# Innovation and Discovery

Queenstown

15 September 2016

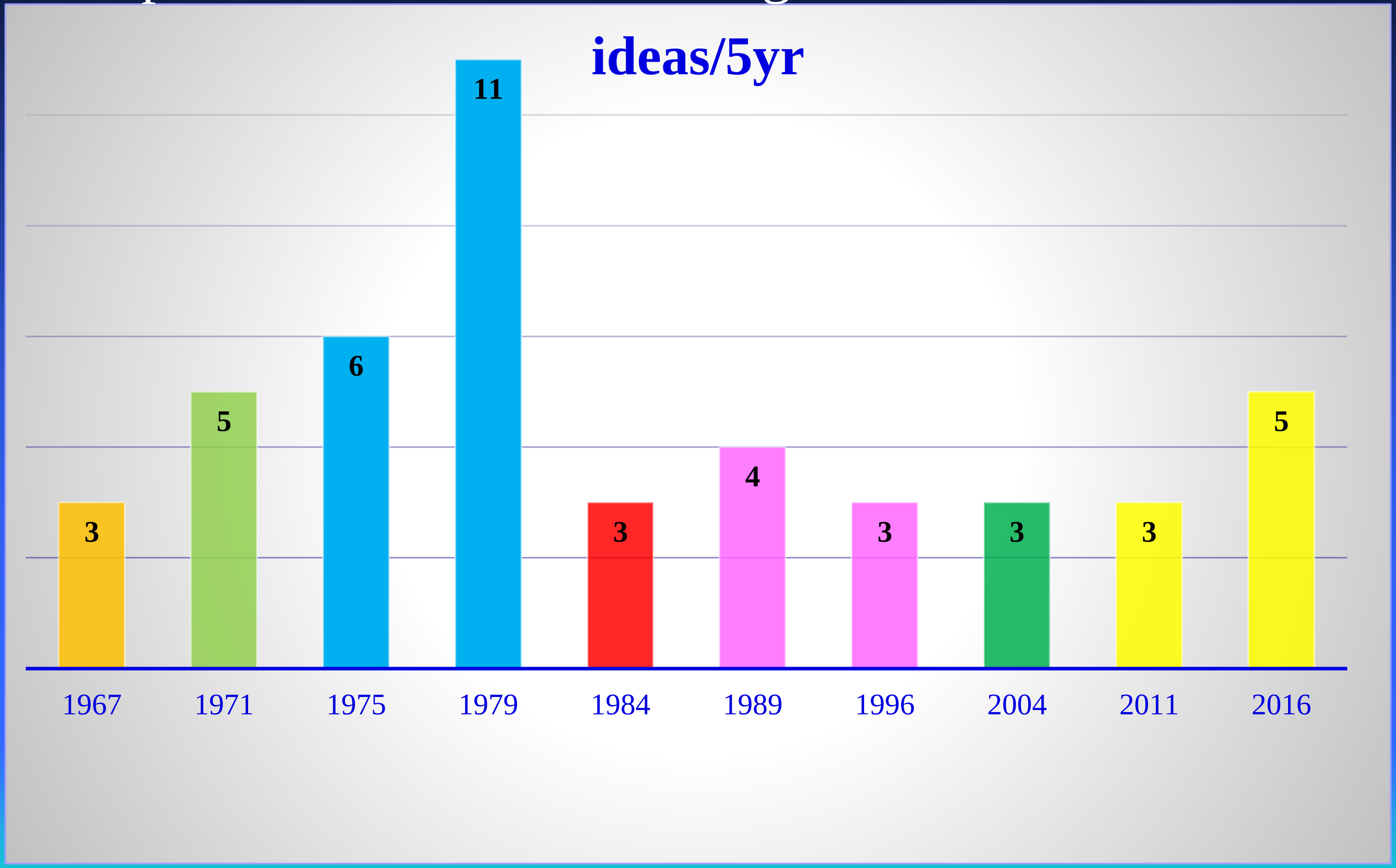
Ron Ekers

CSIRO, Australia

# Distribution of innovative ideas over time

PhD CIT WSRT VLA ATNF FF retired

student postdoc researcher manager researcher retired



# Getting into Radio Astronomy in 1963

- Summer school at CSIRO radiophysics
  - lectures from Bolton, Bowen, Christiansen, Kerr....
- visit to Parkes Telescope
- ANU grad student
  - Bart Bok enabled flexibility
  - Bolton (CSIRO) co-supervisor

- The contrast between high tech radio astronomy and old fashioned optical instrumentation made my choice obvious
- Only one extragalactic astronomer in Australia!
  - Bengt Westerlund

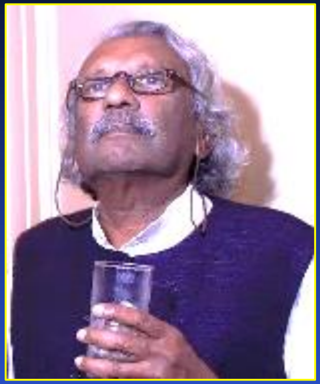
# Summer School Jan 1963

SUMMER VACATION COURSE IN RADIO ASTRONOMY. JANUARY 1963

| DATE | MORNING (09.30) | LECTURERS | AFTERNOON (1400) | LECTURERS |
|---|---|---|---|---|
| MON. JAN. 14 | Welcome<br>Introduction | E.G. Bowen<br>R.X. McGee | Types and theories of cosmic radio emission processes. | J.H. Piddington |
| TUES. JAN. 15 | Radio astronomical spectroscopy. | F.J. Kerr | Radio Waves in a Plasma. | S.F. Smerd |
| WED. JAN. 16 | Thermal radio emission from the Sun | S.F. Smerd | Observation and Interpretation of Solar Bursts. Part I. | A.A. Weiss.<br>K.V. Sheridan |
| THURS. JAN. 17 | The radio structure of the Galaxy. | E.R. Hill | Extra-galactic radio emission | D.S. Mathewson<br>B.J. Robinson |
| FRI. JAN. 18 | Observation and Interpretation of Solar Bursts. Part II. | A.A. Weiss<br>K.V. Sheridan | Radio astronomy receivers. | B.F.C. Cooper |
| MON. JAN. 21 | Data processing in radio astronomy | A.W.L. Carter | * Achievement of high angular resolution in radio astronomy. | W.N. Christiansen |
| TUES. JAN. 22 | VISIT TO DAPTO FIELD STATION | | | |
| WED. JAN. 23 | The Parkes 210ft. Radio Telescope | E.G. Bowen | Neutral hydrogen in the Galaxy | F.J. KERR |
| THURS. JAN. 24 | Meteor astronomy | A.A. Weiss | Radio astronomy of planets. | J.A. Roberts |
| FRI. JAN. 25. | Observing radio sources | J.G. Bolton | Cosmological aspects of radio sources. | A.W.L. Carter |

9.30 - 10.30 Lect.
Tea
11.00 - 12.00 Questions
14.00 - 15.00 Lect.
15.00 - 15.30
11.00 extra three lect.

# Mentors



- John Bolton
  - *Anyone can get a PhD with a telescope like this (Parkes), but you will have to earn your PhD!*
  - the beginning of the networks
    - meeting people - eg Fred Hoyle…. at Parkes
  - beginning of my obsession with questioning things
- Radhakrishnan
  - Was supposed to teach me interferometry
    - arrived by sail boat just as I finished my PhD
  - thought experiments and the deep physics
- Jan Oort
  - the value and simplicity of the big picture
- Dave Heeschen on management
  - how to herd cats
  - *Too much paperwork work indicates weak management*
  - value your user community
    - in CSIRO speak - understand you customers

# Parkes Aerial View 1963

# On Wavelength Chauvinism

- I eventually realised that specializing in one observational field (radio astronomy) but being an astronomy generalist was not only a credible approach to research but possibly a better approach.
- The modern mainstream consensus is that astronomers should be multi-wavelength observers while specializing in a narrow area of astronomy.
- This may not be the best approach!

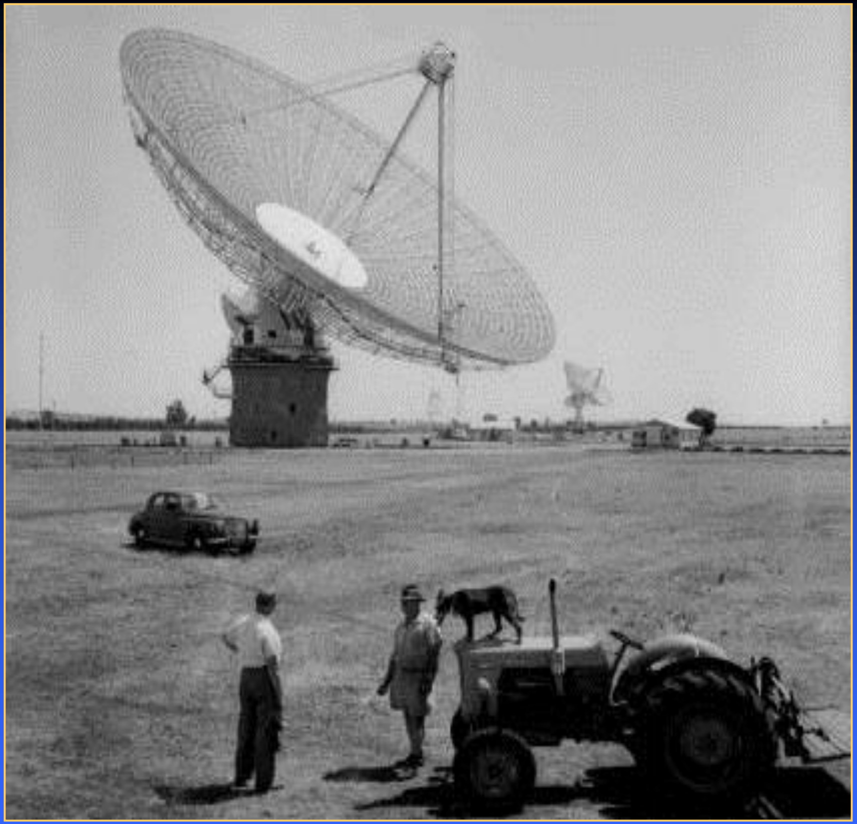
# Specialise in the instrument not in a narrow field of astronomy.

- Many discoveries are made by instrumental experts not astronomical specialists
- Matching an opportunity enabled by new technology to an astronomical problem is easier if you can cover all areas of astronomy
- Cross fertilization generates innovation
  - an instrumental specialist will be interacting with astronomers from many areas
- A diversity of research styles enriches the research community

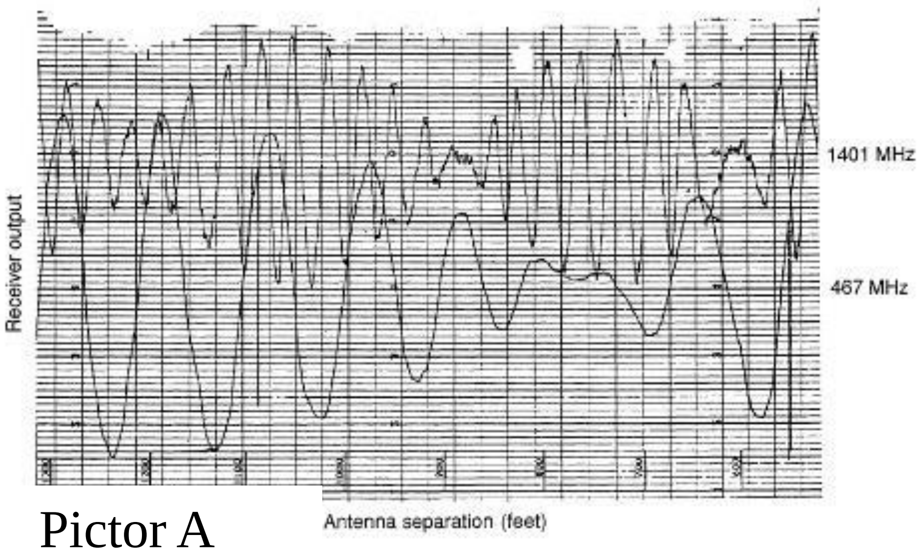
# The technology path

- The following examples from my career shows how I followed a technology driven path

# Parkes Variable Baseline Interferometer: 1965



# Fitting models to visibility amplitudes



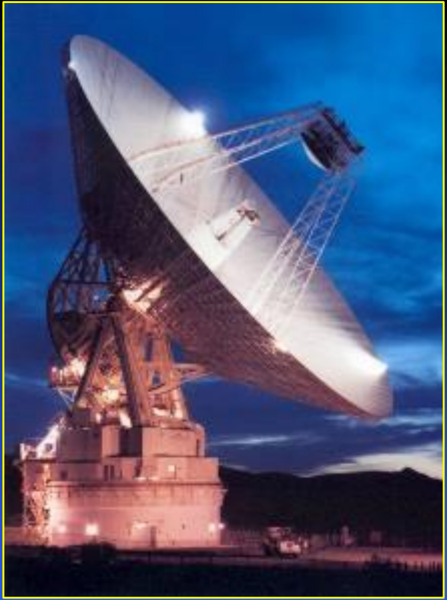

Pictor A

Double source with outer hotspots and spectral gradient

- What are the Radio Galaxies?
- Luminosity v Linear size plot
  - Evolutionary model accepted in the community
  - But the predictions were wrong!
  - Is this the way to do science?

# Pulsars at Caltech 1968

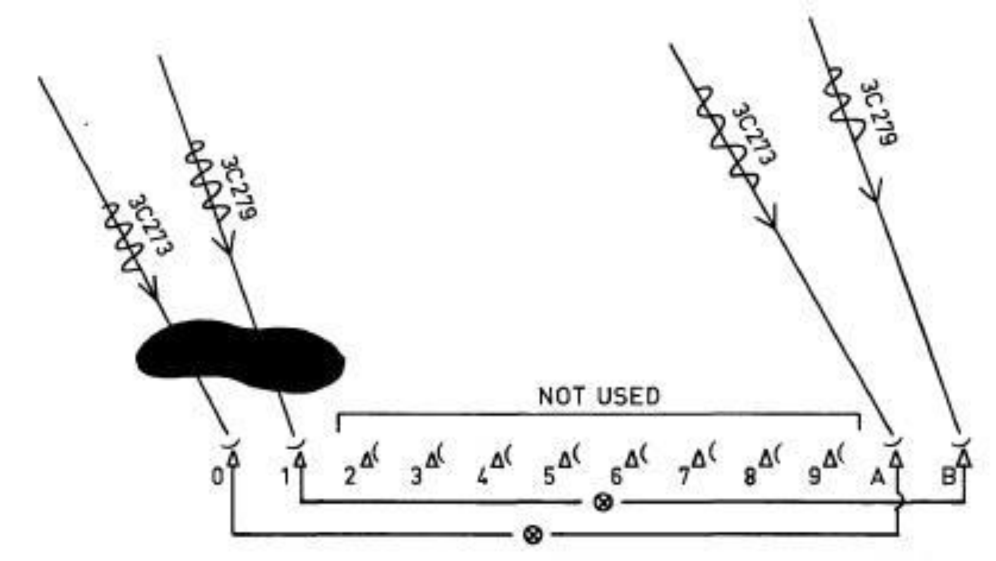
- doing IPS experiments at Goldstone when pulsars were discovered
- Interactive system to display pulses
- New York pulsar meeting
  - almost all discussion was about pulsating white dwarfs
  - only Tommy Gold spoke of rotating n-stars



- Polarization
  - discovered rotation of polarisation in Vela and Peter Goldreich correctly modelled it
  - same results obtained at Parkes and published by Radhakrishnan and Cooke
  - Peter Goldreich's response: *saves us having to do the work*

# General Relativity Experiments

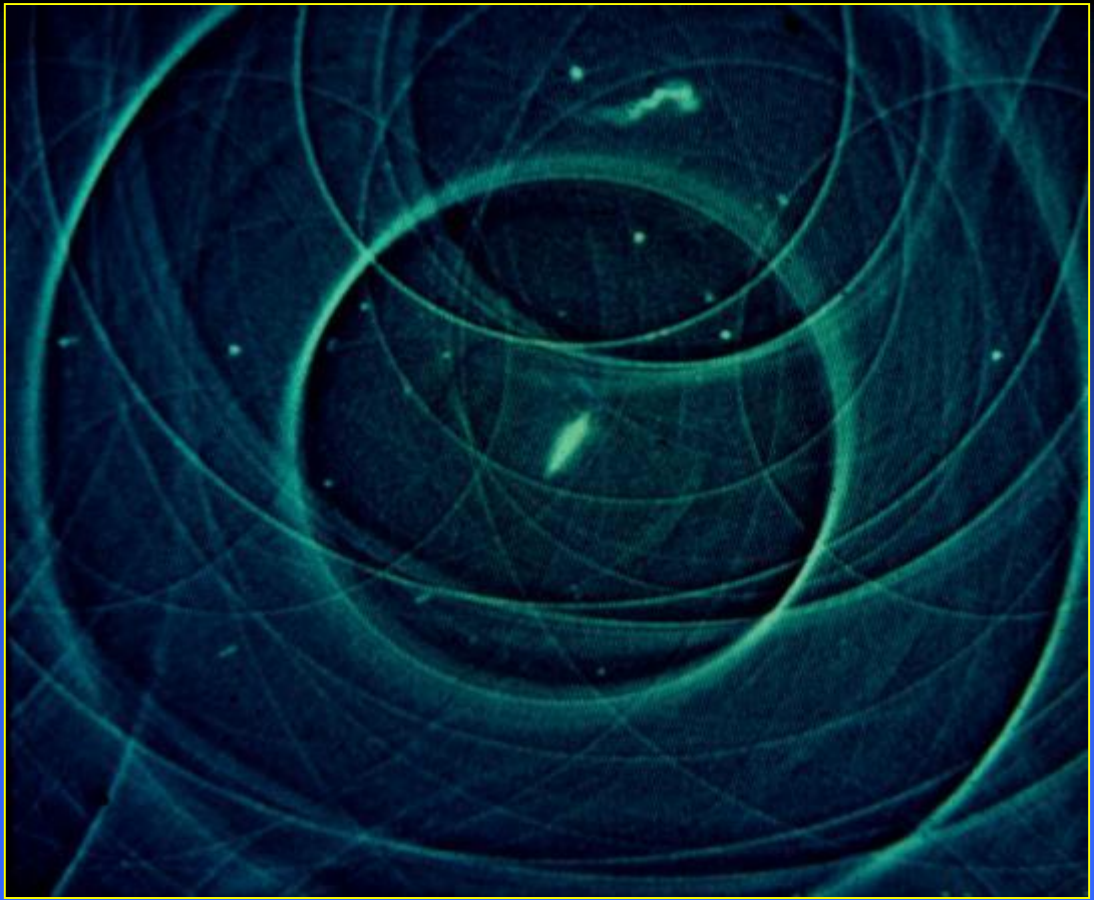
- Goldstone 1970
  - improvised an interferometer using NASA dishes
  - Measured the light bending
- WSRT 1974
  - two sources simultaneously to remove troposphere
  - example of pushing the instrumental boundary
  - But no where in the form for two sources!



# Westerbork: 1970

- 12 x 25m dishes
  1.5km linear array
  - Two moveable
  - 10 redundant spacings
  - Self calibration
  - Two more dishes at
    3km  added later

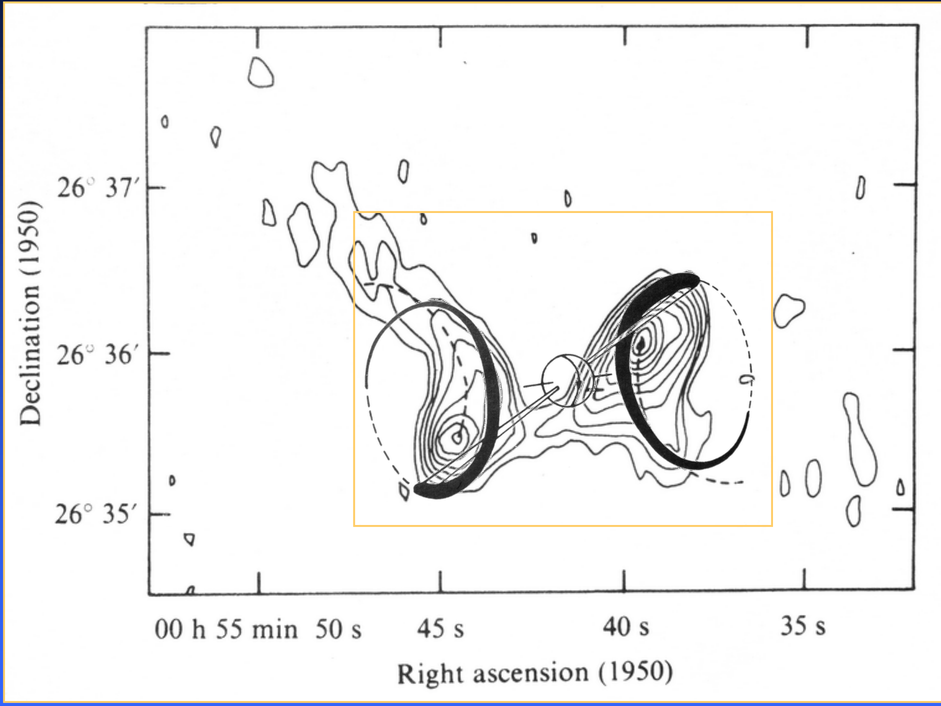
# Understanding sidelobes

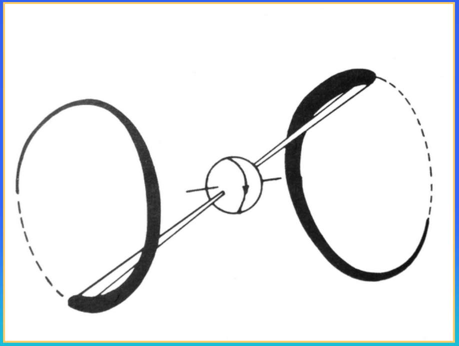


- Simple linear array made it conceptually easier
- Hogbom Clean
- Snapshots possible
  - Could observe many sources
  - Low luminosity radio galaxy sample

# NGC326 – pressing jet
# Binary Black hole?

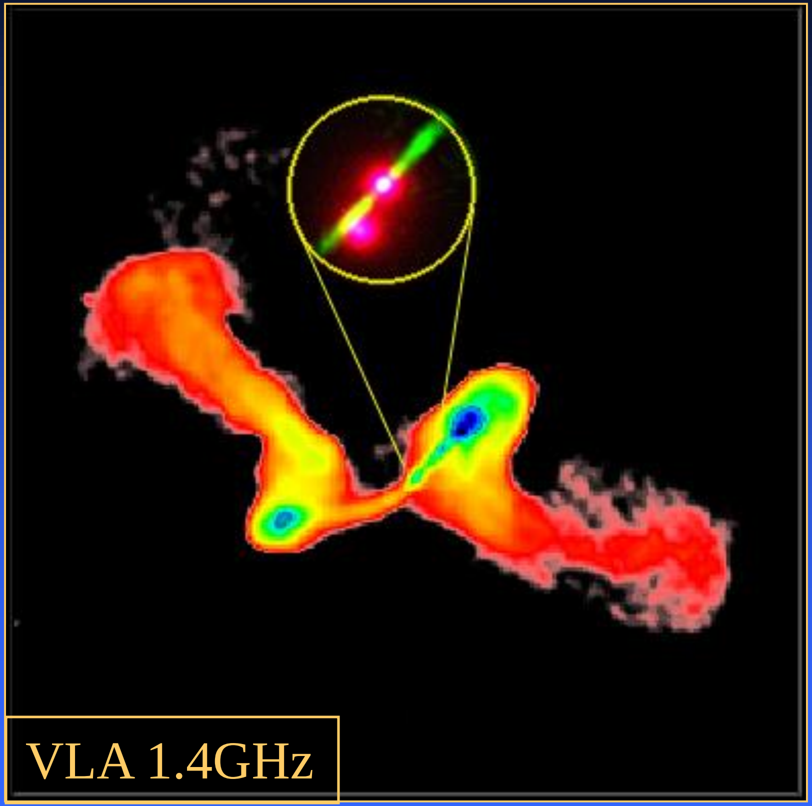
- From the WSRT low luminosity snap shot project



# NGC326 – pressing jet Binary Black Hole?

- Martin Rees 1978
  - *One black hole already pushes credibility – two was a step too far*
- Binary Black holes?
  - Evidence for super massive binary black hole mergers and Gravitational wave predictions




Murgia et al, A&A 380, 102-116 (2001)
Merritt & Ekers Science (2002)

# Back to back in Nature Dec 1978



~6 × 10$^8$ yr for the full circle. In the inner part of elliptical galaxies where solid body rotation is seen the rotation periods are about 10$^7$ yr (ref. 20), which may be too short to explain the radio data on the basis of the offset beam. If the motion of the beam is caused by precession of a gaseous disk the longer time scale implied by the radio data becomes reasonable.

If the radio axis is associated with a much smaller object such as a black hole in a tilted accretion disk then the motion of the axis will be related to the Bardeen and Petterson effect[21] as discussed by Rees[22].

We thank Drs R. Sanders and M. Rees for helpful discussions. The Westerbork Observatory is operated by the Netherlands Foundation for Radio Astronomy with the financial support of the Netherlands Organization for Pure Research (Z.W.O.).

R. D. EKERS

*Kapteyn Astronomical Institute,*
*University of Groningen, The Netherlands*

R. FANTI
C. LARI
P. PARMA

*Laboratorio di Radioastronomia CNR,*
*Universita di Bologna, Italy*

Received 29 August; accepted 2 October 1978.

1. Mackay, C. D. *Mon. Not. R. astr. Soc.* **154**, 209 (1971).
2. Burch, S. F. *Mon. Not. R. astr. Soc.* **181**, 599 (1977).
3. Miley, G. K., Wellington, K. J. & van der Laan, H. *Nature* **244**, 502 (1975).
4. Cooper, B. F. C., Price, R. M. & Cole, D. J. *Aust. J. Phys.* **18**, 589 (1965).
5. Riley, J. M. *Mon. Not. R. astr. Soc.* **157**, 349 (1972).
6. Jenkins, C. J., Pooley, C. G. & Riley, J. M. *Mem. R. astr. Soc.* **84**, 61 (1977).
7. Hargrave, P. J. & Ryle, M. *Mon. Not. R. astr. Soc.* **166**, 305 (1974).
8. Pooley, C. G. & Henbest, S. N. *Mon. Not. R. astr. Soc.* 169, 477 (1974).
9. Miley, G. K. *The Physics of Non-Thermal Radio Sources* (ed. Setti, G.) 1 (Reidel, Dordrecht, 1976).
10. Colla, G. *et al. Astr. Astrophys. Suppl.* **20**, 1 (1975).
11. Fanti, C. *et al. Astr. Astrophys. Suppl.* **29**, 279 (1976).
12. Lari, C. & Perola, G. C. *IAU Symp.* 79, (eds M. S. Longair & J. Einasto) (Reidel, Dordrecht, in the press).
13. Rees, M. J. *Nature* **229**, 312 (1971).
14. Longair, M. S., Ryle, M. & Scheuer, P. A. G. *Mon. Not. R. astr. Soc.* **164**, 243 (1973).
15. Blandford, R. D. & Rees, M. J. *Mon. Not. R. astr. Soc.* **169**, 395 (1974).
16. Knapp, G. R., Kerr, F. J. & Williams, B. A. *Astrophys. J.* **222**, 800 (1978).
17. Reif, K., Mebold, U. & Goss, W. M. *Astr. Astrophys.* **67**, L3 (1978).
18. Pacholczyk, A. G. & Scott, J. *Astrophys. J.* **203**, 313 (1976).
19. Ekers, R. D., Fanti, R., Lari, C. & Ulrich, M.-H. *Astr. Astrophys.* (in the press).
20. Illingworth, G. *Astrophys. J. Lett.* **218**, L43 (1977).
21. Bardeen, J. M. & Petterson, J. A. *Astrophys. J.* **195**, L65 (1975).
22. Rees, M. J. *Nature* **275**, 516 (1978).

## Limits on cosmic radio bursts with microsecond time scales

IT has been suggested[1] that black holes of mass ≤10$^{15}$ g evaporate in ~10$^{10}$ yr, ultimately annihilating into a burst of energetic photons and particles. This explosion would produce γ-rays directly, and a radio pulse with a characteristic frequency of ~3 GHz and an energy of ~10$^{32}$ erg may also be generated[2]. It has been shown[2–4] that such a radio burst would be far more easily detected than the corresponding γ-ray burst. Estimates of the energy in the radio burst are uncertain by many orders of magnitude, and it is, of course, not known whether any primordial black holes exist at all; however, the implications of a

10 MHz band at 5 GHz we would
pulses to ≥10 μs. It is interesting
character would not be detected wi
monly used in radio astronomy
although such a pulse can easily b
designed receiver. The existence of t
for astrophysical phenomena provi
such a search.

Limits on the radio pulse emission
holes have already been set by u
wide-beam searches for radio pulses
by supernovae[14]. In contrast to the small, low-gain ante
used in those searches, we have used the 25-m Dwing
radiotelescope; our objective was not only to probe l
volumes of space for possible bursts from exploding black h
but also to observe a variety of specific objects with
sensitivity and time resolution.

**Table 1** Sources observed

| | Source | Time on-source (h) | Limiti energ (erg |
|---|---|---|---|
| Planet | Jupiter | 2 | 6 × 10 |
| Star | Algol | 3 | 1 × 10 |
| Pulsars | PSR0950+08 | 3 | 3 × 10 |
| | PSR1133+16 | 3 | 3 × 10 |
| Supernova remnant | Crab | 1 | 2 × 10 |
| X-ray sources | Sco X1 | 2 | 3 × 10 |
| | Her X1 | 1 | 5 × 10 |
| | Cyg X1 | 6 | 5 × 10 |
| | Cyg X2 | 6 | 7 × 10 |
| Globular clusters | M3 | 4 | 3 × 10 |
| | M92 | 6 | 2 × 10 |
| | M15 | 2 | 5 × 10 |
| Normal galaxy | M31 | 3 | 5 × 10 |
| Radio galaxy | M87 | 2 | 2 × 10 |
| Quasar | 3C273 | 3 | 1 × 10 |

We used a 5 GHz cooled parametric receiver providing a
system temperature of 65 K and an instantaneous bandwid
100 MHz. The beamwidth was 10′ arc and the sensitivity
~0.1 K Jy$^{-1}$. The detection instrumentation was based
single channel high speed receiver, which could be optimise
the range of dispersion measures expected. The bac
consisted of an input filter of 10 MHz bandwidth with a cha
teristic double hump shape to facilitate dispersed
identification. A detector with a 2 μs time constant follo
Pulses were detected by a comparator which compare
adjustable fraction of the instantaneous power with the ave
power. Pulses were thus detected when the observed temp
ture exceeded the average system temperature by a p
factor.

These events were recorded in two ways. Initially, a si
pulse duration discriminator was used to discriminate ag
pulses which were shorter than expected from dispersion,
the remaining events were indicated on a chart recorder. I
in the observing period it became possible to photograph such

medium determines τ, and for our observing frequency and bandwidth τ(μs) ≈ *DM* (pc cm$^{-3}$). The dispersion measure (*DM*) was estimated using a model of the electron distribution in the galaxy[6,7], and substituted in equation (1) to give

Observations of all sources listed in Table 1 can be used together with the reference observations to set an overall limit on the rate of 10$^{32}$ erg radio bursts from exploding black holes. Taking the maximum distance sampled in each direction as that for which $E_{lim}$ from equation (2) is 10$^{32}$ erg, we find a limit of 9 × 10$^{-6}$ pc$^{-3}$ yr$^{-1}$. This compares with the limits derived in the earlier analyses[3,4] of radio data, and is far superior to limits obtained from searches for γ-ray bursts.

It may be more interesting to consider the globular clusters separately from the other sources. If the primordial black holes have a space distribution similar to that of the visible matter in the Universe, then there would be concentrations of them in globular clusters. Taking 10$^5$ $M_\odot$ as a typical mass for a globular cluster, the limits in Table 1 imply an upper limit of 10$^{-20}$ yr$^{-1}$ for the fraction of the total mass which evaporates due to 10$^{15}$ g black holes exploding and generating 10$^{32}$ erg radio bursts. In other words, primordial black holes of <10$^{15}$ g can never have exceeded 10$^{-10}$ of the total mass.

An even larger mass is sampled in the M31 observations where our beam corresponds to a linear size of 2.6 kpc. However, the additional dispersion in M31 and the greater distance result in a much higher detection limit.

These limits could be improved by using larger telescopes for longer times and simultaneous observations with more than one antenna. Interference rejection in particular would be greatly facilitated by using two or more widely spaced antennas. Large improvements could be achieved either by using a fast multichannel dedispersing backend or possibly by observing at higher frequencies.

We thank V. Radhakrishnan for discussions. The Dwingeloo radiotelescope is operated by the Netherlands foundation for Radioastronomy (S.R.Z.M.) with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

J. D. O'SULLIVAN

*Netherlands Foundation for Radio Astronomy,*
*Dwingeloo, The Netherlands*

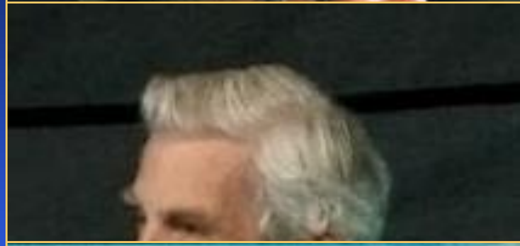
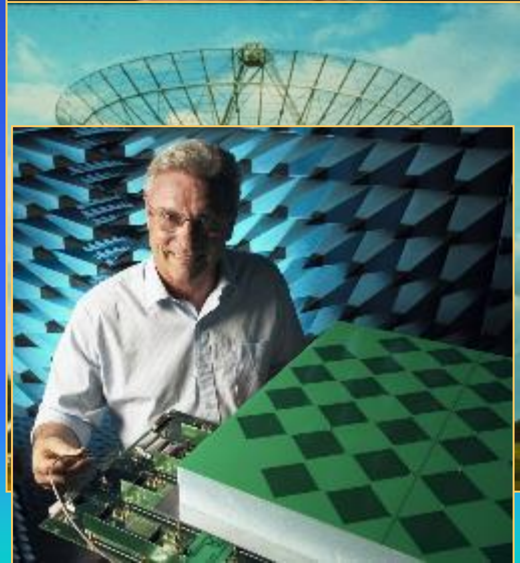
R. D. EKERS
P. A. SHAVER

*Kapteyn Astronomical Institute,*
*University of Groningen,*
*Groningen, The Netherlands*

0028–0836/78/0276—0591$01.00

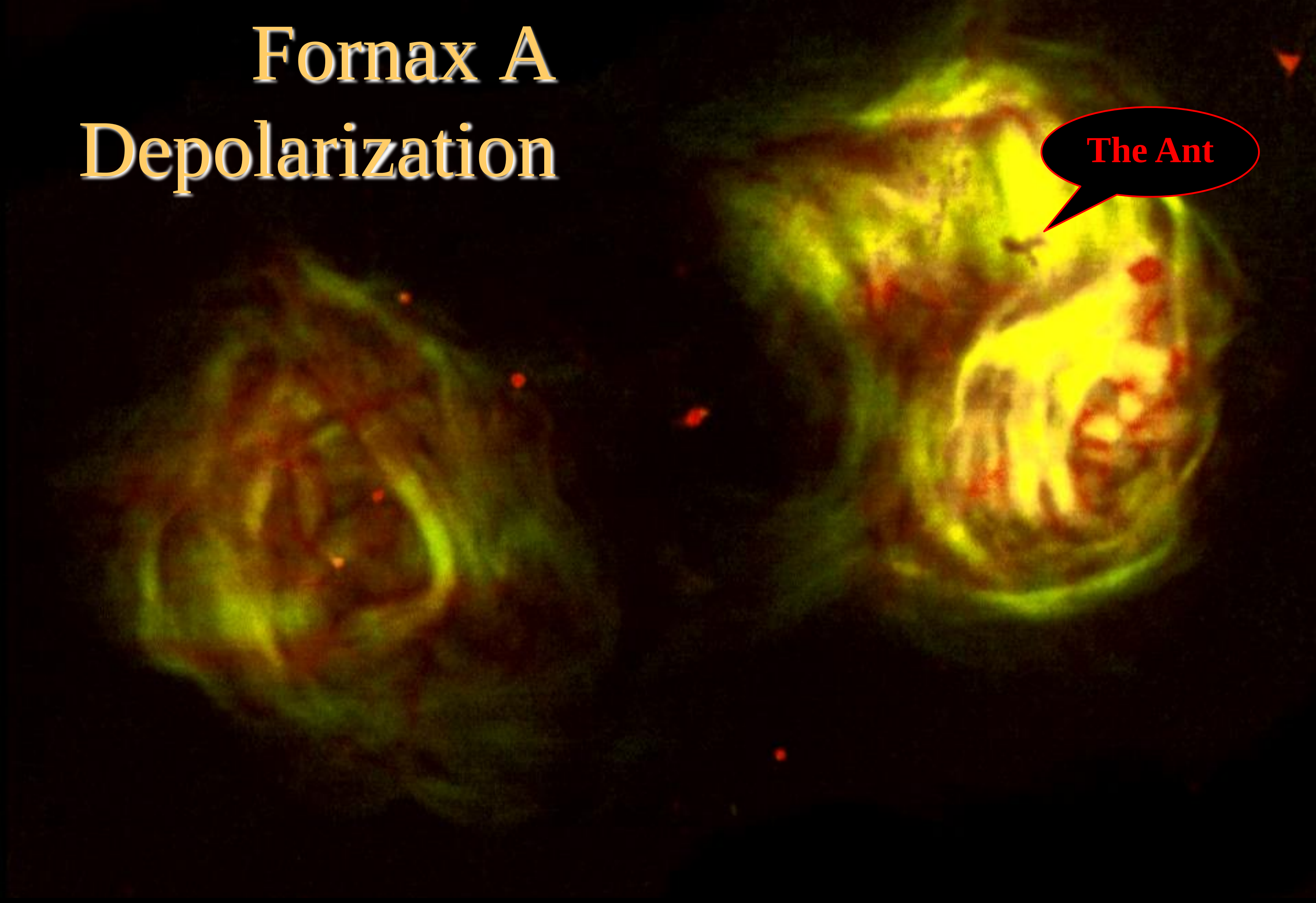
# From Cambridge to The Netherlands 1970 then to Australia 1996

- Steven Hawking: black holes radiate
- Small black holes evaporate in less than the age of the Universe
- Martin Rees: a radio pulse might be observable when they disappear
- John O'Sullivan: and collaborators build a special instrument to look for the exploding black holes using Dwingeloo and Westerbork *"there has to be a better way!"*
- John O'Sullivan: Fourier Transform on a chip
  - ⇒ IEEE 802.11 wireless internet standard

# Fornax A on optical image

# Fornax A Depolarization

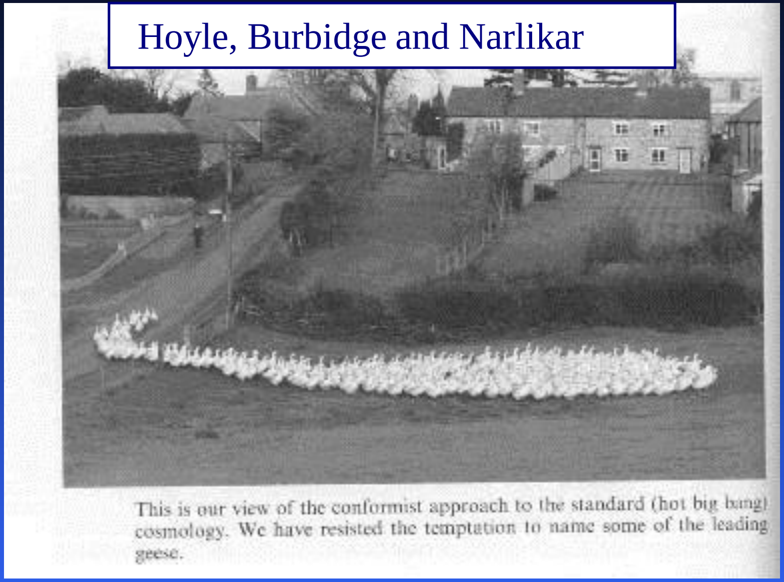


# Fornax A
# and the ant like feature

- Need a turbulant magneto-ionic medium
- RM > 20 rad $m^{-2}$
- Size 14”
- Eg
  - Ne = .03 $cm^{-3}$
  - B = 2 μG
  - L = 100pc
  - M = $10^9$ Mo
- Bland-Hawthorne ApJ 447, L77 (1995)
  - Halpha detection at v = 1610km/s

# On Conformity

- You can follow a beaten path set by the community but if you don't it is easy to get lost. *Mark Walker*




- Avi Loeb (Breakthrough 2016)

*I avoided the mainstream, many ideas failed but some succeeded and then they sometimes became the mainstream. But you cant blame me for that*

# The Broader View

- The instrumentalists in my theme need not be radio astronomers
  - Optical, IR, X-ray, Gamma-ray, particle physicist, ….
- Theorists who are also generalists have been just as valuable to me as the instrumentalists
  - Rees, Woltjer, Loeb, Walker….
- You don't have to be an astronomer to use your skills
  - Haida, Ilana, Neil, …
- Its not all about discoveries – we also advance by observations and incremental advances in knowledge