Remembering Weinberg: A Texas Giant[1]

By

Paul R. Shapiro

Before his untimely death in July at age 88, Steven Weinberg was widely regarded as the greatest living physicist. He was certainly a living legend. As a Texan for 40 of those years, he was *our* living legend, too, and our claim to a piece of physics history, productive to the end, as a theoretical physicist, cosmologist, historian of science, teacher, mentor, author, communicator and the deepest of thinkers about the deepest of questions. From the moment he arrived in Austin in 1981, dust hardly settled on his newly-minted Nobel prize, to the last weeks of his life, Steve continued to create and produce and influence the progress of fundamental physics—and of Texas Physics, too – including Astronomy.

When I delivered the *Weinberg Memorial Lecture* in October, at the Joint Fall 2021 Meeting of the Texas Sections of the APS and AAPT and the Society of Physics Students, it was the first chance I had to express my sadness at his departure, publicly, just a few months after his death. "At moments of such great sadness like this," I said, "it is customary to honor the person whose loss we wish to acknowledge by a moment of silence. In this case, I will presume to *fill* some of that silence with my personal recollections of Weinberg, as my colleague, teacher, collaborator, inspiration and friend, with a particular focus on cosmology, a subject of our mutual interest." All the while, I was thinking that, whatever I said, I imagined Steve was listening, and, as I knew he loved a good story, well told, especially good history, and if it made him laugh, too, all the better, I wanted more than anything for mine to live up to that standard, as I had always done while he was still

[1] A brief talk by Shapiro (with accompanying slides) at the Reception which followed the first Weinberg Memorial Lecture (by Frank Wilczek), at The University of Texas at Austin, March 21, 2021.

alive. Today, unfortunately, my remarks will be too brief for that – almost over, in fact, before I can even begin. However, I am still *thinking* that thought, still anticipating that stentorian voice that always seemed to rise above the din, as he entered a crowded room, still hoping to hear him laugh and still hoping to answer the scientific questions he flattered me to ask – never knowing if that one would lead us to another collaboration.

With that in mind, I *will* mention only *one* story before I go, about that *collaboration*. [There are many other stories I *could* tell, actually, since I knew Steve for almost half a century, almost continuously, from my time as an undergrad and grad student at Harvard, taking his classes, and then, picking up again a couple of years later, when I arrived to take a faculty position at UT just as Steve and Louise were starting theirs.]

In 1989, Steve wrote a review of "the cosmological constant problem" in *Rev Mod Phys*, which he later described as "a litany of failed attempts." In 1917, before Hubble discovered the expansion of the Universe, Einstein realized he could add a term to his equations of General Relativity (without violating any known physical principle or observational evidence), that would allow the Universe to remain static, by balancing gravitational attraction with a repulsive force. He did so before he knew the Universe was expanding and later expressed regret, but the possibility remained that such a term exists in nature. The problem Steve worried about is that the quantum nature of the Universe predicts there should be a rather large and unavoidable amount of "vacuum energy density" which behaves exactly as does Einstein's cosmological constant in its effect on the Universe. Since this would be a complete catastrophe, causing expansion to accelerate exponentially, contrary to our very existence, physicists had struggled mightily to find a process that could either "zero it out" or else manage to cancel it out perfectly with Einstein's original term (a constant of nature of unknown value), to make their combination so small as not to matter. Either way, the fine-tuning required was unimaginably perfect, like balancing a budget to a part in 10^{120} !

Steve had one idea he hoped might save the day, involving the ***anthropic principle***, according to which, if we must be here to observe the Universe, then the net amount of vacuum energy density must not be so large as to prevent galaxies from forming by gravitational collapse as the Universe expands, or else no observers would ever form. Unfortunately, when he tried to calculate how large that was, he found only that that it must not exceed a few times the mean density of matter in the universe when the earliest known galaxy formation took place, which he estimated (in the 1987 paper in which he first published this idea) could still be hundreds of times the mean density of our Universe today – and there was no anthropic reason it had to be much smaller than that, as it was known to be. In fact, if that were the final argument, then the discovery of more galaxies and quasars since then, formed even further back in time, only served to make his anthropic argument another failure – as Steve's own paper admitted.

But that's not the end of the story. By 1996, astronomical evidence had accumulated that the Universe was flat, which requires that it be filled with a critical amount of energy density, but a variety of measures of the average *mass-energy* density fell far short, by a factor of three. Suddenly it seemed like there might be good reason to want to make up this difference by postulating just the right amount of vacuum energy to take up the slack. Alas, this made the cosmological constant problem even worse. Now, it could not be solved even by finding a mechanism that would zero it out by 120 orders of magnitude.
Now, it was necessary to explain why it was ***almost*** zero, but ***not*** zero -- ***and so close to the matter density today!!!***

That's where I came into the story. By the summer of '96, Weinberg was grappling with this ***NEW cosmological constant problem***, and I had just become a father for the first time. One day, as I held baby Sofia, helping her fall asleep after a bottle, the telephone rang. It was Steve. He asked a question,

> "How does one calculate the probability of forming galaxies in the Cold Dark Matter model?"

I told him.

> "And what if there is a cosmological constant?"

I told him that, too, including the statistical nature of the process, as the nonlinear outcome of Gaussian random noise density perturbations. He thanked me, we said our goodbyes -- and, fortunately, Sofia was still asleep.

That call led to another, and another, and, as it was always my guiding principle to drop everything and answer Steve's questions, I eventually made my way back to the office and, together with my postdoc Hugo Martel, followed up Steve's questions and the notes we had exchanged by calculating the anthropic likelihood that a random observer would *observe* a vacuum energy density as small as any *particular* value, if that observer lives in a ***subuniverse*** which is just one in an infinite ensemble of subuniverses (with different values in each) -- ***the multiverse***. To assess whether or not this anthropic likelihood is a viable explanation for the cosmological constant problem, we gathered all the observational constraints on matter density, the cosmic expansion rate, and the age of the Universe, in our assumed flat, "ΛCDM" universe (***Remember***: *there were no measurements yet of a nonzero cosmological constant!!*). From this, we identified the amount of vacuum energy density in our *own* subuniverse that best satisfied all these constraints. The data suggested a value between 60 and 70% of the critical energy density, for which the ***anthropic*** likelihood was as high as several percent, which we took to be an extremely positive outcome, suggesting the anthropic explanation was viable.

By the end of 1996, we submitted our paper to *The Astrophysical Journal*. Soon after the paper's publication in early 1998, observations of luminosity distances to Type Ia Supernovae found the first evidence that cosmic expansion was *accelerating*, implying that, if the cosmological constant was the cause, its contribution to the total energy density had to be more than half that of the matter. Within a few more years, measurements of the cosmic microwave background determined cosmological parameters to great precision, homing in on the value of 70% of critical. ***The anthropic likelihood predictions seem to have been born out!***

That's my Weinberg story for today. I am forever grateful to Steve for that telephone call – and for all his telephone calls before and since. And for all the other private moments, too – including the countless times he asked me to walk with him (or ride with him, as he drove us from one end of campus to the other) as we left the Friday Astrophysics Lunch or his Tuesday Theory Group Lunch, at The Campus Club, to ask another question. I will miss his questions -- and his personal warmth – and the inestimable value of his high regard…I will miss him, entirely… I already do.

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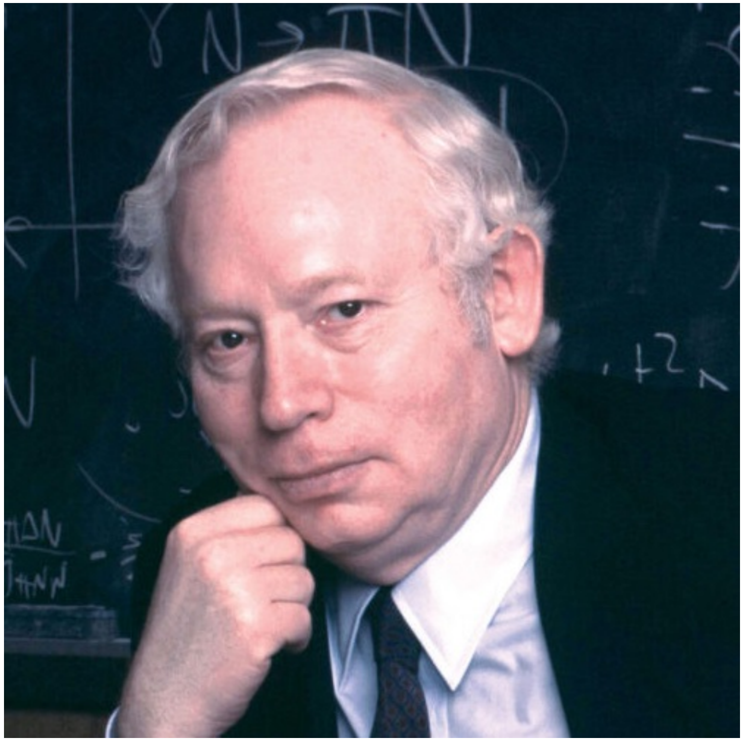

1933-2021

Paul Shapiro

The University of Texas at Austin

Steven Weinberg: Remembering a Texas Giant

Steve and Louise Weinberg

The Red-headed Stranger Comes to Texas

The Cosmological Constant Problem

"Yesterday, upon the stair,
I met a man who wasn't there!
He wasn't there again today,
Oh how I wish he'd go away!”

--- from Antigonish (1899)
by Williams Hugh Mearns

- So began Weinberg’s highly cited 1989 *Rev Mod Phys* review, “On the Cosmological Constant Problem”, based upon his May 1988 Morris Loeb Lectures in Physics at Harvard (RevModPhys, 61, Issue 1, 1)

New

The Cosmological Constant Problem: Life in the Multiverse

THE ASTROPHYSICAL JOURNAL, 492:29–40, 1998 January 1

LIKELY VALUES OF THE COSMOLOGICAL CONSTANT

HUGO MARTEL AND PAUL R. SHAPIRO
Department of Astronomy, University of Texas, Austin, TX 78712; hugo@sagredo.as.utexas.edu, shapiro@astro.as.utexas.edu
AND
STEVEN WEINBERG
Theory Group, Department of Physics, University of Texas, Austin, TX 78712; weinberg@utaphy.ph.utexas.edu
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TABLE 1

PROBABILITY THAT A RANDOM ASTRONOMER WOULD OBSERVE A VACUUM ENERGY DENSITY AS SMALL AS THE VALUE ρ_V^* IN OUR SUBUNIVERSE[a] FOR VARIOUS VALUES OF ρ_V^*

		$R_G = 1$ Mpc		$R_G = 2$ Mpc	
Ω_Λ	ρ_V^*/ρ_0	σ	$\mathscr{P}(\leq \rho_V^*)$	σ	$\mathscr{P}(\leq \rho_V^*)$
0.1	0.11	0.0067	0.0005	0.0042	0.0019
0.2	0.25	0.0063	0.0013	0.0040	0.0045
0.3	0.43	0.0059	0.0025	0.0038	0.0084
0.4	0.67	0.0054	0.0049	0.0036	0.015
0.5	1.00	0.0048	0.0097	0.0032	0.027
0.6	1.50	0.0041	0.021	0.0029	0.054
0.7	2.33	0.0033	0.054	0.0024	0.12
0.8	4.00	0.0023	0.19	0.0017	0.35
0.9	9.00	0.0011	0.90	0.0008	0.98

[a] For $s = 1$, $H_0 = 70$ km s^{-1} Mpc^{-1} and $n = 1$.

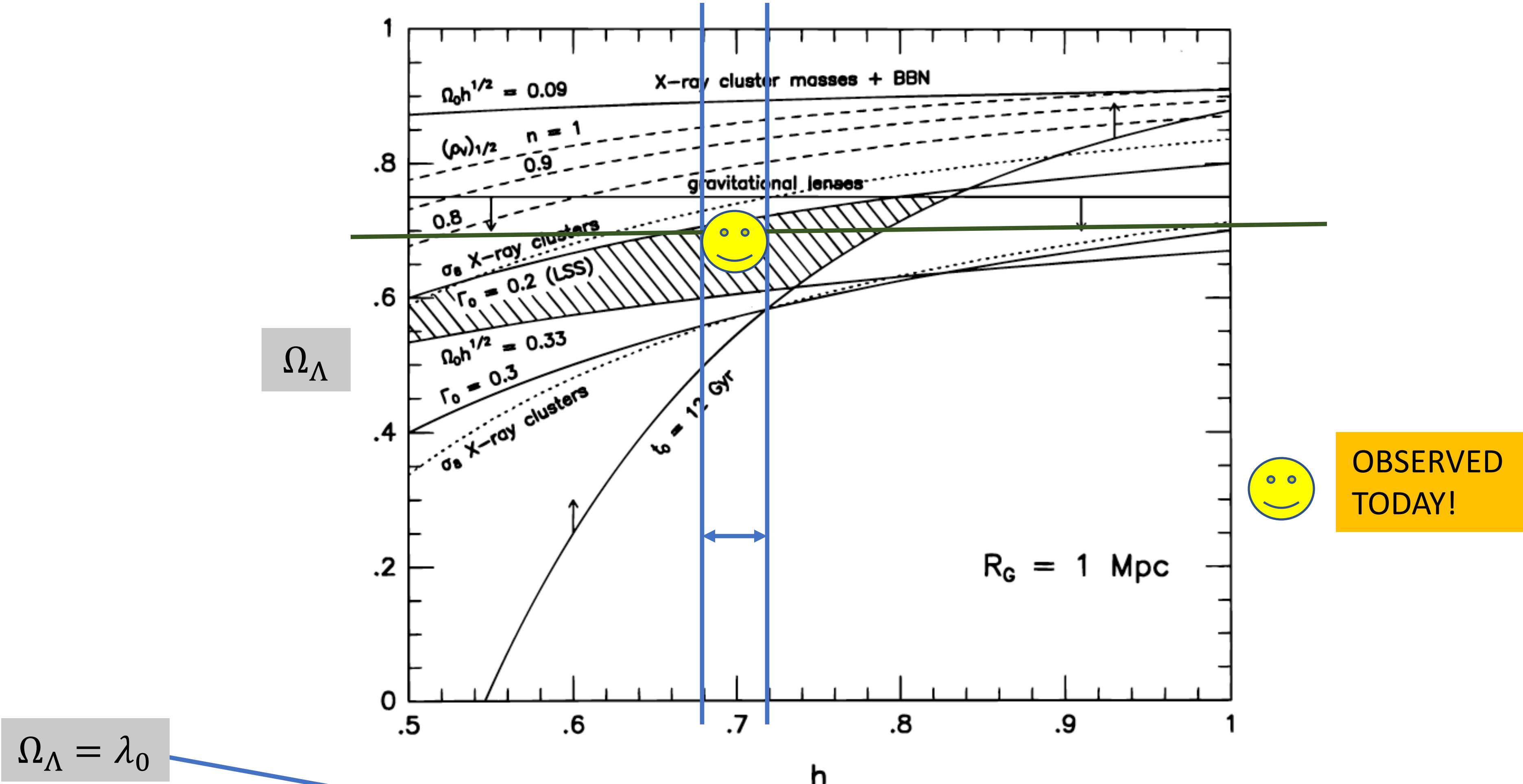

FIG. 3.—Observational constraints on $\lambda_0 \equiv \rho_V^*/(\rho_V^* + \rho_0)$ and $h \equiv H_0/(100 \text{ km s}^{-1} \text{ Mpc}^{-1})$. (Curves labeled "LSS" and "$\Gamma_0 = 0.2$" or "$\Gamma_0 = 0.3$" bound the region allowed by the constraint $\Gamma_0 = \Omega_0 h = 0.25 \pm 0.05$, derived by matching the spatial and angular correlation statistics from galaxy surveys with the theoretical predictions of the large-scale clustering of galaxies in a *COBE*-normalized flat CDM model with primordial power spectrum index $n = 1$. The curves labeled "σ_8 X-ray clusters" bound the values of λ_0 and h that make this CDM model satisfy the constraint on the present space density of X-ray clusters. The curve labeled "$t_0 = 12$ Gyr" indicates the lower limit that makes the age of the universe at least as large as current estimates of the minimum age of globular clusters. The curves labeled "$\Omega_0 h^{1/2}$" indicate the boundaries defined by the X-ray–measured total and baryonic masses of clusters of galaxies, together with the big bang nucleosynthesis limits on the baryon mean density and the assumption that the ratio of baryon to total mass inside each cluster equals the ratio of universal mean values. The curve labeled "gravitational lenses" indicates the upper limit imposed by counts of quasars lensed by intervening galaxies. The dashed curves labeled "$(\rho_V)_{1/2}$" are the values for which our own subuniverse has the median value of ρ_V for all subuniverses, if $R_G = 1$ Mpc and $n = 1$ (*top dashed curves*), 0.9 (*middle dashed curve*), or 0.8 (*bottom dashed curve*).

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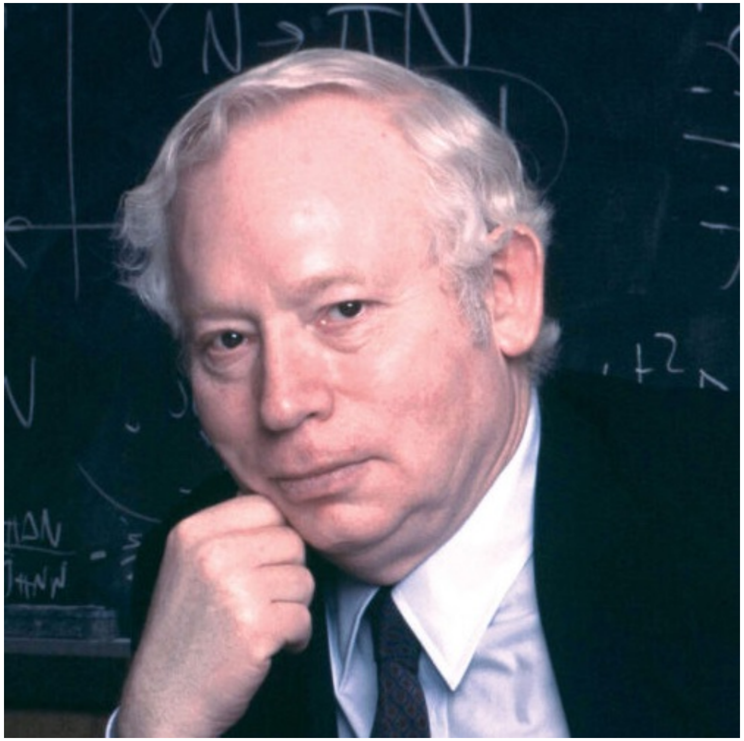

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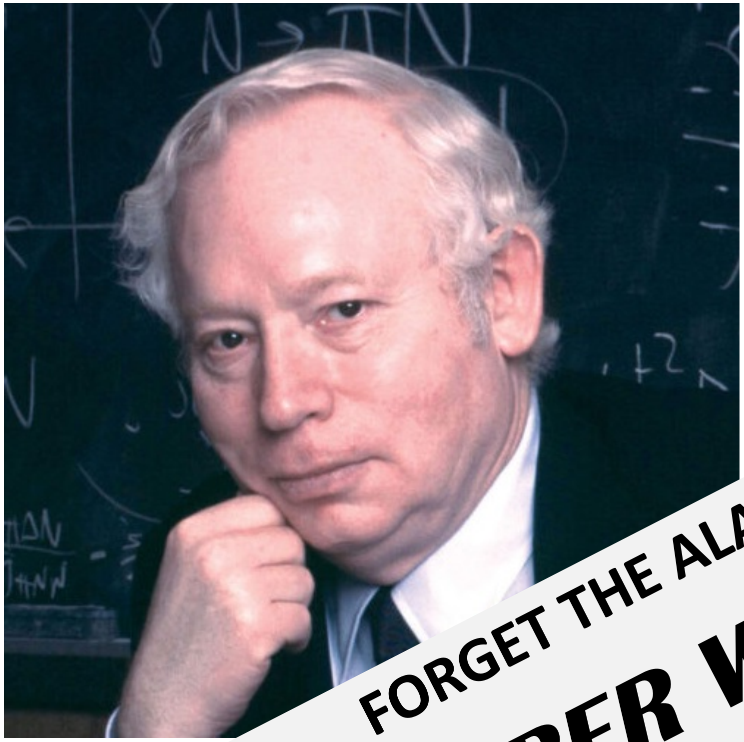

FORGET THE ALAMO…….

REMEMBER WEINBERG!!

Postscript: A Tornado Touches Down Near Austin

- Just before 6 PM on Monday, March 21, 2022, as the Weinberg Memorial Lecture Reception was about to begin its program with this talk, a confirmed tornado passed over highway I-35 and the SH 45 overpass in Round Rock, TX, just north of Austin, during rush hour traffic, triggering a tornado warning on the UT Campus, which forced participants to seek shelter in the ground-floor auditorium.
- There, after regrouping, we attempted to resume our program, only to be interrupted again by the public address system, endlessly repeating its dire warning. Like the orchestra playing on the deck of the Titanic as lifeboats descended, we gritted our teeth and talked over it…