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IN MEMORIAM

James B. Pollack
(1938–1994)

Jim Pollack died at home in San Jose, California, on June 13, 1994. He was a young man, only 55 when he died, near the peak of his career. He fought a long battle with a rare form of spinal cancer and refused even at the end to admit that he might not win. Despite several major operations and many months in a weakened condition from chemotherapy, Jim continued to work on the science questions that had always intrigued him.

Jim had tremendous energy, talent, and intellectual curiosity. He loved planetary science above all else, and he dedicated his life to it. He contributed major ideas to our knowledge of virtually every solar system object and participated in almost every planetary mission following the Apollo era. He was a member of the imaging teams of Mariner 9 for Mars, of the Viking Lander for Mars, and of Voyager for Saturn, Uranus, and Neptune. He was an interdisciplinary scientist for Pioneer Venus, for the Galileo orbiter and probe bound for Jupiter, and for Mars Observer. Until the week before his death Jim was playing an active role in defining a Discovery mission to probe the atmosphere of Venus. He greatly enjoyed team efforts and made major contributions to planning these spacecraft missions.

The hallmark of his work was to carry out each of his many studies for prolonged periods while continually developing, expanding, and improving his mastery of the subject. Jim loved to work with others. He was a genius at finding and encouraging people to work on complex interdisciplinary subjects. Jim shaped the careers and lives of a significant number of planetary scientists through his devotion to his colleagues and through his penchant for building long-lasting research groups, many of which survive him. Jim had too many collaborators to mention even a small fraction of them. An unusually large fraction of his collaborators were young scientists to whom he became a mentor and a friend.

Jim grew up on Long Island in Woodmere, New York, where he was the valedictorian of his high school and was on the high school track team. Jim's family owned "Pollack's," a family clothing business that had been in operation since the beginning of the century. However, from an early age his interests were in science. He was a Phi Beta Kappa at Princeton, where he graduated *magna cum laude* in physics, class of 1960. Jim always had a good sense of humor, perhaps refined while he was on the staff of the *Princeton Tiger*, a humor magazine. He went on to obtain a masters degree in nuclear physics from Berkeley in 1962.

Jim transferred to Harvard for his doctoral work in astronomy, becoming Carl Sagan's first graduate student. After graduating from Harvard in 1965 and spending a few years at the nearby Smithsonian Astrophysical Observatory, Jim moved to Cornell in 1968 where Carl had become a professor of astronomy. During this time Jim began working with Ray Reynolds, whom Jim had met at a Gordon conference. Ray convinced Jim to move to NASA's Ames Research Center in 1970. Jim remained at NASA Ames for the rest of his life. He had a major influence on the planetary science group at Ames not only through his intellectual achievements, but also by recognizing and attracting talented young scientists and forming research groups in a broad range of planetary sciences.

Jim's thesis dealt with the greenhouse effect on Venus, a subject which continued as a major area of research throughout his career. During the late 1950s microwave observations showed that Venus might have a surface temperature near 600 K. However, there were debates about the interpretation of these data. The high microwave temperatures might have originated from Venus's ionosphere rather than from its surface or been due to nonthermal emission processes in the atmosphere, for example. Studies of limb darkening by Mariner 2 in 1962 showed that indeed the microwave emissions came from the surface of Venus. By 1967, Venera 4 entry probes, the Mariner 4 flyby, and earth-based radar studies all confirmed a high surface pressure and temperature for Venus. During the 1960s Jim worked on a number of issues concerning Venus, but the most enduring were his development of increasingly sophisticated models for calculating the temperature profile and radiative properties of the atmosphere of Venus.

He first thought that the greenhouse might be dominated by water vapor, as did several other researchers.

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Jim developed methods to handle the wavelength dependence of the water opacity, which he expanded to include carbon dioxide and other gases as more was learned about the atmosphere of Venus. Jim and Carl originated a two-stream technique for calculating the scattering by clouds in the atmosphere of Venus. This technique was widely copied and dominated calculations of scattering in the atmospheres of Earth and the other planets for more than a decade until computers became fast enough to allow more accurate techniques to be used. Numerous papers published in 1994 concerning Venus used derivatives of this technique to perform data analysis. Jim Pollack and his co-workers also compiled a set of infrared optical properties for water and ice. These optical constants were used by many investigators studying a wide range of solar system objects. This work began one of Jim's recurrent interests: compiling accurate data on wavelength-dependent refractive indices of solids, gases, and liquids. These data formed the foundations of his many detailed theoretical models.

For example, during the early 1970s Jim's fascination with the composition of the clouds of Venus led to his analysis of their near-infrared spectrum using data from a jet aircraft based at Ames. He showed conclusively that the clouds were composed of sulfuric acid. During this time Jim and his co-workers began to develop models of the dynamics of Venus. The 1978 Pioneer Venus entry probe obtained profiles of the thermal, radiative, and constituent properties of the atmosphere of Venus, allowing Jim to make comprehensive calculations of the vertical thermal profile. He showed that a greenhouse effect was indeed the source of the high surface temperature, that CO_2, not water was the dominant source of opacity in the atmosphere, and that the vertical temperature gradient, including shallow regions of instability, could be understood radiatively.

Jim based the last of his more than 40 papers about Venus on the recent Galileo flyby. Probing deep into the atmosphere at near-infrared wavelengths, and using his formidable skills at interpreting radiative transfer through nongray multiple scattering atmospheres, Jim was able to place tight limits on the abundance of water in the atmosphere of Venus and to determine the vertical profiles of several other gases. These analyses resolved decades of debate about the water abundance and the vertical profiles of sulfur-bearing gases such as OCS in the atmosphere of Venus.

Shortly after graduating from Harvard, Jim became interested in understanding temporal variations in the albedo of Mars, which some had ascribed to seasonal changes in vegetation on the surface. Jim and Carl Sagan suggested that the albedo variations were more likely due to planetary-scale dust storms altering the transmission of the atmosphere of Mars. Using considerations of atmospheric scattering, they also showed that Mars must have topographic relief on the order of a scale height, which they had also found from radar studies of Mars. These studies initiated another of Jim's lifelong interests, the climate and meteorology of Mars, which he characteristically pursued in every possible way. Over about 30 years he collaborated with a broad range of planetary scientists, writing more than 75 papers dealing with Mars.

Jim's early work on Mars dealt largely with atmospheric dust. In the 1970s Jim and several collaborators established a large wind tunnel at NASA Ames in order to determine the wind speeds needed to lift dust from the surface of Mars. Through these experiments they developed theories for dust lifting in planetary atmospheres. Inspired by theoretical simulations of the winds on Mars by Conway Leovy and Yale Mintz, Jim became interested in the dynamics of the atmosphere of Mars. He and his collaborators daringly and successfully applied a general circulation model, including topography, to estimate the winds at the Viking Lander sites. Jim then used the Viking Lander cameras to measure the optical depth of dust and to monitor the rise and fall of the dust opacity during several dust storms. Inspired by his success with the wind field calculations for Viking Lander sites, Jim initiated a project to create a Martian General Circulation Model which included dust opacity and other important features of the present and past climates of Mars. Jim and his collaborators expanded this model until it became a very sophisticated simulation of the Martian atmosphere. The model has provided many insights into the polar heat budgets, the role of dust in modifying the vertical and horizontal temperature structure on Mars, and the path that future balloons might follow if launched into the Martian atmosphere. This group effort, brought together by Jim and guided by him, is one of many which will survive him and continue to influence planetary science for years to come.

Another major theme of Jim's work involved the outer planets. He originally moved to NASA Ames to study the formation of the giant planets. Jim and his collaborators created the first detailed models of the early stages of Jupiter's formation. These models treated Jupiter like a small star. For the first time, accurate calculations of the total luminosity of these young hot objects could be made. The luminosities are prodigious—100 times that of the young sun itself for short periods of time. The model was used to explain the different compositions of the moons of Jupiter and Saturn. Jim proposed that the inner moons formed in a region which was too close to the hot, glowing proto-Jupiter for ice to persist. As a consequence the inner moons are rocky, and the outer ones icy, in parallel with the composition of planets in the solar system.

Jim's interests in the early evolution of the Jovian system transferred directly to the Saturnian system, with its even more impressive array of companions. It was timely because the first strong radar echoes from Saturn's rings were observed in 1972; they caused a small sensation because the rings emitted no observable energy at centimeter wavelengths and were thought to be composed entirely of particles too small to emit microwaves. A flurry of theories emerged involving direct backscatter from corner reflectors, perfect spheres, or even large jagged metal objects. Jim correctly realized that perfectly normal ice particles, if they were a wavelength or even several in radius, could resolve these seemingly inconsistent observations. Our intuition about scattering by realistic nonspherical particles was challenged by this problem, and Jim led the development of an approximate theory, constrained by lab measurements, to replace the idealized spherical particle calculations. This study and subsequent work with collaborators led to conclusions about the particle size distribution (centimeters to meters in radius) that were verified by Voyager observations. The conclusion that the ring particle material had to be unusually poor in anything else but water ice, diverging from normal cosmic composition, was a big puzzle. The scenario Jim put forth at the time may not be correct in detail but is still stimulating to consider, and the puzzle remains. His interests in planetary rings continued over the years, and he coordinated the planning of Galileo observations of the Jovian ring.

Jim's interests in the early evolutionary history of the giant planets continued throughout the Voyager exploration of the outer solar system. His detailed scattering and thermal structure analyses of the atmospheres of Jupiter, Saturn, and Titan were motivated largely by the need for a highly accurate constraint on the global heat balance of these planets. Voyager measurements over all angles could determine both the total thermal emission and the total reflected solar energy. The current global heat balance (specifically, the excess internally radiated heat) is a predictable remnant of the primordial luminosities, from Jim's luminosity and cooling histories. Thus, the birth-state of the gas giants could be better understood once the scattering properties of these planets were carefully tied down.

Careful radiative transfer modeling of a variety of observations led Jim and collaborators to a measurement of the optical constants of the Titan haze, which paved the way to the conclusion that the Titan aerosol was a form of organic smog, similar to the tholins produced in laboratory experiments. The surface temperature and pressure of Titan were unknown prior to Voyager. After Voyager discovered a slight greenhouse effect, Jim and collaborators demonstrated how the observed thermal structure could be maintained by a combination of gaseous and particulate scattering and absorption.

The thread of Jim's questioning about the outer planets is clear, and it leads directly back to the origins of the planets. Overall, his work represented a unique blend of rigor (in his radiative properties and modeling work) and imagination (in his prolific building of planetary origin scenarios). In his later years he became increasingly involved with studies of the radiative transfer and fluid dynamics of the primarily gaseous protoplanetary nebula itself, and of others like it. It seemed clear that when the first little blue planet was found around another star, Jim would be modeling its atmospheric structure.

Jim was interested in the origins of all planetary atmospheres. With a long series of talented young scientists he studied the implications of noble gas abundances for the origin of planetary atmospheres, the mechanism for the loss of water from the atmosphere of Venus, the impact-generated atmospheres in the outer solar system, and the relationship between the rising solar luminosity over geologic time and declining carbon dioxide concentrations driven by geological recycling of carbonates on the terrestrial planets. One of Jim's most interesting papers on the origin of terrestrial atmospheres included an estimate of the short time period that Mars might maintain a dense carbon dioxide atmosphere against carbonate formation in the presence of liquid water.

Jim's greatest successes and some of his most trying problems came in the area of climate changes on the terrestrial planets. Jim's interest in Martian dust led him to look for terrestrial problems to which he might apply his expertise. He decided that the effects of volcanoes on climate might be useful to pursue. At nearly the same time that he became interested in volcanoes and climate, the Mariner 9 spacecraft observed both ancient river beds and polar laminae on Mars which resembled sedimentary layers on earth. Suddenly a second planet had a climate history.

Jim and his collaborators began working on the optical constants of a number of rocks in anticipation of using them both to understand the composition of Martian dust and to simulate volcanic clouds on Earth. By about 1975 they realized that volcanic clouds were composed of sulfuric acid, not rock dust. Although this composition was not accepted by volcanologists and other climatologists until the 1980 and 1982 eruptions of Mount St. Helens and El Chichon, it prompted them to encourage Dudley Williams and his co-workers at Kansas State University to find the optical constants of sulfuric acid. Here fate played a trick on Jim. Louise Young heard about the work on sulfuric acid optical properties. Andy Young assumed that Jim was interested in the Venus clouds. This assumption led Andy and Louise to look into sulfuric acid as a component of the clouds of Venus and allowed them to beat Jim with this discovery.

By the mid-1970s Jim and his collaborators had written a number of papers on volcanic clouds. They were the first to show that such clouds could heat the earth's stratosphere by absorbing infrared radiation. They were also the first to show with realistic optical properties and considering both solar and infrared wavelengths that such clouds could cool the earth's surface by an amount close to that observed after eruptions.

Jim was not content to merely theorize about volcanic eruptions. He initiated a large experimental effort to explore such clouds using the U-2 and Convair 990 aircraft then based at NASA Ames. Jim defined the outstanding questions to be addressed in this area of climate research and established a program to study them under the newly initiated NASA climate program. He searched out those researchers who could build instruments to answer the outstanding questions and in doing so helped develop the careers of a number of terrestrial researchers.

With the eruption of Mt. St. Helens, and then of El Chichon, this work in developing an instrument payload for the aircraft paid off. Jim led a number of expeditions with each aircraft to obtain data on the clouds. This work clearly showed the importance of sulfuric acid in volcanic clouds, it produced evidence of new particle formation in the atmosphere, and it defined the sizes of volcanic particles and their optical properties. Coincidentally, as OCS fell out of favor relative to SO_2 as the sulfur-bearing gas that supported the clouds of Venus, the experimental studies that Jim led produced just the opposite conclusions for the nonvolcanic particles in Earth's upper atmosphere.

During the late 1970s polar stratospheric clouds were observed by satellite and were found to be much more abundant than anyone expected from ground-based instruments. Jim wrote one of the first papers describing their potential effects on the earth's polar heat budget. At this time Jim and several others proposed to NASA Headquarters that a major expedition with the U-2 and Convair 990 be sent to the tip of South America to investigate the polar stratospheric clouds. Jim's interest was mainly in possible climate effects of these clouds. However, the group also knew that there were inconsistencies in the nitrogen budget of the polar regions. When the formal proposal to study polar stratospheric clouds was sent to NASA Headquarters, the British Antarctic survey had discovered that something was wrong with the ozone over Antarctica, but had not yet announced this finding. NASA Headquarters rejected the proposal saying that polar stratospheric clouds could not possibly be of enough interest to merit such an aircraft-based study. Within 4 years just such a study was launched on an emergency basis to investigate the ozone hole, which indeed is caused by polar stratospheric clouds in part because of their effects on the nitrogen budget through condensation.

Although Jim did not participate in studies of the ozone hole, the momentum he generated in the 1970s propelled him toward two of his most interesting projects. When the Alvarez group first discovered that an asteroid impact with Earth may have caused the extinction of the dinosaurs, Jim was quick to realize that this group of collaborators was well poised to address this problem. The resulting calculations showed that any dust clouds generated by the impact would clear within a few months, but that such clouds would reduce light levels at the surface to below the threshold for vision, which is far below the threshold for photosynthesis to maintain plants, and would lead to precipitous declines in surface temperature.

This work was quickly followed by studies of nuclear winter. Inspired by the work on the impact-generated dust cloud, Brian Toon and Rich Turco began to consider the amount of dust that might be lofted by nuclear weapons and discovered it could have significant climate effects. Soon after that Paul Crutzen of the Max Planck Institute and John Birks of the University of Colorado pointed out the great amounts of smoke that might come from fires set by nuclear explosions in wooded areas. Turco extended this idea to fires set in urban areas which turned out to be the dominant source of optically thick debris following a nuclear attack. Carl Sagan had been studying nuclear war independently. Carl had a long-term interest in nuclear wars because of their possible role in limiting the spread of life in the universe, and he had made nuclear war part of the final episode of his TV series, *Cosmos*. He and Jim traced their nuclear winter work back to the climatic change on Mars following the 1971 dust storm, as observed by Mariner 9. Jim was at the center of the various groups making these minidiscoveries and soon organized them into a team effort involving Turco, Toon, Ackerman, Pollack, and Sagan to produce the TTAPS paper on nuclear winter.

Jim was appalled at the thought of nuclear war and found it a difficult subject to work on, as did all of the TTAPS group. There was also considerable opposition to conducting this work from NASA and other government agencies. Despite this government opposition, and considerable negative political attacks, the group persevered. Eventually numerous independent scientific bodies which reviewed the work, including the U.S. National Academy of Sciences and the International Council of Scientific Unions, came to the conclusion that the nuclear winter work was fundamentally sound science. This work undoubtedly received more press coverage than any other in which Jim was involved. The high point of it to Jim was the response from his family, who felt that he had at last done something useful.

Jim's extensive involvement with the Earth's climate led him to continually search for parallels between the Earth and the planets. He received the Kuiper Prize from the Division for Planetary Sciences in 1989 for his work on climate change on the planets. He contrasted the greenhouse effects of Mars, Venus, and Earth and compared the divergent evolution of their atmospheres to understand why the planets had developed such different climates. He explored orbital drives for the shorter term climate changes on Mars and compared these with the similar causes of ice ages on Earth. Jim was one of the first to realize that the polar laminae on Mars might be caused by preferential deposition of dust in the polar regions due to condensation of water and CO_2 at high latitudes during winter. He ascribed the layers in the laminae to variations in the frequency of dust storms due to large modifications in the surface pressure of Mars which were in turn driven by changes in the polar heat budget as the orbit of Mars slowly evolved.

One of Jim's last papers was jointly authored with Carl Sagan, with whom he began his career. Together in a 1993 paper titled "Planetary Engineering" they speculated on terraforming the planets to make them more habitable. The paper includes ideas to reform a future polluted Earth.

Jim's kindness and gentleness were as extraordinary as his scientific accomplishments. He was always looking ahead to the next challenge and had many plans for future projects. It is a great loss to planetary science that he will not be able to fulfill these dreams. However, he leaves behind a legacy of important published works, of widely used scientific techniques, and most important of people whose careers he developed and who populate research groups he initiated that will continue to pursue his visions.

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Jeff Cuzzi
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