AVN Training Program

History of radio astronomy in South Africa and origins of the SKA and AVN Projects

George D Nicolson

Overview

- During the 1950s, ***a national policy decision was taken NOT to support radio astronomy*** in South Africa, because Britain and Australia were ahead and well established in this field. It was also very costly to establish new facilities.

- Because of this, one attempt at the University of Natal failed. There were, however, two other streams of development in radio astronomy that were successful:

  - During the second half of the 1950s, a group at the Rhodes University Physics Department started a program to observe the Sun using inexpensive home-built equipment

  - Subsequently in the early 1960s they initiated a second program to observe decametric radio emission from the planet Jupiter at frequencies in the 20 MHz range.

  - In 1961 I proposed using the 26m antenna at the newly constructed NASA Deep Space Instrumentation Facility , Hartebeesthoek, for mapping the Milky Way

- I will describe how these two programs came into being, how they developed separately and then converged when NASA withdrew from South Africa in 1974 and the Deep Space station became a full time radio astronomy observatory, and then subsequently a national research facility in 1988.

The SKA ERA.

- In early 2001 South Africa became an observer at planning meetings for the SKA.

- We submitted an ***Expression of Interest*** to host the SKA in May 2003, a ***Proposal to Host*** in 2005, and were *shortlisted with Australia in 2006*

- The ***Final South African proposal*** was submitted in ***2011*** and ***in 2012 hosting rights were awarded to South Africa.***

- The story is an unlikely one, and describes how against the odds, one of the smallest and under-resourced radio astronomy communities became the future centre for mid-frequency radio astronomy in the World, and the host for the mid-frequency SKA.

Overview - The origins of the AVN

- The idea of an ***African VLBI Network (AVN)*** had its origins in the South African design for the configuration, or layout, of the Square Kilometer Array (SKA).

- The requirements for the SKA called for an array of radio receptors with a ***dense core in the centre*** and ***spirals arms radiating outwards to 180 km***, and then an additional set of ***remote stations extending to 3000 km.***

- ***Why 3000 km?*** This is the size of North America and Australia. Nobody considered Africa which has potential for 5000-6000 km baselines.

- Our preliminary design for the SKA covered almost the entire African continent, with ***remote stations in eight African countries***, and ***extending to 5000 km***.

- This made ***VLBI*** a natural choice to for us to involve the eight countries in radio astronomy and to demonstrate that Africa ***could host the SKA.***

Connections to Radar Development during World War II

- It is now well known that radio astronomy grew rapidly after World War II, using former World War II radar equipment
- Scientists and engineers who developed radar returned to Cambridge and Manchester Universities in the UK, and to the Radio Physics Laboratory in Sydney, Australia, and laid the foundations for modern radio astronomy.
- These three groups dominated radio astronomy for a number of years, with the Netherlands, France, the US and other countries joining in later.

South Africa's role in radar development

- During the war, Britain contacted governments in Canada, Australia, New Zealand and South Africa to inform them about the invention of radar.
- They were provided with technical details and encouraged to develop radar systems for the defence of their own coastlines.
- In South Africa this project was led by ***Dr Basil Schonland,*** Director of the Bernard Price Institute and a world authority on the study of lightening.

Basil Schonland -
Scientist and Soldier

Basil Schonland was a brilliant South African scientist.

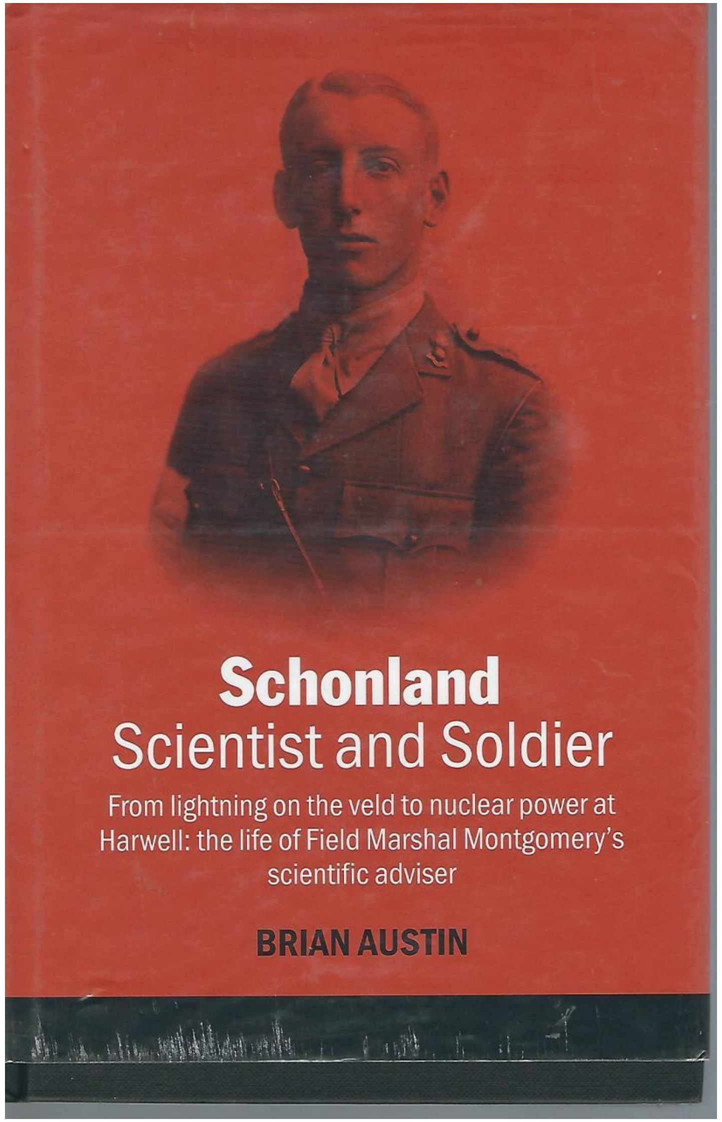
Educated at Rhodes University and Cambridge and after returning to South Africa he established an international reputation for his studies of the lightening process during 1920s and 1930s

He was appointed to lead the development and deployment of radar sets throughout Africa during Word War II

He became Field Marshal Mongomery's scientific adviser during the War, with rank of Brigadier

After the War General Smuts, PM of South Africa, asked him to establish the SA Council for Scientific and Industrial Research, CSIR, becoming its first President.

Subsequently, he became Director of the Harwell Nuclear Reactor Research Centre in the UK.



Early policy decision against Radio Astronomy Research in South Africa

- Schonland took an early decision ***not*** to support radio astronomy in South Africa.
- He felt that the UK and Australia had an unassailable lead by then and he knew the calibre of the people involved in those countries.
- He also argued that it would be far too expensive to then start from scratch.

South African radio astronomers abroad – Cambridge and Jodrell Bank

Because of this, a number of South Africans went abroad to study radio astronomy, both at Cambridge and Jodrell Bank

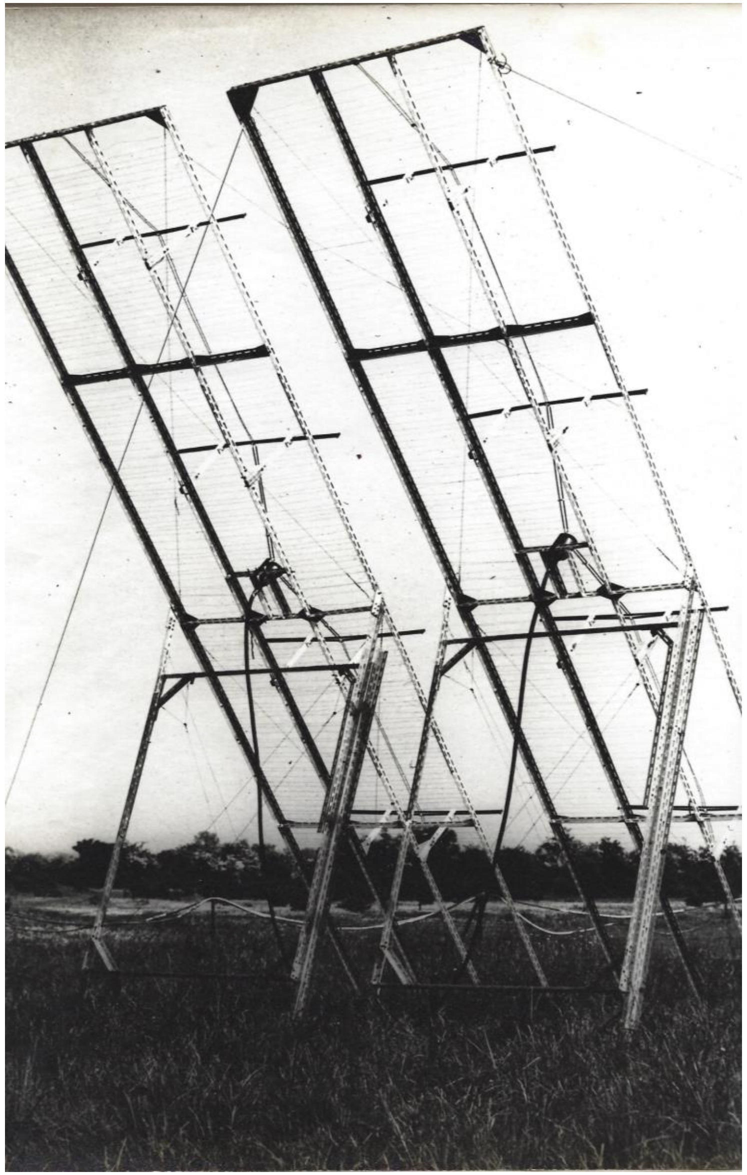
- The first was P. A. O'Brien, who studied for a PhD in Martin Ryle's group in the early 1950s at Cambridge.
- He was followed by others, among them Bernie Fanaroff who led and directed the successful SA proposal to host the SKA and to con structthe MeerKAT Telescope .
- Others went to Jodrell Bank, among them Raymond Vice , my one time boss.
- He was followed by WLH (Bill) Shuter, about whom we will hear later, and a succession of other South Africans.

The first South African Radio Astronomer – Pat O'Brien is fourth from left, rear row

Figure 8.9. The Cavendish radio astronomy group in front of their observing hut in 1954: (back row, l. to r.) John Thomson (joined group in 1952), John Baldwin (52), George Whitfield (53), Patrick O'Brien (50), Peter Scheuer (51), Robin Conway (53), Ronald Adgie (51), Charles Sharp (technician); (middle) Graham Smith (47), Martin Ryle (45), Antony Hewish (48); (front) Michael Turner (technician), John Shakeshaft (52), John Blythe (53), Bruce Elsmore (48).

Pat O'Brien: Pioneer of Synthesis Imaging

- Pat O'Brien was the first person use ***aperture synthesis interferometry*** to produce an image.
- He moved one of the interferometer elements manually throughout the day to generate different spacings!
- He then measured the amplitude and phase of the fringe patterns and was he first person to produce an image by Fourier inversion using both amplitude and phase.
- He did the Fourier transform ***manually*** using ***Lipson-Beevers strips***, strips of paper which had values of sine and cosine at regular intervals hand written on to them!!
- This was before computers became available.



The first paper on radio astronomy by a South African

This is probably the first paper on radio Astronomy by a South African, P.A. O'Brien, working at Cambridge in 1950 -1955.

He subsequently returned to South Africa, to the University of Natal and tried to set up a T-shaped antenna with a movable north/south element similar to one at Cambridge .

But Schonland's policy of not supporting radio astronomy prevailed and he left South Africa in 1961.

Ironically, it was just then that the opportunity to carry out radio astronomy research on a reasonable scale developed, as we shall see.

THE DISTRIBUTION OF RADIATION ACROSS THE SOLAR DISK AT METRE WAVE-LENGTHS

P. A. O'Brien

(Communicated by M. Ryle)

(Received 1953 March 27)

Summary

Measurements of the distribution of radio "brightness" across the solar disk have been made at wave-lengths of 1·4, 3·7 and 7·9 metres, using interferometers of variable aperture. The size of the emitting disk was observed to increase with increasing wave-length, the averaged equivalent temperature being reduced to 10 per cent of its central value at radii of 1·6 R_0, 2·2 R_0 and 2·8 R_0 for the wave-lengths 1·4, 3·7 and 7·9 metres respectively.

At 1·4 metres, using interferometers with axes inclined at various angles to the solar axis of rotation, it was shown that the shape of the Sun was approximately elliptical; the radial distance at which the brightness temperature was reduced to half was about 25 per cent greater at the equator than in the polar direction.

1. *Introduction.*—The earliest attempts to determine the distribution of radio "brightness" across the solar disk were based on eclipse observations at centimetre wave-lengths (1, 2), and such observations have now been made over the range 8·7 mm to 1·95 metres (3, 4, 5, 6, 7, 8). The results obtained in most of these experiments were not very conclusive, particularly at the longer wave-lengths where the large effective diameter of the Sun makes the observed eclipse curves insensitive to changes in the radial distribution of the emission.

The determination of the distribution by Fourier synthesis, using an interferometer aerial of variable aperture, was suggested by McCready, Pawsey and Payne-Scott (9), and this method was first used by Stanier (10) at a wave-length of 60 cm, and later by Machin (11) at 3·7 metres. In the interpretation of these results it was assumed that the emission was distributed over the solar disk with circular symmetry. The distributions obtained did not agree with those derived theoretically (12): at 60 cm the predicted limb-brightening did not occur and at 3·7 metres the amount of radiation from the outer corona was considerably greater than the theoretical values.

The present paper describes further experiments, using interferometers of variable aperture, during the period 1951 July to 1952 July. The method has been extended to wave-lengths of 1·4 and 7·9 metres, and further measurements have also been made at 3·7 metres. At 1·4 metres it has been possible to determine the distribution by a method which does not assume that the source has circular symmetry.

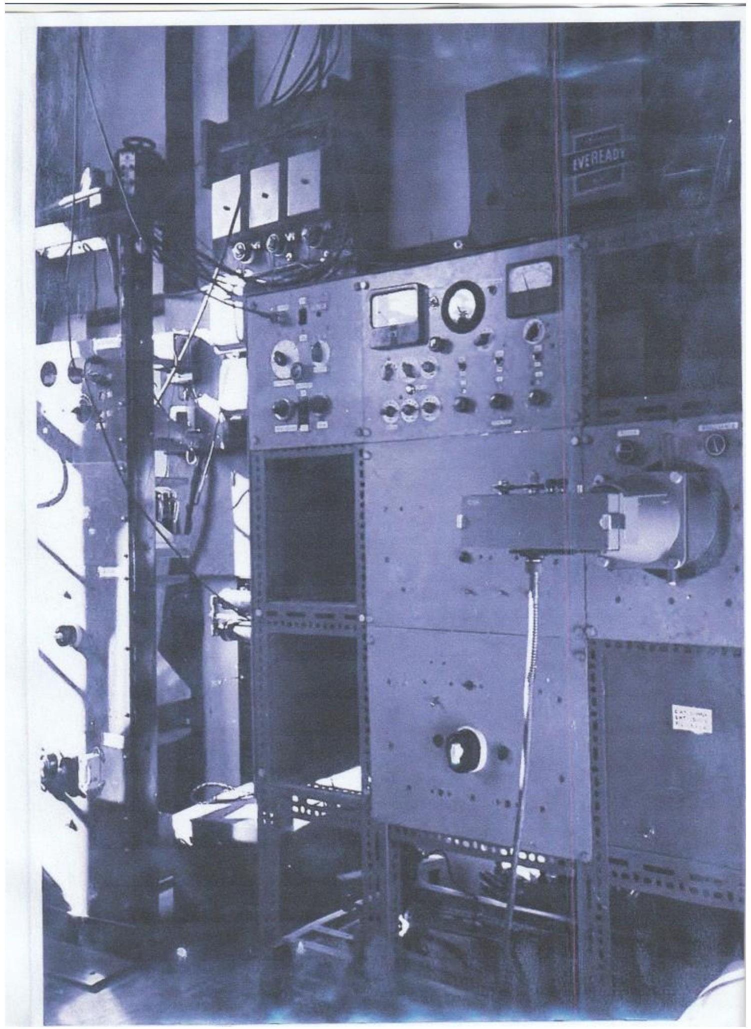
Radio Astronomy At Rhodes University

- While Pat O’Brien was trying to get funding to build a T-radio telescope in Natal, the Physics Department at Rhodes University began a program to observe isolated bursts of radio noise emanating from the Sun.

- WLH (Bill) Shuter completed an MSc using the equipment shown on the right in September 1958 and then proceeded to Jodrell Bank, where he competed a PhD.

- In the early 1960s, Prof Gledhill initiated a new program to study decametric radio noise from the planet Jupiter. In the course of this work, Gledhill made a break though in the understanding of Jupiter’s magnetic field .

- This work continued into the late 1960’s.



The Rhodes 22 GHz Radio Telescope

- In 1965, Bill Shuter returned to Rhodes and began a project to build a 2 metre 22 GHz radio telescope.
- He left after a short while and moved to Canada where he pursued a successful career in radio astronomy at the University of British Columbia.
- The small telescope project continued under Dr Eddie Baart who was later supported by Dr Gerhard de Jager, a South African who had recently completed a PhD at Jodrell Bank.
- The 2m telescope produced a number of MSc projects.

Construction of the Deep Space Station 51 at Hartebeesthoek 1960-61

At the beginning of 1960, I graduated with a degree in electrical engineering. I was offered a job at the NASA satellite tracking station station about 5 km NW of OR Tambo International airport. It was operated by the National Institute for Telecommunications Research NITR).

At the time, DR FJ Hewitt, the Director of NITR, was negotiating with NASA for the 26m station to be built here.

In his motivation to the South African Government, he clearly stated that it would be possible to use the facility for radio astronomy, allowing South Africa to make up for lost ground.

Patrick O'Brien's plans for a T-radio Telescope were not successful, although he met with Dr Hewitt, several times, including a joint visit to Ryle in Cambridge.

Hewitt's view favoured using the new NASA 26 m Deep Space facility for South Africa to start research in radio astronomy, and O'Brien was not a part of that.

Political obstacles

There were political obstacles, because the US Government were reluctant to build in South Africa and negotiate with the apartheid government.

However, the importance of the South African location was such that they eventually agreed, a contract was signed, and after a long search the Hartebeesthoek valley was chosen to complement stations in California and Australia, providing a network with continuous coverage.

The first foundations were poured on Christmas day 1960, such was the pressure to have the station ready by July 1961, ready for the first Ranger spacecraft launch to the moon.

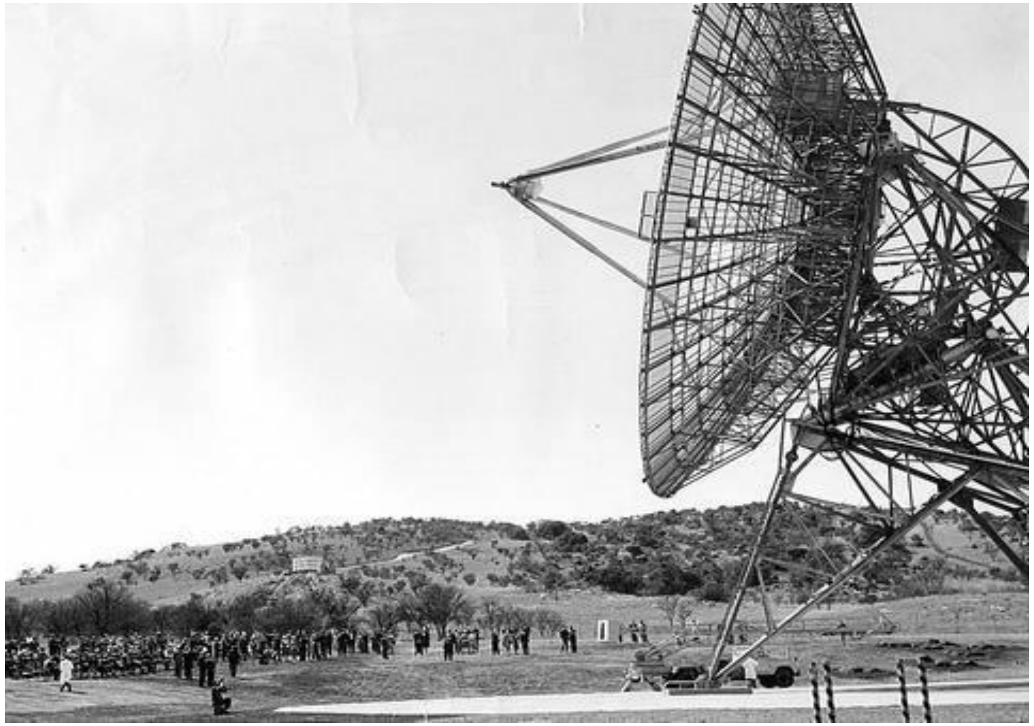
All this while, I was on the sidelines waiting to get a chance to get radio astronomy started, with encouragement from my Director, Dr Hewitt.

DSS51 ready for operation in July 1960.

The structural work was completed by Easter 1961, which is when I transferred to Hartebeeshoek . After three months an American team, working with the South African team had installed all equipment and the station was operational.

It was officially opened with much fanfare later in the year, with various dignitaries present.

Although invited, the US government and NASA representatives chose not to attend, as they did not want be associated directly with the Apartheid SA Government.



The early missions

The first missions were the Ranger spacecraft, which were designed to photograph the moon right up until they crash landed on the moon. The early launches were spectacularly unsuccessful.

Ranger 1: Launched 23 August 1961

Failed to leave earth orbit

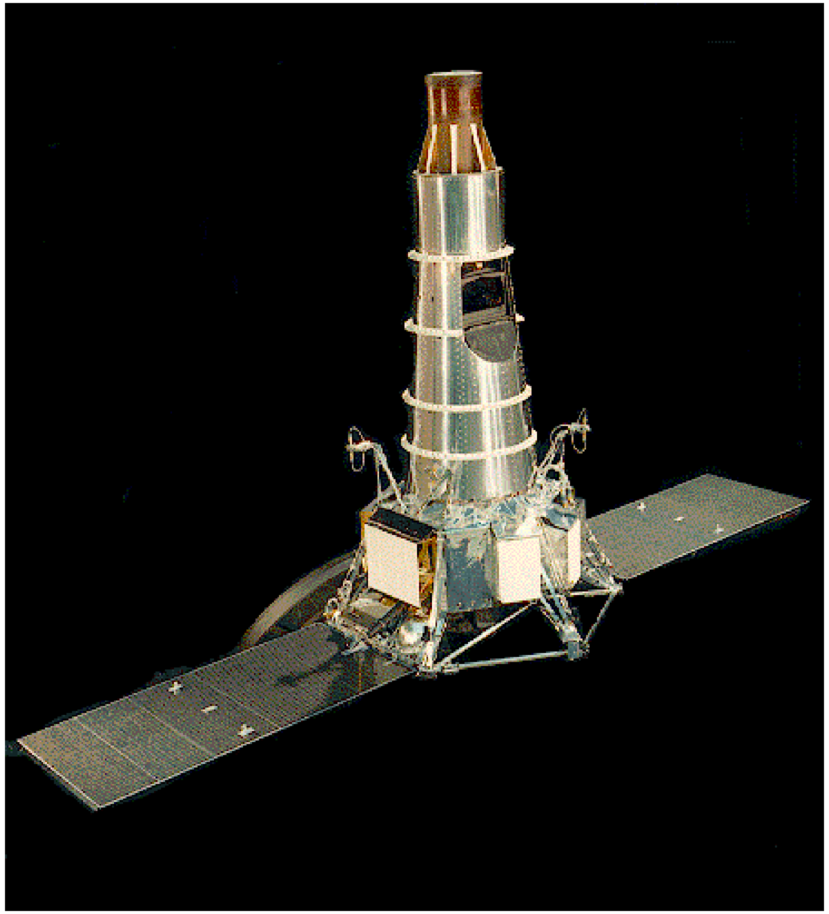
Ranger 2:Launched 18 November 1961

Failed to leave earth orbit

Ranger 3:Launched 26 January 1962

Earth contact lost, missed moon by 37000 km.

After successive failures the program was suspended for 1 year.

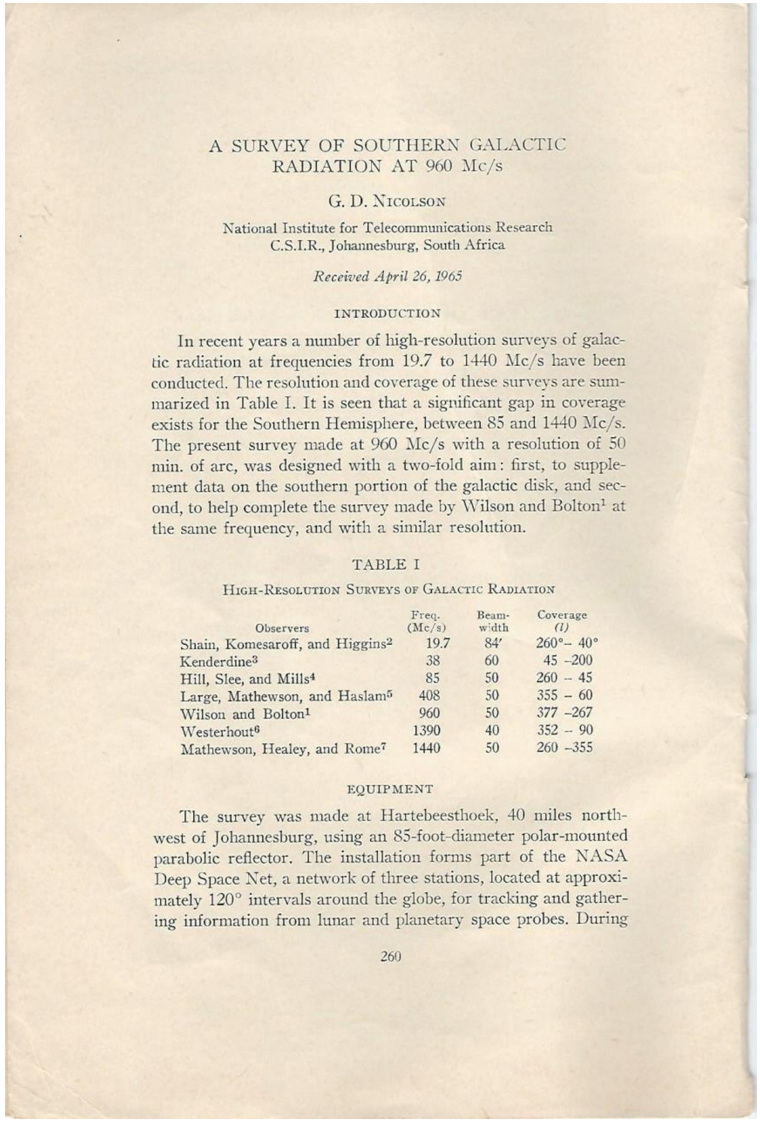


The start of Radio Astronomy at Hartebeesthoek

In 1960 and 1961 I had two meetings with Dr O'Brien to discuss possible projects.

At the second meeting he suggested a survey of radio emission from the Southern Milky Way, to complement a recent survey in the North. The station receiver operated at the same frequency, so minimal changes were needed.

I wrote a proposal to carry out the survey and built the additional components to convert the 26m antenna for operation as a radio telescope. I had free access to the telescope, and used the results for an MSc degree, and published the first paper in 1965.



A SURVEY OF SOUTHERN GALACTIC RADIATION AT 960 Mc/s

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Received April 26, 1965

INTRODUCTION

In recent years a number of high-resolution surveys of galactic radiation at frequencies from 19.7 to 1440 Mc/s have been conducted. The resolution and coverage of these surveys are summarized in Table I. It is seen that a significant gap in coverage exists for the Southern Hemisphere, between 85 and 1440 Mc/s. The present survey made at 960 Mc/s with a resolution of 50 min. of arc, was designed with a two-fold aim: first, to supplement data on the southern portion of the galactic disk, and second, to help complete the survey made by Wilson and Bolton[1] at the same frequency, and with a similar resolution.

TABLE I

High-Resolution Surveys of Galactic Radiation

Observers	Freq. (Mc/s)	Beam-width	Coverage (l)
Shain, Komesaroff, and Higgins[2]	19.7	84′	260°– 40°
Kenderdine[3]	38	60	45 –200
Hill, Slee, and Mills[4]	85	50	260 – 45
Large, Mathewson, and Haslam[5]	408	50	355 – 60
Wilson and Bolton[1]	960	50	377 –267
Westerhout[6]	1390	40	352 – 90
Mathewson, Healey, and Rome[7]	1440	50	260 –355

EQUIPMENT

The survey was made at Hartebeesthoek, 40 miles north-west of Johannesburg, using an 85-foot-diameter polar-mounted parabolic reflector. The installation forms part of the NASA Deep Space Net, a network of three stations, located at approximately 120° intervals around the globe, for tracking and gathering information from lunar and planetary space probes. During

260

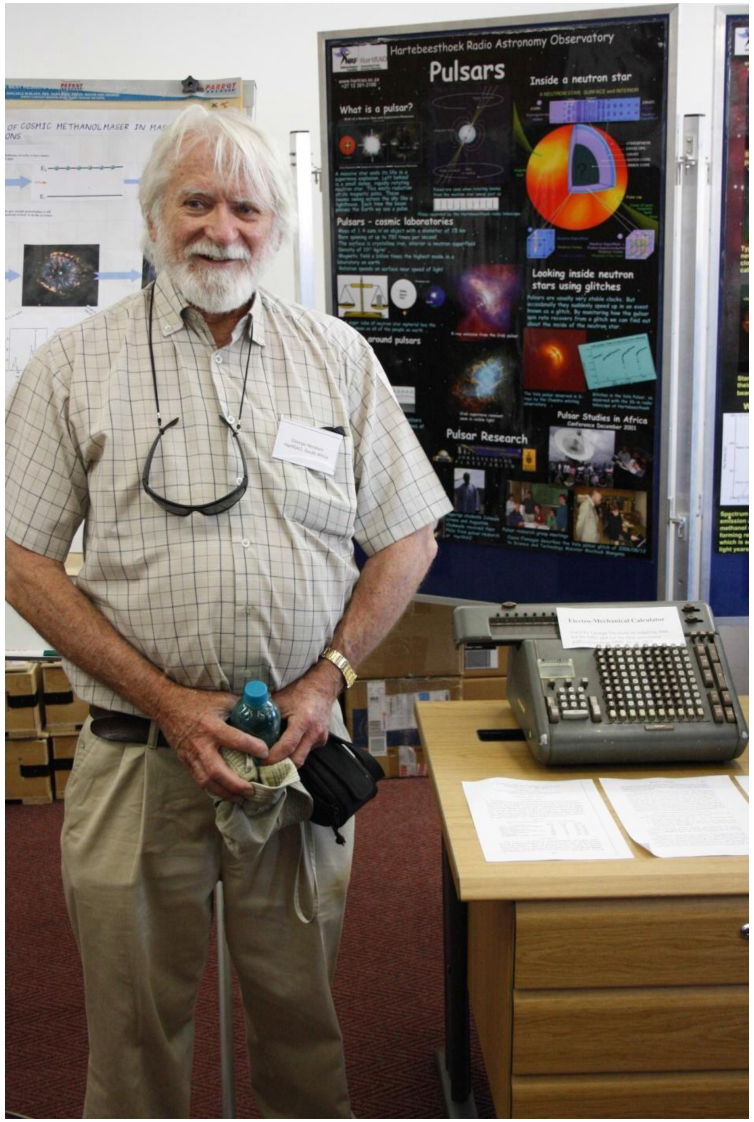
Pre-digital age technology

There were no digital computers that could be used for processing the data.

The map was made by scanning the telescope across the milky way.

I used a mechanical Friden calculator to process the data.

The results were in equatorial co-ordinates, and I created a graphical conversion chart by plotting equatorial coordinates onto a rectangular galactic coordinate grid using Lund Tables.



Antenna upgraded in 1964 to Cassegrain and new Maser receiver installed.

- In 1964 the telescope was upgraded to Cassegrain focus, and a new extremely sensitive receiver installed at the higher frequency of 2300 MHz.

- I developed a new noise adding radiometer, and started studying variability in quasars and other radio sources beyond the Milky way. I used this work for my PhD, and published a number of papers on this work.

The Start of VLBI in 1970

- A group in Australia, led by Dr David S Robertson, were among the first in the world to develop VLBI, using the NASA Deep Space Stations . Others used telescopes at various radio astronomy observatories.

- By then there were several NASA stations in Australia, three near Canberra, and the original one 1000km away in the Australian desert - ideal for starting VLBI.

- They also used the California DSS14 station, with 64m antennas at each end of the trans-Pacific baseline. This provided exceptional sensitivity at the time.

- The station computer was used to record data onto magnetic tape and the tapes which were correlated on a CDC mainframe computer in Adelaide. Once they were successful they invited us to join them and extend the southern hemisphere baseline to South Africa.

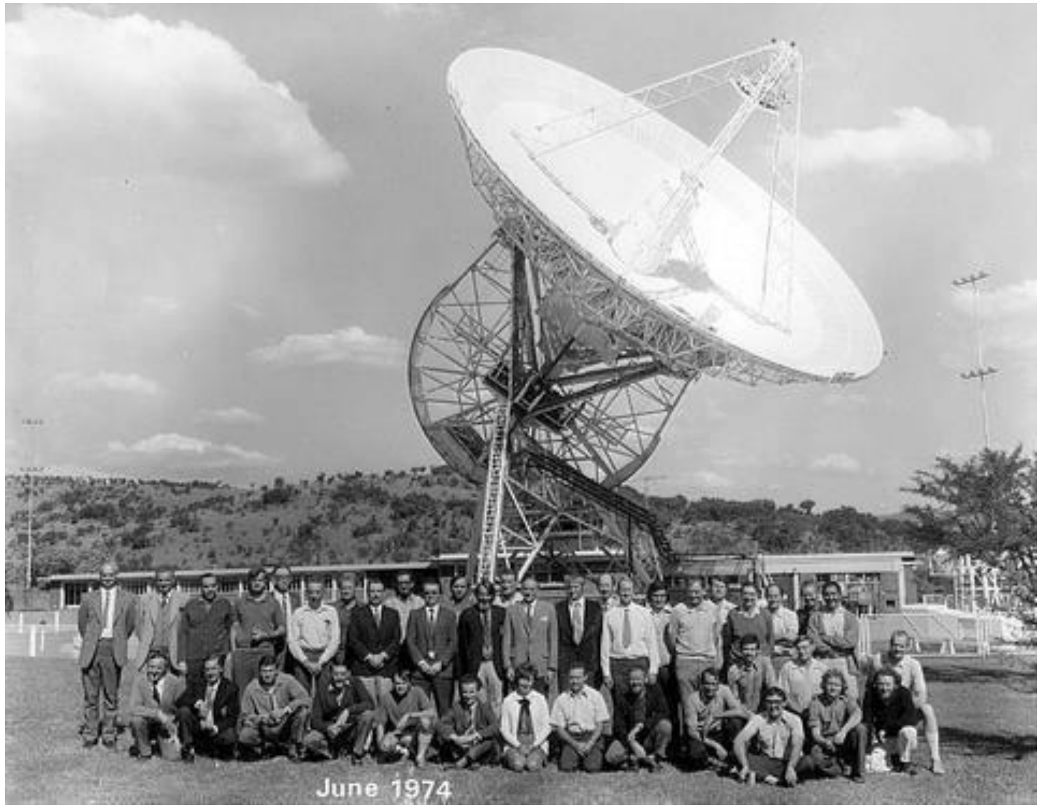
- We had a very successful program for nearly three years, studying objects that I had been observing to measure how they changed with time, and using VLBI to mesure how their angular size varied.

NASA withdraws from South Africa.

Political pressures that were building up in the US congress eventually forced NASA to close DSS51. By then NASA had enough resources elsewhere to support the Deep Space Program without a South African station.

It was a bolt out of the blue. Tracking staff at the station heard it on the 6 AM news service. I read it in the Rand Daily Mail, which quoted Dr Hewitt as saying ***"Although NASA operations would terminate, South Africa will continue the radio astronomy program."*** Good news for me, at least.

At the time I was the only radio astronomer and had one electronics technician working with me. We were paid by NITR/CSIR, so our jobs were safe.



Converting from DSS51 to HartRAO

- The last operation as a NASA station was in June 1974.
- JPL/NASA removed most of the equipment but left enough of the older equipment so that we could get going as a basic radio telescope.
- We applied for funds to retain eight of the technical staff to help maintain and upgrade the facility and HartRAO became operational in April 1975, but at the time it was known as RAO. The Hart got added later to make the name unique.
- Slowly we grew the research staff from two people to a peak number of ten by 1991, and added new receivers. We became a National Facility operating under the National Research Foundation (NRF) in 1990.
- We obtained the standard equipment for VLBI and resumed VLBI operations, starting with programs that carried on the earlier work carried out with Deep Space Network and eventually becoming members of international networks.

Key developments at HartRAO.

- The proposal to convert the station to a Radio Observatory was ambitious:
- We extended operation to multiple frequencies from 1.6 – 22 GHz.
- We developed equipment and capabilities for Spectroscopy, Pulsar Timing, Continuum Radiometry and VLBI.
- We invited Rhodes University, who had a small program in radio astronomy to join us in using the facility and gave them an allocation of 25% of telescope time.
- Over the years Rhodes University produced a number of MSc and PhD graduates, and used the telescope to map the entire sky at 2300 MHz. The played an important part in the automation and control of the 26m telescope and in software development.

Geodesy at HartRAO

- In 1996 we signed a contract with NASA to operate a precision GPS at HartRAO and in 2000 a second contract to operate their MOBLAS 6 Satellite Laser Ranging (SLR) station.
- We are now one of the few multi-technique geodetic stations in the world, and I believe one of the best –

- ***33 years of precision geodetic VLBI measurements***
- ***23 years of precision GPS***
- ***19 years of SLR***

- As a result of this HartRAO is now the reference datum for the South African mapping service – a tribute to the many dedicated staff who have made HartRAO a success.