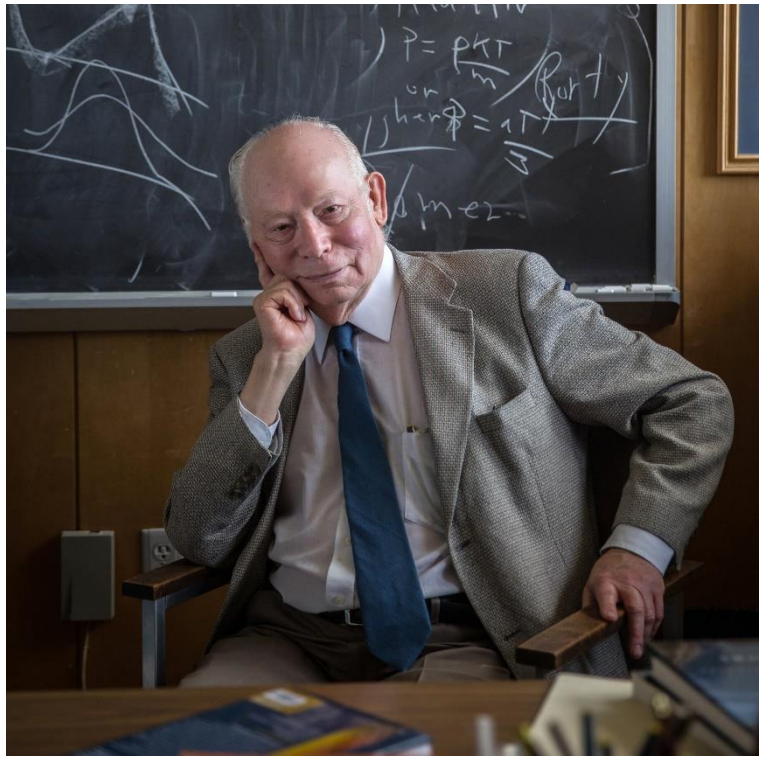
Steve Weinberg's Universe



Kamir Talifa / New York Times

INSTITUTE FOR QUANTUM INFORMATION AND MATTER

John Preskill

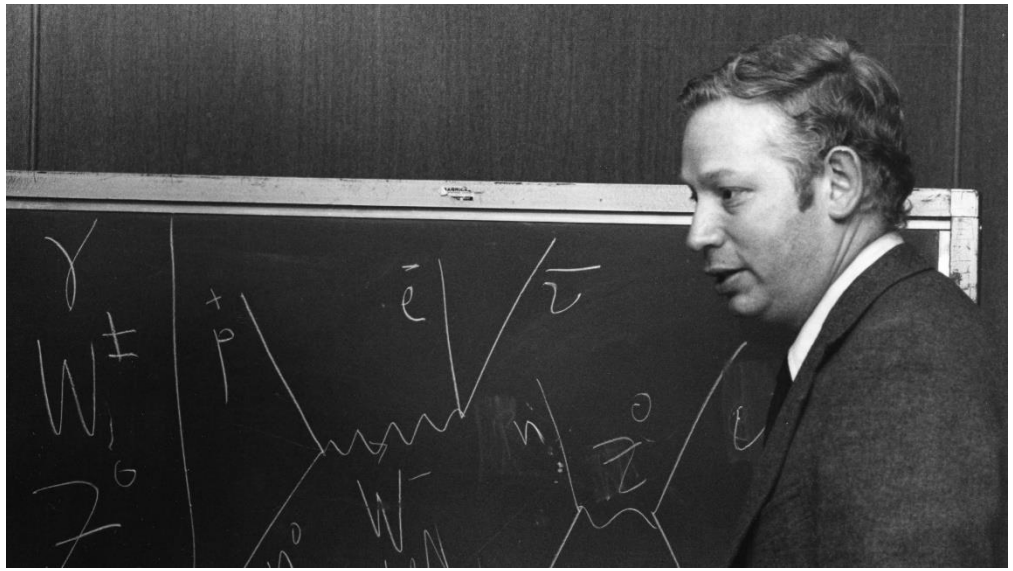
Weinberg Conference

15 November 2024

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

Weinberg Worldline

1933 Born in New York City May 3
1950 graduated from Bronx High School of Science
1950-54 Cornell AB
1954 Married Louise Goldwasser
1954-55 Copenhagen
1955-57 Princeton PhD (advised by S. Treiman)
1957-59 Columbia
1959-67 Berkeley
1963 Elizabeth Weinberg born in Berkeley
1967-73 MIT
1973-82 Harvard
1982-2021 University of Texas at Austin
2021 Died in Austin July 23, age 88



AIP Emilio Segrè Visual Archives, Weber Collection

Nobel Prize in Physics 1979

(shared with Sheldon Glashow and Abdus Salam)
"for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current."

National Medal of Science 1991

"For his contributions to the discovery of the structure of the fundamental forces of nature; the development of the standard model, and the unification of the weak and electromagnetic forces."

Some of Steve's distinctive qualities as a researcher

Solitary: Mostly single-author papers (but he consulted extensively with colleagues).

Not a visual thinker: He had little use for figures (reluctant migration from MS-DOS to Windows).

Explicit: Not one for "index-free" notation.

Notation: He didn't mind if his was nonstandard.

General and methodical: Sweeping conclusions from general principles.

Connecting formalism and phenomenology.

Meticulous about references (and expected the same from others).

Scholarly about history.

Gifted communicator, orally and in writing.

Not a model builder (except once).

He kept the TV on while working.

Why he kept the TV on

“I need the distraction to keep at my desk because the actual work is so, well…it’s so chillingly non-human. I need to feel that I am still part of the human race while I’m doing it.”

CERN Courier, 2017

Some of Steve's greatest hits.

Of 50 top-cited papers, 42 are single author

1967	A model of leptons (20235 citations)
1989	The cosmological constant problem (9021)
1978	A new light boson (6648)
1979	Phenomenological Lagrangians (5407)
1962	Broken symmetries (with Goldstone and Salam) (4054)
1979	Baryon and lepton nonconserving processes. (3016)
1977	Natural conservation laws for neutral currents (with Glashow) (2687)
1976	Implications of dynamical symmetry breaking (2608)
1966	Pion scattering lengths (2578)
1974	Hierarchy of interactions in unified gauge theories (with Georgi and Quinn) (2447)
1979	Implications of dynamical symmetry breaking: an addendum (2297)
1990	Nuclear forces from chiral Lagrangians (2183)
1983	Supersymmetry as the messenger of supersymmetry breaking (with Hall and Lykken) (2135)
1977	Cosmological lower bound on heavy neutrino masses (with Lee) (2112)
1974	Gauge and global symmetries at high temperature (2026)
1991	Effective chiral Lagrangians for nucleon-pion interactions and nuclear forces (2017)

Citation counts from Google Scholar, 10 November 2024

Textbooks

Gravitation and Cosmology, 1972

The Quantum Theory of Fields – Vol. 1: Foundations, 1995

The Quantum Theory of Fields – Vol. 2: Modern Applications, 1996

The Quantum Theory of Fields – Vol. 3: Supersymmetry, 2000

Cosmology, 2008

Lectures on Quantum Mechanics, 2013

Lectures on Astrophysics, 2020

Foundations of Modern Physics, 2021

Popular books

The First Three Minutes, 1977

The Discovery of Subatomic Particles, 1982

Dreams of a Final Theory, 1993

Facing Up – Science and its Cultural Adversaries, 2001

Glory and Terror – The Growing Nuclear Danger, 2008

Lake Views – This World and the Universe, 2010

To Explain the World, 2015

When writing for the lay public, Steve always respected the intelligence of his audience.

What seemed exciting: 1975-80

Nonperturbative QFT (monopoles, instantons, large N, lattice gauge theory, …)

Grand unification (calculating Weinberg angle, detectable proton lifetime, …)

Particle cosmology (baryogenesis, cosmological monopoles, inflation, …)

Renormalization group, critical phenomena, effective field theory (Wilson, Weinberg, …)

Naturalness, speculation about new strong interactions and compositeness (Technicolor, …)

High energy behavior in quantum field theory, 1960

Weinberg's theorem:
A multiple integral converges if it is superficially convergent and all sub-integrations also converge.

Completed the Dyson-Salam renormalization program.

Asymptotic high-energy behavior of far-off-shell Green's functions.

Steve took pride in having applied the Heine-Borel theorem.

Arthur Wightman: "There's blood on every page."

Roots of Steve's interest in cosmology

Read popular books (e.g., George Gamow's *The Creation of the Universe*) while in high school. Was aware of Palomar, Sandage, etc.

Serious interest ignited by reading Hermann Bondi's *Cosmology* around 1960. He loved that the homogeneous isotropic universe must have Friedman-Robinson-Walker metric.

Until microwave background was discovered, he was attracted to Steady State cosmology --- no initial conditions or evolutionary effects means stronger predictions.

First cosmology papers (1962) were on the neutrino background in cold big bang model.

To learn the subject, Steve volunteered to teach graduate courses on Gravitation and Cosmology at both Berkeley and MIT.

AIP Oral History Interview with Alan Lightman, 1988

Three Books:

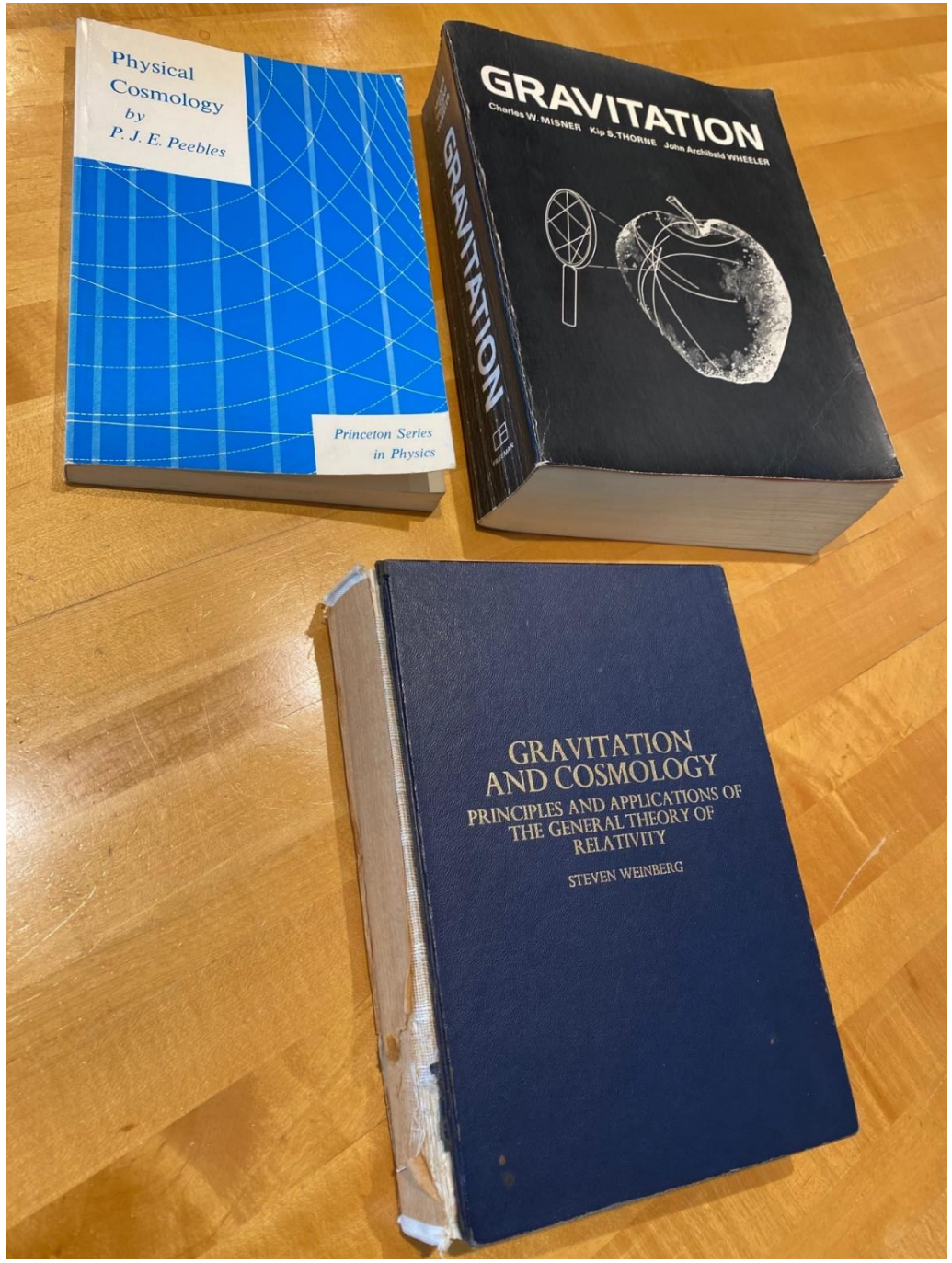
P. J. E. Peebles, *Physical Cosmology*, Princeton, 1971

Steven Weinberg, *Gravitation and Cosmology*, Wiley, 1972

Charles W. Misner, Kip S. Thorne, John Archibald Wheeler, *Gravitation*, Freeman, 1973

Part V of G&C. Cosmology (250 pages).
Chapter 15. The Standard Model (140 pages, 173 references)

MTW also speak of the “Standard Model”



“I believe that the geometrical approach has driven a wedge between general relativity and the theory of elementary particles … The passage of time has taught us not to expect that the strong, weak, and electromagnetic interactions can be understood in geometrical terms, and too great an emphasis on geometry can only obscure the deep connections between gravitation and the rest of physics.”

Gravitation and Cosmology, 1972

“The two books [Peebles 1971, Weinberg 1972] signal the change of physical cosmology from its near dormant state in the early 1960s to the start of a productive branch of research in physical science by the late 1960s.”

Peebles Nobel Lecture, 2019

“I remember that during the time that I was a student and then began my own research (on other problems) in the 1950s, the study of the early universe was widely regarded as not the sort of thing to which a respectable scientist would devote his time. Nor was this judgment unreasonable … Now in just the past decade, all this has changed. A theory of the early universe has become so widely accepted that astronomers often call it “the standard model.”

The First Three Minutes, 1977

Steve wrote *Gravitation and Cosmology* during 1969-71.

"I should have dropped everything I was doing and worked on proving that the spontaneously broken gauge theories were renormalizable … I'd rather make discoveries than write books."

AIP Oral History Interview with Alan Lightman, 1988

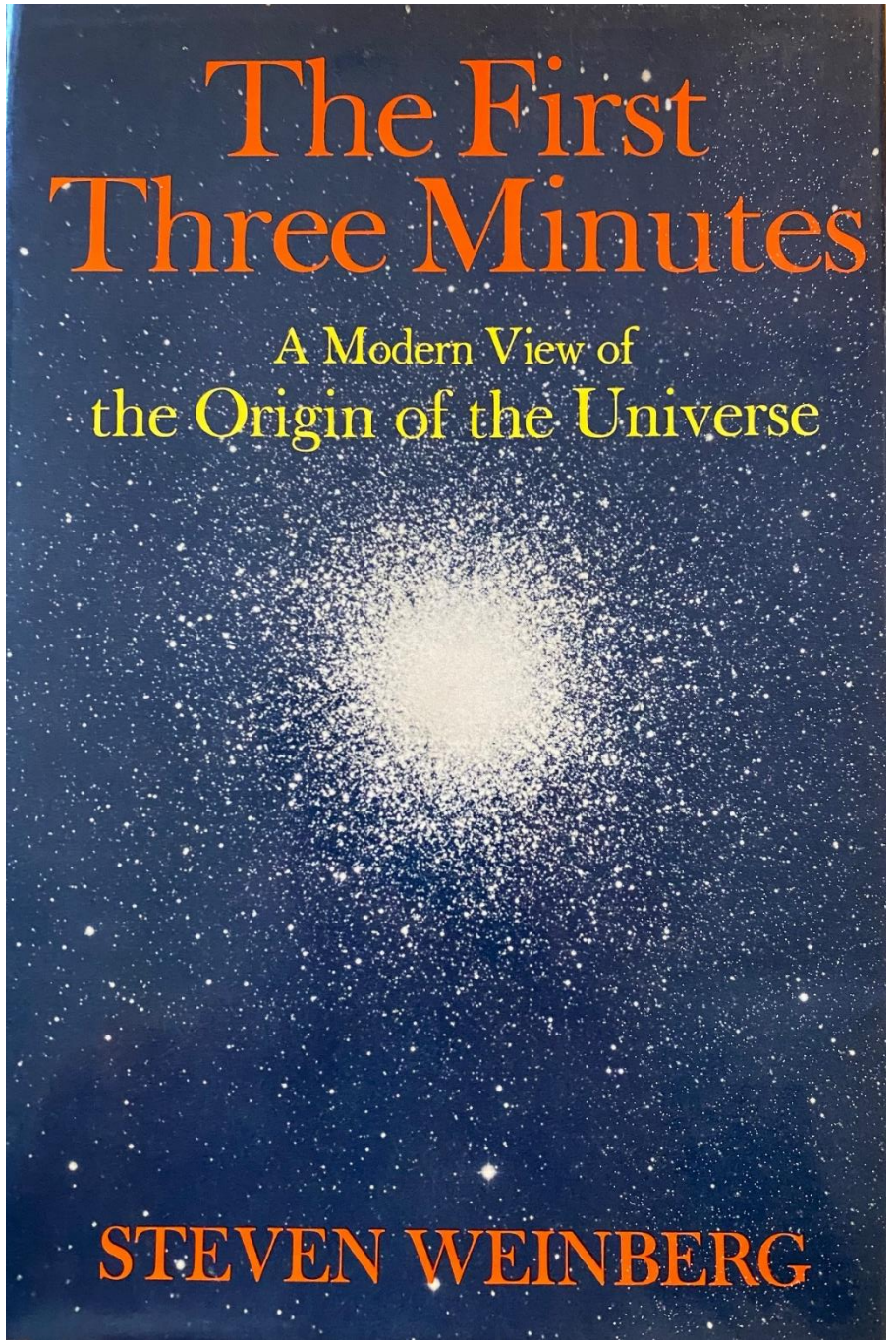
The First Three Minutes, 1977

Based on a 1973 Public Lecture.

Isaac Asimov: "What I had thought to be the guesswork and semi-mysticism of scientists turns out to be nothing of the sort and you have no idea how wonderful that makes me feel."

R. H. Dicke: "It is an exciting book and I recommend it to both laymen and scientists. It is comprehensible to the former, significant to the latter and interesting to both."

Inevitably, the (brilliant) title invited jokes …

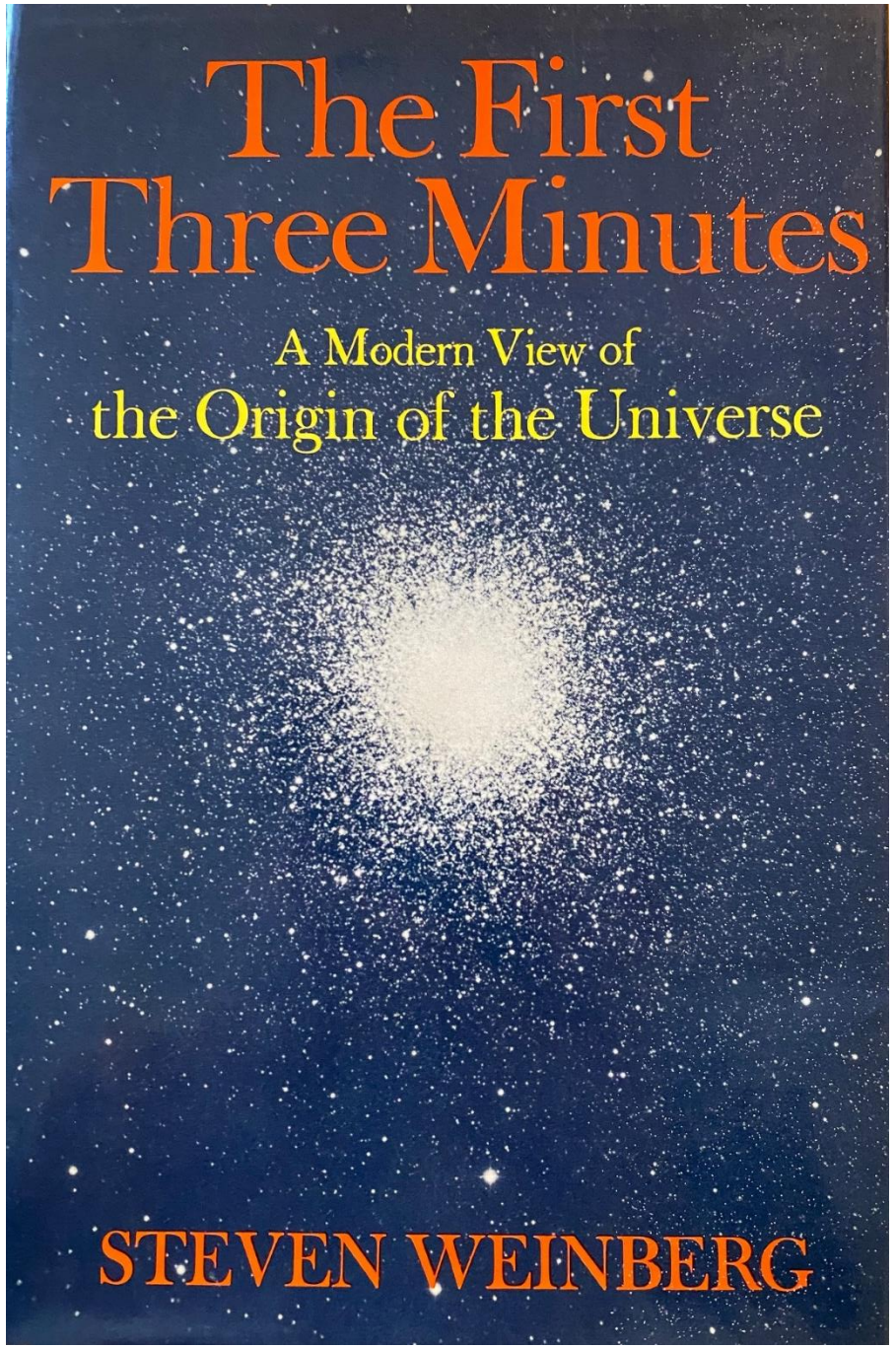


The First Three Minutes, 1977

Alan Guth (*The Inflationary Universe*, 1997) regarding his first seminar about cosmic inflation at SLAC, 23 Jan 1980:

"There was also the fear that I would reveal my status as a greenhorn cosmologist. To shore up my general background in cosmology, I had crammed from Steven Weinberg's excellent popular-level book, *The First Three Minutes*."

By then, asymptotic freedom made it possible to follow the thermal history back to the grand-unification scale or the Planck scale. (That had not been the case in 1972.)



Lee and Weinberg, Cosmological lower bound on heavy-neutrino masses, 1977

Cowsik and McClelland, 1972. An *upper* bound on neutrino mass from cosmology ~ 40 eV.

Steigman, Schramm, and Gunn, 1977. Number of neutrino species from ^{4}He abundance.

Lee and Weinberg, 1977: A *lower* bound on "neutrino mass" ~ 2 GeV.
(That is, an excluded region between 40 eV and 2 GeV.)

Estimate the freeze-out temperature for particle annihilation with weak-interaction strength, where expansion rate crosses the annihilation rate. If well below the particle mass, strong Boltzmann suppression of cosmological abundance.

Similar arguments apply to other hypothetical stable particles: the "WIMP ~~miracle~~ hint."

Tragically, Ben Lee died in an automobile accident a month after the paper was submitted.

Cosmological production of baryons, 1979

The small excess of baryons over antibaryons in the universe is odd under B, C, CP, CPT.

To generate it starting from a symmetric state, we need:
Departure from thermal equilibrium.
Microscopic interactions violating B, C, CP.

A drift and decay scenario:
Heavy X bosons mediate baryon nonconservation.
Decays of X bosons and their antiparticles violate CP.
Inverse decay is blocked by a Boltzmann factor.
→ A formula for the ratio of baryon number to entropy.

Yoshimura; Dimopoulos and Susskind; Toussaint, Treiman, Wilczek, and Zee.
Sakharov, 1967.

Anthropic bound on the cosmological constant, 1987
The cosmological constant problem, 1989

Dicke, 1961 (answering Dirac, 1937): The age of the universe must be compatible with the existence of stars and heavy elements.

Observed cosmological constant (vacuum energy) ρ_V . Tune bare parameters at the Planck scale to ~ 120 orders of magnitude. A "naturalness" problem.

Steve systematically reviewed the possible explanations for small ρ_V ; he argued that the anthropic one is preferred, and favors a nonzero value.

Large positive cosmological constant → gravitational condensation is impeded.
Large negative cosmological constant → universe collapses before life can appear.

Example: (String) landscape and eternal inflation to populate it.

But the rules of the game are not so clear.

Steve on the multiverse

"It would be a disappointment if this were the solution of the cosmological constant problems, because we would like to be able to calculate all the constants of nature from first principles, but it may be a disappointment that we will have to live with. We have learned to live with similar disappointments in the past."

The cosmological constant problems, 2001

"In the multiverse, could you actually detect the presence of the other universes? I don't see how. [Some] feel it's not science ... I don't agree with that. … If there is some fundamental theory that implies the multiverse, and we can experimentally test that theory in other ways, maybe in laboratory experiments, then because it implies the multiverse we'll believe it."

Interview with Paul Goldbart, Open Questions at the Physics Frontier, 25 Feb 2021

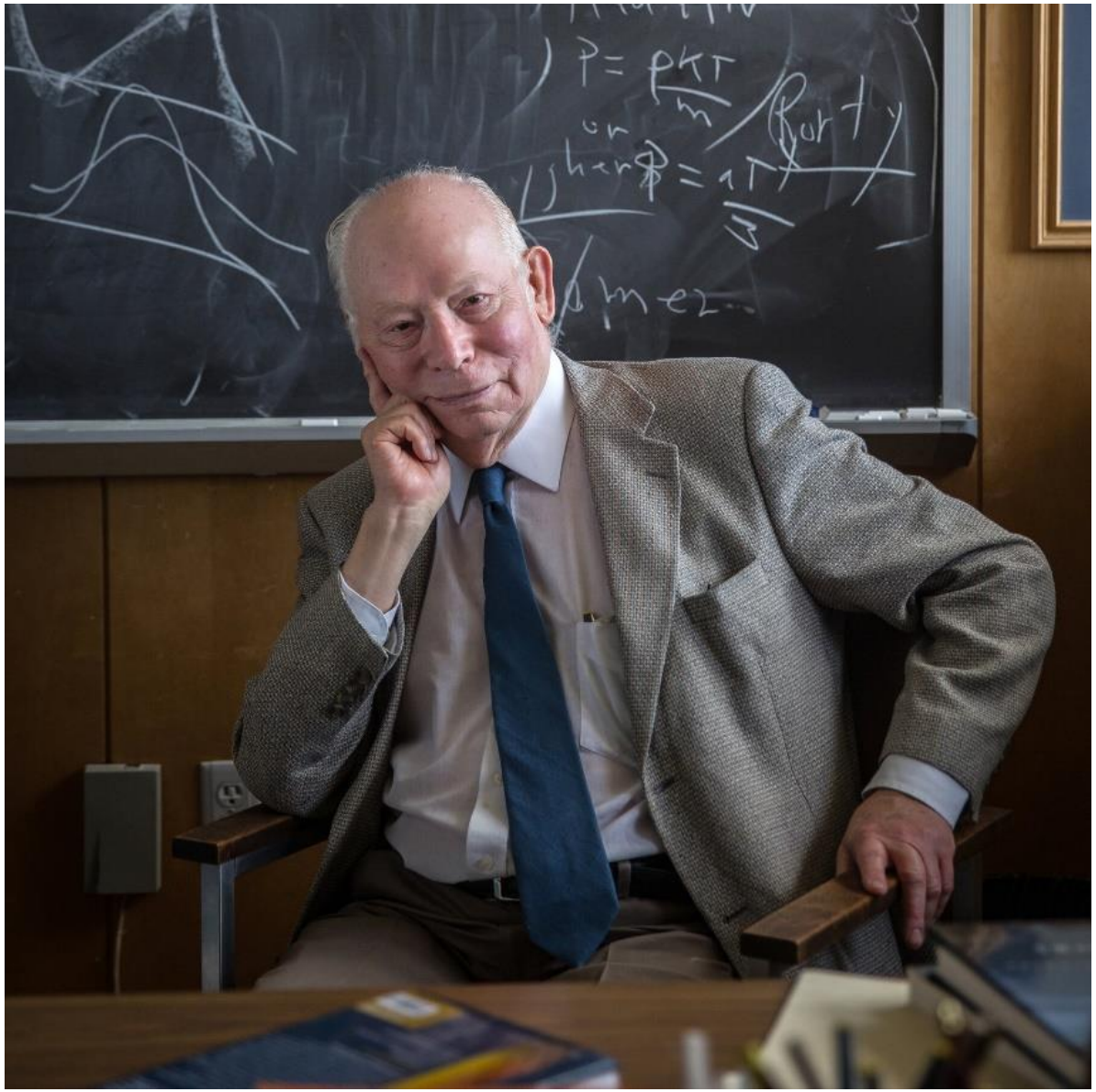
“Louise and I did the same thing!”

Salt in the ice cream maker?

“The present generation of young physicists may envy those of us who had the excitement and delight of developing the standard model. This might be a mistake, just as it turned out that my generation would have been mistaken to envy the earlier heroes of quantum electrodynamics. Our newly minted experimentalists and theorists now have a chance to participate in making the next big step beyond the standard model. They may even be able to see their way clear to the very high energy scale where a final theory will be revealed.”

Half a century of the standard model, 2018

Matt Valentine



Kamir Talifa / New York Times

Steven Weinberg 1933-2021