History of Radio Astronomy
celebrating 90 years of innovation and discovery

URSI GASS 2023,

Ronald D Ekers

23 Aug 2023, Sapporo, Japan

100 years of URSI
90 years of Radio Astronomy

- 1914 Brussels International Committee for Wireless Telegraphy
  - Commission Internationale de Telegraphic Sans Fil Scientific
  - Established to study radio communication – eg fading, skip distance
- 1922 first URSI GA
  - 1929 CCIR "[*radio] waves which extend over the whole earth…may perhaps even penetrate into interplanetary space*
- 1933 Jansky discovers of radio emission from the centre of our galaxy
  - first presented at US URSI meeting in Washington
- 1948 URSI Commission V "Extra-terrestrial radio noise"
  - 1950 renamed "Radio Astronomy"
- 1952 IAU Commission 40 "Radio astronomy" (20 years after URSI)
- 1975 URSI re-organization: commission V → J

CSIRO

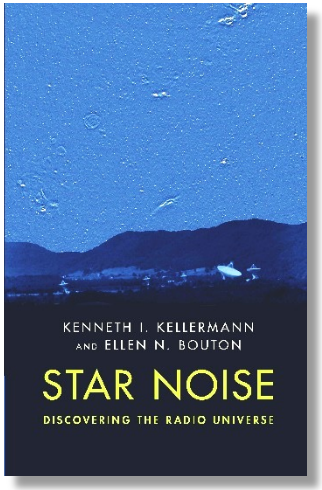
Preface to this lecture

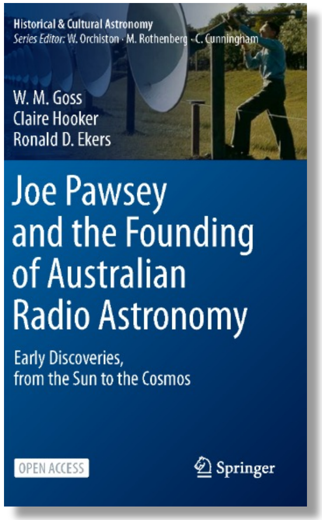
- A historical review of discoveries in radio astronomy exploring the circumstances leading up to the discoveries
  - Many of these stories are not generally known, but they provide the background and the context.
  - I will emphasise the role played by technology
- I draw heavily on two recent publications

  Kellerman and Bouton, "Star Noise" (2023) CUP

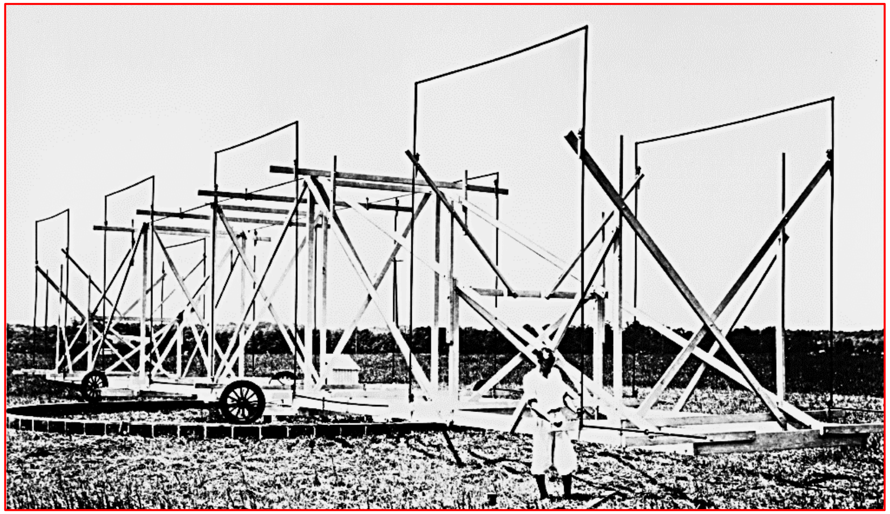
  Goss, Hooker and Ekers, "Joe Pawsey and the Founding of Australian Radio Astronomy" (2023) Springer
  - See the Springer exhibit at this meeting
- These details are often excised from the standard scientific narrative but are essential to understand the roles played by serendipity, prediction, and new technology.
- There is "nothing fortuitous" in so-called serendipitous discoveries. As Pasteur famously quoted

"*In the field of observation, chance favours only the prepared mind.*"

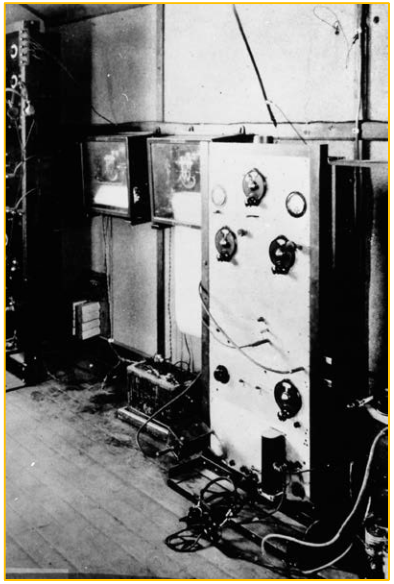




Beginning of Radio Astronomy - 1932



Karl Jansky, Bell Telephone Laboratories in 1932, built this antenna to study the effect of "atmospherics" on long distance communications.



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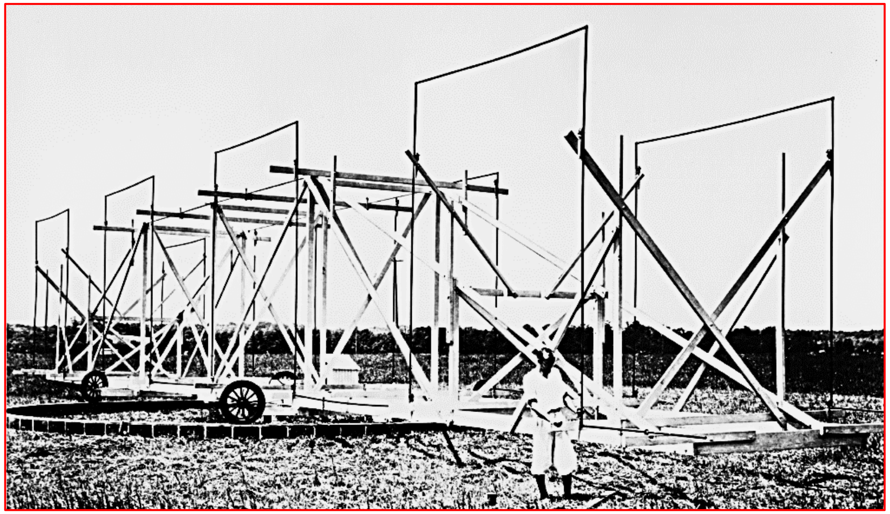

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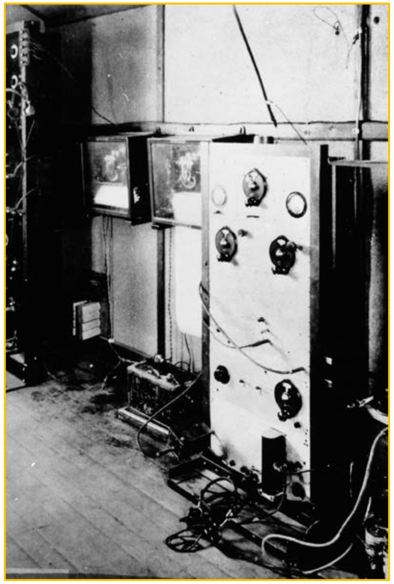

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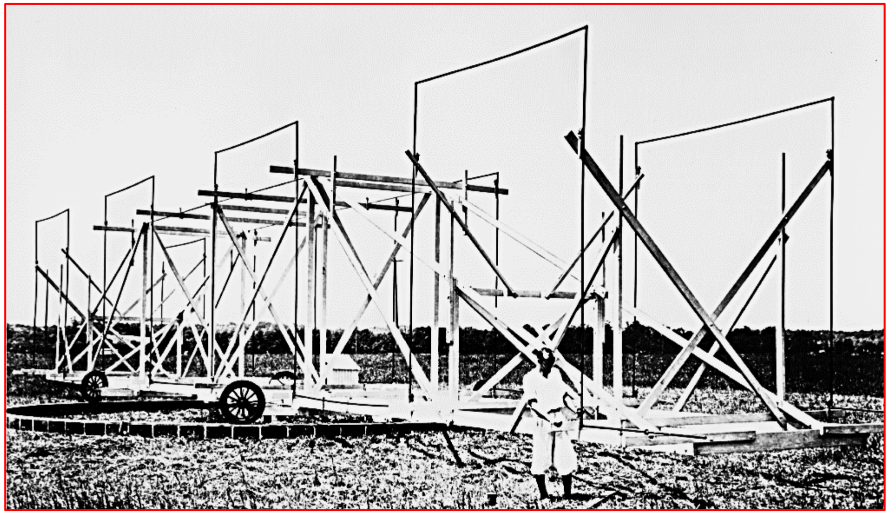

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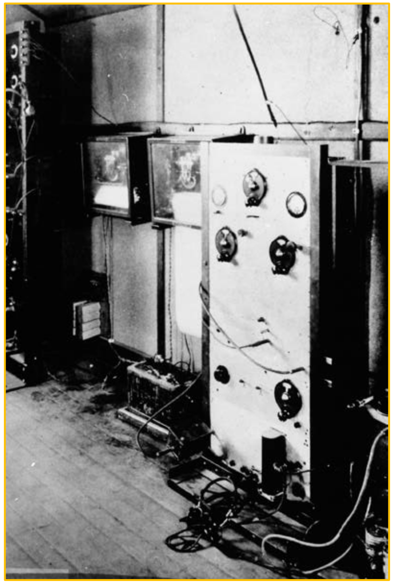

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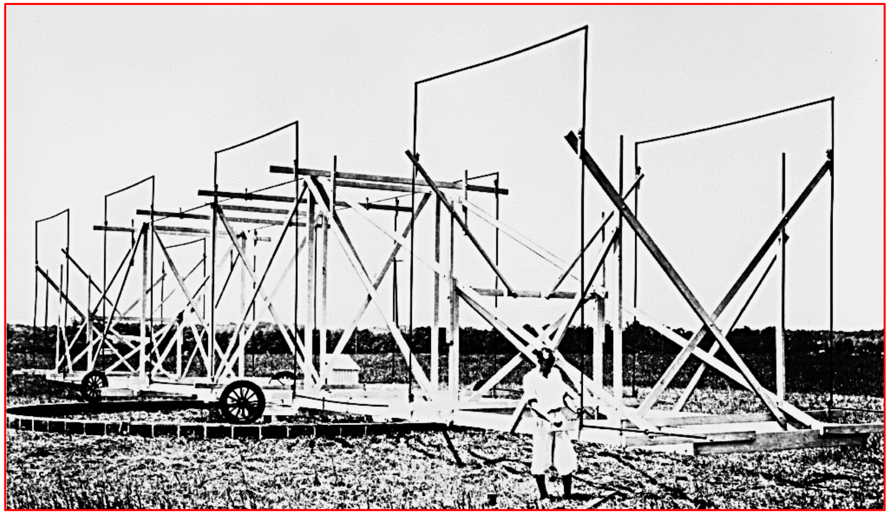

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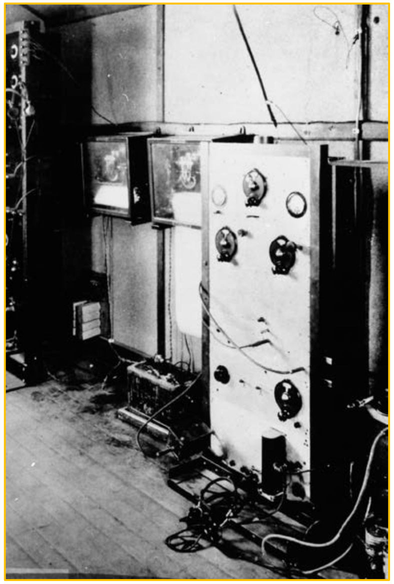

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  - "*so faint not even interesting as a source of radio interference*!"
  - Jansky's boss assigned him to other projects

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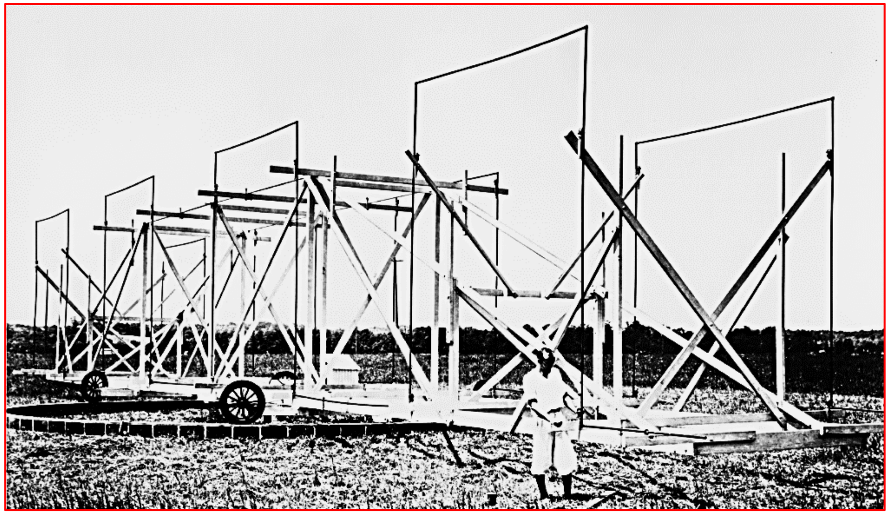

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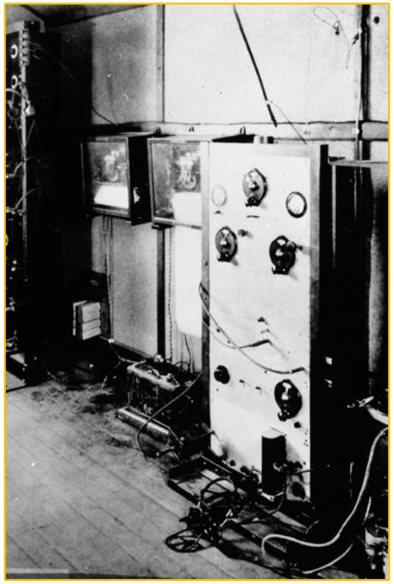
- not accepted by the astronomical community at the time
  - no theoretical framework for non-thermal emission



First presentation of Jansky's discovery

US National Committee for URSI

27 April 1933, Washington DC

Program.

Resolution and remarks in honor of Dr. L. W. Austin. By Dr. A. E. Kennelly (President of the U.R.S.I.), Capt. S. C. Hooper (representing the Navy Dept.), and Dr. A. H. Taylor (representing the Institute of Radio Engineers).

The effect of the electrical properties of the earth on the radiation from a simple antenna. L. P. Wheeler (Naval Research Laboratory).

A decade system for frequency comparisons. R. M. Page (Naval Research Laboratory).

Measurement of piezo-resonator constants by an impedance method. W. G. Cady (Wesleyan University).

A magnetostriction filter. Harry H. Hall (introduced by Prof. E. L. Chaffee). (Harvard University).

Audio frequency atmospherics. E. T. Burton (Bell Telephone Laboratories).

A note on hiss type atmospheric noise. K. G. Jansky (Bell Telephone Laboratories).

A compact direction finder for atmospheric disturbances. W. B. Burgess (Naval Research Laboratory).

No discussion - meant nothing to anybody

URSI is "an almost defunct organization …attended by a mere handful of old college professors."

Karl Jansky letter to his father

"All the News That's Fit to Print."

The New York Times

May 5, 1933

Copyright, 1933, by The New York Times Company.

VOL. LXXXII....No. 27,495. Entered as Second-Class Matter, Postoffice, New York, N. Y. NEW YORK, FRIDAY, MAY 5, 1933. P TWO CENTS In New York City. | THREE CENTS Within 200 Miles | FOUR CENTS Elsewhere Except In 7th and 8th Postal Zones

ROOSEVELT ASKS PAY RISE FOR WORKERS; PROMISES TO HELP BUSINESS END CHAOS; HE SENDS RAILROAD BILL TO CONGRESS

NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

Mysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

DIRECTION IS UNCHANGING

Recorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

ITS INTENSITY IS LOW

Only Delicate Receiver Is Able to Register—No Evidence of Interstellar Signaling.

Discovery of mysterious radio waves which appear to come from the centre of the Milky Way galaxy was announced yesterday by the Bell Telephone Laboratories. The discovery was made during research studies on static by Karl G. Jansky of the radio research department at Holmdel, N. J., and was described by him in a paper delivered before the International Scientific Radio Union in Washington.

The galactic radio waves, Mr. Jansky said, differ from the cosmic rays and also from the phenomenon of cosmic radiation, described last week before the American Philosophical Society at Philadelphia by Dr. Vesto M. Slipher, director of the Lowell Observatory at Flagstaff, Ariz.

Unlike the cosmic ray, which comes from all directions in space, does not vary with either the time of day or the time of the year, and may be either a photon or an electron, the galactic waves, Mr. Jansky pointed out, seem to come from a definite source in space, vary in intensity with the time of day and time of the year, and are distinctly electro-magnetic waves that can be picked up by a radio set.

New Waves Have High Frequency.

The cosmic radiation discovered by Dr. Slipher is a mysterious form of light apparently radiated independently of starlight, originating, Dr. Slipher concluded, at some distance above the earth's surface.

Flier Asks Blame in Crash, But Inquest Absolves Him

By The Canadian Press.

LONDON, May 4.—A chivalrous attempt to assume responsibility for the fatal crash of a Royal Air Force plane on May 1, in which Viscount Knebworth, pilot, and Aircraftman Harrison lost their lives, was made by Flight Lieutenant Eric Hobson at the inquest today. Despite Lieutenant Hobson's action, a verdict of "death due to misadventure" was returned.

Lieutenant Hobson, the leader of the section of which Lord Knebworth was a member, described how he unaccountably lost his height and at the end of a 2,000-foot dive got dangerously near the ground.

"The error in judgment was certainly not due to carelessness or recklessness," said Lieutenant Hobson, adding that Lord Knebworth was "absolutely blameless for what had happened, but had simply followed him according to orders."

KIDNAPPERS URGED TO ANSWER PLEAS

New Yorker Named to Act as Secret Agent for Return of McMath Child.

FRIEND READY AS HOSTAGE

Watch Kept at Detroit and in Tryon, N. C.—Massachusetts Police Refuse 'Armistice.'

Special to The New York Times.

HARWICHPORT, Mass., May 4.—Desperate at the failure of all attempts to establish a contact with the kidnappers of Margaret McMath, abducted from her school here Tuesday, William Lee, spokesman for the family, tonight offered himself as a hostage to those who had taken the girl.

In New York City Aaron Davis, an advertising man, was appointed by Neil C. McMath, father of the missing 10-year-old girl, as his agent to get in touch with the kidnappers if they wished to approach him. Mr. Davis, an uncle of Mr. Lee, will hold himself ready at all times to meet demands of the kidnappers without police interference.

BIG NEW INVASION PLANNED BY JAPAN ON ROAD TO PEIPING

Larger-Scale Offensive Than Last Is Announced to Open Soon in North China.

CHIANG RUSHES AID NORTH

Famous Units That Fought at Shanghai Are Dispatched to Help 50,000 at Front.

BRITISH QUIT MANCHURIA

Concerns Assert the Open Door in Commerce Is Being Rapidly Shut Against Foreigners.

By HALLETT ABEND.

Wireless to The New York Times.

TIENTSIN, May 4.—Partially revealing Japan's plans for renewed military incursion in North China, an official spokesman at the headquarters of the military attaché said today:

"Active preparations are under way for an attack on a much larger scale than ever before, especially through the participation of airplanes."

The main invasion is planned from Kupei Pass through Miyun, said the spokesman, frankly revealing that the adversaries principally sought were 50,000 of General Chiang Kai-shek's own troops at present in the Miyun area under the direct command of General Ho Ying-ching, the War Minister.

Declaring the Japanese assault was scheduled for "a very early date," the spokesman admitted that smaller simultaneous engagements were likely south of other portions of the Jehol frontier.

"Decisive action has become necessary," he added. "The present ambiguous situation has lasted too long and become intolerable."

Hope was expressed that the United States and Europe would not misinterpret the motives for Japan's actions.

Truculence Is Charged.

"The provocative situation has left no alternative," the spokesman declared, deploring the fact that

League Reserve Cut Million By Drop in Dollar Value

Special Cable to The New York Times.

GENEVA, May 4.—The League of Nations supervisory committee dispersed today after finding its already difficult task of balancing the League's $6,000,000 budget made much harder by the dollar leaving gold.

Practically all of the League's reserves, totaling $5,000,000, are kept in dollars. When the bank moratorium was proclaimed, League officials, after consulting bankers, decided to trust in the dollar. They have now sustained a paper loss of nearly $1,000,000 and have had to exchange part of the reserve at a loss of between 15 and 20 per cent.

The committee has decided to study until the July meeting further drastic cuts in League activities, including about a 50 per cent reduction in the information section.

FARM BILL CLAUSE BLOCKS AGREEMENT

Conferees Reach Accord on All Except the Cost-of-Production Section.

PEEK SLATED FOR TASK

Illinois Equipment Maker Is Roosevelt's Choice to Be Administrator.

Special to The New York Times.

WASHINGTON, May 4.—Senate and House conferees reached a complete agreement on all parts of the farm relief bill today except the cost-of-production section. The clash over the one section will force reconsideration of the measure in the House on Monday, with consequent delay of the inflation program incorporated in an amendment to this measure.

While the conferees were discussing the measure it became known that administration of the broad powers contained in the bill is expected to be entrusted to George N. Peek, a farm equipment manufacturer of Moline, Ill. Mr. Peek has not yet been named, but his formal selection by President Roosevelt is expected as soon as the bill has been signed. As chief ad-

RAIL PROGRAM WIDENED

Recapture Repeal Made Retroactive Under a Far-Reaching Plan.

RATE-MAKING RULE EASED

And I. C. C. Jurisdiction Would Be Extended to Embrace Holding Companies.

HEARINGS TO OPEN SOON

President Asks Swift Action, but Amendments in Senate Are Indicated by Dill.

Special to The New York Times.

WASHINGTON, May 4.—Broadened to provide retroactive repeal of the recapture features of the interstate commerce act, a more flexible rule of rate-making and extension of the jurisdiction of the Interstate Commerce Commission to include holding companies, the administration's emergency railroad program was transmitted to Congress today, along with a message from President Roosevelt asking adoption during the present session.

The President cited in his message the lack of available traffic to utilize fully existing railway facilities, together with the supplementary services provided by new forms of transportation. The former, he said, "still constitute the main arteries of commerce in the United States," although all transportation agencies would eventually have to be so coordinated as to maintain adequate service.

The President was not yet ready to submit to Congress "a comprehensive plan for permanent legisla-

Features of Railroad Bill

Special to The New York Times.

WASHINGTON, May 4.—High lights of the administration's emergency railroad bill, transmitted to Congress today, are as follows:

Title I provides for the creation of the office of Federal Coordinator of Transportation, the coordinator to be appointed by the President with the advice and consent of the Senate, or designated by him from the membership of the Interstate Commerce Commission.

The primary purpose is to provide the railroads with means for remedying their problem by themselves through joint agreements. To this end the bill sets aside the application of the anti-trust laws and all other Federal and State statutes which would operate to prevent accomplishment of its purposes.

The railroads are divided into Eastern, Southern and Western groups, with a coordinating committee of five members selected by the railroads for each region.

Where agreements on pooling were not voluntary, the committees would recommend to the Federal coordinator orders requiring compliance by the roads. Appeals to the Interstate Commerce Commission against such orders are provided for.

The rights of collective bargaining are preserved for the labor unions and the bill would not modify contracts entered into under the railway labor act.

The bill extends the jurisdiction of the Interstate Commerce Commission to include holding companies, and authorizes the commission to require the divestment of securities when their possession is subversive of the consolidation plan.

It provides for the retroactive repeal of the recapture provisions of the Interstate Commerce act, under which the railroads have incurred an excess income liability of some $360,000,000. Over $10,000,000 of such revenues in excess of the fair return of 6 per cent recaptured by the government would be returned to the roads.

A more flexible rule of rate-making is provided under which rates should enable the railroads to earn a "fair return" on their investment. The new rule would enable the commission to take into consideration the effect of rates on the movement of traffic and "the need of revenues sufficient to enable the carriers, under honest, economical and efficient management, to provide such service."

BRITISH DEMANDING TARIFF 'SAFEGUARDS'

MacDonald Tells Commons He Informed Roosevelt Truce Would Need Reservations.

ITALIANS NOW BACK BRITISH ARMS PLAN

Jung Tells Roosevelt Rome Holds Positive Action Essential in Situation.

PRESIDENT TELLS OF GAINS

Chamber of Commerce Is Asked to Cooperate on Three Points.

NATIONAL UNITY URGED

Prosperity Held Possible Only If All the Branches of Industry Recover.

GOVERNMENT AID PLEDGED

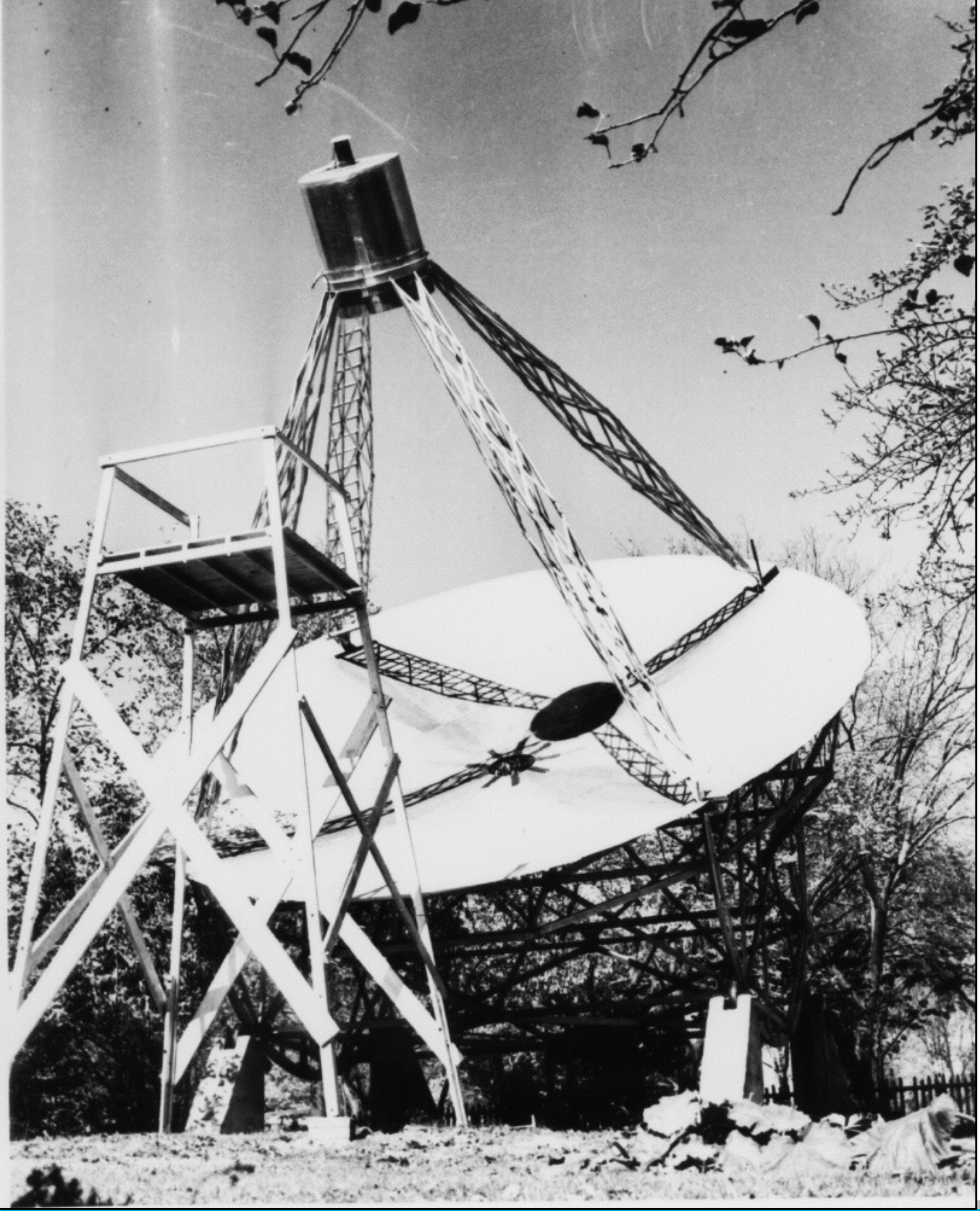
Unfair Competition and Cut-throat Prices Must Be Fought, He Says.

Text of President Roosevelt's speech is printed on Page 2.

Special to The New York Times.

WASHINGTON, May 4.—President Roosevelt took an optimistic view of the industrial situation based on the recent rise in commodity prices and industrial output, in a speech tonight before the Chamber of Commerce of the United States. He also reassured business by promising its leaders government cooperation in stamping out unfair competition in wages, overproduction and working conditions.

Coming after many of the outstanding business men of the country had expressed their desire for a greater industrial cooperation to alleviate industrial evils, and the reiteration of their hope for the legalization of trade agreements which would enable all units to work toward cooperation between capital and labor for the stabilization of industry and employment, the President's speech was received

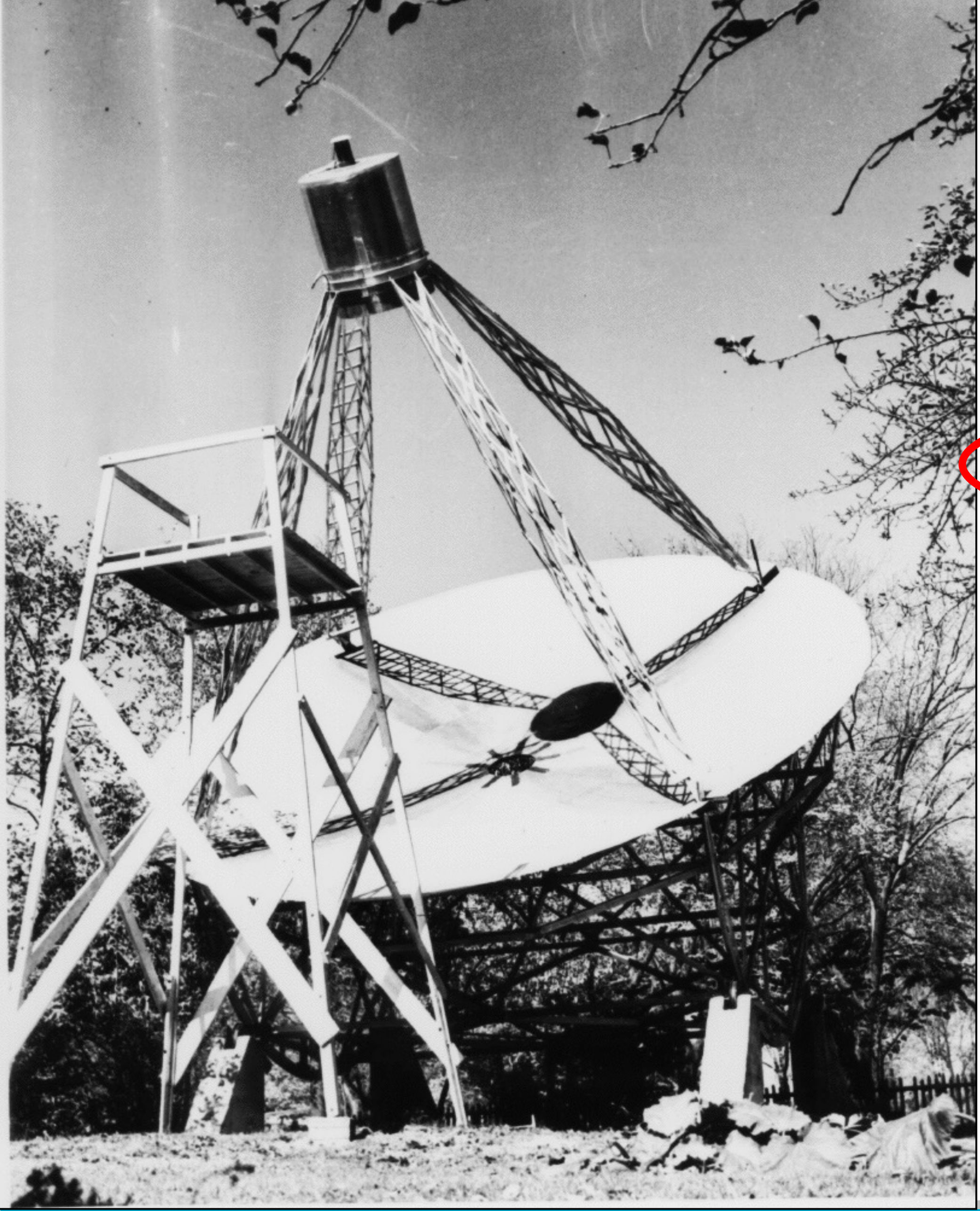


Grote Reber

One person did notice Jansky's discovery

Wheaton, Illinois 1937

- Parabolic dish for frequency flexibility
- 32' antenna, privately funded - $2K



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The Discovery of the Non-Thermal Universe

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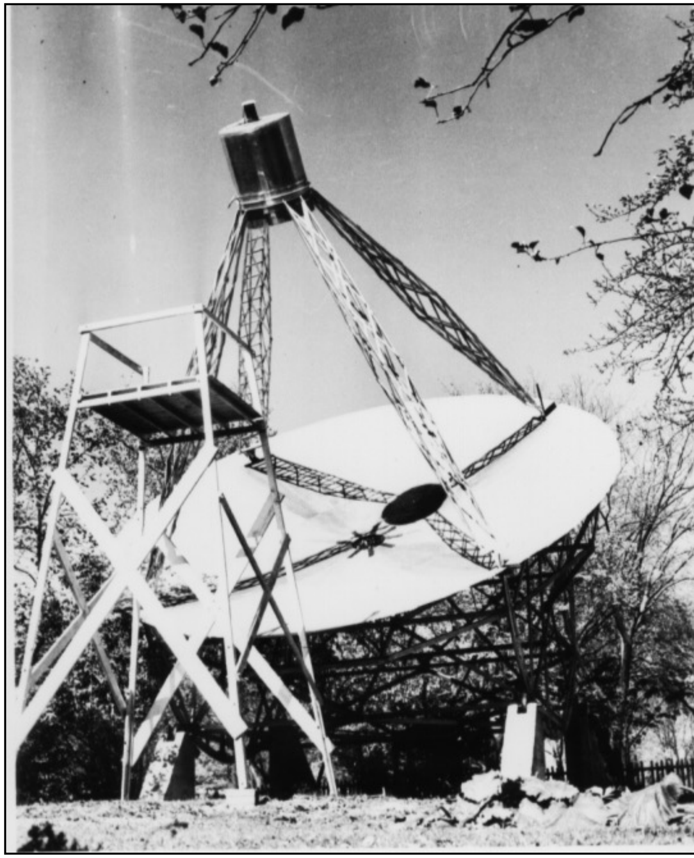
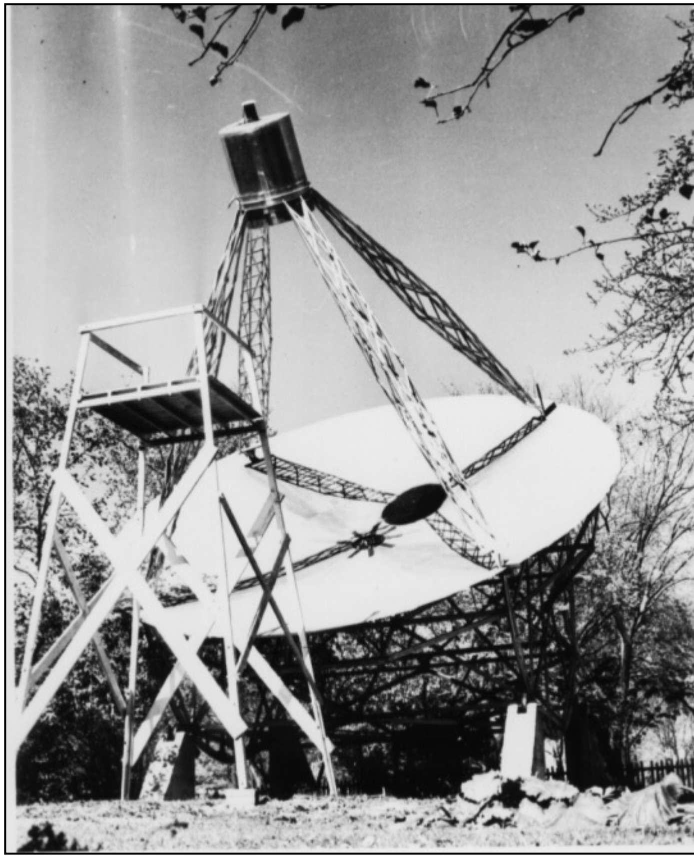


The Discovery of the Non-Thermal Universe

- 1939 finally detected cosmic static by going to **longer** wavelengths
  - ✗ 3300 MHz
  - ✗ 900 MHz
  - ✓ 160 MHz



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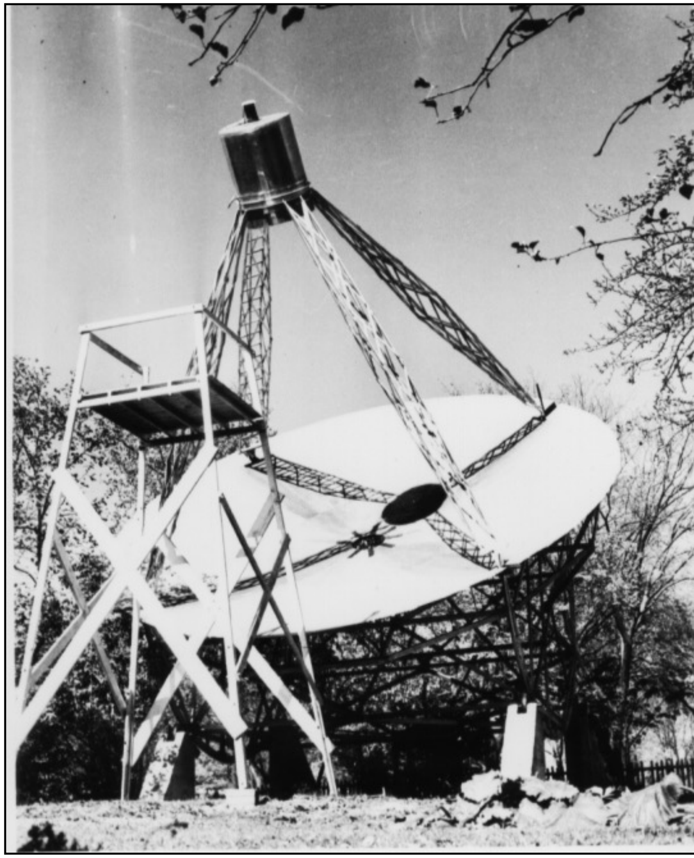
  - ➢ 1950 Synchrotron radiation theory
    - – 10 years after Reber



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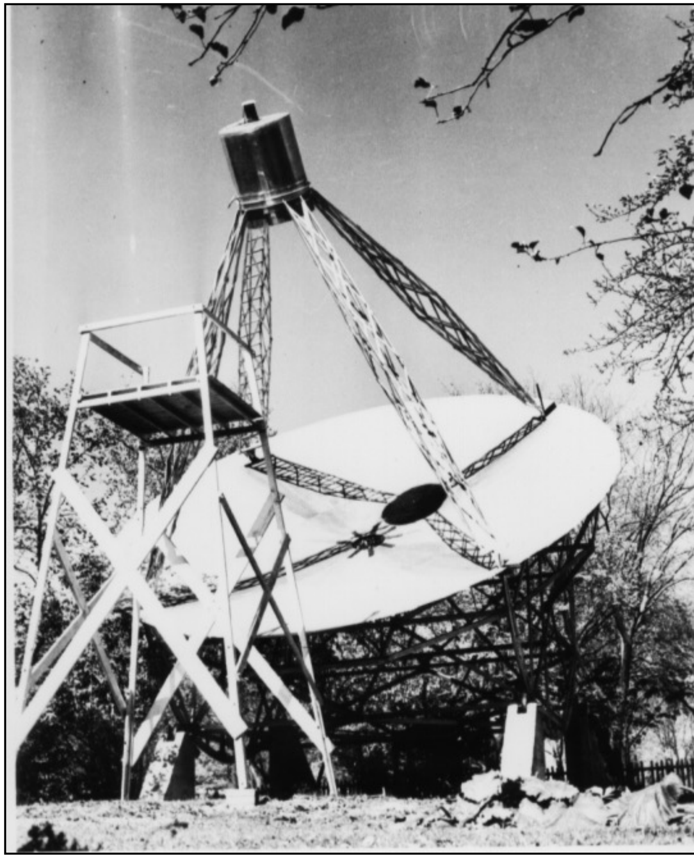
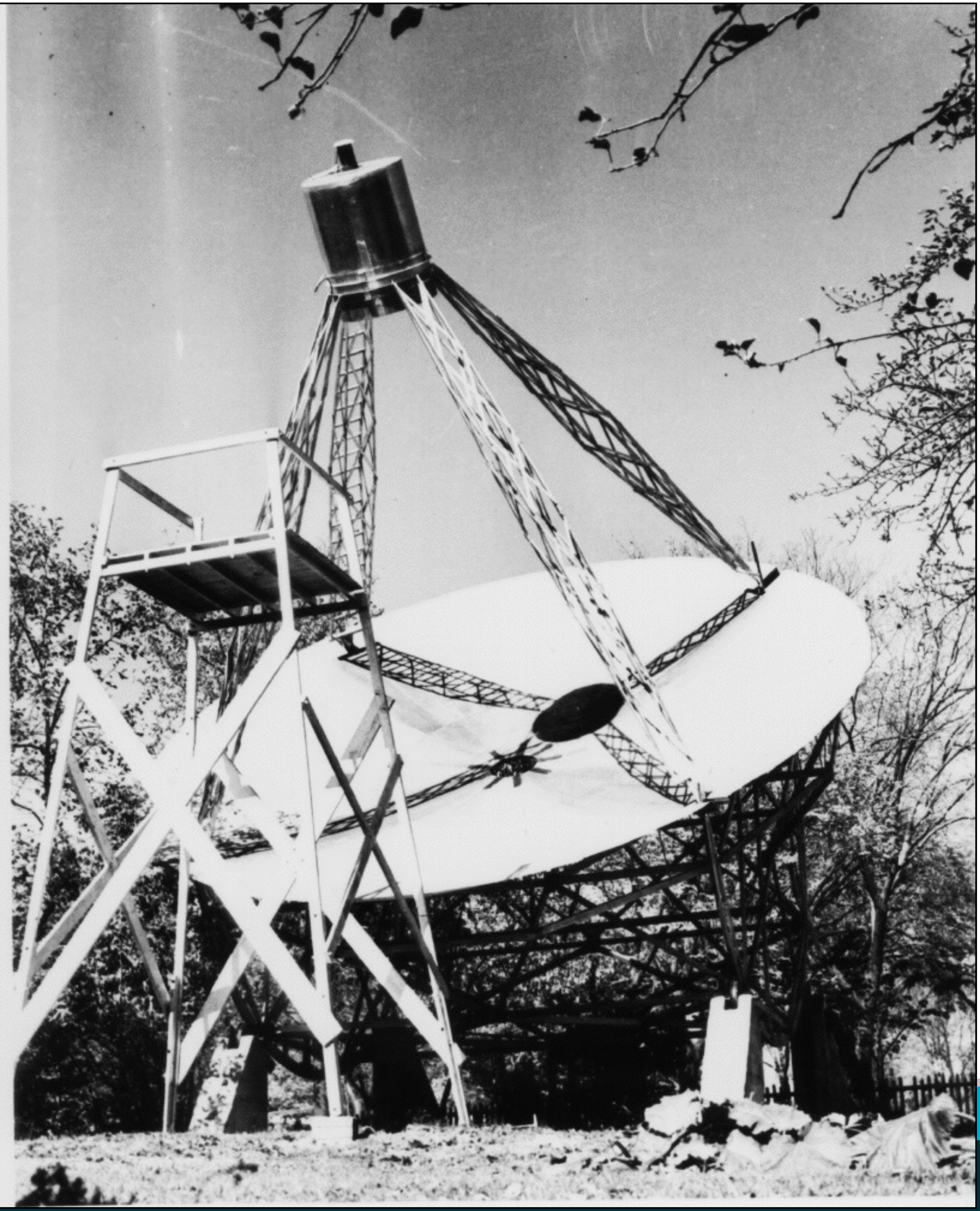
- First radio map of sky
  - ➢ Great difficulty getting published





The Dish

Wheaton, Illinois 1937

The Dish

Parkes 64m, Australia
1960

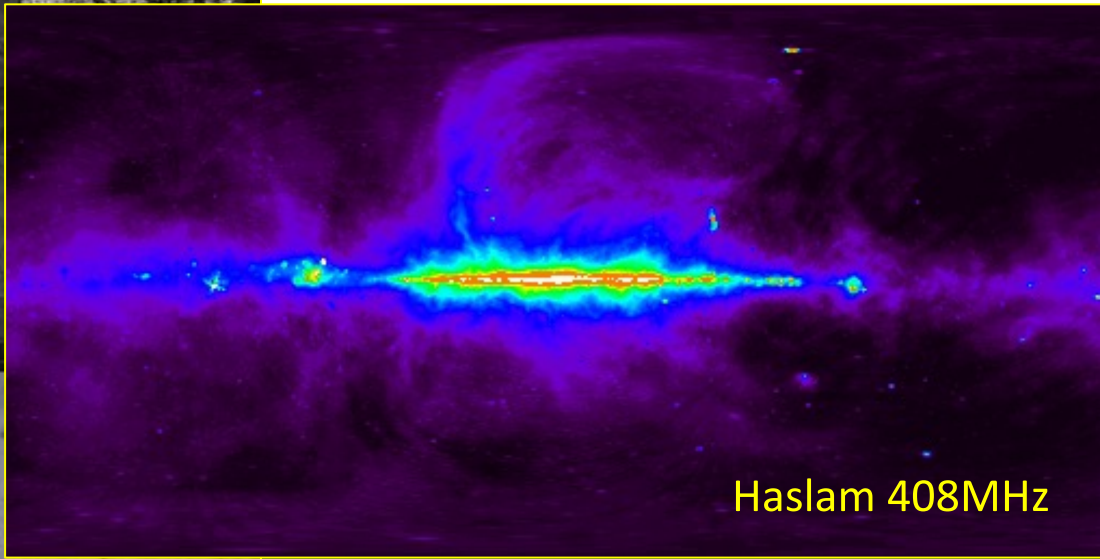
Bruce Thomas
hybrid mode feed

The Dish

NASA Goldstone, California
1980

The Dish

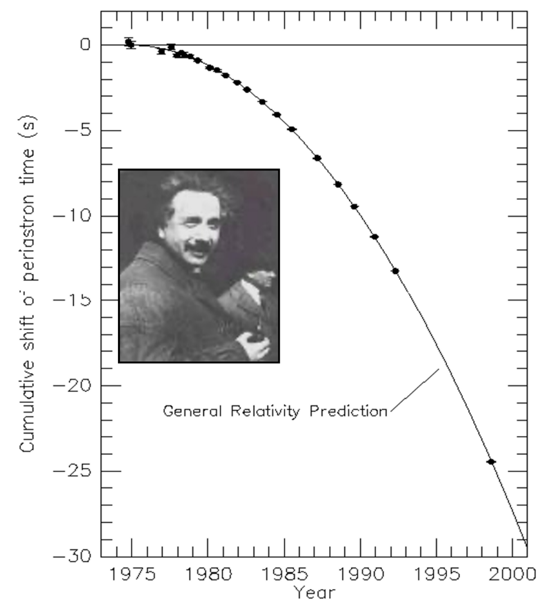
MPI Effelsberg 100m, 1972



Arecibo

- 300m spherical dish
- 1963 - 2020

- Confirmed the predictions of General relativity
  - ➢ 1993 Noble Prize to Taylor and Hulse
  - ➢ For the discovery of the binary



GBT – 2000
off axis (clear aperture) parabolic dish

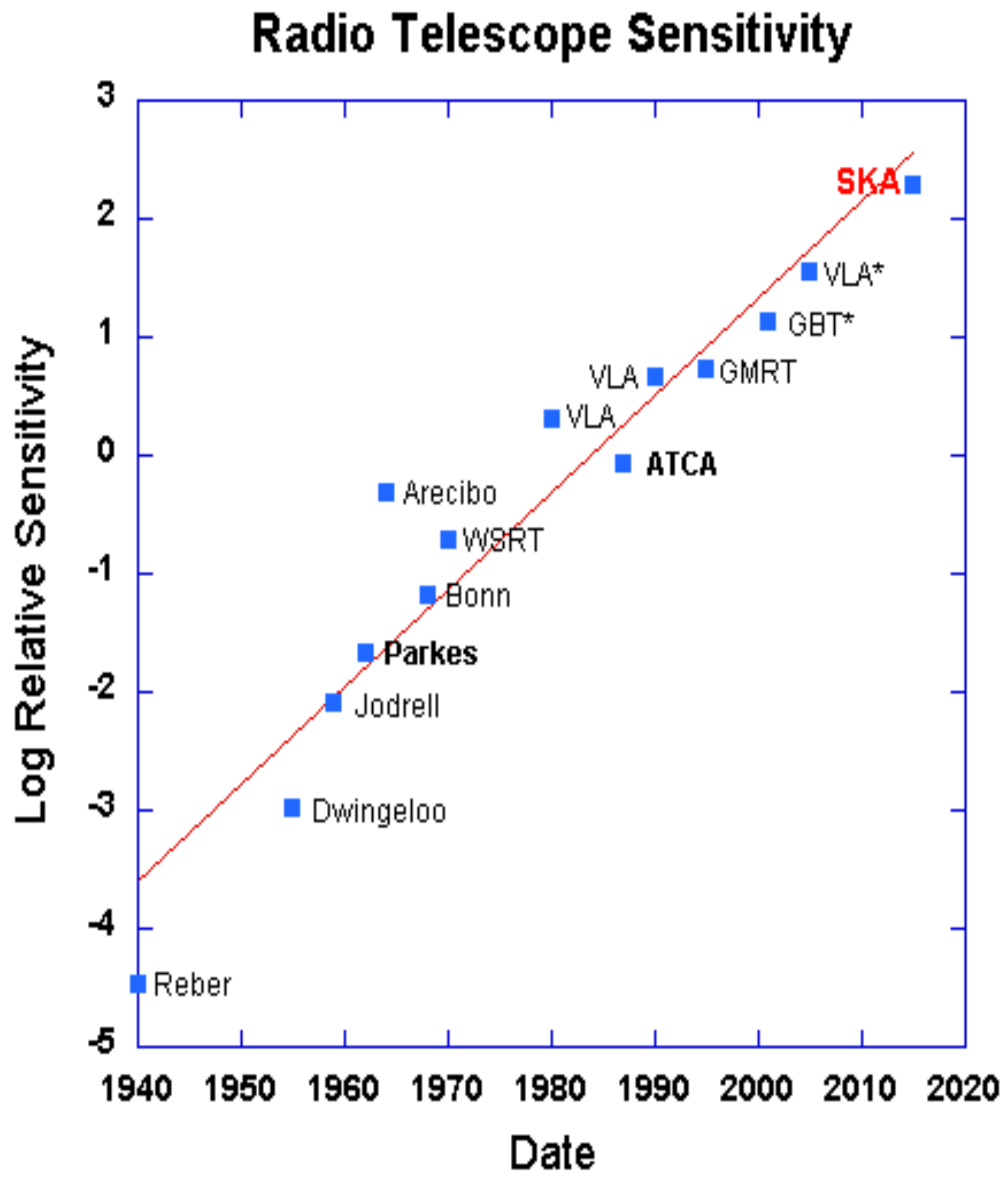
History of radio astronomy, URSI GASS: R D Ekers

FAST

- SKA triggered innovation
- Active surface becomes locally parabolic

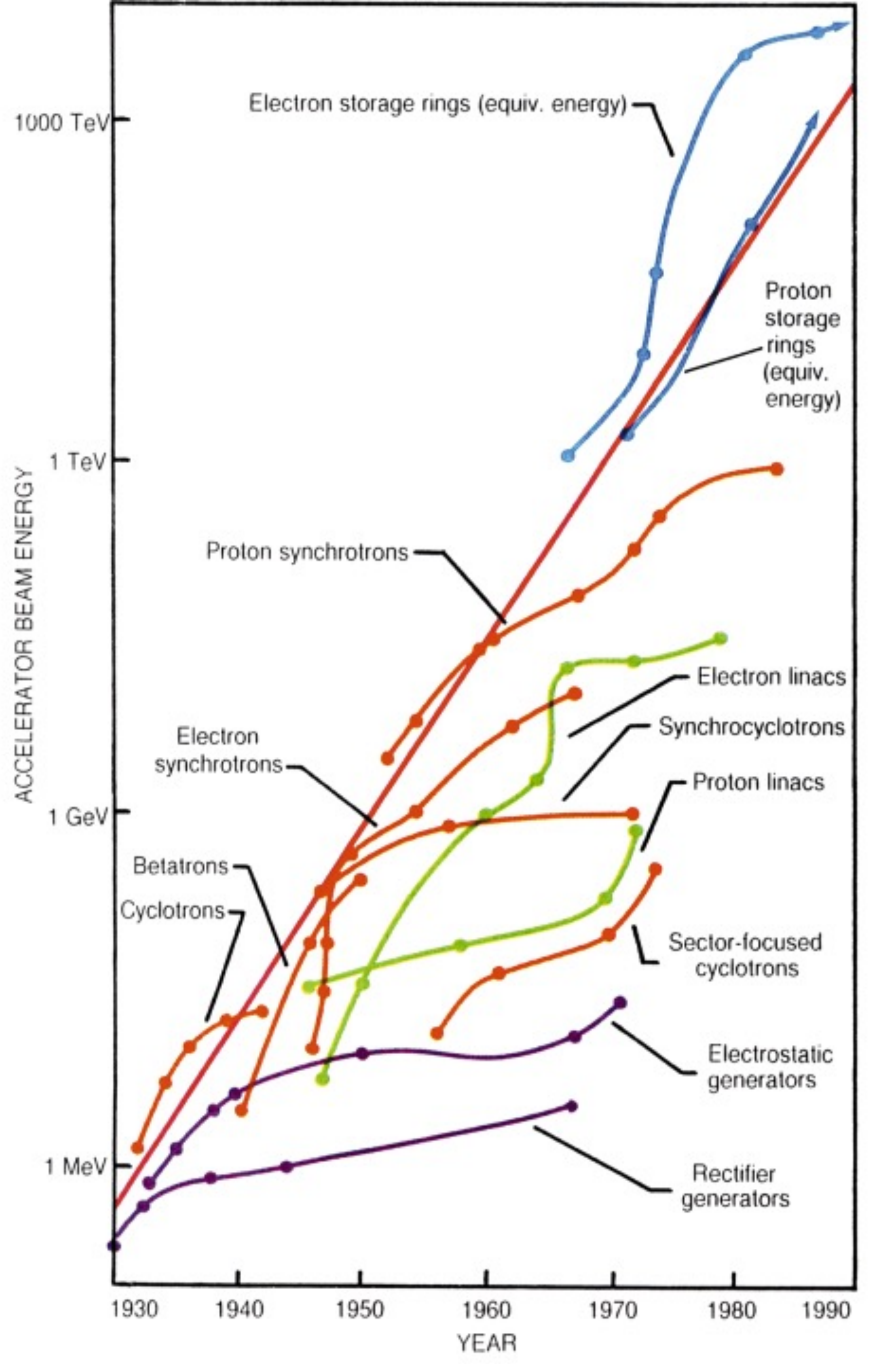
Radio Telescope Sensitivity

- Earlier version shown at the URSI GA Prague 1990
  - ➢ General lecture
- Exponential increase in sensitivity x 10^5 since 1940 !
  - ➢ 3 year doubling time for sensitivity
- GL- 1 Masataka Nakazawa
  - ➢ Showed a similar exponential growth in communications capacity.



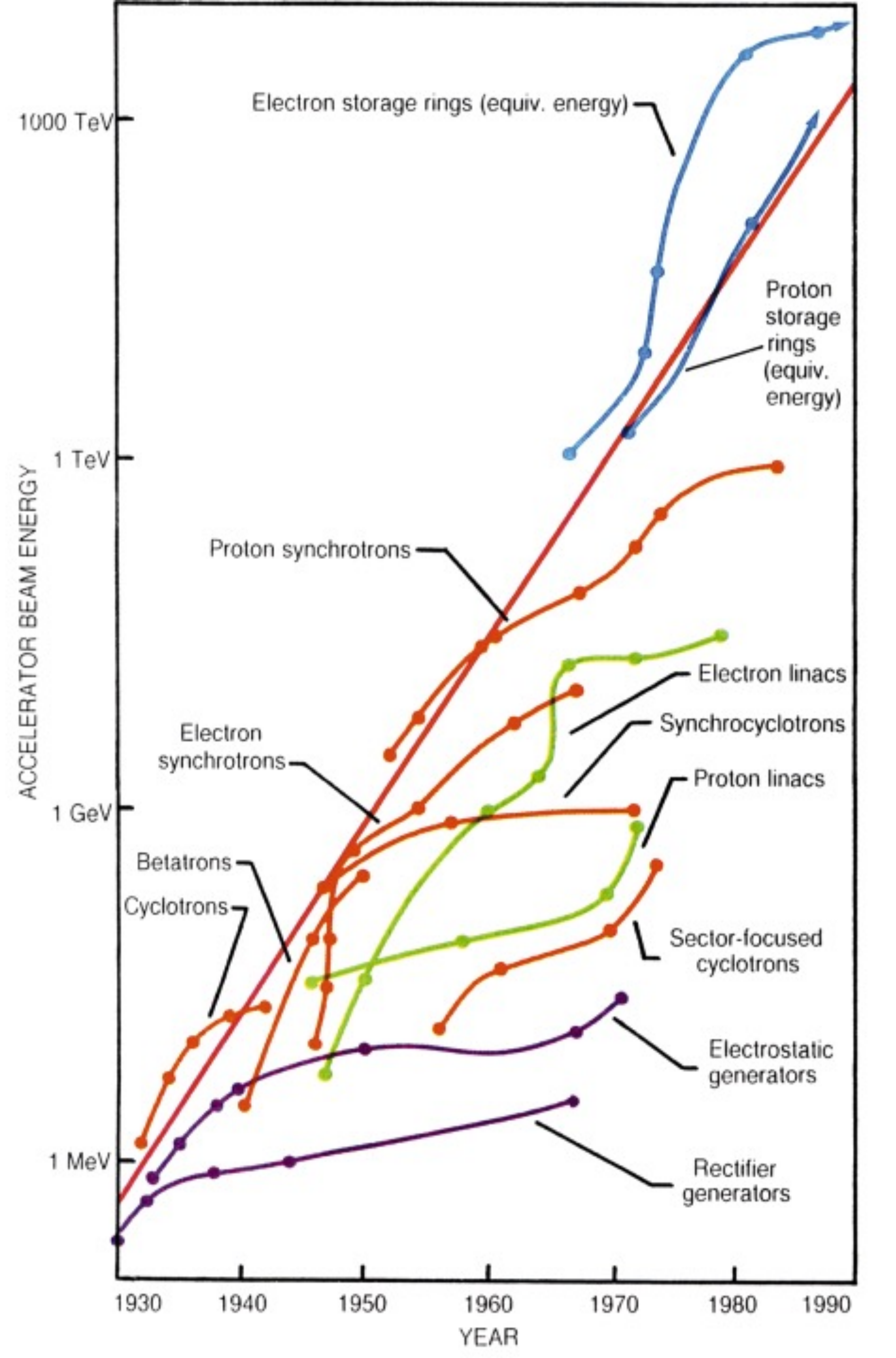
23 Aug 2023

Exponential Growth



Exponential Growth

- Livingstone Curve
  - Blewett, Brookhaven 1950
  - Fermi 1954
  - Livingstone 1962



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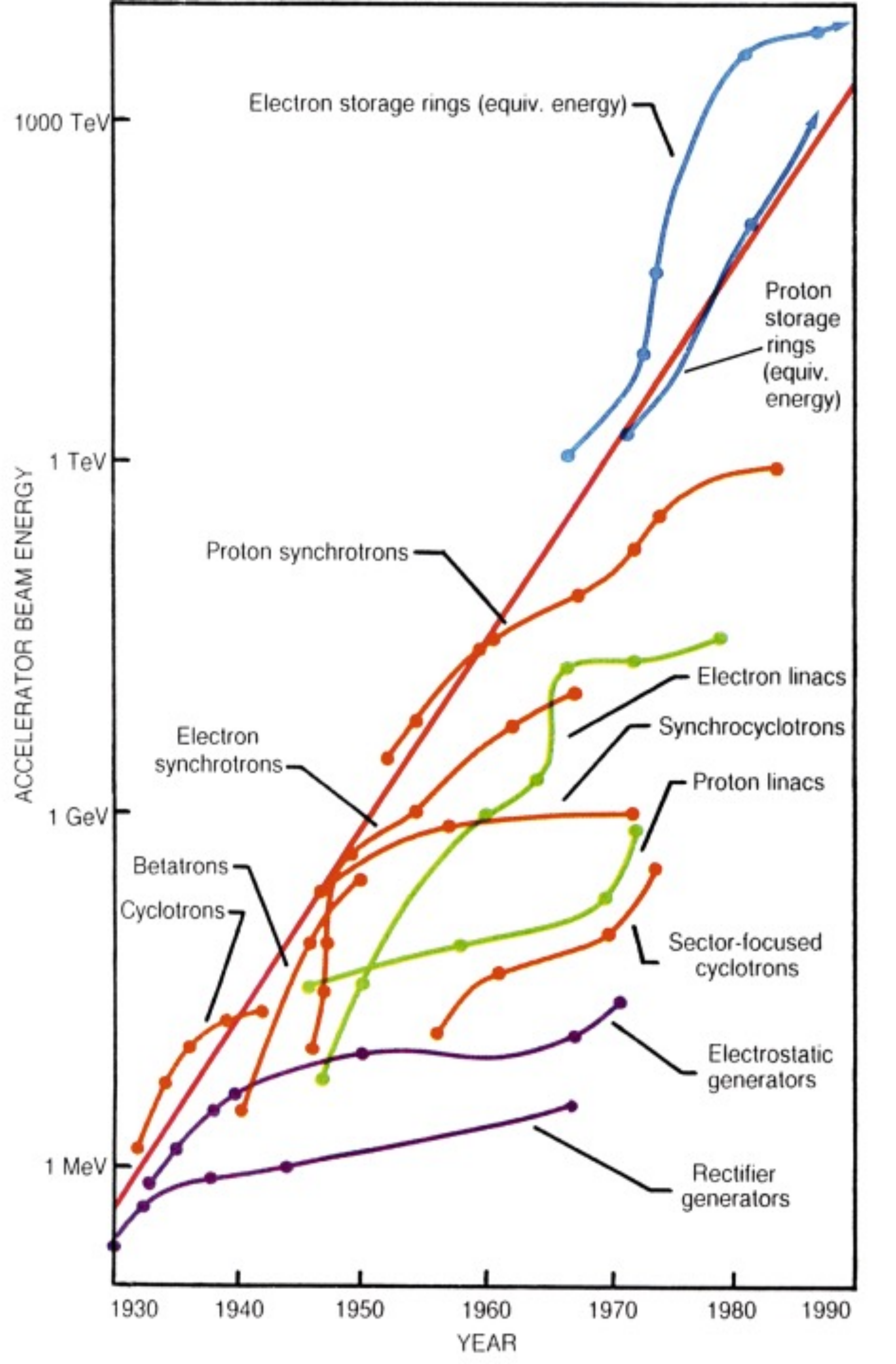
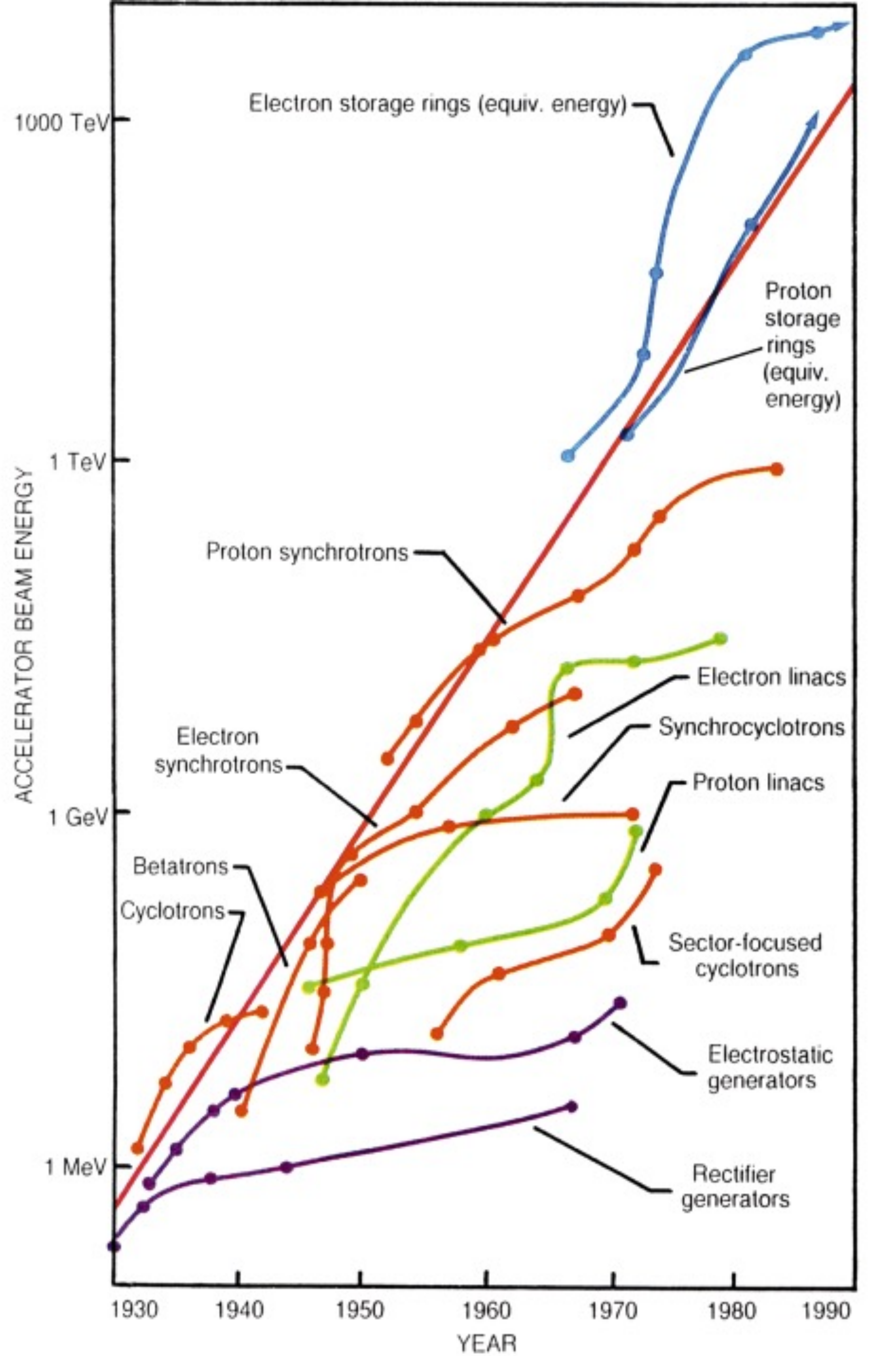


23 Aug 2023

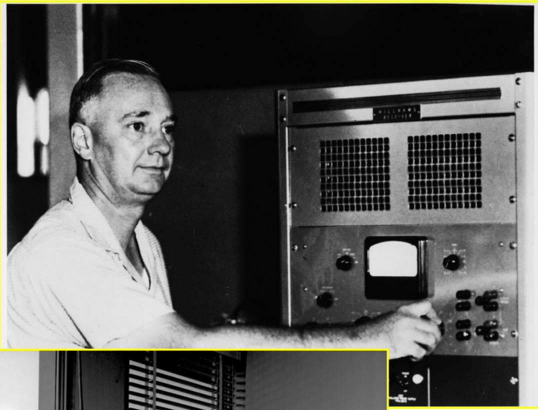
Exponential Growth

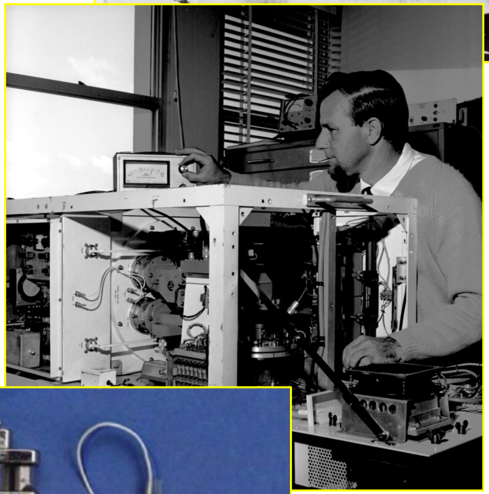
- Livingstone Curve
  - Blewett, Brookhaven 1950
  - Fermi 1954
  - Livingstone 1962
- Envelope is exponential
- Each technology saturates

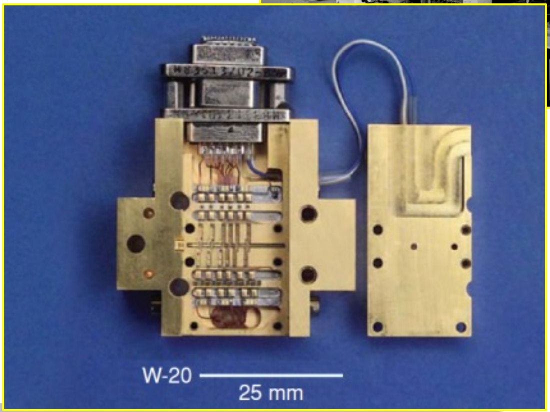


Receiver developments (Radio Astronomy)

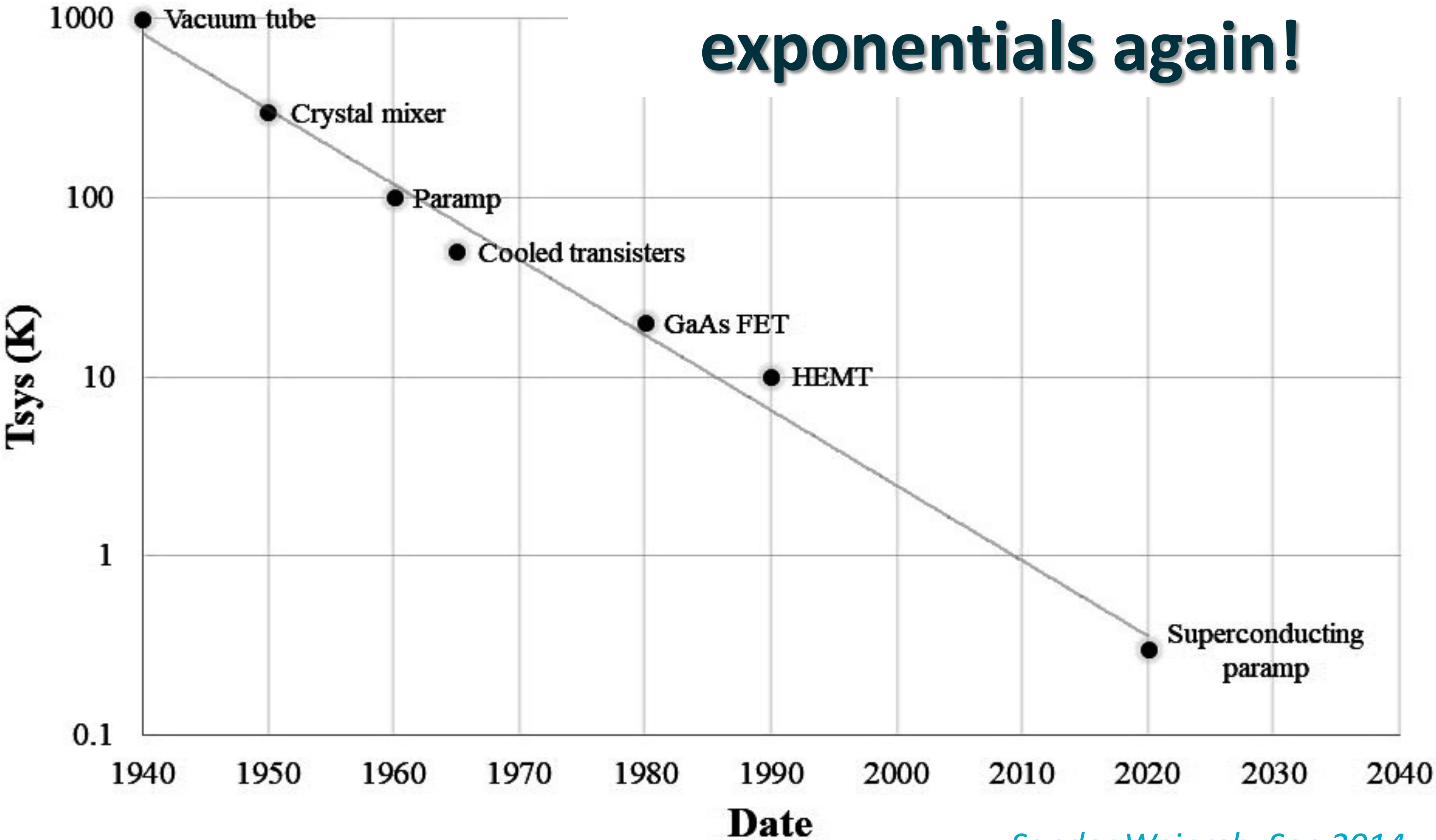
- 1940 Vacuum tubes (>1000K)
- 1950 Crystal mixers (300K)
- 1960 Parametric amplifiers (100K)
- 1960 Masers (65K)
- 1960 Diode mixers
- 1965 Cryogenically cooled transistors (50K)
- 1980 GaAs FETs (20K)
- 1990 HEMT (10K)
- 2000 SIS (high frequency)
- 2020 Superconducting paramp (0.3K)







Receiver Sensitivity exponentials again!



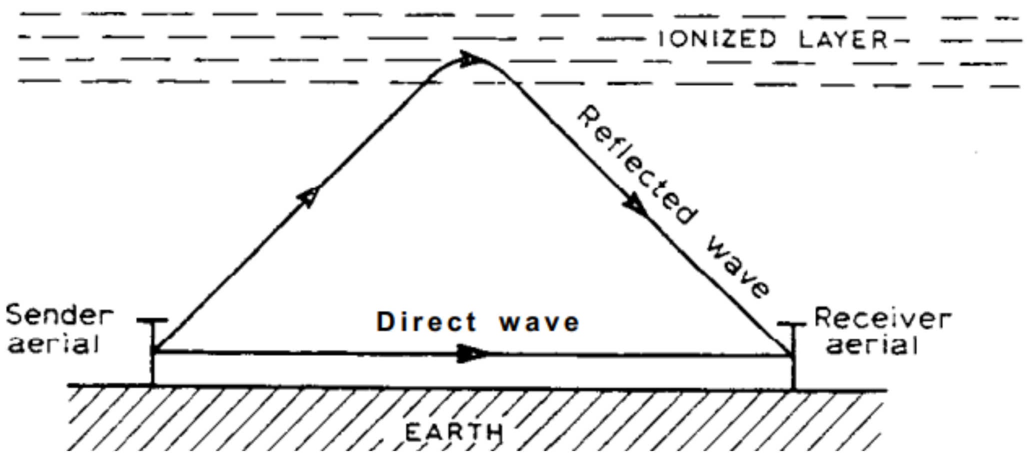
Sander Weinreb, Sep 2014

Technology leads scientific discoveries

- De Solla Price (1963):
  - *most scientific advances follow laboratory experiments*
- Martin Harwit (1981):
  - *Most important discoveries result from technical innovation*
  - Usually within 5 years of the technical capability
- While many discoveries are serendipitous, they depend on the development of new technology.
- It is often the telescopes, the instruments connected to the telescopes, and the data analysis that leads to new discoveries.
- The scientific discoveries for which facilities become famous are rarely those included in the initial science goals.

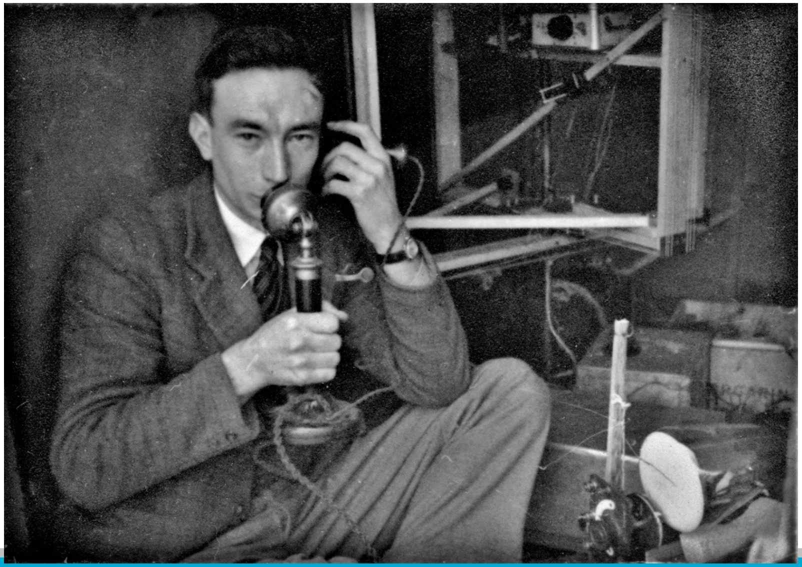
1924 – Edward Appleton (URSI president 1932-1952)

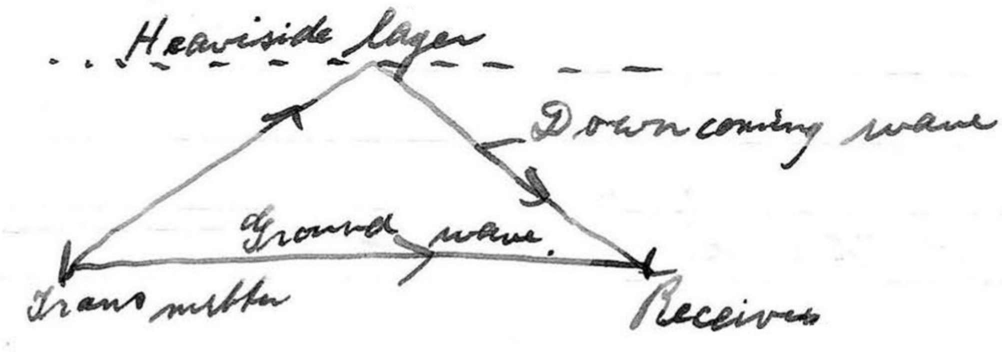
- Conclusive evidence for the existence of an ionosphere
  - ➢ As had been proposed by Heavyside
- Measured the interference between the ground and reflected wave while sweeping frequency.
  - ➢ Separates delay and phase – measured height of ionosphere
  - ➢ Appleton got the name and the Nobel prize (1974)
    - – Cambridge academic physicist advantage?
- Used powerful radio broadcast transmitter
-



1931 – Pawsey PhD in Cambridge

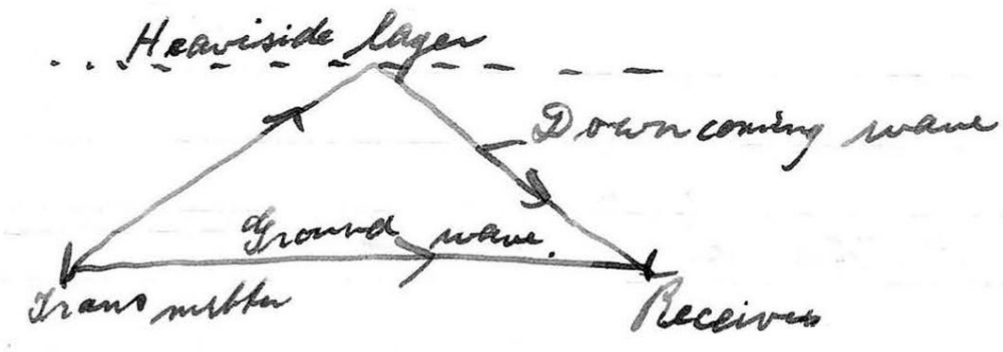
- Appleton's research provided the context for Pawsey's PhD project in Cambridge with Jack Ratcliffe
- Using interference between direct and reflected radio waves to measure structure in the ionosphere

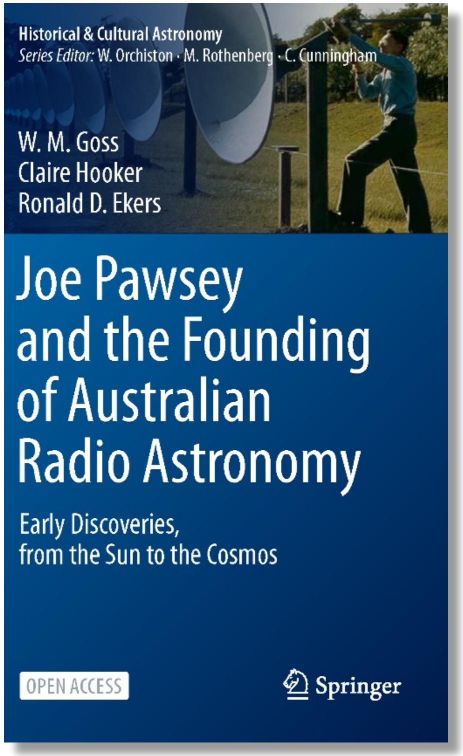




1947 – Cliff interferometer

- Pawsey wanted to measure the structure of the solar radio emission?
- Collaroy Plateau and Dover Heights near Sydney





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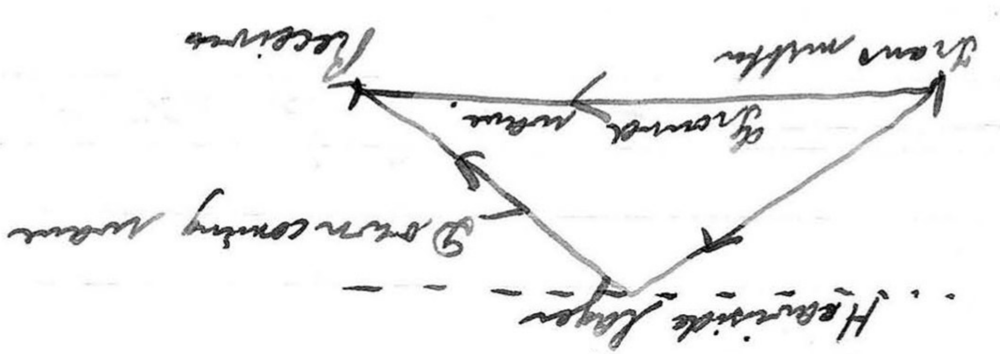

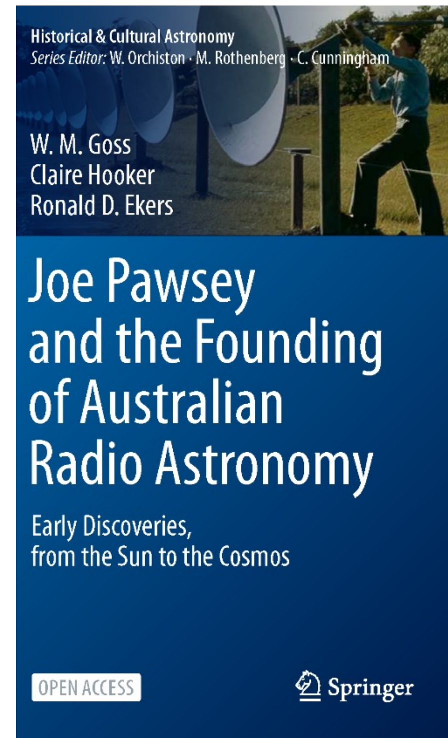

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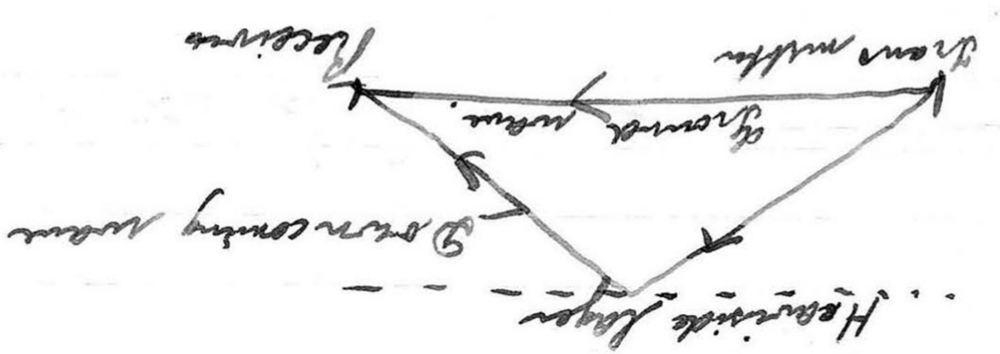
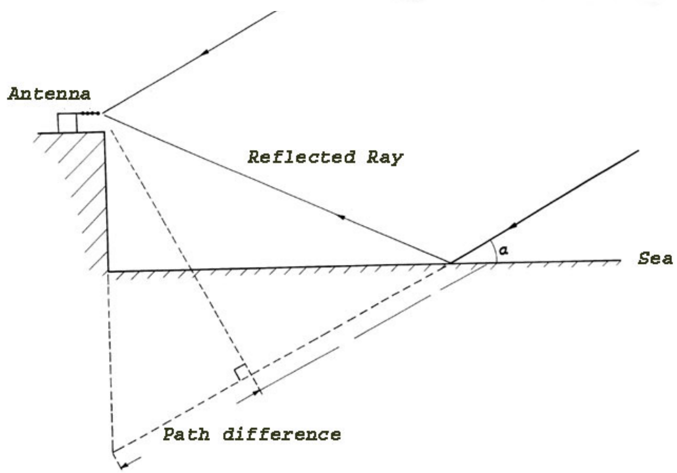
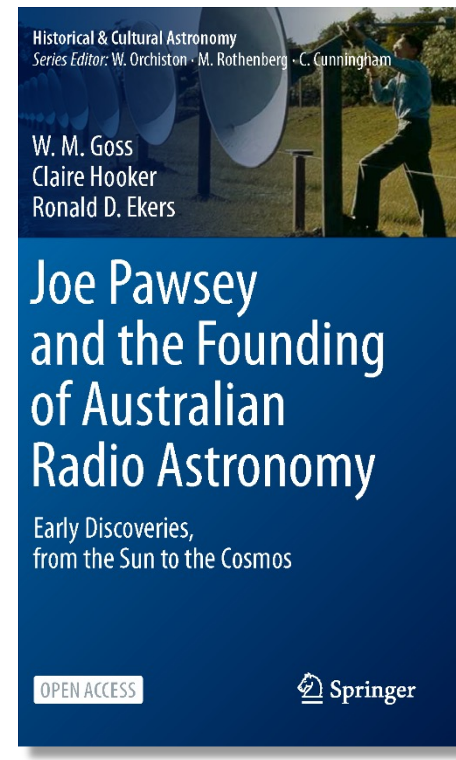
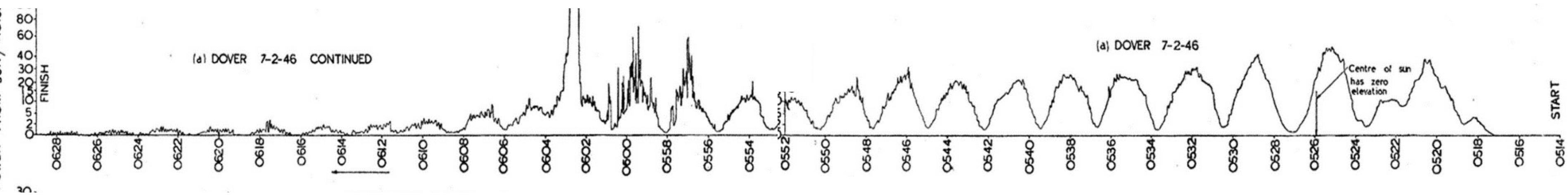






First interferometer fringes
The sun, Dover Heights, 7 Feb 1946



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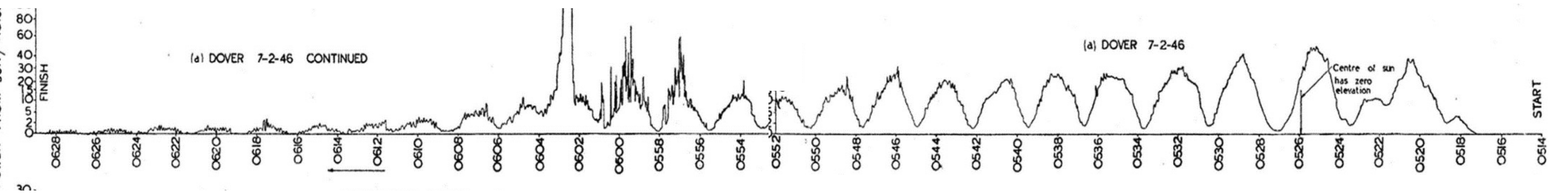

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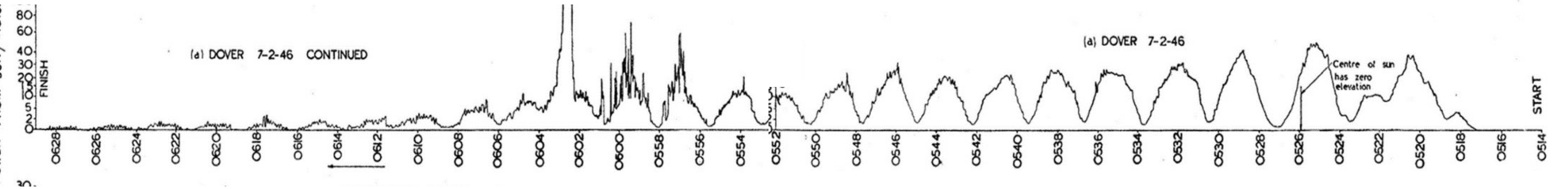

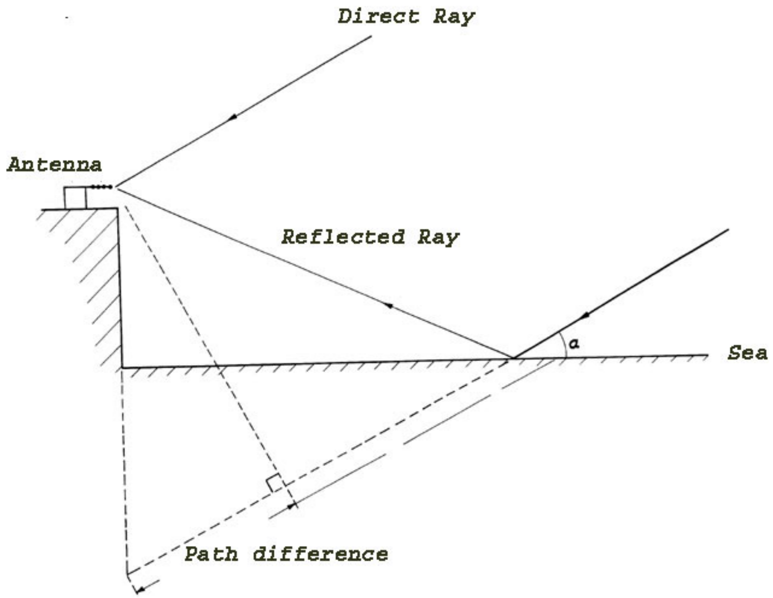

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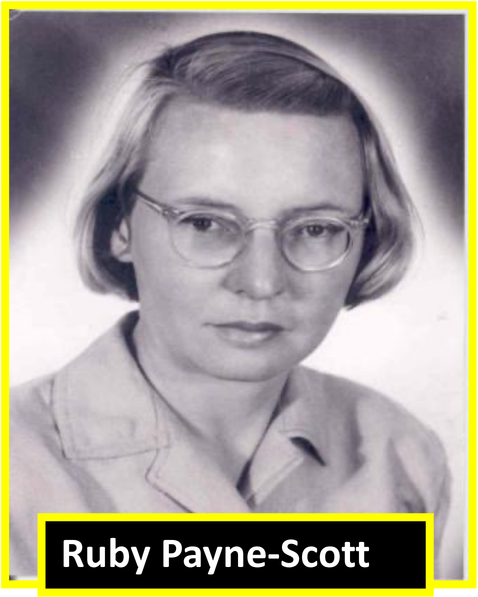

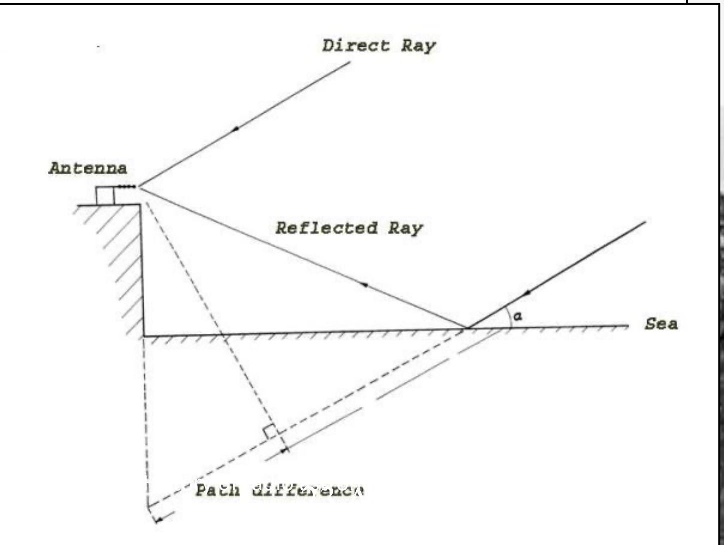

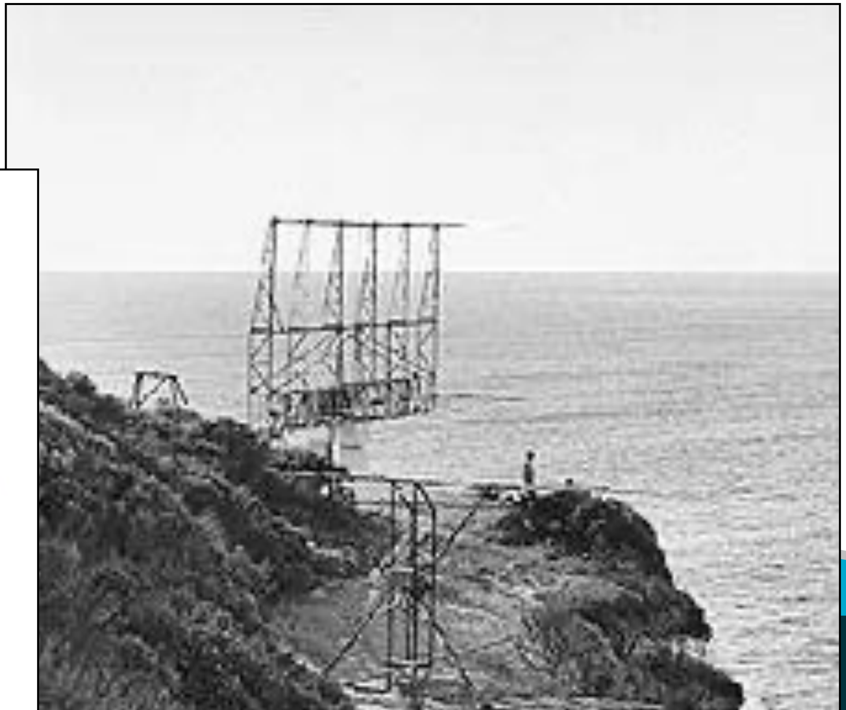

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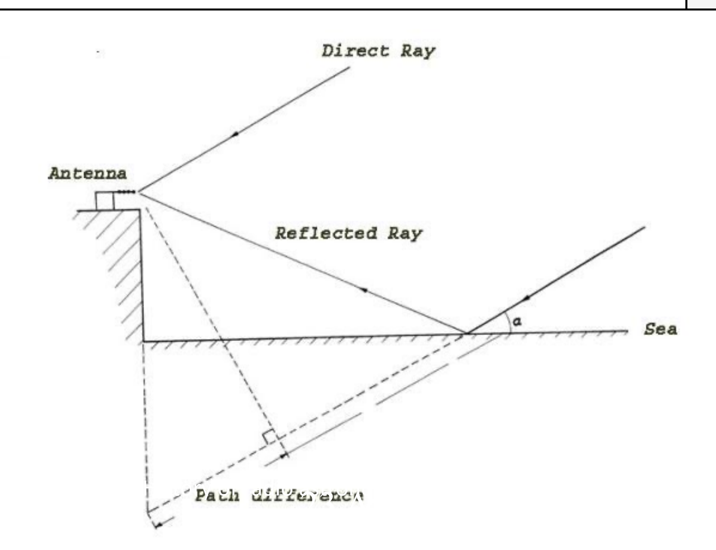

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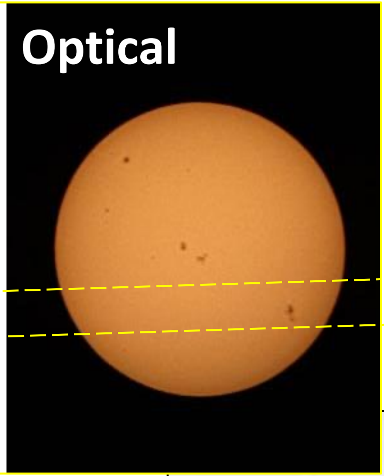

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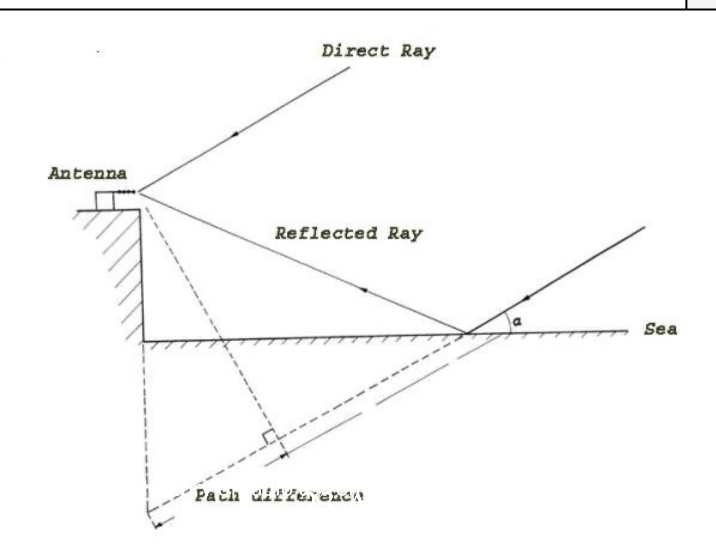

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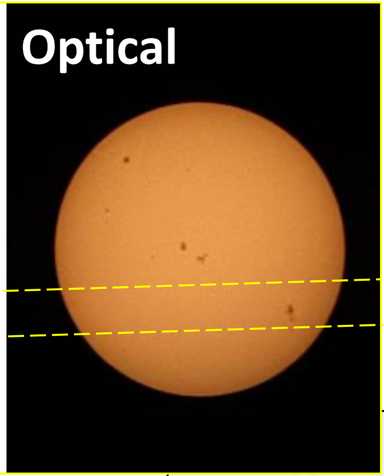

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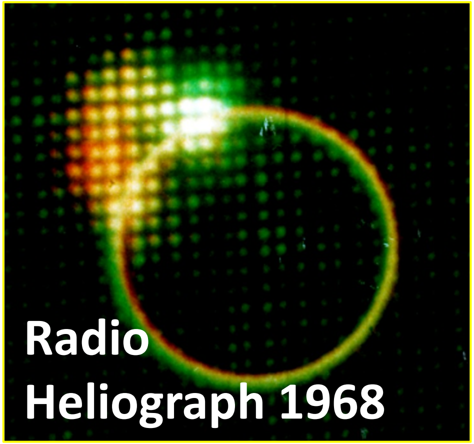

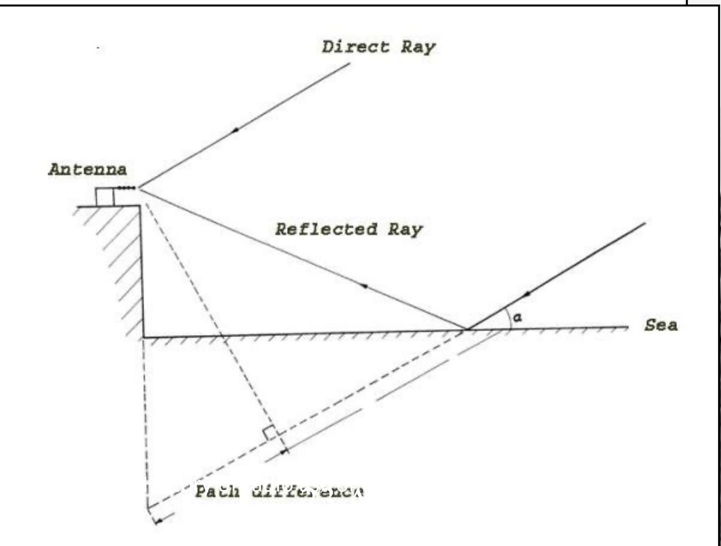

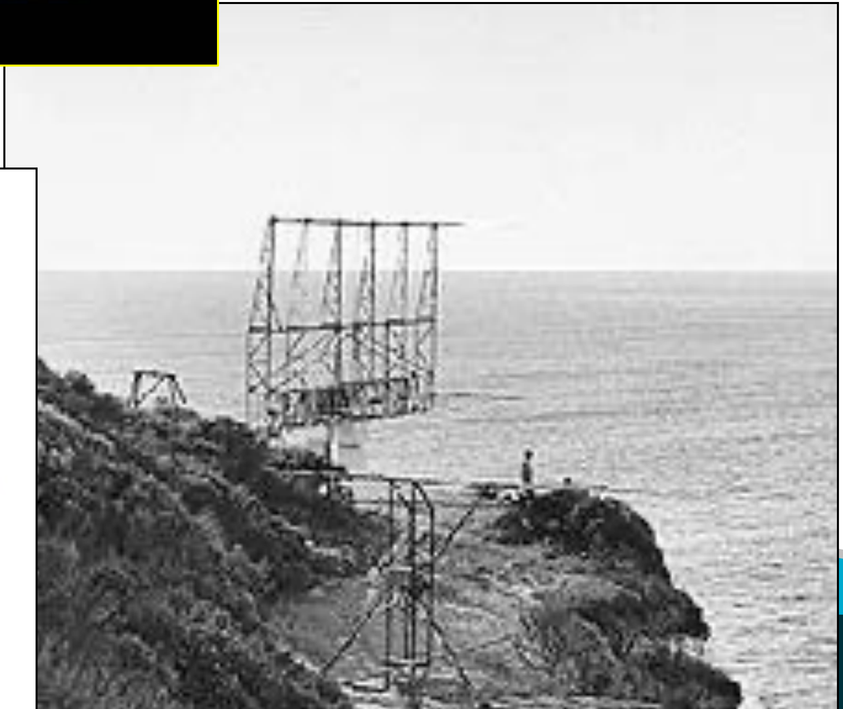

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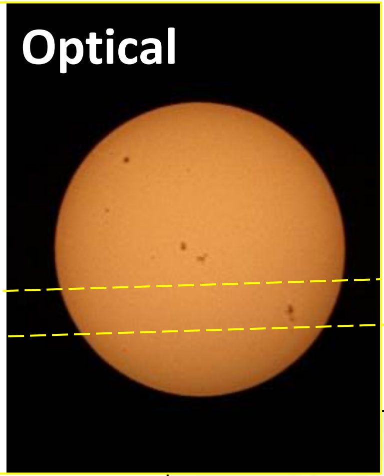

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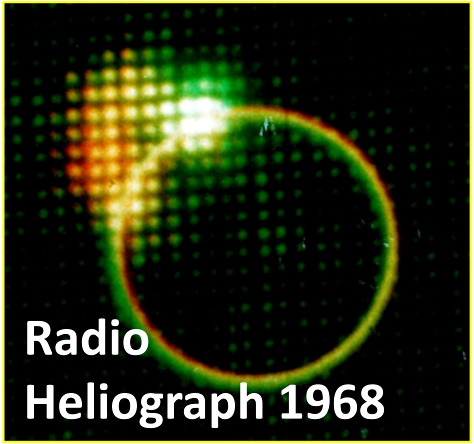
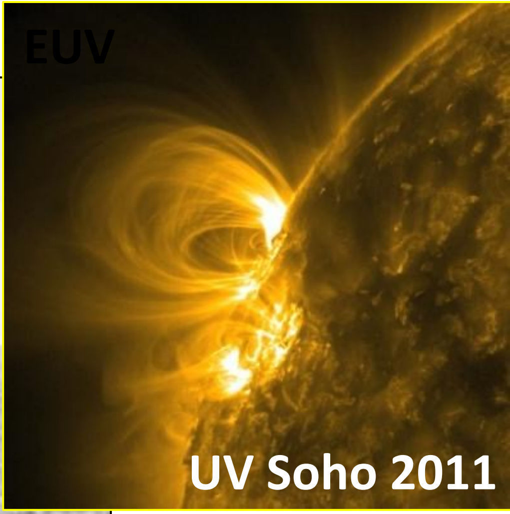
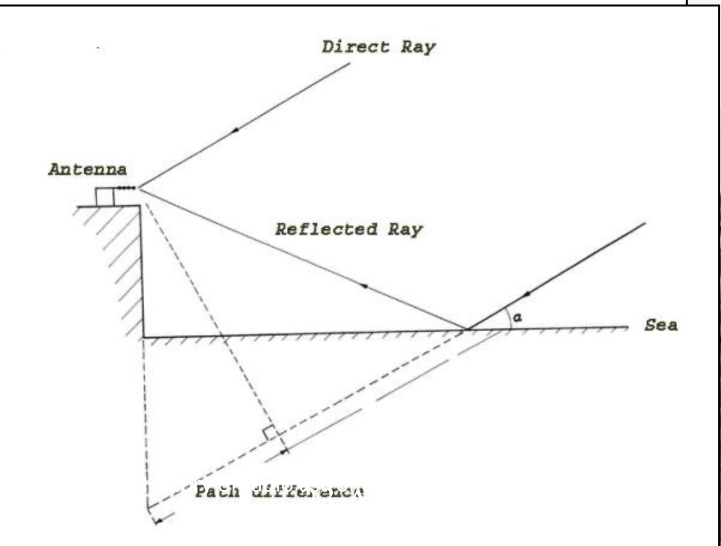
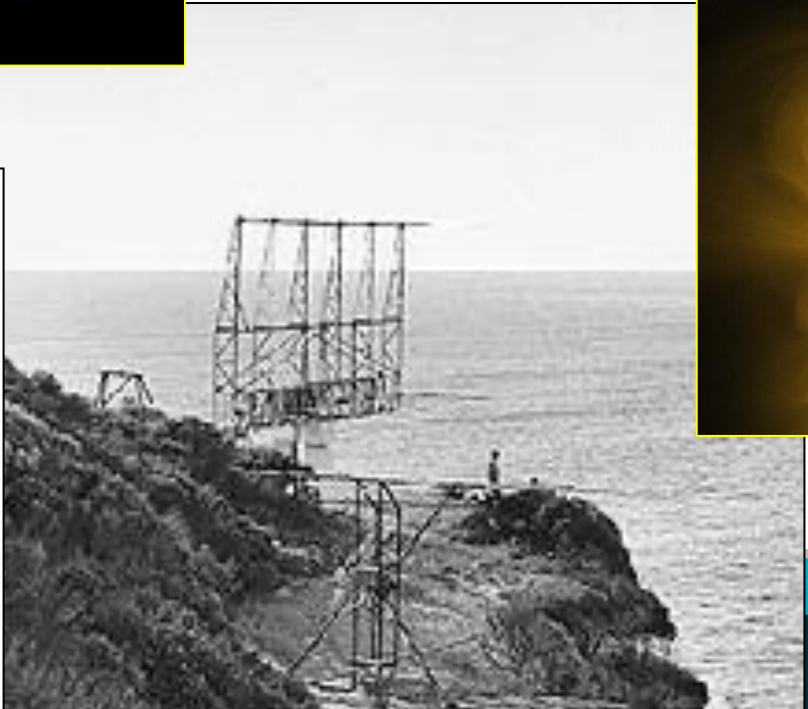


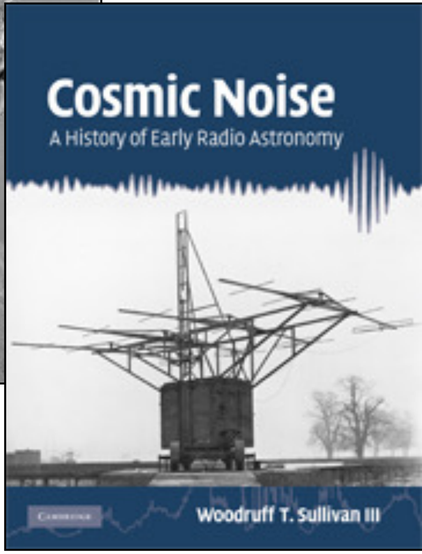






Cygnus A
strongest discrete radio source in sky

- Hey 1946
  - source with variable intensity
  - time scale of seconds to minutes
  - must be small diameter
  - the first “radio star”
- What was it?
  - no optical counterpart
  - was the whole galactic plane made of such stars?

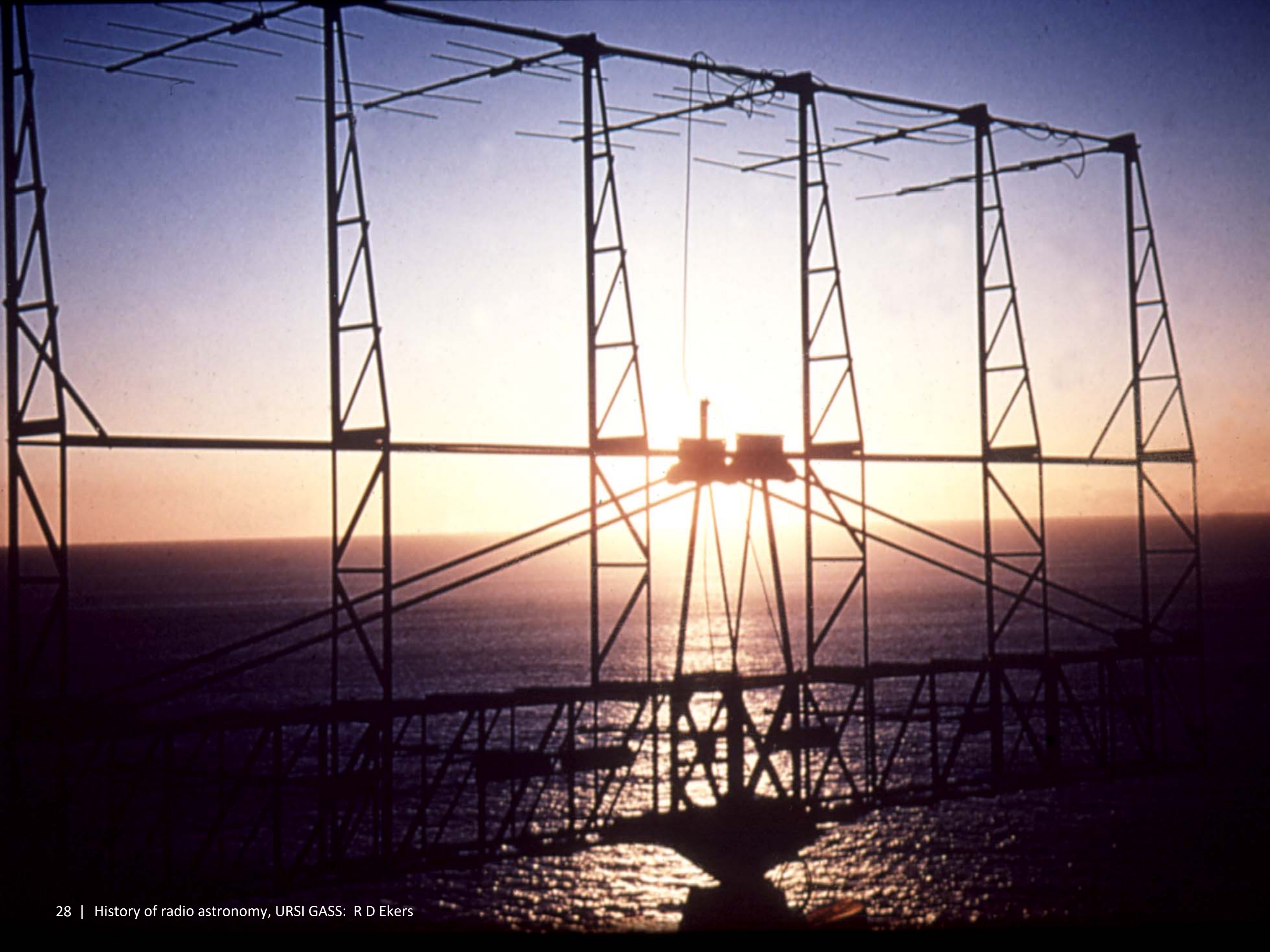


At the end of WWII the discrete radio sources were assumed to be stars

- Clever but incorrect application of Occam's razor
  - The Galaxy had been detected (Jansky)
  - The sun had been detected (Hey),
  - would not expect multiple different mechanisms and since the galaxy is full of stars the galactic emission must be the sum of all the stars like the sun
  - Hence the discrete sources will be stars.
- Strong evidence against this interpretation was ignored
  - not enough stars to explain the galactic emission if they are like the sun - easily fixed, special bright stars
  - Evidence for extended emission ignored
  - Intensity interferometry invented to resolve the “stars”

Cliff Interferometer

- Sydney, Australia 1948
- Needed more accurate positions to identify the sources of radio emission



Cliff interferometer CSIRO, Australia (1948)

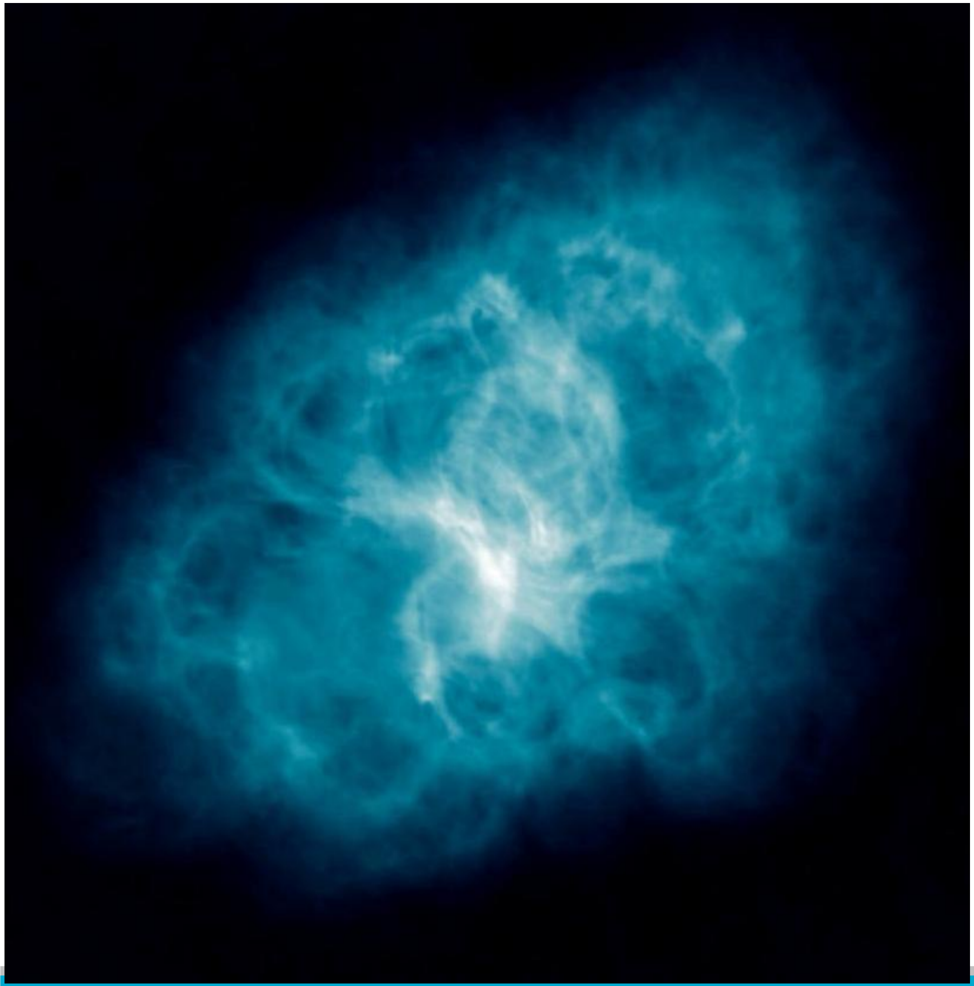
Built to identify the radio stars (John Bolton)

Discovery of the Crab Nebula radio emission

Discovery of extragalactic radio sources at great distances

Centaurus A , Virgo A

Crab Nebula
July 4, 1054 AD



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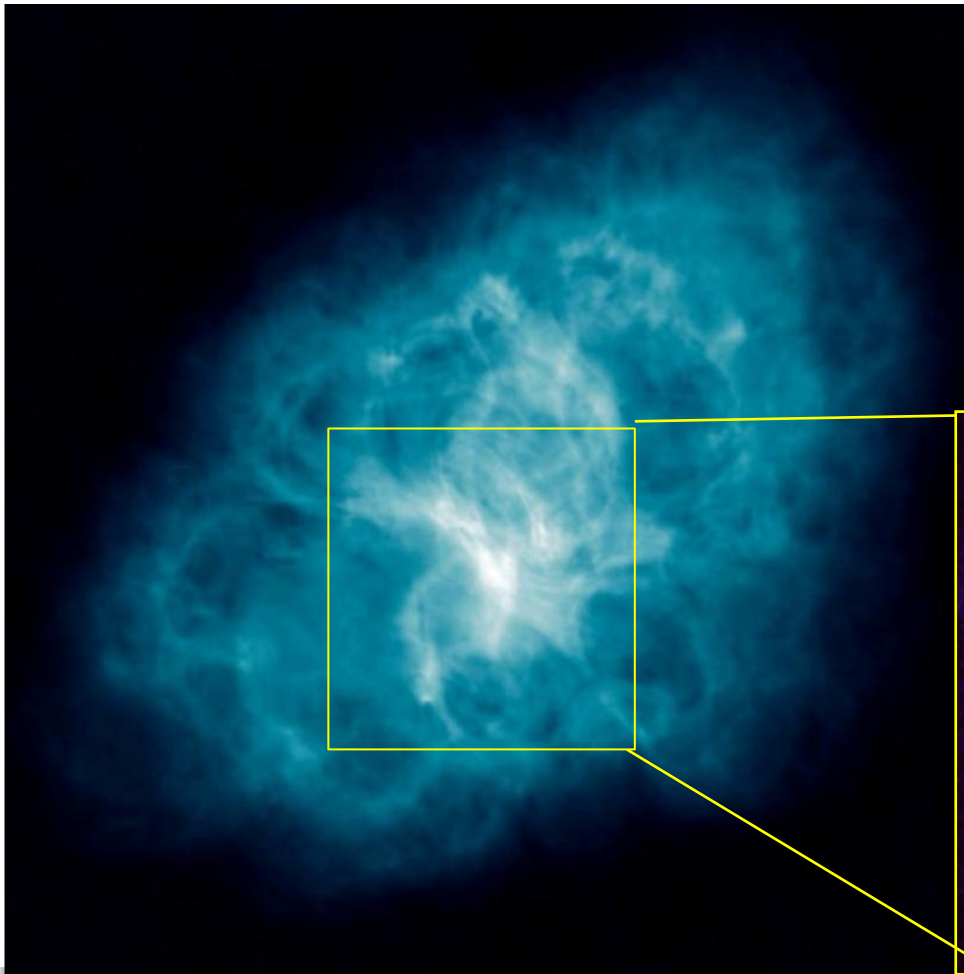
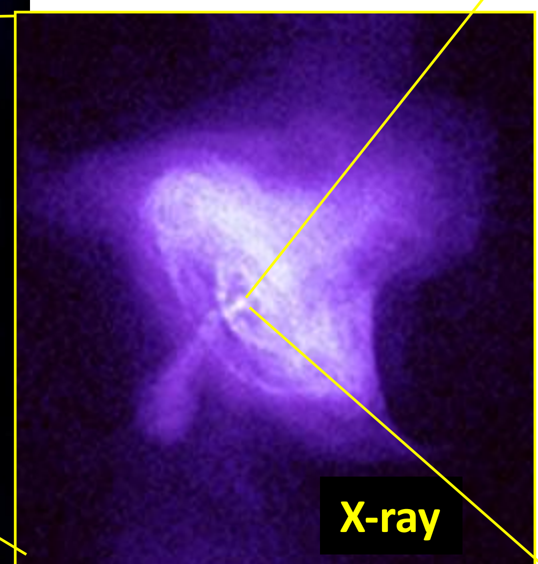


Radio VLA



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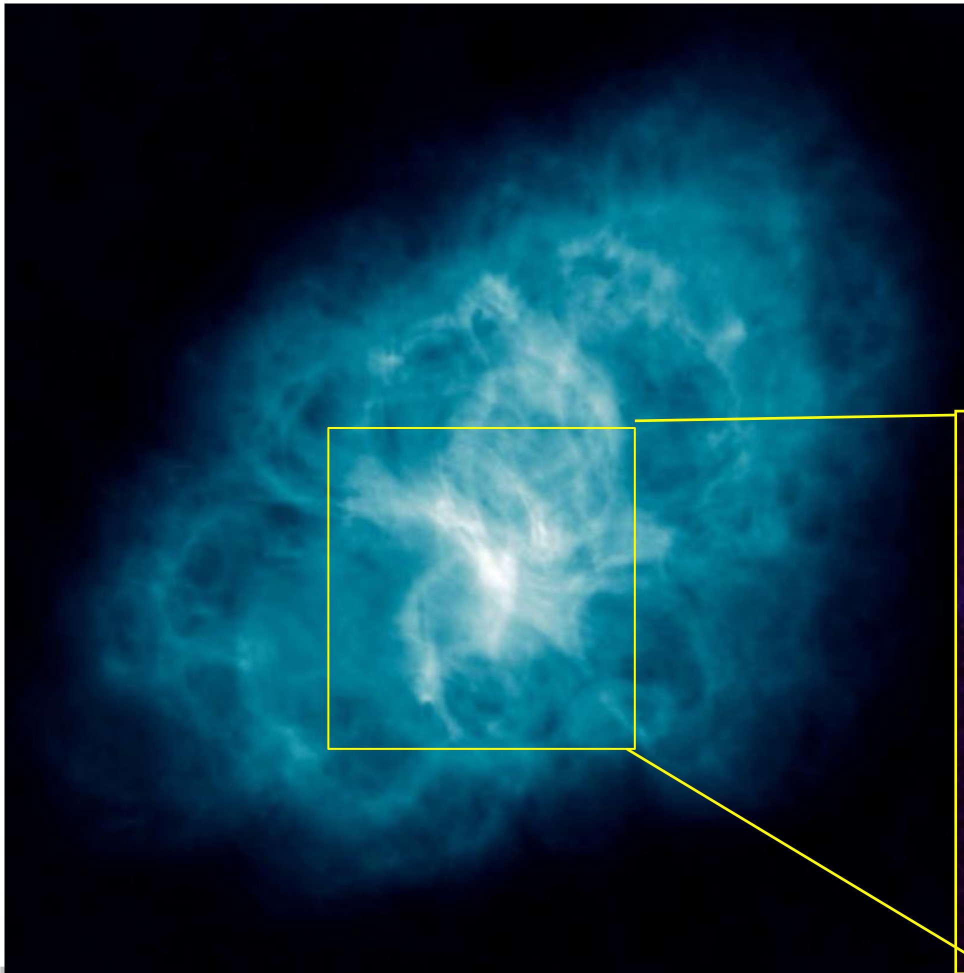
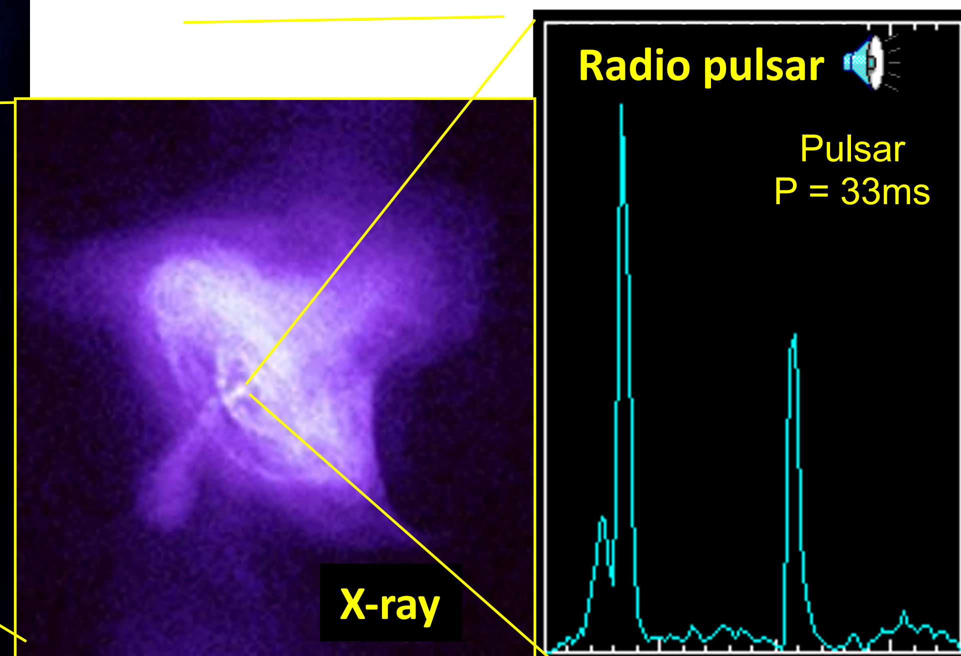




NGC5128 Galaxy

NGC5128 Galaxy

10 million

NGC5128 Galaxy

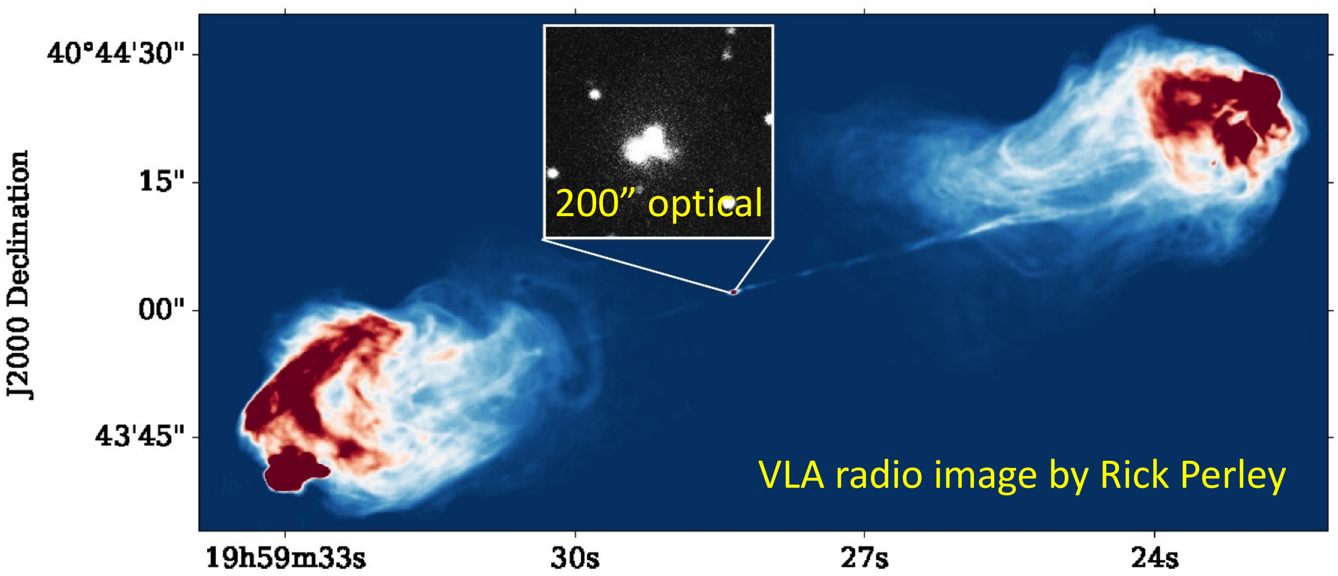
Centaurus A

Centaurus A

Centaurus A
ATCA Mosaic

Cygnus A

- The radio galaxies were ignored until the identification of the strongest discrete radio source Cygnus A by Rudolph Minkowski
  - Colliding galaxy theory to support the identification – wrong
  - But the identification was correct
  - This triggered a massive change – radio galaxies at cosmological distances
  - "*Cosmic noise*" becomes "*Radio Astronomy*"



Discoveries

Kellerman and Bouton, Star Noise, 2023

- Harwit's definition
  - Named, conference, …..
  - Consensus (Ekers, Kellermann, Lazio, Cordes), but clearly subjective
  - Discoveries may not be a single event or a single scientist
  - Doesn't include sub-categories. Eg radio galaxies but not tail sources….

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1956	Evolving Universe	Ryle
1960	Jupiter Radiation Belts	Multiple observers[e]
1961	AU and Venus Rotation	MIT & JPL teams
1962	Synthesis Imaging	Ryle[b]
1962	Mercury Rotation& Temperature	Pettingill
1963	Quasars	Schmidt
1963	First Interstellar Molecule	Weinreb, Barrett
1964	4th Test of GR	Shapiro
1964	Interplanetary Scintillations/Solar Wind	Clarke
1964	Radio Recombination Lines	Dravskikh & Sorochenko
1965	CMB	Penzias & Wilson[b]
1965	Cosmic masers (OH)	Gunderman
1967	Pulsars - netron stars	Bell[c]
1968	Water Masers	Cheung
1970	CO and Interstellar molecules	Wilson, Jefferts, Penzias
1970	GR Solar Deflection	Sramek
1971	Superluminal Motion	NRAO and MIT teams
1974	Binary Pulsar	Hulse & Taylor[b]
1974	SgrA*	Balick & Brown
1979	Graviational lensing	Walsh
1991	Exoplanets	Wolzczan, Frail
1996	COBE Spectrum and Anisotropy	Mather & Smoot[b]
2007	FRBs	Lorimer
2019	SMBH image	Large team effort

Technology enabled discoveries

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CSIRO

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Nobel probability
Radio astronomy
4x physics!

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

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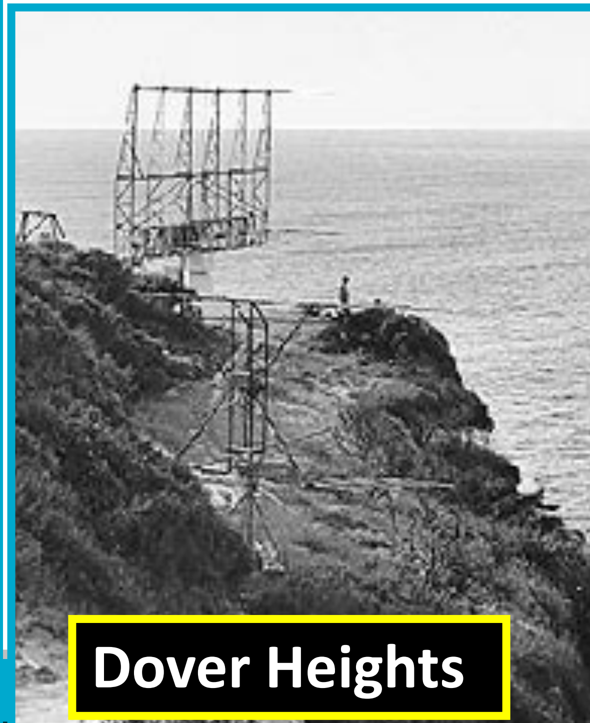

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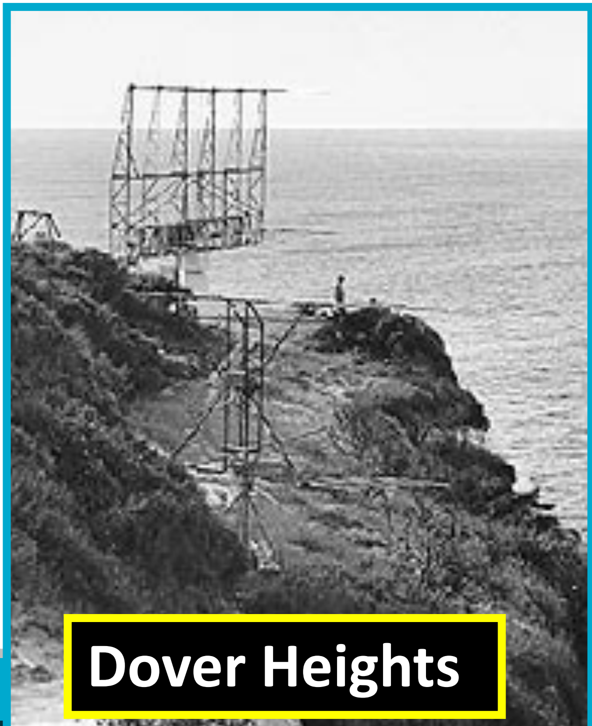

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McCready, Pawsey & Payne-Scott 1947

- It’s possible in principal to determine the actual distribution by Fourier synthesis using the phase and amplitude at a range of height or wavelength.
- Using wavelength as a suitable variable is unwise since the solar bursts are likely to have frequency dependent structure.
- Getting a range of cliff height is clumsy, a different interference method would be more practical.

Christiansen and Warburton earth rotation synthesis (1955)

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- EW array makes analogue fan beams which rotate on sun
- Chris takes the 1D FT of each strip distribution & then does a 2D Fourier synthesis using all strips
  - The way in which a 2D radio brightness distribution may be derived from a number of 1D scans is not obvious. However rather similar 2D problems have arisen in crystallography and solutions for these problems, using methods of Fourier synthesis have been found.

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Computers and signal processing

- 1958
  - EDSAC II completed and applied to Fourier inversion problems
  - 360 38-point 1D transforms took 15 hours (Blyth)
  - Output was contours!

1960 user queue for programming the EDSAC 2

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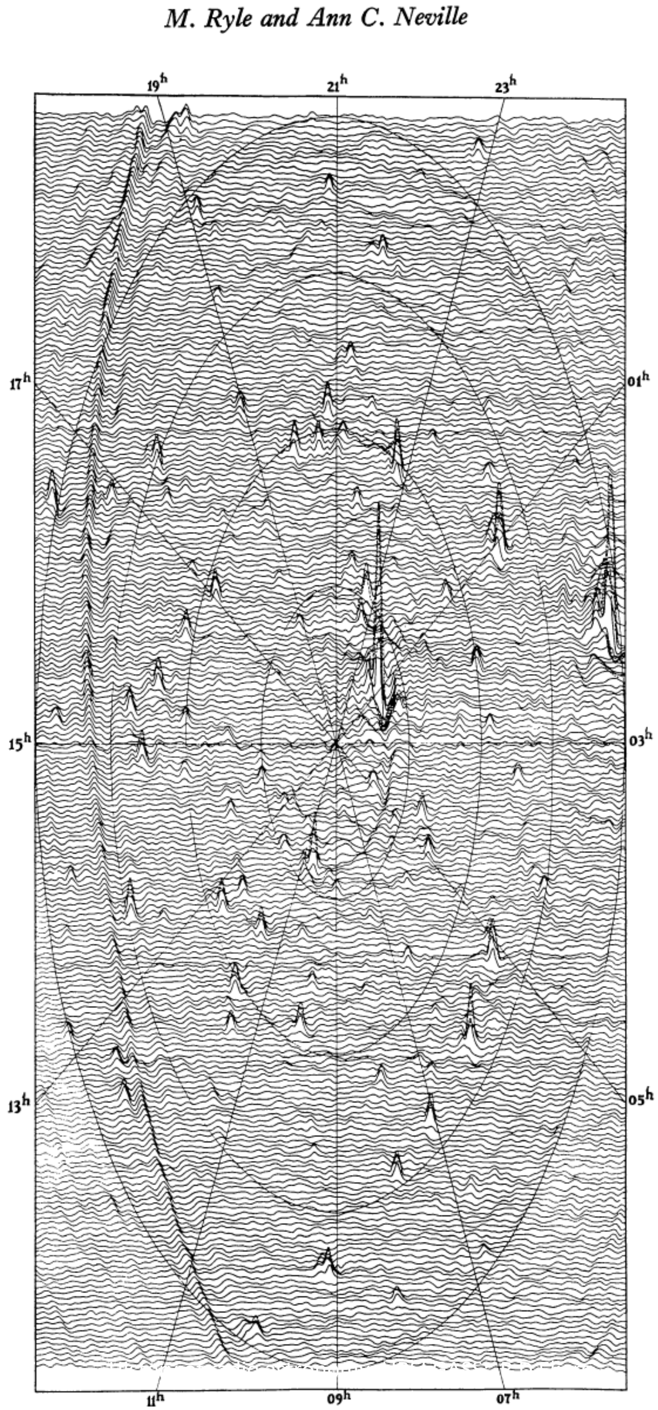
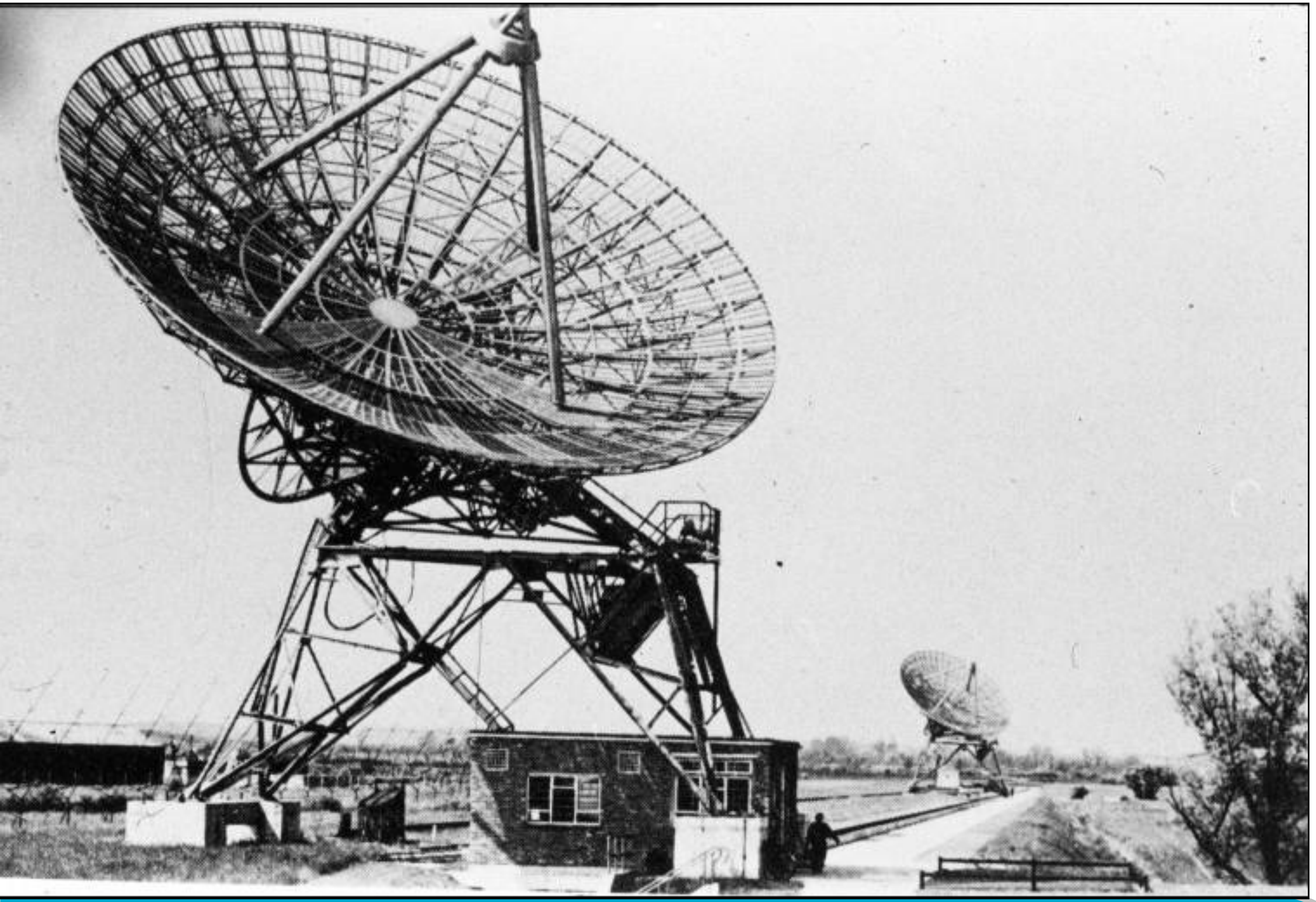
- 1965
  - Cooley & Tukey publish a *convenient* implementation of the FFT algorithm

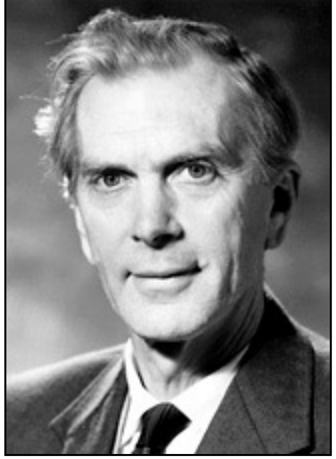


First Cambridge Earth Rotation Synthesis Image

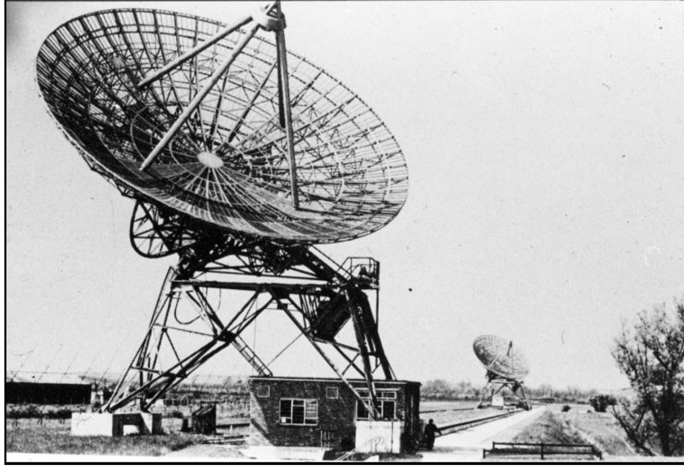
- Ryle & Neville, MNRAS 1962
- North pole survey
- 178 MHz
- 200x200 pixels took a full night to compute on EDSACII
- Now Moore's law and the massive improvements in computing power give us LOFAR and MWA

Cambridge One-Mile Telescope: 1962





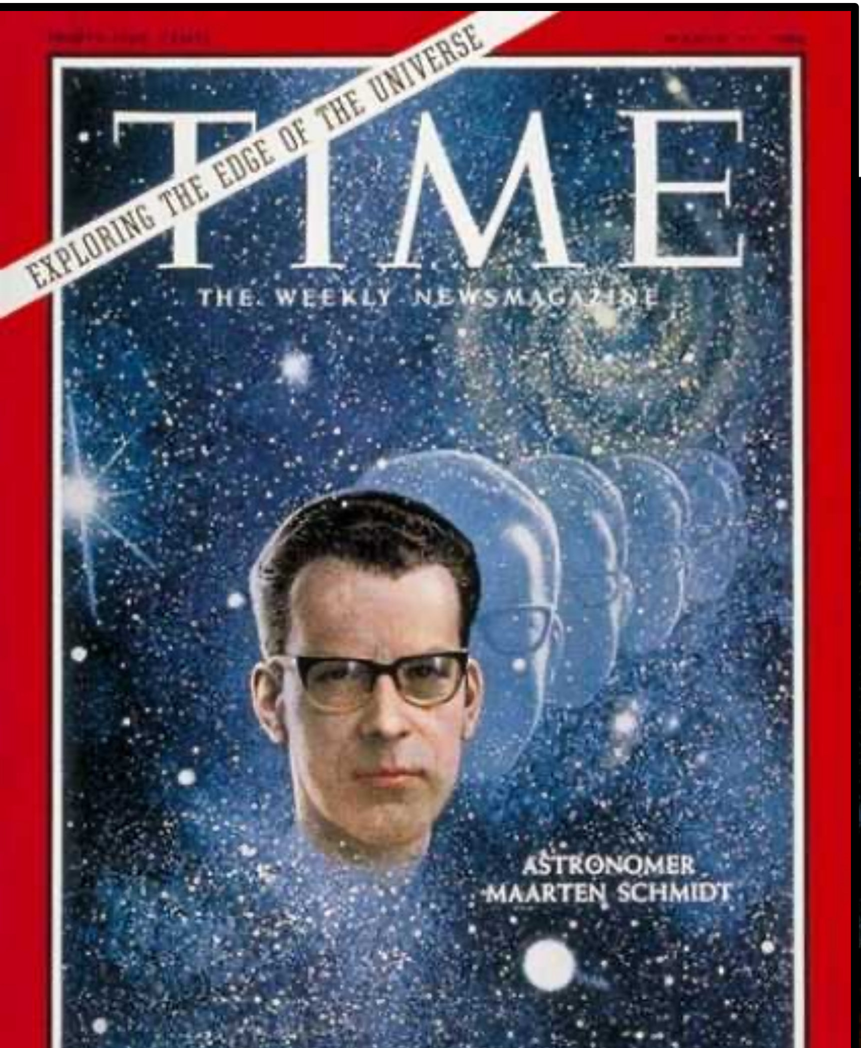
Nobel Prize 1974
Sir Martin Ryle



from the Nobel 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.”

60th Anniversary of the Discovery of Quasars



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NATURE March 16, 1963 Vol.

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By Dr. M. SCHMIDT

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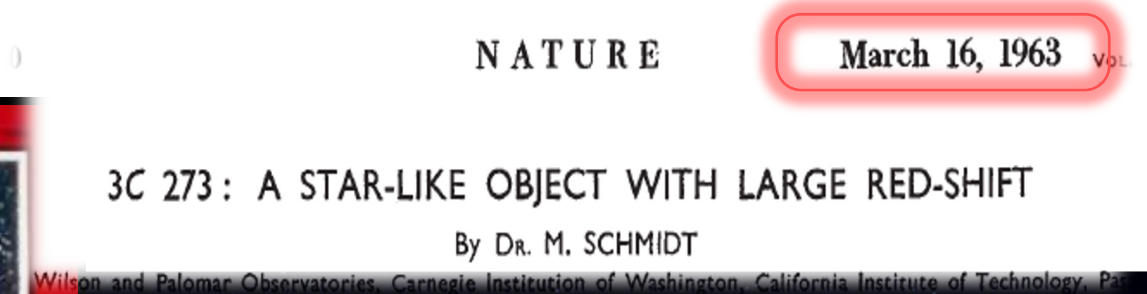
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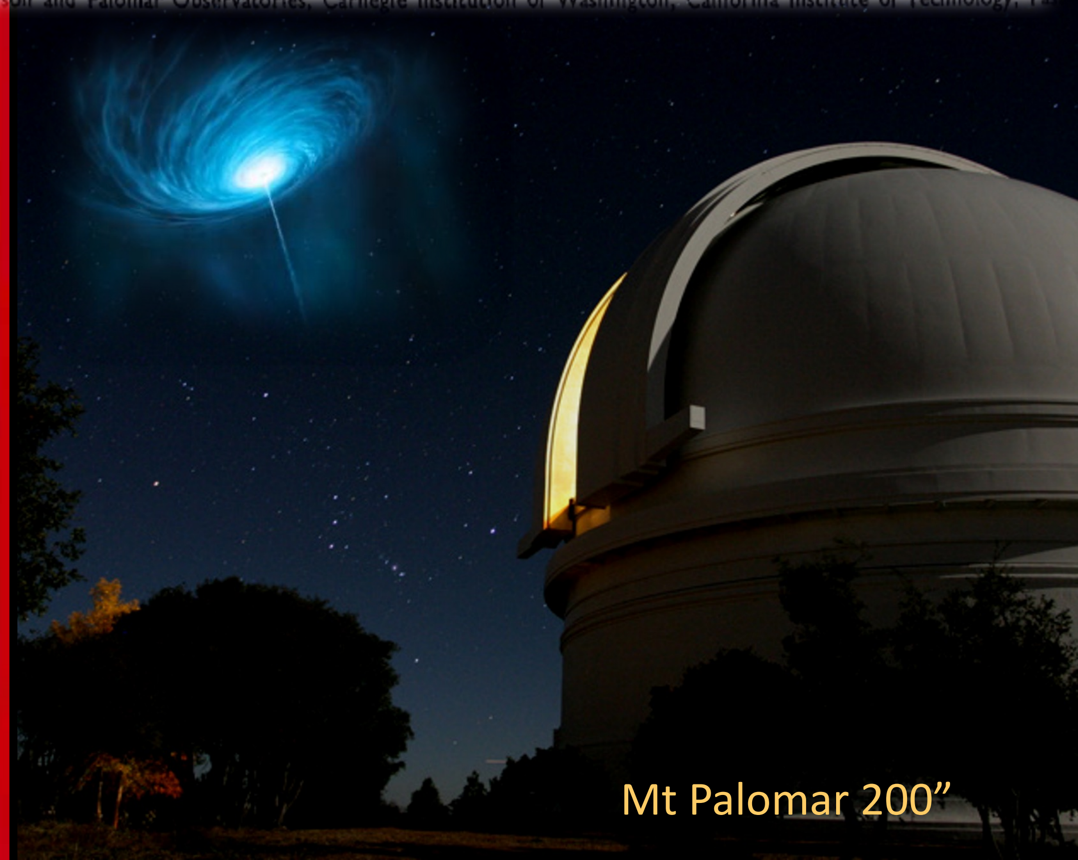

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- A few small diameter radio sources are identified with stars
  - These weird stars known to have variable light so *"couldn't be extragalactic"*

Parkes Radio Telescope observes the Lunar occultation of a radio source

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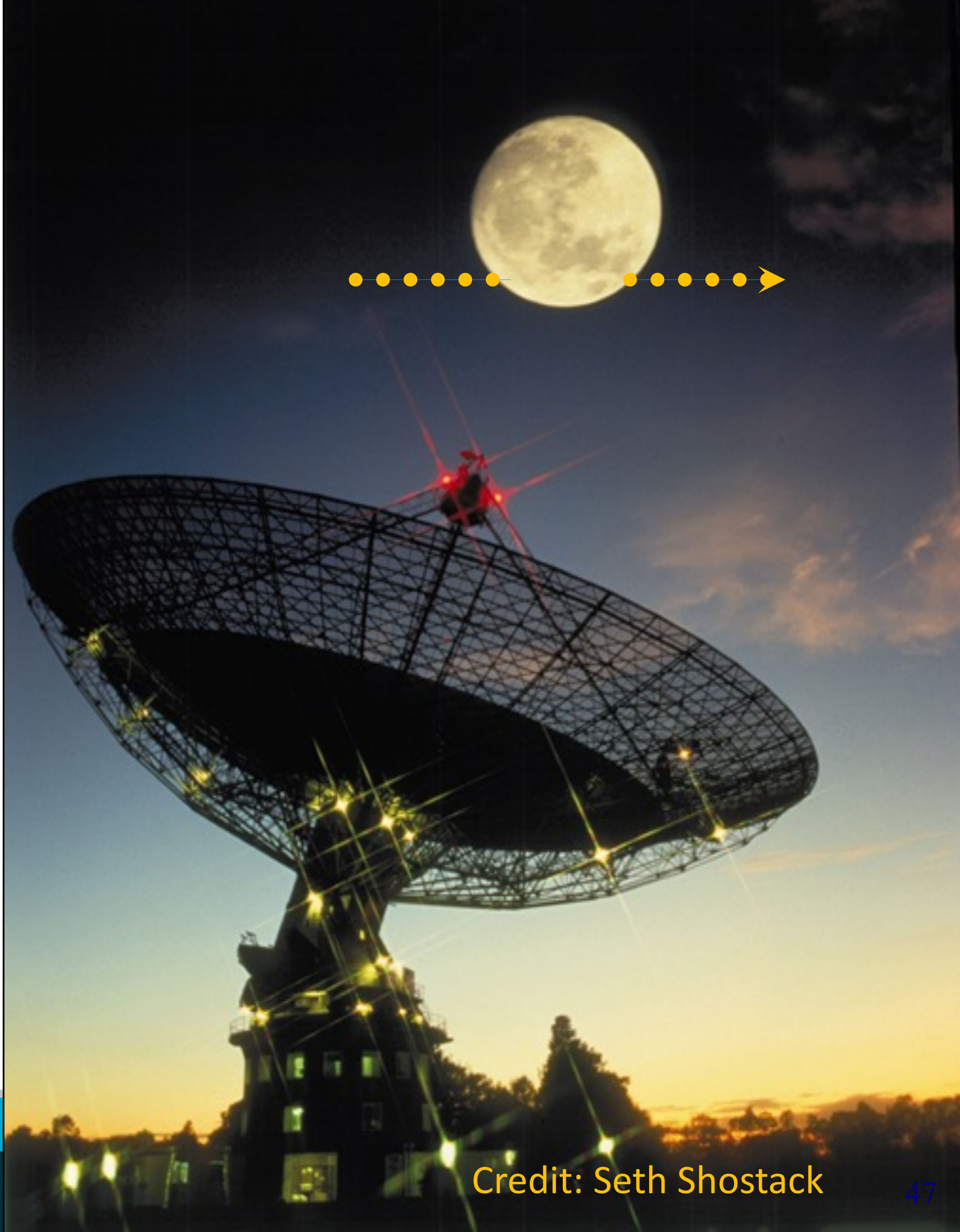
- time disappearance
- and reappearance

- Core jet structure identified with a 13 mag “star” at a red shift of 0.158



Impact of the Discovery of Quasars

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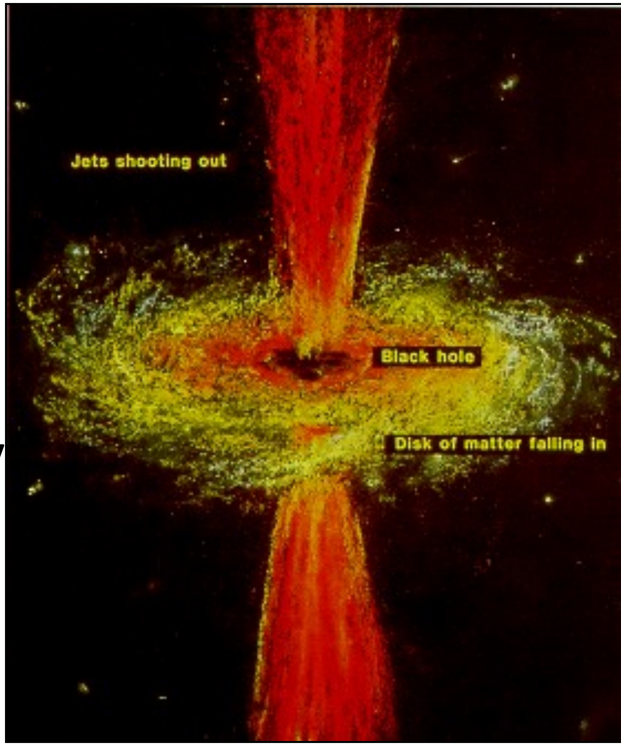
- The collision of two cultures
  - Astronomers
  - General Relativity Theorists

Impact of the Discovery of Quasars

- The collision of two cultures
  - Astronomers
  - General Relativity Theorists
- Gravitational Collapse and Relativistic Astrophysics
  - Dallas, Texas, Dec 1963
  - only gravity of a massive object in the nucleus of a galaxy could provide the energy



The Netherlands
1970

- Steven Hawking - black holes radiate

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The Netherlands
1970

- 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 the Westerbork radio telescopes
  - *There has to be a better way*

IEEE 802.11 wireless network standard

- 1977 O'Sullivan explains why adaptive optics works
- 1980's Fourier Transform on a chip
  - ➢ This was the *better way*
- 1990s O'Sullivan leads a multidisciplinary CSIRO team
- 1996 CSIRO obtains US patent #5,487069
- 2001 Skellern develops a wireless chip meeting IEEE standard
- 2013 1.5 billion devices sold using this technology

Westerbork: 1970

- Oort 1961 vision
- Bennelux Cross an International project
  - ➢ Hogbom (Cambridge)

    +
  - ➢ Christiansen (Sydney)

⇨ WSRT

- 12 x 25m dishes 1.5km
  - ➢ Two moveable
  - ➢ 10 redundant spacings
  - ➢ Self calibration
- HI and dark Matter (1978)

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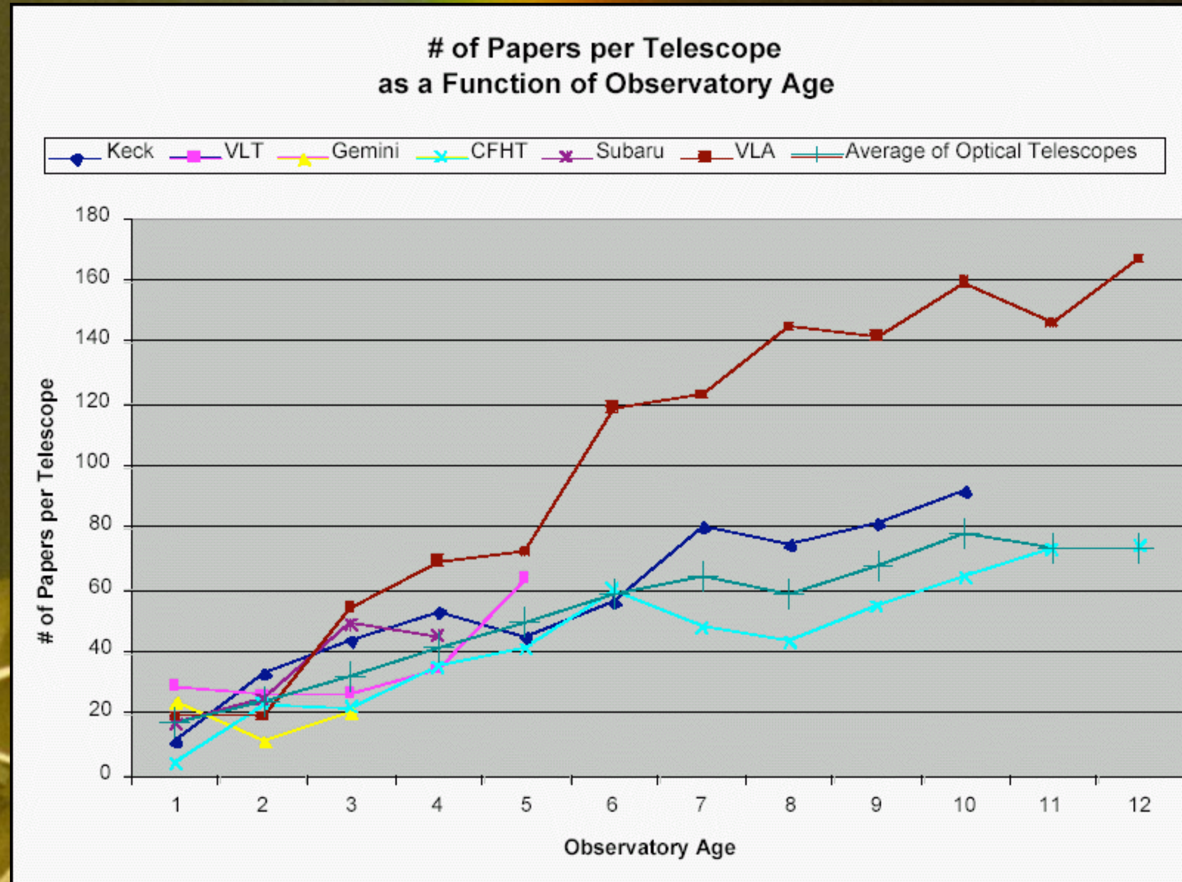
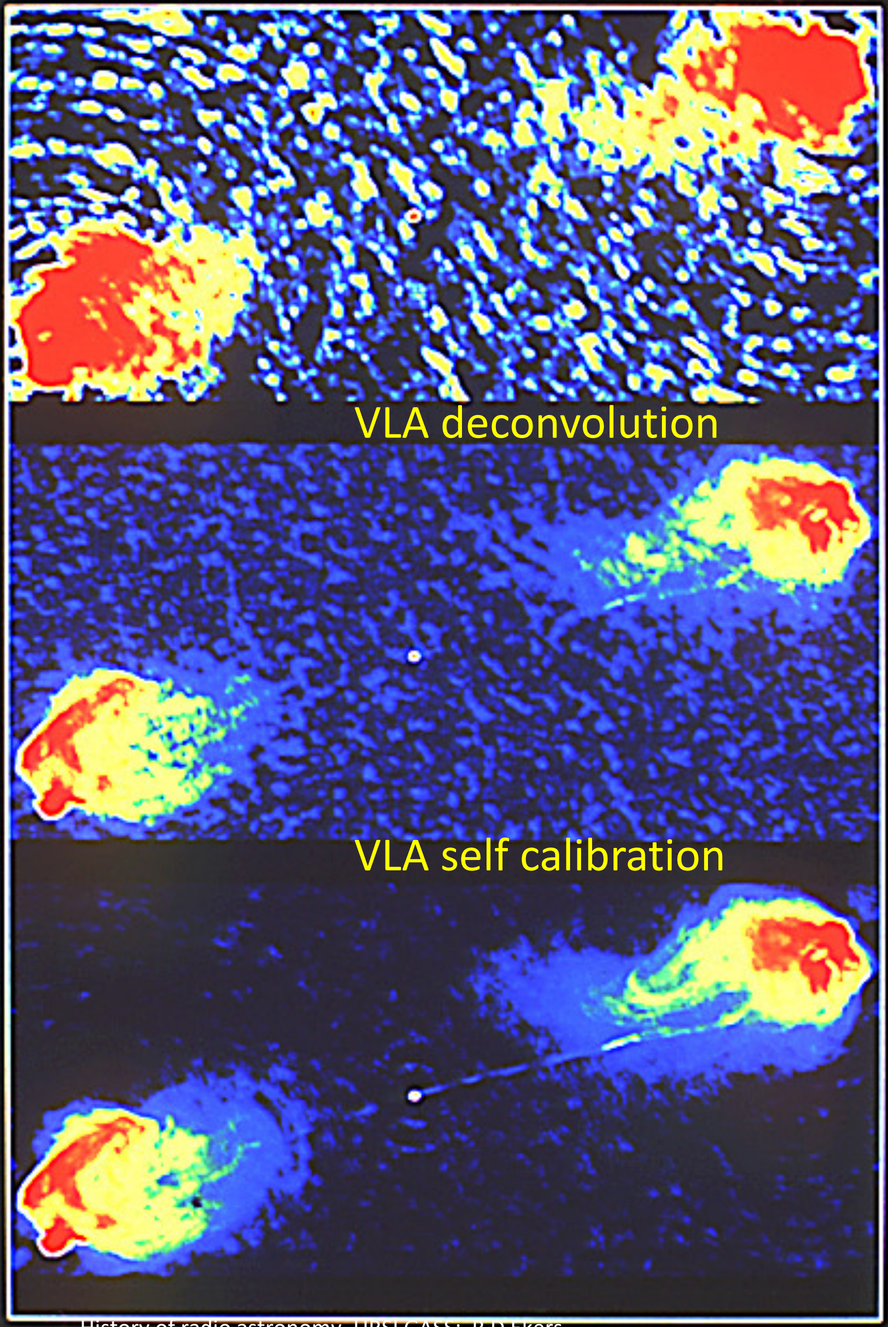
Built to observe quasars with optical resolution!

VLA
New Mexico
1980



Built to observe quasars with optical resolution!



History of radio astronomy, URSI GASS: R D Ekers

Algorithms are discovered too

- VLA uncorrected image meet the design specifications
- But then we had:
  - ➢ Deconvolution
  - ➢ Self Calibration (adaptive optics)
- and now we also have
  - ➢ Mosaicing
  - ➢ Bandwidth Synthesis
  - ➢ Rotation Measure Synthesis

Very Long Baseline Interferometry (VLBI) from Earth and Space

- **Global VLBI network**
- **VSOP – HALCA**

by Paul Boven <boven@jive.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Very Long Baseline Interferometry (VLBI) from Earth and Space

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Very Long Baseline Interferometry (VLBI) from Earth and Space

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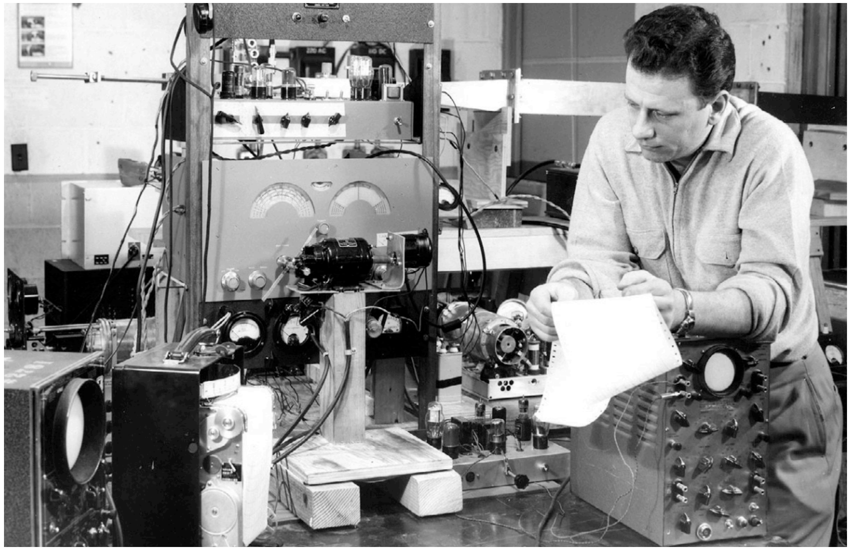
Hirax Hirabyashi
2023 URSI
Dellinger Medal

CSIRO

1950: 21cm Hydrogen Line Detected
the standard story

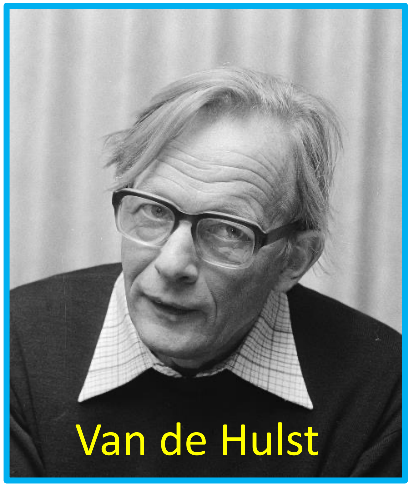
- Predicted by van de Hulst
  - Leiden 1944
- Detected by Ewen & Purcell,
  - Harvard 1950
- Confirmed by Dutch and Australians

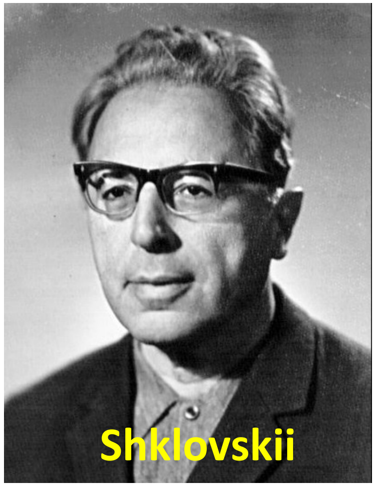


prediction → observation → confirmation ?
but this was not the real story

Kellerman and Bouton, Star Noise (2023) CUP

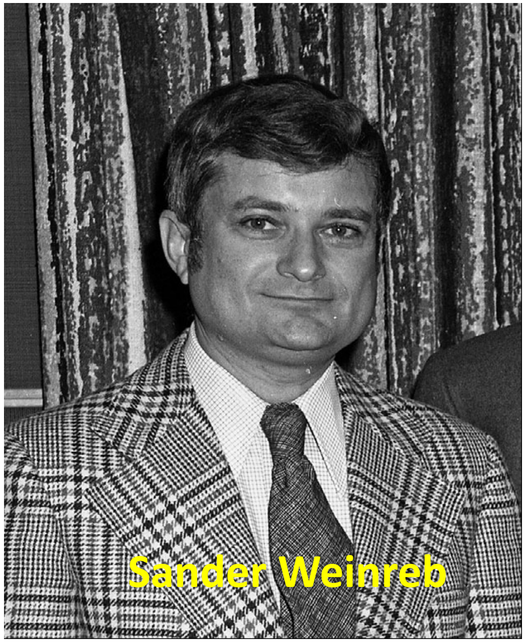
- 1944 van de Hulst prediction
  - ➢ Published in Dutch and not widely accessible outside the Netherlands
- 1946 van de Hulst visits Reber in the US.
  - ➢ Reber not enthusiastic – does not follow up
- 1949 Shklovskii reads review, but doesn't have v d Hulst paper
  - ➢ Re-derives the prediction from first principals!
  - ➢ Published in Russian but this is translated and distributed in the West.
  - ➢ Landau dismisses theory – no search was made in the Soviet Union
- March 1951 Atomic physicists, Ewen and Purcell, detect line
  - ➢ They had read the translation of Shklovskii's paper
  - ➢ They were interested in the atomic physics (not the astronomy)
- May 1951 Confirmed by the Dutch and the Australians





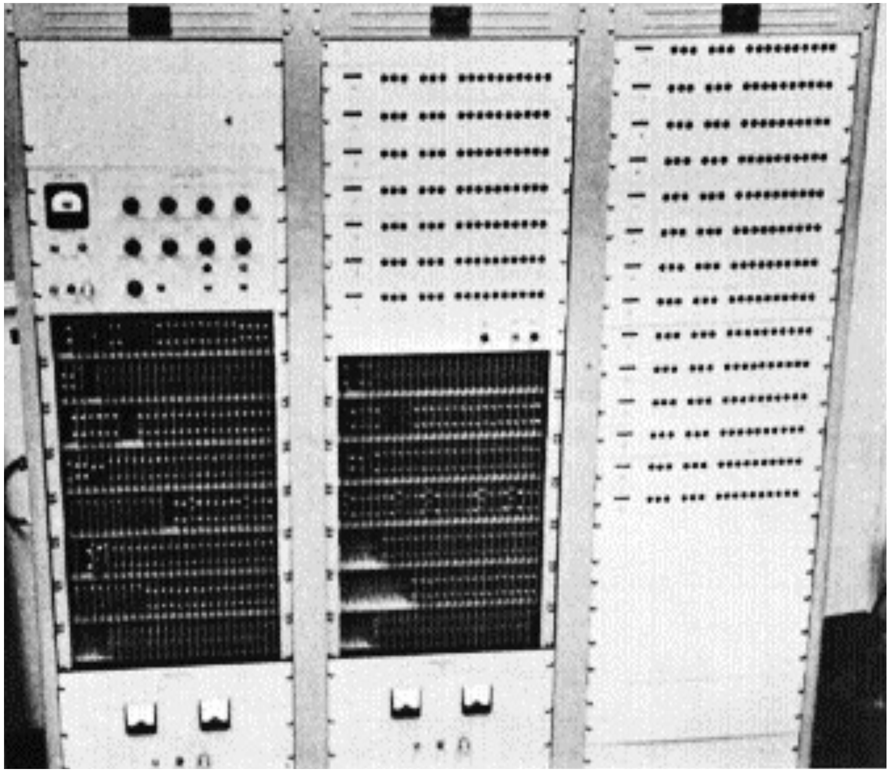
Spectral lines and the first digital correlator

- Various predictions in 1955 including OH, NH_3, H_2O
- OH detected by Weinreb and Barret 1963
  - digital auto-correlation spectrometer
  - Parkes confirmed in only 1 day with a receiver modification



21 lags
300kHz clock
discrete transistors

$19,000



There were many more spectral lines

Massive clouds of Molecules in the space between the stars

- Radio Recombination Lines (RRL)
  - Soviet prediction and detection in 1964 but not believed in West.
  - Theoreticians repeatedly discouraged observers - incorrect estimate of Stark broadening
  - These lines were easily detected with the new 140’ telescope in 1965
- OH line detected in 1965 but initially called mysterium
- NH_3 1967
- H_2O 1968
  - detected at Berkeley but NRAO had rejected proposal to look
  - H_2O was so strong it could have been detected before HI!
- By 1969 this was a thriving research area with many more lines being detected

CSIRO

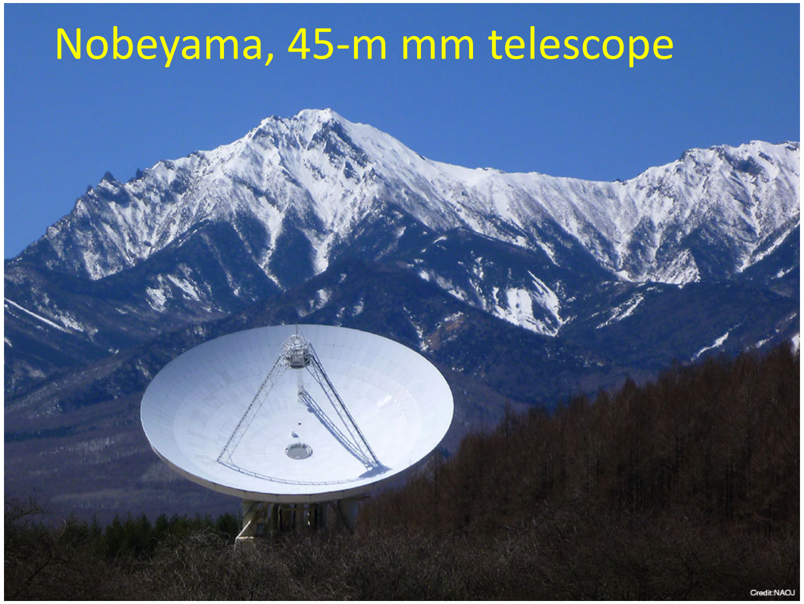
The Masers – more serendipity

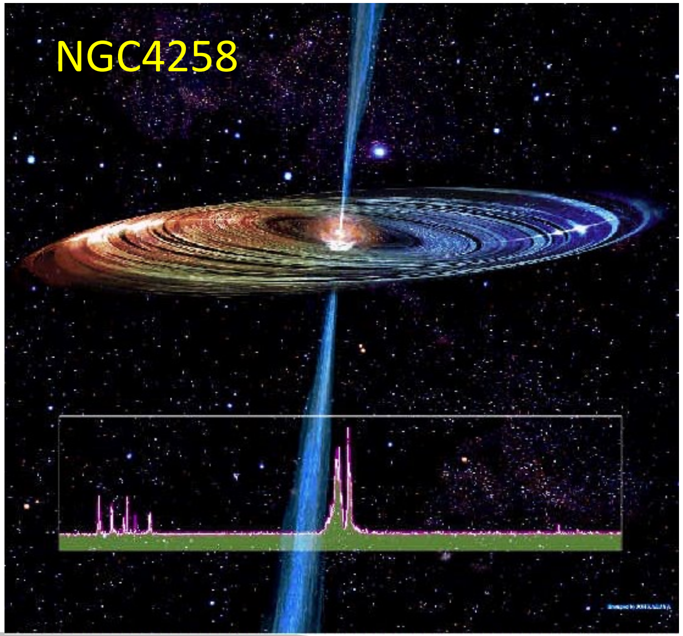
- Theorists were aware of the maser amplification process but the required conditions in the interstellar medium were considered so unlikely that this was never pursued
  - Maser amplification first recognised through observations of spectral lines of OH with 100% polarization
  - Maser amplification was confirmed by high angular resolution (VLBI) observations

Extragalactic Masers

- Extragalactic H_2O mega masers were discovered in 1971
- NGC4258 H_2O maser detected at Nobeyama in 1992
  - This provided the first direct evidence for a black hole in the nucleus of a galaxy
  - broad (1000km/s) line and VLBI size -> 36 x 10^6 solar mass black hole

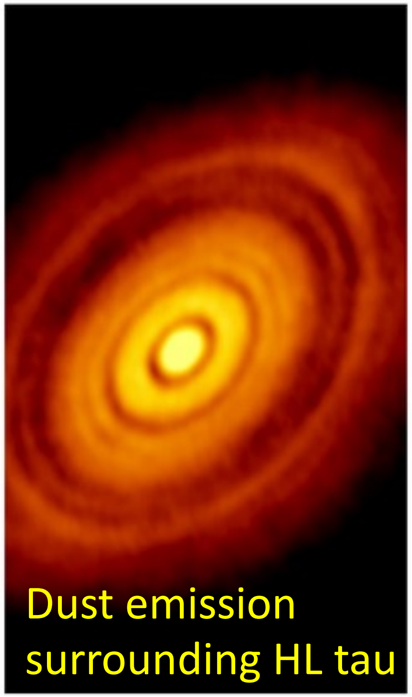
Myoshi et al (1995) [SN#77]



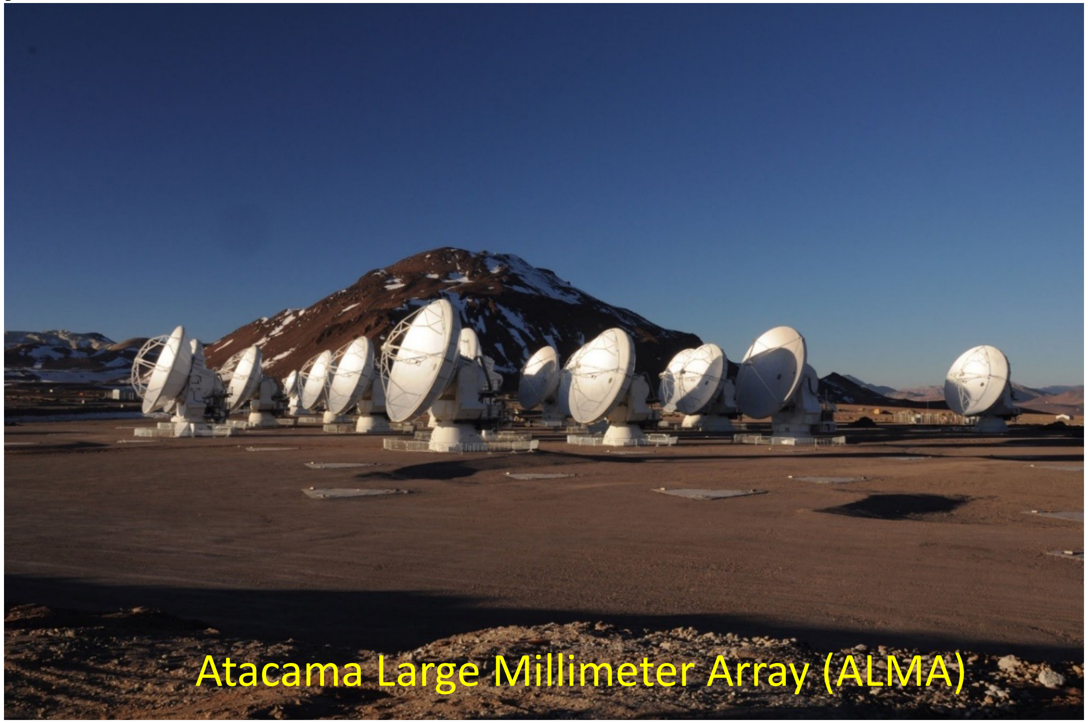


ALMA and mm radio astronomy

- CO was not detected until 1970
  - receivers at 2.6mm were too difficult before then
- A huge new area of astronomy has now opened up but I have no time to include this in my review

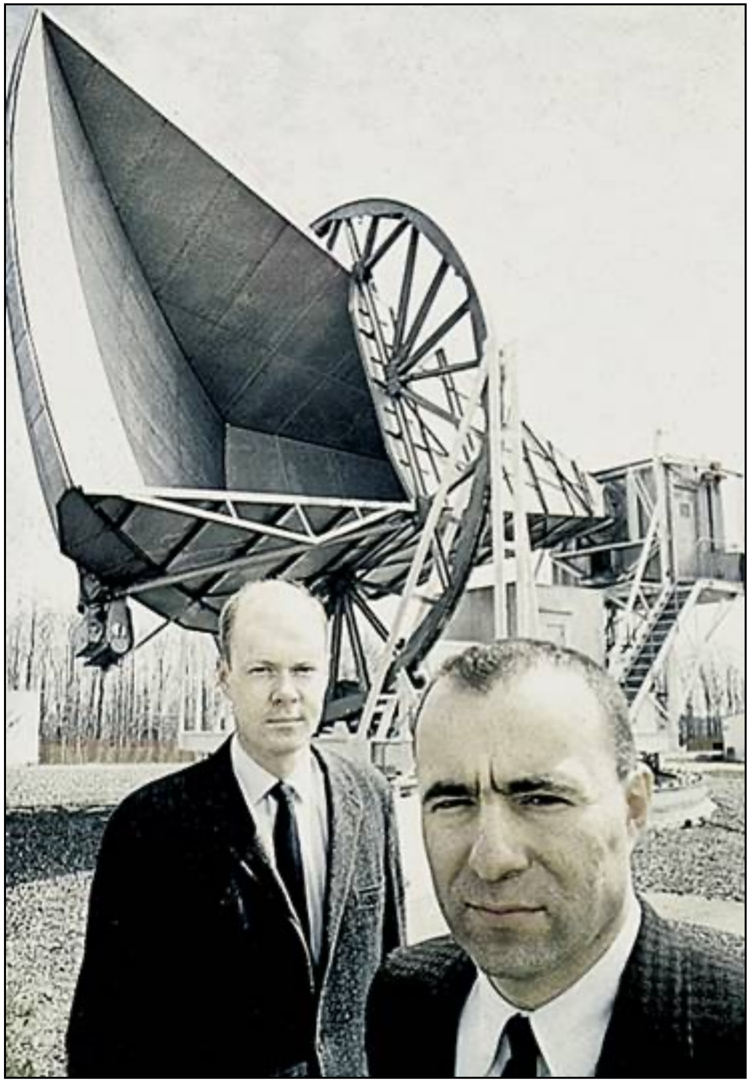


Dust emission surrounding HL tau



Atacama Large Millimeter Array (ALMA)

Bell Telephone Laboratories 1965



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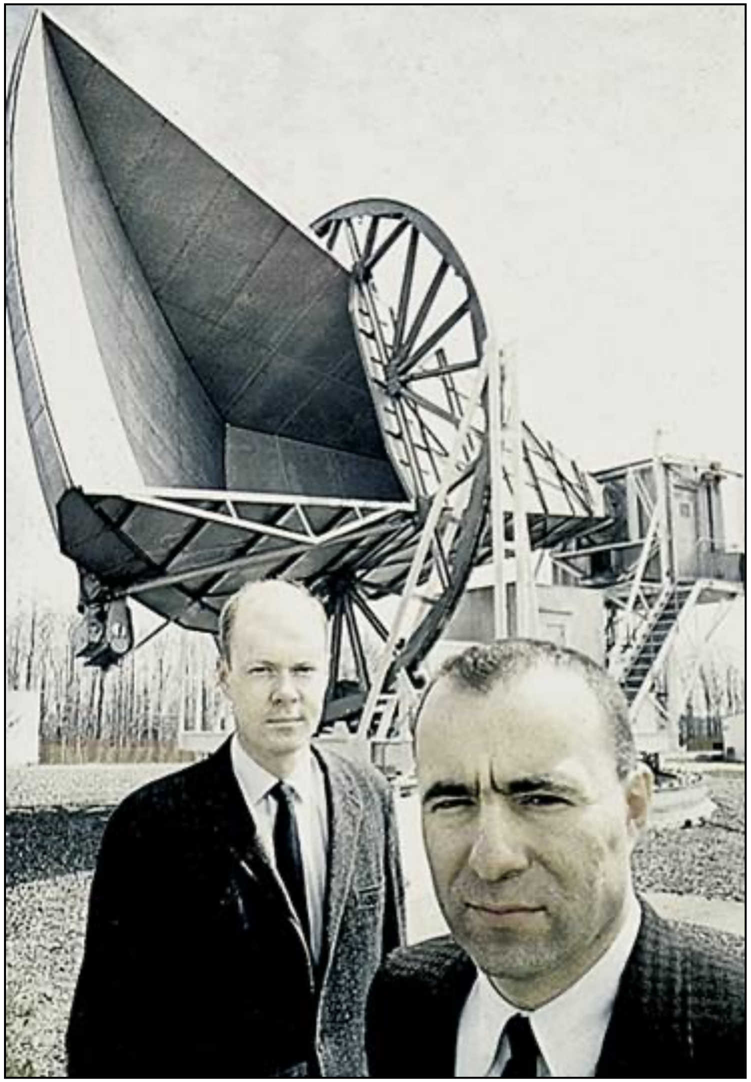

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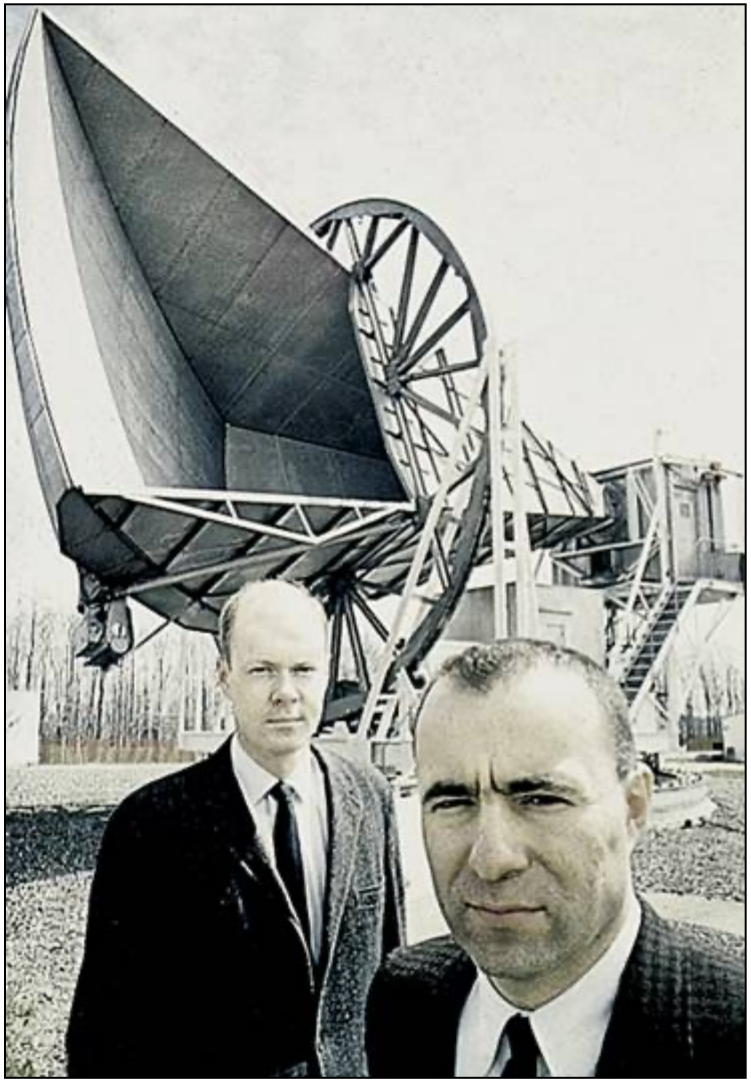

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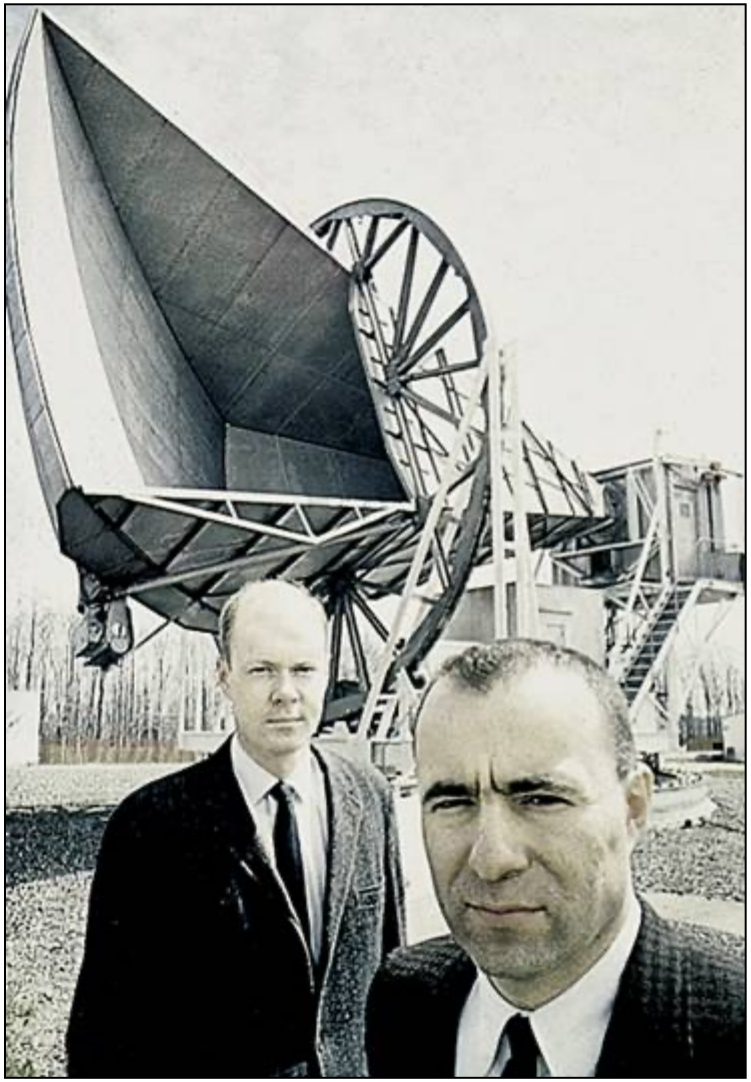
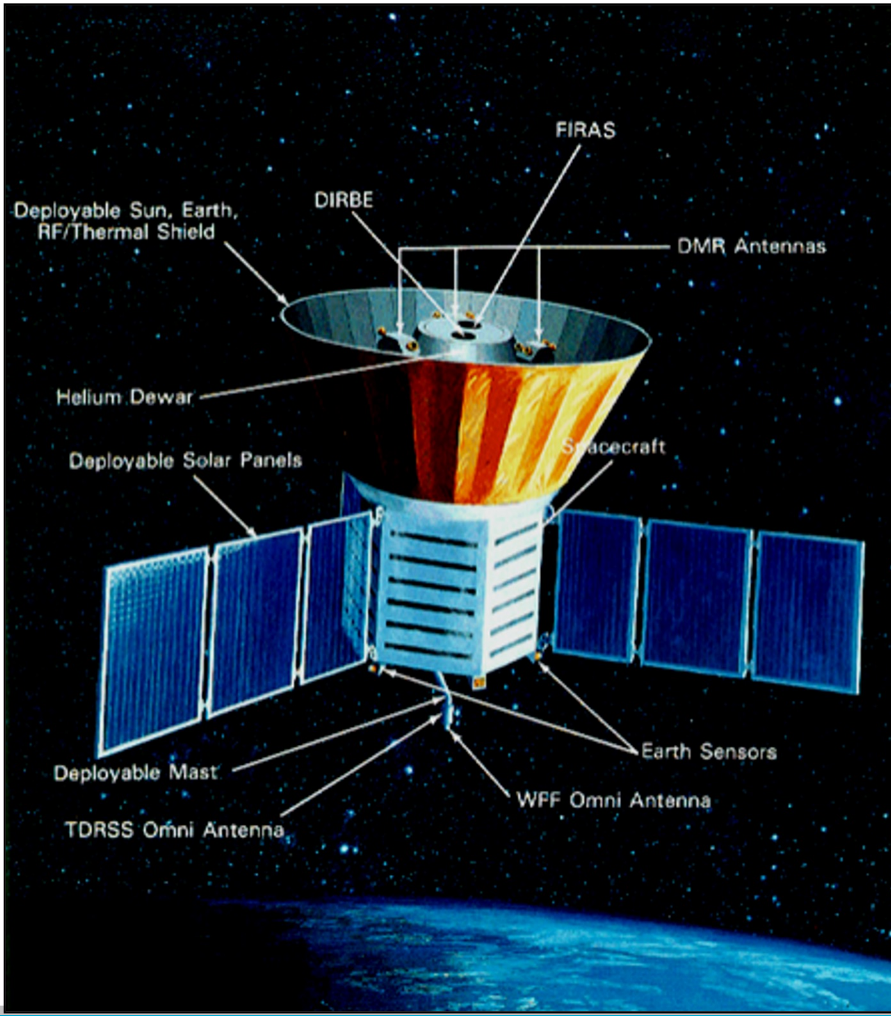
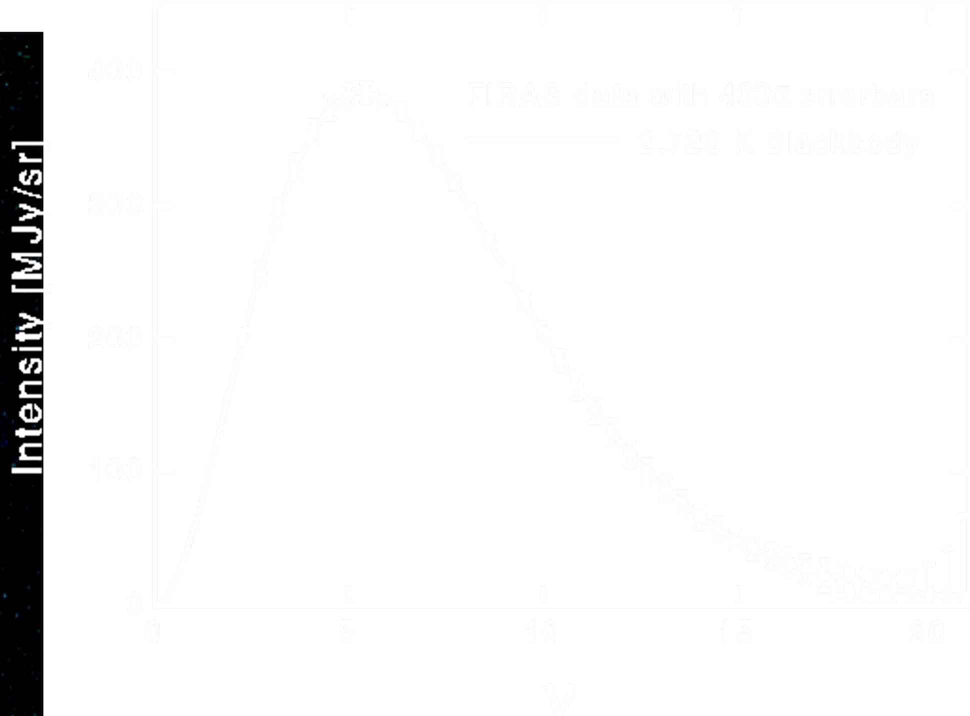
- Serendipitous observation of a predicted phenomena
  - Bob Dicke's experiment to search for this was already in progress at Princeton



COBE 1989
The microwave background





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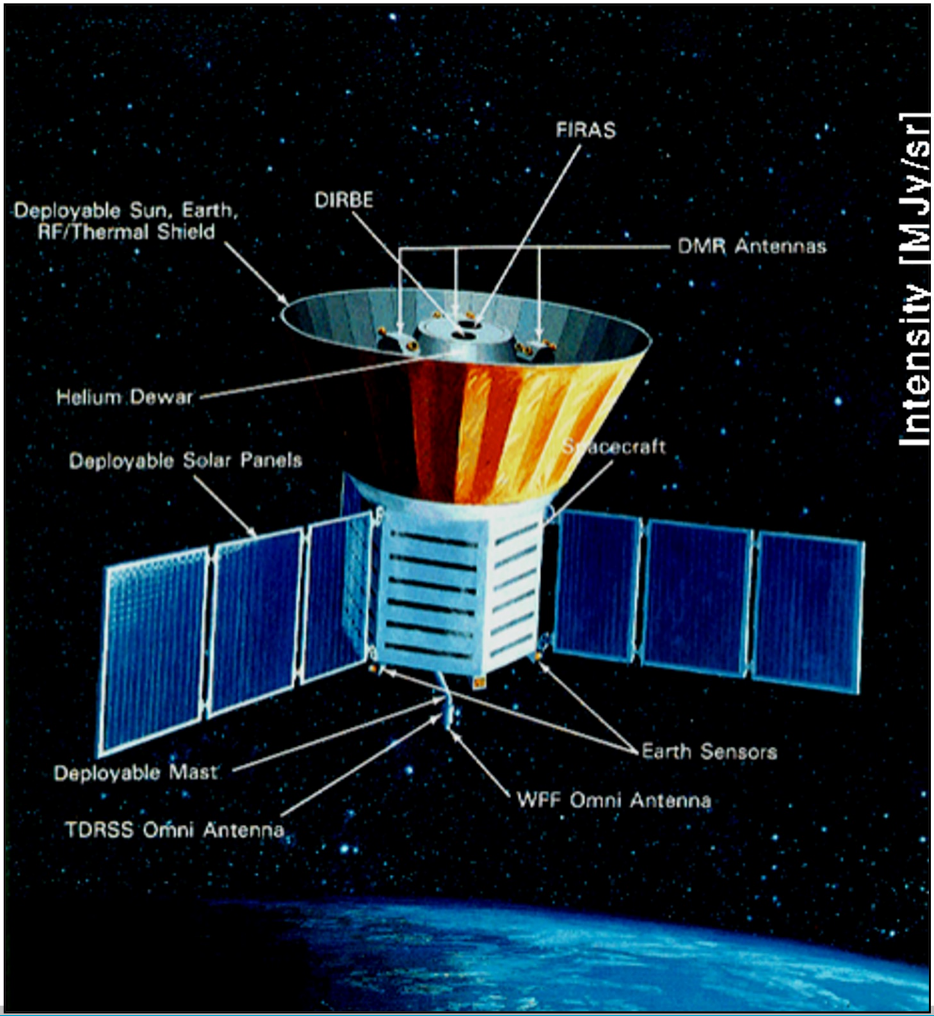

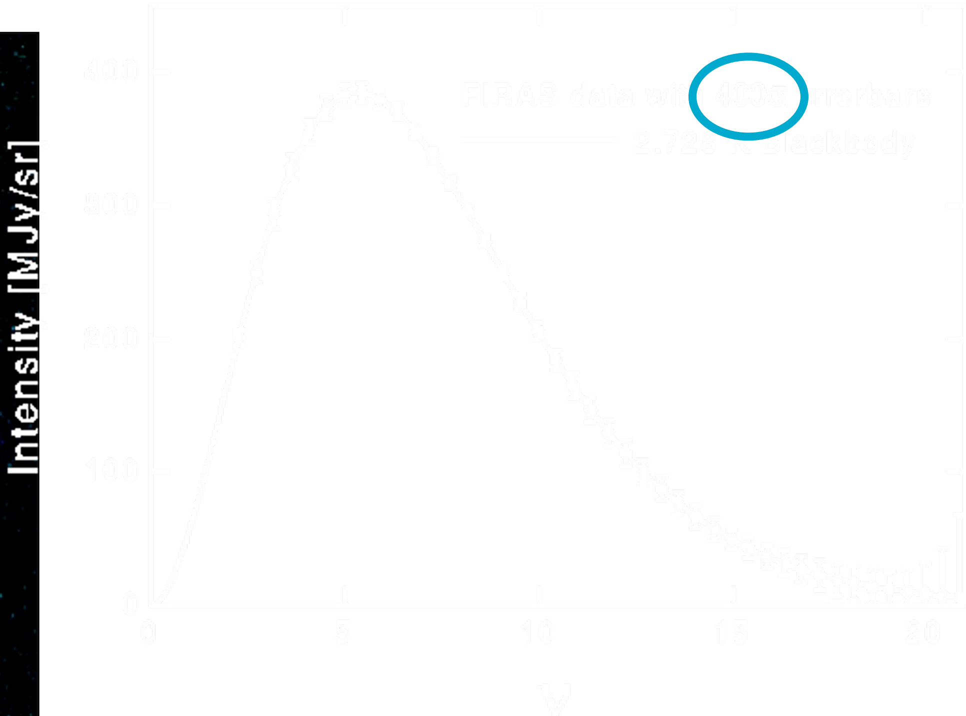

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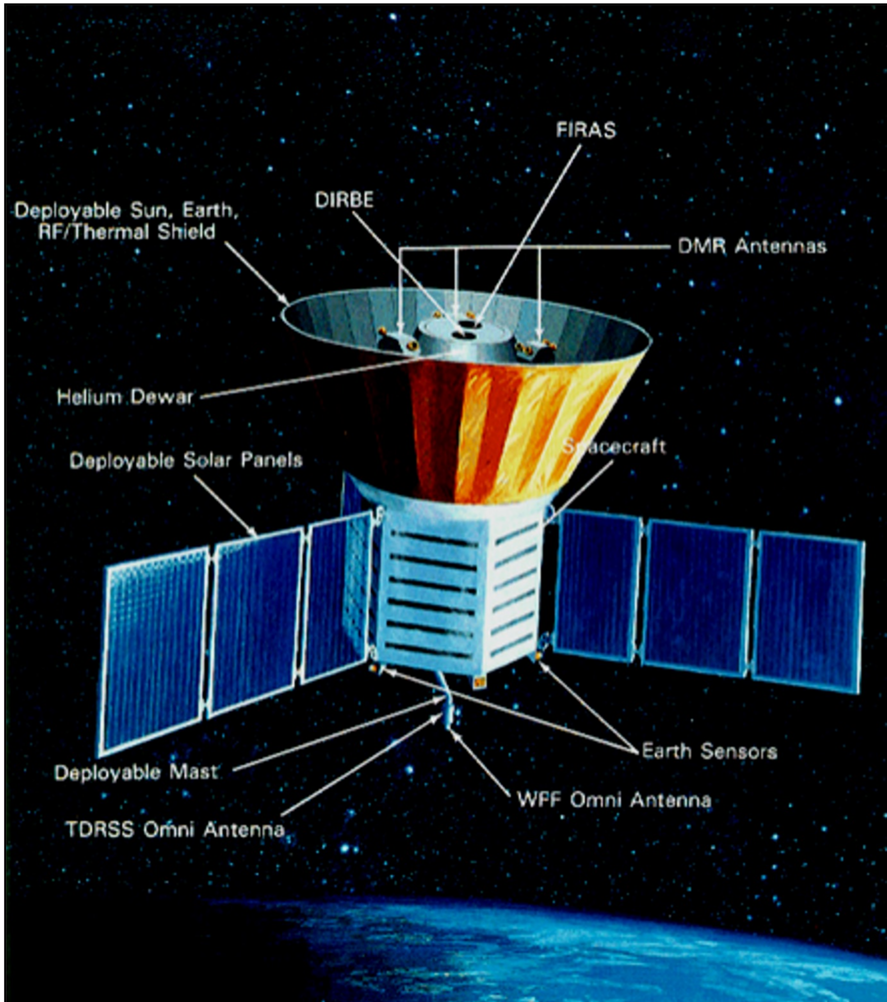

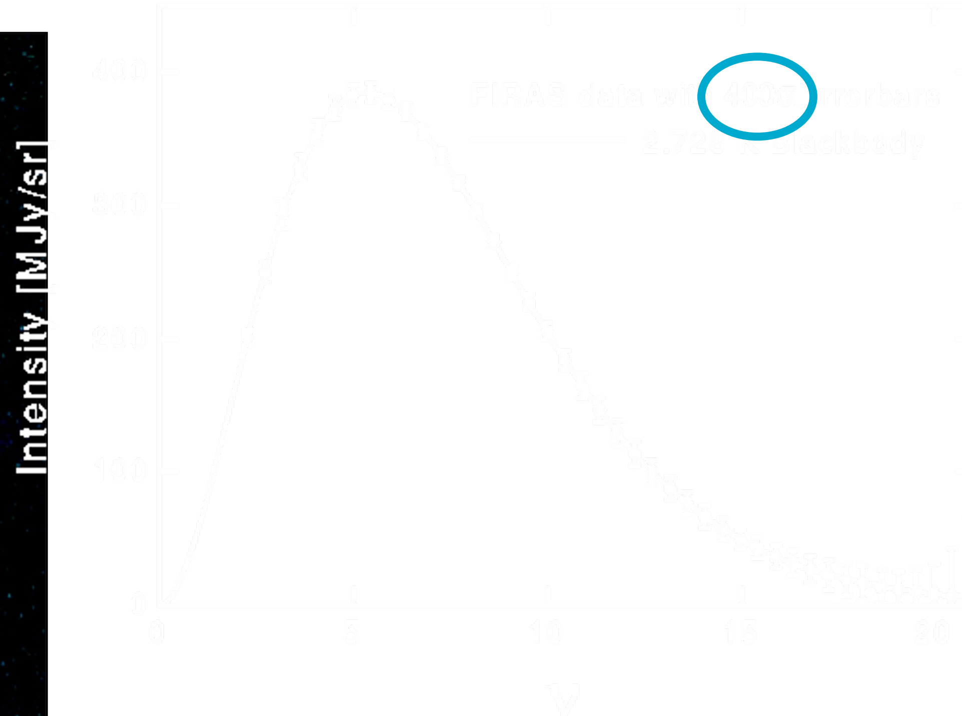

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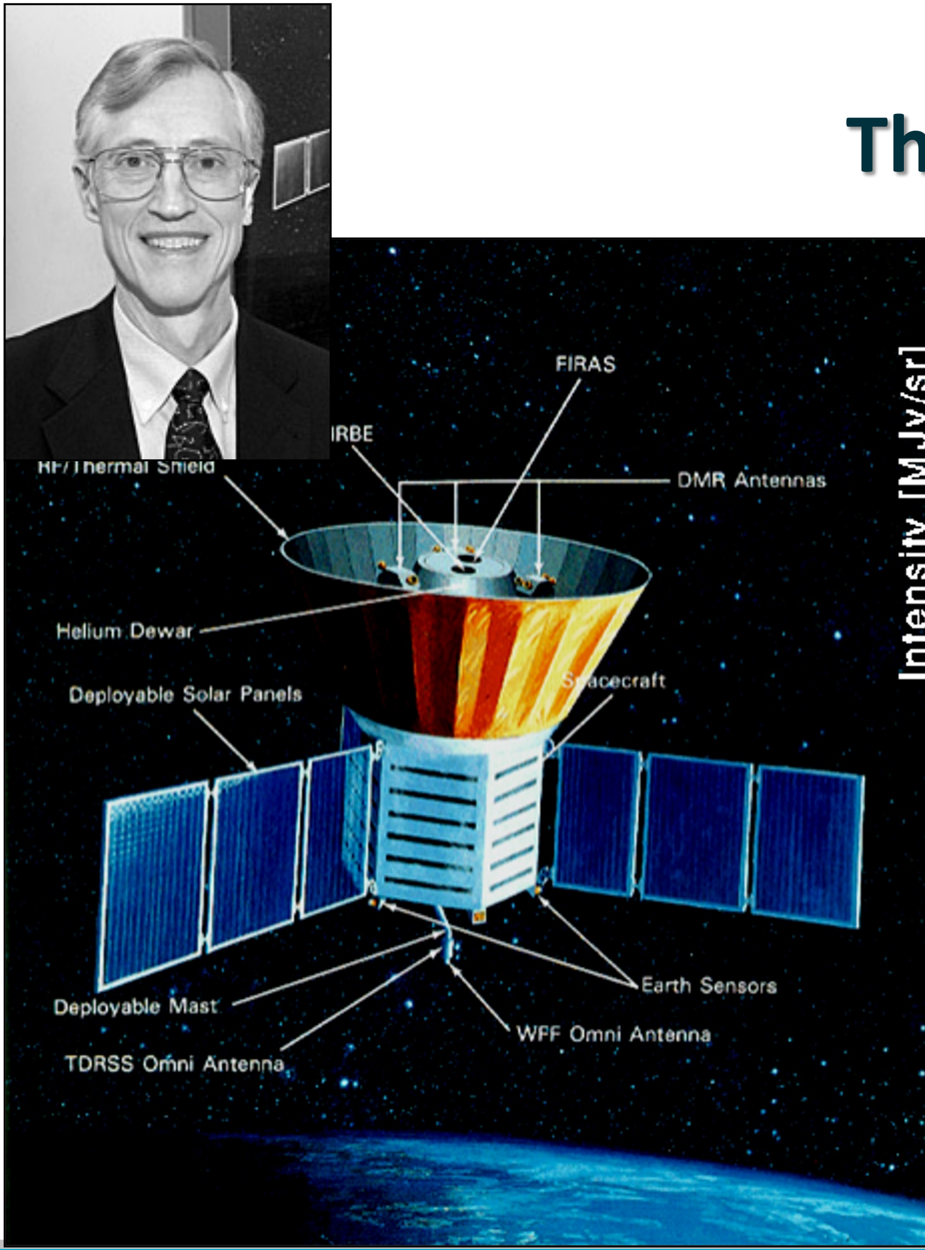

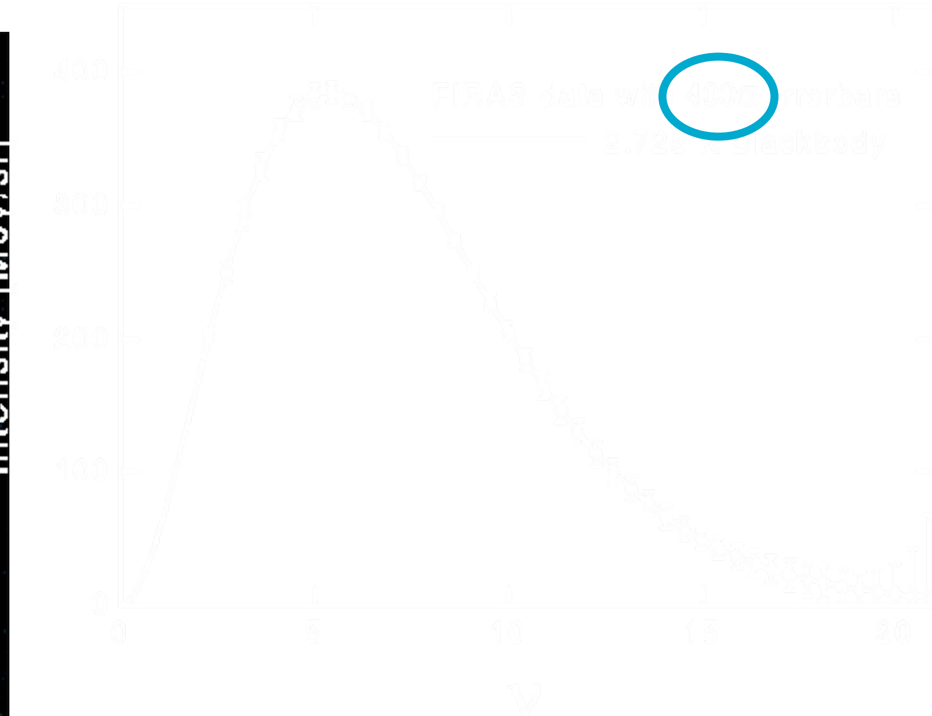

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  - ➢ John Mather – spectrum

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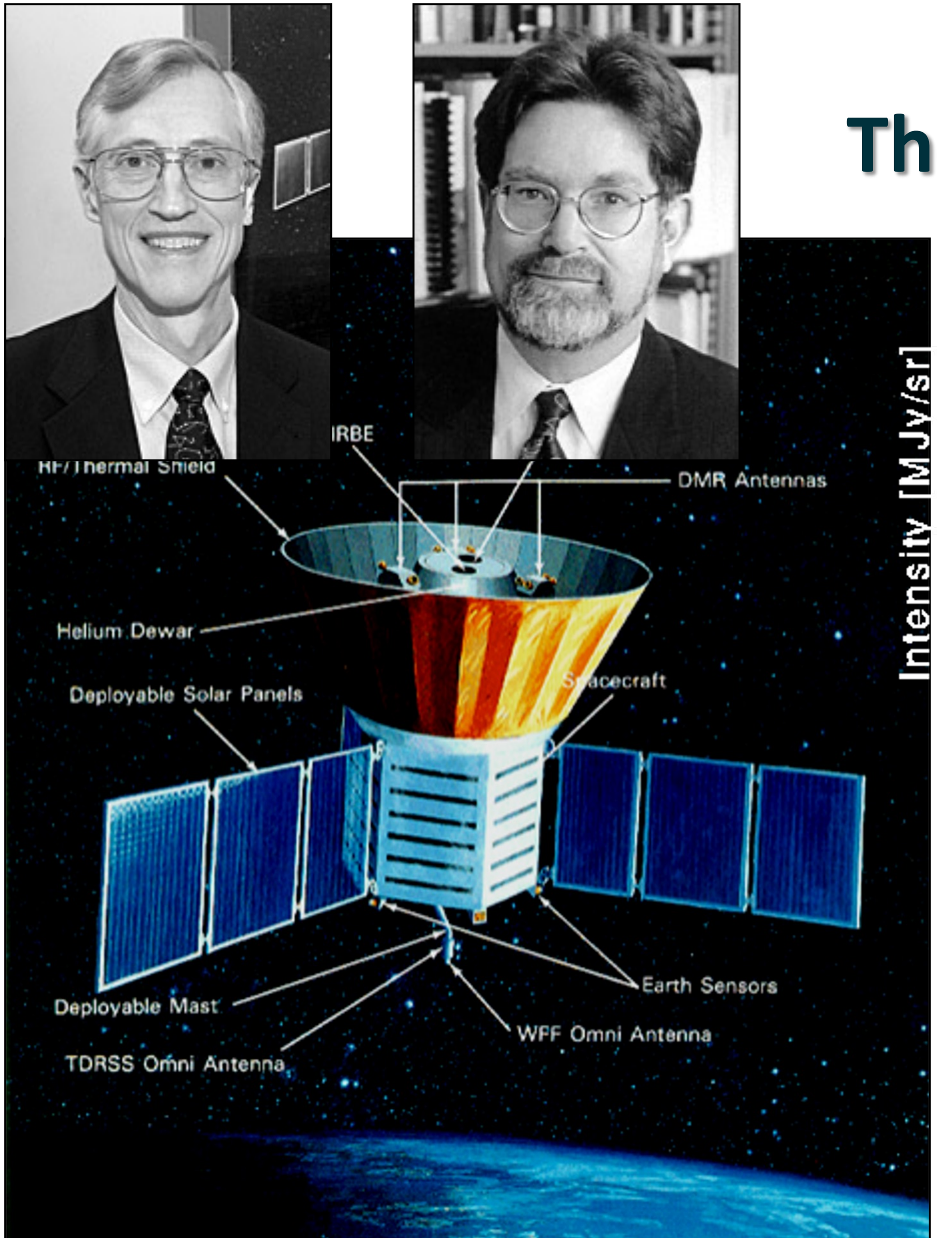
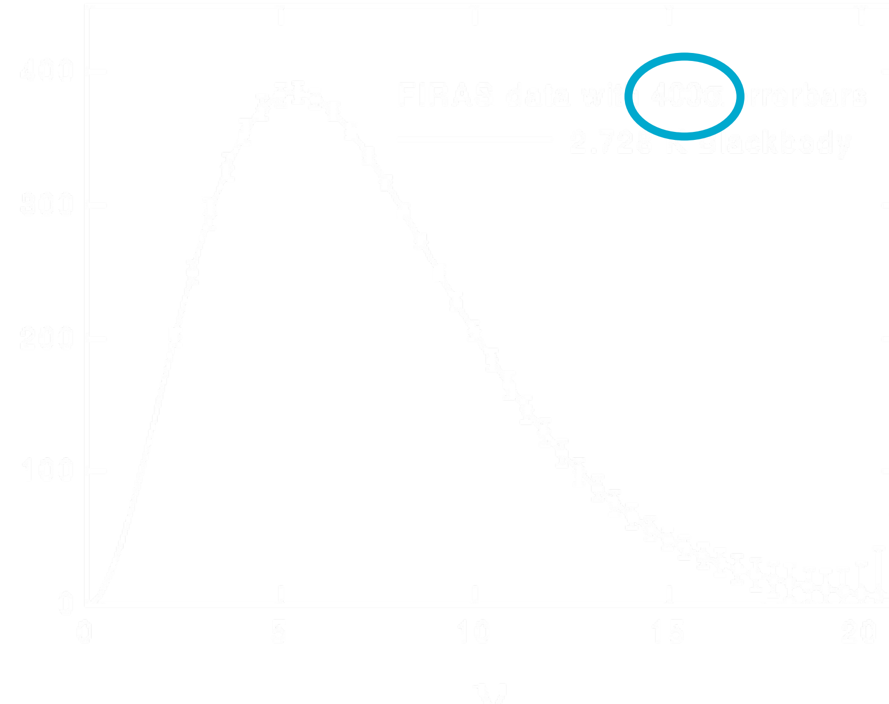
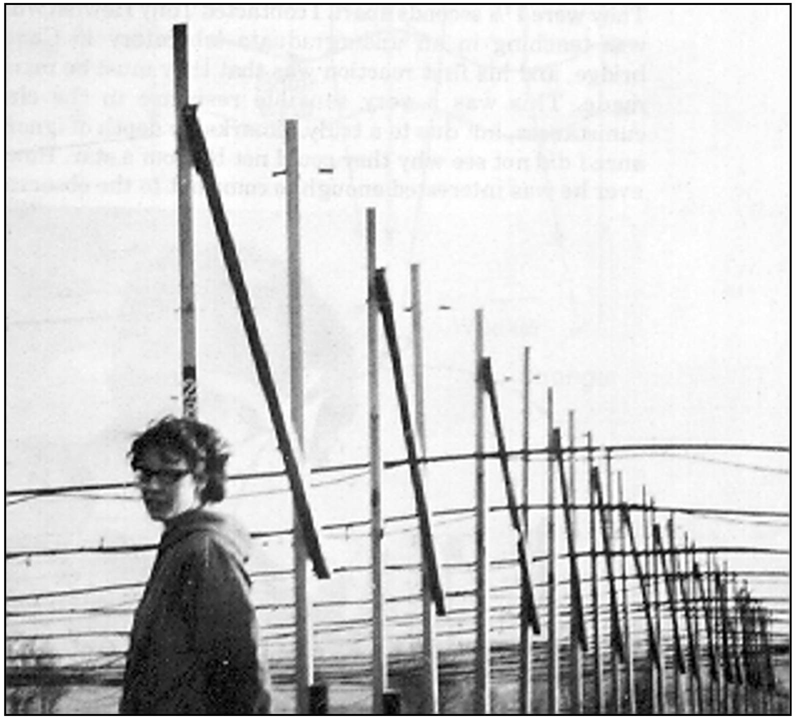




- 2006 Nobel Prize
  - ➢ John Mather – spectrum
  - ➢ George Smoot – anisotropy
  - ➢ A rare case of predictions confirmed by observation.

Pulsar discovery: 1967



- Jocelyn Bell & Tony Hewish
- Cambridge 1967
- Telescope built for IPS survey
- Short time constant for IPS

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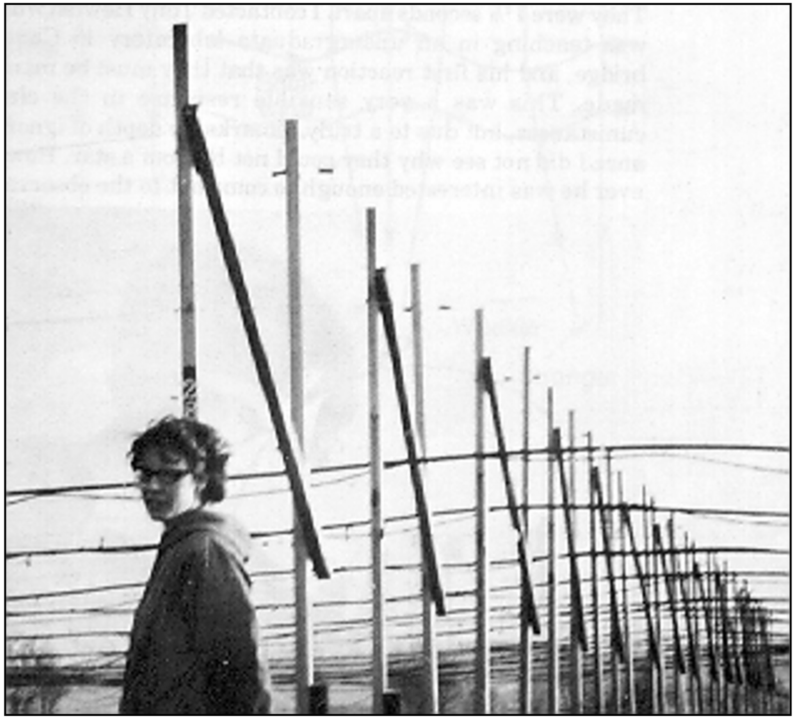

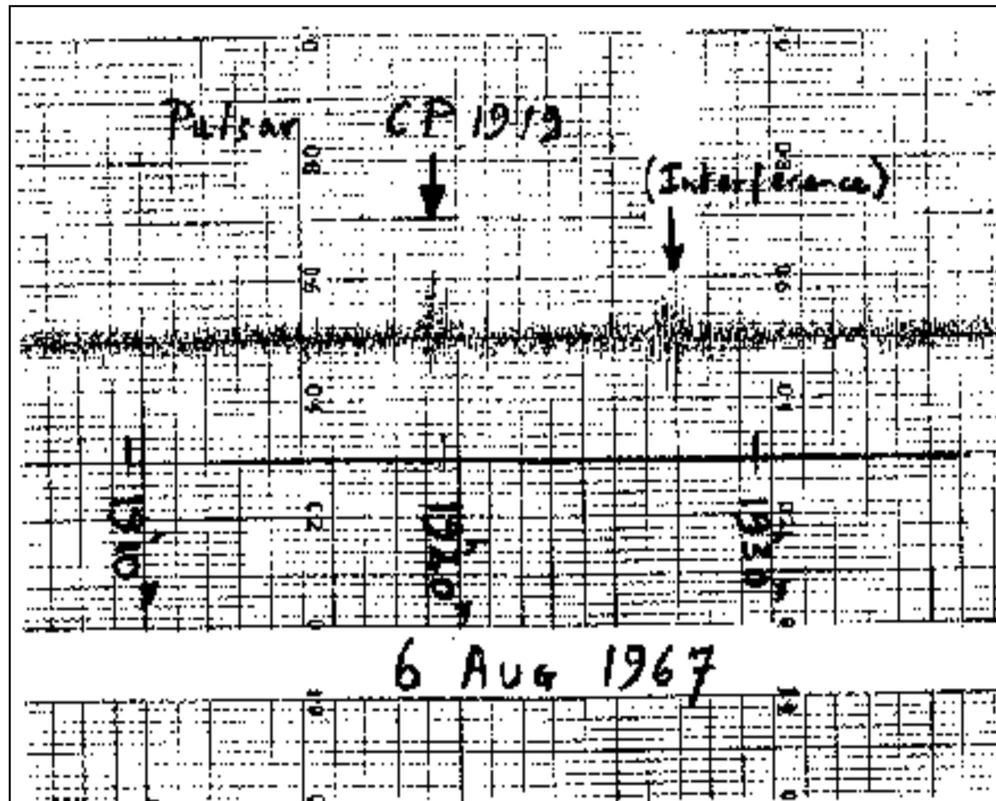

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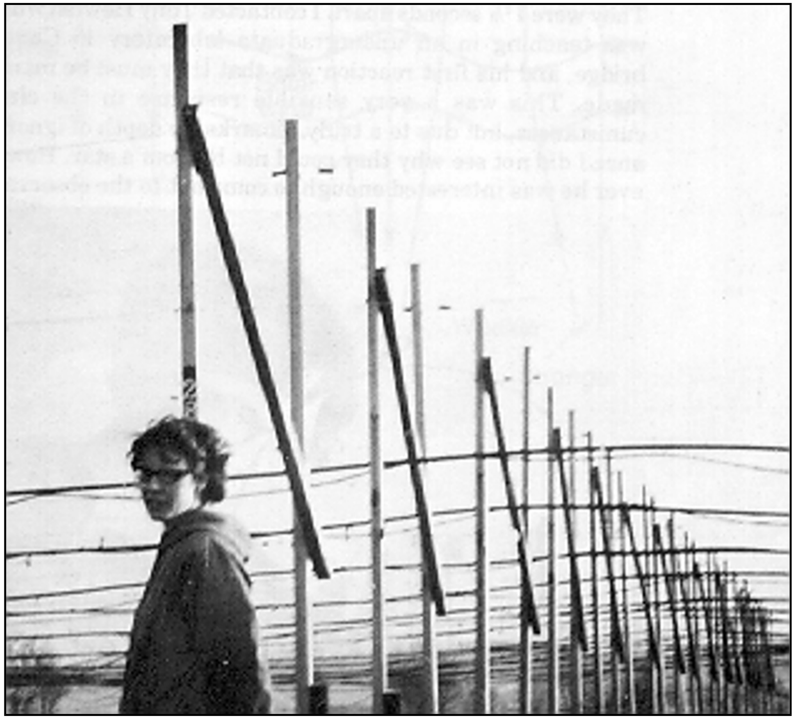
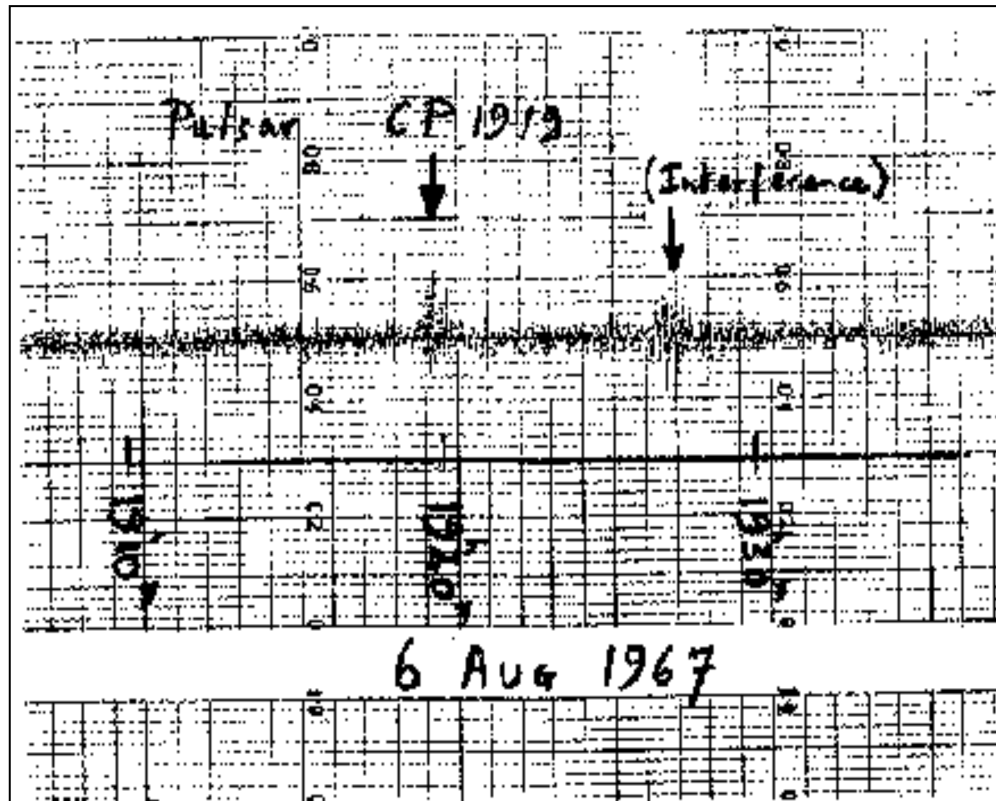


- 1974 Nobel Prize to her supervisor Tony Hewish

  “A decisive role in the discovery”



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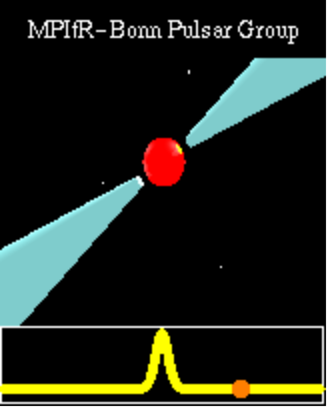
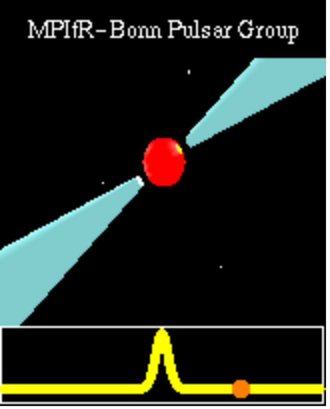
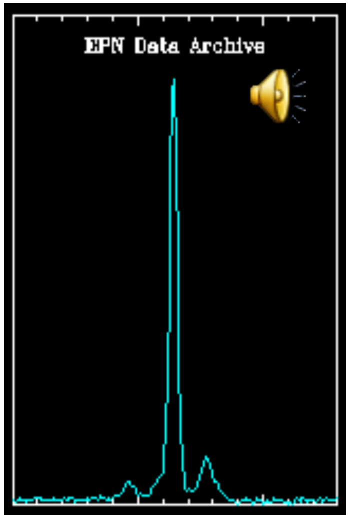


The sound of a Pulsar

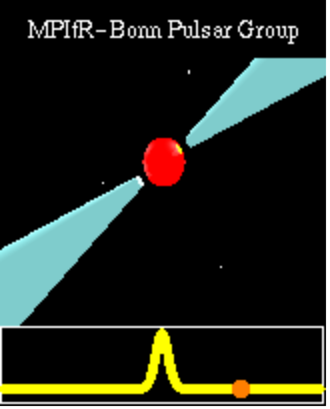


The sound of a Pulsar

B0329+54



P = 0.7145s
1.4/s

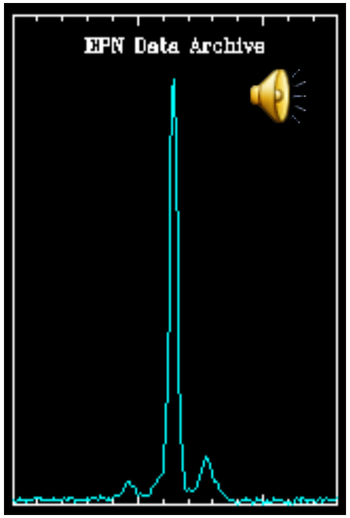


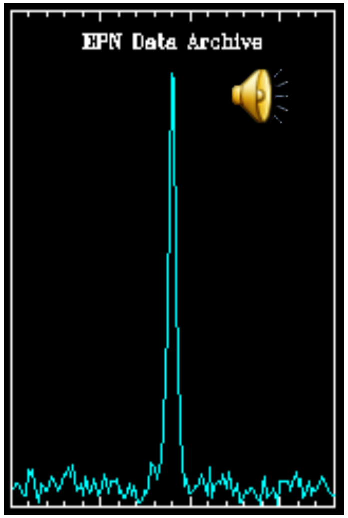
The sound of a Pulsar

Vela

B0833-45

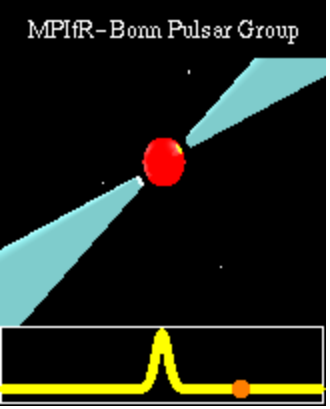
B0329+54



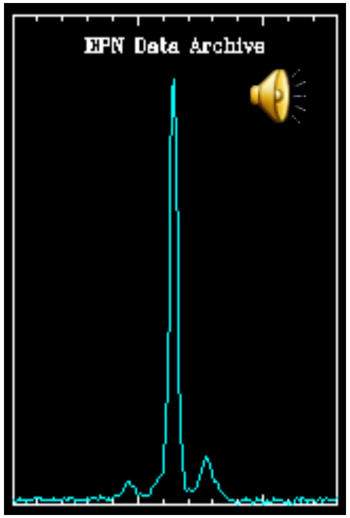
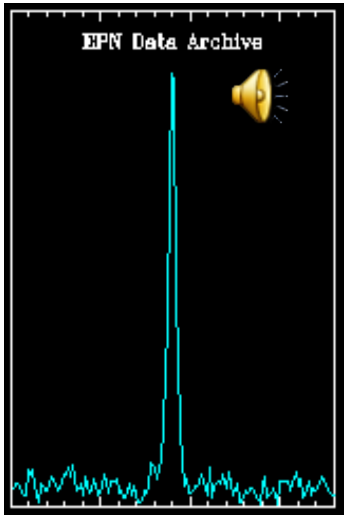
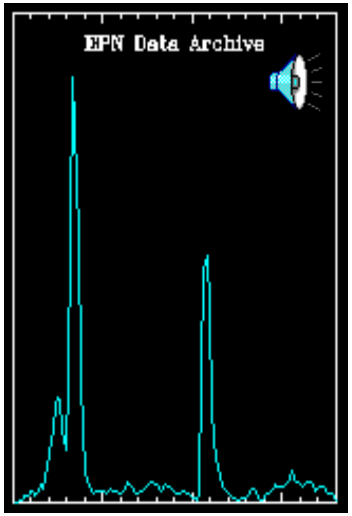


P = 0.7145s
1.4/s

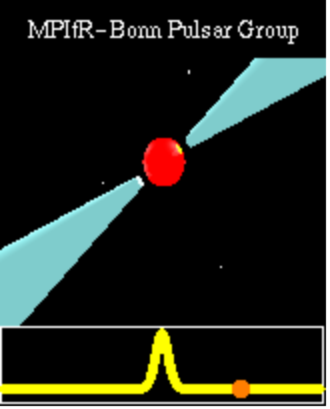
P = 89ms
11.2/s



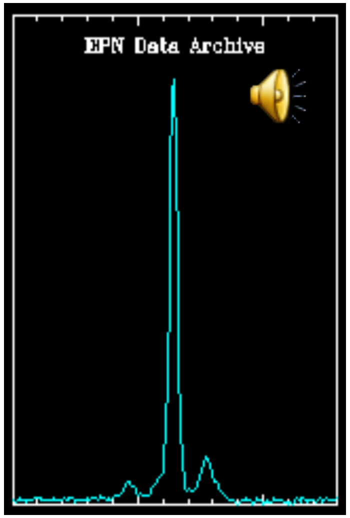
The sound of a Pulsar

B0329+54	Vela B0833-45	Crab B0531+21
		
P = 0.7145s 1.4/s	P = 89ms 11.2/s	P = 33ms 30/s

The sound of a Pulsar

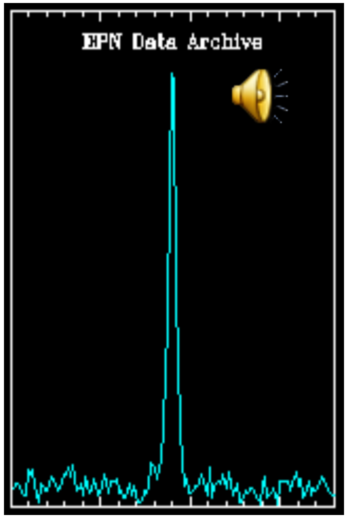


B0329+54



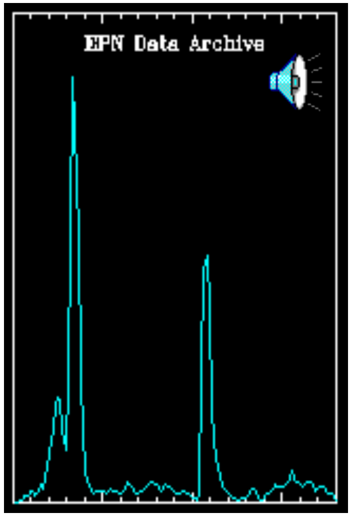
P = 0.7145s
1.4/s

Vela
B0833-45



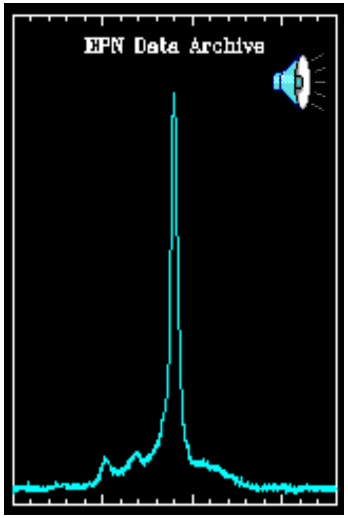
P = 89ms
11.2/s

Crab
B0531+21

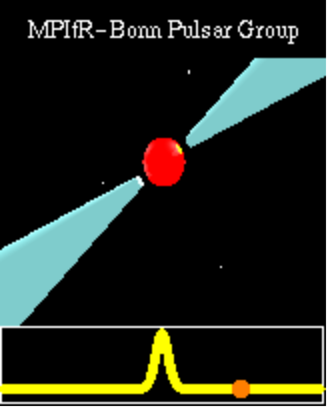


P = 33ms
30/s

J0437-4715

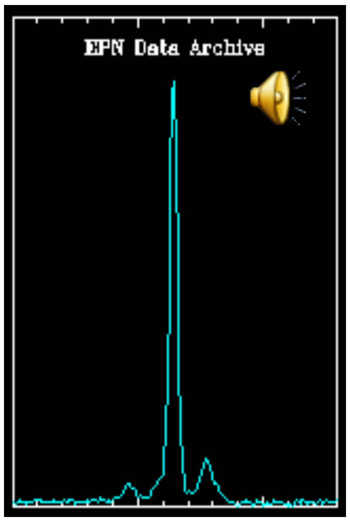


P = 5.75ms
174/s



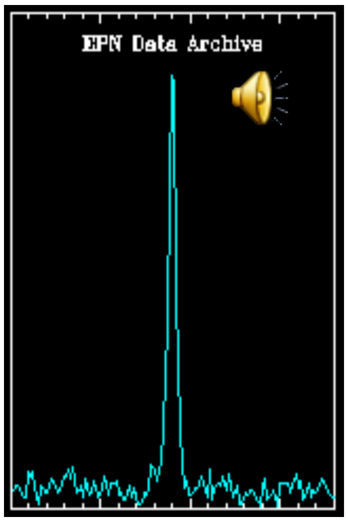
The sound of a Pulsar

B0329+54



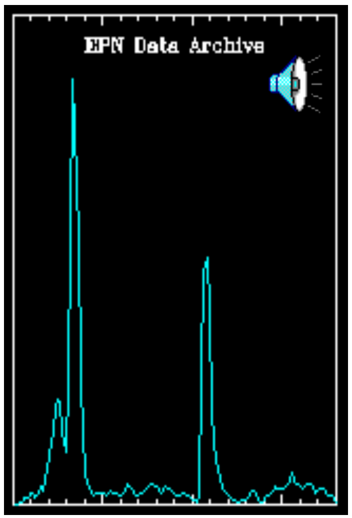
P = 0.7145s
1.4/s

Vela
B0833-45



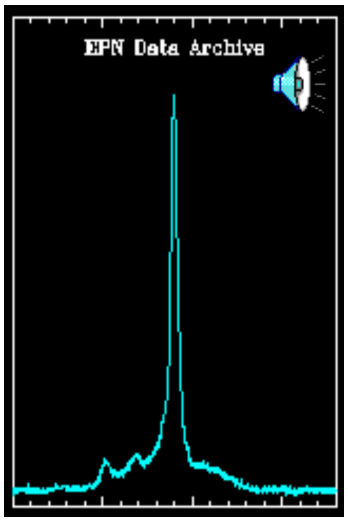
P = 89ms
11.2/s

Crab
B0531+21



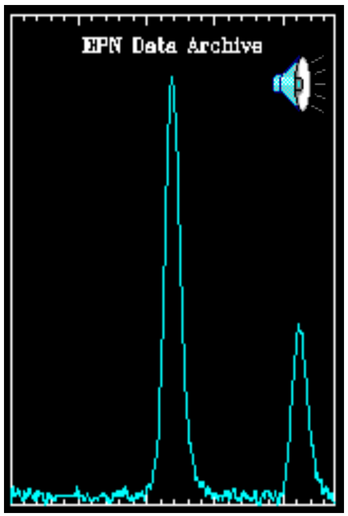
P = 33ms
30/s

J0437-4715



P = 5.75ms
174/s

B1937+21

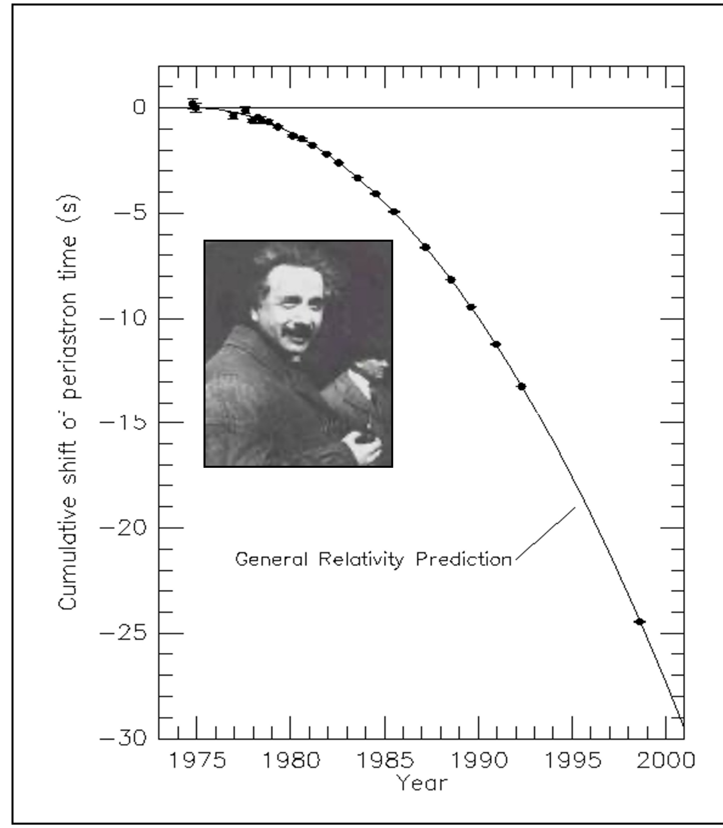


P = 1.56ms
642/s

1993 Noble prize
"Gravitational Radiation"

1993 Noble prize “Gravitational Radiation”

- 1993 Noble prize to Joe Taylor and Russell Hulse
  - Often considered a classic example of the scientific method
  - But the Nobel citation is for the serendipitous discovery of a binary pulsar
  - Verification of Einstein's prediction of gravitational radiation was not included in the citation!



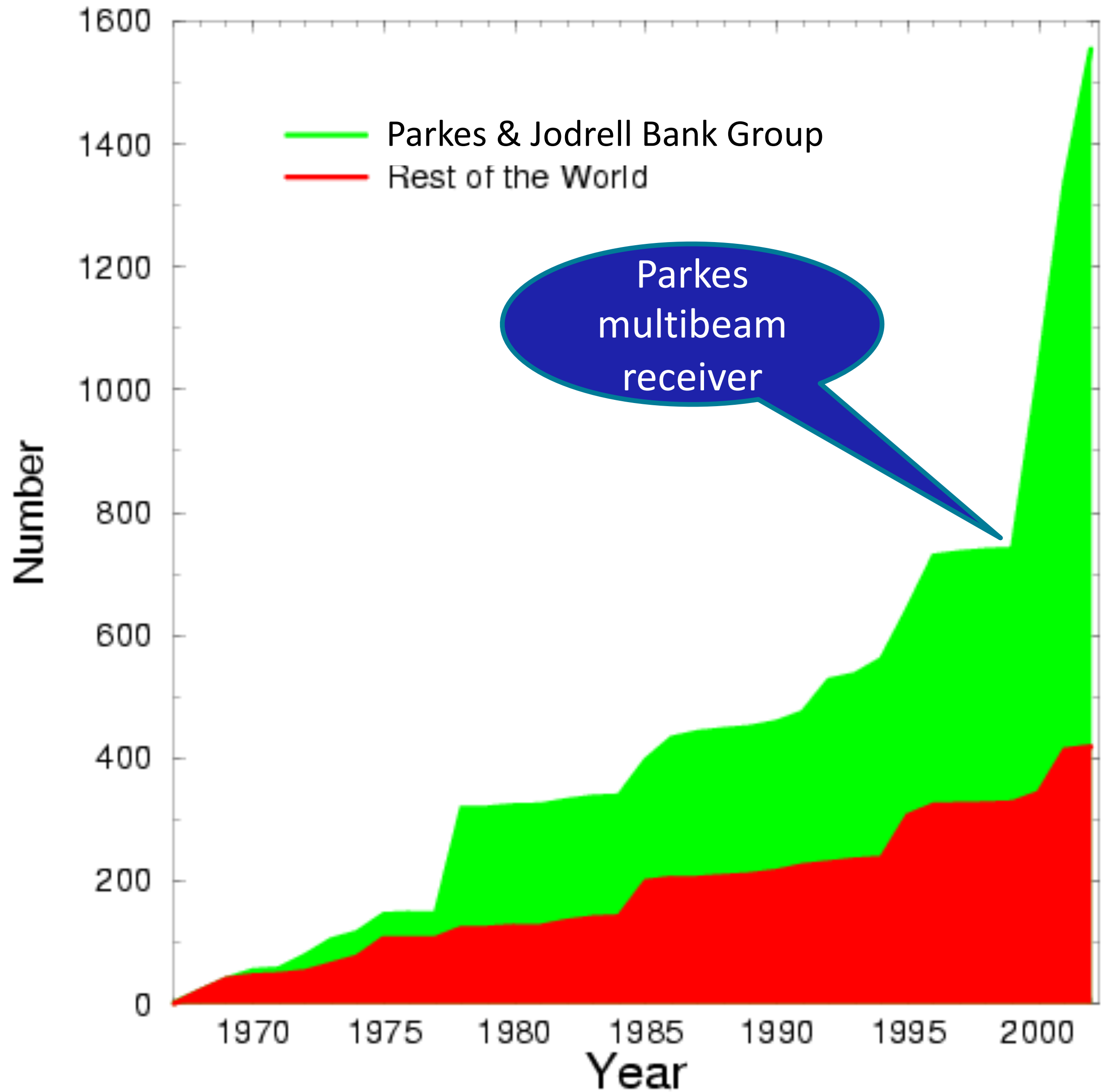
Parkes Multibeam Receiver

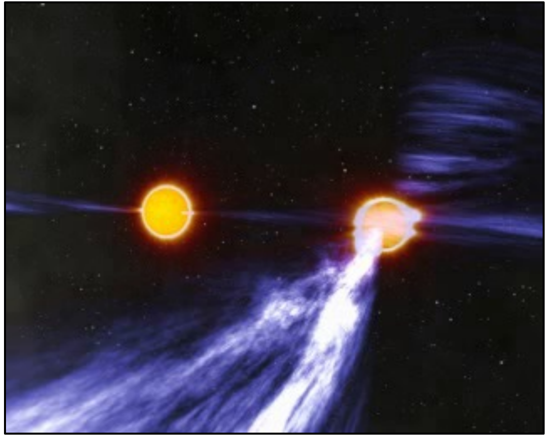
- 21 Jan 1997
- Installing the Parkes 21cm Multibeam Receiver
- 13 beams
  - Same as having 13 64m telescopes for surveys!
- HI survey
- Pulsar survey

Parkes Multibeam Receiver

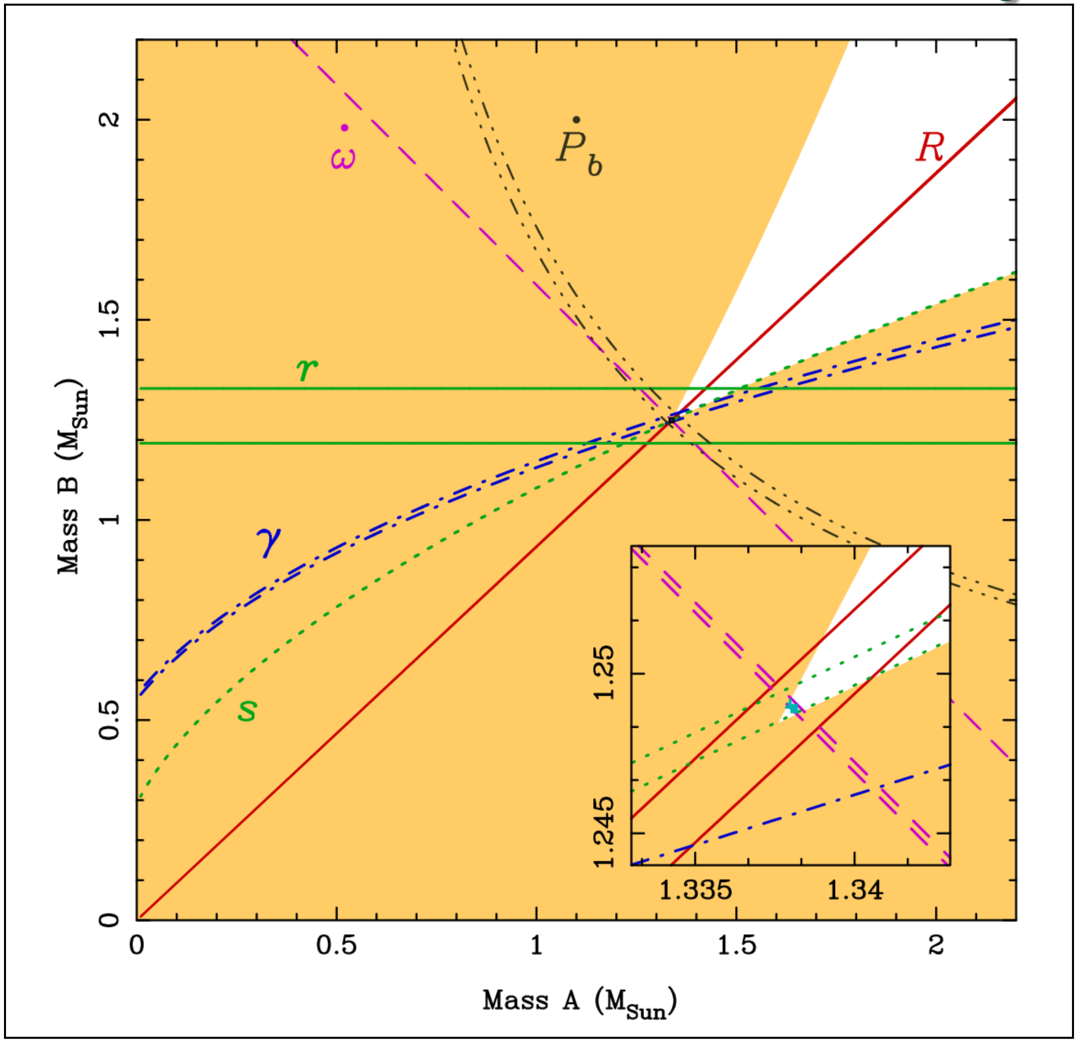
Pulsar discovery rate

- Dramatic impact of a receiver development
- Using all the focal plane of a big dish





Double Pulsar
Tests General Relativity

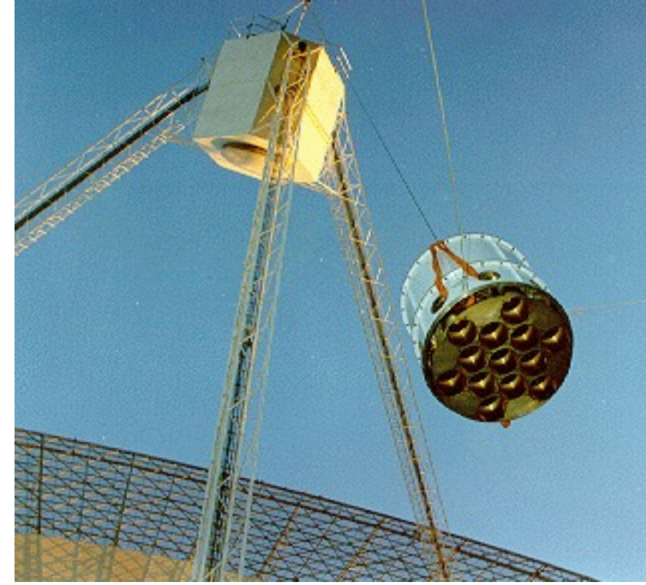


- Parkes Pulsar Survey
- Two neutron stars in 2.4 hour orbit
- General Relativity tested to 0.05%
  - 6 General Relativity parameters tested
  - *Kramer et al (2006)*

CSIRO

The impact of Field of View

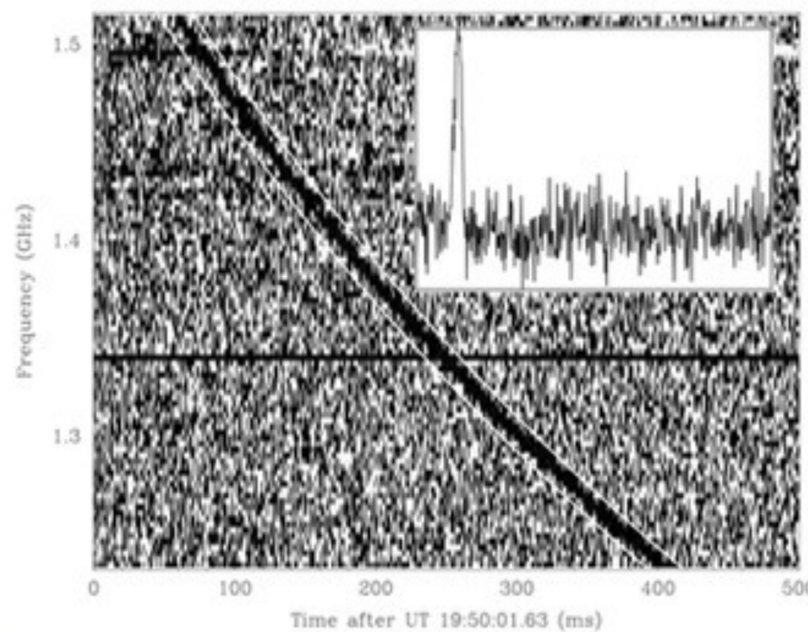
- **Lorimer burst and the Parkes multibeam**
  - Discovered 2007
  - Parkes multibeam - 13 beams = 13 x FoV
  - A single beam may have never discovered the Lorimer burst, even though the s/n was huge
  - Would any FRBs be discovered yet!



Bailes

Lorimer

McLaughlan



The impact of Field of View

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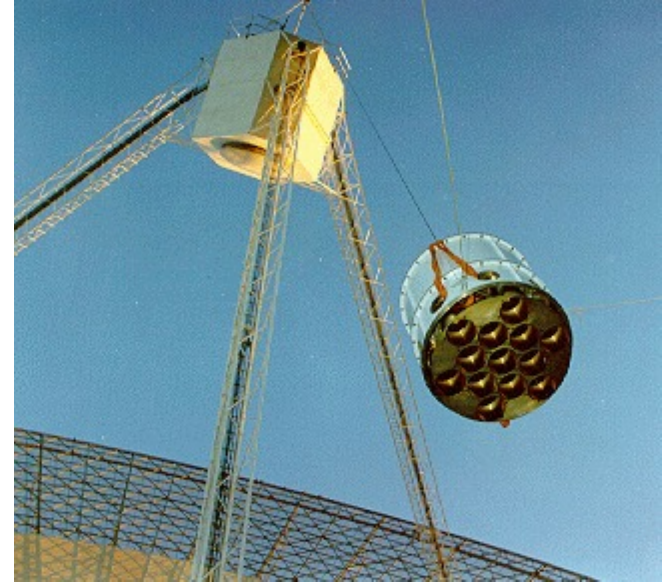
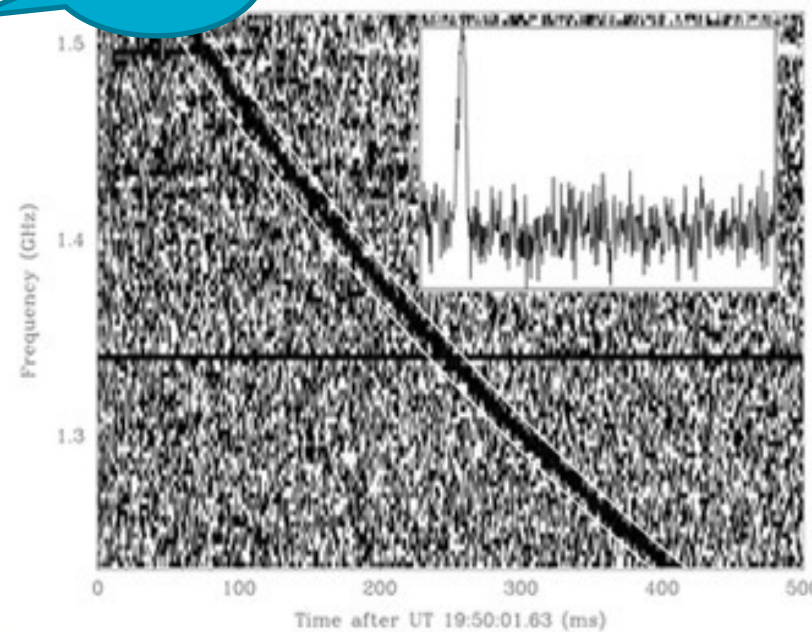
  - Would any FRBs be discovered yet!

No !





Bailes

Lorimer

McLaughlan

Using all the information at the focus

Using all the information at the focus

- **CHIME**
  - ➢ Line feeds and cylindrical reflectors
  - ➢ Most successful FRB survey telescope

Using all the information at the focus

- **CHIME**
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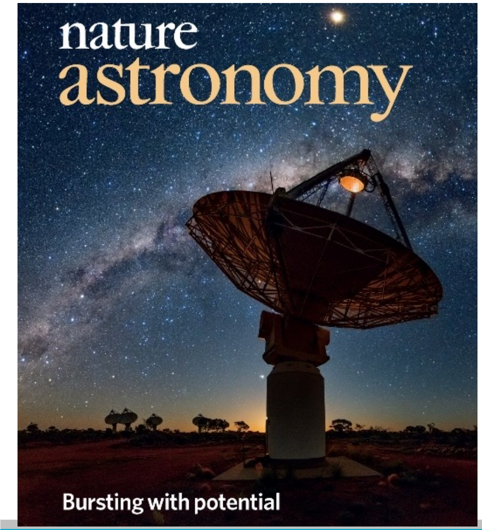
  - Most successful FRB survey telescope

- **ASKAP**
  - aperture and focal plan array technology
  - 36 12m antennas
  - 36 beams in each antenna
    - → 30 deg^2 per antenna



Using all the information at the focus

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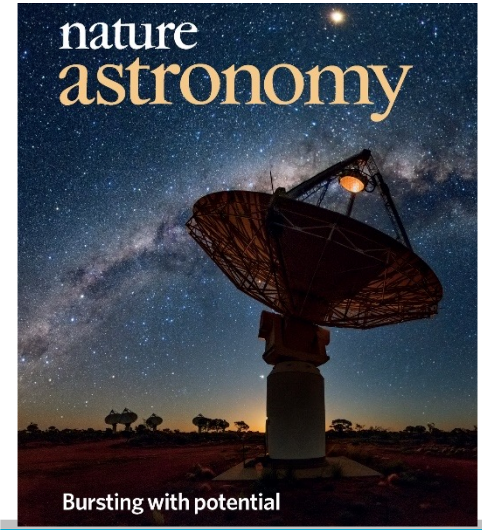
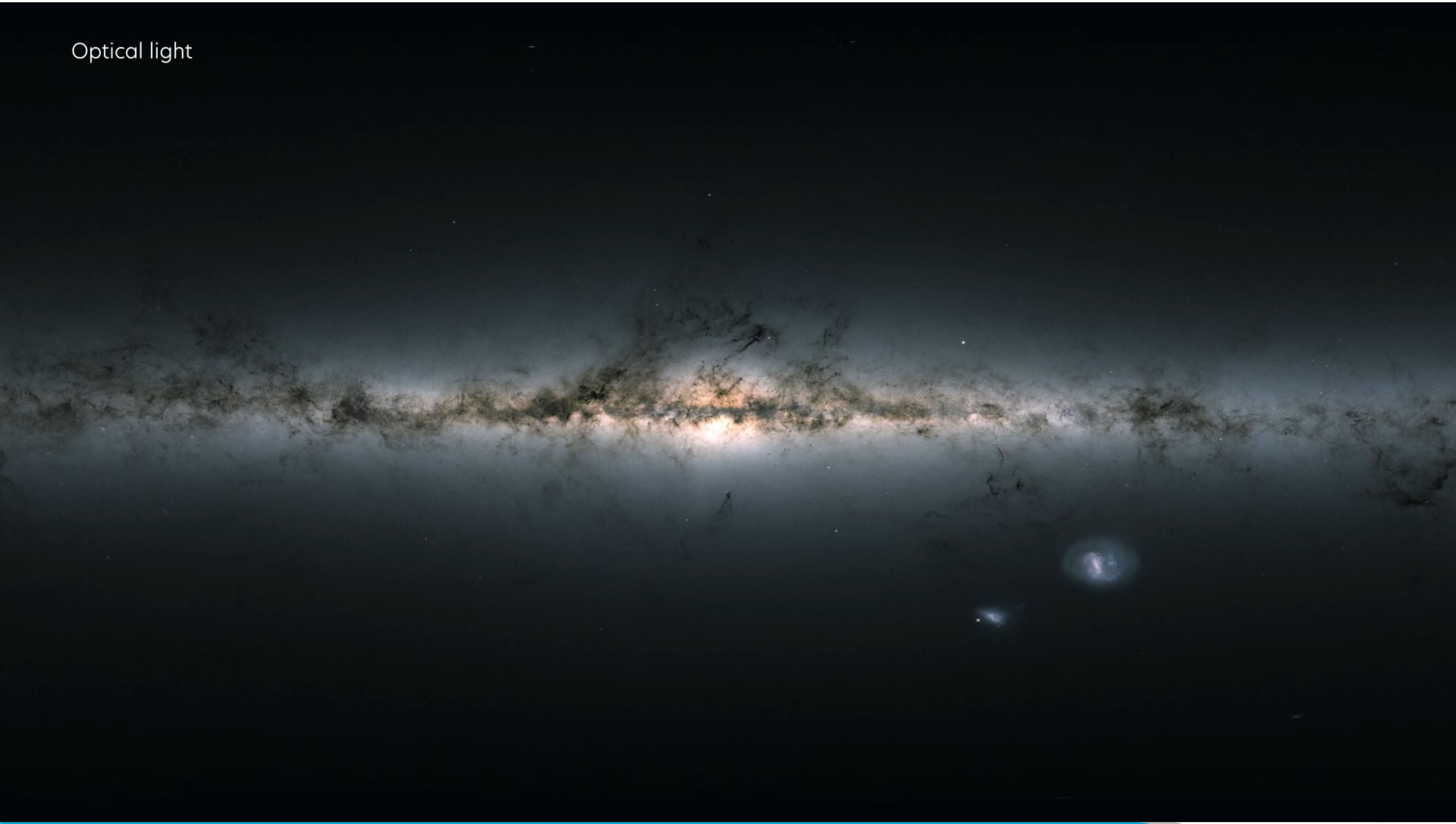
See ASKAP in Virtual Reality

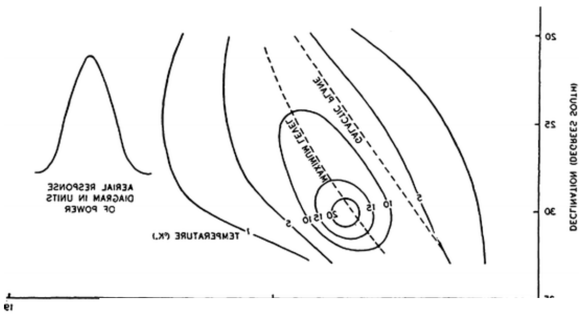


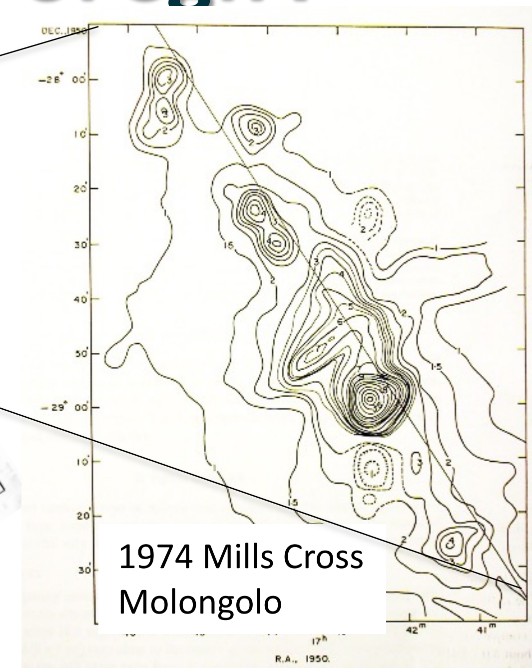
The Event Horizon Telescope team Zoom into the Galactic Centre

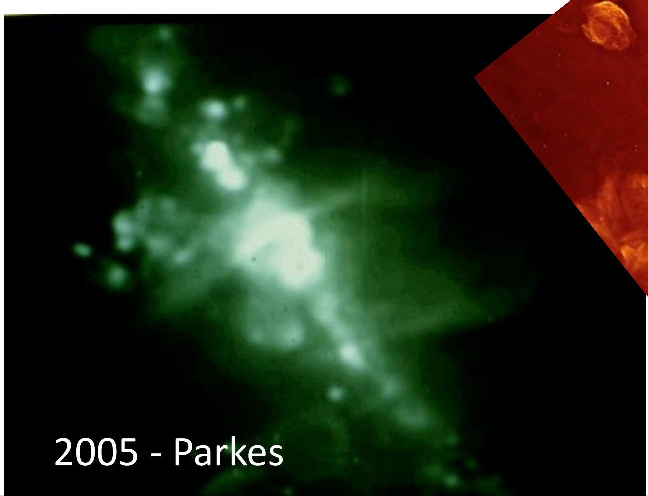
video created by Radboud University, Nijmegen

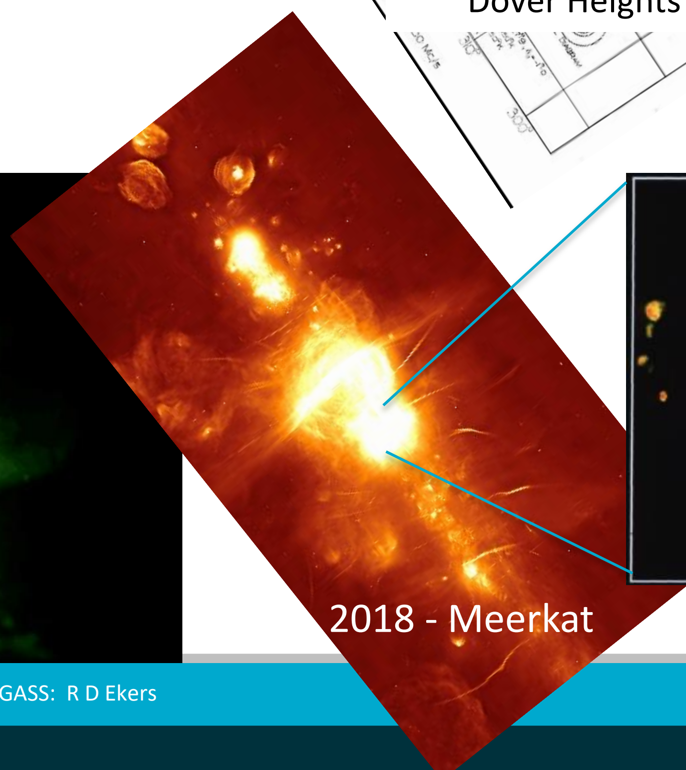


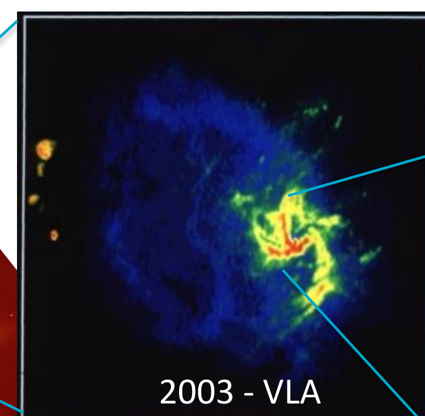
A brief history of the discovery of SgrA*

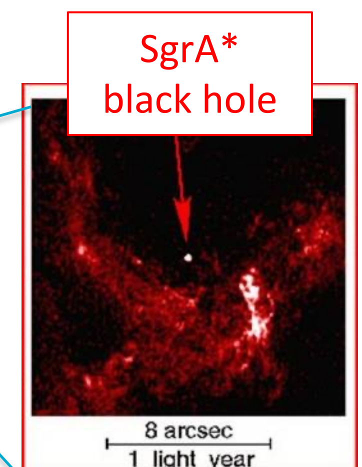




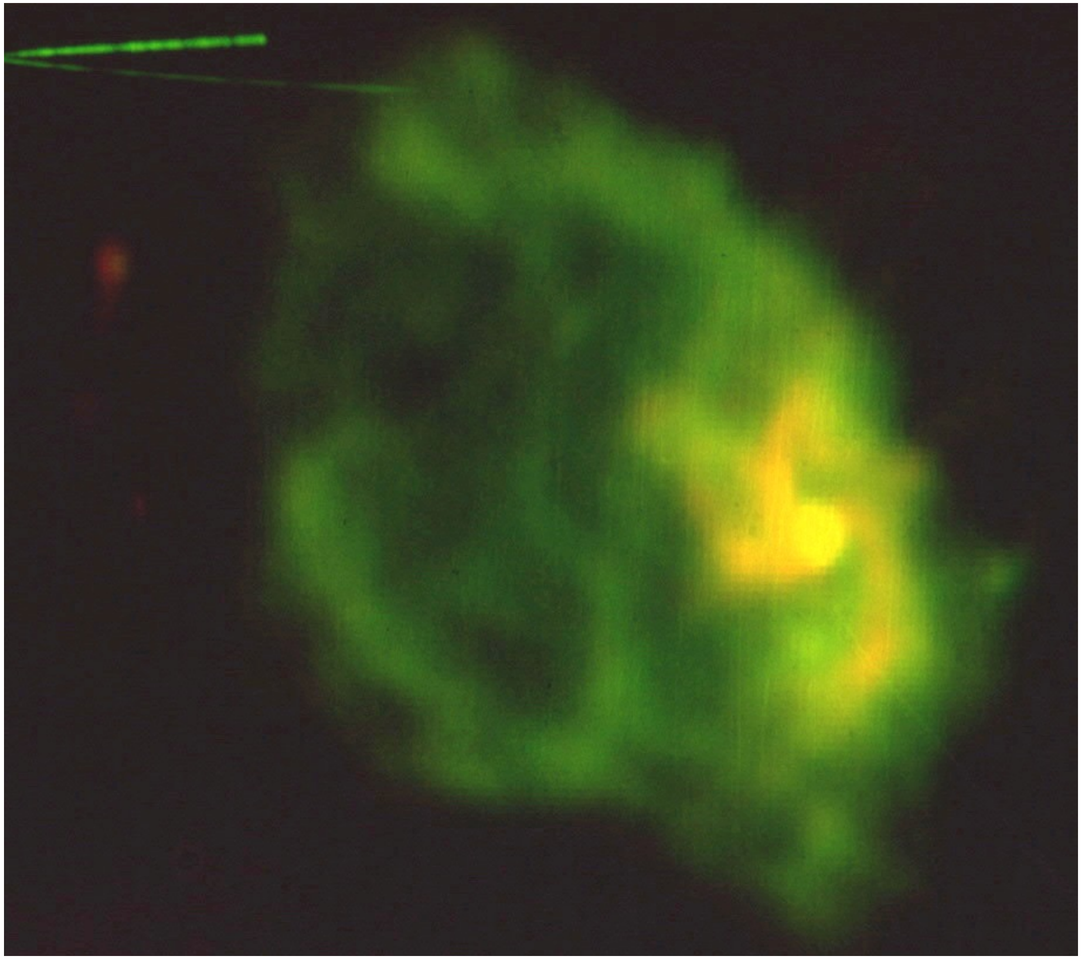


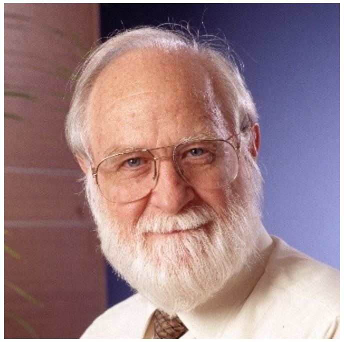






1981 VLA observes our Galactic Centre my greatest discovery moment





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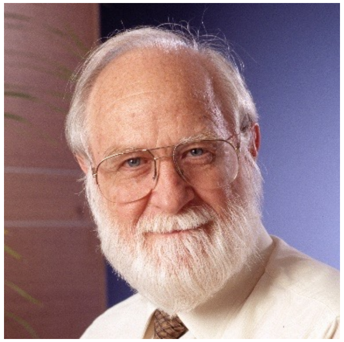
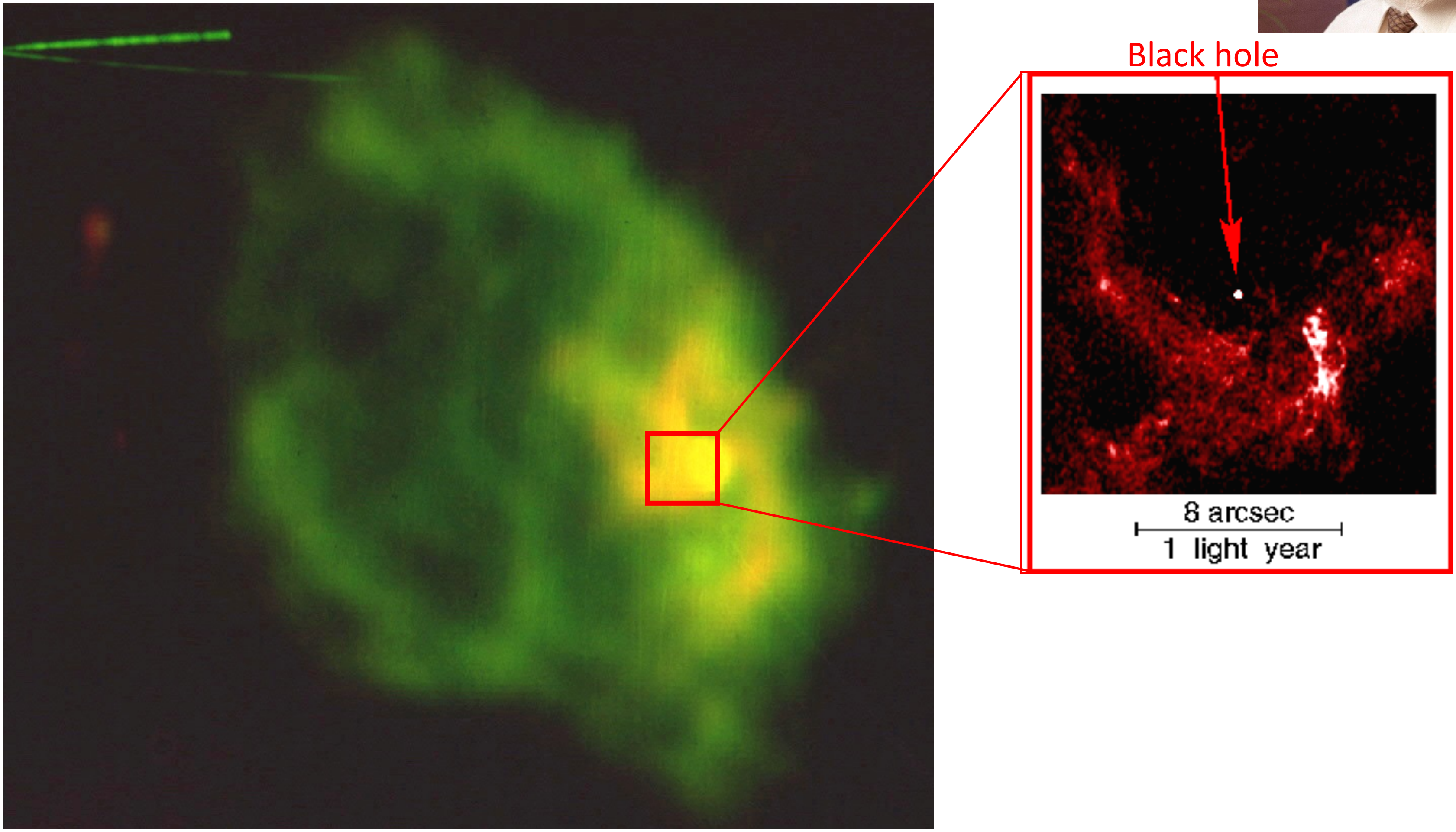
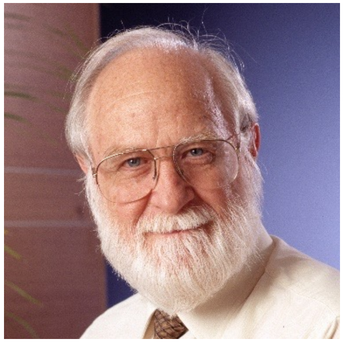
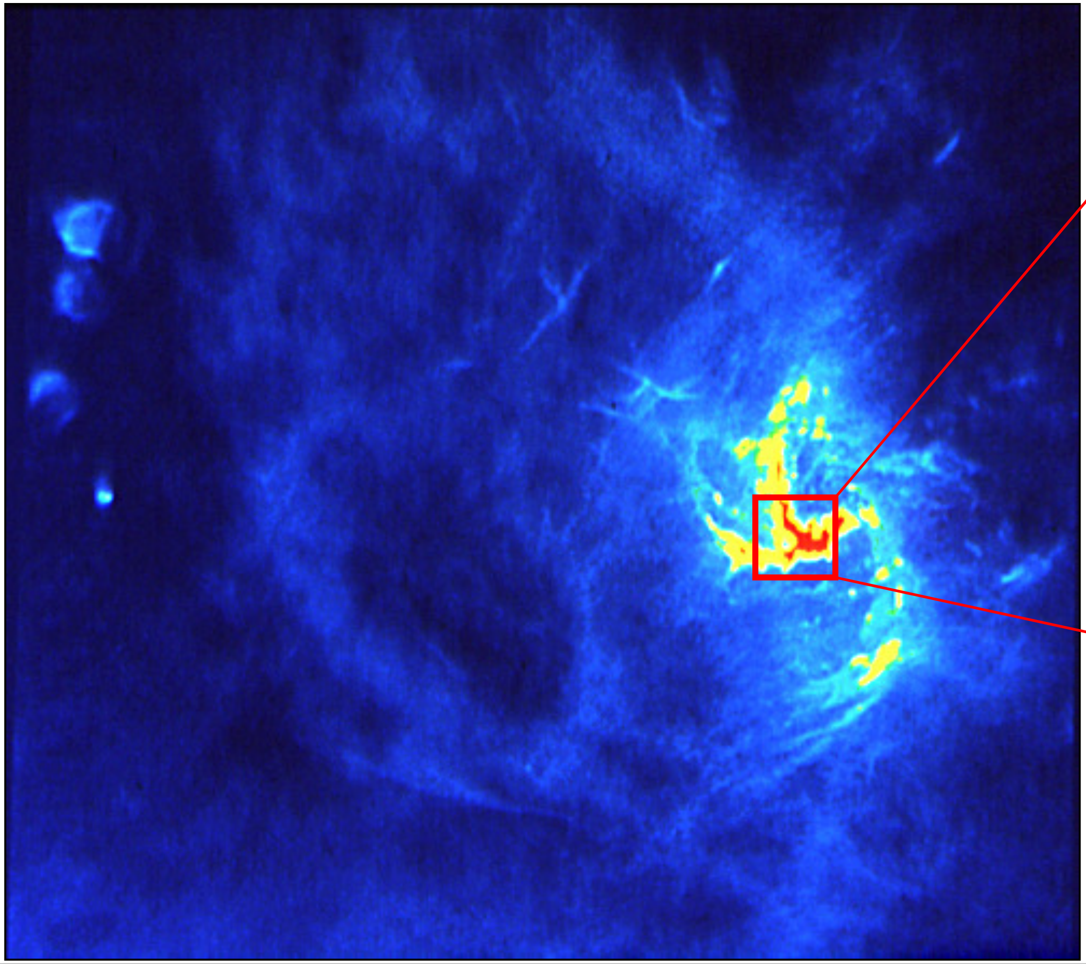
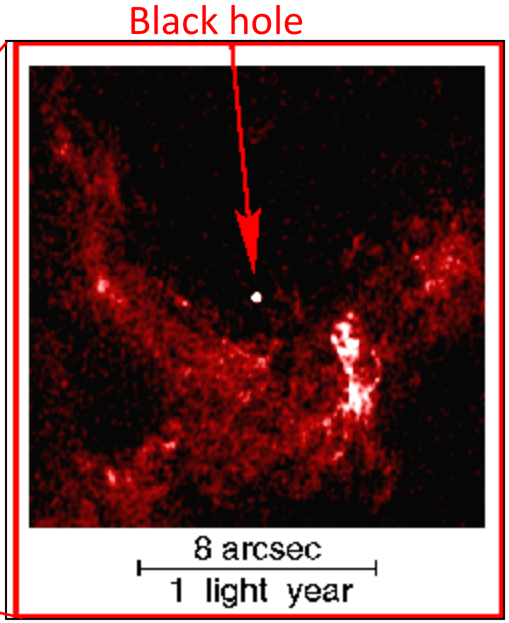




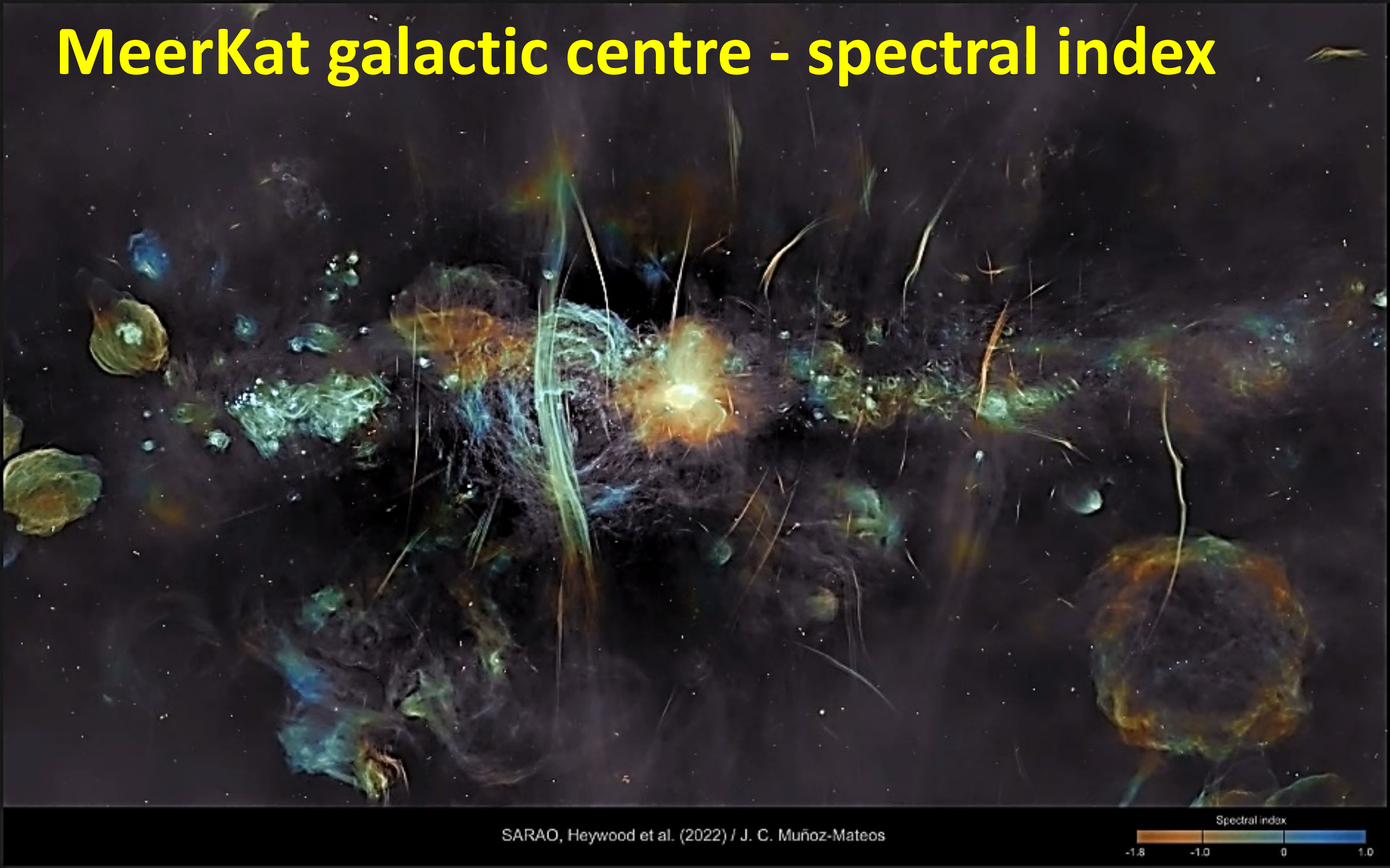
2003 VLA observes Sgr A
my greatest discovery moment





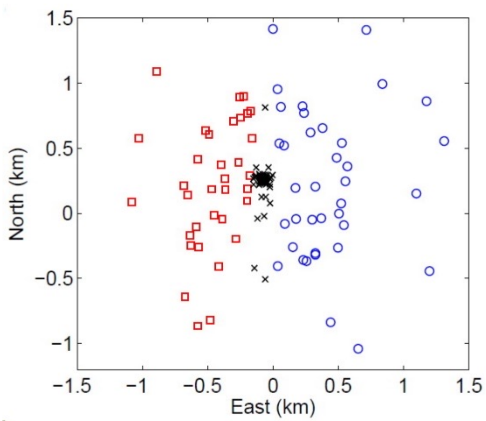


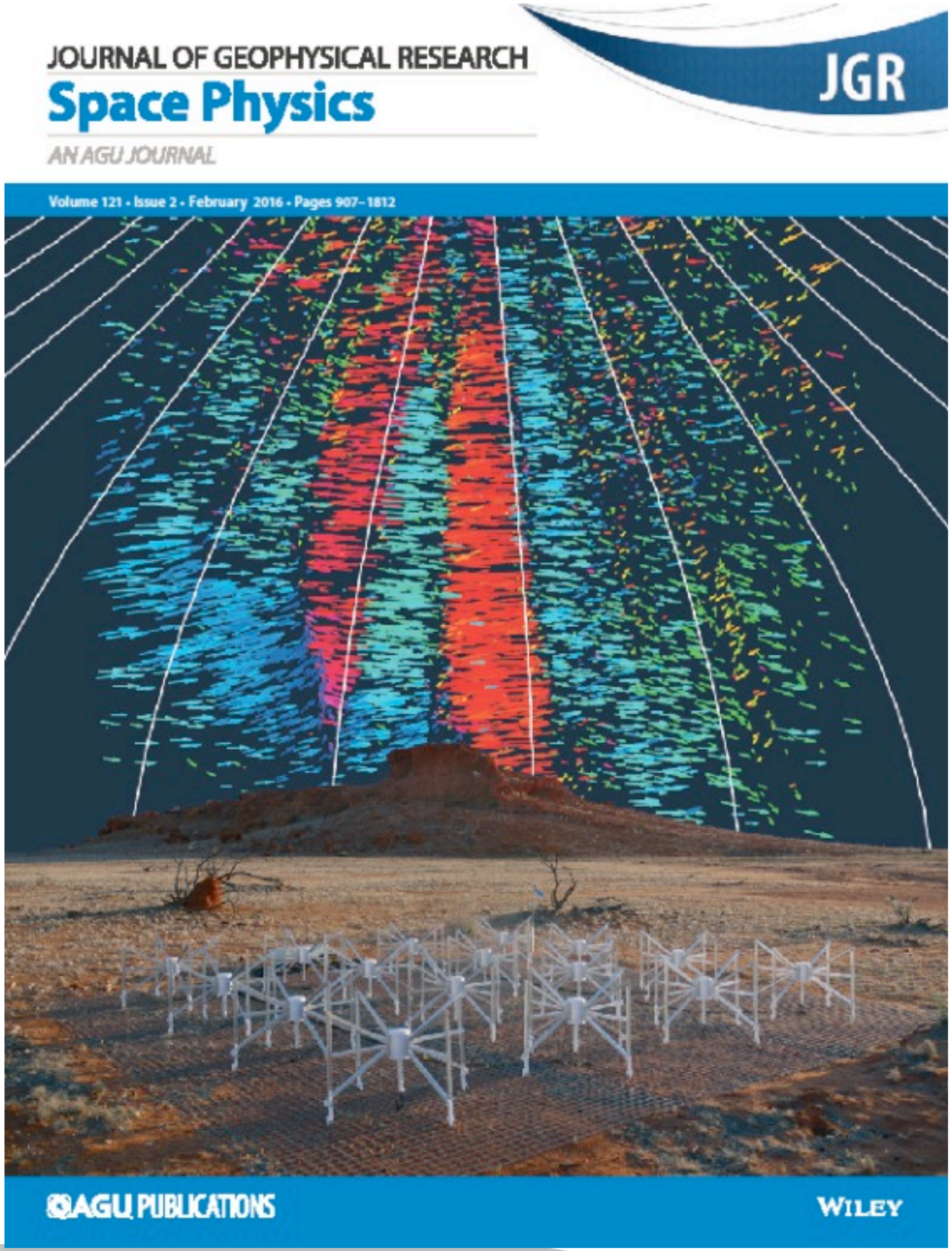
MeerKat galactic centre - spectral index



MWA and Ionosphere

- Shyeh Tjing Loi (Cleo) and Tara Murphey
- Transient search leading to the discovery of ionospheric ducts
- Cleo split the MWA to make a parallax measurement





Space weather and Interplanetary Scintillation

- URSI General Lecture 3 by Craig Rodger
  - Space weather disturbances in electrical power networks: Space weather features in MWA IPS data
  - John Morgan, Angie Waszewski
  - New generation Radio Telescopes with very wide FoV essential