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RICHARD TOUSEY
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A Biographical Memoir by

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Richard Tousey.

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May 18, 1908–April 15, 1997

BY WILLIAM A. BAUM

RICHARD TOUSEY WAS THE leading pioneer in solar research from space. Using a V-2 rocket in 1946, he and his collaborators at the Naval Research Laboratory were the first to record the spectrum of the Sun in the ultraviolet, which is blocked from reaching instruments on Earth's surface (or even on the highest balloons) by gases in Earth's atmosphere. This solar spectrum was, in fact, the very first astronomical observation to be made successfully from above Earth's atmosphere, and it marked the dawn of the space age. Using rockets and Earth-orbiting spacecraft, Tousey devoted the next three decades to increasingly sophisticated studies of the Sun and Earth's atmosphere, resulting in a number of important firsts. In private life, Tousey was interested in baroque music, harpsichords, hiking, sailing, and bird watching. He was a soft-spoken person with a probing mind and a strong sense of purpose.

Richard Tousey was born on May 18, 1908, in Somerville, Massachusetts, the son of Coleman and Adella Hill Tousey. From the time he was a child Richard had a great fondness for nature and the outdoors, where he liked to hike and where he developed a lifelong interest in ornithology. His family usually spent summers on the Atlantic coast, first south of Boston and later on the coast of Maine, where they particularly enjoyed sailing. According to family lore, Richard's mother feared her children might be at risk of encountering a mountain lion in the Maine woods, but she felt that they were safe at sea. The family also traveled to Europe and went hiking in the Alps. At home in Boston, Richard took an early interest in ham radio and got his license at the age of 12, the youngest person to do so in Boston at that time. He spent hours tapping Morse code to radio amateurs in distant countries, and he had a collection of cards from those who had received his transmissions. He also developed and printed his own photographs.

Tousey majored in physics and mathematics at Tufts University from which he graduated summa cum laude in 1928. From there he entered graduate school at Harvard, earning an M.A. in physics in 1929 and a Ph.D. in physics in 1933 under Professor Theodore Lyman, who 20 years earlier had discovered the fundamental emission line of atomic hydrogen at 1216 A in the ultraviolet (the Lyman-alpha line), which today we know to be an important component of the radiation field of the Universe. As a graduate student Tousey designed a specialized vacuum spectrograph for determining the optical constants of fluorite, a very clear crystal that is transparent far down into the ultraviolet and has optical properties useful in lenses and optical instruments. His thesis was titled "An Apparatus for the Measurement of Reflecting Powers with Application to Fluorite at 1216 A."

While at Harvard, Tousey was a Whiting fellow (1929-31), a Tyndall scholar (1931-32), and a Bayard Cutting fellow (1932-33). He thus finished his Ph.D. at the depth of the Great Depression, but he had an opportunity to stay on at Harvard as an instructor in physics until 1936, supported in part during the last year by another Bayard Cutting Fellowship. Taking his Harvard research apparatus with him, Tousey then returned to Tufts in 1936 as a research instructor in physics, a position he held until 1941, when he took a leave of absence to enter wartime research at the Naval Research Laboratory in Washington, D.C.

In 1932, while still in graduate school, Tousey married Ruth Lowe, who shared his interest in classical music, especially baroque music. They assembled a collection of wire-stringed keyboard instruments that included three harpsichords (one of which they found in the basement of a church in Oxford, England), a virginal, a clavichord, and a piano. In the 1940s and 1950s professional musicians frequently gathered at Tousey's home for a chamber music soiree and for one of Ruth's excellent home cooked meals. Richard played the piano or the harpsichord, and Ruth played the viola or the violin. Their daughter, Joanna, attended the Eastman School of Music on a scholarship, went to Paris as Jean-Pierre Rampal's first Fulbright scholar, obtained a master's degree and later a doctorate at the University of Michigan, and established a career as a professional flautist. In the late 1940s Tousey tinkered (and interested me in doing so, too) with the recording of live music, using vacuum-tube amplifiers and wire recorders. By today's standards the sound fidelity was poor, and the wire had a frustrating tendency to break rather often.

Tousey maintained his outdoor interests throughout his life. Although not especially athletic, he tended to walk quite fast. And he particularly enjoyed sailing. It was in fact while anchored at Bucks Harbor, Maine, that Tousey first became acquainted with E. O. Hulburt, the director of research at the Naval Research Laboratory (NRL), a connection that resulted in Tousey spending most of his career at NRL. In addition to their love of sailing, Tousey and Hulburt shared some personality traits; both were unusually tranquil, undemonstrative, and soft-spoken. I do not recall either one ever raising his voice or speaking rashly.

In 1941 Hulburt asked Tousey to join him in wartime research at NRL. Part of that research pertained to the visibility of stars in the daytime sky, because of the need at that time for the celestial navigation of military aircraft by day as well as by night. That project included determining the brightness and polarization of the daytime sky at high altitudes. Another part of the wartime research at NRL pertained to the nighttime visibility of objects, particularly the effects of night myopia and dark adaptation. Tousey also worked on the visibility of near infrared light sources because of the need to maintain security against visual detection of sources used with infrared military systems. Tousey's interests in physiological and atmospheric optics continued throughout his career, and they account for about one third of his scientific publications. Along with various colleagues Tousey also did extensive work on ultraviolet transmitting and reflecting materials, and the data published from that work are standard references for the properties of those materials.

When World War II ended in 1945, Tousey had an opportunity at NRL to do the fundamental scientific research for which he became best known and which is described in the sections that follow. He was elected to the National Academy of Sciences in 1960. Other honors and milestones of his career included the 1960 Frederic Ives Medal of the Optical Society of America, 1963 Henry Draper Medal of the National Academy of Sciences, 1963 Navy Award for Distinguished Achievement in Science, 1963 George Darwin Lectureship of the Royal Astronomical Society, 1964 Eddington Medal of the Royal Astronomical Society, 1964-1966 vice presidency of the American Astronomical Society, 1966 Henry Norris Russell Lectureship of the American Astronomical Society, and the 1974 NASA Exceptional Scientific Achievement Award.

Richard Tousey retired from NRL on June 30, 1978, but remained connected as a consultant. Ruth Tousey died in 1994, and Richard died of pneumonia on April 15, 1997, at Prince Georges Hospital Center in Maryland at the age of 88.

DAWN OF THE SPACE AGE

It was Tousey's group at NRL that obtained the very first successful astronomical observation ever made from above Earth's atmosphere. In 1946 they recorded the ultraviolet spectrum of the Sun down to 2100 A with an instrument mounted in a high-altitude rocket. It was an historic first, and Tousey's ingenuity was the key to its success. As one of those involved, I can offer a first-hand account.

At the end of the war in 1945 a team of German rocket scientists headed by Werner von Braun was brought to the United States together with about 100 unused German V-2 rockets and a supply of parts. The V-2 was a huge liquid-fuel missile about 2 meters in diameter and 14 meters tall that weighed 13 metric tons at launch and traveled to its target area on a high parabolic trajectory above most of Earth's atmosphere. (V-2 stands for *Vergeltungswaffe Zwei*, or Vengeance Weapon 2, and Germany launched many V-2s against targets in England in 1944-45.)

Although sounding rockets for upper-atmosphere research had been under development in the United States, nothing compared with the V-2 for payload capacity and attainable altitude. The V-2 could not only reach more of Earth's upper atmosphere but also offered the tantalizing possibility of exploring the ultraviolet spectrum of the Sun, which had never been seen below about 2900 A; that part of the solar spectrum is blocked by ozone and oxygen from reaching instruments on the ground or in balloons. Space aboard V-2 rockets for installing scientific instruments was made available to several research organizations, including NRL, and launches began in April of 1946 at White Sands Proving Ground in New Mexico. David DeVorkin's 1992 book, *Science with a Vengeance* (Springer-Verlag), not only documents the history of V-2 science but also conveys the excitement and the sense of exploration we all felt.

It was Tousey's ingenious scheme for catching sunlight and feeding it into the spectrograph that was key to the success of his group in recording the first ultraviolet spectrum of the Sun. The V-2 rocket not only rotated about its axis during flight, but it also yawed and tumbled, and the technology for keeping an instrument pointed at a target in the sky (in this case the Sun) was not yet developed. So Tousey devised the use of a tiny sphere of lithium fluoride (2 mm in diameter), mounted much like the ball of a ballpoint pen, that acted as a fish-eye lens to catch the Sun over a wide field of view and produced a tiny astigmatic image of the Sun in place of an entrance slit to the spectrograph. Although transparent in the ultraviolet down to Lyman-alpha (1216 A), lithium fluoride is a brittle crystal and is slightly water soluble; so the making and handling of the tiny sphere was a formidable challenge. Spectra were recorded on a strip of 35-mm film with a fluorescent coating on the front to make it ultraviolet sensitive and an electrically conducting coat on the back to preclude static electricity when the film was moved. The exposed film was wound into a cassette of armor-piercing steel about the size of a coffee mug so as to survive rocket impact. For the first NRL launch in June of 1946 Tousey's spectrograph was mounted in the conical nose of the V-2 warhead, but the massive warhead buried itself in a deep crater and was never recovered. At the suggestion of von Braun later spectrographs were mounted in one of the tail fins, because the V-2 could be blown apart during re-entry into the atmosphere, causing the lighter parts to be scattered about on the surface of the desert, where retrieval was more likely.

NRL's second V-2 launch on October 10, 1946, was successful, the spectrograph functioned, and the film cassette was recovered. It was a dramatic moment in a darkroom at NRL 10 days later when the film was developed and we had our first peek at the solar ultraviolet spectrum down to about 2100 A. The result, which was reported in November 1946 in *The Physical Review*, was only a modest first step, but it marked the beginning of science in space.

All together NRL spectrographs were flown on 10 V-2 rockets during 1946-48, of which 4 flights were successful. Ozone in the upper atmosphere is the principal absorber of extraterrestrial ultraviolet in the 2100-2900 A range, and oxygen is the main culprit at shorter wavelengths. Tousey's group used the V-2 solar spectra recorded at a series of altitudes to derive for the first time nearly the whole vertical profile of the ozone layer. After 1948 American-made sounding rockets began to replace the V-2s. In 1949 Tousey's group flew two spectrographs in an Aerobee rocket near sunset, when the slant path through the atmosphere was long, so as to improve the accuracy of the upper part of the ozone profile and thereby relate it to a theoretical model for the production of ozone due to solar irradiation of oxygen in that altitude range. These studies, led by Tousey, became the definitive work on the ozone layer. Later, Tousey's group used rocket-borne photoelectric detectors and monochromatic filters to obtain the first direct measurements of the vertical distribution of the nighttime airglow (e.g., the altitudes at which various luminescences are produced).

But solar Lyman-alpha remained the elusive Holy Grail that Tousey sought. Prior to December 1952 spectra had failed to reach that far into the ultraviolet. What would be the form and intensity of this most important line of the most abundant of all elements? On V-2 flights between 1948 and 1950 Kenichi Watanabe and Tousey had succeeded in proving the existence of solar Lyman-alpha by means of a device that, during flight, exposed a thermoluminescent phosphor behind lithium fluoride and calcium fluoride windows. The lithium fluoride was transparent to Lyman-alpha, whereas the calcium fluoride was not. The intensity of Lyman-alpha inferred from that experiment was later confirmed by data obtained from spectra.

AFTER INSTRUMENTS COULD BE AIMED

The first spectrographic detection, albeit near threshold, of solar Lyman-alpha was obtained in December 1952 by a University of Colorado group using a biaxial Sun tracker to keep their instrument pointed at the Sun. Tousey, always eager to adopt any advance in technology, attached an NRL spectrograph to one of Colorado's biaxial Sun trackers and recorded well-exposed spectra of the solar Lyman-alpha feature in February 1954. It was found to be an intense emission line with wide wings. Tousey had made several improvements in solar spectrograph design, aimed at achieving higher spectral resolution and more ultraviolet throughput. Because the Colorado Sun tracker eliminated the need for a wide field of view, the lithium fluoride sphere could be replaced by an entrance slit.

As a result of these advances in instrumentation Tousey's group also succeeded in recording more than a thousand absorption lines of the solar photosphere, mostly longward of 2000 A, and they found nearly 200 emission lines in the extreme ultraviolet down to 977 A. In fact, NRL spectra obtained in 1955 showed that the solar spectrum shortward of 2000 A is composed principally of emission lines from the chromosphere. In 1959, using a pre-disperser to largely eliminate stray light of longer wavelengths, Tousey's group obtained a clean spectral profile of the broad Lyman-alpha feature. They also obtained an excellent image of the Sun in Lyman-alpha light (i.e., a spectroheliogram) for comparison with images obtained simultaneously at longer wavelengths with ground-based instruments.

In April 1960 Tousey's NRL colleagues Herbert Friedman and Richard Blake photographed the first X-ray image of the Sun in wavelengths shorter than 60 A by an amusingly simple device; for a lens they used a pinhole covered with a filter of aluminized Mylar. In 1961 Tousey's group pushed the limit of the solar spectrum down into the soft X-ray region (specifically to 171 A) by using a spectrograph with grazing-incidence optics, together with an unbacked aluminum foil to reduce scattered light by blocking all radiation longer than about 800 A. That yielded the first identification of the Fe XVI coronal lines in the solar spectrum. Then in September 1963 they succeeded in pushing the limit of the solar spectrum down to 30 A.

Also in 1963 Tousey's group was the first to photograph the Sun's outer white-light corona without the help of a solar eclipse. This was accomplished with an externally occulted coronagraph in a rocket, and the photographs showed a long straight streamer extending to 10 solar radii. A number of subsequent flights were made, including some only a day or two apart in 1968 and 1969, from which it became evident that surprisingly large changes in the corona can occur within only a day or two, a phenomenon that ground-based photographs of coronae during solar eclipses had not revealed.

ORBITING SOLAR OBSERVATORIES

To monitor variations in solar radiation on various time scales really requires an instrumented satellite, not rockets. The National Aeronautics and Space Administration (NASA) selected Tousey to be the principal investigator for both an extreme ultraviolet spectroheliograph and a white-light coronagraph to be carried aboard spacecraft of the *Orbiting Solar Observatory* (OSO) series. The main goals of Tousey's NRL group were to find out (1) how solar flares produce effects in Earth's atmosphere that cause radio blackouts and (2) how flares and solar variability relate to the 11-year sunspot cycle. In 1965 an NRL spectroheliograph aboard OSO-2 monitored three solar ultraviolet emission lines by mechanically scanning the images with tiny Bendix photomultipliers. Although the OSO spacecraft provided solar pointing with a short-term stability of better than 5 arcsec, the image resolution of the scanning scheme was rather coarse, yielding only about 30 pixels across the Sun's diameter. Even so, the results showed where the active regions on the Sun were.

Tousey's coronagraph was flown on OSO-7 and was outstandingly successful. It provided nearly daily monitoring of the white-light solar corona from October 1971 to July 1974. This made it possible to record transient changes in the corona on a wide range of timescales. The first great transient to be observed was in December 1971, when clouds of solar plasma were observed traveling out through the corona at 1000 km/sec.

SKYLAB AND THE APOLLO TELESCOPE MOUNT

Tousey was named principal investigator for four solar experiments to be done aboard an Earth-orbiting facility called *Skylab*, which was part of NASA's manned space program following the Apollo lunar landing program. The *Skylab* project began in 1965 and *Skylab* was launched into orbit with a Saturn V rocket on May 14, 1973. The modus operandi of space research had changed dramatically from the era of the V-2 rockets in the 1940s, when experimenters made their own instruments, took them (plus a tool kit) to the launch site, and personally installed them into a rocket. Responsibility for the management and funding of American space research had been assigned to NASA when that agency was created in 1958. By the 1970s space science projects had become very complex bureaucratic enterprises involving contractors, subcontractors, managers, committees, science teams, engineers, design specifications, design reviews, mission planning, proposals, contracts, budgets, grants, cutbacks, changes of course, and cancellations. The tortuous evolution of NASA plans for solar research, from the OSO series to *Skylab*, was only a small part of that story, but it took nearly a decade and is recounted by Tousey in the April 1977 issue of *Applied Optics*. He wrote,

> We have weathered crisis after crisis, found solutions to seemingly unsolvable problems, and learned a great deal in many new fields, especially about large scale engineering methods. I believe that we now understand a little better how engineers think; and on the other hand, I hope that the engineers have learned something of the stringent requirements of scientific experimentation and have come to understand the way scientists think. It has been a fascinating and highly rewarding experience.

Tousey evidently accepted these trends with equanimity.

Aboard *Skylab* a number of solar instruments, including Tousey's, were attached to a stabilized platform, called the Apollo telescope mount (ATM), which was able to keep instruments aimed precisely at a desired point on the Sun, regardless of disturbances, such as those caused by crew movement. The four *Skylab*/ATM instruments for which Tousey had leadership responsibility included the extreme ultraviolet spectroheliograph (S082A), the ultraviolet spectrograph (S082B), the photoelectric spectroheliograph, and the grazing-incidence solar spectrograph (S020). To eliminate stray white light that would otherwise overwhelm the ultraviolet Tousey developed large-area aluminum films, only a few micrometers thick, that could be placed near the focal planes of the *Skylab* spectrographs and that had good ultraviolet transmittance. These very thin films were floated off their glass substrate onto a coarse mesh screen, which provided enough support for the films to survive the *Skylab* launch.

Skylab observations were made during three astronaut visits of 29, 59, and 84 days. The project ended in February 1974, nine months after launch. Tousey rarely used superlatives, but in 1977 he wrote, "the ATM observations alone were of extraordinary value, and in quantity they were staggering." Tousey retired from NRL the following year, but continued to participate in the analysis of the *Skylab* results. In collaboration with Charles Brown (NRL) and Charlotte Moore Sitterly (U.S. Bureau of Standards) he worked on line identifications in the high-resolution solar spectrum obtained from *Skylab*. Images of the spectra as well as tables of line identifications were published by NRL, as were spectroheliograms of remarkably high resolution.

This biographical memoir is based partly on my personal recollections, partly on Tousey's scientific publications, and partly on input from other people. I am especially indebted to Professor Donald Osterbrock of the University of California, Santa Cruz; Joanna Tousey of the Tucson Symphony and Arizona Opera; Martin Koomen of NRL; and Herbert Gursky of NRL for supplying or calling attention to helpful background material. My personal debt to Richard Tousey is large: Working with him on the quest for the solar ultraviolet spectrum in the 1940s led me to devote my career to astronomical research, a career that took me from NRL to new challenges at Mount Wilson and Palomar observatories, later at Lowell Observatory, and finally where I am now at the University of Washington in Seattle.

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