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FRED LAWRENCE WHIPPLE
1906–2004

A Biographical Memoir by

GEORGE FIELD

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Fred L. Whipple

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November 5, 1906–August 30, 2004

BY GEORGE FIELD

THE PERSON

WHEN HALLEY'S COMET APPROACHED THE Sun in 1910, Fred Whipple was three years old. When it approached again in 1986, he was 79. By then Fred had a brilliant career as an astronomer and scientific administrator behind him. Over the course of those years he had become the world's leading authority on the nature of comets. His pair of papers on the subject in 1950-1951 had become classics, and the model of comets that they propounded was fully confirmed by space probes that were sent to study Halley's comet in 1986.

I first met Fred in 1955 when I arrived at the Harvard College Observatory (HCO) as a postdoctoral fellow. At that time he was busy organizing the Smithsonian Astrophysical Observatory (SAO), so I did not get to know him well. When I returned to Harvard in 1972, we met in his office, surrounded by models of astronomical instruments that he had designed and built. At that time I was a candidate for the directorship of HCO, which is located in the same group of buildings as SAO, and Fred welcomed me graciously.

The Smithsonian Astrophysical Observatory was a big institution, the home of many diverse astronomical projects, almost all of them initiated by Fred since becoming the SAO director in 1955. His quick intelligence was obvious. His dedication to science became apparent as he described his research on comets. I shared his delight in being able to estimate the magnitude of all sorts of things, from costs of building telescopes to the sizes of astronomical objects. Despite his administrative responsibilities, he was directly involved in interpreting observations of comets. He enthusiatically told me of his latest ideas, and how they were faring. This was a style everyone recognized as Fred's. If colleagues or others were ignorant of comets, he would rapidly introduce them to the subject, and get them interested.

My wife, Susan, caught his enthusiasm, and came to admire and love Fred, finding him enormously entertaining. When he and his wife, Babette (also called "Babbie"), first entertained us at their home, we were startled to find a huge kinetic painting on the wall in the dining room, which morphed from one color pallet to another in ever-changing patterns. In their living room a variety of sculptures, surrounded by flowering plants, set the stage for a sweeping view of Boston. Looking down into the yard, we saw a lovely rose garden tended by Fred.

Talk on those evenings involved astronomy, politics, psychology, and of course, our children. Babbie has a Ph.D. in psychology, and her thoughts on the love and care of children were always worthwhile.

Fred was an energetic and optimistic person. He had played tennis at the University of California, Los Angeles, and loved to do so whenever he could. Unfortunately, he was struck by polio when he was younger, leaving him with one leg shorter than the other, and thus unable to compete at his skill level. But he noticed that there was space for a tennis court on the observatory grounds, and was one of the people who helped build it. Were it not for his disability, he might have been the Harvard College Observatory tennis champion every year.

Fred biked to work six days a week throughout the year, rain or shine. The round trip was 5 miles on busy streets, but Fred kept biking into his nineties. When illness overtook him, his doctors suggested that he walk a mile or so every day to keep his leg muscles working. He walked around the block in Cambridge until he could no longer do so, and then began to walk the corridors of the observatory. Then in his middle nineties, he would walk by the seminar room where we were working, and we all thought, "There goes one tough guy."

Fred loved scuba diving at his and Babbie's home on Great Camanoe Island in the British Virgin Islands. He was known among the divers there as an incorrigible explorer. No sooner would a group of divers reach the bottom, than Fred was off on his own, far from any help should he need it (personal communication, J. Giacinto of Dive BVI, Virgin Gorda, British Virgin Islands, May 31, 2006). For those visitors who did not dive, Fred graciously introduced them to snorkeling, a much less strenuous sport, but still a thrilling way of seeing the varieties of fish and coral that are available.

When he addressed the staff of the Smithsonian Astrophysical Observatory, he did so with a twinkle in his eye. Invariably the staff ended up smiling and laughing. On such occasions he would be wearing a tie from his large collection of comet designs. He ate lunch at Armando's Pizza, where he became such a fast friend of Armando that Armando treated all astronomers who came in as friends of his also. No doubt Armando's attitude toward Fred was affected by the fact that when Fred returned from a visit to the Vatican, he thoughtfully gave to Armando a medal that had been blessed by the Pope.

One of Fred's famous habits was to ask that jam be on the table at home at all times, whatever was being served for dinner. Another was his interest in gadgets. There were several hard-to-solve puzzles in the living room, and I recall his pleasure in demonstrating to me a new acquisition, a shaver activated by a wind-up spring. Somewhat surprising was his fascination with occult phenomena, such as clairvoyance and astrology; he concluded that classical astrology has no scientific basis. His own religious beliefs appeared in an unpublished paper titled *My Conversion to Atheism.*[1]

Fred appreciated the many honors bestowed upon him. He bore them lightly but was justly proud of his accomplishments. In particular, I recall how happy he was to have been chosen as the UCLA alumnus of the year in 1976. In his published interview with Ursala Marvin, a senior scientist at the Smithsonian Astrophysical Observatory, he was reminded that in the year 2000 he had been named a "living legend" by the Library of Congress. Fred's comment was, "I don't feel very legendary, but I am pleased to be still living."[2] Although he was intolerant of persiflage and would dismiss it with a wave of the hand, he chatted easily with everybody, earning the respect of the entire staff of SAO.

THE SCIENTIST

From 1924 to 1927 Fred attended UCLA, where he obtained a B.A. degree in mathematics. At UCLA he took an astronomy course with Frederick Leonard, which he found to be "extremely interesting."[3] He decided to pursue astronomy as a career, but because UCLA had no astronomy department at the time, in 1927, he moved up the coast to the University of California, Berkeley, where he obtained a Ph.D. in astronomy in 1931. Fred studied under A. O.

Leuschner, whose work centered on celestial mechanics, including the orbits of comets.

Fred's membership in the Berkeley astronomy department afforded him access to the Lick Observatory on Mount Hamilton in California, one of the leading observatories in the United States. Within a short time Fred became an accomplished observer. When he completed his Ph.D. in 1931, he was offered a research position at Harvard College Observatory (HCO) by its director, Harlow Shapley. The astronomy department was in the HCO building, and Fred became a faculty member there. Fred demonstrated a strong interest in comets by examining 70,000 plates in the HCO collection of astronomical photographic plates for serendipitous images of comets. He was successful in this search, finding six new comets, for each of which he was awarded the Donahoe Medal of the Astronomical Society of the Pacific.

In this period he was aware of the claim of Ernst Öpik, a famous Estonian astronomer whom Fred admired greatly, that contrary to common opinion not all meteors follow closed orbits around the Sun. Öpik believed that some meteors follow a hyperbolic trajectory that comes in from outer space and goes out again. Meteors are objects that often are ejected by comets and are later seen entering Earth's atmosphere when Earth crosses the orbit of a comet. Thus, studies of meteors have implications for the study of comets. To investigate Öpik's claim, Fred set up a network of cameras that could track meteors as they entered the atmosphere. This called for a fast camera with a wide field of view, with a rotating shutter that would interrupt the trail of the meteor as it streaked across the sky, enabling one to calculate its velocity. Viewing it with cameras located at different points enabled its geometric path to be defined. The results were clear: None of the meteors observed follows a hyperbolic orbit. Öpik disagreed with this result for many years, but in 1959 wrote Fred a letter apologizing for his stubborn opposition.[4]

The Harvard Meteor Project succeeded in tracking thousands of meteors. The physics of the entry of a meteor into the atmosphere depends upon both the atmospheric density at the observed altitudes and the physical properties of the meteor. Separating the two effects in the data was finally accomplished. One important result indicated that the density of most meteors is less than that of water, suggesting a spongy ice composition. Because at least some meteors are known to originate from comets, this raised the possibility that comets also contain ice, an idea that Fred developed much further in two famous papers to be considered more fully below. A very useful result of the meteor project was a table of the density of Earth's atmosphere at altitudes above 100 kilometers, data hard to obtain by other methods.

Fred harbored the hope of measuring the track of a meteorite, that is, a solid body large enough to survive entry into the atmosphere and reach the ground intact (known as a "fall"). Such a meteorite could be analyzed in the laboratory to find its age, type, and composition. By observing its track through the atmosphere one could infer where in the Solar System it originated. To accomplish this Fred established another network of telescopes, this time 16 stations spread over the Great Plains, called "The Prairie Net." A number of near misses ensued until January 4, 1970, when a participating scientist drove out to look for a meteorite in the neighborhood where its track indicated it had fallen. There was snow on the ground, perhaps favorable to spotting a meteorite. In Lost City, Oklahoma, there was a rock in the middle of the road that turned out to be a meteorite.[5] Its orbit indicated that it originated in the asteroid belt, well known to astronomers as the home of countless solid bodies believed to be fragments of a long-gone planet. The Lost City meteorite had a high density, not the low density associated with meteors. Fred realized that because of their low densities, meteors are more likely to burn up in the atmosphere, and are therefore unlikely to reach the ground.

In 1946 Fred joined the Rocket and Satellite Research Panel, a group of scientists charged with advising the Naval Research Laboratory on the best ways to acquire information about space, using rockets acquired from Germany after World War II. The panel also considered the future use of artificial satellites, enabling observations of Earth and its surroundings, and the use of orbiting telescopes, pointing away from Earth, allowing astronomical research. This panel played an important role in space research before the establishment of NASA in 1958. In 1952 a series of articles originally printed in *Collier's* magazine were published as a book, *Across the Space Frontier*.[6] With articles by Wernher von Braun and Willy Ley, this book served to inform the public about the possibilities of science in space. Fred authored a chapter titled "The Heavens Open," which described how telescopes in Earth orbit could open the whole electromagnetic spectrum to observation, including ultraviolet radiation, X rays, and gamma rays.

With his experience in tracking meteors, Fred pointed out to the panel that a network of telescopes should be established to track artificial satellites and compute their orbits. When the National Aeronautics and Space Administration was created in 1958, Fred was ready to take on the responsibility of tracking scientific satellites if and when they should be launched. But that is another story to which I will return below.

Without doubt, Fred's most significant contribution to science was the pair of papers he published in 1950 and 1951 in the *Astrophysical Journal*, titled "A Comet Model."[7] In them he used what he had learned about comets from a study of their orbits, in particular, information gleaned from the fact that the orbits often do not conform exactly to the predictions from strictly Newtonian gravitation. Specifically, both Halley's and Encke's comets deviated from their expected arrival times. Fred realized that material that leaves the comet nucleus to form the fuzzy head must, by the law of action and reaction, exert a force on the nucleus, effectively forming a rocket. Fred calculated the magnitude of the force, drawing on the chemistry of the material, the physics of evaporation, the theory of heat transfer into the nucleus, and the properties of frangible material. Comparing his calculations with the observed deviations of orbits from the Newtonian values, he was able to fit the data only if the comet's nucleus were composed of ices of water and other volatile materials, forming a fluffy matrix in which mineral grains were embedded. His theory fits the data, and thus began the modern era of research into the nature of comets. Fred referred to his model as the "Icy Conglomerate Model," but the press quickly coined the term "dirty snowball," and Fred became famous as its originator.

The nucleus of a comet is too small to image from Earth, so for years Fred's model provided the best concept of what a comet really is. In 1986 mankind got its first look at the nucleus of a comet when Halley's comet approached the Sun. The European *Giotto* mission to Halley's comet found that its size, composition, and surface properties agreed with Fred's 1950 model.[8] In paper II of the series Fred compared his model with what he and others had learned about meteor streams associated with the tails of known comets. As indicated above, many meteors required a low density to fit the observations, agreeing with Fred's conclusion that the nucleus of a comet is made primarily of ice.

The Stardust mission to Comet Wild 2 returned a sample of the comet to Earth on January 15, 2006. Crystalline silicates have been found in the particles that have been analyzed.[9] It will take years to completely analyze the data, and unfortunately, Fred did not live to see it. Babbie Whipple writes, "Fred was deeply interested in this project, which would bring back to Earth samples of the material that formed the Solar System, dating from 4.5 billion years ago, material he believed would answer many big questions as to the source of life on Earth. For example, did it originate in interstellar space (a theory supported by Sir Fred Hoyle) or did it originate here?"[10]

Fred was both an observational astronomer and a theorist, a rare combination nowadays. As time went on, he spent less time at the telescope and in the Harvard Collection of Astronomical Photographs, and more time analyzing data and proposing and testing theoretical models. He was always involved in advancing the art of instrumentation, through endeavors such as the Harvard Meteor Project and the Prairie Net.

Fred choose to focus his research on comets and meteors. Other leading astronomers of his generation chose to study stars and galaxies. Although Fred began his career analyzing cometary orbits, his Ph. D. thesis at Lick Observatory, supervised by Donald Menzel, was on variable stars, and when he arrived at Harvard in 1932, he started to work on galaxies. But "I soon learned that [Harlow] Shapley considered galaxies to be his own topic and he did not care to have any competition."[11] As new techniques were developed, the physics of planets and comets posed challenging questions.

Fred anticipated this development by focusing on the physics of comets: Their tails could be studied with current telescopes, and the meteors they left behind could be studied as they fell toward the ground.

Everything changed in 1958 when President Kennedy decided to send a man to the Moon. Up until then few scientists studied the Moon. Suddenly large sums were available from NASA to study its surface and plan experiments that astronauts would carry out. NASA's contractor at Caltech, the Jet Propulsion Laboratory, initiated unmanned missions to the Moon, Venus, and Mars, and later to the outer planets, and still later to comets and asteroids. It does not take a rocket scientist to see that this activity would be a boon to Solar System science. When a spacecraft encountered Halley's comet in 1986, Fred lived to see the object of his 1950 research become the target of a major scientific and engineering effort.

It has become increasingly apparent that there are excellent scientific reasons for studying comets as part of an effort to understand the formation of the Solar System. Moreover, many planetary systems beyond our Solar System have been found recently. From the time that Immanuel Kant formulated the nebular hypothesis, astronomers have conjectured that the planets formed from a disk of gas and dust orbiting the Sun. Self-gravitation acting on an interstellar cloud drew the material of the Sun together, but any material that had large angular momentum was left behind to form a disk. Study of such disks orbiting other stars has proved that this idea is correct.[13]

Comets provide an important test of this picture. Their orbits, unlike those of planets, do not lie close to a single plane, and do not all revolve in the same direction. They travel vastly larger distances than the planets do. Fred showed that they are composed largely of ices, which could not survive if they were formed close to the Sun. Thus, they may have predated the formation of the Sun, and thus, may represent a sample of interstellar matter that escaped incorporation into the Sun or the planets. I believe with Fred that the study of a comet sample in the laboratory is of greatest importance.[14]

THE ADMINISTRATOR

Many astronomers probably knew of Fred as the director of the Smithsonian Astrophysical Observatory. How did it come about that SAO is collocated with Harvard College Observatory? SAO is part of the Smithsonian Institution in Washington, D.C., best known as the quasi-governmental organization that runs museums like the Natural History Museum and the National Air and Space Museum. But it also supports research on many topics, including meteorites, the history of art, tidal estuaries, and at SAO, astrophysics.

It all started when Samuel P. Langley was appointed secretary of the Smithsonian Institution in 1887. A former physics professor, he was interested in measuring the infrared radiation from the Sun—a major contribution to the total solar energy—and in 1890 established a laboratory for that purpose called the Smithsonian Astrophysical Observatory, or SAO, with Charles C. Abbott as the director. Using ground-based instruments, Abbott measured the energy emitted by the Sun, and concluded that it varies over time by as much as 1 percent. Measurements from spacecraft have since shown that the emission does indeed vary, but only by about 0.1 percent. Abbott succeeded Langley as secretary of the Smithsonian, continuing to support SAO as a bureau within the institution, funded under the annual federal appropriation to the Smithsonian.

When Leonard Carmichael became secretary in 1953, he wanted to expand SAO's mission to encompass the major fields of astrophysics and discussed this idea with Donald Menzel, the director of the Harvard College Observatory (HCO).[15] Menzel suggested that SAO be linked with a university in Washington but later concluded that HCO would be a better match. When he proposed this to his HCO colleagues, including Fred Whipple, they responded enthusiastically. In 1955 Harvard University and the Smithsonian Institution signed an agreement to move SAO to Cambridge, and Fred was appointed director of SAO, a federal civil service position, while remaining a Harvard professor.

What happened next was unexpected. As a member of the Rocket and Satellite Research Panel, Fred had proposed a plan to establish a network of stations to track any artificial satellites of Earth that might be launched. Various nations, including the United States and the Soviet Union, proposed to launch such satellites in support of the International Geophysical Year, sponsored by many nations in 1957 to improve our knowledge of Earth. Fred proposed to the U.S. government that SAO establish an optical satellite tracking network. This required a rapid expansion of SAO staff from 5 to 500. Overnight SAO became the largest observatory in the United States.[16]

As luck would have it, the Soviet Union surprised the world by orbiting *Sputnik I* on October 4, 1957. The automated SAO network was not ready to track *Sputnik* until October 17, but thanks to Fred's foresight, SAO had set up a backup network staffed by volunteers with small telescopes and stopwatches who recorded enough information for SAO to find *Sputnik*'s orbit within four days. Fred's photograph appeared on the cover of *Life* magazine when the press learned of this feat. The Satellite Tracking Network was soon up and running, and providing precise information to

NASA. The network continued into the 1970s, providing information on the shape of Earth and the density of its atmosphere.

Fred was very interested in using space technology to put a telescope into space. Under contract with NASA, he organized the first Orbiting Astronomical Observatory (OAO), which successfully reached orbit on December 7, 1968. Unfortunately, its batteries failed, and little data was obtained. However, the two follow-on missions OAO II and III succeeded in gathering large amounts of information about both stars and diffuse matter between the stars.

Fred always aspired to have a ground-based observatory at SAO. Recognizing that the skies of Massachusetts are too brightened by city lights for it to be located nearby, he settled on a site at Mount Hopkins, Arizona. Believing that it was important to have an instrument there as soon as possible, in 1968 he commissioned a telescope of novel design to detect the tracks of incoming high-energy gamma rays by means of the Cerenkov radiation from the particles in their wake. This facility succeeded in detecting astronomical sources of such radiation, one of which turned out to be a massive black hole. Believing that understanding the source of such radiation may require new physics, physicists are now constructing a number of similar telescopes.

In 1970 Fred also built a 1.5 meter optical telescope on Mount Hopkins in collaboration with the University of Arizona. This telescope was used to conduct the first major red shift survey of galaxies in 1983.[17] The observed red shifts of galaxies were used with Hubble's law of the expansion of the universe to find the galaxies' positions in three dimensions. When a slice of the sky was plotted, it was apparent that galaxies form walls and filaments surrounding apparent voids, a great surprise at the time. Theorists have now reproduced these results by using computers to follow small perturbations in the density of matter in the Universe as they grow by mutual gravitation to form galaxies. Thus, one of the great discoveries in cosmology was made with a telescope that Fred initiated.

Fred wanted to build a larger telescope. He concluded that to keep costs down, one should use many smaller mirrors, each focused on the same point, rather than a single large one. Thus was born the MMT, or Multiple Mirror Telescope, a joint SAO-University of Arizona project, completed in 1979. In it, six 1.8 meter mirrors were combined to form the equivalent of a single 4.5 meter telescope, at the time one of the largest in the world. The principle having been established, two 10 meter Keck telescopes on Mauna Kea were later built, each with 36 mirrors. Fred could be proud of his participation in this revolution in telescope design.

BIOGRAPHY

Fred was born on November 5, 1906, in Red Oak, Iowa. In his words, "As an Iowa farm boy, I contracted a case of polio, and it prevented me from becoming a professional tennis player. When I entered UCLA, it was my main ambition to excel at tennis . . . but I never made the tennis team."[18] Before attending UCLA, Fred moved with his family to Long Beach, California in 1922, where he attended the Long Beach High School and worked in his family's grocery store. In 1923-1924 he attended Occidental College and from 1924 to 1927 he attended UCLA, where he received a B.A. degree in mathematics. When he decided to pursue astronomy as a career, he enrolled in the graduate program at UC, Berkeley, obtaining a Ph.D. in astronomy in 1931. His thesis on variable stars was supervised by Donald Menzel, who at the time was an astrophysicist on the staff of the Lick Observatory of the University of California, and who later became director of the HCO. Fred was invited by Harlow Shapley to join the staff of HCO and to take charge of its Oak Ridge Station; appointed instructor in the astronomy department, he moved up through the ranks, attaining the rank of professor in 1950 and becoming department chair in 1949. He was appointed Phillips Professor of Astronomy in 1968, serving in that position until his retirement from the faculty in 1977. His colleagues at Harvard included Shapley, Bart Bok, Cecilia Payne-Gaposhkin, and Donald Menzel. His first marriage, to Dorothy Woods, in 1928, ended in divorce in 1935; they had one son, Earle Raymond Whipple. Fred married Babette Frances Samelson in 1946, and they had two daughters, Dorothy Sandra ("Sandy") Whipple and Laura Whipple.

Fred served on advisory committees to the House Committee on Science and Astronautics of the U.S. Congress, to NASA, the International Geophysical Year, the National Research Council, the U.S. Air Force, the National Science Foundation, the National Advisory Committee on Aeronautics, the Office of Naval Research, and the University Corporation for Atmospheric Research. He was a member of the International Astronomical Union, the International Scientific Radio Union, the Committee on Space Research, the International Astronautical Federation, and the International Academy of Astronautics.

Fred was a member of many honorary societies, including, of course, the National Academy of Sciences, to which he was elected in 1959. Others included the Royal Society of Arts (London), the American Academy of Arts and Sciences, and the American Philosophical Society. His professional societies included the American Astronomical Society, of which he served as vice-president from 1948 to 1950, the American Astronautical Society, the American Geophysical Union, the American Institute of Aeronautics and Astronautics, the American Rocket Society, and the American Standards Association.

His many honors included Donohoe medals (in 1933, 1934, 1937, 1941, 1942, and 1943), a Presidential Certificate of Merit (for "Window," a radar countermeasure used by the Air Force in World War II), the J. Lawrence Smith Medal of the National Academy of Sciences, the Space Flight Award of the American Astronautical Society, the Distinguished Federal Civil Service Award by President John F. Kennedy, the NASA Public Service Award, the Leonard Medal of the Meteoritical Society, the Kepler Medal of the American Association for the Advancement of Science, the Joseph Henry Medal of the Smithsonian Institution, the Gold Medal of the Royal Astronomical Society, the Kuiper Award of the American Astronomical Society, the Bruce Medal of the Astronomical Society of the Pacific, the Henry Norris Russell Lectureship of the American Astronomical Society, and finally, the establishment of the Fred L. Whipple Lectureship of the Planetary Division of the American Geophysical Union.

From simple beginnings Fred became a world authority on the nature of comets. When he started his career, many astronomers were ignorant of the subject. Now, largely as a result of Fred's work, we realize that comets carry unique information about the formation of the Solar System. Fred was an observer, an analyst, and a theorist, scientifically active in spite of heavy administrative commitments. He carried his physical disability without complaint, and he continued his commitment to rational thinking into every sphere he encountered. In short, he was a person that every scientist can admire.

IT IS A PLEASURE TO acknowledge conversations with Ursula Marvin, my colleague at the Smithsonian Astrophysical Observatory. Brian

Marsden at SAO graciously helped me to select Whipple's most significant works, reviewed a draft of the memoir, and made many helpful comments. I am indebted to Babbie Whipple for her comments on the manuscript.

NOTES

1.F. L. Whipple. My conversion to atheism. Personal copy of G. Field.
2.U. B. Marvin. Oral histories in meteoritics and planetary science. XIII. Fred L. Whipple. *Meteorit. Planet. Sci.* 39(suppl.)(2004):A199-A213.
3.Ibid.
4.Ibid.
5.Ibid.
6.C. Ryan, ed. *Across the Space Frontier.* New York: Viking Press, 1952.
7.See "Selected Bibliography" (1950, 1951).
8.U. B. Marvin. Oral histories in meteoritics and planetary science. XIII. Fred L. Whipple. *Meteorit. Planet. Sci.* 39(suppl.)(2004):A199-A213.
9.D. S. Burnett. NASA returns rocks from a comet. Science 314 (2006):1709-1710. (See also other papers in this issue.)
10.E-mail message dated Jan. 11, 2006, from Babette Whipple.
11.U. B. Marvin. Oral histories in meteoritics and planetary science. XIII. Fred L. Whipple. *Meteorit. Planet. Sci.* 39(suppl.)(2004):A199-A213.
12.G. Marcy, R. P. Butler, D. Fischer, S. Vogt, J. T. Wright, C. J. Tinney, and H. R. A. Jones. Observed properties of exoplanets: Masses, orbits, and metallicities. *Prog. Theor. Phys.* 158(suppl.)(2005):24-42.
13.K. E. Haisch, E. A. Lada, and C. J. Lada. Disk frequencies and lifetimes in young clusters. *Astrophys. J.* 553(2001):L153-156.
14.Personal communication from Fred L. Whipple; as indicated in Note 9, this wish has already been granted, although Fred did not live to see the sample returned from Comet Wild 2 by NASA's Stardust mission. The crystalline nature of Stardust particles suggests to some that these particles cannot be unprocessed interstellar dust, as might be expected if Comet Wild 2 formed in the cold outer reaches of the solar system. However, lively debates will ensue before this issue

is settled. If Fred were now alive, he would surely be an active participant in the discussions.

15.U. B. Marvin. Oral histories in meteoritics and planetary science. XIII. Fred L. Whipple. *Meteorit. Planet. Sci.* 39(suppl.)(2004):A199-A213.

16.Ibid.

17.M. Davis, J. Huchra, D. Latham, and J. Tonry. A survey of galaxy redshifts, *Astrophys. J.* 253(1982):423-445.

18.F. L. Whipple. Of comets and meteors. *Science* 289(2000):728.

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