MELVIN CALVIN: NOBEL-WINNING CHEMIST AND SETI SCIENTIST WANNABE

By

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B.A. Physics and English
Elon University, 2016

SUBMITTED TO THE PROGRAM IN COMPARATIVE MEDIA STUDIES/WRITING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN SCIENCE WRITING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2017

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Program in Comparative Media Studies/Writing
May 22, 2017

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ABSTRACT

Melvin Calvin spent more than a decade answering one longstanding question in biochemistry: how did plants use carbon dioxide to manufacture carbohydrates in photosynthesis? This research earned Calvin a Nobel Prize—an honor that catapulted him to international fame, secured him spots on presidential advisory committees, and got him plenty of textbook mentions. But even though Calvin's claim to fame was his work on photosynthesis, his longest-running passion project was investigating the origins of life in the universe. Astrobiology efforts peppered his career, from theorizing about chemical evolution to inspecting meteorites and moon rocks to joining the Order of the Dolphin at the first Search for Extraterrestrial Intelligence (SETI) conference in 1961.

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Melvin Calvin's light bulb moment arrived under the most innocuous of circumstances. He was parked on the curb, waiting for his wife to emerge from a corner market. As he sat idle, Calvin's mind drifted to a problem that had been nagging him for several months.

In his lab at the University of California, Berkeley, Calvin was leading an investigation into the pathway of carbon in photosynthesis—that is, all the steps that plants follow to transform carbon dioxide taken from the atmosphere into sustenance. Over several years, Calvin and his colleagues had seen carbon crop up in one molecule, then another, and so on down the line. But what befuddled Calvin was that *first* molecule that subsumed carbon. Calvin had pored tirelessly over data in the lab, but it wasn't until he was sitting in the driver's seat, staring at his steering wheel that—aha!

The cyclic nature of the steering wheel gave Calvin an idea: What if carbon wasn't passed down a *line* of different molecules, but instead moved through a *loop*? What if the first molecule that connected with carbon dioxide was also one of the final products of a plant's carbon-converting operation?

"It occurred just like that—quite suddenly," Calvin recalled many years later. "I don't know what made me ready at that moment, except that I didn't have anything else to do but sit and wait." That key insight helped lead to Calvin's Chemistry Nobel Prize in 1961 and ultimately reshaped the latter half of his career.

Calvin's ability to draw inspiration from a steering wheel might seem like serendipity, but this was likely only the latest of dozens of explanations for the data that popped into Calvin's head. With Calvin, "new ideas, not a few of them outrageous, flowed thick and fast," said Vivian Moses, who worked in Calvin's lab for several years.

Calvin's propensity for throwing out many ideas and seeing what stuck harkened back to his childhood. When he was a high schooler, Calvin frustrated his physics teacher by shouting out half-cocked answers to questions and being overly confident about his rapid-fire responses. One day, the physics teacher snapped at Calvin that he'd never make a good scientist, because he didn't "collect all the data."

"I have since told my students that there's no trick to get the right answers when you have all the data; just the computer can do that," Calvin said. "The trick is to get the right answers when you have only half the data, and half of the data you've got is wrong and you don't know which half. Then when you get the right answer, you are doing something creative." His persistent desire to understand everything as quickly as possible, even before all the facts were in, probably served Calvin well in fields as speculative as the origins of life and search for extraterrestrial intelligence, or SETI.

Whatever his physics teacher thought, Calvin was a born scientist. When he was a boy growing up in Detroit, Michigan in the 1910s, he liked to dismantle his toys to see how they worked. When he was eight years old, Calvin performed his first "science experiment" with his best (and only) friend, Abraham. The two boys set up shop in the back yard with a pan of water and some grasshoppers. They drowned the insects until they stopped kicking, laid them out in the sun, and then watched in amazement when the bugs sprang to life and hopped away. "We did it over and over again," Calvin recalled. They were determined to understand how the grasshoppers managed such miraculous resurrection.

When Calvin was in high school, his family opened up a mom-and-pop grocery. It was then that he began to focus on chemistry. Spending his Saturdays working at the market gave Calvin a lot of time to think about foodstuffs, and he realized that everything that went into food production, from the ingredients to the packaging, involved chemistry. Chemists, Calvin figured, must never be out of a job. And after growing up in a working class family, watching his father get periodically laid off, job security was at the forefront of Calvin's adolescent mind.

Calvin attended the Michigan College of Mining and Technology on scholarship, and earned the university's first B.S. in chemistry in 1931. All his electives were Earth science classes like paleontology, which made Calvin appreciate the long history of Earth and its inhabitants. Strange as it seems, given that so much of Calvin's later research had a biological slant, he never took a single biology course. In the long run, though, Calvin viewed his lack of formal training as an advantage in adding new knowledge to the field. "Then you aren't bothered by the dogma of the day, because you don't know what it is," he reasoned.

Calvin followed his undergrad studies with a chemistry PhD in 1935 from the University of Minnesota, and a post-doctoral fellowship with chemist Michael Polanyi at the University of Manchester in the U.K. Polanyi's recommendation ultimately helped Calvin land a job at U.C. Berkeley in 1937, where he remained for the rest of his career.

The early years at Berkeley saw Calvin continuing some of the work he'd begun under Polanyi and teaching organic chemistry. "His lectures usually began hesitatingly, as if he had little idea of how to begin or what to say. This completely disarmed his audiences," wrote two of Calvin's colleagues, Glenn Seaborg and Andrew Benson, in his National Academy of Sciences biography. "Soon enough, however, his ideas would coalesce, to be delivered like an approaching freight train, reaching a crescendo of information at breakneck speed and leaving his rapt audience nearly overwhelmed."

Calvin wasn't just like this in lectures. In all his work, he gushed ideas like a popped bottle of champagne. "Most of them were probably wrong in the long term," said Tack Kuntz, one of Calvin's former graduate students, "but very stimulating."

When Calvin wasn't holed up in the lab, he enjoyed socializing at the Berkeley Faculty Club, where he and a few of his other bachelor friends lived. A handful of them regularly gathered in Calvin's room for drinks before heading down to dinner, where they would flirt with the waitresses in the faculty dining room. Seaborg remembered Calvin as being a fairly smooth operator, but just five years after Calvin arrived at Berkeley, he got married.

Calvin's wife, Gen, was a social worker, but she was also heavily involved in his work. Over the years, Gen coauthored several of Calvin's publications, participated in scientific conferences, and embarked on personal side projects with him. For instance, when the Calvins lost their first son to complications during pregnancy, they teamed up with a medical doctor and microbiologist to figure out the chemical factors that caused the problem. The Calvins went on to have three other children, two daughters and a son.

The course of Calvin's career was abruptly altered in the wake of World War II. Ernest Lawrence, founder of Berkeley's radiation laboratory where Calvin was then Director of the Bio-Organic Chemistry Group, stopped Calvin one day when he was coming back from lunch. Lawrence told Calvin that he was holding onto a bunch of radioactive carbon, which had built up in the ammonium nitrate bottles surrounding the lab's particle accelerator. He wanted Calvin to "do something useful with it." Calvin, primed by the research he'd done on light absorption and chemical pigments at Polanyi's lab, decided to use the radioactive carbon to break open the black box of photosynthesis.

By that time, it was well known that plants consumed carbon dioxide, using the carbon part for making carbohydrates—the energy-providing molecules in the food we eat. The nitty-gritty details of this process, however, were largely unknown. The problem was that once carbon dioxide entered a plant, its carbon couldn't be distinguished from the carbon already making up the organism.

Lawrence's radioactive carbon offered a clever work-around. Although this "radiocarbon" did everything that normal carbon could do, it was also unstable. The atoms gradually disintegrated and emitted high-speed particles that were detectable as radioactivity. So by feeding a plant carbon dioxide laced with radiocarbon, an experimenter could observe which chemicals in the plant became radioactive after different periods of time, and thus discern the steps the plant followed to transform carbon dioxide into food.

A few Berkeley scientists had undertaken this type of investigation before the war, but Pearl Harbor had diverted their research efforts to defense projects. By 1945, all the original participants were either dead or gone to other institutions. Calvin was left to take up the torch of photosynthesis work, and he ran with it for over a decade.

For each trial of their experiment, Calvin and his colleagues filled a flask with green algae and tube-fed it carbon dioxide spiked with radioactive carbon. They waited some predetermined period of time, and then flushed the algae into hot alcohol, killing it instantly. To determine which molecules had subsumed radioactive carbon in that particular time span, the researchers analyzed algae samples using a technique called paper chromatography.

Paper chromatography allowed the scientists to separate the algae out into its molecular components. First, they dripped a bit of dead algae onto one corner of a piece of paper and let it dry. Then, they dipped the edge of the paper into a specially prepared bath of chemicals so that the blot of sample was almost submerged. As the liquid spread across the paper, it dragged along the algae. But some of the algae molecules, depending on their size and other characteristics, were swept away more swiftly than others. Just as floodwaters flowing through a neighborhood can carry away a pile of leaves more easily than a parked car, the paper chromatography chemicals could move some molecules faster than others. So by the time the liquid permeated the entire paper, that original splotch of sample had spread into an array of molecules along the side of the paper perpendicular to the dipped edge.

To get an even finer separation, Calvin's team dipped the edge of paper now smeared with molecules in a different chemical bath. Knowing how fast each chemical bath should carry different molecular species, they could read the paper like a chemical recipe card to identify all the different molecules in the original algae sample.

Now all the chemists had to do was find out which molecules contained radioactive carbon. They were able to do this by scanning their sample-coated papers with a device designed to detect radioactivity, like a Geiger counter. Wherever the detector picked up signals of radioactivity, those locations revealed which molecules were complicit in the path of carbon.

All told, it took Calvin's crew over a decade to map out carbon's course. It was tedious to work backward from the products of a process to pick out all the intermediate steps—to identify the molecule that first welcomed carbon dioxide into the cell by connecting it to another five-carbon molecule, only for that new conglomerate to break up into a pair of three-carbon molecules, which were then given makeovers by other molecules to become two *other* three-carbon molecules, and so on.

This marathon project garnered twenty-three papers, two books, and plenty of name recognition for Calvin. According to Dick Lemmon, one of his first graduate students back in the 1940s, this was good for the lab, too. Calvin's reputation as "Mr. Photosynthesis," as *Time* magazine later dubbed him, attracted scientists from all over the world. "Everybody wanted their papers published with Calvin," Moses said.

By the late 1950s, the photosynthesis research was pretty much "under control and felt sort of routine," Kuntz said. Which wasn't to say it was a cakewalk. The team hit roadblocks, like trying to identify the five-carbon molecule that carbon dioxide first hooked up with when it entered the cell, which Calvin finally did in the driver's seat of his car. But Lemmon suspected that by the mid-50s, Calvin was "smelling a Nobel Prize." After one of Calvin's photosynthesis conference lectures, microbiologist Cornelius Bernardus van Niel actually leapt up from his seat in the front row and, eyes shining with his tears, congratulated Calvin on his incredible work.

Van Niel wasn't alone in his awe. Calvin's path of carbon work "will live forever," Kuntz said. Without the efforts of Calvin and his colleagues, "that would've been an enormous hole [in biochemistry] that would've taken years to fill." Sauer agreed that the path of carbon was a cornerstone discovery in photosynthesis research because it fed into many new lines of investigation in botany.

One of Calvin's lingering questions was how the cycle of photosynthesis got started in the first place. The series of handoffs he'd tracked between carbon-containing molecules couldn't have been the way life originally arose. "It's just way too complicated," he said. "There must have been a simpler way." And, insatiably curious as always, Calvin was determined to figure out just what that was.

Much like SETI itself, the story of life's chemical genesis was a realm of exploration that was only just transitioning from the speculative to the scientific. The topic first snagged Calvin's attention in 1949, during the early days of his photosynthesis enterprise, when he read *The Meaning of Evolution*. The book traced the development and downfall of species over the course of Earth's history and made Calvin wonder, *What jump-started life on Earth?*

The prevailing theory was that billions of years ago, some source of energy—either the sun's ultraviolet radiation, or cosmic rays from outer space, or radioactivity emanating from rocks—struck simple molecules in a body of water on Earth's surface. This jolt of energy tore the molecules asunder and ultimately caused the fragments to regroup into more complex, organic molecules, which were the building blocks of life as we know it.

The mid-1920s had seen some early experimental efforts to test that idea, but a gulf of 25 years separated those forays and the investigation into life's origins at Calvin's lab. Calvin and his colleagues filled a flask with carbon dioxide, hydrogen, and water vapor—the ingredients they believed made up Earth's primitive atmosphere—and used a particle accelerator to bombard the mixture with a beam of helium ions, which were meant to imitate a shower of cosmic rays. They ended up producing a handful of simple organic molecules.

The scientists were after more complex molecules, but this first step was encouraging. After the experiment was written up in *Science*, Calvin was visited by a University of Chicago chemist named Harold Urey, who thought Calvin's experiment had assumed the wrong chemical makeup for Earth's prebiotic atmosphere. Sure enough, two years later Urey and his doctoral student Stanley Miller published their own genesis-in-a-bottle experiment, which replaced the carbon dioxide that Calvin's team used with methane and ammonia. They zapped their chemical concoction with electricity and, after the curiously biblical duration of seven days, confirmed that they'd cooked up a variety of amino acids, which make up proteins.

According to Calvin, "that's where things took off" for the study of life's origins. After that, other groups used radiation from particle accelerators or radioactive materials to achieve the same kinds of chemical syntheses.

Still, Calvin remained unsatisfied. After all, a primordial soup of life's basic ingredients was still a far cry from a fully-fledged biosphere. How did these primitive organic molecules become more complex and coalesce into life as we know it? Calvin wrote his first paper on the subject in 1955. He envisioned a Darwinian-style evolution that prompted increasing chemical complexity from that first synthesis of organic compounds to the appearance of Earth's first organisms. Originally posed by Darwin himself, this concept had fallen out of fashion in the latter half of the nineteenth century. It was picked up by British biologist JBS Haldane in the 1920s and Soviet biochemist Alexander Oparin in the 1930s.

Like standard biological evolution, Calvin imagined that chemical evolution relied on the interplay between random variation and some means of selecting among those variations. Following the type of event that Miller and Urey created in their experiment, Calvin imagined organic molecules accumulating in Earth's water. He suggested that there were a few molecules in this primordial soup that could catalyze—or speed up—the breakdown of other energy-rich molecules, and that such a chemical reaction would create more of the catalyzing molecule. The self-catalyzing molecules were like animals, "eating" other molecular species to produce more of their own kind. And, like animals subject to biological evolution, random variations in these molecules gradually led to more complex, more efficient self-catalyzers.

Now, all this molecular natural selection was still taking place in the disordered wilderness of a watery solution. A vital step in creating life, Calvin realized, was imposing some order on this chaos. Fortunately, he said, "there is a beautiful way in which this kind of order can arise." When they reach high enough concentrations, some types of organic molecules—like nucleotides and amino acids—automatically start stacking up like a deck of cards. That kind of order is a crucial characteristic of large molecules like DNA, and would set those free-floating organic molecules on their way to constructing primitive life forms.

Alas, Calvin didn't think it possible to experimentally test the idea of chemical evolution, because it would have taken billions of years to unfold. But that didn't stop Calvin thinking about it. "There was no question in my mind about the Darwinian behavior of molecules," said Calvin, who, in 1969, would write a book on chemical evolution. This belief fed directly into his curiosity about extraterrestrial life. After all, if chemical evolution occurred on Earth, then it surely occurred elsewhere in the universe, which Calvin knew was chockablock with carbon, hydrogen, and nitrogen—the elements that spring-boarded chemical evolution here at home.

Calvin's conviction about extraterrestrial life was reinforced by astronomers' estimations for the vast numbers of sun-like stars in the universe and the number of planets with temperatures suitable to life that were thought to orbit those suns. "There must be other places just like ours," he said, "and we've got to find them."

At first, Calvin didn't think he had much to contribute to the search for E.T. He was a chemist, not an astronomer. But soon, the U.S. government had given Calvin outlets for his fascination with alien life. In 1959, Calvin was put in charge of a National Academy of Sciences committee on extraterrestrial life. At around the same time, he was appointed to a panel organized by the military on life in outer space.

Calvin was joined in both groups by a young Carl Sagan, who was writing a series of astrobiology papers for his doctoral dissertation. Sagan admired Calvin a great deal, and the two regularly exchanged letters about Sagan's research and other space science news. It was Sagan who would draw Calvin's attention to Project Ozma—the first search for alien signals conducted by Frank Drake at the National Radio Astronomy Observatory in spring 1960.

The year 1959 was a boon for Calvin's alien interests, not only because he made some new astrobiology friends, but also because he found a practical way to look for alien life: scrutinizing meteorites. Calvin speculated that within the next five years, humans would visit the Moon or Mars to hunt for organic matter. But in the meantime, a bounty of extraterrestrial material was falling from the sky every year in the form of meteorites. In retrospect, Calvin said, inspecting meteorites was "a pretty obvious thing to do."

But just because Earth gets bombarded with thousands of meteorites every year doesn't mean that it was easy for Calvin to get his hands on one. Most meteorites either hit Earth's oceans or land in remote, inaccessible areas. "We can't place an order for the meteorites," Calvin lamented. "We have to take them when they come, and that isn't very frequent, and, what is more, they get into museums and you can't get them out." Calvin would know. He and his colleagues solicited materials from museum after museum, from Arizona to Moscow, before finally getting some material from the Smithsonian Institute in Washington, D.C.

"As we often do, we started the analysis quite blindly," Calvin said. Just as they were getting samples, Calvin scrounged up some literature on analyzing meteorites for carbon content. He found that this had been "quite a popular sport" fifty years prior—although, back then, organic chemistry hadn't been advanced enough to get researchers very far.

It might seem odd that anyone would take on such an unfamiliar project with so little preparation, but that was always Calvin's style. He was "a fearless scientist, totally unafraid to jump into new fields," Seaborg and Benson wrote. By reading quickly and having no shame when it came to badgering better-informed colleagues with questions, Calvin sprinted up learning curves. Meteorite research was no exception.

Calvin's team presented the results of their study at a conference in January, 1960. They hadn't found any amino acids on their meteorites, but they did see evidence of one organic molecule that was chemically similar to cytosine—one of the four main bases found in a strand of DNA. As far as Calvin was concerned, that was pretty persuasive evidence that the conditions leading to life on Earth existed in outer space.

In the fall of 1961, Calvin received a letter from Otto Struve, director of the National Radio Astronomy Observatory, where SETI pioneer Frank Drake had conducted Project Ozma. Struve invited Calvin to participate in a Conference on Extraterrestrial Intelligent Life, which was to be held at the observatory in Green Bank, West Virginia in early November. Struve urged all the invitees—of which there were fewer than two dozen—to exercise discretion. The meeting was meant to be held privately, with no press coverage.

Calvin was intrigued and jumped at the chance to spend time with more E.T.-interested scientists. Besides, a two-day meeting across the country was business as usual for Calvin by 1961. Every month of the year, his calendar was riddled with trips to various committee meetings and guest lectures. In fact, Green Bank was but one leg on a two-week tour for Calvin. He arrived to West Virginia late Halloween night aboard a train from a conference in D.C.

Frank Drake, who was helping host the conference, welcomed Calvin to Green Bank. "Calvin gave an immediate impression of warmth and sincerity," Drake wrote in his 1992 SETI memoir *Is Anyone Out There?* "I liked him from the very first." Drake was also struck by how calm Calvin seemed, given that Drake's conference co-organizer, biologist James Pearman, had heard that Calvin was a shoe-in for the chemistry Nobel. The winner was going to be announced during the meeting, but Calvin appeared cool as a cucumber, utterly focused on the matter at hand.

In truth, Calvin was simply exhausted from Nobel-related speculation. The anticipation over the past week, Calvin admitted, "made life very difficult for me, my family, and my personal staff." Remote, sparsely populated Green Bank must have been a breath of fresh air, and perhaps the meeting provided a mental escape from his Nobel angst.

No one recorded the conference proceedings, so it is unknown exactly what Calvin contributed to the conversation. But Struve's program, which he distributed to the attendees a week before the conference, indicates that Calvin was slotted to present his research on the chemical origins of life, and lend his biological expertise to discussions about the likelihood of aliens developing humanlike intelligence. According to Drake, during the debate over the probability of habitable planets developing life forms, Calvin teamed up with his old pal Carl Sagan to argue that the birth of a biosphere was a common, if not inevitable step in a planet's evolution.

Whatever Calvin said at the meeting, he made his most memorable mark during the wee hours of the morning on the second day of the conference. All the scientists had long retired to their quarters in the residence hall and farmhouses clustered on the observatory campus. Around 4 a.m., the dead silence of Green Bank was shattered by a telephone ring in the administration building. The night watchman answered. It was the Karolinska Institute in Stockholm, Sweden, to announce that Calvin had been awarded the Nobel Prize in Chemistry for elucidating the path of carbon in photosynthesis.

The guardsman dashed across the dark grounds to the residence hall and shook Calvin awake to give him the good news. Of course, it wasn't long before everyone else was out of bed, too. They broke out the spirits that Pearman had purchased in anticipation of this merry occasion, toasted Calvin, and then—as Sagan so eloquently put it—"got smashed on champagne." At some point in the midst of all this fraternal merriment, the conference attendees collectively dubbed themselves "The Order of the Dolphin," in honor of the closest proxy to alien intelligence here on Earth.

There was an onslaught of phone calls and telegrams from well-wishers and reporters, but by midmorning, Calvin "felt it at least good manners to talk about extraterrestrial life again," Drake said. "He seemed a bit apologetic that all the hubbub was disrupting our agenda."

Calvin was pretty overwhelmed by the whole ordeal. A few weeks later, when he sent a thank-you note to Struve for hosting the conference, Calvin wrote, "I certainly appreciate the kindness and generosity of you and your colleagues during my time of trial."

But if Calvin thought the reception he enjoyed with the Order of the Dolphin was staggering, that paled in comparison to the merrymaking of the next several weeks. Calvin cut his two-week trip short and flew straight home from West Virginia to celebrate. The first couple days back in Berkeley were filled with press conferences, a party at home for old friends, and yet another champagne party with colleagues at the Faculty Club.

A month later, Calvin and his family travelled to Sweden for Nobel festivities. Their plane touched down in Stockholm in the pitch-black at 3 p.m., in the middle of a snowstorm, but there was still a sizable delegation standing by to meet them planeside. "We were anticipated or recognized everywhere," Gen Calvin wrote to a friend after they'd returned home, "always with the greatest kindness and courtesy, but there were not nearly enough minutes for sleep."

The formal presentation of awards at the Stockholm Concert Hall was followed by a banquet and ball hosted by the king and queen. For the next two weeks, Calvin travelled around Europe for various receptions and guest lectures, and the following spring, he attended a Nobel Laureates' dinner at the Kennedy White House.

Despite all these lavish gatherings and international accolades, the "ultimate prize" of his Nobel, Calvin declared, was a free, reserved parking space on the U.C. Berkeley campus—which he didn't even receive until twenty years later.

Although Calvin felt guilty for stealing the spotlight at Green Bank, the hullaballoo over his Nobel was perhaps the greatest gift he could have given the Order. "This may sound crazy, but sharing that moment with Calvin was almost like sharing in the prize itself," Drake said. "I felt somehow that our group and the topic we were discussing had suddenly been raised to a higher credibility level by Calvin's new standing in the public eye."

Drake wasn't wrong. A *New York Times* article on the conference published in April of 1962 reported that attendees "included men of the caliber of Dr. Melvin Calvin." The article made special mention of Calvin's Nobel and meteorite work.

But a retroactive celebrity endorsement wasn't Calvin's only gift to the Order. The week after Green Bank, Calvin delivered a series of lectures at Harvard. While he was in Cambridge, Calvin—along with fellow Green Bank attendees John Lilly and Dana Atchley—inducted biophysicist Arthur Solomon and Doxie Woodward, the wife of a Harvard chemist, into the Order of the Dolphin. Calvin declared them officers of the Order's Boston Chapter and commissioned them to have dolphin-inscribed lapel pins made for all the members. The "charter" members who were at Green Bank were delighted to receive their pins the following spring.

In the aftermath of the Green Bank meeting, Calvin clearly wanted the Order to become a sustained society. His correspondence to other members alluded to future meetings, his hopes to see some activity out of the Boston Chapter, and intentions to induct new members. Three decades on, Calvin still referred to the Order as the inner circle of his SETI compatriots. But in the end, Calvin's pins never became the membership badges that Order members might flash to one another at regular meetings. Rather, they were merely souvenirs of a strange, solitary event.

Even if the Order had continued to meet, it's unlikely Calvin could have kept up with it. Nobel Prize winners, Calvin soon discovered, are persons of high demand. "Science goes on after the prize," he said, "but the instant fame and interruptions can be overwhelming."

By the end of 1961, Calvin was turning down guest lecture invitations left and right because he was already booked out for eight months. In the years after the Nobel, Calvin was recruited to federal science advisory boards and served as president of two national science societies. Calvin's prior commitments, like his position on a National Academy of Sciences committee, fell by the wayside.

Some of Calvin's colleagues started to think Calvin was getting rather big for his britches. Lemmon had always found Calvin easy to talk to, but after the Nobel, "he became somewhat stiffer, more formal and harder to communicate with," Lemmon said. "He tended to annoy people by seeming to be an expert on any subject that came up, however remote from science... He saw himself differently."

Even if they didn't agree with that particular assessment of Calvin's character, Berkeley colleagues couldn't help but notice the radical changes to his calendar. Moses noted that Calvin was hardly ever around the lab. Kuntz recalled one meeting with Calvin that was delayed ten times to accommodate Calvin's other commitments.

When Calvin wasn't bouncing from city to city for meetings, he flitted from place to place around Berkeley like a hummingbird. By the early 1960s, his research group had overflowed into three different labs across campus. Calvin had a little electric cart to zip him up and down the hills of Berkeley, and Sauer remembered how Calvin used to offer him rides on the back of the cart if they were heading in the same direction.

Fortunately, in 1963 Calvin consolidated all his far-flung lab members under a single roof. Calvin helped specially design his new building: round, and filled with lab benches that radiated out from the center of the room. Calvin thought this layout would encourage teamwork among scientists from various disciplines. The lab's strange shape earned it nicknames like "the Round House" and "the Calvin Carousel."

"It had a very interesting philosophical direction," Kuntz said. "I think [Calvin] was quite a pioneer in trying to get collaborative research together, and just managing this huge group...I'm not going to say it was without rumble and grumble now and then. But by and large it was a lot of people working on very different areas that turned out to be quite productive."

Calvin's lab was "a congenial group," Sauer said. The people went hiking together, invited each other over for dinner, and had Christmas parties. The Calvins themselves liked to invite people to the 500-acre ranch Calvin had bought with his Nobel winnings. The group even gathered in the center of the laboratory for a weekly coffee hour to socialize and discuss their work.

Unifying so many researchers with disparate backgrounds and interests wasn't easy, Moses said, but Calvin was the "cement" that held the whole group together. For instance, Moses said, Calvin could talk shop with the physicists "pretty much on a physics level" even though he didn't have any formal training in that area. It also helped, Moses thought, that there was no hierarchy within the lab. Calvin was head honcho, and since there was "no conceivable competition" for his position, lab mates had pretty relaxed relationships.

As sole leader of the lab, Calvin ran a tight ship. Longtime lab members came to notice a distinct shift in the atmosphere when Calvin was around, compared to the days he was away. "When he was in, one could feel the tension in the air," three of Calvin's colleagues wrote in his American Philosophical Society memoir. "At any moment, Calvin could pop up suddenly in the hall and say, 'Well, Joe, how did the experiment turn out?'" People had to keep interesting tidbits on hand, just in case they ran into him.

Calvin was equally relentless in weekly lab meetings. Once everyone was gathered for the seminar, Calvin would pick someone at random to present their work. "On the spot. No preparation at all," Sauer said. In later years, Calvin gave people 48 hours' notice, but Friday morning seminars were still hard on presenters. A speaker might only get out a sentence or two before Calvin started firing questions at them, and he had no patience for imprecise answers.

"He asked very direct questions and he expected a clear answer," Kuntz said, "and he would correct people if he thought they were on the wrong track."

Calvin didn't mean to put his lab mates down, Moses explained. He was just asking questions he really thought needed answering. This was not much consolation to newbies when they were put on the hot seat. "They were very frightened of him," Moses admitted.

Despite Calvin's tendency to intimidate his underlings, he made for a very supportive lab director. He'd always been adept at securing grant money, but Calvin found that being a Nobel Laureate was, unsurprisingly, a significant leg-up. "And he had contacts back in Washington," Sauer said, "so he had access to the money that he needed. If we wanted to buy an expensive instrument to do a set of experiments, he said, 'Okay, let's put in for it,' and the way was cleared."

In addition to directing over a hundred lab members, Calvin personally advised a few graduate students. Kuntz admitted that it was "not a very hands-on mentorship." His ten cancelled meetings were evidence enough of that. And in retrospect, Kuntz could see some technical issues with his work that a more involved advisor might have caught and helped him amend. But Kuntz liked the fact that Calvin gave his graduate students a long leash for independent exploration, especially in the largely unchartered territories on the border between physics and chemistry. It was nice to feel like they were taking on new challenges, rather than just dotting the i's and crossing the t's of projects that had already seen a dozen post-docs and grad students.

One criticism that other Berkeley professors wielded against him was that Post-Nobel Calvin didn't really *do* much science. He was just a "cheerleader" for other lab efforts. This was an understandable impression. Calvin's own work in the lab—what little he had time for, these days—no longer scaffolded some serious, long-term project like the photosynthesis work. "He went off in all different directions," Kuntz said. "A number of Nobelists have done that, basically taking it as a license to have interesting ideas. I think the good and the bad is that he was definitely super interested in all this stuff, and he just didn't have enough time to be what you'd call a real expert at these areas."

True to form, even when Calvin's research focus spiderweb-cracked, it still touched upon a couple of astrobiology ideas. In 1962, Calvin netted a quarter-million-dollar grant from the new NASA Life Sciences Office to create a catalog of infrared light reflections off an assortment of biological specimens. This effort was meant to help interpret the observations of an astronomer who'd noticed patterns in the infrared light reflected off Mars, which hinted at the presence of organic matter. Perhaps the most immediate payoff from Calvin pursuing this project was a credibility boost for NASA Life Sciences, which had initially struggled to attract grant applicants to the fringe field of astrobiology.

Meanwhile, Calvin kept on with his meteorites. In 1964, Calvin received samples from Harvard, Australia, and Norway by request, and he also started getting unsolicited samples from non-scientists who heard about his work and wanted to donate meteorites they'd found for study.

That same year, Calvin was invited to join a band of meteorite-studying scientists who aimed to establish some standard for analysis, because there were so many conflicting results coming out of different labs. Meteorites, said Al Burlingame, who then worked with Calvin in the Berkeley Space Sciences Lab, "are not the world's greatest source of material" because of all their Earthly contamination. Carefully considered, stringently standardized methods were crucial, if scientists were to avoid wasting what precious few meteorites they had to work with. Calvin was immediately on board. But, as with Calvin's astrobiology committees, these meetings started slipping through the cracks of Calvin's schedule, which bowed under the weight of all his responsibilities.

From meteorite research, it wasn't too far a stretch for Calvin to get in on lunar sample analysis. After Apollo 11 returned, Calvin and Burlingame were among the dozens of researchers who got access to lunar samples for various types of investigations. As far as Burlingame remembered, Calvin did more supervising and supporting than actual lab work. "I think his main role was to keep NASA management from getting themselves into trouble by going off the deep end with other people in the program," Burlingame said. "He was very critical and he kept people honest [in their analyses]."

In September 1969, Calvin's team at Berkeley put their moon rock through the ringer with a series of lab tests to characterize the organic matter in the sample, if there was any to be found. They detected a few carbon-containing molecules, but no evidence for lunar life. At least Calvin got a souvenir: a piece of moon rock that he showed off to his Berkeley colleagues (to much ooh-ing and ahh-ing, as Moses recalled) and then proudly put on display in his office.

After 1970, Calvin largely dropped out of the SETI/astrobiology scene. Once again, he felt like he had no research to contribute. Calvin saw himself more as a spokesman for SETI than anything else. He continued to lecture and attend conferences, and when Sagan circled a petition through the scientific community in 1982 to get endorsements for SETI research, Calvin proudly penned his name.

Calvin reconnected with another Order member, Philip Morrison, in the late 1970s. Morrison had just wrapped up his series of NASA SETI workshops and wanted Calvin to chair a similar series that would review prospects for origins of life research. "Your manifest expertise," Morrison wrote, "would help a great deal."

Calvin's secretary, who received this note while Calvin was out of town, enthusiastically responded to "Dolphin Morrison" with her hopes that Calvin would accept his invitation, and that the workshops might make for an Order reunion of sorts. They might have been, if not for the fact that Calvin ended up skipping most of the meetings. He did review a draft of the official workshop report in 1981, but his notes were merely, "Fine. When do we get a [final] copy?"

Calvin's lack of involvement is perhaps more forgivable in light of the fact that he'd already officially retired. Calvin stepped down as lab director in 1980, although he did maintain a small research group at Berkeley for the next sixteen years that investigated artificial photosynthesis as a means of renewable energy.

Order of the Dolphin member Barney Oliver shared Calvin's interest in this particular topic, so these two SETI friends started up a back-and-forth about renewable energy, interspersed with conversation about astrobiology-related news. When Oliver became head of NASA's SETI Science Working Group, and he sent Calvin copies of the group's reports for leisure reading. A decade later, when NASA defunded its SETI program and Oliver helped establish the non-profit SETI Institute, Calvin became a donor and continued supporting the organization until he passed away in 1997.

In 1990, an interviewer asked Calvin when he thought humanity might pick up alien signals from the stars. "That could be today, or that might not be for one hundred years," Calvin said. "I don't think we're ready today." Yet when the interviewer asked what scientists should do, in the event of a signal detection, Calvin responded, "Broadcast it as widely as possible over Earth," humanity's readiness be damned. Even in the realm of hypotheticals, Calvin was a man of action.

Two years later, Calvin published his autobiography, *Following the Trail of Light*. In one of the book's final chapters, Calvin explained that the title was a reference to the core philosophy of his scientific career: doggedly pursue an idea of interest, wherever it might lead. That guiding principle took Calvin down the trail of carbon and won him a Nobel Prize. It also took Calvin on a meandering excursion into astrobiology that left him with an unsatisfying origins of life experiment, a book on a theory of chemical evolution he didn't think it possible to prove, and a cache of meteorites and moon rocks with a disappointing lack of microbial hitchhikers. But for all the dead and loose ends of Calvin's astrobiology enterprise, it was his fearlessness in charging down these new scientific frontiers, forever full speed ahead, that made him a quintessential SETI scientist.

NOTES

Abbreviations

BBL	Berkeley Bancroft Library archives
NRAO	National Radio Astronomy Observatory archives

3 **He was parked on the curb...several months**: Calvin (1992), p. 68.

3 **In his lab...into sustenance**: Kauffman and Mayo (1996), p. 414.

3 **The cyclic nature..."sit and wait"**: Calvin (1992), p. 68.

3 **Chemistry Nobel Prize in 1961**: Seaborg and Benson (1998), p. 17.

3 "**New ideas...thick and fast**": BBL, Calvin Papers, Carton 32. Folder "Obituaries, 1997." Obituary of Melvin Calvin written by Vivian Moses for *Advanced Carbohydrate Chemistry & Biochemistry*.

3 **Calvin's propensity..."something creative"**: Swift (1990), pp. 119-20.

4 **growing up in Detroit**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 **in the 1910s**: Otvos, Taylor, and Connick (2000), p. 457.

4 **liked to dismantle his toys**: Kauffman and Mayo (1996), p. 412.

4 **when he was eight..."science experiment"**: Swift (1990), p. 118.

4 **best (and only) friend, Abraham**: Calvin (1992), p. 7.

4 **the two boys set up shop...**: Swift (1990), p. 118.

4 **When Calvin was in high school**: Seaborg and Benson (1998), p. 3.

4 **Spending his Saturdays working...involved chemistry**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 **must never be out of a job**: Swift (1990), p. 117.

4 **growing up in a working class family...**": interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 **Michigan College of Mining and Technology**: Otvos, Taylor, and Connick (2000), p. 457.

4 **on scholarship**: Calvin (1992), p. 10.

4 **first B.S. in chemistry in 1931**: Seaborg and Benson (1998), pp. 3-4.

4 **All his electives...like paleontology**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 **appreciate the long history...biology course**: Swift (1990), p. 118.

4 **in the long run..."don't know what it is"**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 **chemistry PhD in 1935 from the University of Minnesota**: Otvos, Taylor, and Connick (2000), p. 454.

4 **post-doctoral fellowship...rest of his career**: Seaborg and Benson (1998), p. 4.

4 **early years at Berkeley...work he'd begun under Polanyi**: Calvin (1992), p. 26.

4 **teaching organic chemistry**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

4 "**His lectures...nearly overwhelmed**": Seaborg and Benson (1998), pp. 6-7.

5 "**most of them...very stimulating**": interview with Tack Kuntz, January 6, 2017.

5 **enjoyed socializing...got married**: Seaborg and Benson (1998), p. 17.

5 **Calvin's wife...personal side projects with him**: Bailey (2017).

5 **lost their first son...caused the problem**: Kauffman and Mayo (1996), p. 413.

5 **two daughters and a son**: Bailey (2017).

5 **Earnest Lawrence... Bio-Organic Chemistry Group**: Calvin (1992), p. 102.

5 **stopped Calvin...a bunch of radioactive carbon**: interview of Melvin Calvin by Clarence Larson on July 16, 1984.

5 **built up...surrounding the lab's particle accelerator**: interview with Ken Sauer, January 10, 2017.

5 "**do something useful with it**": interview of Melvin Calvin by Clarence Larson on July 16, 1984.

5 **primed by the research...Polanyi's lab**: BBL, Calvin Papers, Carton 32. Folder "Obituaries, 1997." Obituary of Melvin Calvin written by Vivian Moses for *Advanced Carbohydrate Chemistry & Biochemistry*.

5 **it was well known...**: Bailey (2017).

5 **the problem was...gone to other institutions**: "The Calvin Lab" (2000), pp. Intro/1-Intro/3.

6 **filled a flask...killing it instantly**: Calvin (1992), p. 58.

6 **technique called paper chromatography**: Kauffman and Mayo (1996), p. 414.

6 **dripped a bit...perpendicular to the dipped edge**: Kimball (2011).

6 **To get an even finer separation...**: Kimball (2016).

6 **sample-coated papers...which molecules were complicit in the path of carbon**: email from Ken Sauer, April 13, 2017.

6 **over a decade**: Seaborg and Benson (1998), p. 13.

6 **molecule that first welcomed carbon dioxide...and so on**: Gould (2013).

7 **twenty-three papers, two books**: Calvin (1992), p. 57.

7 **Dick Lemmon...good for the lab**: "The Calvin Lab" (2000), pp. 6/2-6/6.

7 "**Mr. Photosynthesis**": Schulz (1997), p. 11.

7 **attracted scientists... "published with Calvin"**: The Calvin Lab" (2000), p. 17/35.

7 "**under control and felt sort of routine**": interview with Tack Kuntz, January 6, 2017.

7 "**smelling a Nobel Prize**": The Calvin Lab" (2000), p. 6/9.

7 **Cornelius Bernardus van Niel...congratulated Calvin**: Seaborg and Benson (1998), p. 7.

7 "**will live forever**": interview with Tack Kuntz, January 6, 2017.

7 "**would've been an enormous hole...investigation in botany**": interview with Ken Sauer, January 10, 2017.

7 "**It's just way too complicated**": Swift (1990), p. 118.

7 **in 1949**: Swift (1990), p. 130.

7 **read *The Meaning of Evolution*...**: Calvin (1969), p. v.

7 **the prevailing theory...**: Calvin (1963), p. 40.

8 **the mid-1920s... investigation into life's origins at Calvin's lab**: Calvin and Vaughn (1959), p. 9.

8 **filled a flask...simple organic molecules**: Drake and Sobel (1992), p. 50.

8 **helium ions**: Kauffman and Mayo (1996): p. 415.

8 **after the experiment...prebiotic atmosphere**: Calvin (1992), pp. 74-75.

8 **two years later...which make up proteins**: Turse et al. (2013), p. 539.

8 "**that's where things took off**": Swift (1990), p. 121.

8 **other groups...same kinds of chemical syntheses**: Calvin and Vaughn (1959), p. 10.

8 **wrote his first paper on the subject in 1955**: Calvin (1955).

8 **Darwinian-style evolution...1930s**: Calvin (1960), p. 318.

8 **standard biological evolution...Earth's water**: Calvin (1955), pp. 13, 8.

8 **a few molecules...efficient self-catalyzers**: Avery (2012), pp. 60-61.

9 **molecular natural selection...billions of years to unfold**: Calvin (1955), pp. 15-17, 22.

9 "**There was no question...**": Swift (1990), p. 121.

9 **in 1969**: Calvin (1969).

9 **This belief fed directly...here at home**: Calvin and Vaughn (1959), p. 18.

9 **reinforced by astronomers...the search for E.T.**: Swift (1990), p. 121.

9 **in 1959...on extraterrestrial life**: Space Studies Board (1959), p. ref. 1; Darling and Schulze-Makuch (2016), p. 444.

9 **around the same time...in both groups**: Darling and Schulze-Makuch (2016), pp. 313, 414.

9 **young Carl Sagan...doctoral dissertation**: Spanenburg and Moser (2009), p. 42.

9 **Sagan admired Calvin...Project Ozma**: BBL, Calvin Papers, Box 18. Folder "Sagan, Carl (Yerkes Observatory, University of Chicago, 1959-62."

9 **spring 1960**: Drake and Sobel p. 35.

9 **Calvin speculated...in the form of meteorites**: Calvin (1960), p. 335.

10 "**pretty obvious thing to do**": Calvin and Vaughn (1959), p. 20.

10 "**We can't place an order...can't get them out**": Calvin (1960), p. 335.

10 **from Arizona to Moscow**: BBL, Calvin Papers, Box 64. Folder "Meteorites—Information."

10 **from the Smithsonian...get researchers very far**: Calvin and Vaughn (1959), p. 20.

10 "**a fearless scientist," by reading quickly...better-informed colleagues**: Seaborg and Benson (1998), p. 5.

10 **conference in January...pretty persuasive evidence**: Calvin and Vaughn (1959), pp. 31-35.

10 **fall of 1961...**: BBL, Struve to Calvin, September 25, 1961.

10 **no press coverage**: NRAO, Conferences, Symposia, and Colloquia Subunit, Folder "Conference on Extraterrestrial Intelligent Life, Green Bank, 1-2 November 1961." Struve to Invitees, September 18, 1961. Retrieved from http://www.nrao.edu/archives/NRAO/nraorecords_item_conf.shtml

10 **every month...guest lectures**: BBL, Calvin Papers, Carton 23. Folder "Travel Files, 1960-1989."

11 **late Halloween night aboard a train from a conference in D.C.**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Struve, October 9, 1961.

11 "**Calvin gave an immediate impression," how calm Calvin seemed...on the matter at hand**: Drake and Sobel (1992), pp. 48-54.

11 "**made life very difficult**": Calvin (1992), p. 111.

11 **no one recorded the conference proceedings**: Drake and Sobel (1992), pp. 54.

11 **Struve's program...humanlike intelligence**: NRAO, Conferences, Symposia, and Colloquia Subunit, Folder "Conference on Extraterrestrial Intelligent Life, Green Bank, 1-2 November 1961." Struve to Invitees, October 25, 1961. Retrieved from http://www.nrao.edu/archives/NRAO/nraorecords_item_conf.shtml

11 **during the debate...a planet's evolution**: Drake and Sobel (1992), p. 56.

11 **Around 4 a.m....toasted Calvin**: Drake and Sobel (1992), p. 59.

11 "**got smashed on champagne**": Baur (1975), p. 31.

12 **an onslaught... "disrupting our agenda"**: Drake and Sobel (1992), p. 59.

12 "**I certainly appreciate the kindness**": BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Struve, November 15, 1961.

12 **flew straight home...at the Faculty Club**: Calvin (1992), p. 113.

12 **a month later... "enough minutes for sleep"**: Ibid.

12 **The formal presentation...guest lectures**: BBL, Calvin Papers, Carton 23. Folder "Travel Files, 1960-1989."

12 **Nobel Laureates' dinner at the Kennedy White House**: Seaborg and Benson (1998), p. 17.

12 **the "ultimate prize"...twenty years later**: Calvin (1992), p. 122.

12 "**This may sound crazy**": Drake and Sobel (1992), p. 59.

12 **A New York Times article...Calvin's Nobel and meteorite work**: Sullivan (1962).

13 **a series of lectures at Harvard**: BBL, Calvin Papers, Carton 23. Folder "Travel Files, 1960-1989."

13 **While he was in Cambridge...into the Order**: NRAO, Conferences, Symposia, and Colloquia Subunit, Folder "Conference on Extraterrestrial Intelligent Life, Green Bank, 1-2 November 1961." List of Order of the Dolphin members. Retrieved from http://www.nrao.edu/archives/NRAO/nraorecords_item_conf.shtml

13 **Calvin declared them officers...made for all the members**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Solomon, November 14, 1961.

13 **The "charter" members...future meetings**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Woodward, March 29, 1962.

13 **hopes to see some activity out of the Boston Chapter**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Struve, November 15, 1961.

13 **intentions to induct new members**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Woodward, March 29, 1962.

13 **three decades on...SETI compatriots**: Swift (1990), p. 121.

13 "**Science goes on**": Calvin (1992), p. 111.

13 **booked out for eight months**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Brown, December 27, 1961.

13 **federal science advisory boards...national science societies**: Seaborg and Benson (1998), pp.14-16.

13 **prior commitments...fell by the wayside**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Lederberg March 6, 1962.

13 **some of Calvin's colleagues...ever around the lab**: "The Calvin Lab" (2000), pp. 6/2, 6/22.

13 **one meeting with Calvin that was delayed ten times**: interview with Tack Kuntz, January 6, 2017.

13 **By the early 1960s...heading in the same direction**: interview with Ken Sauer, January 10, 2017.

14 **1963 Calvin consolidated all his far-flung lab members**: Bailey (2017).

14 **Calvin helped specially design...center of the room**: interview with Ken Sauer, January 10, 2017.

14 **thought this layout would encourage teamwork... "the Calvin Carousel"**: Kauffman and Mayo (1996), p. 415.

14 "**It had a very interesting...turned out to be productive**": interview with Tack Kuntz, January 6, 2017.

14 **"congenial group"...Christmas parties**: interview with Ken Sauer, January 10, 2017.

14 **invite people to the 500-acre ranch**: Otvos, Taylor, and Connick (2000), p. 456.

14 **bought with his Nobel winnings**: Calvin (1992), p. 120.

14 **weekly coffee hour to socialize and discuss their work**: interview with Ken Sauer, January 10, 2017.

14 **Unifying so many researchers…relaxed relationships**: "The Calvin Lab" (2000), pp. 17/23-17/24.

14 "**When he was in…**": Otvos, Taylor, and Connick (2000), p. 456.

14 **people had to keep interesting tidbits on hand**: Seaborg and Benson (1998), p. 5.

14 "**On the spot**": interview with Ken Sauer, January 10, 2017.

14 **A speaker…imprecise answers**: interview with Vivian Moses, January 24, 2017.

15 "**He asked very direct questions**": interview with Tack Kuntz, January 6, 2017.

15 "**They were very frightened of him**": interview with Vivian Moses, January 24, 2017.

15 **He'd always been adept…a significant leg-up**: Calvin (1992), p. 122.

15 "**And he had contacts back in Washington**": interview with Ken Sauer, January 10, 2017.

15 **In addition to directing… "real expert at these areas"**: interview with Tack Kuntz, January 6, 2017.

15 **In 1962…biological specimens**: Strick (2004), p. 145.

15 **This effort…presence of organic matter**: BBL, Calvin Papers, Carton 24. Folder "Chronological correspondence files, outgoing, 5/1958-8/1962." Calvin to Silver, February 28, 1962.

15 **credibility boost…field of astrobiology**: Strick (1004), pp. 139-142.

16 **In 1964…they'd found for study**: BBL, Calvin Papers, Box 64. Folder "Meteorites—Information."

16 **That same year…out of different labs**: BBL, Calvin Papers, Box 64. Folder "Meteorites—Group for Analysis of Carbonaceous Chondrites."

16 "**not the world's greatest source of material**": interview with Al Burlingame, January 13, 2017.

16 **meeting started slipping…all his responsibilities**: BBL, Calvin Papers, Box 64. Folder "Meteorites—Group for Analysis of Carbonaceous Chondrites."

16 **After Apollo 11 returned… "kept people honest"**: interview with Al Burlingame, January 13, 2017.

16 **In September 1969**: BBL, Calvin Papers, Box 62. Folder "NASA Lunar Sample Analysis Contract (LSAC)—Correspondence."

16 **moon rock through the ringer…no evidence of lunar life**: BBL, Calvin Papers, Box 44.

16 **much ooh-ing and ahh-ing**: interview with Vivian Moses, January 24, 2017.

12 **on display in his office**: Kauffman and Mayo (1996), p. 415.

16 **After 1970…spokesman for SETI**: Swift (1990), pp. 126, 133.

16 **continued to lecture and attend conferences**: BBL, Calvin Papers, Box 44. Folder "Travel - Lunar Science Conference (Houston, Texas), January 11-14, 1971" and "Travel - Cosmic

Evolution Lecture Series (San Francisco), August 14, 1972"; BBL, Calvin Papers, Carton 32. Folder "Young, Richard S—NASA/ISSOL, 1970-1974."

16 **Sagan circled a petition...penned his name**: Drake and Sobel (1992), p. 197.

17 **Morrison had just wrapped up... "a final copy?"**: BBL, Calvin Papers, Box 40. Folder "NASA Origin of Life Science Workshop—Correspondence, 1978-83."

17 **Calvin stepped down...turned into petroleum**: Seaborg and Benson (1998), p. 18.

17 **the late 1970s...leisure reading**: BBL, Calvin Papers, Carton 22. Folder "Oliver, Bernard M—Hewlett-Packard, 1979-1988."

17 **a decade later...until he passed away**: BBL, Calvin Papers, Carton 32. Folder "SETI Institute (Project Phoenix), 1994-1996."

17 **1997**: Bailey (2017).

17 **"That could be today"... "widely as possible over Earth"**: Swift (1990), pp. 125, 135.

17 "**autobiography he published two years later**": Calvin (1992)

17 "**final chapters...wherever it might lead**": Calvin (1992), p. 134.

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