X rays from the galaxies and the interstellar medium.[83] In another one, he specifically mentioned E. Margaret Burbidge, Geoffrey R. Burbidge. William A. Fowler, and Fred Hoyle's 1957 paper (the famous B^2FH paper) on the creation of elements in stars, which resolved some of the problems associated with the formation of light elements during the early moments of the big bang.[84] Much earlier, on Gamow's outline for his lectures at the 1953 Michigan Summer School on Astrophysics, he wrote, "Possibility of formation of heavy elements in stellar explosions."[85] Later, after Penzias and Wilson's measurement of the CMBR, Alpher was a member of a Task Force that produced a lengthy "Action Plan for Space Science" on January 18, 1967, which suggested more basic-science experiments aboard space vehicles, including cosmological research.[86]

During the nine years, 1955–1964, between Alpher's departure from the JHUAPL and Penzias and Wilson's discovery of the CMBR, Alpher and Herman's colleagues in physics and radio astronomy offered little hope to them that their prediction of the CMBR would be confirmed, owing to their belief that there were too many sources of extraneous interference to measure the ambient interstellar radiation in the far infrared region of the blackbody spectrum. Nevertheless, they continued their ceaseless efforts to promote the measurement of the CMBR while pursuing their "day jobs." Their proposals in the 1960s are similar to those that Van Allen collected in his 1956 book, *Scientific Uses of Earth Satellites*,[87] including recommendations for Voyager in 1963 that would have measured the CMBR without interference from terrestrial radiation sources, and which would have to wait until the launch of the Cosmic Microwave Background Explorer (COBE) in 1989. They continued to work as a team: Each pushed the other onward as they continued to work on cosmological and astrophysical problems "avocationally." Their geographical separation, in stark contrast to their contiguousness in Washington, D.C., was simply a barrier to be overcome.

Soviet Work on the CMBR

Peebles, Page, and Partridge included recollections of Russian physicists and astrophysicists who were involved in cosmological research in the 1960s,* such as

* In response to an e-mail from Partridge in 2006, Alpher declined to submit a paper to Peebles, Page, and Partridge's book. He felt that he already had contributed a sufficient number of "reminiscences" to the literature, and he also was seeking to avoid a clash with Peebles. Alpher in failing health had participated in two long interviews, one with Marcelo Gleiser in Tampa, Florida, for Brazilian TV-GLOBO on December 3, 2005, that was broadcast around April 2006, and one with Matthew Hickey of Workaholic Productions, Inc., in Austin, Texas, on September 1, 2006, for a program on the History Channel entitled "Beyond the Big Bang"; its first airing was on September 4, 2007. Alpher passed away three weeks earlier, early in the morning of August 12, 2007.

Igor D. Novikov, Andrei G. Doroshkevich, and Rashid Sunyaev.[88] Yakov Zel'dovich was the senior physicist in a team of younger cosmologists in Moscow; he and Novikov sent Alpher a Russian New Years' card for 1965, after Novikov and Doroshkevich had reworked Alpher's prediction of the CMBR in 1964.[89] Sunyaev, who began his doctoral thesis work with Zel'dovich in 1963, recalled that Penzias and Wilson's and Dicke and his colleagues' 1965 papers caused a great stir in Zel'dovich's group in Moscow.[90]

Owing to Zel'dovich's propensity to write review papers, his acceptance of Gamow's "hot model" of the expanding universe almost overshadowed the prediction and possible observation of the CMBR in the USSR. The Russian expatriate Gamow likely helped his rehabilitation in the USSR by sending packets of reprints to Zel'dovich along with his colorful stationery and handwritten notes. Sunyaev, however, recalled that Iosif S. Shklovsky was the first to receive the crucial 1965 issue of *The Astrophysical Journal* and to coin the popular Russion term for the cosmic "relict radiation" (*Реликтовое Радиация*).[91] As Zel'dovich and his colleagues then reworked the paths previously trod by Alpher and Herman, Gamow's name attracted their attention. Novikov, in his reflections of the 1960s, highlighted that Penzias mentioned Doroshkevich and Novikov's brief 1964 paper in his Nobel Lecture.[92] They had interpreted the "theoretically computed atmospheric noise" at 2.4°K, which they considered as supporting "the correctness of the Gamow theory,"[93] a misconception that continues to be prevalent among cosmologists.[94] Steven Weinberg is a notable exception: Alpher regarded his book, *The First Three Minutes*,[95] very favorably. Alpher and Herman felt that the "Matthew effect" played a continuing role in their lack of recognition, according to which significant joint work is usually attributed to the senior, well-known scientist.[96]

Helge Kragh's monumental history of cosmology covers the period from the 1920s to the 1990s, in which he notes that "'Physical cosmology' is often seen as a characteristic of post-1965 development, but in fact both the program and its partial realization go much farther back in time."[97] I wrote to Kragh, attempting to obtain a copy of one of the letters to which he referred, but in his replies of August 2 and 16, 2009, he regretfully stated that it apparently had been lost, that he was unable to find the file containing the "material concerning the cosmological controversy in the 1950s," and that, "I am sorry (and annoyed) that I cannot be of help."[98]

Alpher, Herman, and Gamow Redux

By now many if not most cosmologists and astrophysicists are aware of Alpher and Herman's early prediction of the CMBR, but not of the tortuous history of its neglect. Gamow eventually accepted their prediction, but he did not cite their seminal papers when publishing his own calculations.[99] A head-to-head observational test of the big bang and steady-state theories was apparently not on his agenda, although he lived to see the former supersede the latter. Alpher and Herman, who had sought tirelessly to promote a measurement of the CMBR, were

Fig. 9. Ralph A. Alpher in 1950. *Credit*: Alpher Papers.

not really satisfied with any explanation of Gamow's attitude toward their prediction.* They did, however, offer an opinion about the frequent attribution of their work to Gamow:

> The tendency now of some to attempt to raise Gamow's stature further by attributing to him achievements that have no proper basis is in our opinion doing a disservice to his memory….

Gamow certainly had a strong personality, mainly an intense and joyful approach to science, and it is precisely this very robust enthusiasm that made some of the more conventional members of the scientific community look at him with less than affectionate approval.[100]

Alpher (figure 9) and Herman wanted their work to stand on its own merits, as I heard repeatedly from them.** My goal has been to reveal what they knew, as

* Herman's motivation and attitude should be differentiated from Alpher's. As founder of the science and theory of traffic flow after he joined the General Motors Research Laboratories in 1956, Herman had seen a new field develop from the ground up, and I suspect that he did not observe the kind of confused scholarship that attended that of the CMBR and big bang. Moreover, by the time he and Alpher began collaborating in 1948, he was a seasoned researcher, and he continued his research in his new field of traffic-flow theory when he left General Motors for The University of Texas at Austin in 1979.

** I know from discussions with my father and Herman that Herman was outraged that Alpher was never elected to the U.S. National Academy of Sciences.

they themselves were loathe to put their feelings on paper, and in this way to elucidate their contributions to cosmology.

George Gamow's legacy is secure. Whether his ebullience was appreciated or not, he is remembered as a giant of 20th-century physics, and as the author of the "Mr. Tompkins" series and of many other popular-science books, which influenced later generations of students, including the radioastronomer-cosmologist Robert W. Wilson.[101] Historian Roger H. Stuewer has noted that Wolfgang Pauli expressed Gamow's great productivity by using his name as a German verb, saying "Es Gamowt wieder," like "Es regnet wieder" ["It's raining again"].[102] Still, misconceptions remain: Alan Lightman and Roberta Brawer asserted erroneously that Alpher, Gamow, and Herman predicted the CMBR in 1948, and that Dicke and his colleagues *independently* predicted it seventeen years later.[103] John C. Mather stated erroneously in his Nobel Lecture that Robert Herman was one of Gamow's students.[104]

The CMBR Today

Barely twenty-five years after Penzias and Wilson's detection of the CMBR, NASA devoted billions of dollars to developing the Cosmic Microwave Background Explorer (COBE) to obtain a more precise measurement of the CMBR. Alpher and Herman attended its launch in 1989.[105] The CMBR is now known a thousand times more precisely than before COBE's three measuring instruments were employed.[106] We can pause to re-evaluate the early history of the CMBR,[107] and to note its place in popular culture,* but most importantly, the CMBR and the expanding universe are now central to the field of cosmology.

Ralph A. Alpher was awarded the National Medal of Science for 2005. Prior to the award ceremony in 2007, I discussed the award with astrophysicist Neil deGrasse Tyson, who told me that Alpher is considered to be "the father of modern astrophysics and cosmology."[108] I accepted the award for my father from President George W. Bush in the East Room of the White House on July 27, 2007.** The citation reads:

* On April 16, 2004, the following question and answer appeared on the hit American television program, *Jeopardy*. Question: "In 1948 Gamow, Herman and Alpher developed this 'large' cosmological theory." Answer (worth $600): The Big Bang"; see website <http://www.j-archive.com/showgame.php?game_id=3170>. The Columbia Broadcasting Company now also has a hit situation-comedy program entitled "The Big Bang Theory"; see website <www.cbs.com/shows/big_bang_theory/>.

** The international press photograph shows President Bush draping the medal with its red, white, and blue ribbon over my shoulders. Over 200 comments appeared on the internet, asking why the octogenarian Alpher appeared to be so young! Reuters did publish a correction: The Good, the Bad, & the Ugly Editor, "He's not 84" (August 28, 2007); see website <http://blogs.reuters.com/gbu/2007/08/28/hes-not-84/>, which shows the photograph. Prior to the ceremony, I was told by one of the White House personnel that I simply would be handed the medal in its presentation box. Apparently this was not communicated to the Naval Officer who handed each medal on a ribbon to the President to hang over the shoulders of the recipient.

> For his unprecedented work in the areas of nucleosynthesis, for the prediction that universe expansion leaves behind background radiation, and for providing the model for the Big Bang theory.

Two weeks later, on August 12, 2007, Ralph A. Alpher passed away at the age of 86. He knew, finally, that his singular and pioneering work in cosmology had been acknowledged by the community he had served for over sixty years. Seeking such recognition, however, had never been part of his constitution, or of his attitude toward scientific inquiry.

Acknowledgments

I am most indebted to my father, Ralph Alpher, and to Robert Herman for sharing with me their views on their work and its history. My mother, Louise Ellen (Simons) Alpher, was also supportive of my work. I thank Dwight E. (Ed) Neuenschwander (Southern Nazarene University) and Marcelo Gleiser (Dartmouth College) for encouraging me to publish my recollections and views of my father's work, Stephen G. Brush (University of Maryland) for his help and interest in my work, and Robert W. Wilson, Virginia Trimble, and Bev Orndorff (former science writer for the *Richmond Times-Dispatch*) for their insights related to my paper. For their support and encouragement, I also thank James Van Allen, Donald White, James Comly, Janie Schwartz, Phillip Kosky, Christine Bogert, Ivar Giaever, Gerard J. Connors, William P. Henry, III, James R. Hay (Captain, USN, Retired), Maurice ("Mike") Rindskopf (Rear Admiral, USN-Retired, d. July 27, 2011), Juliya Borschevskaya, Anthony J. Johnson, Dudley Primeaux, Mary Jane Valachovic, and Elizabeth Hammerle. I thank Christy Costlow (M.A., University of Texas at Austin) for her archival and organizational work), and Kevin D. Miller and C. Jay Lyons (Lieutenant Colonel, USAF, Retired) for reading drafts of my paper. I deeply appreciate the help of Joe Anderson, Melanie Brown, and Stephanie Jankowski of the American Institute of Physics Niels Bohr Library and Archives, and Judith Theodori and Catherine Hudson of The Johns Hopkins University Applied Physics Laboratory Library, Molly White (University of Texas Physics Mathematics Astronomy Library), and Allyson Raines (University of Maryland Archives). Finally, I thank Roger H. Stuewer for his meticulous and thoroughgoing editorial work on my paper.

References

[1] Ralph A, Alpher and Robert C. Herman, "Early work on 'big bang' cosmology and the cosmic blackbody radiation," in R. Bertotti, R. Babinot, S. Bergia and A. Messina, eds., *Modern Cosmology in Retrospect* (Cambridge, New York, Port Chester, Melbourne, Sydney: Cambridge University Press, 1990), pp. 129–157, on p. 129.

[2] Interview of Ralph A. Alpher and Robert C. Herman by Martin Harwit on August 11, 1983, Niels Bohr Library and Archives, American Institute of Phyiscs, College Park, MD USA, www.aip.org/history/ohlist/LINK, p. 17 of 78.

[3] Ralph A. Alpher and Robert C. Herman, "Evolution of the Universe," *Nature* **162** (November 13, 1948), 774-775; Ralph A. Alpher and Robert C. Herman, "On the Relative Abundance of the Elements," *The Physical Review* **74** (1948), 1737-1742.

[4] Ralph A. Alpher, "George Gamow and the Big Bang Model. Part I. Cosmochemistry in the Early Universe," in E. Harper, W.C. Parke, and G.D. Anderson, ed., *The George Gamow Symposium.* Sponsored by The George Washington University and the Carnegie Institution of Washington 12 April 1996 (San Francisco: Astronomical Society of the Pacific, 1997), pp. 49-68, on p. 53.

[5] James D. Watson, *The Double Helix: A personal account of the discovery of the structure of DNA* (New York: Antheneum and London: Weidenfield & Nicolson, 1968).

[6] Alpher to Bernard Scharfstein, August 25, 1975, Alpher Papers, Estate of Ralph A. Alpher, Victor S. Alpher, Executor; hereafter Alpher Papers.

[7] For a list of the topics and participants at the annual Washington Conferences on Theoretical Physics from 1935-1942 and 1946-1947, see Harper, Parke, and Anderson, *George Gamow Symposium* (ref. 4), pp. 12-15.

[8] Ralph A. Alpher, curriculum vitae, Alpher Papers.

[9] R.A. Alpher, H. Bethe, and G. Gamow, "The Origin of Chemical Elements," *Phys. Rev.* **73** (1948), 803-804; see also Victor S. Alpher, "The History of Cosmology as I have Lived Through It. Part 3," *Radiations* (Spring 2009), 8-18, website <http://www.sigmapisigma.org/radiations/2009/alpher_part3.pdff>.

[10] R.A. Alpher, "A Neutron-Capture Theory of the Formation and Relative Abundance of the Elements," *Phys. Rev.* **74** (1948), 1577-1589; for comments on the large value of the CMBR, see Michael S. Turner, "From $\alpha\beta\gamma$ to precision cosmology: The amazing legacy of a wrong paper," *Physics Today* **61** (December 2008), 8-9.

[11] P. Balaram, "The mores of publishing in science," *Current Science* **83** (2002), 1429-1430; Paul R. Halmos, "'Nicolas Bourbaki'," *Scientific American* **196** (May 1957), 88-91, 93-94, 96, 99.

[12] S. Chandrasekhar and Louis R. Henrich, "An Attempt to Interpret the Relative Abundances of the Elements and Their Isotopes," *The Astrophysical Journal* **95** (1942), 288-298.

[13] Ralph A. Alpher and Robert C. Herman, "Theory of the Origin and Relative Abundance Distribution of the Elements," *Reviews of Modern Physics* **22** (1950), 153-212.

[14] Interview of Ralph A. Alpher by Martin Harwit on August 11, 1983, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD USA, http://www.aip.org/history.ohlist/LINK, pp. 21-22 of 36.

[15] G. Gamow, "Concerning the origin of chemical elements," *Journal of the Washington Academy of Sciences* **32** (December 15, 1942), 353-355.

[16] Alpher interview (ref. 14), p. 22 of 36.

[17] A.A. Penzias and R.W. Wilson, "A Measurement of Excess Antenna Temperature at 4080 Mc/s," *Astrophys. J.* **142** (1965), 419-421.

[18] Helge Kragh, "The Construction of Cosmology as a Physical Science," unpublished paper presented at the History of Astronomy Workshop, Notre Dame University, July 6, 2001; title only at website <http://www.nd.edu/~histast/workshops/2001ndv/index.shtml>.

[19] Stephen G. Brush, "How Cosmology Became a Science," *Scientific American* **267** (August 1992), 62-65, 68-70.

[20] Virginia Trimble, "Early photons from the early universe," *New Astronomy Reviews* **50** (2006), 844-849.

[21] Ralph A. Alpher and Robert Herman, *Genesis of the Big Bang* (Oxford and New York: Oxford University Press, 2001).

[22] R.H. Dicke, P.J.E. Peebles, P.G. Roll, and D.T. Wilkinson, "Cosmic Black-Body Radiation," *Astrophys. J.* **142** (1965), 414-419; see also P.G. Roll and David T. Wilkinson, "Cosmic Background Radiation at 3.2 cm–Support for Cosmic Black-Body Radiation," *Physical Review Letters* **16** (1966), 405-407.

[23] Alpher and Herman, "Evolution of the Universe" (ref. 3).

[24] Alpher, Bethe, and Gamow, "Origin of Chemical Elements" (ref. 9).

[25] Gamow to Bethe, April 15, 1948, Alpher Papers.

[26] Alpher "Neutron-Capture Theory" (ref. 10).

[27] Alpher and Herman, "On the Relative Abundance" (ref. 3); they first announced their CMBR of 5^{o}K in "Evolution of the Universe" (ref. 3).

[28] Alpher interview (ref. 14), pp. 23-24 of 36.

[29] Alpher-Herman interview (ref. 2), pp. 21-22 of 78.

[30] *Ibid.*, pp. 31-32 of 78.

[31] *Ibid.*, pp. 33-34 of 78.

[32] Alpher and Herman, *Genesis of the Big Bang* (ref. 21), pp. 121-122.

[33] Alfred Behr, "Zur Entfernungsskala der extragalaktischen Nebel," *Astronomische Nachrichten* **279** (1951), 97-104.

[34] Trimble, "Early photons" (ref. 20), p. 846.

[35] Ralph A. Alpher, George Gamow, and Robert Herman, "Thermal Cosmic Radiation and the Formation of Protogalaxies," *Proceedings of the National Academy of Sciences* **58** (1967), 2179-2186.

[36] Walter S. Adams, "Some Results with the Coudé Spectrograph of the Mount Wilson Observatory, *Astrophys. J.* **93** (1941), 11-23; Andrew McKellar, "Evidence for the Molecular Origin of Some Hitherto Unidentified Interstellar Lines," *Publications of the Astronomical Society of the Pacific* **52** (1940), 187-192.

[37] G. Gamow, "The Physics of the Expanding Universe," *Vistas in Astronomy* **2** (1956), 1726-1732, on 1731.

[38] Ralph A. Alpher, "Talk to Science Writers at the American Physical Society" (1983), Alpher Papers.

[39] Ralph A. Alpher and Robert Herman, "Remembrance of Things Past: Some Recollections of the Development of the Big Bang Model," in Behram N. Kursunoglu and Arnold Perlmutter, ed., *Unified Symmetry in the Small and in the Large* (Commack, New York: Nova Science Publishers, 1994), pp. 3-54. A long list of their talks and colloquia between 1948 and 1955 is in the Alpher Papers.

[40] "Proceedings of the Philosophical Society," October 11, 1947, to May 22, 1948. *J. Wash. Acad. Sci.* **38**, No. 8 (August 15, 1948), 283-288.

[41] V.S. Alpher, "The Mark 9 Torpedo Exploder Mechanism: A Contact-Influence Successor to the Mark 14 Mod 6 During WWII," *The Submarine Review* (October 2009), 117-133; *idem*, "Torpedo Exploder Mechanisms of World War II: A New Perspective," *ibid.* (April 2010), 83-105; *idem*, "Degaussing Policy in World War II (Part I)," *ibid.* (October 2010), 57-70; i*dem*, (Part II), *ibid.* (January 2011), 93-105.

42 Ralph B. Baldwin, personal communication, January 16, 2009; see also Ralph B. Baldwin, *The Deadly Fuze*: *Secret Weapon of World War II* (San Rafael, California: Presidio Press, 1980), p. 203; *idem*, *They Never Knew What Hit Them: The Story of the Best Kept Secret of World War II* (Naples, Florida: Reynier Press, 1999).

43 Benjamin K. Malphrus, *The History of Radio Astronomy and the National Radio Astronomy Observatory: Evolution Toward Big Science* (Malabar, Florida: Krieger Publishing Company, 1996), pp. 25-26. For a broader perspective, see Woodruff T. Sullivan, III, ed., *The early years of radio astronomy: Reflections fifty years after Jansky's discovery* (Cambridge, London, New York, New Rochelle, Melbourne, Sydney: Cambridge University Press, 1984); *idem*, *Cosmic Noise: A History of Early Radio Astronomy* (Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Dehli: Cambridge University Press, 2009).

44 J.P. Hagan, A.E. Lilley, and E.F. McClain, "Absorption of 21-cm Radiation by Interstellar Hydrogen," *Astrophys. J.* **122** (1955), 361-375 + 2 plates.

45 Alpher-Herman interview (ref. 2), p. 24 of 78.

46 "Notes," *Radio astronomy conference, Washington, D.C.* [January 4-6, 1954], *Journal of Geophysical Research* **59** (1954), 140; "Radio Astronomy Conference," *Science* **119** (April 30, 1954), 588-591.

47 James B. Comly, personal telephone conversation, January 11, 2012.

48 "Radio Astronomy Conference" (ref. 46).

49 H.I. Ewen and E.M. Purcell, "Observation of a Line in the Galactic Radio Spectrum," *Nature* **168** (1951), 356; see also John S. Rigden, "Edward Mills Purcell, August 30, 1912-March 7, 1997," *Physics in Perspective* **13** (2011), 91-103, on 97-98.

50 J.A. Giordmaine, "Centimeter Wavelength Radio Astronomy including Observations using the Maser," *Proc. Nat. Acad. Sci.* **46** (March 15, 1960), 267-276, on 267.

51 *Ibid.*, p. 268.

52 R.H. Dicke, "The Measurement of Thermal Radiation at Microwave Frequencies," *The Review of Scientific Instruments* **17** (1946), 268-275; Robert H. Dicke, Robert Beringer, Robert L. Kyhl, and A.B. Vane, "Atmospheric Absorption Measurements with a Microwave Radiometer," *Phys. Rev.* **70** (1946), 340-348.

53 Trimble, "Early photons" (ref. 20), p. 646.

54 A.E. Salamonovich, "The First Steps of Soviet Radio Astronomy," in Sullivan, *early years* (ref. 43), pp. 268-288.

55 Luis J. Boya, "La Prediccion de la Radiacion Cosmica de Fondo," *LLULL: Boletin de la Sociedad Española de las Ciencias* **16** (1993), 5-21.

56 Alpher and Herman to Boya, April 13, 1995, Alpher Papers.

57 *Ibid.*

58 Interview of P.J.E. Peebles by Martin Harwit on September 27, 1984, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD, USA, <http://www.aip.org/history/ohilist/4814.html>. Interview with David Wilkinson by Martin Harwit on September 27, 1984, *ibid.*, <http://www.aip.org/history/ohilist/4967.html>. Interview with Robert Dicke by Martin Harwit, June 18, 1985, *ibid.*, <www.aip.org/history/ohilist/4572.html>. All quoted by permission.

59 Interview of Peebles (ref. 58), p. 23 of 109.

60 R.W. Wilson, "Two astronomical discoveries," in P. James E. Peebles, Lyman A Page, Jr., and R. Bruce Partridge, ed., *Finding the Big Bang* (Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Dehli: Cambridge University Press, 2009), pp. 157-176, on p. 173. For

much more, see Helge Kragh, *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton: Princeton University Press, 1996), pp. 318-388.

[61] Interview with Edward Purcell by Katherine R. Sopka, June 8, 1977, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD, USA, <www.aip.org/history/ohilist/4835_1,html>, pp. 35-36 of 50. Quoted by permission.

[62] Alpher-Herman interview (ref. 2), p. 38 of 78.

[63] P. James E. Peebles, "How I learned physical cosmology," in Peebles, Page, and Partridge, *Finding the Big Bang* (ref. 60), pp. 185-200, on p. 192.

[64] R.H. Dicke and P.J. Peebles, "Gravitation and Space Science," *Space Science Reviews* **4** (1965), 419-460.

[65] Peebles, "How I learned physical cosmology" (ref. 63), p. 192.

[66] Dicke, Peebles, Roll, and Wilkinson, "Cosmic Black-Body Radiation" (ref. 22).

[67] Alpher and Herman, "On the Relative Abundance" (ref. 3).

[68] Peebles, "How I learned physical cosmology" (ref. 63), p. 192.

[69] Peebles, Page, and Partridge, *Finding the Big Bang* (ref. 60), p. 530.

[70] Helge Kragh, *Higher Speculations: Grand Theories and Failed Revolutions in Physics and Cosmology* (Oxford and New York: Oxford University Press, 2011), p. 215, n. 51.

[71] J.J. Holley, Technical Employment Manager of The Glenn L. Martin Company, to Alpher, August 20, 1955, Alpher Papers.

[72] Ralph A. Alpher and Robert Herman, "Big Bang Cosmology and the Cosmic Black-Body Radiation," *Proceedings of the American Philosophical Society* **119** (1975) 325-348.

[73] Robert Herman, "George Gamow and the Big Bang Model. Part II. The Prediction of the Cosmic Microwave Background Radiation," in Harper, Parke, and Anderson, *George Gamow Symposium* (ref. 4), pp. 71-83, especially pp. 72-73.

[74] James A. Van Allen, "My Life at APL," *Johns Hopkins APL Technical Digest* **18** (1997), 173-177.

[75] Donald White, personal communication, November 18, 2011. Alpher and Freeman K. Hill translated, for the U.S. government, the first text on supersonics, Robert Sauer's *Theoretishe Einführung in die Gasdynamik* (Berlin, Springer-Verlag, 1943). See also *The First Forty Years: A Pictorial Account of the Johns Hopkins University Applied Physics Laboratory Since its Founding in 1942* (Baltimore: Schneidereith & Sons, 1983) and William K. Klingaman, *APL—Fifty Years of Service to the Nation: A History of The Johns Hopkins University Applied Physics Laboratory* (Laurel, Maryland: The Johns Hopkins University Applied Physics Laboratory, 1993).

[76] Ralph A. Alpher and Donald R. White, "Optical Refractivity of High-Temperature Gases. I. Effects Resulting From Dissociation of Diatonic Gases," *Physics of Fluids* **2** (1959), 153-161; *idem*, "Optical Interferometry in Plasma Diagnostics," Report No. 64-RL-3627C, April 1964, General Electric Research Laboratory, Schenectady, NY: Research Information Section, The Knolls Atomic Power Laboratory, Alpher Papers.

[77] R.A. Alpher, "On Using Optical Masers to Measure Electron Concentration," Memo Report, General Electric Research Laboratory, No. C-61-188, November 1961, *ibid.*, pp. 1, 11-12, Alpher Papers.

[78] P. Cannon, and R.A. Alpher, "On the Use of the Mössbauer Effect at Very High Pressures," Memo Report, General Electric Research Laboratory, No. C-62-5, January 1962, *ibid.*

[79] R.A. Alpher, "Suggested Experiments for Solar Orbiting Vehicle," Memo Report, General Electric Research Laboratory, No. MO-0700C, July 1963; *idem*, "Cosmological Experiments

Aboard Voyager Spacecraft," Memo Report, General Electric Research Laboratory, No. MO-0697C, July 1963, *ibid*.

[80] Alpher, "Suggested Experiments" (ref. 79), p. 2.

[81] Alpher, "Cosmological Experiments" (ref. 79), p. 1.

[82] C. Guy Suits, *Speaking of Research* (New York, London, Sydney: John Wiley & Sons, 1965), especially pp. 15-25.

[83] R.J. Gould and G.R. Burbidge, "X-Rays from the Galactic Center, External Galaxies, and the Intergalactic Medium," *Astrophys. J.* **138** (1963), 969-977.

[84] E. Margaret Burbidge, G.R. Burbidge, William A. Fowler, and F. Hoyle, "Synthesis of the Elements in Stars," *Rev. Mod. Phys.* **29** (1957), 547-650 + 4 plates.

[85] Vera C. Rubin, "What George Gamow Did Not Know about the Universe (Dec. 29, 1996)," in Harper, Parke, and Anderson, *George Gamow Symposium* (ref. 4), pp. 96-101, on p. 98.

[86] Ralph Alpher, *et al.*, "Action Plan for Space Science" (January 18, 1967), Alpher Papers.

[87] James A. Van Allen, ed., *Scientific Uses of Earth Satellites* (Ann Arbor: The University of Michigan Press, 1956), especially pp. v-vi.

[88] Igor Dmitrievich Novikov, "Cosmology in the Soviet Union in the 1960s," in Peebles, Page, and Partridge, *Finding the Big Bang* (ref. 60), pp. 99-106; Andrei Georgievich Doroshkevich, "Cosmology in the 1960s," in *ibid.*, pp. 107-108; Rashid Sunyaev, "When We Were Young…," in *ibid.*, pp. 108-132.

[89] A.G. Doroshkevich and I.D. Novikov, "Mean Density of Radiation in the Metagalaxy and Certain Problems in Relativistic Cosmology," S*oviet Physics Doklady* **9**, No. 2 (August 1964), 111-113.

[90] Sunyaev, "When We Were Young…," (ref. 88), p. 112.

[91] *Ibid.*

[92] Novikov, "Cosmology in the Soviet Union in the 1960s" (ref. 88), p. 103; Arno A. Penzias, "The origin of the elements,"*Rev. Mod. Phys.* **51** (1979), 425-431, on 430.

[93] Doroshkevich and Novikov, "Mean Density of Radiation" (ref. 89), p. 113.

[94] Victor S. Alpher, "Ralph A. Alpher, George A. Gamow, and the Prediction of the Cosmic Microwave Background Radiation" (2009), website <www.physics-online.ru/php/paper.phtml?jrnid=null&paperid=6847&option_lang=eng>. Regarding A.D. Chernin's erroneous attribution of Alpher and Herman's work to Gamow, see Kragh, *Cosmology and Controversy* (ref. 60), p. 416, n. 143; for other recent erroneous attributions, see Brian Greene, *The Hidden Reality: Parallel Universes and the Deep Laws of the Cosmos* (New York: Alfred A. Knopf, 2011), pp. 39-41, and Doroshkevich, "Cosmology in the 1960s" (ref. 88), p. 107.

[95] Steven Weinberg, *The First Three Minutes: A Modern View of the Origin of the Universe* (New York: Basic Books, 1977), pp. 122-132; *idem*, *Cosmology* (Oxford and New York: Oxford University Press, 2008), pp. 102-103, 159-160, n. 1.

[96] Robert K. Merton, "The Matthew Effect in Science," *Science* **159** (January 5, 1968), 56-63; *idem*, "The Matthew Effect in Science, II. Cumulative Advantage and the Symbolism of Intellectual Property," *Isis* **79** (1988), 606-623; Alexander M. Peterson, Woo-Sung Jung, Jae-Suk Yang, and H. Eugene Stanley, "Quantitative and empirical demonstration of the Matthew effect in a study of career longevity," *Proc. Nat. Acad. Sci.* **108** (January 4, 2011), 18-23.

[97] Kragh, *Cosmology and Controversy* (ref. 60), p. xi.

[98] Kragh to V. Alpher, August 2 and 16, 2009: I note that Kragh, in his *Higher Speculations* (ref. 70), has five index entries to Gamow in the text but none to Alpher or to Alpher and Herman.

[99] Ralph A. Alpher and Robert Herman, “Calculation of Cosmological Parameters and Their Approximations in the Standard Big Bang Model,” in Behram N. Kursunoglu, Stephen Mintz, and Arnold Perlmutter, *Unified Symmetry In the Small and in the Large 2* (New York and London: Plenum Press, 1995). pp. 53-86.

[100] *Ibid.*, p. 83.

[101] Robert W. Wilson, personal communications, July 27, 2007, September 11, 2007, and January 16, 2012.

[102] Roger H. Stuewer, “Gamow, Alpha Decay, and the Liquid-Drop Model of the Nucleus,” in *George Gamow Symposium* (ref. 4), pp. 30-43, on p. 35.

[103] Alan Lightman and Roberta Brawer, *Origins: The Lives and Worlds of Modern Cosmologists* (Cambridge, Mass.: Harvard University Press, 1990), p. 17.

[104] John C. Mather, “Nobel Lecture: From the Big Bang to the Nobel Prize and beyond,” *Rev. Mod. Phys.* **79** (2007)**,** 1331-1348, on 1333.

[105] *Ibid.*, p. 1341.

[106] *Ibid.*, pp. 1337-1340; John C. Mather, “Infrared Measurements from the Cosmic Background Explorer (COBE),” *Infrared Physics and Technology* **35** (1994), 331-336.

[107] Erica Westly, “No Nobel for You: Top 10 Nobel Snubs,” *Scientific American online* (October 6, 2008), website <www.scientificamerican.com/slideshow.cfm?id=10-nobel-snubs>.

[108] Neil deGrasse Tyson, personal communication, July 26, 2007.

6605 Mesa Hollow Drive
Austin, TX 78750-8141, USA
e-mail: alphervs@gmail.com