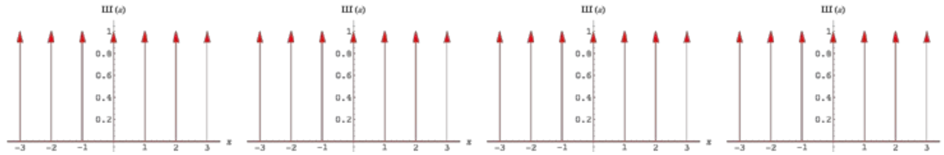


> It is an amazing thing that the human brain, which is a tiny subset of the material universe, composed of hydrogen atoms created in the Big Bang, oxygen atoms synthesized inside long-gone stars, and some impurities, can observe the rest of the Universe. How can the part comprehend the whole, let alone begin to consciously manipulate it, as we are doing?
>
> - Ron Bracewell (1986)

## Ronald N. Bracewell (1921-2007)

Ron Bracewell was born and educated in Sydney, Australia, and later obtained his Ph.D. at Cambridge University. During World War II he designed radar equipment for the Allies as part of the CSIRO Radiophysics Laboratory in Sydney. After the war he and his colleagues established Australia as a world leader in the nascent field of radio astronomy. Bracewell's particular contributions came from his background in physics, electronic engineering and mathematics and involved the mathematical theory of how the signals from many antennas can be combined to form a detailed radio image of a small patch of the sky. This theory was developed in the 1950s and 1960s and is at the heart of how the Jansky Array still operates in the 21st century. Bracewell also applied this same mathematics to the task of constructing X-ray images of the human body using computer-assisted tomography (CAT) scans, and was honored for his pioneering role in that medical application. From 1955 onwards his career was spent as a professor at Stanford University, where over a five-year period he built a cross-shaped array of 32 10-ft-diameter dishes in order to study the radio sun and further his mathematical techniques. He also published several fundamental textbooks, which still today are used and admired for their clarity and elegance.

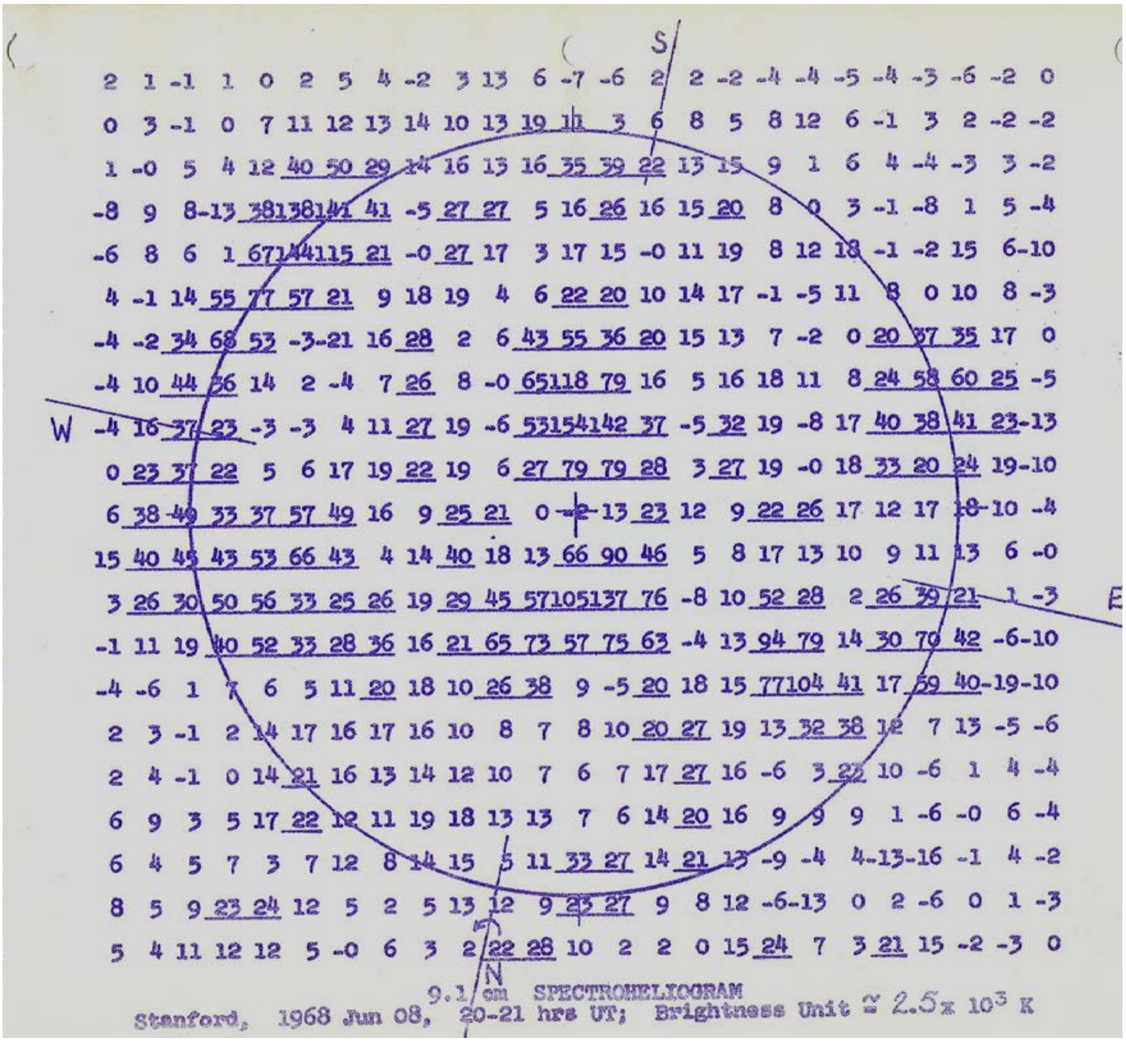
Bracewell was a polymath, for example also publishing books on trees and on the search for extraterrestrial intelligence (SETI). He had a particular fondness for sundials and designed and built several near Stanford, including one at his radio observatory and one still on a campus building. All who interacted with him were impressed not only by his mental acuity, but his genuine friendliness.

## The Stanford array and the signatures

Each of the concrete piers that form part of the Bracewell Radio Sundial originally supported one of the 10-ft-diameter dishes (each identical to the one on display) of the array that Bracewell operated on the Stanford campus for over a decade beginning in 1961. Thirty-two dishes were arranged in the form of a cross with 400-ft-long arms and together they continuously monitored the variable radio emission from the sun at a wavelength of 9 cm, making one complete image of the sun (containing about 100 pixels) every day (an example is shown on the next page). Besides increased knowledge of the sun, these data served the very practical purpose of warning NASA and the military of impending problems associated with solar bursts, such as damaging earth satellites and endangering moon-bound Apollo astronauts of that era.

Each dish of the array was mounted on a 5-ft-tall concrete pier. Bracewell invited all visitors to his radio observatory to wield a chisel and hammer and inscribe their name on the side of a pier. Thus over a 20-year period he collected over 200 signatures in his unique "Guest Book." When painted white (see the photo of Bracewell doing just that in the 1970s to the present "Noon" pier), they looked quite handsome, not unlike a team-autographed baseball, but in this case the "team" represented many of the most important astronomers of the mid-20th century. Among the signatories were two Nobel Prize winners, observatory directors from around the world (including traditional optical observatories), and a large fraction of the pioneers who established the vibrant field of radio astronomy after World War II.

By 1980 the array with all of its historical signatures had become obsolete and was abandoned to the vicissitudes of weather and poison oak (see the 2005 photo below). In 2010 the idea arose to save many of the piers and two years later ten of the most interesting were cleared of brush, sawed off, and shipped to New Mexico. A careful census reveals about 215 total signatures here, including some in Chinese, Russian and Greek.


A typical 9.1-cm wavelength radio map of the sun made with the Stanford array (for 8 June 1968). The circle represents the optical sun. The numbers give the radio intensity at each spot on the sun. Notice that on this day strong radio emission came from several regions across the solar atmosphere.

# Commemorative Markers on the Sundial

Scattered around the sundial are three small markers in the shape of a dish. These refer to the locations of three observatories related to this sundial: Stanford University, where Bracewell's array was; Green Bank, West Virginia, where NRAO's first radio dishes were located in the late 1950s and where the Byrd 100-meter-diameter dish is still located; and the brand-new, international ALMA array in the high-altitude Atacama desert of Chile. When the ball's shadow indicates the same time as does the marker's location, then it is solar noon at the corresponding observatory.

Other small markers (squares) honor important dates in the history of radio astronomy and of NRAO. The center of the ball's shadow crosses a given square on the very date that is being commemorated, as indicated on each marker. The significance of these dates are mentioned in the following very brief history of radio astronomy, in which *[*marker*]* indicates that the event or person or place is commemorated with a small marker as part of the radio sundial.

In 1933 American Karl Jansky [*marker*], for whom the Jansky Very Large Array is named, accidentally discovered radio waves coming from our Milky Way Galaxy [*marker*]. Although this was the beginning of what later became radio astronomy, except for follow-up observations by another American, Grote Reber, little attention was paid to the discovery until the widespread development of radar during World War II. In 1942 in England Stanley Hey accidentally discovered that the sun also emitted strong radio waves [*marker*]. After the war research groups around the world studied in detail the Milky Way radiation and the solar radiation. They also found that certain sky positions emitted copious radio waves and yet usually showed nothing on a photograph - these became known as "radio stars," now called radio sources. Three of the most famous of these (see Fig. L) were Cas A (later found to be the remnant of a 17th-century supernova explosion); Cen A (later understood to be a distorted galaxy harboring a giant black hole in its center); and Cyg A (another very peculiar galaxy with an active galactic nucleus and at a huge distance). The JVLA still often conducts observations of these radio sources.

A major problem for early radio astronomy was that finely detailed images of the sky could not be constructed with a single antenna. Interferometers, in which two or more separated antennas are linked, were therefore developed, in particular at Cambridge University under the leadership of Martin Ryle, as well as in Sydney, Australia, where Joseph Pawsey led a large group that included Ron Bracewell [*marker*]. Interferometers have continually been improved until today, with ALMA in Chile [*marker*] and the JVLA around you (dedicated in 1980 [*marker*]) now being the world's most sensitive and versatile.

The United States at first lagged in the development of radio astronomy, with the one exception of the discovery of the 21-cm wavelength hydrogen line by Harold Ewen and Ed Purcell in 1951 [*marker*] - this "fingerprint" of hydrogen remains today one of the radio astronomer's most valuable tools for studying the Universe. In order to catch up, the National Radio Astronomy Observatory (NRAO) was created in 1956 by the National Science Foundation and a consortium of universities [*marker*]. First (and still) located in Green Bank, West Virginia [*marker*], NRAO continues to lead US radio astronomy over half a century later.