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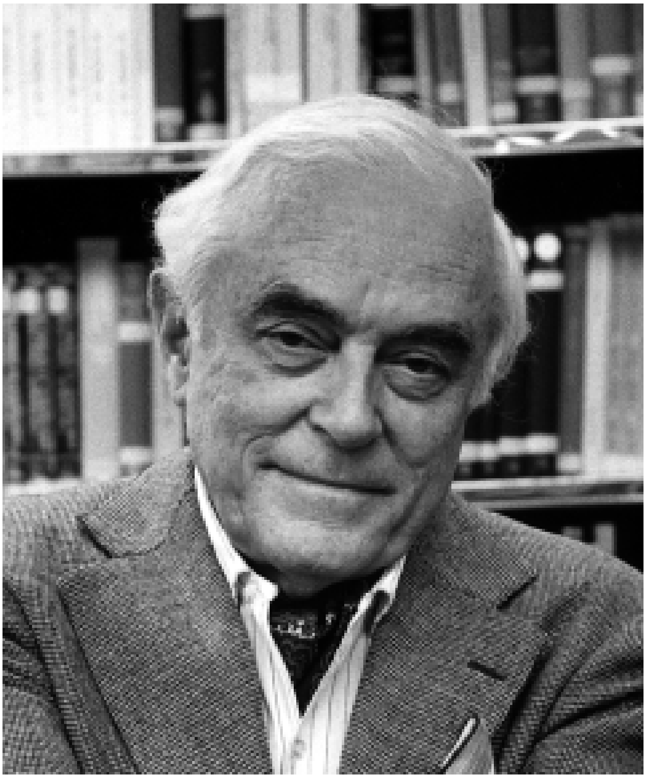

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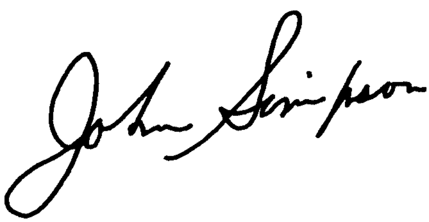

JOHN ALEXANDER SIMPSON

November 3, 1916–August 31, 2000

BY EUGENE N. PARKER

JOHN SIMPSON WAS A visionary experimental nuclear and cosmic ray physicist, a prolific inventor, a vigorous booster of colleagues and university, and was deeply committed to communicating science and its implications to the public and political leaders. His eyes were continually on the next generation of science as he worked with the present tasks, anticipating the next leap forward. Thus his specific scientific measurements invariably had profound implications.

Simpson began his professional career in 1943 as a group leader on the Manhattan Project. He recognized the social and human implications of nuclear energy for both sustained and explosive release, and he and many others of the project began serious discussion of the future of nuclear energy and the human relation to it. Such group discussions were forbidden under the wartime regulations imposed on the project, but the ideas were developed and shared among the concerned scientists nonetheless. The upshot was that John Simpson became a founding member and first chairman of the Atomic Scientists of Chicago, formally founded August 7, 1945, the day after the United States dropped the atomic bomb on Hiroshima. He was a cofounder of the *Bulletin of the Atomic Scientists* later in 1945. The doomsday clock on the cover of the bulletin is familiar to all. Henry

Luce, publisher of *Time* and *Life* magazines, was sufficiently impressed with the thoughts and concerns of the Atomic Scientists of Chicago that he provided them with two full pages in the October 20, 1945, issue of *Life* to spell out the implications of the atomic bomb and possible rational courses of action in response to the implications.

In 1945 Simpson joined the faculty of the University of Chicago as an instructor in the Physics Department. He remained at the university throughout his career, active in his research to within a few weeks of his death on August 31, 2000, from pneumonia contracted in the hospital following successful heart surgery. Simpson's first act as a new instructor was to take a leave of absence to work as an unofficial advisor to Senator Brian McMahon of Connecticut. The product of this collaboration was the McMahon Act of 1946, placing the control of atomic (nuclear) energy in civilian hands rather than leaving it under the military jurisdiction that spawned its creation. It was a milestone in the history of atomic energy. Simpson was just 30 years old at the time of the McMahon Act. Born on November 3, 1916, in Portland, Oregon, Simpson earned an A.B. degree in physics from Reed College in 1940. His graduate training was in physics at New York University, where he earned an M.S. in 1942 and a Ph.D. in 1943 before joining the Manhattan Project. His research advisor was Prof. Serge Korff.

One of Simpson's first contributions was the invention of a gas flow α-particle proportional counter for measuring plutonium yields in the presence of high intensity fission products. It must be appreciated that α-particles (helium nuclei) emitted in the radioactive decay of plutonium, and other transuranic elements, have but little penetrating power. A sheet of paper stops them. They do not penetrate the thin window of particle counters, so the trick was to pipe the plutonium-bearing gas through the counter itself.

Simpson patented the device, which was the first of the 15 patents that now bear his name, ranging from the multiwire proportional counter to a device that assists in improving reading speed and accuracy. During his professional career he kept a file of his many (unpatented) ideas (e.g., a modification of the profile of a clarinet reed to provide different tone qualities). He was an accomplished clarinetist and saxophonist, already recognized in high school with an award for his virtuosity.

COSMIC RAYS

When Simpson returned to the University of Chicago in 1946, his scientific curiosity turned to cosmic rays. At this point it is desirable to say a few words about the scientific problem posed by cosmic rays then and now, for the fact is that Simpson's immense contribution to science lies in that little known field. The basic nature of cosmic rays was only in the process of being established in 1946, and their origins were a matter of speculation. It was recognized, from the variation of the cosmic ray intensity with geomagnetic latitude and from the east-west asymmetry of their arrival at the surface of Earth, that cosmic rays are mostly charged particles, as distinct from energetic photons, with the majority of the particles positively charged. It was not long before photographic emulsions, carried on balloons to the top of the atmosphere, showed that the incoming cosmic ray particles are indeed mostly protons, with a small but surprising distribution of heavier nuclei.

It must be appreciated that these incoming "primary" cosmic rays are not the cosmic rays found down here in the lower atmosphere. The primary particles collide with the nuclei of the air atoms in the topmost tenth of the atmosphere (the first 100 gm/cm^2) producing a spray of gamma rays, mesons, electrons and positrons, protons and neutrons. It is these secondary particles that are observed at the surface of Earth. It should also be appreciated that the magnetic field of Earth is horizontal at the equator, so an incoming proton can reach the atmosphere only by moving across the magnetic field. That cross motion deflects the proton so much that a minimum energy of about 15 GeV is required for vertical arrival at the top of the atmosphere. This energy restriction declines smoothly to zero at the magnetic poles, where the field extends vertically outward into space. Thus, the observed cosmic ray intensity is greater at the high than at the low geomagnetic latitudes—the so-called latitude effect. By 1946 the work of S. E. Forbush had identified time variations in the cosmic rays, closely correlated with outbursts of activity on the Sun and the associated magnetic storms here at Earth. Solar activity generally had the effect of diminishing the intensity of the cosmic rays arriving at the surface of Earth.

Today we know that the cosmic rays are created throughout the galaxy by such energetic phenomena as supernovae and that the cosmic rays in the large represent a tenuous relativistically hot gas, with dynamical pressure comparable to the magnetic fields and other gases in interstellar space and in the galactic halo. The story of the development of the modern cosmic ray concept is to a large degree the story of Simpson's scientific investigations. The interesting thing is that he accomplished this work in a way that boosted the scientific accomplishments and careers of those around him—graduate students, research associates, and fellow faculty. For instance, in 1955 he gave me a job as a research associate in what is now the Enrico Fermi Institute of the University of Chicago. My subsequent progress up through the academic ranks was in no small way a consequence of his continuing support. This was only typical of his general approach to his work, his colleagues, and the university.

Returning to the scientific narrative: Simpson chose to begin his investigations with a study of the cosmic ray neutrons in the lower atmosphere, whose existence had been established before World War II by Serge Korff. Almost all of the cosmic ray measurements up to that time used Geiger counters and ionization chambers, responding largely to the mesons. Simpson discovered that the latitude effect seen with neutrons is about 20 times greater than observed with ionization chambers, and it was soon apparent that the time variations are much greater, too (1949, 1951). The neutrons are produced mostly by incoming cosmic ray protons of 15 GeV or less, while the mesons are produced mostly by protons above about 15 GeV. Simpson recognized the potential of the neutrons and the lower energy cosmic ray particles for probing the causes of the time variations. That is to say, the strong time variation of the lower energy cosmic rays is a thumbprint of whatever is happening out in space.

A stable ground-based neutron detector was needed, so Simpson invented the neutron monitor. This instrument was bulky, with layers of both lead shielding and paraffin moderator, but it was inexpensive, stable, and could be built large to obtain any desired counting rate. It had the big advantage that the diurnal atmospheric corrections required little more than the local barometric reading. Ionization chambers, for instance, must include the height (temperature) of the atmosphere in the corrections, as a consequence of the decay of the downward propagating mesons. Simpson recognized the importance of determining the energy dependence of the time variations, so he established neutron monitor stations at Chicago, Illinois; Climax, Colorado; Sacramento Peak, New Mexico; Mexico City, Mexico; and Huancayo, Peru. The Peruvian station responded only to cosmic rays above 15 GeV, while the Chicago station responded to cosmic rays above about 2 GeV, with the other three stations distributed between.

TIME VARIATIONS

The energy dependence of the time variations soon showed that the reduction of the cosmic rays during times of solar activity arose from the partial disappearance of cosmic ray particles at the lower energies (1954, 1955). This demolished the idea, popular at the time, that the abrupt Forbush-type decrease, occurring at the time of a geomagnetic storm, was a consequence of the storm modification of the geomagnetic field in such a way as to make it more difficult for cosmic ray particles to arrive at Earth. The other popular notion was that interplanetary space is a hard vacuum, and electrostatic fields in space, with potential differences of a billion volts and more, decelerate the cosmic rays. Passing through such a potential difference would reduce the energy of each particle by the same amount, and that did not produce the energy dependence found from the neutron monitors.

Simpson explored the global variation and time variation of cosmic rays around the world with neutron monitors and other detectors carried on Air Force B-25's, B-29's, and Globemasters, on Navy ships to and from the Antarctic, and with helium-filled balloons going to the top of the atmosphere. The neutron monitor stations were intercalibrated, and there were many other cosmic ray detectors up and running elsewhere, too.

So it was that the giant cosmic ray flare of February 23, 1956, emitting an immense burst of protons up to 25 to 30 GeV, provided the first direct glimpse of the state of things in interplanetary space. Briefly, the leading edge of the burst of energetic particles arrived promptly at Earth from the direction of the Sun. Over the next 10 minutes or so the whole space around Earth was filled with solar energetic particles, providing a roughly isotropic sea, which soon began to decay away, very approximately going over into the declining form $t^{-3/2}$ for the next several hours.

This behavior and the precise timing suggested that the inner solar system (out to about Mars) is enclosed by a disordered magnetic field beyond Mars that greatly impedes the free escape of energetic particles. The abrupt arrival of the first particles from the direction of the Sun indicated that any magnetic fields between Earth and the Sun must be relatively smooth and more or less in the radial direction (1956). This was the first evidence that interplanetary space is filled with a magnetic field and hence contains a plasma in which the field is embedded. It suggested that the cosmic ray variations are a consequence of variations of the magnetic field and plasma, and it was the beginning of the concept that ultimately led to recognition of coronal expansion and the supersonic solar wind and heliosphere.

By this time there was an active scientific community interested in such topics as solar activity, cosmic ray variations, and geomagnetic storms. The international community got together for the International Geophysical Year (IGY) in 1957-58. Simpson was one of the 12 discipline scientists responsible for organizing and coordinating the international program. The neutron monitor was adopted as the standard for cosmic ray measurements worldwide. Indeed the fundamental role of the neutron monitor is evidenced today by the 23 nations that use them at 51 centers around the world. These centers are part of a network of stations that monitor space weather under the auspices of the National Science Foundation. The IGY was a huge success, with its tightly coordinated worldwide observations providing a general picture that had never before been possible.

SPACE MISSIONS

Simpson realized at this point in time the necessity for sending instruments into space. It was general public knowledge that the development of rocket technology was approaching the capability of launching spacecraft into orbit around Earth. The launch of *Sputnik* by the Soviet Union in the fall of 1957 provided an efficacious prod to rocket development in the United States. At the end of 1957 Simpson went to Lawrence Kimpton, chancellor of the University of Chicago, and outlined the scientific situation and his plans for the future. Kimpton responded with $5,000 to get the project off the ground. Together with Peter Meyer, Simpson started work immediately on the development and construction of small lightweight particle detectors suitable for going into space; his first particle detector was launched into space on *Pioneer 2* in 1958. Rocket failures on the *Ranger 1* and *2* launches delayed things momentarily, so the second instrument to go into space was on *Pioneer 5* in 1960.

It was clear to Simpson that the limited weight and power available on spacecraft made it necessary to invent small detectors that could determine the mass, charge, and energy of the individual energetic particles passing through the instrument. Only with such detailed knowledge of the cosmic ray particles would it be possible to infer their origin. Attention turned first to silicon crystals, and a long program of development in collaboration with A. J. Tuzzolino and others ensued. By 1980 the art of particle detection and measurement had advanced to the point where it was possible to resolve the individual isotopes of nuclei, eventually all the way up through Fe and Ni, at the same time measuring their kinetic energy (1969, 1996, 1997). This technology is now generally employed in the space program for studies of galactic cosmic rays, solar cosmic rays, and energetic particles trapped in planetary magnetic fields.

An offshoot into plastic detectors led to the dust flux monitor instrument (DFMI) developed by Simpson and A. J. Tuzzolino in the 1980s. It is a novel pyroelectric scheme involving a thin sheet of plastic that has been polymerized in the presence of a strong electric field perpendicular to the plane of the plastic; the final sheet is electrically polarized and carries a positive electric charge on one surface and a negative charge on the other. A dust particle or heavy nucleus penetrating though the sheet vaporizes a small area, thereby releasing the charges. The electrical signal indicates the location and size of the hole in the plastic and can be calibrated to give information on the speed and size of the particle (1985, 1989). This device was first carried into space on the Soviet *Vega 1* and *2* spacecraft to Halley's comet in 1986. The ability to handle up to 0.5×10^5 hits per sec made the DFMI indispensable for studying the cometary dust cloud close to the comet and using the results of *Vega 1* to judge how close to send *Vega 2*. Simpson was awarded the Gagarin Medal for Space Exploration in 1986 for his contribution to the success of the *Vega* mission. His instruments were the only ones from the United States to encounter Halley's comet.

A more recent DFMI is carried on the Cassini mission to Saturn, where it will investigate the dust environment of Saturn's gravel rings. DFMI's are flown on the Air Force's unclassified *Advanced Research and Global Observation Satellite* and on the *ARGUS* spacecraft in low Earth orbit, where it monitors the space dust of both natural and human origins. It is evident that the DFMI has joined the silicon detectors and the neutron monitor in the stable of scientific workhorses.

LABORATORY FOR ASTROPHYSICS AND SPACE RESEARCH

Now, going back to pick up the narrative around 1960: The growing complexity of space instrumentation and the analysis of data returned from space by the instrumentation led Simpson to recognize that a closely coordinated infrastructure was a necessity. So in 1962 he and Prof. Peter Meyer established the Laboratory for Astrophysics and Space Research (LASR) within the Enrico Fermi Institute of the University of Chicago. The direct interest to NASA and its future space missions induced NASA to fund a building for LASR, which was completed in 1964. LASR made it possible to consolidate the instrument development and space research under one roof, at the same time providing a home for theoretical research directly or loosely connected with the results of the ongoing space experiments. Equally important in Simpson's eyes was the immersing of the students in all aspects of space research.

Simpson believed in the innate ability of his graduate students, and he saw to it that they shared in the responsibilities of instrument development, operation, and data analysis. The outstanding success of so many of his students in their subsequent professional careers attests to the validity of his assessment. In the course of his academic career he supervised the research of 34 doctoral students, but times were changing. The classical university laboratory, where professor and student worked through the experiment, was giving way by the mid-1960s to the extended space project, stretching beyond the years that a student could reasonably spend in graduate school. So Simpson turned to another training pattern for his students, in which a student does not follow through with all phases of a single space mission but rather gets some experience by working for a time with the laboratory development of an instrument and then moving on to the calibration, perhaps of an instrument about to be launched into space, finally analyzing the accumulated data from a space mission launched at an earlier date.

SPACE EXPLORATION

Exploration of interplanetary space and the planets throughout the solar system was soon underway, with expectations of finding magnetic storms and trapped energetic protons and electrons in the magnetic fields of Jupiter, Saturn, and presumably Uranus and Neptune, in analogy to the active magnetic field of Earth. The magnetic fields and shock waves in interplanetary space were a new subject, of course, and conditions were surely different beyond the orbit of Mars, where the interplanetary magnetic field becomes more nearly azimuthal. So there was high anticipation of surprises and new discoveries all around. Simpson and his students and coworkers built the first cosmic ray (energetic particle) detectors to visit Mars (in 1965), Jupiter (in 1973), Mercury (in 1974), and Saturn (in 1979). The 1973 mission to Jupiter made the first detection of the relativistic (3-30 MeV) electron population emitted by Jupiter, first recognizing the electrons within the Jovian magnetosphere and ultimately detecting the escaping electrons at distances of 1 AU and more. The electron escape from Jupiter is synchronized with the rotation of Jupiter (period of 9 hours, 55 minutes, 30 seconds), so that the electrons are readily identified at large distances from Jupiter by their pulse (1974, 1977).

It was Simpson's detection of the fixed energetic particle populations around Mercury that first established that the magnetic fields observed at Mercury belong to the planet itself, rather than being carried from the Sun by the impacting solar wind (1974). Then Simpson and others detected a tiny gap in the distribution of energetic particles trapped in the magnetic field of Saturn, indicating the presence of a previously undetected small moon of Saturn orbiting at that position in space and absorbing the particles that would otherwise be found there (1980). The moon was subsequently identified optically.

Besides the purely exploratory discoveries, there were several known effects that needed to be mapped throughout the solar system. For instance, the outward sweep of the magnetic fields carried in the solar wind partially excludes the galactic cosmic rays from the solar system. So it is important to measure the outward increase of the cosmic ray intensity, and ultimately to determine the intensity of the full cosmic ray intensity in interstellar space (1973, 1985). Such distant investigations are limited by the mechanics of rocket launches from the orbiting Earth in the plane of the ecliptic. Thus, space far away from the ecliptic was unexplored until a carefully orchestrated swing by Jupiter tossed the *Ulysses* spacecraft over the poles of the Sun. Simpson (1959) was involved with the development of the mission from the beginning of the concept. He ultimately served as the principal investigator of the international team that provided the diverse individual particle detectors harnessed together to measure the wide range of energetic particle populations to be encountered on the journey. As expected, the polar regions, above about 35° magnetic latitude, produce only high-speed solar wind (500-800 km/sec) at solar minimum, with the polar magnetic fields of the Sun stretched radially out through space.

The speculation that the galactic cosmic rays penetrate freely into the Sun along this radial field was found to be incorrect. Evidently, with so many small-scale transverse fluctuations in the field, the cosmic ray intensity is reduced almost as much as near the ecliptic. Then the *Ulysses* cosmic ray measurements showed the puzzling fact that the 26-day variations, produced by the magnetic fields of the rotating Sun caught up in the interacting slow and fast solar wind streams near the ecliptic, are present over the poles of the Sun, where there is only the fast solar wind (1995, 1996). This discovery indicates that the cosmic ray particles disperse widely over heliocentric latitude, which suggests extensive wandering of the field lines relative to the mean field. This whole phenomenon has yet to be fully understood.

PARTICLE ACCELERATION

It is remarkable that wherever one looks around the solar system and wherever one can probe the galaxy, there are vigorous populations of fast particles, from cosmic rays to trapped particle belts in the magnetic fields of planets. The mechanisms responsible for accelerating these particles above the general thermal background pose a fundamental problem in classical physics. The intense bursts of solar cosmic rays from impulsive flares had for many years emphasized that the acceleration process is remarkably efficient (10-50 percent). So Simpson's detection of bursts of energetic particles associated with the passage of shock waves in the solar wind was an important conceptual step (1976, 1982), emphasizing that the shock transition is an efficient accelerator of particles. Subsequent theoretical studies of the acceleration of particles in a shock front have shown just how efficient the acceleration can be.

Another discovery by Simpson eventually led to the realization that plasma waves can also be efficient accelerators. It began with Simpson's (1970) discovery that impulsive flares at the Sun produce energetic particles among which ^{3}He is ten or more times abundant relative to ^{4}He than normal. Subseequently, others observed instances in which ^{3}HE actually outnumbered ^{4}HE. L. A. Fisk showed that this very selective acceleration can be understood in terms of the plasma waves created by current instabilities, and M. Temerin and J. Roth more recently have shown that ion cyclotron waves are another possibility, both processes being remarkably efficient under the right circumstances.

Simpson was particularly interested in the ultimate acceleration problem (i.e., the origin of the galactic cosmic rays) created somewhere else in the galaxy, far beyond the outer reaches of the solar wind and heliosphere. He realized that the detailed isotopic composition of the heavier elements among the cosmic rays should give some idea of their place of origin.

Then Simpson's original interest in the modulation of the galactic cosmic ray intensity by the solar wind became part of the galactic program because it was ever more interesting to know just how high was the cosmic ray intensity out in interstellar space. He and his associates carried out extensive studies of the gradual outward increase of the cosmic ray intensity. His instruments on *Pioneer 10* and *11* indicated an increase of about 1 percent per AU (1973). The net reduction of the low energy cosmic rays (~100 MeV/nucleon) here in the inner solar system is particularly striking. The intensity goes up and down by about a factor of 10 with the 11-year cycle of solar activity. Then Simpson (1975) found that during the activity minimum of 1972 the abundance of cosmic ray helium was peculiarly enhanced at very low energies. It did not drop off with declining energy like the protons, more or less linearly toward zero energy. It was as if an independent source of low energy helium (20-50 MeV/nucleon) was able to get through at that time of minimum solar suppression. These helium nuclei, as well as heavier nuclei (e.g., C, N, O), are now referred to as the anomalous cosmic rays. The theoretical work of Pesses, Jokipii, and Eichler showed that these rays are produced in great numbers in the termination shock of the solar wind. These particles first enter the solar wind as free-falling interstellar neutral atoms, passing freely through the magnetic fields and tenuous solar wind, ultimately being ionized by solar UV somewhere in the general vicinity of the orbit of Jupiter. Upon ionization (becoming a singly charged ion) they are immediately picked up by the solar wind, within which they have a relative velocity comparable to the speed of the wind (about 1 KeV per nucleon compared to the 1 eV thermal energy of the solar wind particles). So they are selectively accelerated to energies of the order of 100 MeV as they pass through the termination shock.

COSMIC RAYS IN THE GALAXY

Finally, then, turning attention to the galactic cosmic rays: The isotopic studies revealed that ^{10}Be is almost entirely missing from among the cosmic rays. One would expect to see modest abundances of ^{3}He and Li, Be, and B as a consequence of collisions of such common massive cosmic ray nuclei as C, N, and O with the nuclei of interstellar atoms knocking chunks out of the heavier nuclei. Indeed, studies of these spallation nuclei show them to be present in about the expected ratios, with the cosmic rays having passed through about 5 gm/cm^2 since being accelerated. A mean interstellar number density of 1 or 2 atoms/cm^3 throughout the gaseous disk of the galaxy would indicate a travel time of about 2×10^6 years. The ^{10}Be nuclei are different, in that they are unstable, with a half-life of 2.6×10^6 years. Simpson pointed out that their scarcity indicates they have been around for about 2×10^7 years, which can only mean that the cosmic rays pass freely between the gaseous disk and the extended magnetic halo of the galaxy, where the ambient gas density is more like 10^{-2} atoms/cm^3 or less (1975, 1977). One infers from this that the magnetic halo is made up largely of lobes of the disk magnetic field inflated outward by the continuing production of cosmic rays (by supernovae, for example) in the disk. Subsequent evaluations of other unstable nuclei confirm the general 2×10^7 year cosmic ray residence time within the magnetic fields of the galaxy. So the study of isotopes provides insight into the galactic range of the cosmic rays.

More recently the isotopic studies have led to the conclusion that the cosmic rays do not represent a sample of nuclei taken from a supernova but rather are close to the expected relative abundances of interstellar atoms. From this one infers that the cosmic rays are accelerated in interstellar space by shock waves from nearby supernovae. The shock waves propagate out ahead of the supernova ejecta, and little or no matter from the ejecta is accelerated to cosmic ray energies. So again the isotopic studies add a piece to the general picture.

IN CONCLUSION

This brief survey of Simpson's contributions to the cosmic ray picture is intended to show how much his work contributed to the present day picture of this vast and powerful galactic phenomenon. The limited space really can do justice neither to the full span of Simpson's work nor to the many others who have worked and contributed to the field.

To say a little more about Simpson's role in the scientific community: He was elected to the National Academy of Sciences in 1959. He was made distinguished service professor at the University of Chicago in 1968, holding first the Ryerson chair and then, from 1974 the first to be appointed to the Compton chair. He became emeritus in 1986. He was awarded the Bruno Rossi Prize by the American Astronomical Society in 1991 for contributions to high-energy astrophysics and the Henryk Arctowski Medal of the National Academy of Sciences in 1993. In June 2000 he was awarded the William Bowie Medal, the highest award by the American Geophysical Union, in recognition of his extensive explorations of the cosmic rays and other energetic particles that continually bombard our planet.

In 1974 he used funds that came with the Compton chair to initiate the weekly Compton Lectures for the public. It is an honor among the junior scientific staff of the Enrico Fermi Institute to be appointed the Compton lecturer for an academic quarter. The lectures are invariably excellent, and the response from the public has been gratifying. In 1982 he established the Universities Space Science Working Group in Washington, D.C., representing the space science laboratories in their dealings with NASA and Congress. He was the first chairman, and the group has enabled the scientific community to be heard more effectively by the Washington bureaucracy.

John Simpson is survived by his wife, Elizabeth, and by his children, Mary Ann and John, from his first marriage.

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