An Old Fogey's History of Radio Jets up to ~1975

a personal view, no doubt biased.

Ralph Spencer

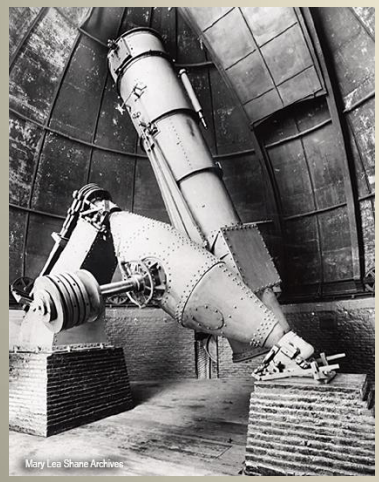
Ierapetra, June 2017

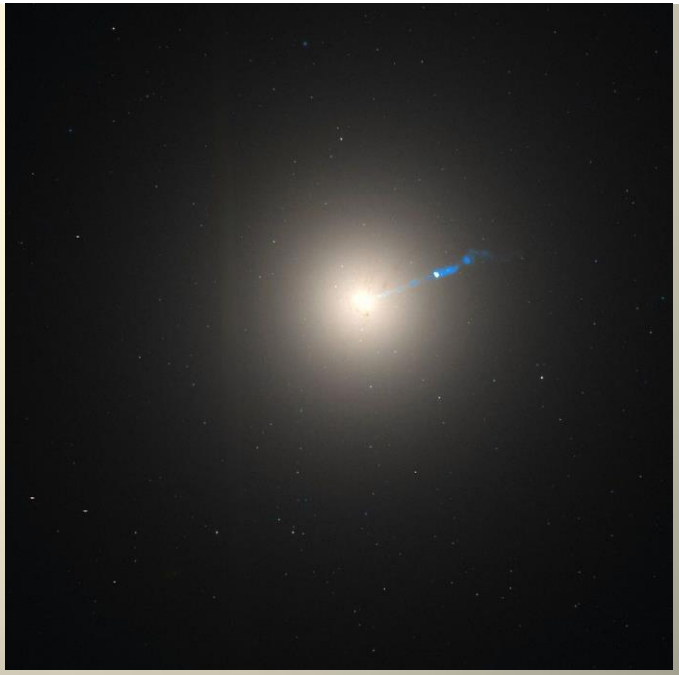
Leahy+ 1996

The Early History: M87

- 1918: NGC 4486: Heber D. Curtis using the Crossley Reflector

Exceedingly bright; the sharp nucleus shows well in 5^m exposure. The brighter central portion is about 0′.5 in diameter, and the total diameter about 2′; nearly round. No spiral structure is discernible. A curious straight ray lies in a gap in the nebulosity in p.a. 20°, apparently connected with the nucleus by a thin line of matter. The ray is brightest at its inner end, which is 11″ from the nucleus. 20 s.n.





So we've know that narrow extended jets exist for a while?

Messier 87 by the Hubble Space Telescope. Image: NASA/ESA

1950's The Structure of Radio sources:

- Jennison and Das Gupta 1952
  - Two-element intensity interferometer at 2.4-m λ with baselines up to 5.4 km
  - Showed Cygnus A to have a double or twin lobed structure

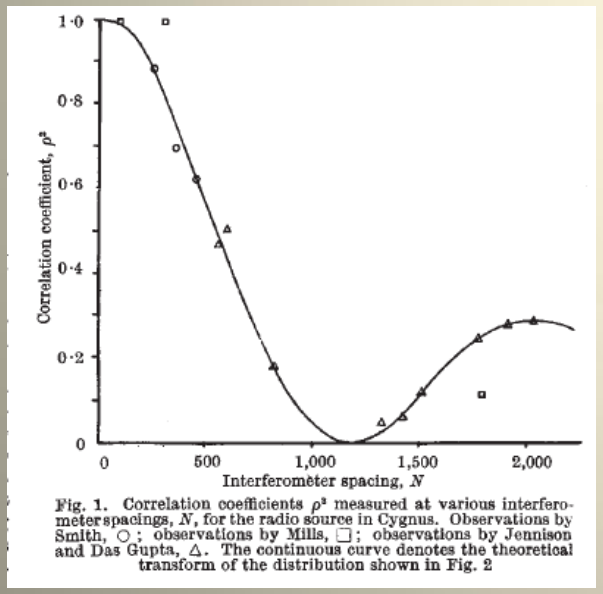


Fig. 1. Correlation coefficients ρ^2 measured at various interferometer spacings, N, for the radio source in Cygnus. Observations by Smith, ○; observations by Mills, □; observations by Jennison and Das Gupta, △. The continuous curve denotes the theoretical transform of the distribution shown in Fig. 2

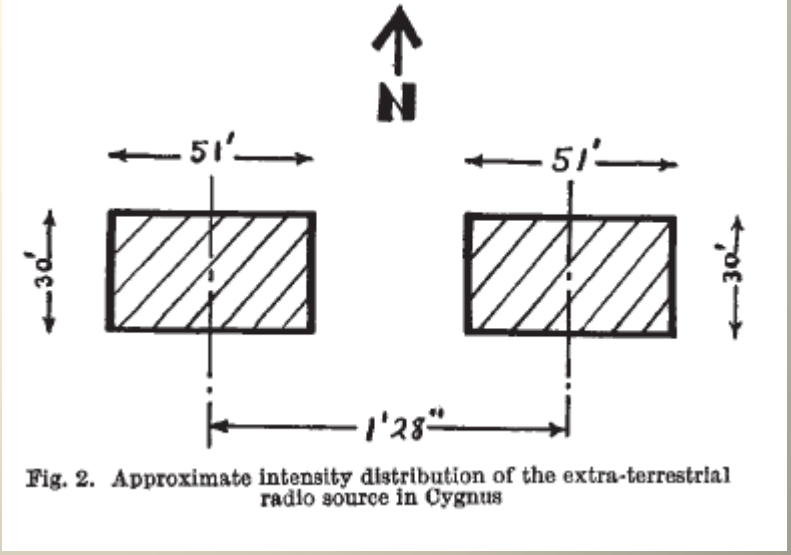
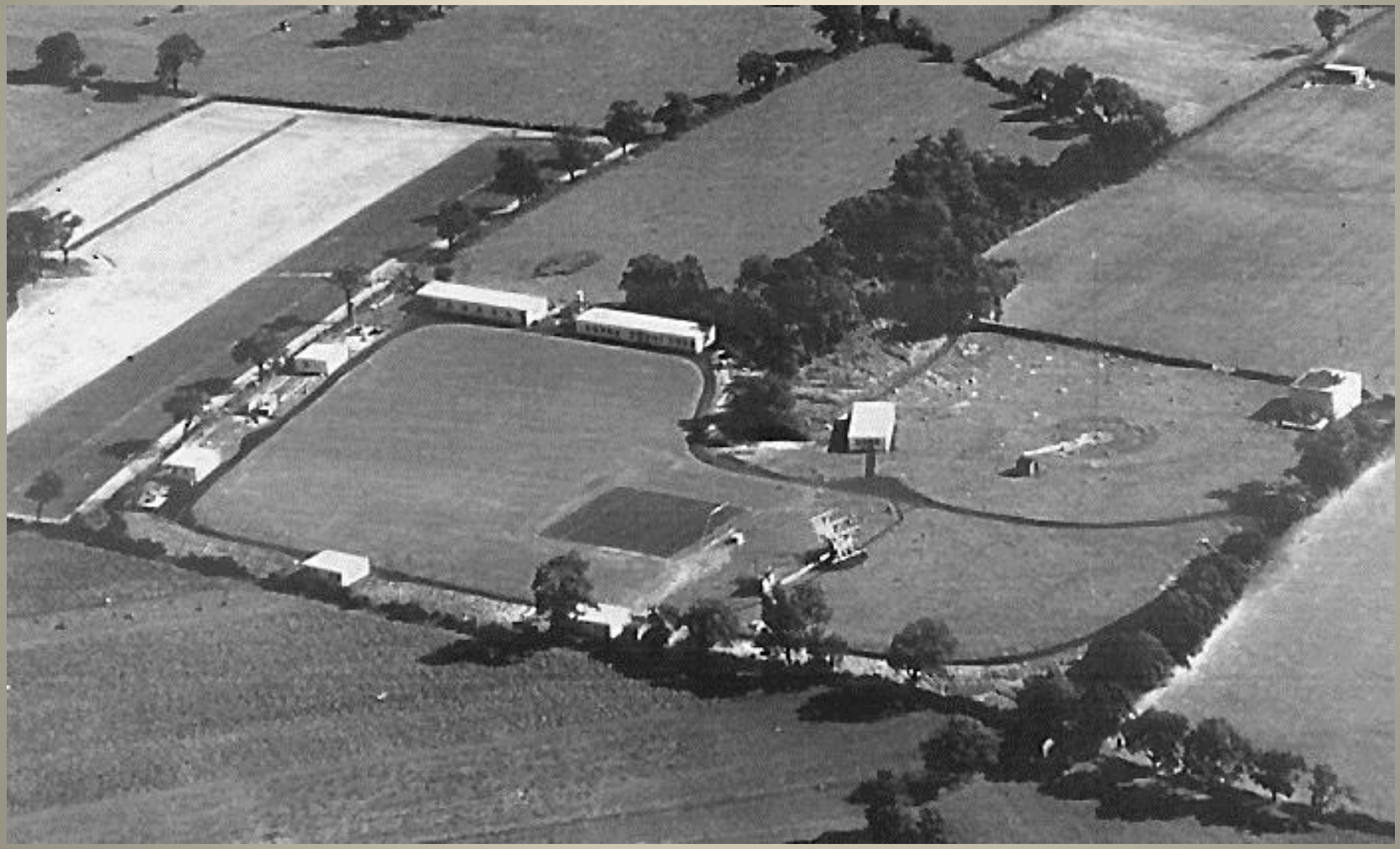
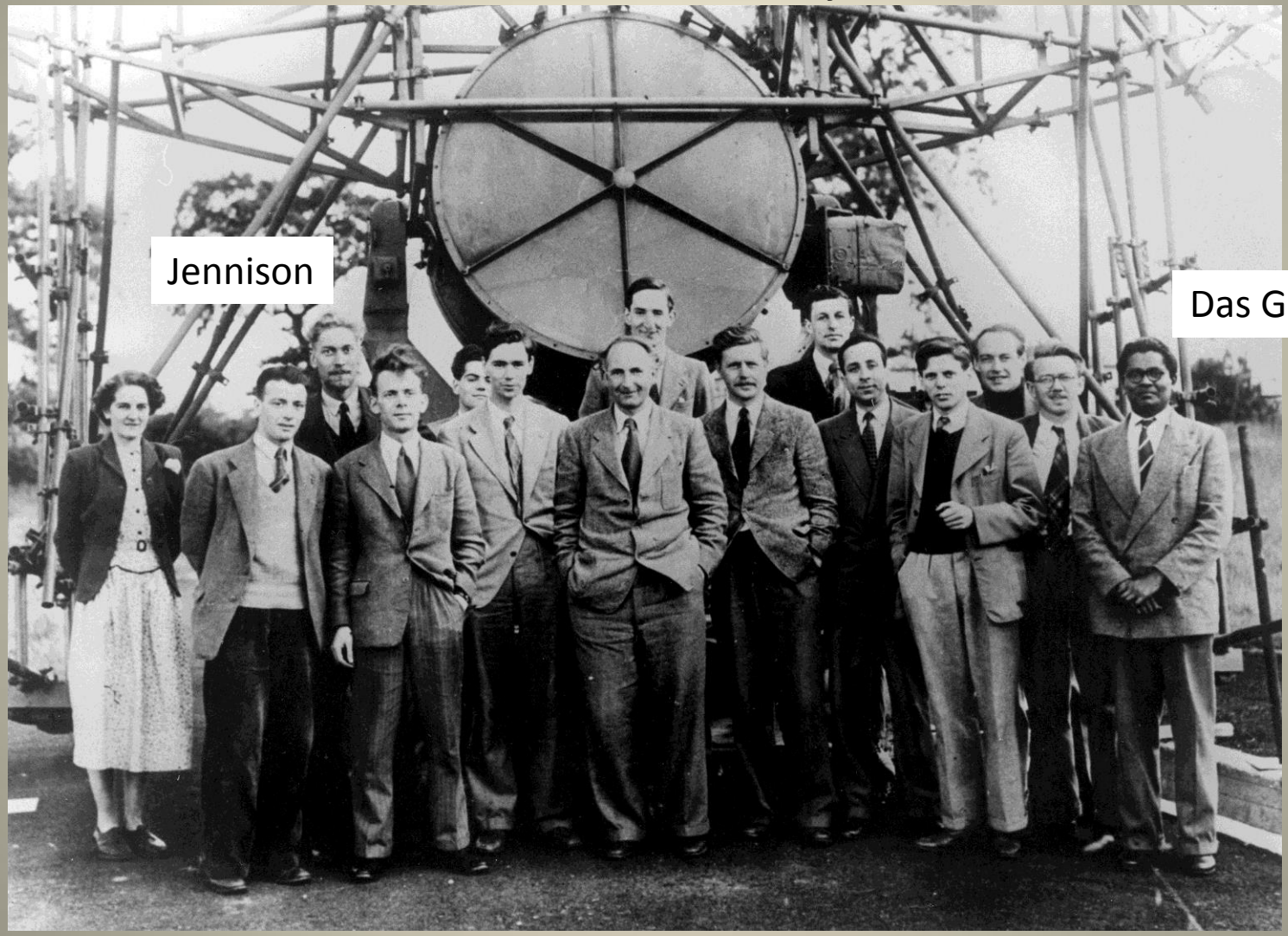


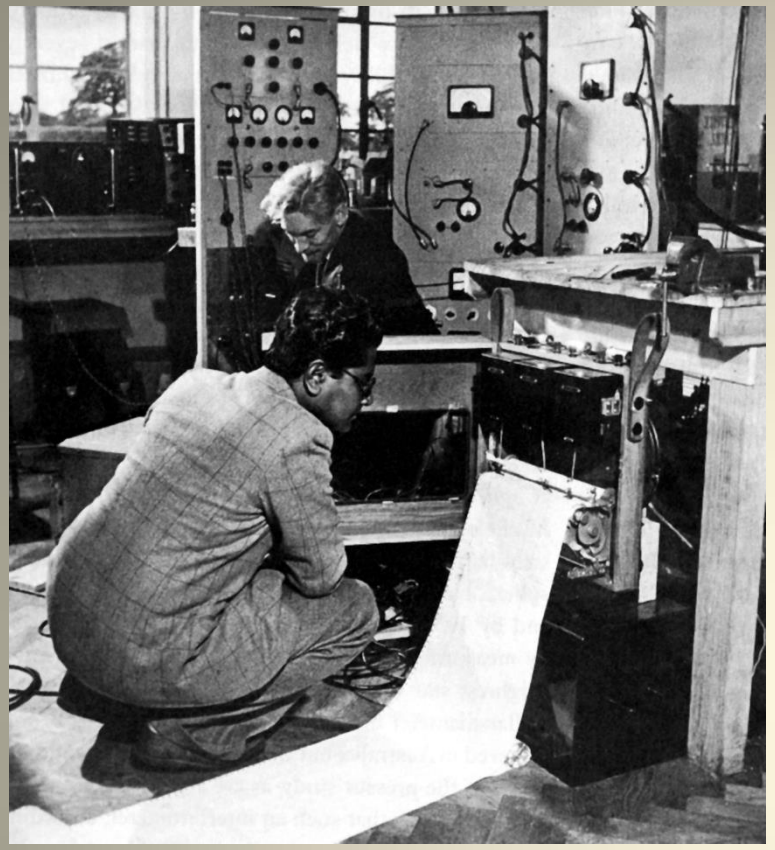
Fig. 2. Approximate intensity distribution of the extra-terrestrial radio source in Cygnus

Jodrell Bank Experimental Station 1950's



Celebrating Bernard Lovell becoming the first Professor of Radio Astronomy 1951

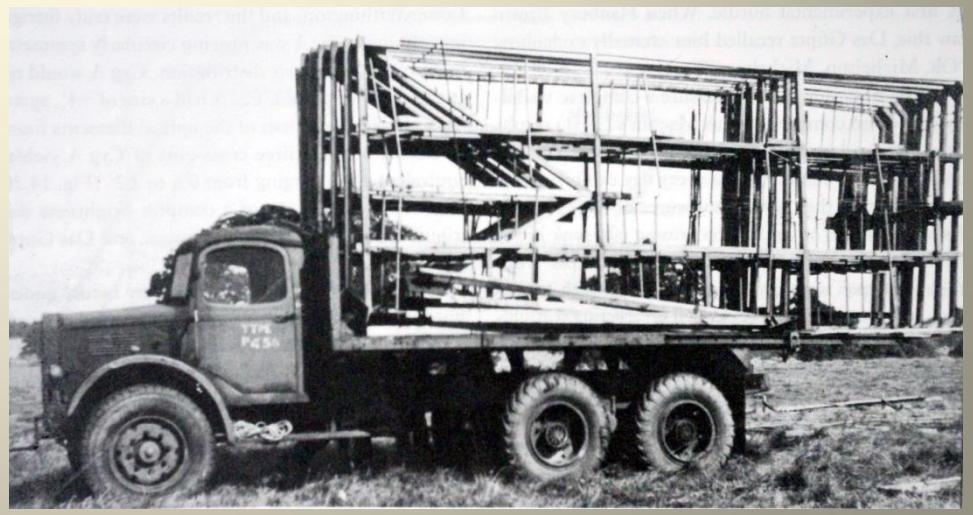




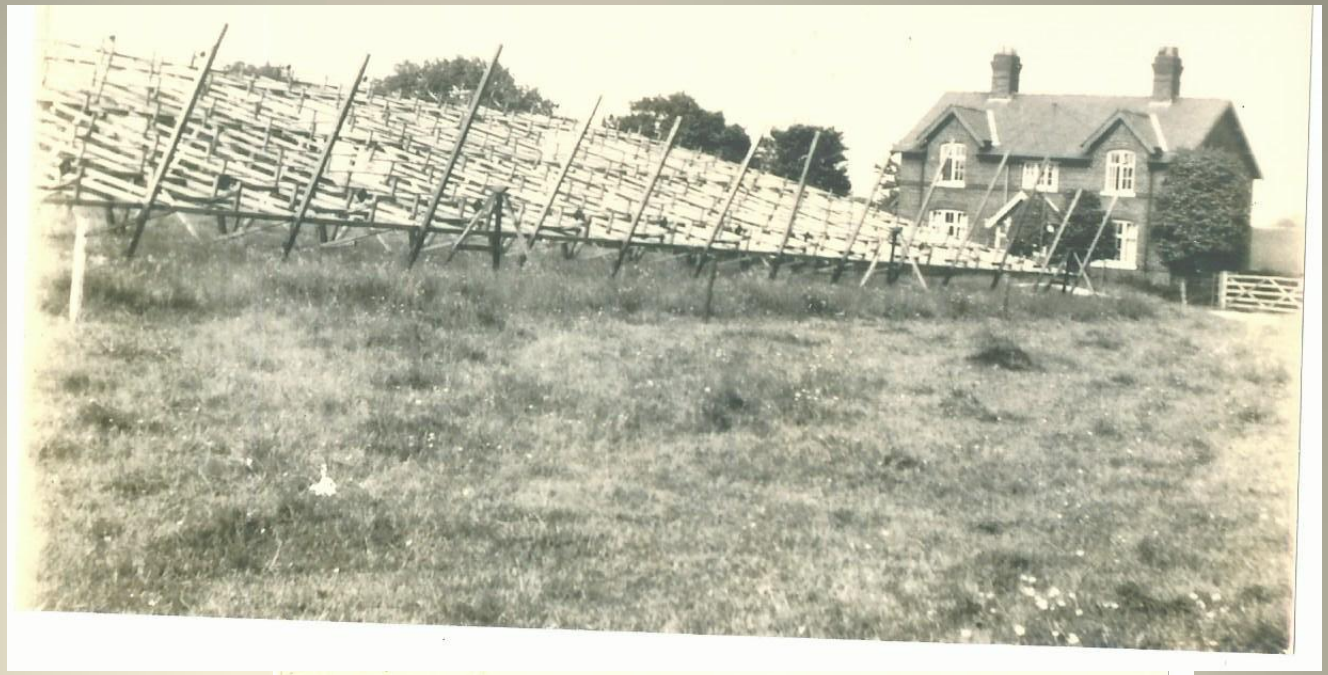
Roger Jennison and
Mrinal Das Gupta

Are there any fringes?

Jennison's Portable Antenna



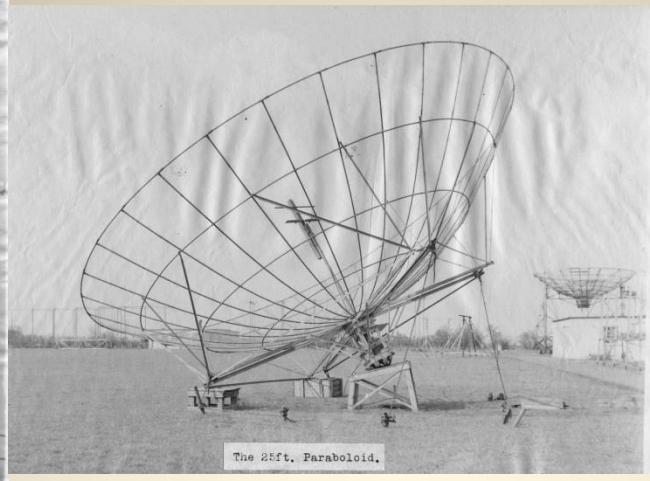
Portable broadside array at 125 MHz (Jennison)



Use of students as cheap labour for dangerous activities

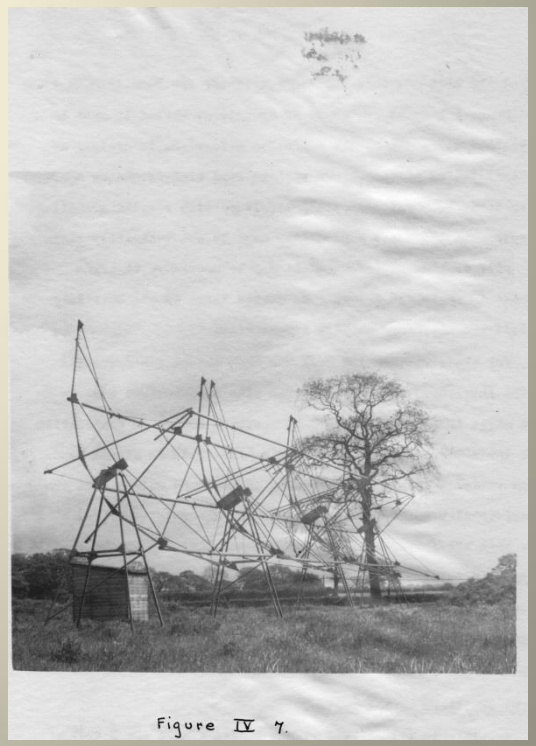
Photos from Das Gupta

Interferometers at Jodrell Bank in the 1950's



<- 30 ft 'Festival of Britain' dish
and a 25 ft dish
A. R. Thompson PhD thesis 1956

Cylindrical paraboloid
D. Morris PhD thesis1959- >

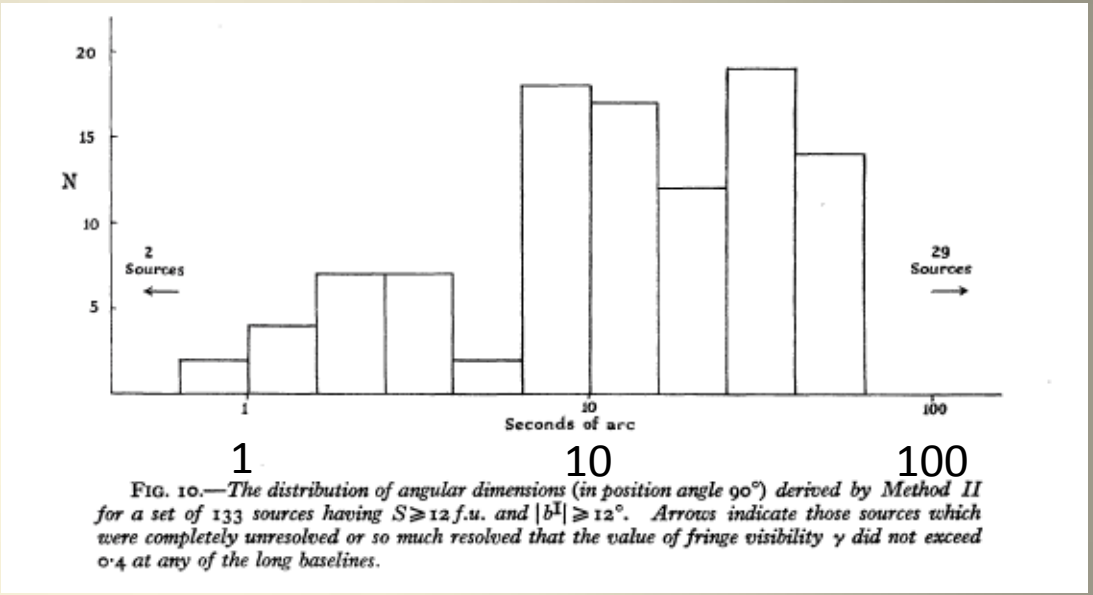


Morris, Palmer and Thompson 1957
– sources <12 arcsec

1957: Completion of the 250 ft Mk1 telescope, with the 218ft transit telescope in the foreground

The push for longer baselines:

- Maltby and Moffet 1962 CTI
  - showed 'double' structure common
  - but many unresolved
- Need longer baelines: radio linked multiplying lobe-rotating interferometers
- Allen et al.1962 ->
  - used Morris antenna and Mk1 250 ft
  - up to 115 km (JB-Lincoln) at 1.9-m λ
  - Several double sources <10 arcsec, some <1 arcsec and therefore distant?
  - Baade and Minkowski Cygnus A: extragalactic



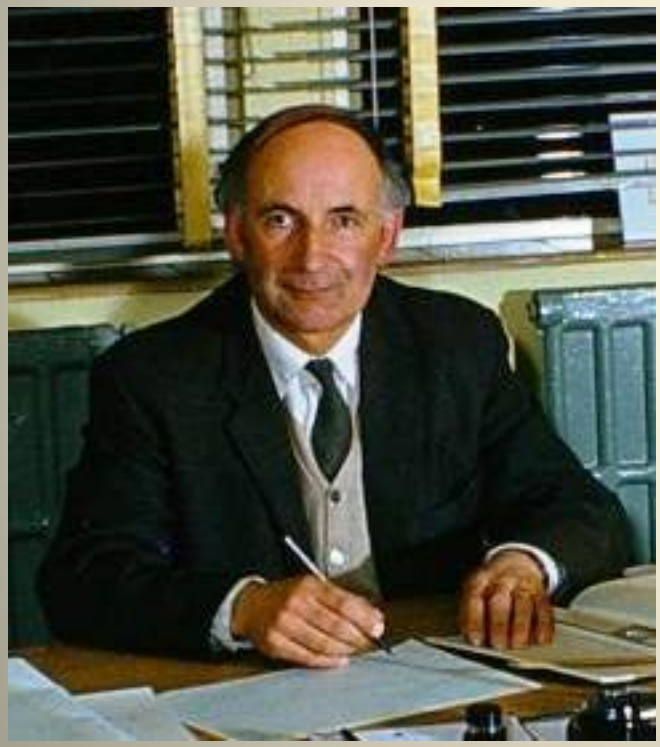
1 10 100

FIG. 10.—*The distribution of angular dimensions (in position angle 90°) derived by Method II for a set of 133 sources having* $S \geqslant 12$ *f.u. and* $|b^{\mathrm{I}}| \geqslant 12°$. *Arrows indicate those sources which were completely unresolved or so much resolved that the value of fringe visibility* γ *did not exceed 0·4 at any of the long baselines.*

1963 Discovery of Quasars

- Hazard, Mackey and Shimmins 1963 Nature 197, 1037 Lunar occultation of 3C273, gave position -also showed double structure
- Same issue has Schmidt: ID, redshift of 3C273, Oke: energetics, Greenstein and Mathews: redshift of 3C48 – Quasars and AGN research started in 5 pages!
- So we know these objects are distant and have high luminosity

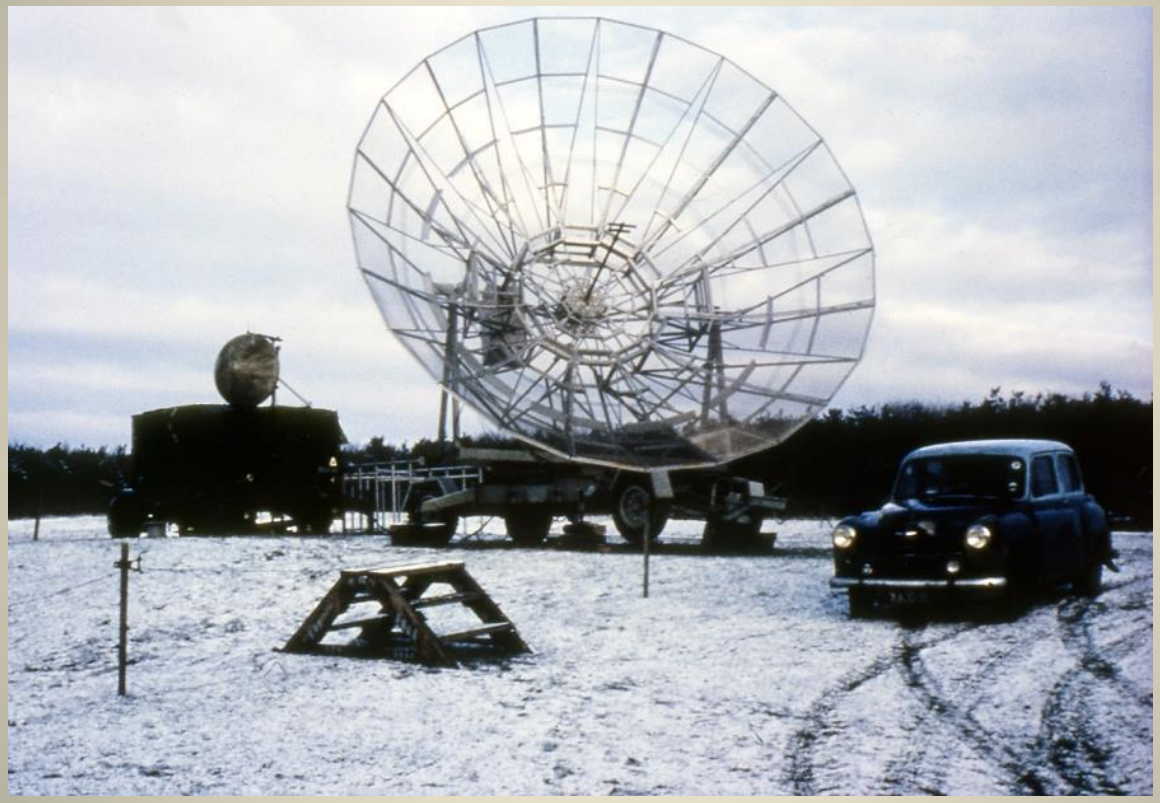
The Problem of the Unresolved Sources 1960's – 1970's



Sir Bernard Lovell

Henry Palmer

More radio links….
25 ft (built by a PhD student - Donaldson)
at Pocklington, N Yorkshire Moors, 131km baseline



Anderson and Donaldson1967
Lots of interesting angular structure but need more sensitivity

Late 1960's Bigger telescopes:

NB Single baselines – model fitting but lots of double and triple structure found – out flow must be occurring

Mk3 24 km

Defford 127 km

- 1st VLBI June 1967 (US), also JB-Arecibo later
- 1974 Phase stable radio link to Mk3 (RS)
- Late 1970's – birth of MERLIN,
  - use of closure phase self-cal etc – another story

Synthesis Imaging and the discovery of Jets

- Cambridge 1-mile : more doubles!
  - Extended sources – how?
  - What generates the lobes?
  - How are they energised?
  - What confines them?
  - Rees 1971 – need for a continuous energy supply
  - Longair, Ryle and Scheuer 1973 clarified the issues
- Cambridge 5km Ryle telescope 1970's
  - Hargrave and Ryle 1974 Cygnus A

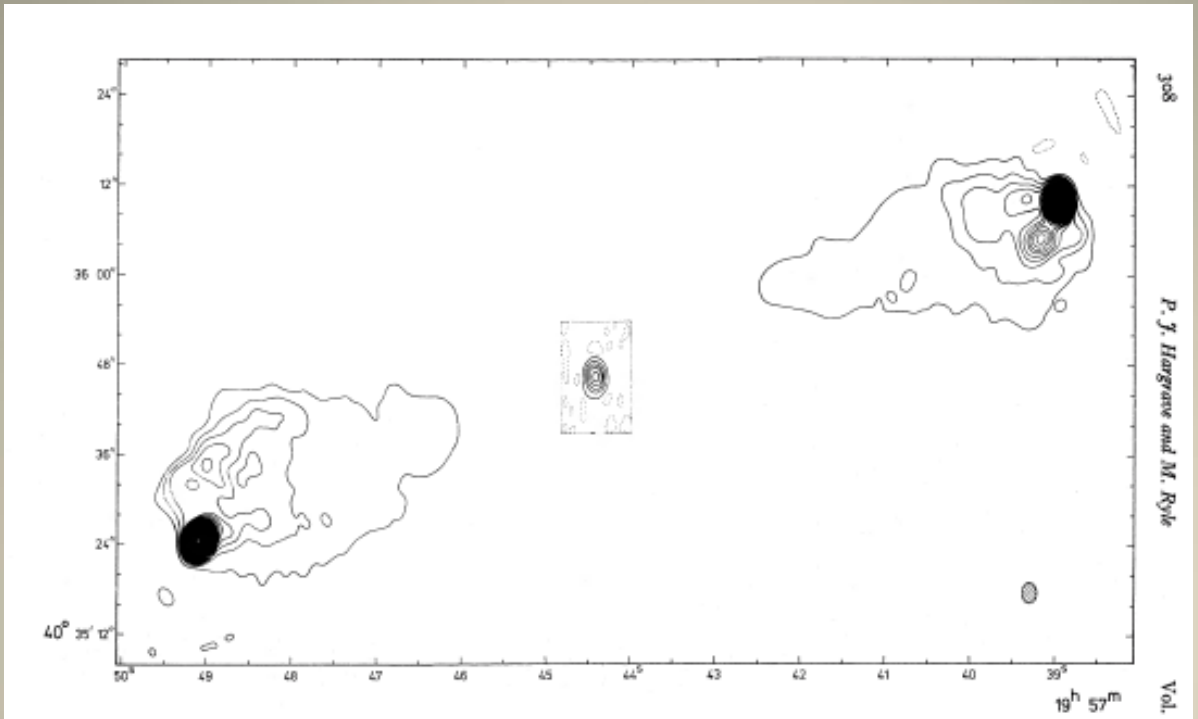


FIG. 2. *The contours of brightness temperature in Cygnus A at 5 GHz. For the two main components the contour interval is 10^4 K and the outermost contour represents a brightness temperature of 0 ± 2500 K. The solid regions in the Np and Sf component reach 31 and 41 contours respectively. The area surrounding the central component is drawn with an interval of 2000 K. The half-power beamwidth is indicated by the shaded ellipse.*

Double lobed, hot spots indicating an interaction with the IGM but no jet visible yet

Turland , B. 1975 3C219 Ryle 5 km at 5 GHz

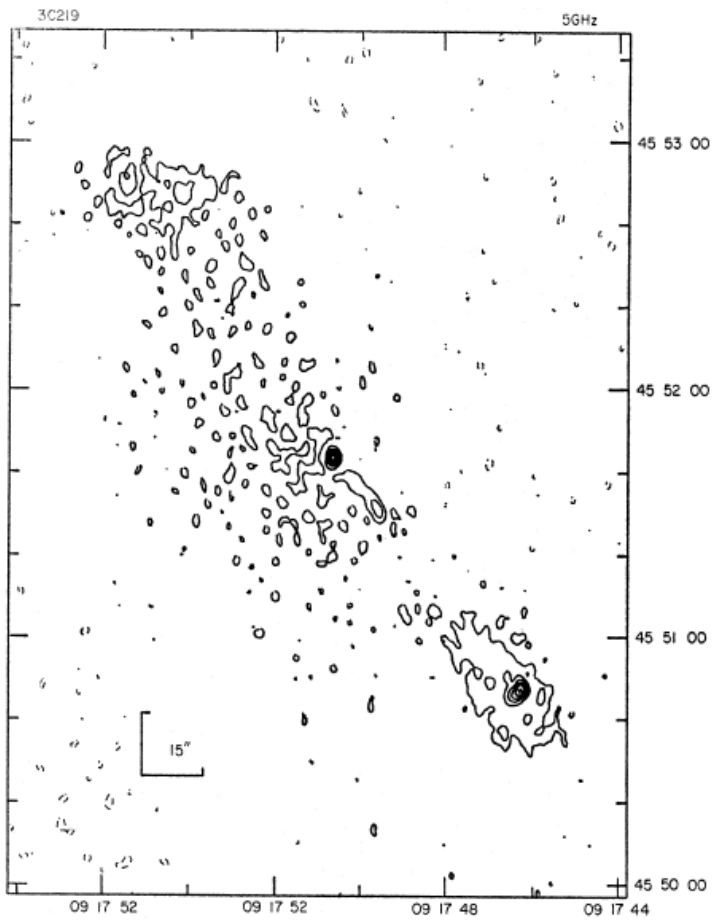


FIG. 1. *Schematic map with beam 2″·0 × 2″·8. The contour interval is 10 mJy beam^{-1}, equivalent to a brightness temperature of 110 K. The first solid contour is at 33 ± 11 K. The dashed contours are negative.*

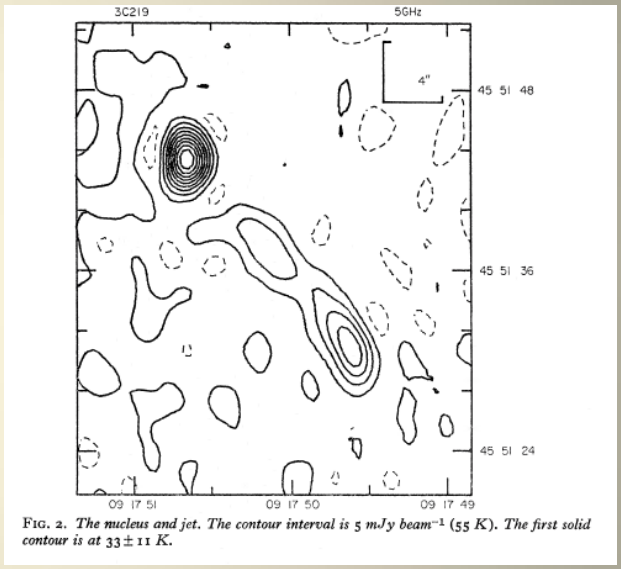


FIG. 2. *The nucleus and jet. The contour interval is 5 mJy beam^{-1} (55 K). The first solid contour is at 33 ± 11 K.*

1974

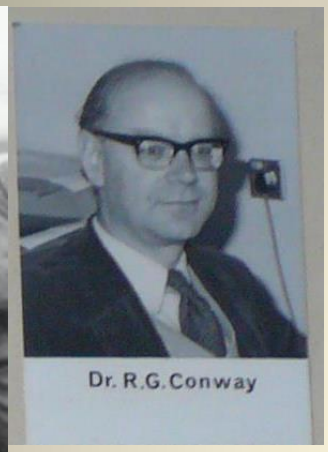
- Extragalactic Jets discovered!
- Blandford and Rees theory 1974
- Now ubiquitous – see current conference!

- But what about polarisation?
  - go back in time to the1960's
  - Morris, Radhakrishnan and Seielstad 1964
    - measure Stokes parameters with circularly polarised feeds

Kronberg and Conway

Nuffield Radio Astronomy Labs 1965

How to cope with non-ideal feeds? – Leakage terms



Robin Conway
1931-2009

Phil Kronberg

$$LL = I + V$$
$$RR = I - V$$
$$RL = Q + jU$$
$$LR = Q - jU.$$

Stokes from Circular feeds and leakage
Conway and Kronberg 1969

Then

$$RR = I + mI(\epsilon_1 e^{-2j\chi} + \epsilon_3 . e^{+2j\chi})$$

$$LL = I + mI(\epsilon_2 e^{+2j\chi} + \epsilon_4 . e^{-2j\chi})$$

$$LR = mIe^{-2j\chi} + I(\epsilon_2 + \epsilon_3)$$

$$RL = mIe^{+2j\chi} + I(\epsilon_1 + \epsilon_4).$$

In most sources the degree of linear polarization is also small, and the ' parallel ' states RR and LL therefore approximate closely to the total intensity. The second term for the ' crossed ' states LR and RL is an error term which is proportional to I, the coefficient being a constant for the instrument which in the main text we have termed the ' instrumental polarization ':

for LR, $r = \epsilon_2 + \epsilon_3$

RL $r = \epsilon_1 + \epsilon_4.$

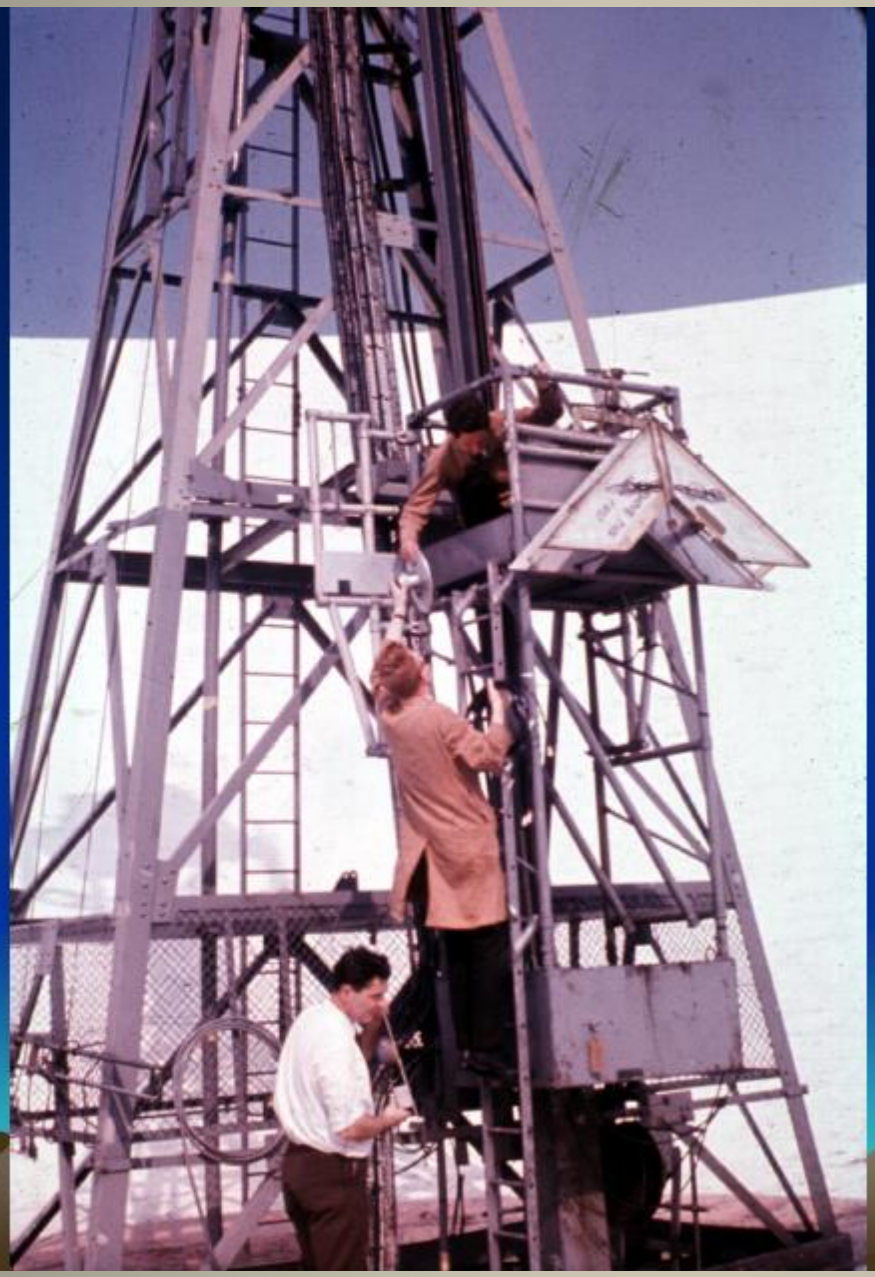
The epsilons became D's
(Bignell 1977? – NRAO late 60's)

$$V_R = G_R(E_R e^{-i\theta} + D_R E_L e^{i\theta})$$

$$V_L = G_L(E_L e^{i\theta} + D_L E_R e^{-i\theta})$$

Mk1-Mk2 Interferometer 1966

Kronberg



Installation of
1420/408 MHz
R/L circularly
polarized feeds
on the Lovell telescope,
(and the Mk II
telescope)

Persons:(Top to bottom)
John Ryder
Chris Church
Bill O'Reilly

Photo by: Phil Kronberg

Summary

- Evidence for jets has existed for a long time, but not confirmed until early 1970's
- Now know lots of the physics (this conference) via polarisation especially
- How they are formed being clarified but still many unknowns
- How they interact with the ISM/IGM and produce lobes not fully understood
- More recent history is another story -AS

Questions?