The history of innovation in Radio Astronomy

From Antikythera to the SKA

Kerastari, Greece

12 Jun 2012

Ron Ekers
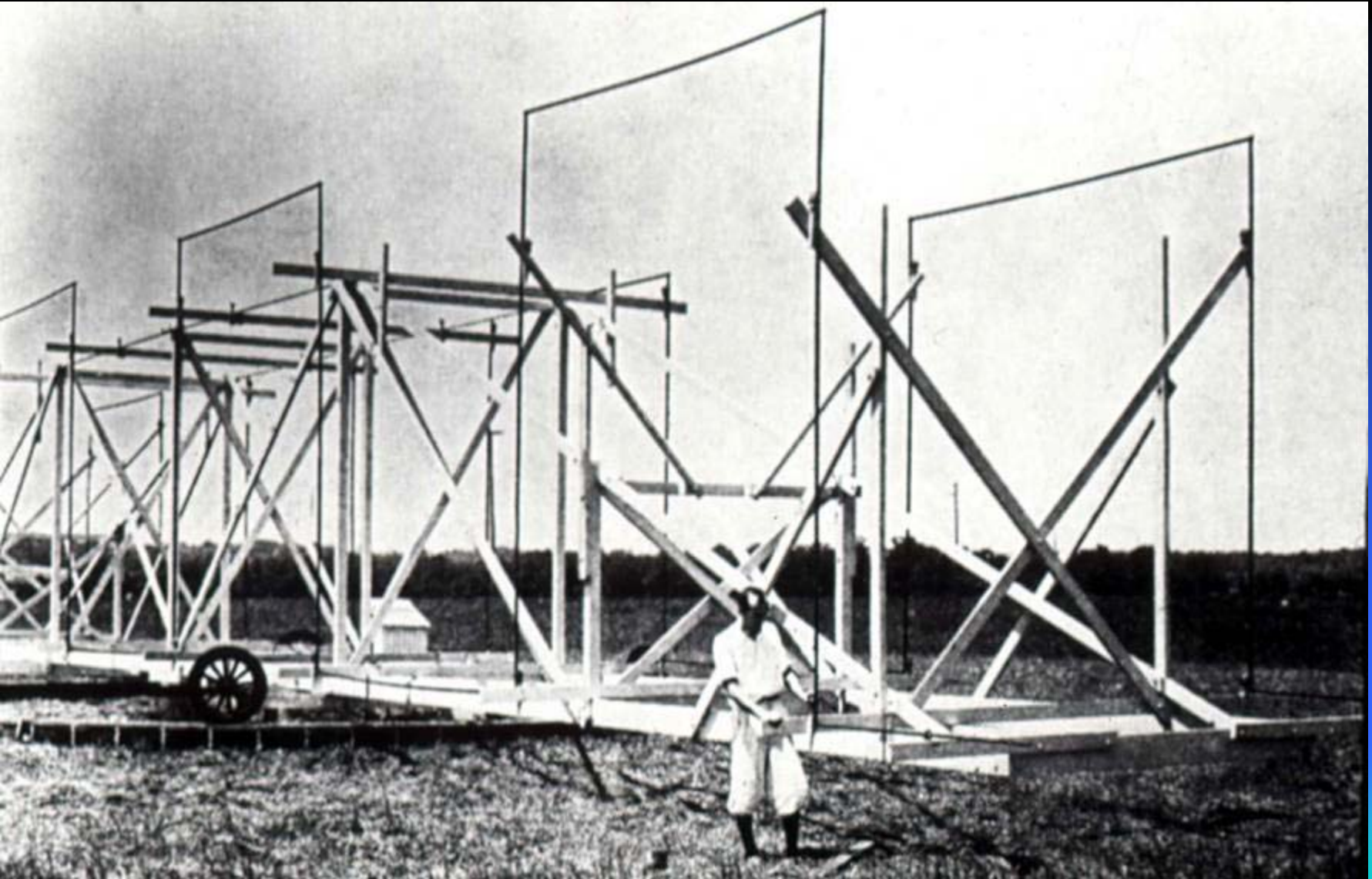
CSIRO, Australia

CSIRO

Galileo Galilei - 1609

- Galileo builds a telescope and he sees the moons of Jupiter.

"Four planets, never seen since the beginning of the World right up to our day"
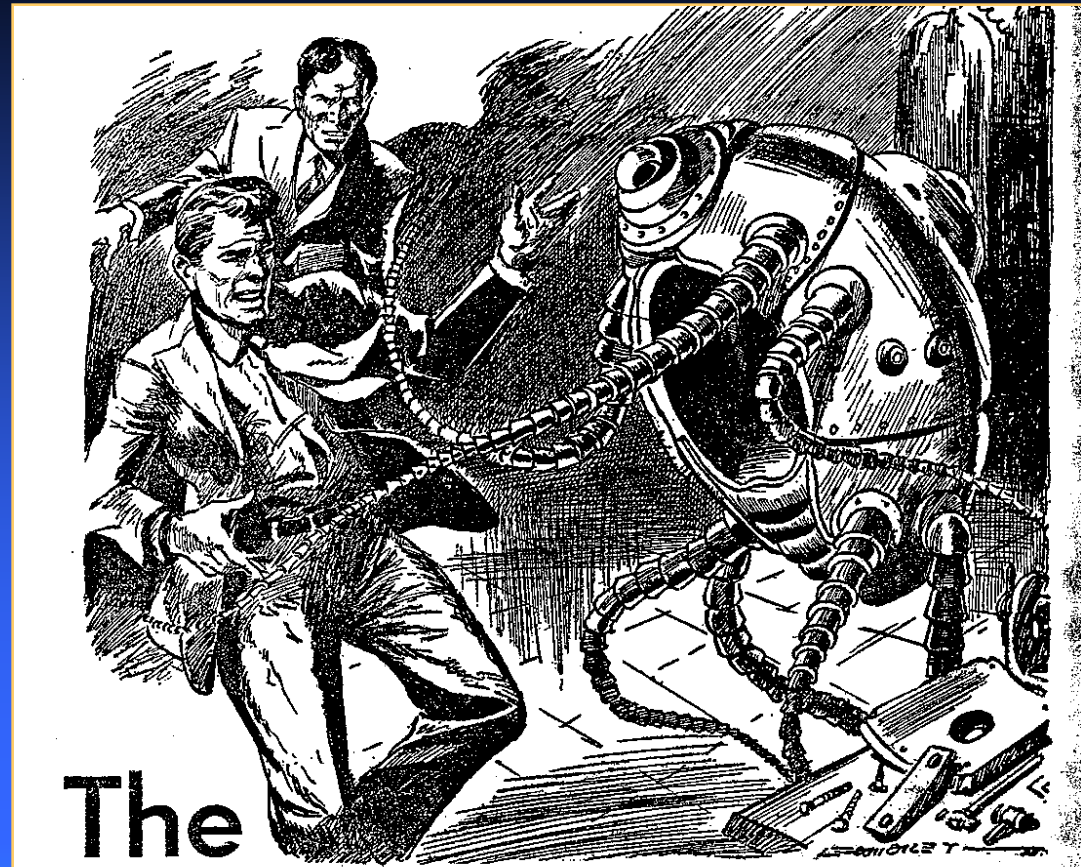
3

Beginning of Radio Astronomy

- Jansky's Cosmic Hiss
  - Unexpected source of noise peaking each day
  - signal arrives *4 min* earlier each day
  - reaction from Bell Labs *"so faint not even interesting as a source of radio interference!"*
  - not accepted by the astronomical community at the time
  - Jansky died in 1944 before the importance of his discovery was appreciated
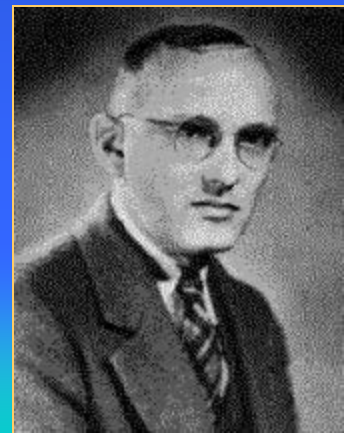
Science Fiction

- Dec 1938
- Edmond Hamilton
  - *The Cosmic Hiss*
  - Based on Jansky's observation of cosmic hiss
- Extra Terrestrial Intelligence?

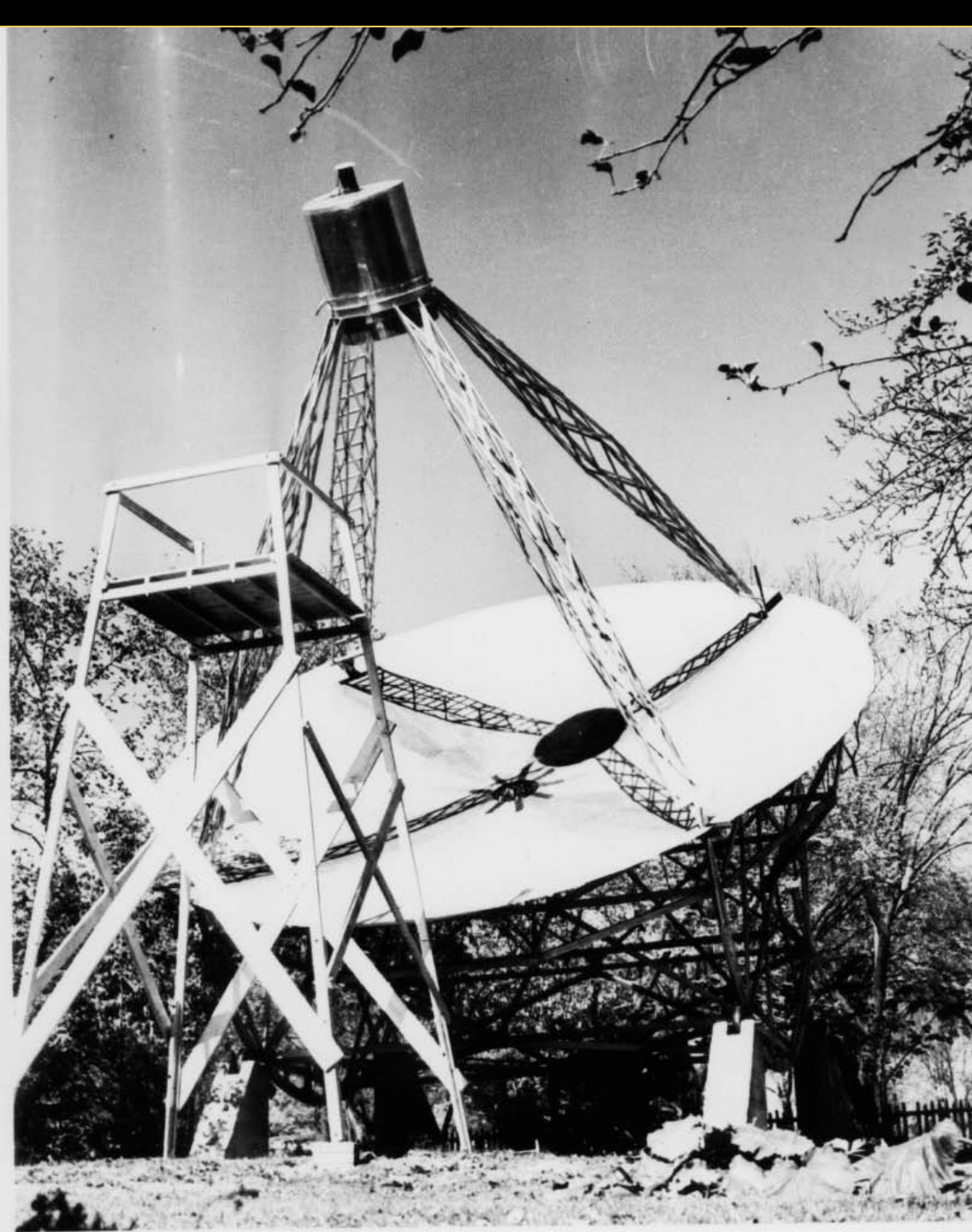The robot, thrusting back a swift tentacle, sent Marlin staggering to the wall

The COSMIC HISS

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- Grote Reber 1911-2002
- Wheaton Illinois
  - 1937
  - 32' parabolic dish
- Cosmic radiation had to be non-thermal
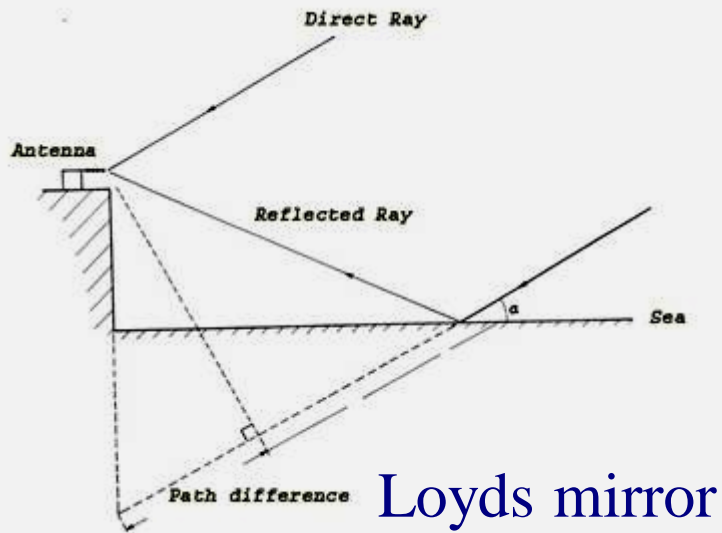 - No theory until 1950

The Dish

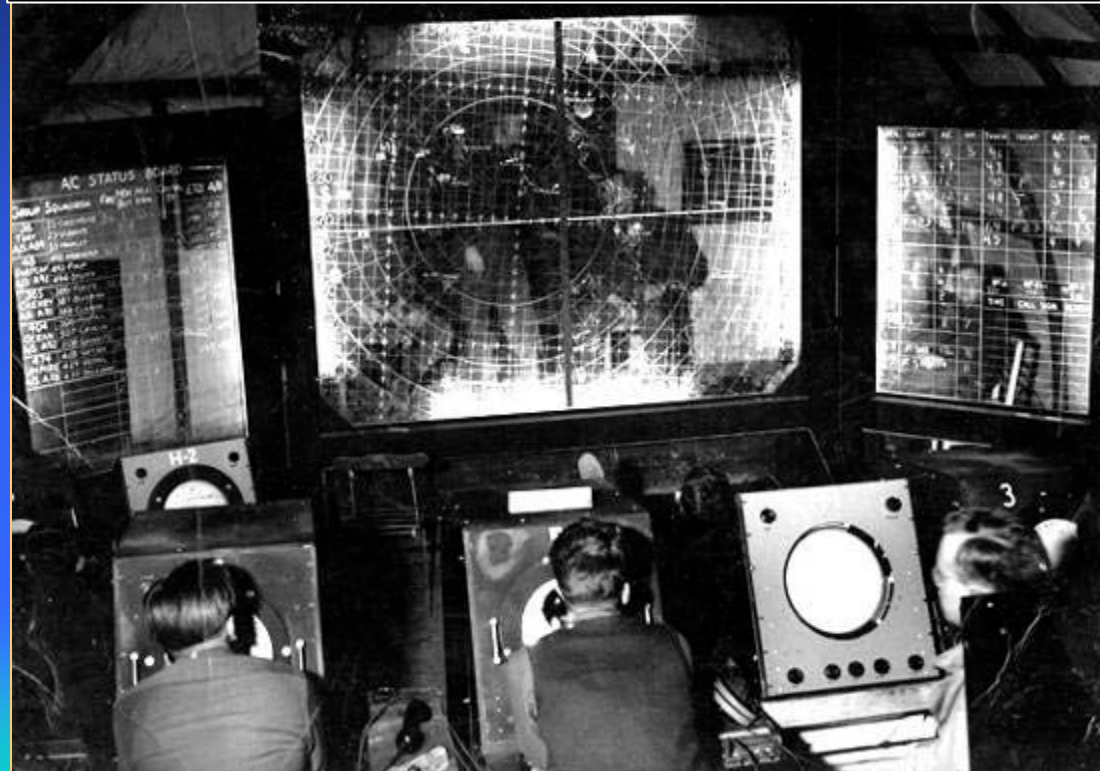Parkes 64m, Australia 1960

What are the Radio Stars?
Cliff Interferometer - 1948

- Bolton, Stanley and Slee (CSIRO, Australia)
  - 100MHz Yagi
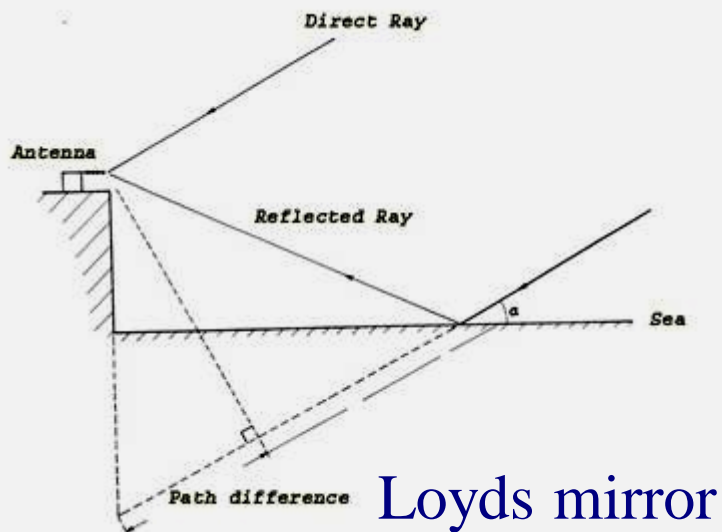

Loyds mirror

WW2 radar used interference from reflected signals to measure elevation
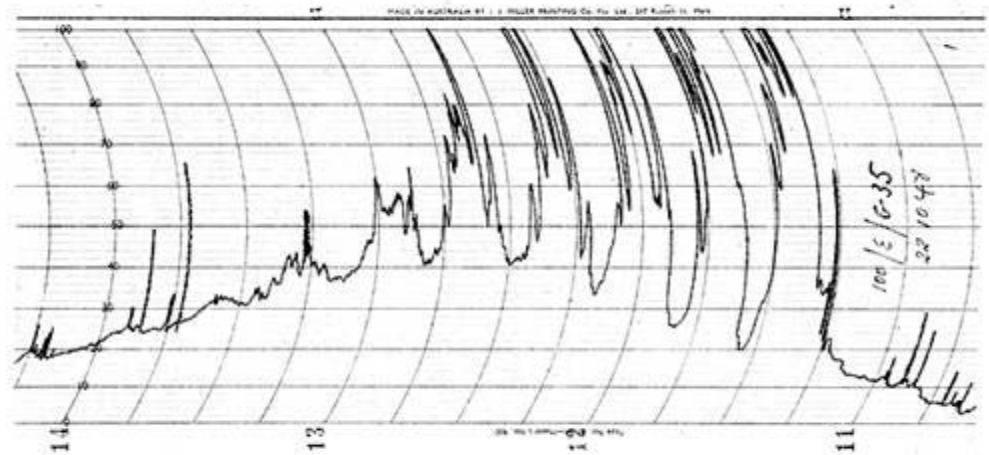
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What are the Radio Stars?
Cliff Interferometer - 1948

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Loyds mirror

Used interference fringes to measure source position

R D EkersR. Ekers
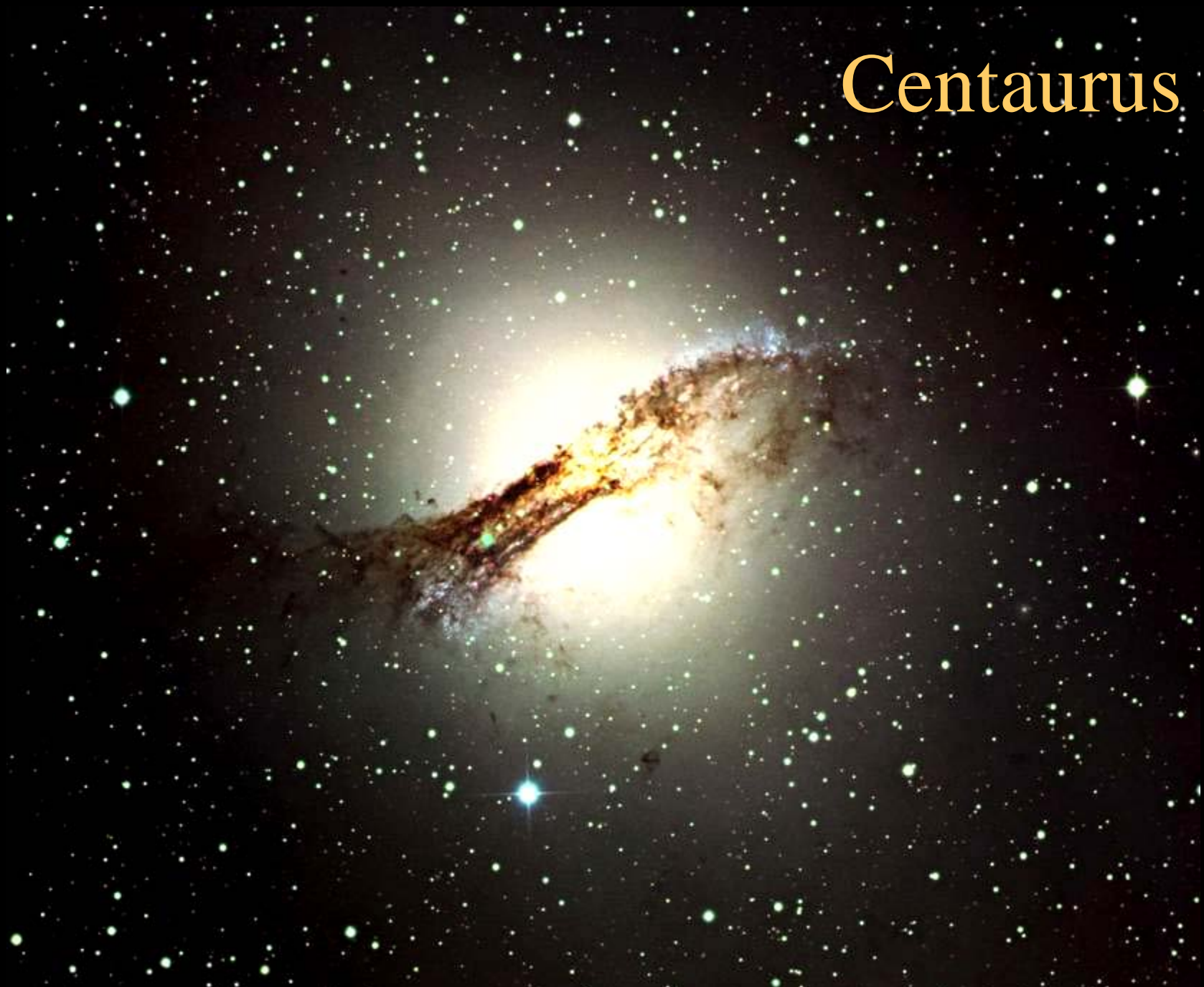
Centaurus A

Centaurus A

Centaurus A
ATCA Mosaic

Centaurus A
ATCA Mosaic

Today we use Aperture Synthesis Images routinely

But the path to developing the underlying concepts has a rich history involving discovery, sociology, and some incredible individuals

Radio Image of
Ionised Hydrogen in Cyg X
CGPS (Penticton)

History of Fourier Synthesis Imaging

- 1891: Michelson defines fringe visibility
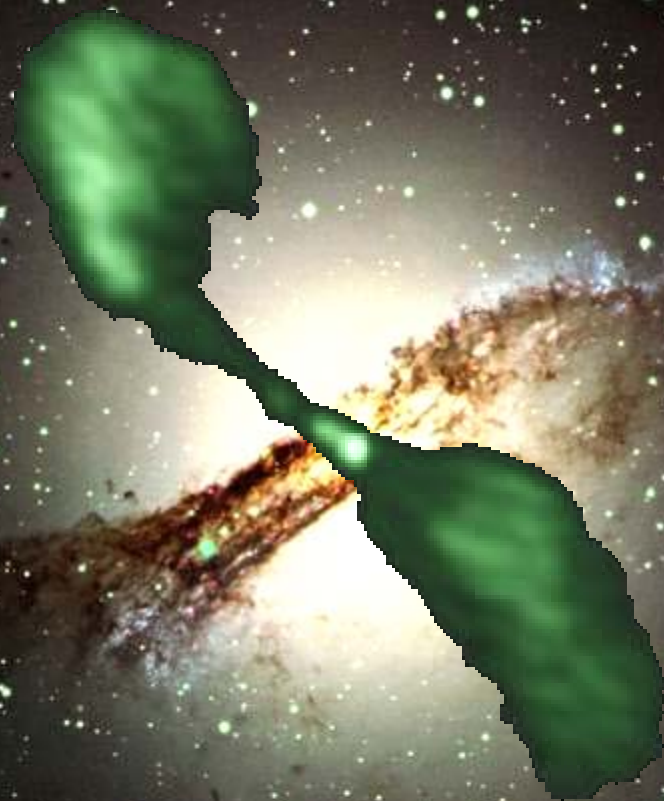 - Gives the Fourier equations but doesn't call it a Fourier transform
- Stereo X-ray imaging
- 1912: X-ray diffraction in crystals
- 1930: van Cittert-Zernike theorem
  - Now considered the basis of Fourier synthesis imaging
  - Played no role in the early radio astronomy developments but appears in the literature after Born & Wolf *Principles of Optics* (1960)
- 1930-38: 3D X-ray tomography
  - Analogue devices to do back projection summation

CSIRO

X-ray Crystallography

- 1912
  - X-ray diffraction in crystals
- 1936
  - Lipson & Beevers strips
  - Fourier synthesis calculations routine in X-ray crystallography
- 1939
  - Bragg's X-ray crystallography group flourishing at the Cavendish Laboratory
    - 2D Fourier analysis
    - phase problem,
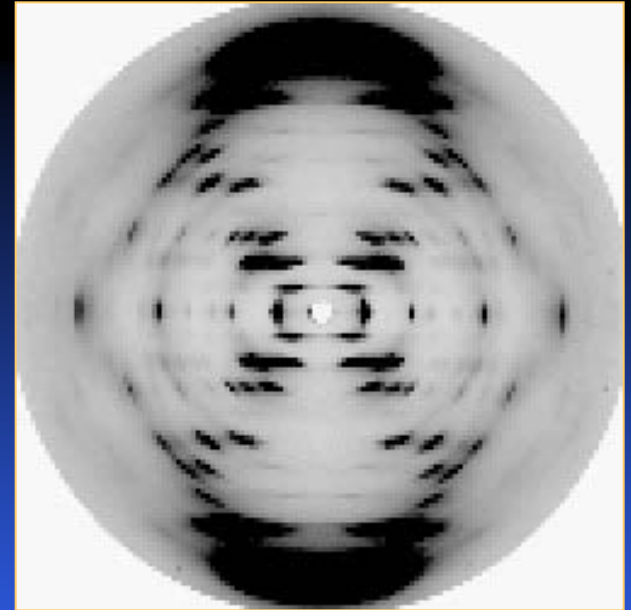
Ratcliffe $\Rightarrow$ Pawsey $\Rightarrow$ Bracewell Cambridge $\Rightarrow$ Sydney

- 1935
  - Pawsey PhD with Ratcliffe at Cambridge (ionosphere)

- 1940
  - Pawsey joins CSIRO Radiophysics Laboratory in Sydney but maintains strong links with Ratcliffe in Cambridge

- 1946-1949
  - Pawsey introduces Bracewell to duality of physical and mathematical descriptions following Ratcliffe's style
  - Bracewell sent from Sydney to work with Ratcliffe

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Ryle and the Cavendish

- 1945
  - Ryle joins Cavendish laboratory
    - uses WWII radar technology for radio astronomy
- 1946
  - Ryle and Vonberg (Nature 158, 339-340 (Aug 1946)
    - interferometric measurement of sunspots
  - introduces the use of a Michelson interferometer to measure the angular diameter of the source of the radiation and references Michelson

McCready, Pawsey & Payne-Scott 1947

- Proc Roy Soc, Aug 1947 - received July 1946!

- Used the phase of the sea interferometer fringes (lobes) to co-locate solar emission with sunspots

- They note that its possible in principal to determine the actual distribution by Fourier synthesis using the phase and amplitude at a range of height or wavelength.

- They consider using wavelength as a suitable variable as unwise since the solar bursts are likely to have frequency dependent structure.

- They note that getting a range of cliff height is clumsy and suggest a different interference method would be more practical.
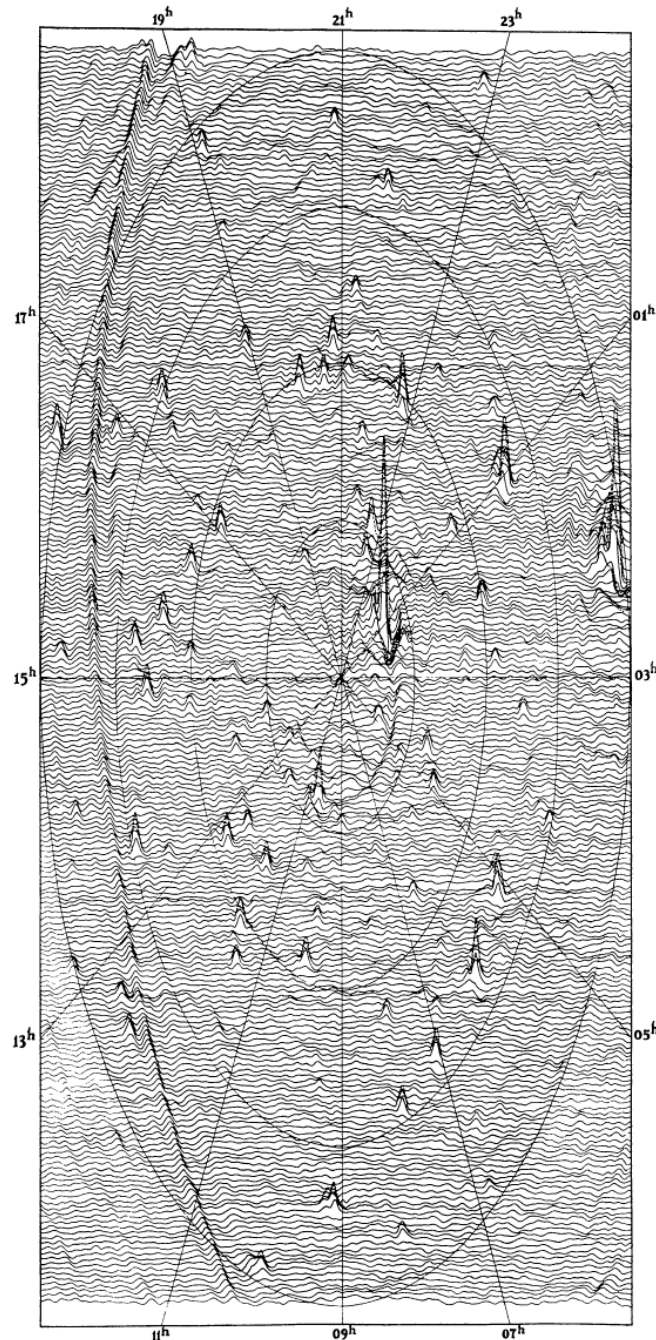
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Fourier Transforms - 1953

- Lipson-Beevers strips
  - 25x25 array to 2 digits 1 person in 24 hours
- Punched card tabulator
  - 25x25 array to 3 digits in 8 hours (4 operators!)
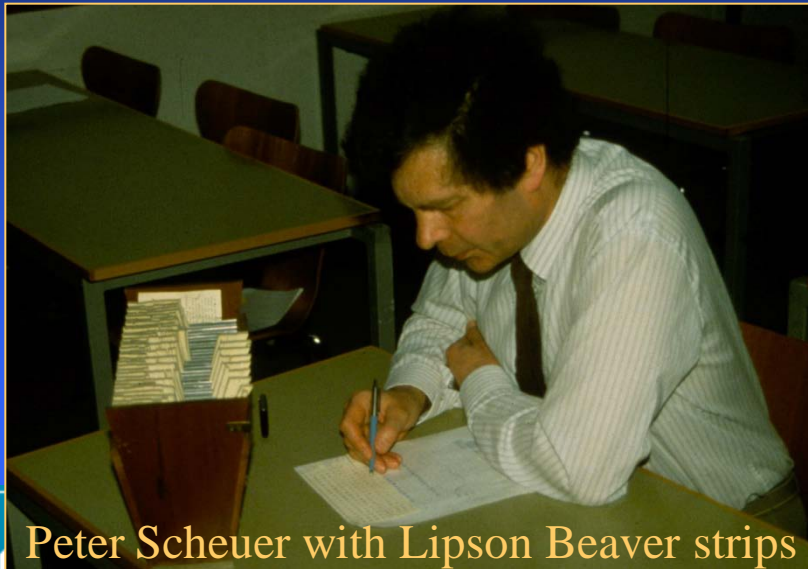
Peter Scheuer with Lipson Beaver strips
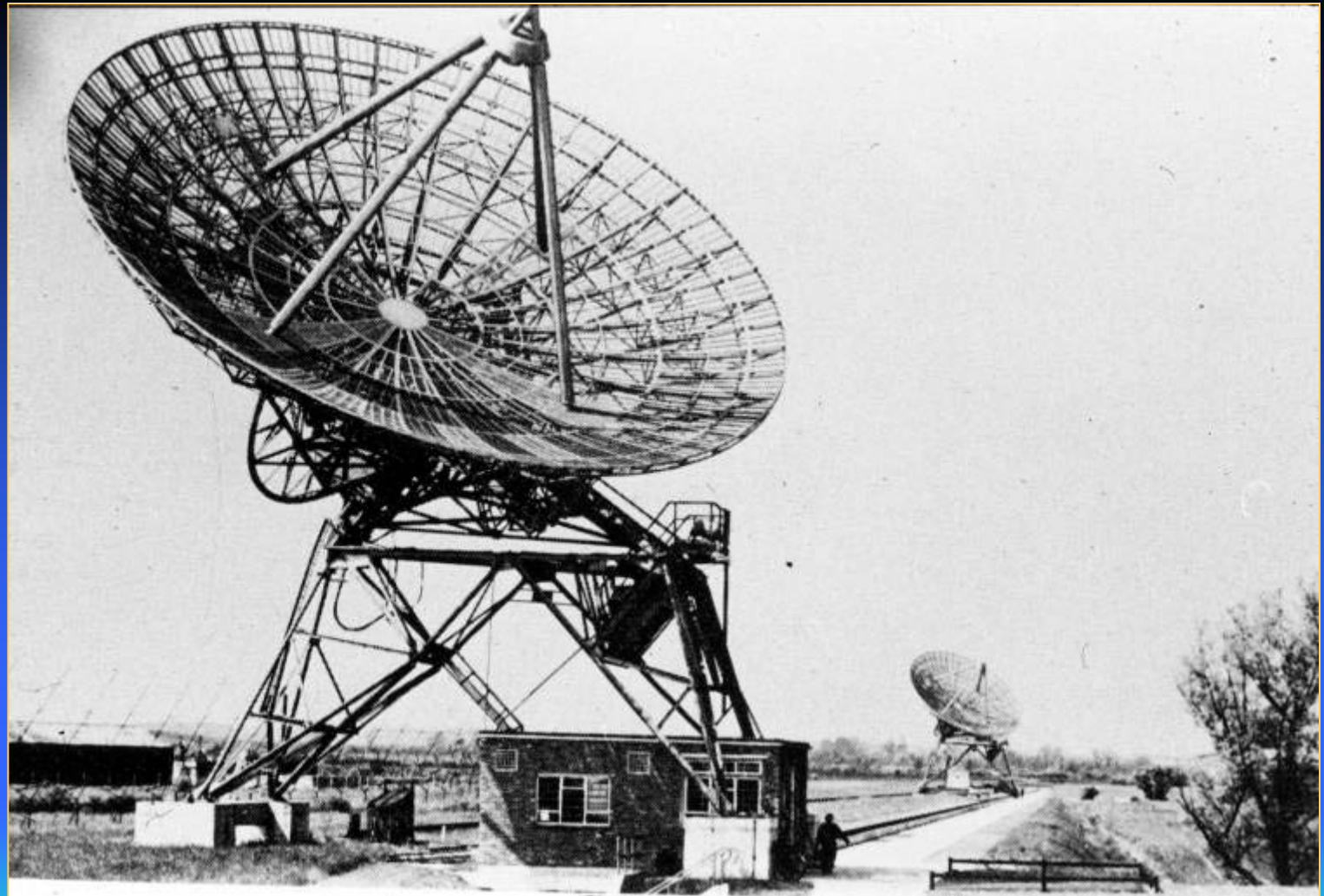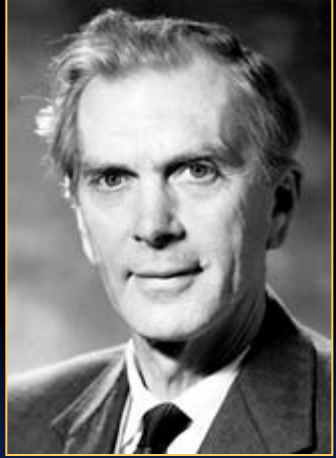
M. Ryle and Ann C. Neville
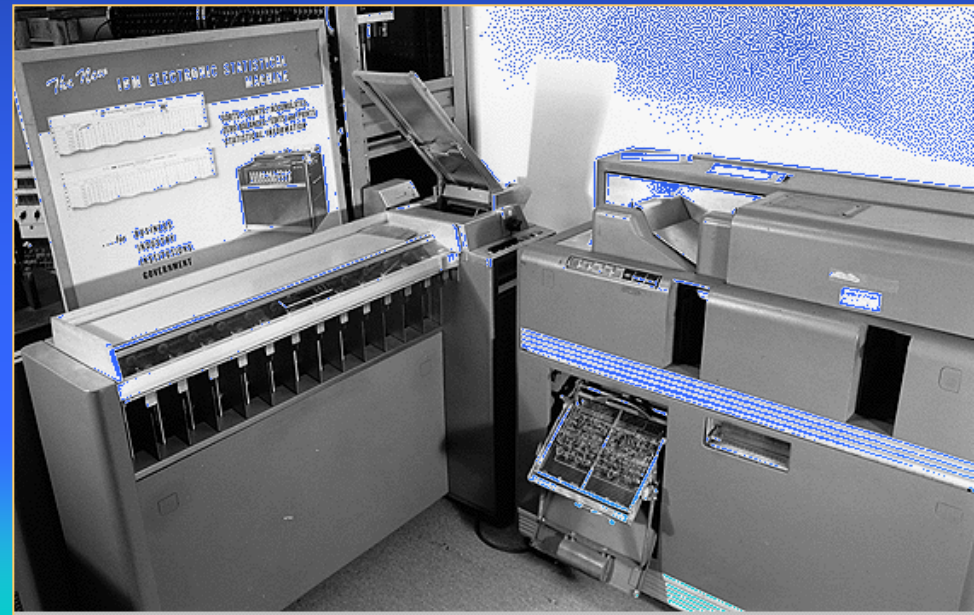
First Cambridge Earth Rotation Synthesis Image

- Ryle & Neville, MNRAS 1962
- June 1961
- North pole survey
- 4C aerials
- 178 MHz
- Not superseded until LOFAR & MWA!

Cambridge One-Mile Telescope: 1962

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Nobel Prize 1974
Sir Martin Ryle

from the presentation

"The radio-astronomical instruments invented and developed by Martin Ryle, and utilized so successfully by him and his collaborators in their observations, have been one of the most important elements of the latest discoveries in Astrophysics."

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Westerbork: 1970

- Hogbom (Cambridge)

    +

- Christiansen (Sydney)

Benelux cross → WSRT

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

1980

VLA
New Mexico

Self Calibration

- 1958: Phase and amplitude closure
  - Jennison (Jodrell Bank)
- 1977: Redundant spacing interferometry
  - Hamaker , O'Sullivan, Noordam (Westerbork)
- 1974-79: Phase closure in VLBI imaging
  - Rogers, Yee, Readhead, Cotton….
- 1980: Antenna based calibration
  - Clark, Schwab (VLA)
- 1983: Self cal $\equiv$ phase closure $\equiv$ adaptive optics
  - Cornwell

Little Science – Big Science

Derek J. de Solla Price (1963)

Little Science, Big Science

Columbia University Press
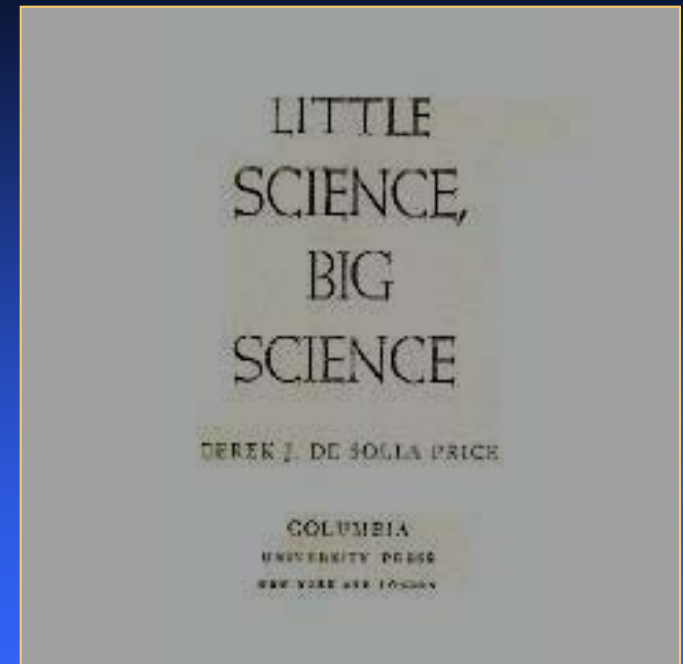
Derek J de Solla Price

- Price worked as a teacher of applied mathematics at Raffles College (University of Singapore) in 1948.
- It was there that he formulated his theory on the exponential growth of science
- The idea occurred to him when he noticed the growth in stacks of the *Philosophical Transactions of the Royal Society* between 1665 and 1850
- He had the complete set in his home while Raffles College had its library built.

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Radio Telescope Sensitivity

- Exponential increase in sensitivity x 10^5 since 1940 !

  – 3 year doubling time for sensitivity

Radio Telescope Sensitivity
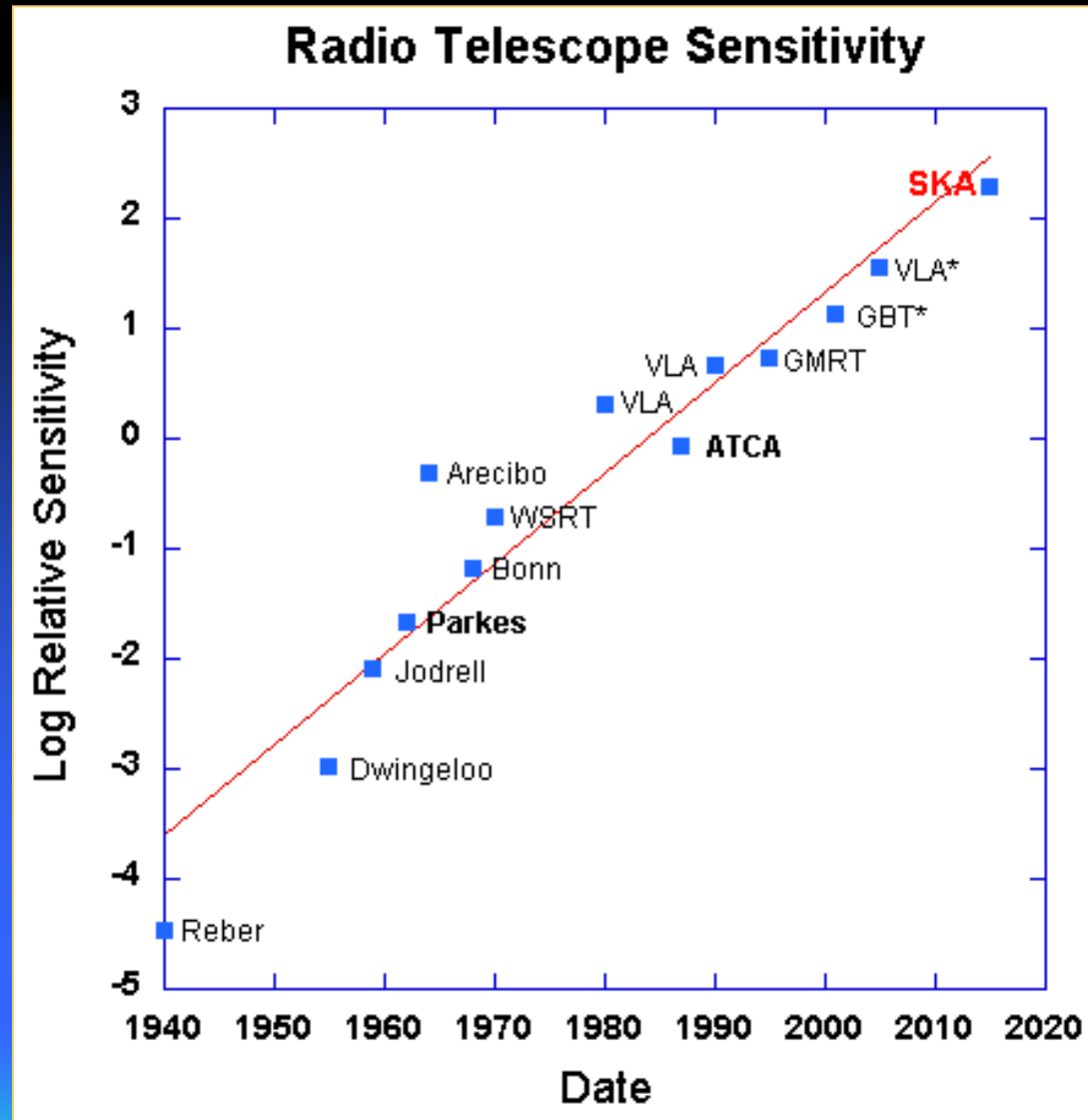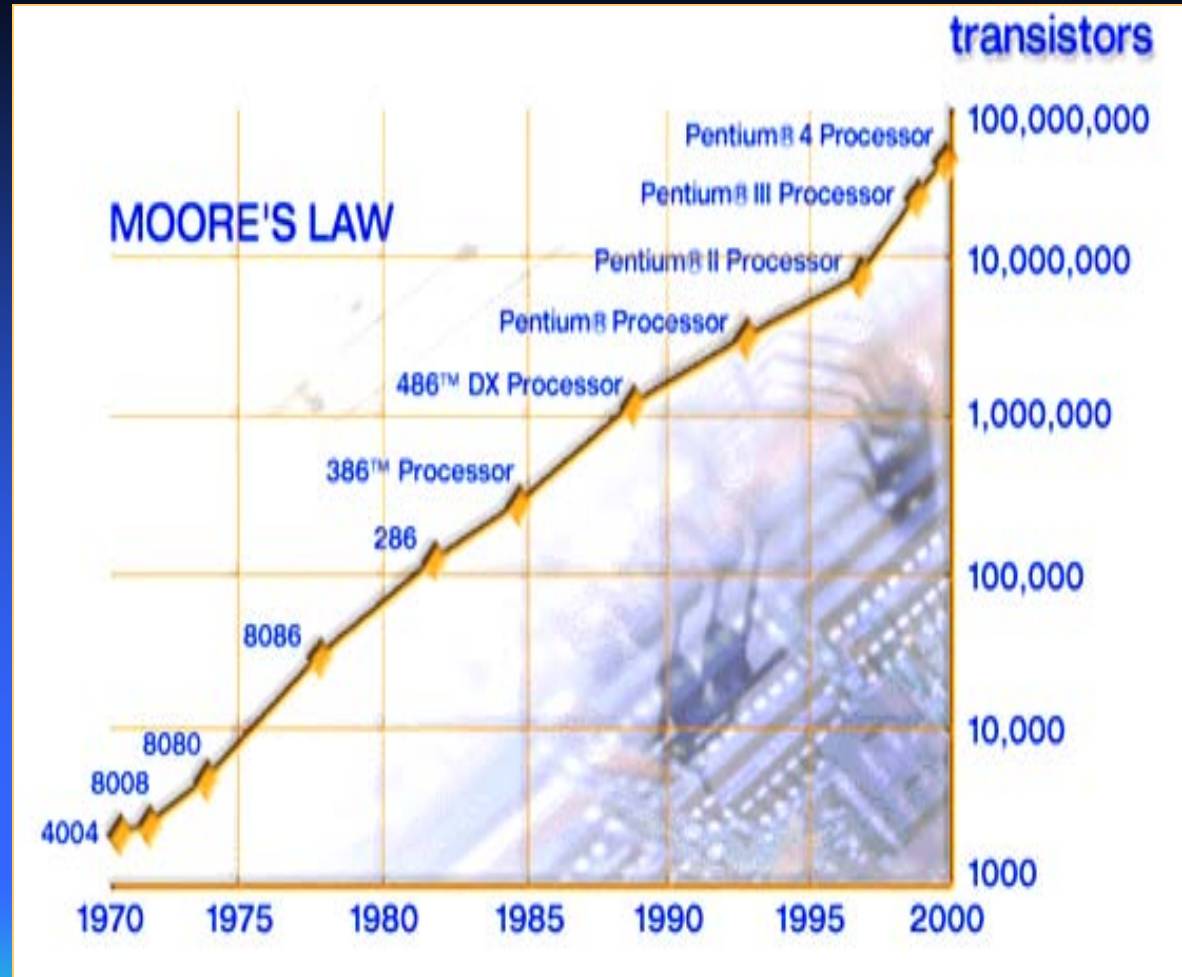
The Original Moore's Law Plot

- In 1965 Gordon Moore (co-founder of Intel) noted that the transistor density of semiconductor chips doubled roughly every 18 months.

Electronics, April 1965

Extrapolation accurate for another 35 years!
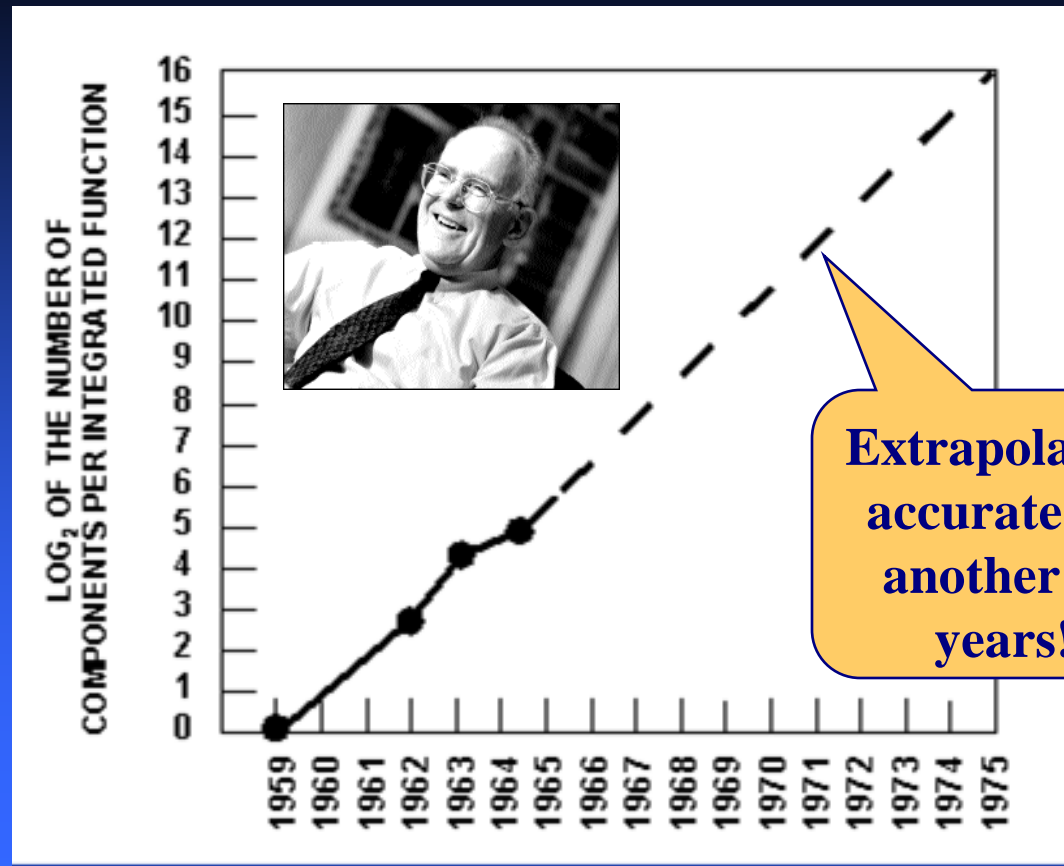
Microprocessor performance

- Moore's Law
  - Intel 2000

Technology leads scientific discoveries

- De Solla Price (1963):   *most scientific advances follow laboratory experiments*
  - exponential growth in capability occurs in all successful science
  - *Little science, big Science*
    Individual researcher

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    Individual researcher
    ↓
    Institute laboratory
    ↓
    National Facility

VLA

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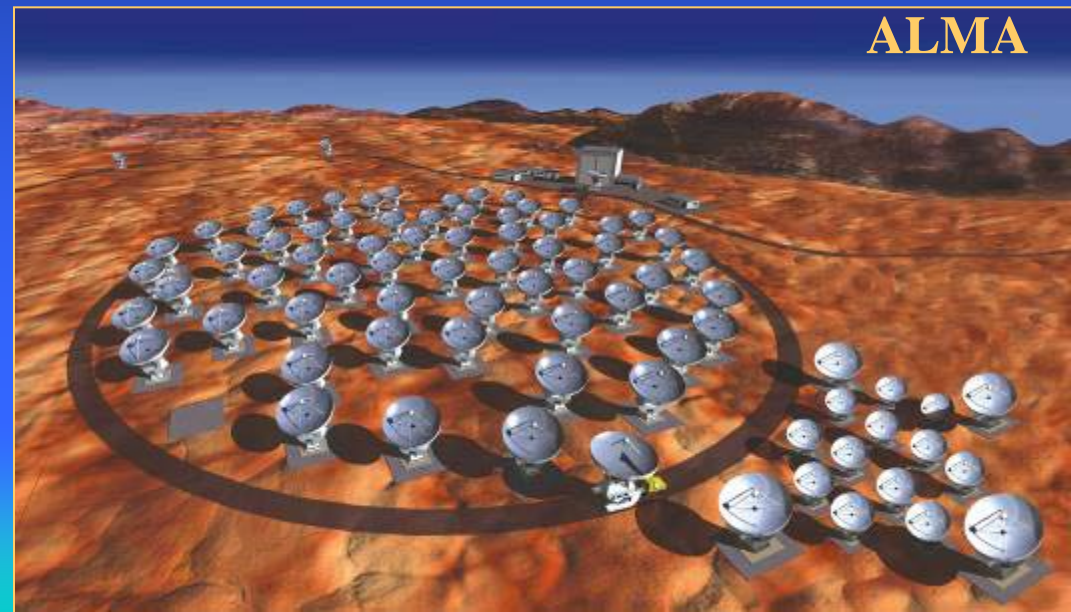 - *Little science, big Science*
    Individual researcher
    ↓
    Institute laboratory
    ↓
    National Facility
    ↓
    International Facility

ALMA

SKA 2020?