John A. O'Keefe (1916-2000)

John A. O'Keefe, a pioneer of the Space Age and the man whom Eugene Shoemaker called "the godfather of astrogeology," died September 8 of complications due to liver cancer. He was a Fellow of the AGU.

O'Keefe's best-known scientific achievement was the 1959 discovery of the third harmonic of the Earth's gravitational field, derived from tracking the Vanguard I satellite. O'Keefe, together with coauthors Ann Eckels (now Bailey) and Ken Squires (now deceased), analyzed the data at the newly formed NASA Goddard Space Flight Center and concluded that "The third zonal harmonic modifies the geoid toward the shape of a pear," with an amplitude of 15 meters.This careful statement was head lined as "the pear-shaped earth." The first discoveries from satellite tracking had already been made by British scientists, who found a new value for the flattening of the Earth from Sputnik 2. However, the third harmonic was the first geodetic result from an American satellite, and its discovery attracted worldwide attention.

John O'Keefe can be called the founder of space geodesy He was the first scientist to propose formally, in 1955, the use of artificial satellites for geodetic measurements. (Fred Whipple had pointed out in 1952 the geodetic value of a space station.) Tracking of a reflective satellite—by searchlights, in those pre-laser days—would permit, among other things, precise measurements of intercontinental distances, now achieved with laser-ranging to LAGEOS and other retroreflector-bearing satellites. O'Keefe and Charles Batchlor showed in 1957 how satellite tracking could be used to study the shape of the Earth with mathematical methods shortly thereafter applied to discovery of the third harmonic.

Originally an astronomer, with degrees from Harvard and the University of Chicago, O'Keefe had in 1938 discovered spectroscopic evidence for solid carbon in the star R Coronae Borealis, since confirmed for these cool stars by modern methods. When the United States entered World War II, he volunteered for the Army Air Corps, but could not pass the physical. However, in 1942 he joined (as a civilian) the mapping division of the Army Corps of Engineers, which became the Army Map Service in 1945. During the war, he helped improve topographic maps of Europe, a vital military necessity. After the war, he spent several months in China, retrieving geodetic data before the communist takeover in 1949. In 1950, O'Keefe headed a team that used a continent-wide array of 12-inch telescopes to time the occultation of 228b Aurigae.They found a two-stage occultation, meaning the star was double, the first time this had been done by occultation measurements.

The strange behavior of the planet Mercury, which rotates 3 times for every two revolutions around the Sun, was studied by Han-Shou Liu and O'Keefe, who demonstrated mathematically that this was a case of spin-orbit coupling, publishing this result in the December 24,1965, issue of *Science*.

In the 1950s, one of his daughters developed malignant melanoma. She fortunately recovered, but this event stimulated O'Keefe to think about biology and more specifically about microscopy beyond the resolving power of visible light. From early work on eclipsing binary stars, he realized that this might be achieved by scanning the diffraction pattern of a sub-micrometer particle. This led him to independently rediscover the principle of the near-field microscope, which E.H. Synge had described in 1928. He actually tried to build one with the help of his teen-aged neighbor, Fred Murphy but they had to give it up as too crude. However, O'Keefe did publish a short note on its principle in the *Journal of the Optical Society of America* (v. 46, p.359) in 1956. Although the note attracted little attention, years later the scanning tunneling microscope, using the same principle, was independently invented by Binnig, Rohrer, and Ruska, earning them the Nobel Prize in Physics for 1986.

O'Keefe left the Army Map Service in 1958 for Goddard Space Flight Center, where he played an important though little-known part in NASA manned space missions. He was influential in persuading NASA to bring the U.S. Geological Survey into its programs, starting a partnership that continues to this day in lunar and planetary mapping. He helped plan scientific experiments for the Mercury astronauts, including the use of hand-held 70-mm cameras for geologic orbital photography. This photography eventually led to the Landsat program, as described by the late director of the USGS, W. T. Pecora. O'Keefe settled a puzzling problem, the origin of the "fireflies" seen by John Glenn in 1962, by showing that they were ice crystals from the spacecraft itself—"an elegant explanation" in Glenn's words.

However, O'Keefe was also deeply involved in the Apollo Program behind the scenes. As a member of the inf luential'Ad Hoc Working Group on Apollo Experiments and Training"—informally "the Sonett committee,"after its chairman, C.P Sonett—he helped plan geophysical investigations such as emplacement on the Moon of a tidal gravimeter (eventually done on the Apollo 17 mission).

O'Keefe received the Goddard Space Flight Center's highest honor, the Award of Merit, in 1992. Carroll Alley in a 1997 AGU session honoring O'Keefe, credited him with "effective internal advocacy" for

the lunar laser ranging retro-reflectors, now the only part of the Apollo Program (other than sample analysis) still being actively carried out. Eugene Shoemaker, at the same session, announced that he and Carolyn Shoemaker had named a newly-discovered asteroid after him.

The latter part of O'Keefe's career was focussed on the study of tektites—small glassy bodies of natural but unknown origin found in various "strewn fields"on the Earth. Convinced that tektites come from the Moon, he published many papers and two books on the subject, and made field trips to Australia, Africa, and various American localities. His most specific argument, still unanswered, was that such nearly pure glasses could not be made by any sudden process such as Earth impact, the origin now favored by the great majority of workers; he felt they had to cook inside lunar volcanoes first. His work on tektites over the decades stimulated research in several other fields, such as the origin of the Moon, the formation of continental crust, and even the impact origin of Ontario's 65-km-long Sudbury Structure.

O'Keefe was a brilliant writer and a superb lecturer, and his long and adventurous career made him a great raconteur. A devoted Catholic and father of nine children, he was a scientist to the end. He had the last word, and one hopes the last laugh, on tektites. On the final page of the program for his funeral, at the bottom, were the words: "Tektitae de luna sunt.'

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