

RADIO LINK INTERFEROMETRY IN THE 1960s

PIONEERING LBI AT JODRELL BANK

PUSHING ANGULAR RESOLUTION TO THE LIMIT

George Miley
Leiden Observatory

- **SCIENTIFIC DRIVERS FOR LBI**
- **JODRELL LBI – EXCITEMENT**
 - “Only show in town” for most of the sixties
 - Combined with sputnik tracking – Jodrell regularly in News
- **LBI - PIONEERING SCIENCE DIPLOMACY**

SCIENTIFIC DRIVER 1

RADIO GALAXIES AND QUASARS

- REVOLUTIONISED ASTRONOMY

- 1948 - Redshift of Cygnus A,
 - $z = 0.056$ (Baade & Minkowski, 1954)
 - 2nd brightest radio source in sky
 - In principle observable to $z > 10$



- 1963 Quasi-STELLAR radio sources (“quasar”) 3C273
 - $z = 0.158$ (Schmidt, 1963)
 - Enormous energy in stellar-like region. HOW COMPACT??

ENORMITY OF UNIVERSE – PHILOSOPHICAL IMPACT

SCIENTIFIC DRIVER 2

STEADY STATE THEORY OF COSMOLOGY 1948

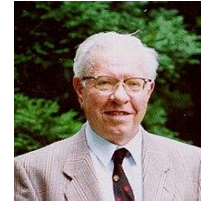
Hermann
Bondi

Age 27



Tommy
Gold

Age 27



Fred
Hoyle

Age 32

THE STEADY-STATE THEORY OF THE EXPANDING UNIVERSE H. Bondi and T. Gold

(Received 1948 July 14)

Summary

The applicability of the laws of terrestrial physics to cosmology is examined critically. It is found that terrestrial physics can be used unambiguously only in a stationary homogeneous universe. Therefore a strict logical basis for cosmology exists only in such a universe. The implications of assuming these properties are investigated.

Considerations of local thermodynamics observations that the universe must be expanding. Hence, there must be continuous creation of matter in space at a rate which is, however, far too low for direct observation. The observable properties of such an expanding stationary homogeneous universe are obtained, and all the observational tests are found to give good agreement.

The physical properties of the creation process are considered in some detail, and the possible formulation of a field theory is critically discussed.

1. The perfect cosmological principle

1.1. The unrestricted repeatability of all experiments is the fundamental axiom of physical science. This implies that the outcome of an experiment is not affected by the position and the time at which it is carried out. A system of cosmology must be principally concerned with this fundamental assumption and, in turn, a suitable cosmology is required for its justification. In laboratory physics we have become accustomed to distinguish between conditions which can be varied at will and the inherent laws which are immutable.

A NEW MODEL FOR THE EXPANDING UNIVERSE F. Hoyle

(Received 1948 August 5)

Summary

By introducing continuous creation of matter into the field equations of general relativity a stationary universe showing expansion properties is obtained without recourse to a cosmical constant.

1. Introduction.—Creation of matter was mentioned about twenty years ago by Jeans (1) who remarked:

“The type of conjecture which presents itself, somewhat insistently, is that the centres of the nebulae (galaxies) are of the nature of singular points, at which matter is poured into our universe from some other and entirely extraneous spatial dimension, so that, to a denizen of our universe, they appear as points at which matter is being continually created”. Subsequent astrophysical developments have, however, shown little support for this particular form of creation.

More recently Dirac (2) has pointed out that continuous creation of matter can be related to the wider questions of cosmology. The following work is concerned with this aspect of the matter and arose from a discussion with Mr T. Gold who remarked that through continuous creation of matter it might be possible to obtain an expanding universe in which the proper density of matter remained constant. This possibility seemed attractive, especially when taken in conjunction with aesthetic objections to the creation of the universe in the remote past. For it is against the spirit of scientific enquiry to regard observable effects as arising from “causes unknown to science”, and this in principle is what creation-in-the-past implies.

The writer's thanks are due to Mr H. Bondi for valuable comments on the present paper and also for many discussions on the general problems of cosmology.

2. Newtonian Universes.—We begin by mentioning the difficulties occurring in current theories of the expanding universe. A comprehensive review of

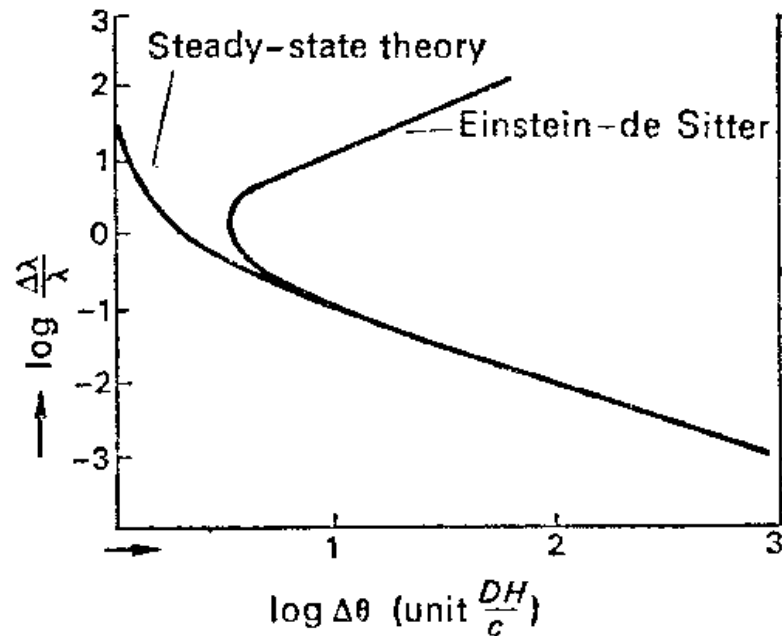
- Perfect Cosmological Principle

- Universe is homogeneous and isotropic in space AND TIME.

- CONTINUOUS CREATION OF MATTER COMPENSATES FOR EXPANSION.

SIZES OF RADIO SOURCES vs REDSHIFT TO DISTINGUISH BETWEEN STEADY STATE AND BIG BANG

Redshift



Hoyle, F. 1959,
Paris Symposium on Radio Astronomy,
IAU Symposium No. 9
URSI Symposium No. 1

Angular Size

5. Apparent diameter $\Delta\theta$ of a source of absolute diameter D , plotted against redshift.

JODRELL BANK - CRADLE OF LBI



Mark I Control Room

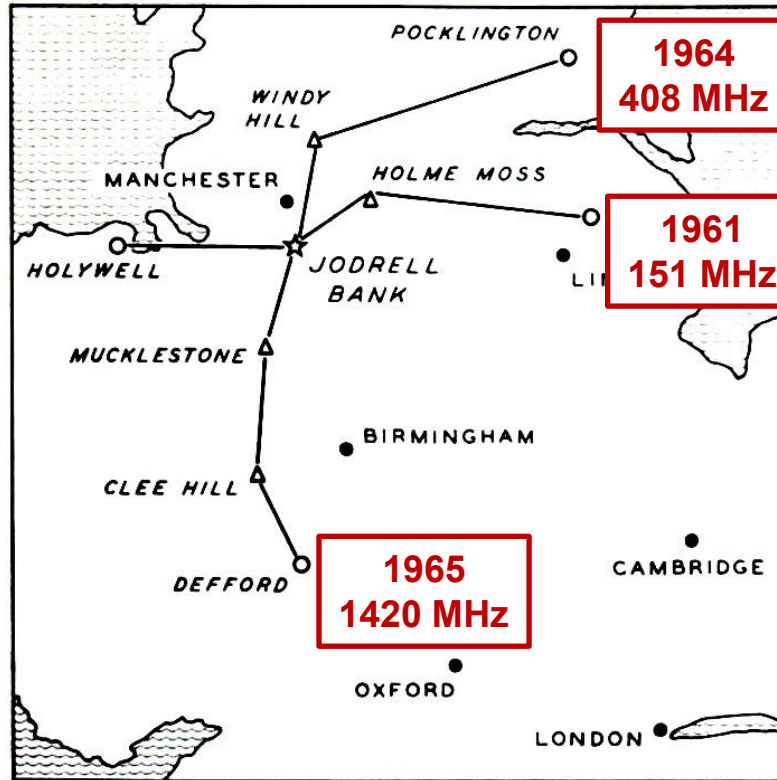


Long baseline
interferometer control room

- 1957 Completion of Mark I Telescope – later Lovell Telescope
 - Largest steerable telescope - 250 ft diameter

THE "HENRY PALMER" LONG BASELINE GROUP

ONLY LONG BASELINE INTERFEROMETRY 1959 - 67



JODRELL GROUP 1963 WHEN I JOINED

- Forgotten heroes of LBI



HENRY
PALMER



BARRIE
ROWSON



BRYAN
ANDERSON



WILF
DONALDSON

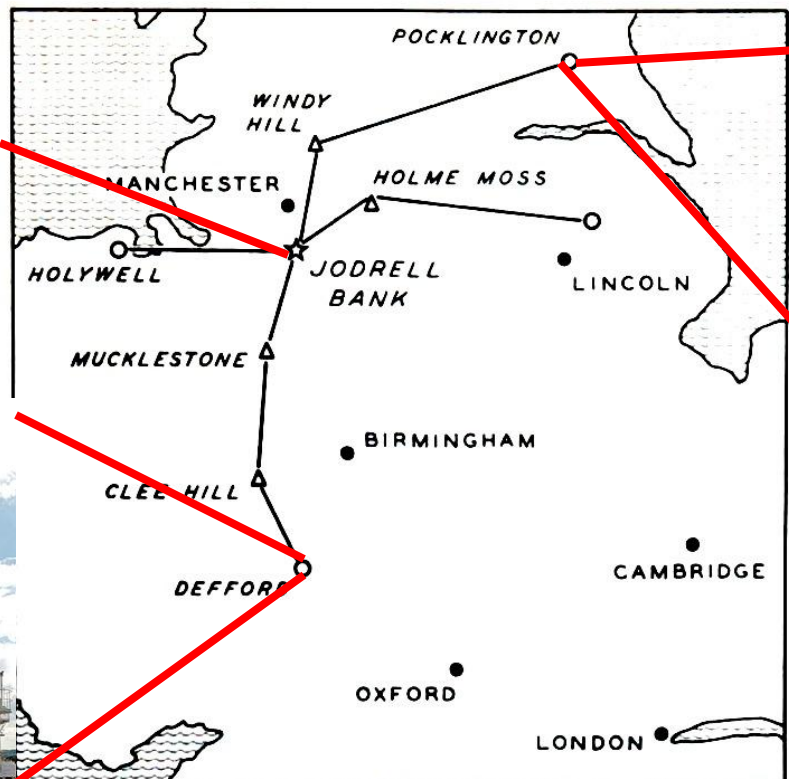
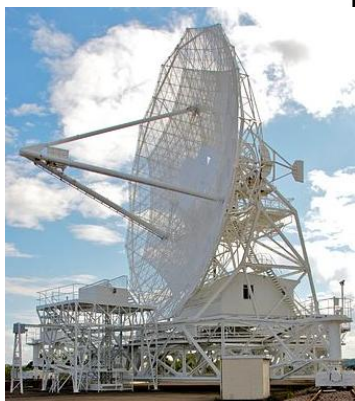
GKM BEGUN PH.D AS "RAW"
21-YEAR OLD IN 1963

MOST RECENT LONG-BASE-LINE EXPERIMENTS

Date	Name	Frequency (mHz.)	Base Line (km.)	(wavelengths)	Collecting Area*
1961	Holywell	158.0	60.3	32,000	710
1963	Lincoln	158.0	115	61,000	710
1964	Pocklington	408.0	131	180,000	390
1965	Malvern (Defford)	1420.0	127	600,000	1,600
1966	Malvern (Defford)	5000.0	127	2,100,000	940 (Mark II)

LONG BASELINE INTERFEROMETRY IN THE SIXTIES

QUEST FOR HIGHER AND HIGHER RESOLUTION



1964, 408 MHz



Wilf's 8m diam. dish at Pocklington
Controlled remotely
Built by a PhD student

Defford 1965 – 67
1.4GHz, 5 GHz

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ELGARROY, MORRIS, ROWSON MNRAS, 124, 395 (1962)

A radio interferometer for use with very long baselines



“FIELD 80”

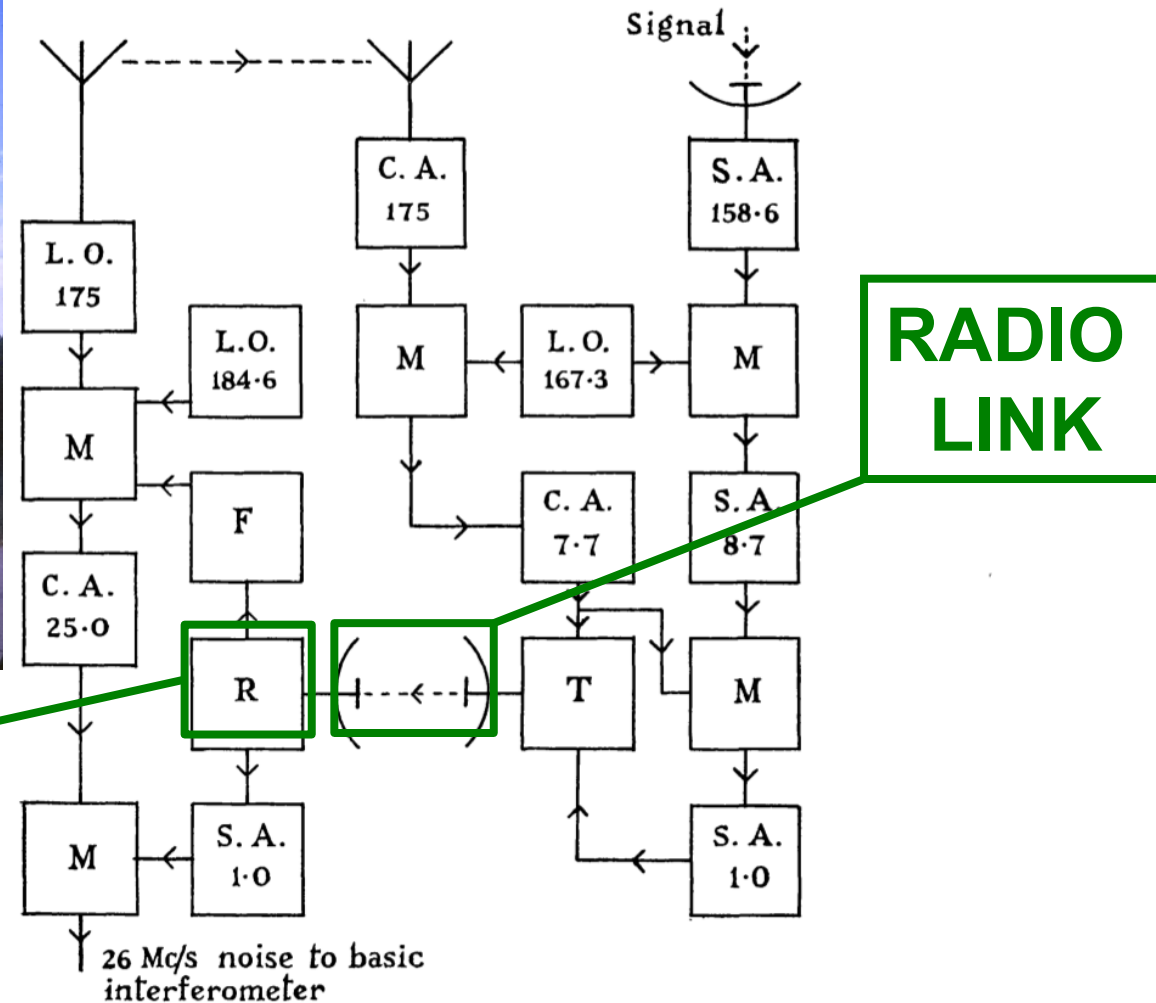


FIG. 3.—Block diagram of radio link system. M, mixer; T, microwave transmitter; R, microwave receiver; S.A., signal amplifier; C.A., continuous wave amplifier; F, frequency multiplier to convert 7.7 Mc/s to 15.4 Mc/s; L.O., local oscillator. The numbers are frequencies in Mc/s.

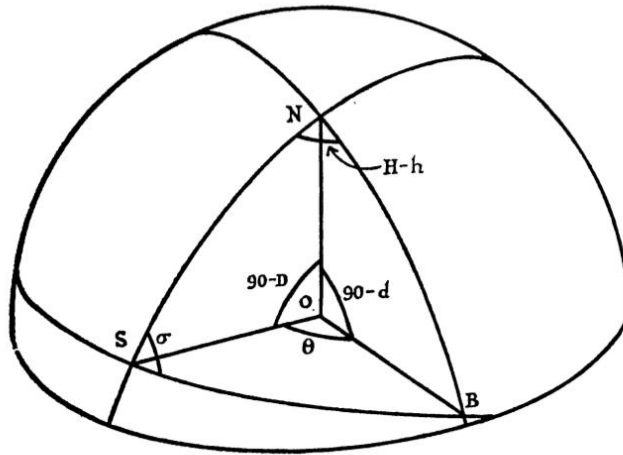
CLASSIC PAPER BY BARRIE ROWSON

MNRAS 125, 177 (1963)



“High resolution observations with a tracking interferometer”

1 THEORY OF THE “U-V” ELLIPSE



-The spherical triangle used for calculating differential delays and resolution.

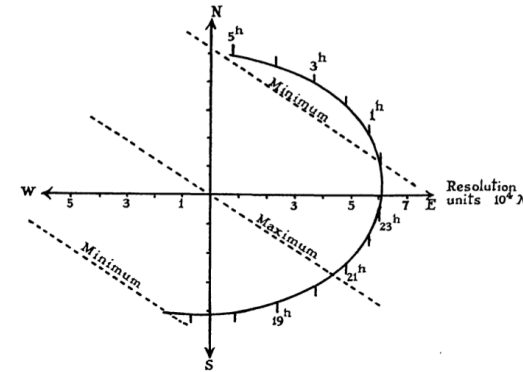


FIG. 7(b).—The locus of observations on the fringe amplitude plane showing the positions of maxima and minima for the source model consisting of two points.

Two deductions can be made from these equations. First, equation (8) shows that, for a given actual baseline, the east-west component of the resolution depends only on the hour angle of the source and not on its declination. Secondly, it can be shown that the locus of the point of observation on the fringe amplitude plane is an ellipse, for if we have an ellipse with semi-major axis a and semi-minor axis b its equation can be given in terms of the parameter ϕ as

$$x = a \sin \phi$$

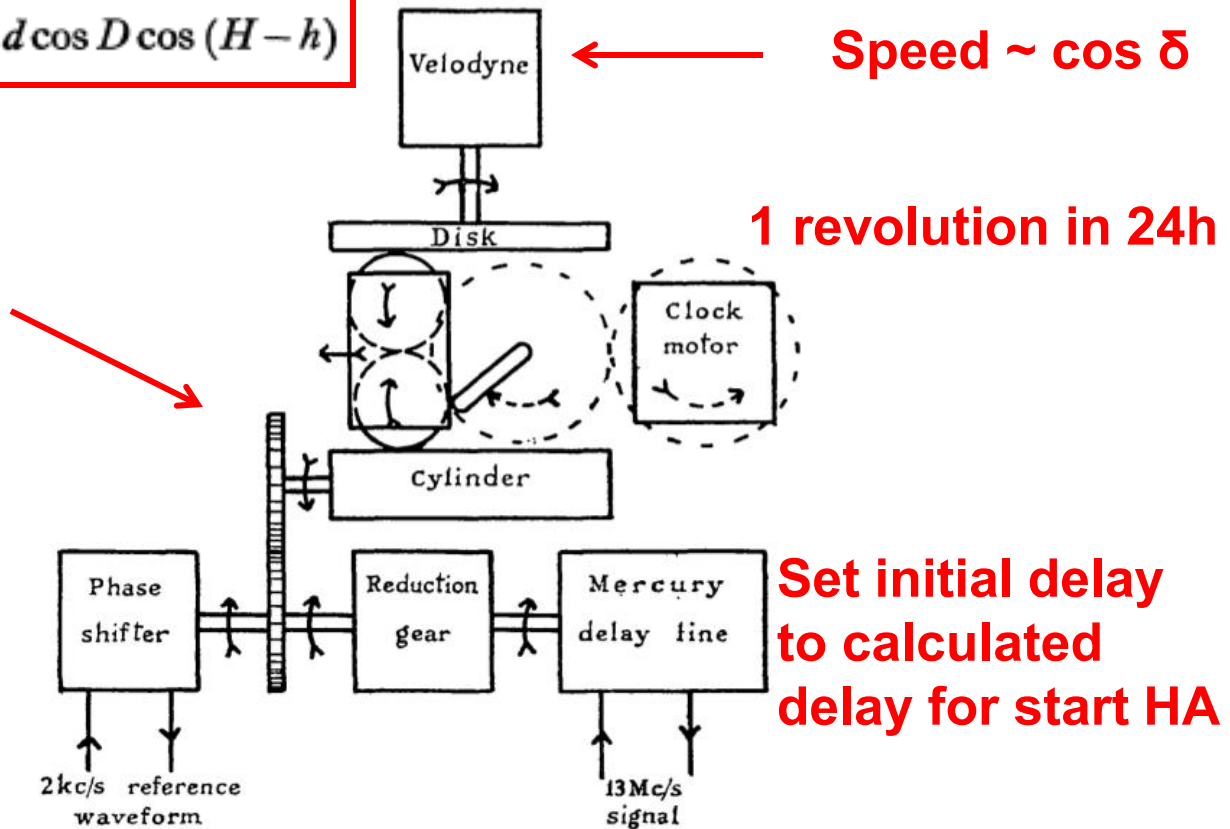
$$y = b \cos \phi$$

ROWSON FRINGE FREQUENCY/ DELAY MACHINE

Tracked fringe frequency and delay

$$\text{Delay} = k + K \int F dt = k + \frac{KLf}{C} \cos d \cos D \cos (H - h)$$

Meccano



TURN ON MOTOR AT CORRECT TIME

ROWSON FRINGE FREQUENCY/ DELAY MACHINE ON TEST BENCH

Tracked fringe frequency and delay out to $B > 100$ km

$$\text{Delay} = k + K \int F dt = k + \frac{KLf}{C} \cos d \cos D \cos (H - h)$$

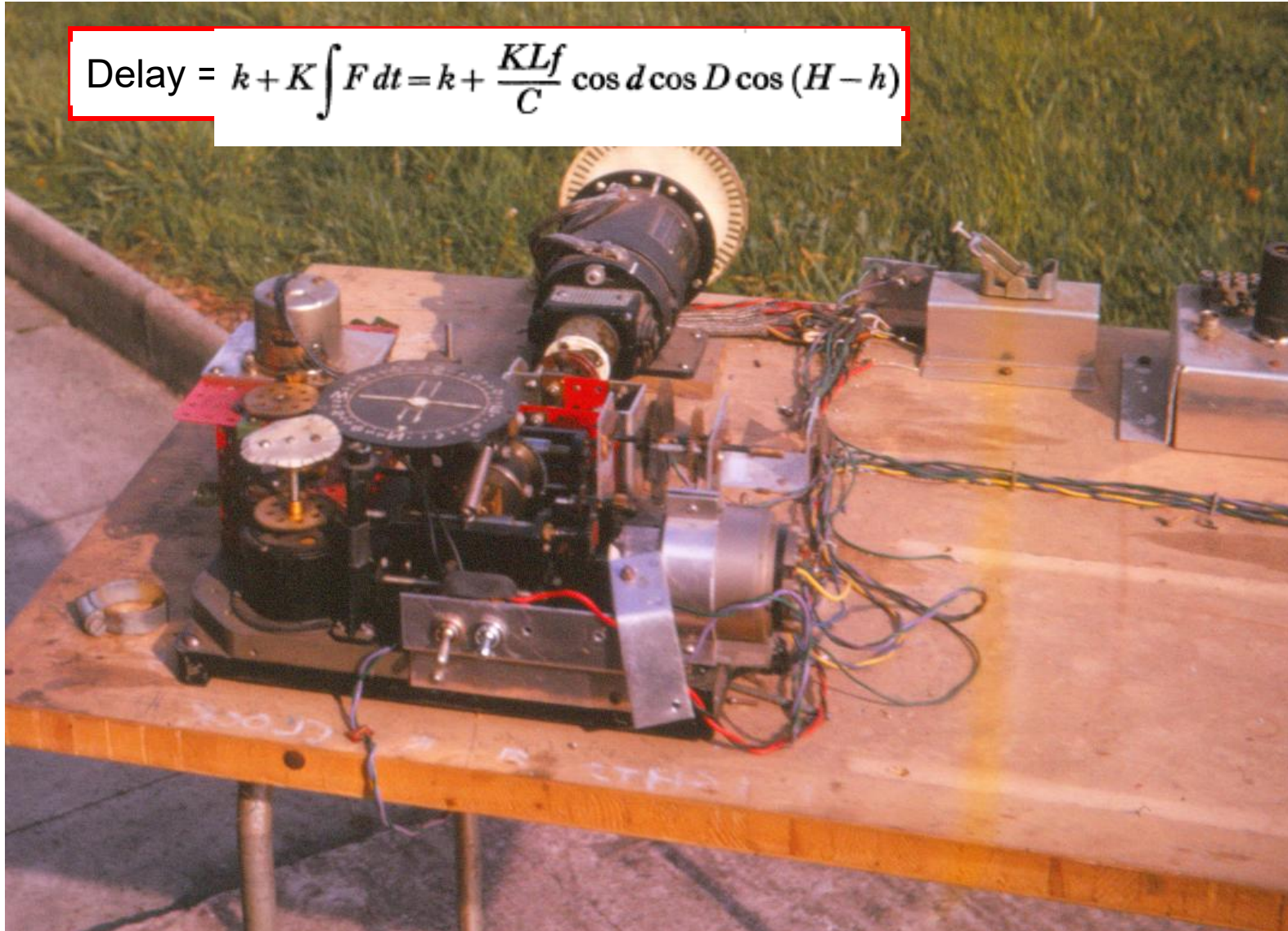


Photo
courtesy
Barrie
Rowson

QUEST FOR HIGHER RESOLUTION - ARE THERE FRINGES?

Jodrell – Defford Baseline - 5 GHz 2 M λ

3C273B

UNRESOLVED

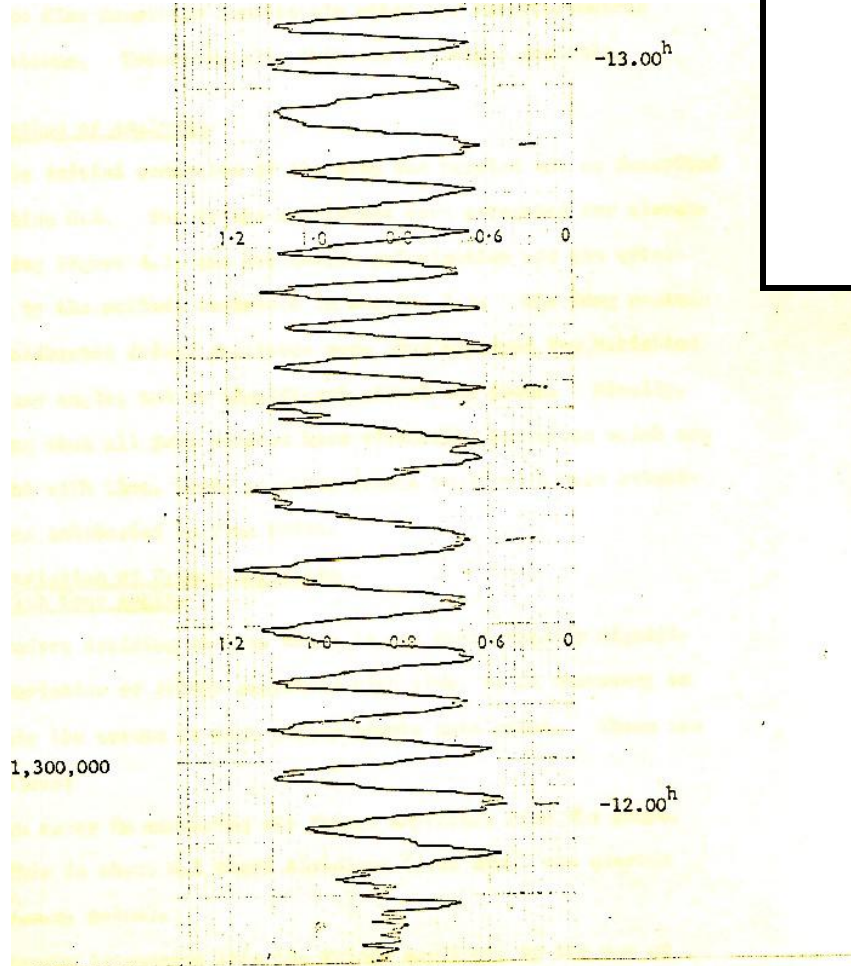


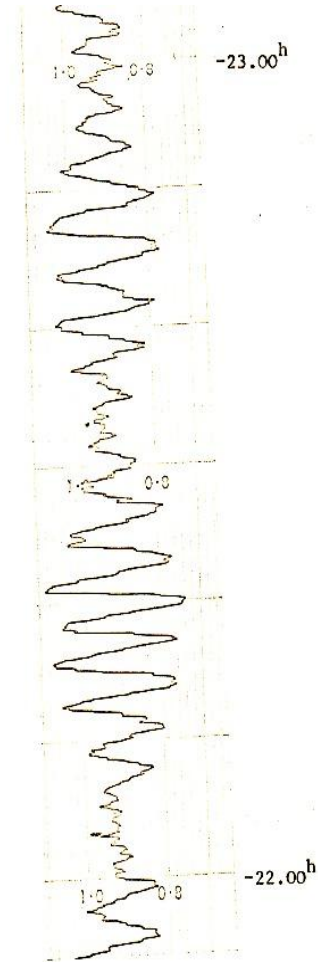
Figure 4.2. Fringes observed from 3C 273 on 19th December 1966 (4998 MHz)

**FRINGES
DURING MY
NIGHT-DUTY**

December 1966

1938-15

RESOLVED



Figures from PKS 1938-15 (1422 MHz)

1960

Letter | Published: 26 November 1960

New Limits to the Diameters of Some Radio Sources

[L. R. ALLEN](#), [H. P. PALMER](#) & [B. ROWSON](#)

[Nature](#) **188**, 731–732 (1960) | [Cite this article](#)

1962

A RADIO INTERFEROMETER FOR USE WITH VERY LONG BASELINES

*O. Elgaroy**, *D. Morris†* and *B. Rowson*

(Received 1962 June 6)‡

1962

962MNRAS...125...574

AN ANALYSIS OF THE ANGULAR SIZES OF RADIO SOURCES

L. R. Allen, *R. Hanbury Brown* and *H. P. Palmer*

(Received 1962 July 18)*

1965

Letter | Published: 01 January 1965

Observations of the Quasi-stellar and Other Radio Sources with an Interferometer of Resolving Power 0.4 sec of Arc

[B. ANDERSON](#), [W. DONALDSON](#), [H. P. PALMER](#) & [B. ROWSON](#)

1965

Article | Published: 01 February 1966

Angular Diameters of Some Radio Sources with Anomalous High-Frequency Spectra

[D. BARBER](#), [W. DONALDSON](#), [G. K. MILEY](#) & [H. SMITH](#)

[Nature](#) **209**, 753–755 (1966) | [Cite this article](#)

JODRELL – DEFFORD (RRE MALVERN)

1967

Letter | Published: 25 February 1967

Radio Diameter Measurements with Interferometer Baselines of One Million and Two Million Wavelengths

H. P. PALMER, B. ROWSON, B. ANDERSON, W. DONALDSON, G. K. MILEY, H. GENT, R. L. ADGIE, O. B. SLEE & J. H. CROWTHER

Nature 213, 789–790 (1967) | Cite this article

LETTERS TO THE EDITOR

ASTRONOMY

Radio Diameter Measurements with Interferometer Baselines of One Million and Two Million Wavelengths

MEASUREMENTS of the angular sizes of radio sources made

Table 1. SUMMARY OF OBSERVATIONS AT WATERBURY A					
Source	Identification and red-shift (Z)	$\lambda=21$ cm.	$\lambda=11$ cm.	$\lambda=6$ cm.	Notes on the observations‡
		Max. baseline =0.6 x 10 ⁶ ft	Max. baseline =1.1 x 10 ⁶ ft	Max. baseline =3.1 x 10 ⁶ ft	
3C 48	Quasar (Z = 0.367)	F	F	—	Resolved at most hour angles but results not yet fully interpreted
0202+14 (NRAO 91)		F	F	—	Unresolved.* $\theta \leq 0.05''$
CTA 21		F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
3C 84	Seyfert galaxy (Z = 0.0172)	F	F	F	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.025''$
NRAO 140		F	F	—	Unresolved.* $\theta \leq 0.05''$
NRAO 150		F	F	—	Unresolved.* $\theta \leq 0.05''$
0403-13	Quasar (Z = 0.571)†	F	F	—	Unresolved.* $\theta \leq 0.05''$
3C 110	Quasar ?	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
0430+05	Galaxy (Z = 0.03)†	F	F	—	Unresolved.* $\theta \leq 0.05''$
0440-00 (NRAO 190)	Quasar	—	F	—	Unresolved.* $\theta \leq 0.05''$
3C 128	Quasar (Z = 0.750)	F	F	—	Double. Component separation $< 0.2''$
3C 147	Quasar (Z = 0.545)	F	F	—	Double. Component separation $< 0.2''$
3C 161	Galaxy	F	NF	—	Dimensions $> 0.2''$
LHE 210		F	F	—	Unresolved.* $\theta \leq 0.05''$
0834-20	Quasar†	—	F	—	Unresolved.* $\theta \leq 0.05''$
3C 227	Galaxy	F	—	—	Double. Component separation $\sim 1''$
1055+01	Quasar	F	F	—	Unresolved.* $\theta \leq 0.05''$
1127-14	Quasar (Z = 1.187)	F	F	—	Unresolved.* $\theta \leq 0.05''$
1145-00	Quasar (Z = 1.982)	F	F	—	Unresolved.* $\theta \leq 0.05''$
3C 273B	Quasar (Z = 0.158)	F	F	F	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.025''$
3C 274	Galaxy (Z = 0.00480)	F	F	—	Unresolved error, $\theta < 0.05''$, containing small percentage of the total flux
1245-19	Quasar†	—	F	—	Unresolved.* $\theta \leq 0.05''$
3C 279	Quasar (Z = 0.540)	F	F	F	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.025''$
3C 280		F	—	—	—
3C 287	Quasar (Z = 1.065)	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
3C 288	Quasar (Z = 0.949)	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
3C 295	Galaxy (Z = 0.460)	F	F	—	Low fringe visibility at minimum resolution
3C 298	Quasar (Z = 1.430)	F	NF	—	—
3C 309-1	Quasar (Z = 0.904)	F	F	—	Unresolved.* $\theta \leq 0.05''$
1506-05		—	F	—	Unresolved.* $\theta \leq 0.05''$
1510-08	Quasar (Z = 0.881)	F	F	—	Unresolved.* $\theta \leq 0.05''$
3C 343		F	—	—	See text
3C 343-1		F	—	—	See text
3C 345	Quasar (Z = 0.595)	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
NRAO 530		F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
3C 380	Quasar (Z = 0.698)	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
1928-15		F	F	—	Double. E-W separation $\sim 2.5''$
3C 405	Galaxy (Z = 0.0570)	F	F	NF	Low fringe visibility at minimum resolution at both 21 and 11 cm
3C 410		F	NF	—	Dimensions $> 0.1''$
3C 418		F	F	—	Unresolved.* $\theta \leq 0.05''$
2127+04		F	F	—	Unresolved.* $\theta \leq 0.05''$
2145+06	Quasar	F	F	—	Unresolved.* $\theta \leq 0.05''$
2205-18	Quasar	F	F	—	Unresolved.* $\theta \leq 0.05''$
3C 446	Quasar (Z = 1.402)	F	F	—	Unresolved.* $\theta \leq 0.05''$
CTA 102	Quasar (Z = 1.037)	F	F	—	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.05''$
3C 454-3	Quasar (Z = 0.86)*	F	F	F	No significant change in fringe amplitude with hour angle. Unresolved. $\theta < 0.025''$

F indicates that fringes were observed. NF indicates that fringes were not observed. — indicates no observations.
* Not observed at all hour angles, but shows no change in fringe amplitude between observations at substantially different resolutions.
† All the identification and red-shift measurements given here have been published, except those marked † which were kindly communicated to us by Professor Bolton in advance of publication. The red-shift parameter $Z = \frac{\lambda - \lambda_0}{\lambda_0}$, where λ and λ_0 are the wavelengths at which the radiation was observed and emitted respectively.
‡ The angular diameter, θ , of each source is given for the shortest wavelength at which the source was observed.

with a 21 cm interferometer between Jodrell Bank and the Royal Radar Establishment, Malvern, over a baseline of more than half a million wavelengths have already been published^{1,2}. Nine sources were shown to be smaller than 0.1 sec of arc in at least one dimension. During 1966 the performance of the digital fringe speed machine was greatly improved and, in addition to further measurements at 21 cm, observations were made at the shorter wavelengths of 11 cm and 6 cm, the radio telescope Mark II being used in place of the Mark I at Jodrell Bank. At the shortest wavelength the maximum effective baseline is greater than two million wavelengths.

DISCOVERY OF QUASARS

Alan Sandage

Ann. Rev. Astron. Astrophys. 1999. 37: 445-486

- “Particularly important for the quasar history was the long base-line interferometry made by the Jodrell Bank radio astronomers.
- They performed interferometry with the Jodrell Bank 250-foot antenna, measuring the fringe visibilities of more than 350 3CR sources. With baselines ranging from 2200 to 61,100 wavelengths (Allen et al 1962, Rowson 1962), they compiled a list of unresolved 3C sources whose angular diameters were smaller than one arcsec, and therefore had "brightness temperatures" larger than 107 K, a telling indication of nonthermal radiation (Palmer 1961). Also from these data, Allen, Hanbury Brown, & Palmer (1962) surmised that many resolved 3CR sources were double, following the previous demonstration by Hanbury Brown & Das Gupta that Cygnus A is double.
- The heroes of the quasar discoveries were clearly Palmer for his brilliant measurements with his Jodrell Bank colleagues of the radio angular diameters,

PAVING THE WAY FOR LOFAR AND LOFAR VLBI

130 KM BASELINE AT 38 MHZ

Discrete Radio Sources at 38 Mc/s

Nature **214**, 971–974 (1967)

by

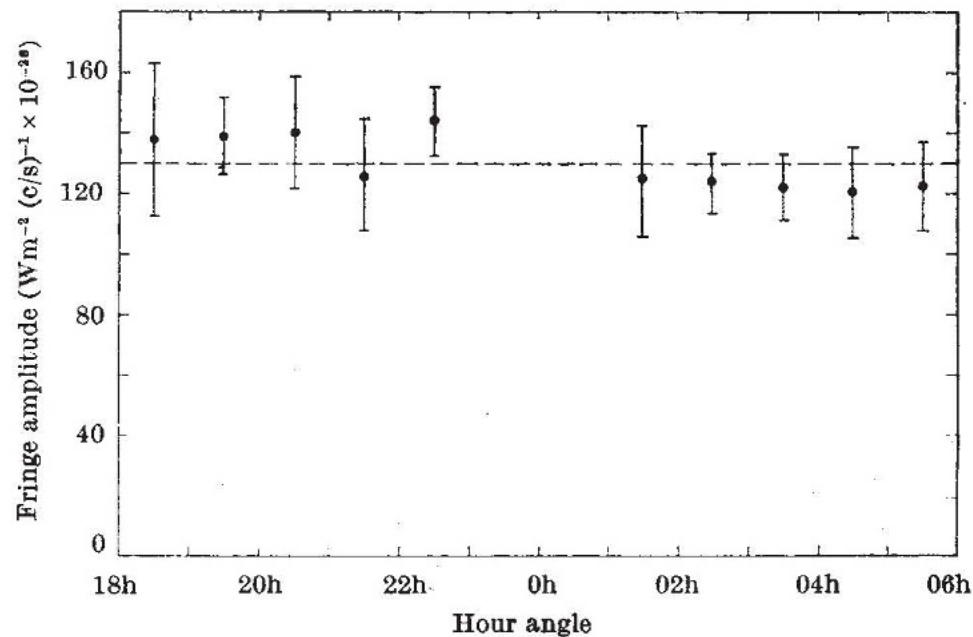
O. B. SLEE*

Royal Radar Establishment, Malvern

P. K. WRAITH

University of Manchester,
Nuffield Radio Astronomy Laboratories,
Jodrell Bank

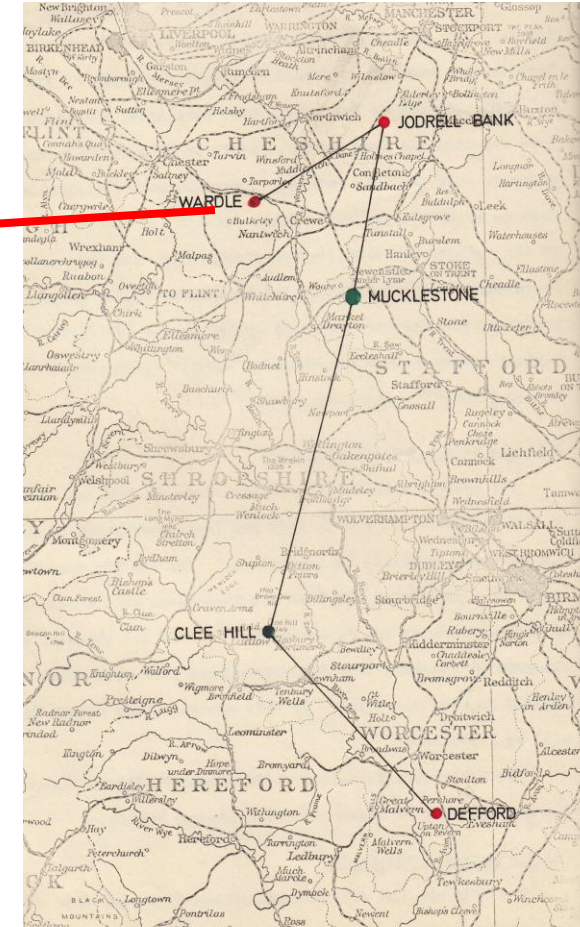
Long baseline interferometer observations between Jodrell Bank and the Royal Radar Establishment of thirty-four radio sources have provided valuable information about radio source structures. Ionospheric and interplanetary scattering effects are present at 38 Mc/s but do not prevent high resolution studies of sources.



3C 273
Unresolved

QUEST FOR MORE SENSITIVITY

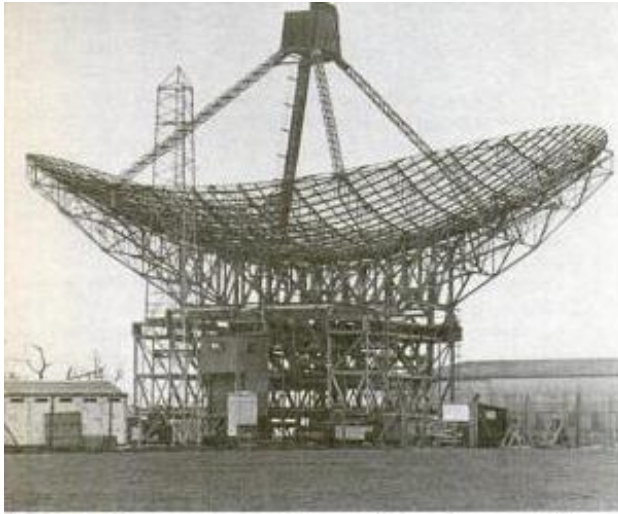
THE MARK III TELESCOPE 1967



- 35m x 28m Increased sensitivity
 - “Transportable”, but never transported
- Used to make size estimates of extended radio sources with z
 - Start discriminate between Big Bang and Steady State Cosmologies

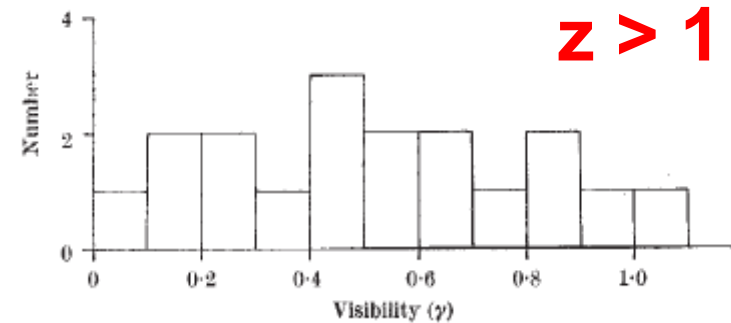
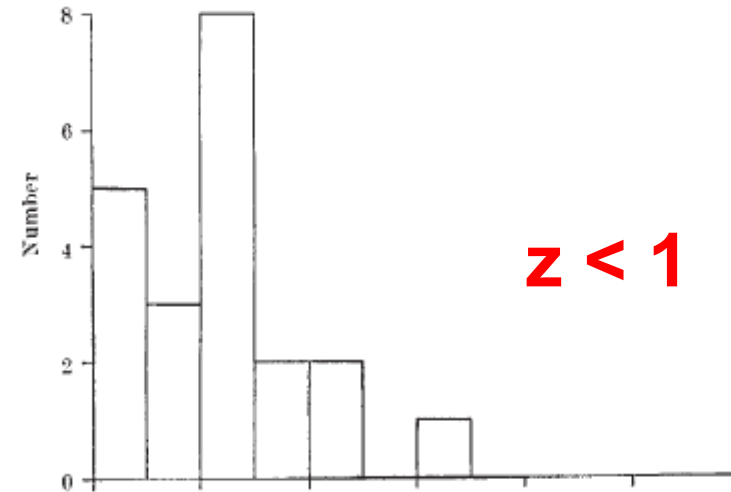
QUASAR ANGULAR SIZES DECREASE WITH REDSHIFT

GM Nature 218, 933 (1968)



STEEP-SPECTRUM QUASARS SPECTRAL INDEX < -0.7

No.



Fringe Visibility

< Large

Small >

DEVELOPMENT OF INDEPENDENT LOCAL OSCILLATOR INTERFEROMETRY

- **1963!** Visit by Lovell to Crimea
 - Discussions with Shklovsky and Matveyenko
 - Crimea – Jodrell 2200 km
 - Memo by Palmer, Anderson, Rowson
 - Impossible/ too expensive with linked interferometers
 - Possibility of phase coherent tape recording interferometer
- 1964 Palmer visits USSR

Lovell



Shklovsky

See Lovell's book "Out of the Zenith"

- 1965- 67 Development of tape recording interferometers
 - Video tape recorders
 - Atomic clocks
 - Just too late
- 1967
 - Canada - Broten et al. (Algonquin-Penticton)
 - U.S. NRAO – Cornell Kellermann, Cohen, Clark ; MIT Moran et al
- 1969
 - --Jodrell – Arecibo

VLBI – UNIQUE TOOL FOR SCIENCE DIPLOMACY

- Astronomy non-threatening discipline
- Interferometry - unique bridging platform
 - Bringing “enemies” together to explore the Universe
 - Geographical interdependence of partners
 - Whole greater than sum of parts
- e.g. VLBI INTERFEROMETRY BETWEEN DURING 1960-70S COLD WAR

John Payne
NRAO Engineer

Viktor Effanov
Crimea Observatory



Ivan Moiseyev, Director,
Crimea Observatory

Petr Stezhka
Simeiz Radio Observatory

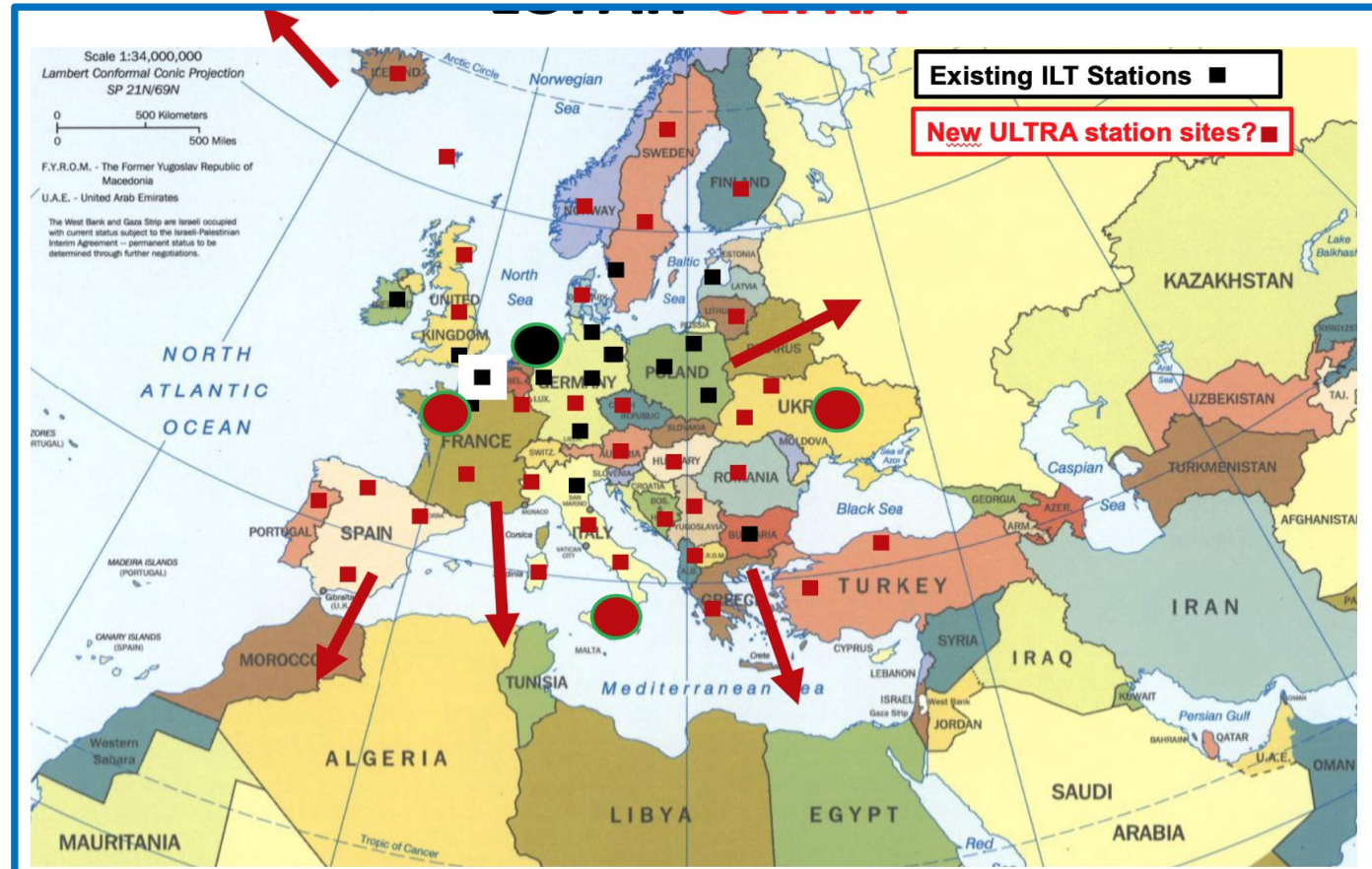
SCIENTIFIC DIPLOMACY HELPED BY A FEW DRINKS!!!

LESSONS FROM LBI AND JODRELL HISTORY

- Difficult to justify expensive astronomy facilities on pure scientific grounds
- Long-term astronomical strategy dependent on politics and diplomacy
 - Jodrell sold to the public as the UK's contribution to the international space race
 - Sir Bernard Lovell - master politician and diplomat
 - intrigued by science
 - pioneered science outreach
- Can present geopolitical situation be exploited for astronomy?
 - Pressure for increased European unification
 - Preferably add multidisciplinary applications
 - Pan-European engine for technology, innovation, education
 - Ensure **VISIBLE** economic and social benefit to Europe

LOFAR-ULTRA 2040

MOST SENSITIVE + HIGHEST RESOLUTION
LOW FREQUENCY RADIO TELESCOPE FEASIBLE



ESSENTIAL HIGH-RES COMPLEMENT TO SKA(Low)

ON REQUEST: 40-PAGE WHITE PAPER

End