The National Radio Astronomy Observatory invites you to the opening of

The Ronald N. Bracewell Radio Sundial

Monday, September 23rd, 2013

At the Karl G. Jansky Very Large Array Radio Telescope Observatory
on the Plains of San Agustin
Socorro, New Mexico, USA

Schedule of Events

Sunday, September 22nd,2013

6:30 PM	Dinner for Donors and Supporters at the home of Miller and Libby Goss 1211 Vista Drive, Socorro Please RSVP to Miller Goss at mgoss@aoc.nrao.edu .

Monday, September 23rd, 2013

10 AM - Noon	VIP Tours at the VLA (Note: Driving time from Socorro to the VLA is 1 hour)
Noon – 1:00 PM	Break (Please bring your own lunch as the VLA no longer has a cafeteria)
1:00 PM – 2:00 PM	Opening of the Sundial including a number of short talks by guests
2:00 PM – 3:00 PM	Time to explore Sundial, Visitor Center Exhibits, and Gift Shop
3:00 PM – 4:00 PM	Reception for guests and local staff (Refreshments will be served)

How to Get There

The Very Large Array and VLA Visitor Center are located 50 miles west of Socorro, New Mexico on the Plains of San Agustin, on U.S. Highway 60. From U.S. Highway 60, look for Mile Marker 93. Turn South on NM highway 52. Signs will point you to the VLA Visitor Center.

GPS Coordinates
34°04′43.497″N
107°37′05.819″W

The nearest major airport is Albuquerque International (ABQ), 2 hours and 10 minutes NE of the VLA.

Where to Stay

For those wishing to stay in Socorro (1 hour east of the VLA), the Socorro County Chamber of Commerce provides a list of Hotels, Motels, and Bed and Breakfasts here:
http://www.socorro-nm.com/Lodging.htm

For More Information

For more information about visiting the VLA, please see:
http://www.nrao.edu/index.php/learn/vlavc

Mon 23 Sept 2013

At 1302:41 MDT = solar noon (22 hrs after the autumnal equinox[1]), this talk will be interrupted for the official "First Shadow" cutting of the ribbon

Remarks at the Dedication Ceremony for the VLA Bracewell Radio Sundial

— Woody Sullivan (and Miller Goss as Emcee)

My pleasant task today is to tell you a little about the genesis and history of this project, as well as about the key players, and then a bit about the unusual features of this "World's First" radio sundial. At some point in my talk, it will be precisely solar noon, when the sun is due South and highest in the sky — we will then interrupt the proceedings for 2-3 minutes for the Official Opening.

Our story starts in 2004 with **Bob Lash**, who fought to save the antennas in two major, but long unused, arrays at Stanford University as historical objects — these had been used by Ron Bracewell for research in the ~1960s, 70s, and 80s.

But despite a major internet campaign and many letters to Stanford and local newspapers, Stanford went ahead and destroyed all the dishes. Now along comes **Miller Goss**, who is working on a double biography of Australian pioneer radio astronomers Joe Pawsey and John Bolton. As part of this he dug into the archives that Ron Bracewell had left behind in his home after his death in 2007, and through Ron's son Mark, he meets Bob Lash, who mentions that although the dishes are all gone (except one, which you see to your left), there still remain dozens of concrete piers that once supported the antennas AND these piers contain the "signatures" of hundreds of astronomers collected over the 1960s and 1970s.

[1] The previous day of the equinox was not chosen because it was a Sunday. The day was sunny and breezy. About 50 persons attended, including Tony Beasley, director of NRAO; Ron Bracewell's children Mark and Wendy; Moreau Jansky Parsons, daughter of Karl Jansky; Stuart Pawsey, son of Joe Pawsey; and two signatories, Barry Clark and Barney Ricketts.

Bob said "Can't we somehow save these? Would NRAO be interested in displaying a few?" But how to display them, and who would pay for their rescue, transport, etc., etc.? Now in early 2010 Miller told **me (WTS3)** about this crazy possibility, and, as is my wont, I suggested that perhaps a couple of piers could be incorporated into some kind of a sundial. You see, it is my nature to interpret anything that casts a shadow as a sundial....So I came up with a tentative design and with that Bob raised donations via his Friends of the Bracewell Observatory Assn. and Miller looked for additional support — before you knew it, we had a budding project. The Friends money was for the major task of bush—whacking (see your handout for a photo of a poison—oak—encrusted pier), sawing off and removing the 10 piers and one dish that we eventually brought from Silicon Valley to the Plains of San Augustin in August of 2012.

Thank you, Bob, for your vision and hard work.
And thank you, Miller, for your masterful management of this project, not unlike the ringmaster at a seven—ring circus.

Now enter two more NRAO characters whose contributions have been indispensable: First, **Judy Stanley**, head of Education and Public Outreach for the VLA, who, as just one example, ended up cleaning all of the piers and restoring all of the signatures to the great condition that you see today. Second, **Guy Stanzione**, head on—site Engineer here at the VLA, who from the start has gone many extra miles in shepherding, designing, ordering (when was the last time that NRAO ordered an 18—inch stainless—steel sphere from China?), and overseeing the construction of this strange beast, aided by many other VLA staff.

Thank you, Judy and Guy, for your ideas, your persistence, and your superb execution.

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I have designed many public sundials over the past two decades (including even one on the Mars Rovers), but this one has been special in many ways. For there are three areas that beautifully intertwine between Ron Bracewell and me.

These are: (1) radio astronomy and its history, (2) SETI (the Search for Extraterrestrial Intelligence), and (3) sundials.

On the back page of your color brochure, as well as in another handout, you can read about Ron and his amazing contributions not only to radio astronomy, but also to medical imaging (in particular, CAT scans). Ron was one of the pioneers of Australian radio astronomy, co—authored the first textbook in the subject in 1955 [HOLD UP my copy of Pawsey & Bracewell], then came to the US in the mid—50s and remained at Stanford for the rest of his life. He developed the mathematical techniques that make possible still today antenna arrays such as the Karl G. Jansky Very Large Array that now surrounds us. His 1972 book on *The Fourier Transform and its Applications* [HOLD UP] was the Bible for many generations of graduate students and their professors — here's an excerpt I came across from the Diary of one young Assistant Professor who in 1974 was teaching his first course on "Radio Astronomy Techniques": [DIARY quote] "Spent the entire afternoon reading Bracewell's book — it is a model text for learning and reference." And 40 years later I still consult that very same book not just for its technical mastery, but also its elegance and clarity.

Ron also wrote pioneering papers in the early days of SETI, as well as a very successful popular book, *The Galactic Club*, and in fact it was through SETI that I first became a colleague of his in the late 1970s. He also had a deep interest in history of all sorts, especially in the Classical Ages, and was very supportive of my long—term project on the history of early radio astronomy.

And of course one aspect of his sense of history — though I doubt that he <u>even he</u> could have foreseen this — is that now in 2013 we have preserved today the names of over 200 astronomers and engineers who, when they visited his array in the 1960s and 1970s, were invited to wield a hammer and to chisel their name out of a concrete pier — who could refuse? Your handout lists them all — please help us identify those with a "?" or where we have made errors. We also provide mini-bio's for a few — there are many luminaries among them, and we are fortunate to have two Signers present today — Barry Clark and Barney Ricketts. Would you please raise your hands?

Ron's passion for sundials started in the 1960s and manifested itself in several ceramic sundials, a dial amongst his antennas using a large gear as its main element, a lovely dial at the Stanford Center in Florence, Italy, and a fascinating and technical wall dial, still extant on the Stanford Campus.

My own passion only began in 1992 when I designed and oversaw fabrication and installation of a large wall sundial for a new Physics/Astronomy Bldg. on my home campus of the U. of Washington. Only in the late 1990s did we learn of our common passion and we exchanged several letters about the subject.

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So you see that for the design of this sundial, I had a personal investment in making it something that would honor him and, more particularly, that he would have been intrigued by. I started with the piers and the signatures, but then given the dial's location and Ron's career, I wanted somehow to make it a RADIO sundial. For a short while actual electronics detecting either radio or optical waves from the sun was considered, but such an approach was deemed just not feasible for years and years of service in all weather and for every brand of visitor. The final decision was to incorporate strong radio sources into the design, as well as commemorative markers important for the history of radio astronomy and of NRAO.

Now a sundial can tell you many things — time of day of course, but also date of the year and even more obscure things like how many hours until sunset, but I decided to have this dial work with **sidereal time**, time by the stars, what astronomers use to locate stars and radio sources alike. But rather than just tell you the sidereal time right now, by following the procedures on p. 3 of the color brochure, you can use this sundial to locate in the sky at this moment any of three strong radio sources, each of which from the days just after World War II has played and continues to play a major role in astronomy: Cas A, the remnant of a supernova that blew up in the 17th century; Cyg A, an active galaxy whose light left some 600 million years ago; and Cen A, a strange radio galaxy much closer to us. By lining up the correct disk with the large sphere, you are looking precisely where the source is located at that moment, that is, you are in the sphere's "radio shadow" — if only you had an antenna in your head! And — a technical comment here for the astronomers — because the declinations of these sources are well outside the range of the Sun every year, the patterns on the ground made by the disks of these 3 radio sources are indeed very strange for those used to looking at the familiar solstices and equinoxes markers on many dials.

Also, one page on your handouts gives details of special markers that are scattered amongst the dials. Seven brass rectangles commemorate

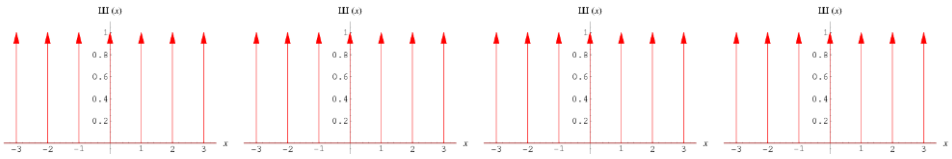
important dates in the history of radio astronomy and of NRAO. For instance, when the shadow of the sphere crosses one of these markers, it is Ron Bracewell's birthday; for another, it is the date of the announcement of Jansky's discovery in 1933; and for another it is the discovery of the 21—cm Hydrogen line. And three further dish—shaped markers are situated such that when the shadow aligns with their hour line, it is then solar noon at that observatory (not here). For instance, noon occurs 58 minutes later at Stanford than it does here at the VLA.

Sundials traditionally have mottos, and this dial in fact has two of them:

> I measure the hours by our nearby star,
> While the dishes around you look light—years afar.
>
> AND
>
> A complex array transforms radio skies;
> A creeping shadow shows us time flies.

It has been an honor and just plain fun to work on this project. So don't worry that you can't use your cell—phone out here to check the time — the Ronald Bracewell Radio Sundial, guaranteed accurate to about one minute, is at your service!

Thank you.



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.

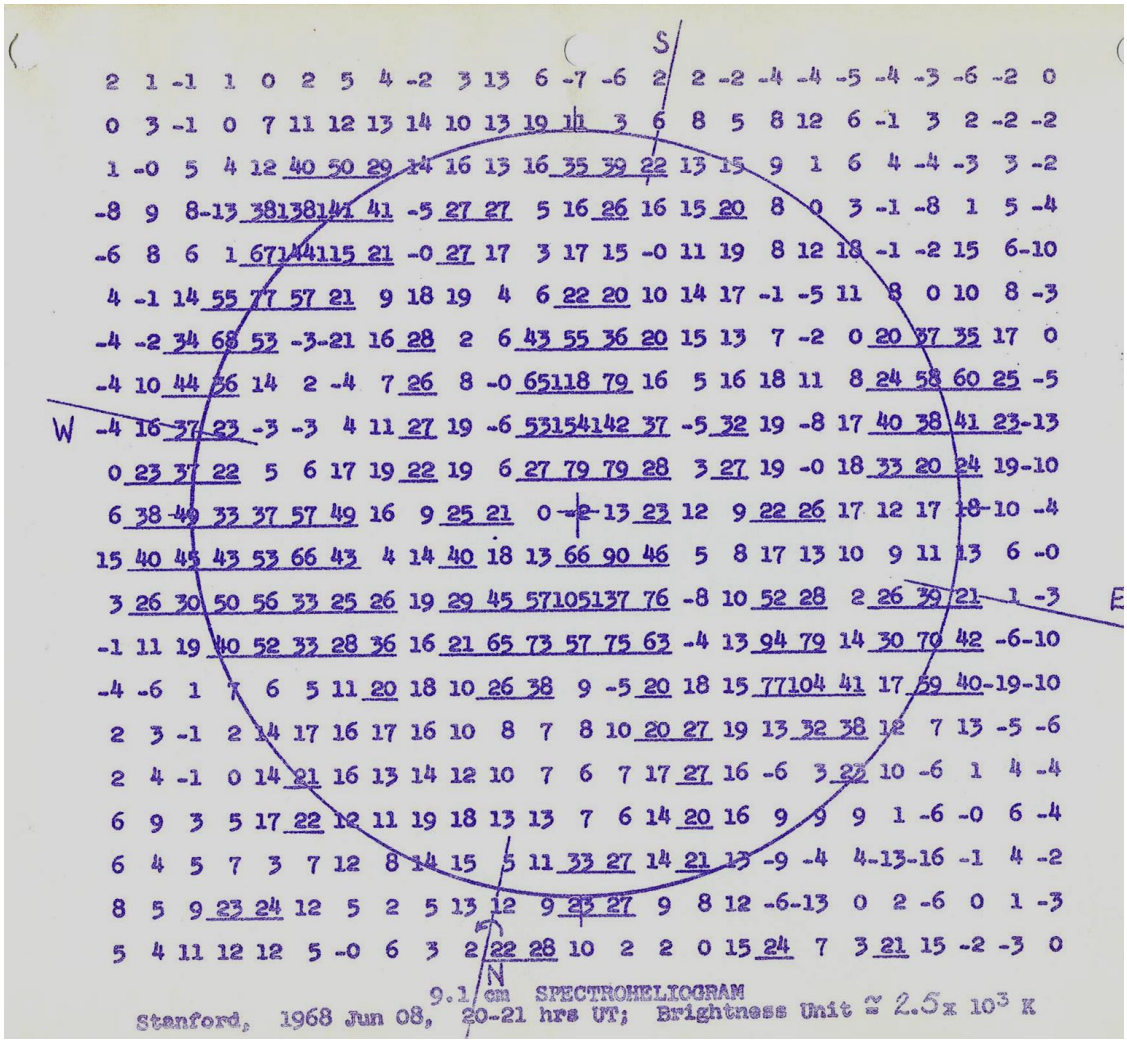
The Stanford array and the signatures

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.