Non-thermal Radio Astronomy

100 Years COSMIC RAYS

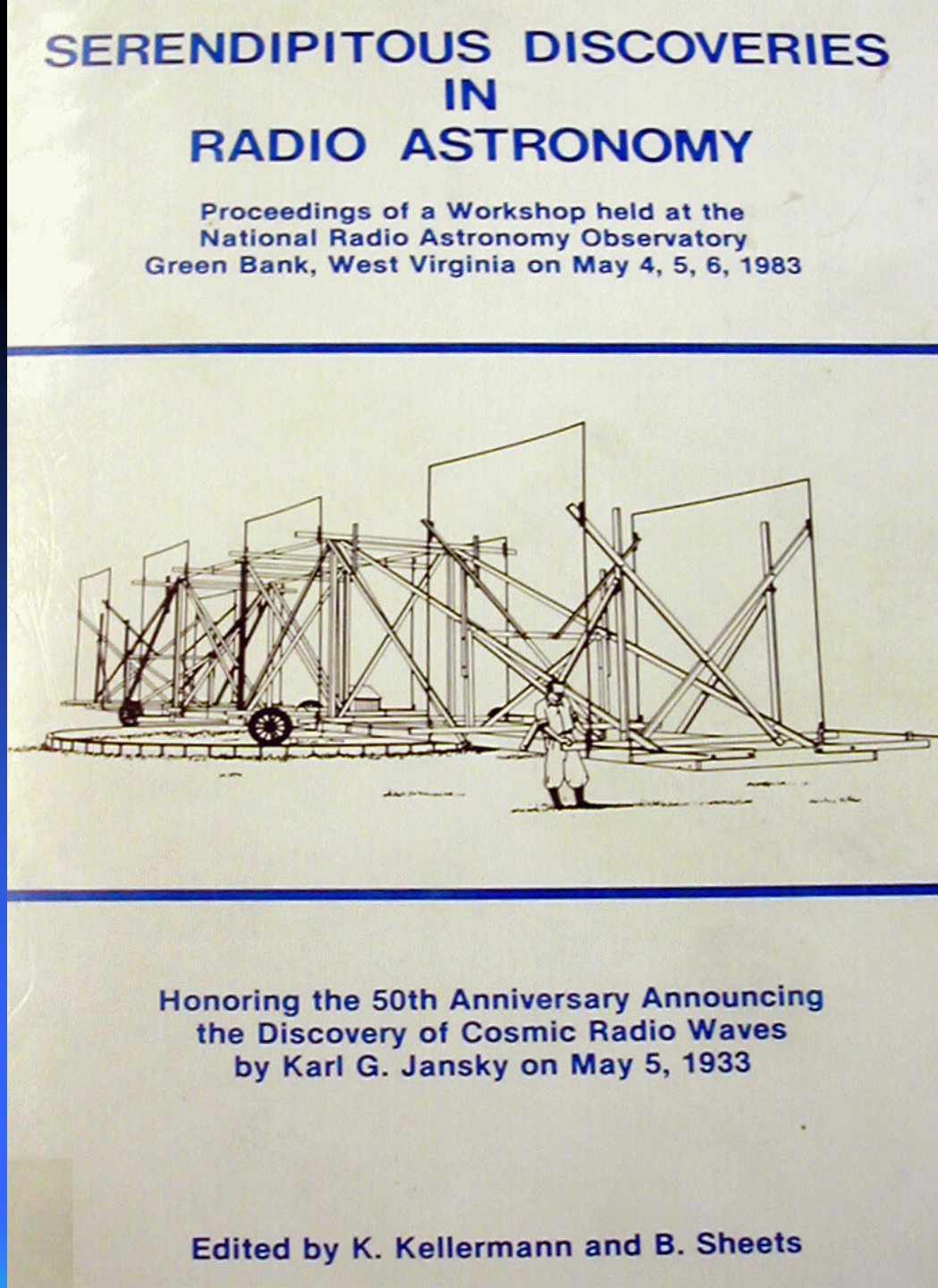
Anniversary of the Discovery by Victor Hess

Bad Saarow, Germany

7-9 Aug 1912

Ron Ekers
CSIRO, Australia

- Identified a common pattern
  - Technology driven
  - Unanticipated
  - Understand instrument
  - Curiosity & persistence
  - Flash of insight
  - Right time



CSIRO

Pasteur

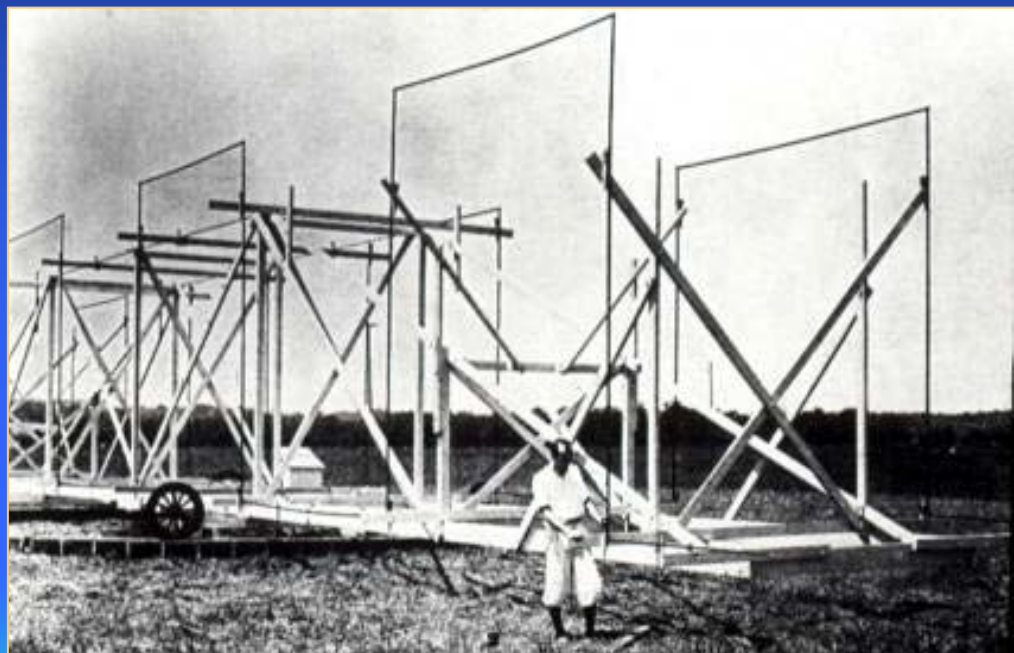
In the field of observation, chance favors only the prepared mind

Summary

- Karl Jansky discovers cosmic radio emission
  - Striking similarities to Hess's discovery of cosmic rays
- Grote Reber discovers non-thermal emission
- Revolutionary impact on astronomy
  - *Radio Astronomy* is born
- The Synchrotron Radiation mechanism
  - Links radio astronomy and cosmic ray research
- Discovery of extragalactic active galactic nuclei
- Radio detection of cosmic rays
- Present status
- Future radio instruments

Karl Jansky
Bell Telephone Laboratory 1932

- Jansky discovers extraterrestrial radio emission
  - opens a new window on the Universe using radio waves
  - reaction from Bell Labs *"so faint its not even interesting as a source of radio interference!"*
- Not accepted by the astronomical community
- Jansky died in 1950 before the importance of his discovery was appreciated
- No Nobel prize !



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Jansky ⇔ Hess

- No equivalent to the *residual radiation*
  - Hence Jansky's role was unambiguous
- Both started a new field of research
- Jansky was an electronic engineer
  - He was not a physicist nor an astronomer
- Hess was an atmospheric electrician
  - He was not a particle physicists nor an astronomer
- Jansky deduced extraterrestrial and from the galaxy
- Hess deduced extraterrestrial and not solar
- Both were ignored by the experts
  - No existing framework, wrong time
- Both discoveries were enabled by technology developments
  - Both built and understood their instruments

Science Fiction

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

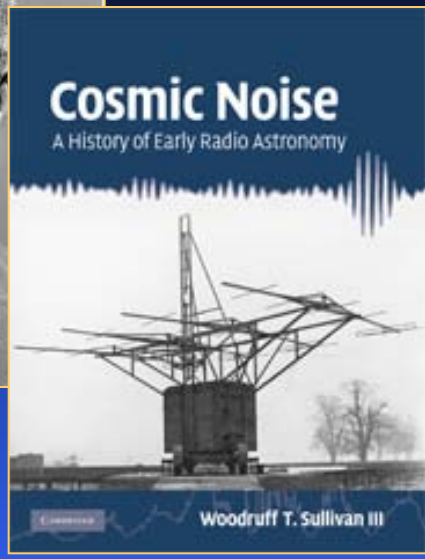
Grote Reber's Challenge

- In 1933 Karl Jansky reported the discovery of radio emission from the centre of the Galaxy
  - Grote age 21 was a very successful radio ham
  - Communicated with amateurs all around the world
  - *"no more worlds to conquer"*

The Discovery of the Non-Thermal Universe

- 1939 detected cosmic static by going to **longer** wavelengths
  - × 3300 MHz
  - × 900 MHz
  - ✓ 160 MHz
- Radiation had to be non-thermal
  - – No theoretical basis at the time
  - – 1950 Synchrotron radiation theory
    - 10 years after Reber
- First radio map of sky
  - – Great difficulty getting published

Cygnus A
strongest 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 was made of such stars?
  - no theory linking diffuse galactic emission to cosmic rays

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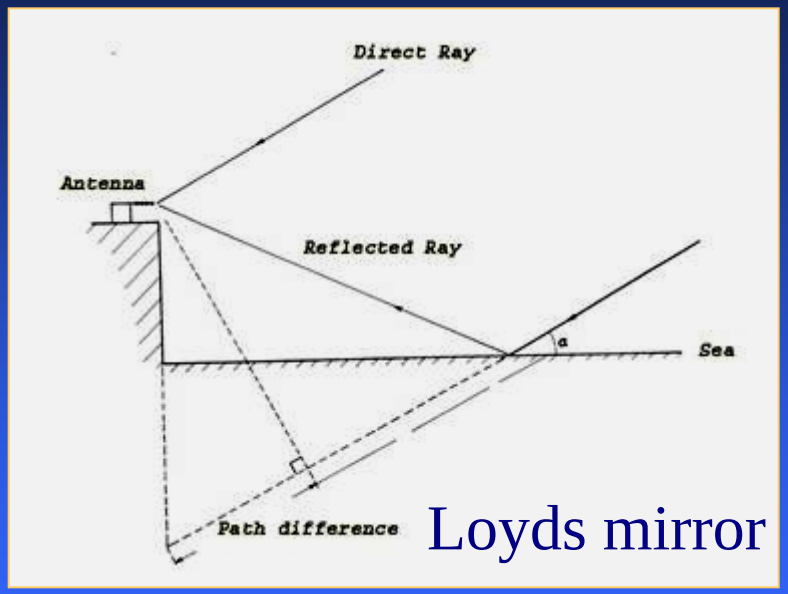
What is the Non-thermal Radio Emission?

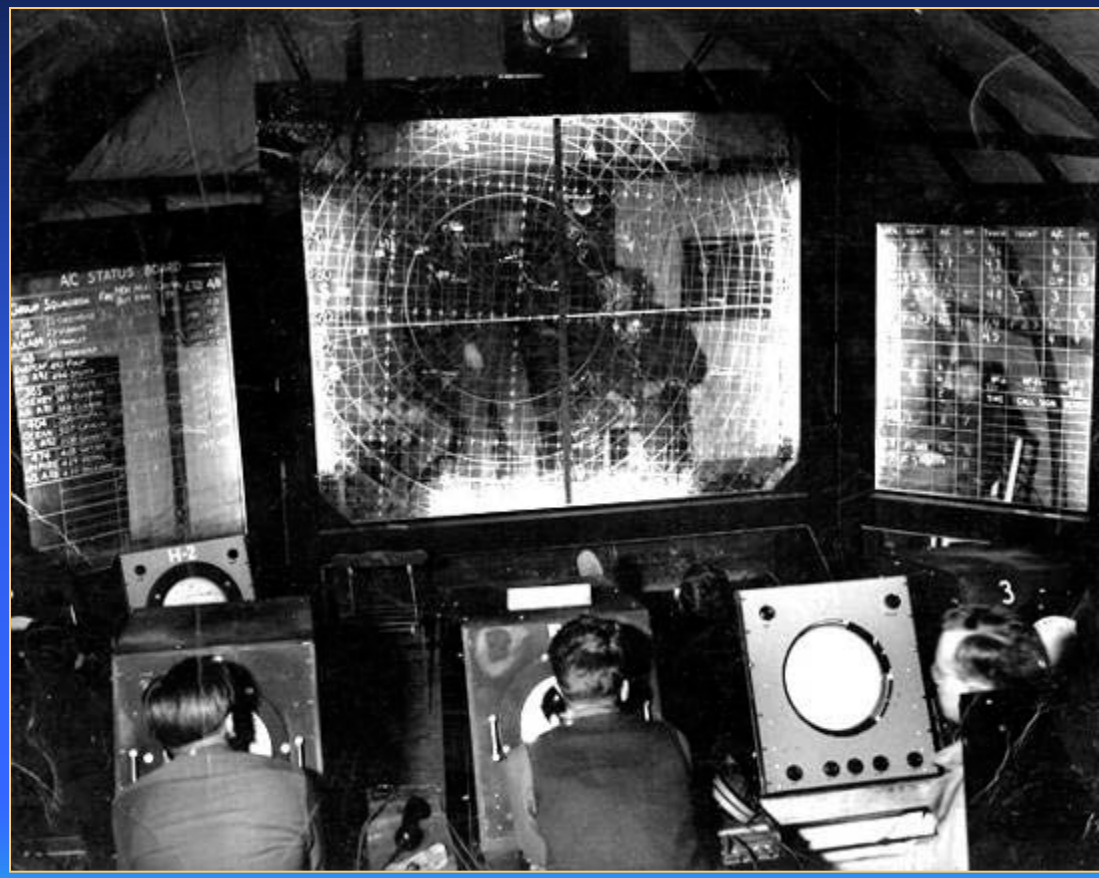
- A very confusing story
- Misinterpretation of radio data added to the confusion
  - some radio sources had small diameter (Hey).
    - Hey was correct but it was incorrectly assumed that all radio emission was the sum of these radio stars
  - It was assumed that the radio stars were like the sun
    - this was also incorrect.
    - they were galactic nebula (SNR) and extra galactic (AGN)

What are the Radio Stars? Cliff Interferometer - 1948

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



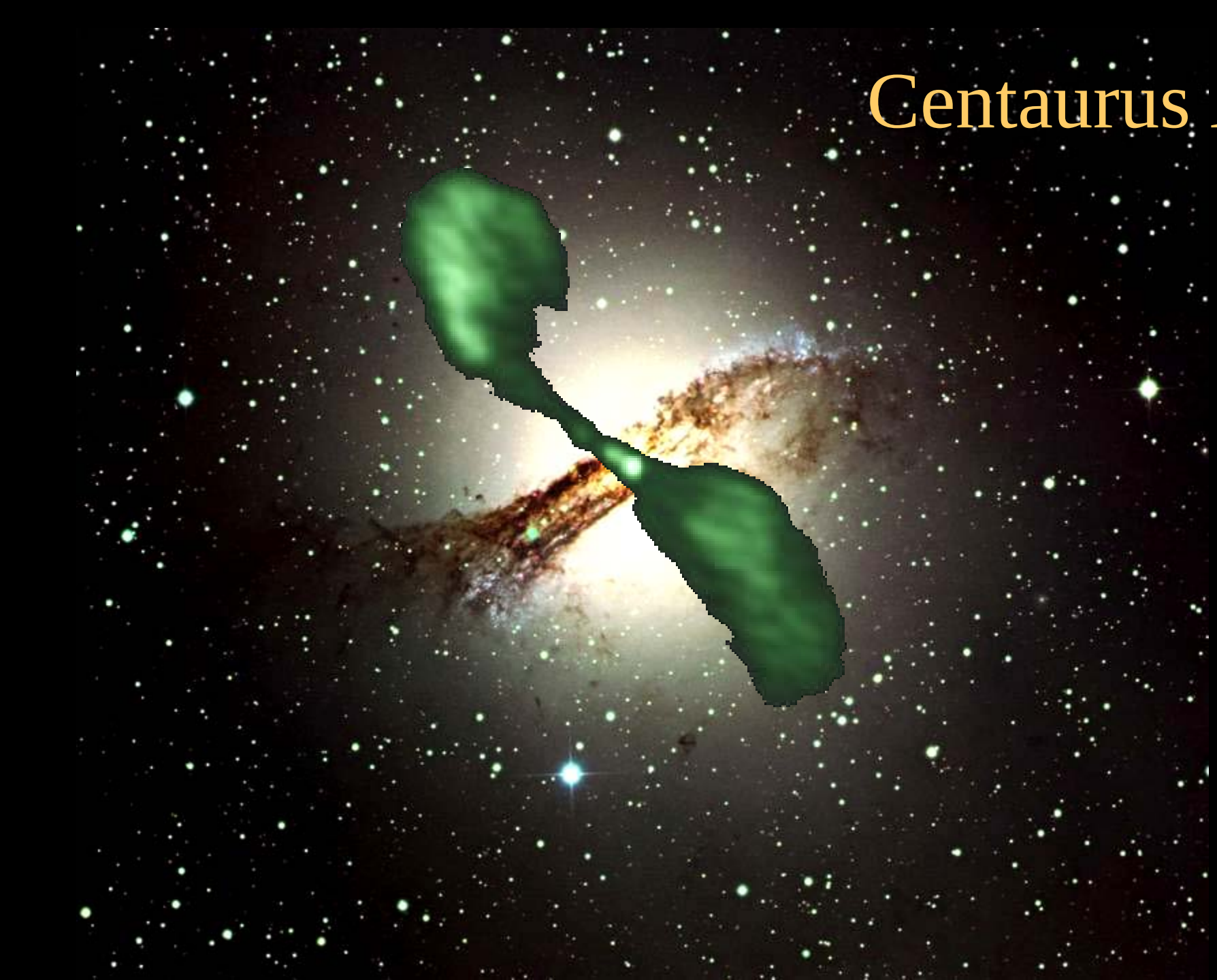
Loyds mirror



Cliff interferometer CSIRO, Australia (1948)

- Built to identify the radio stars (John Bolton)
- Identification of the Crab Nebula super novae remnant
- Discovery of extragalactic radio sources at great distances
  - Centaurus A , Virgo A, Cygnus A, Fornax A
- Had to hedge on extragalactic origin to get paper published

Centaurus A



Synchrotron Model for Radio Emission

- 1949 Unsold: sunspots *anomalous radiation*
  - non-thermal
  - plasma oscillations
- 1950 Alven: synchrotron from sunspots
- 1950 Kippenhauer; proposed the ISM rather than stars
  - needed magnetic field and high energy charged particles
- Mostly ignored in the West but enthusiastically embraced in Russia by Ginzburg and Shklovski

Linking non-thermal radio emission and cosmic rays

- 1951 Ginzburg
  - *Synchrotron radiation by relativistic electrons in Galactic Magnetic fields "is very natural and attractive as an explanation for the general radio emissions of the Galaxy“*
- 1953 Shkolovski: Crab nebula has radio and optical synchrotron
  - polarization
  - No reference to Ginzburg!
- 1957 Burbidge: M87 jet synchrotron in radio and optical

Cosmic Ray Astrophysics comments by Ginzburg (1996)

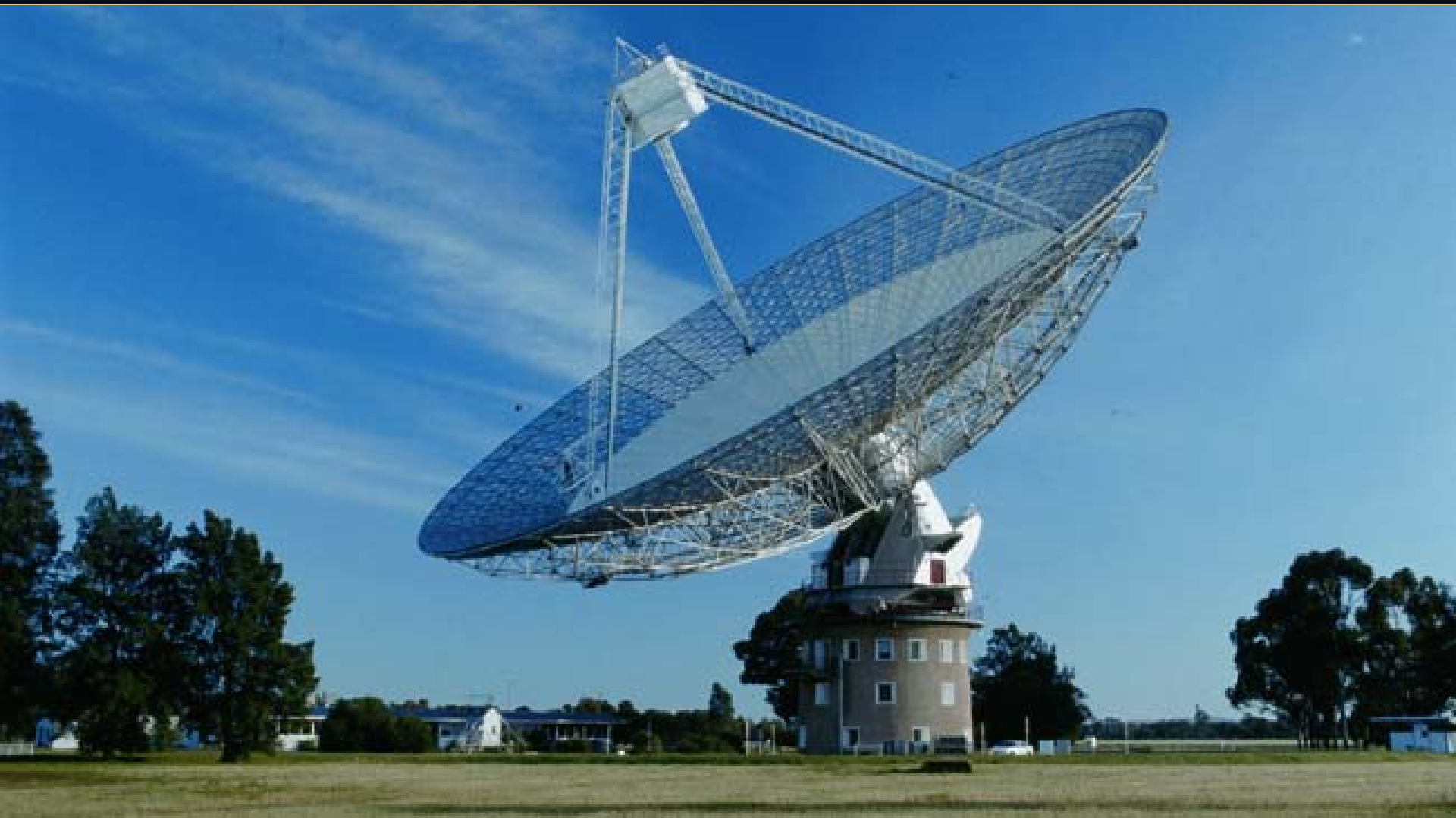
- Cosmic ray astrophysics was born in the early 1950s when it became possible to observe cosmic rays far from the Earth.
  - Non-thermal continuum radio emission is from the synchrotron process
  - Crab nebula, and the first radio galaxies identified
  - Because radio waves propagate rectilinearly, the reception of cosmic radio emission provides a tool to obtain information about the electron component of cosmic rays at a distance from the Earth, in our Galaxy, other galaxies, and quasars.
    - *Physics Uspekhi, Volume 39, pp. 155-168 (1996)*

CR now traced at all wavelengths, and directly in gamma rays and UHE cosmic rays.

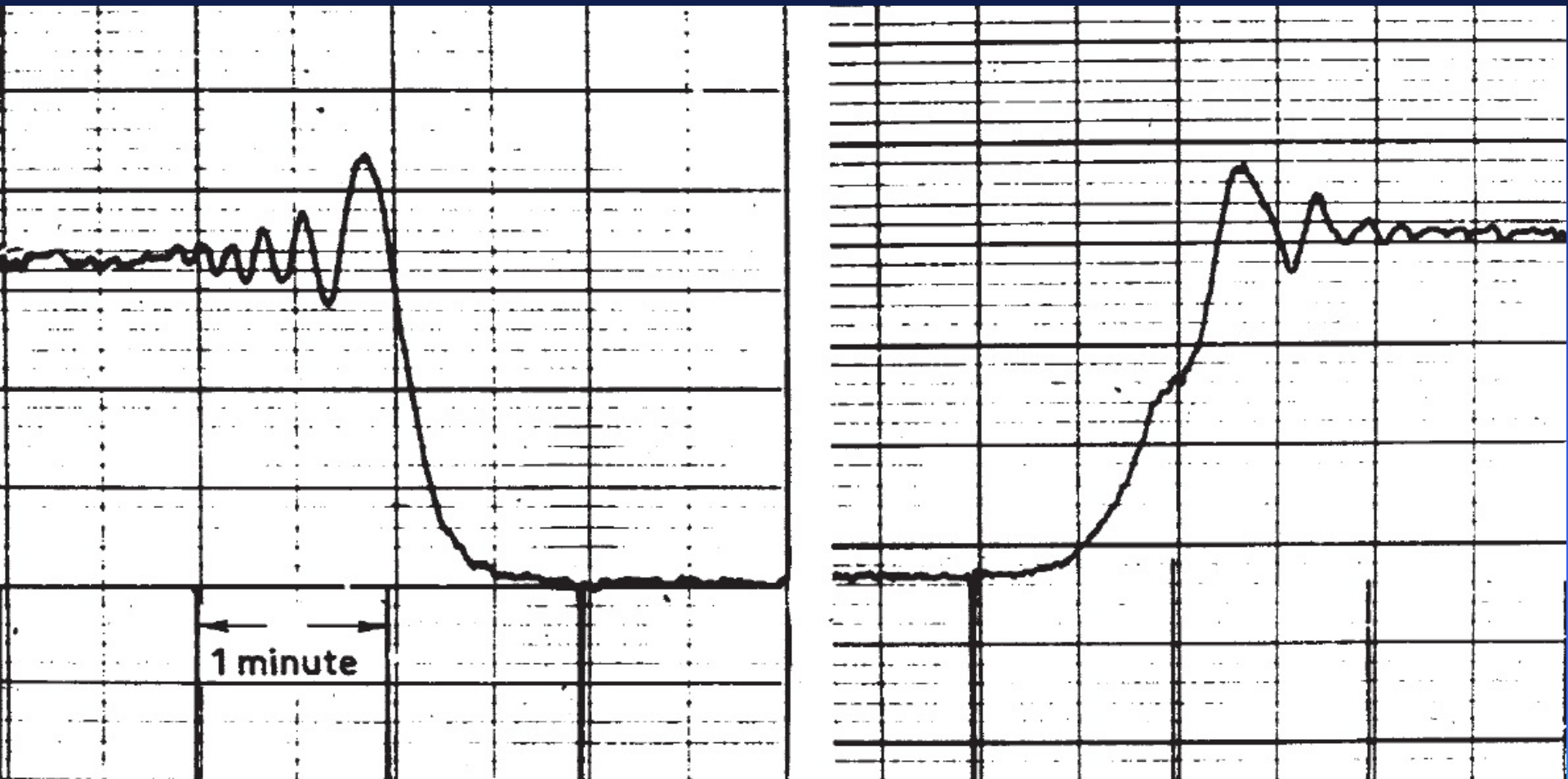
Discovery of Quasars (who gets credited?)

Date	
1960	Tom Mathews identifies 3C48 with a stellar object Spectrum has a possible z=0.36 but not accepted (variability, line fit) Misinterpreted as a peculiar galactic star
1962	Cyril Hazard observes multiple lunar occultations of 3C273 at **Parkes** Core jet structure and position determined
Jan 1963	13mag star identified with 3C273 using position and structure Bolton, Hazard and Mathews all involved in the now obvious identification
Mar 1963	Schmidt observes spectrum and identifies lines with z=0.158
Mar 1963	Greenstein and Mathews now reinterpreted 3C48 as a z=0.36 Quasar Sandage has already measured variability
1963	Variability implies small volume and luminosity implies gravitational energy Requires a black hole potential
Dec 1963	First Texas Symposium on Relativistic Astrophysics, Named Quasars but name not in general use for many years

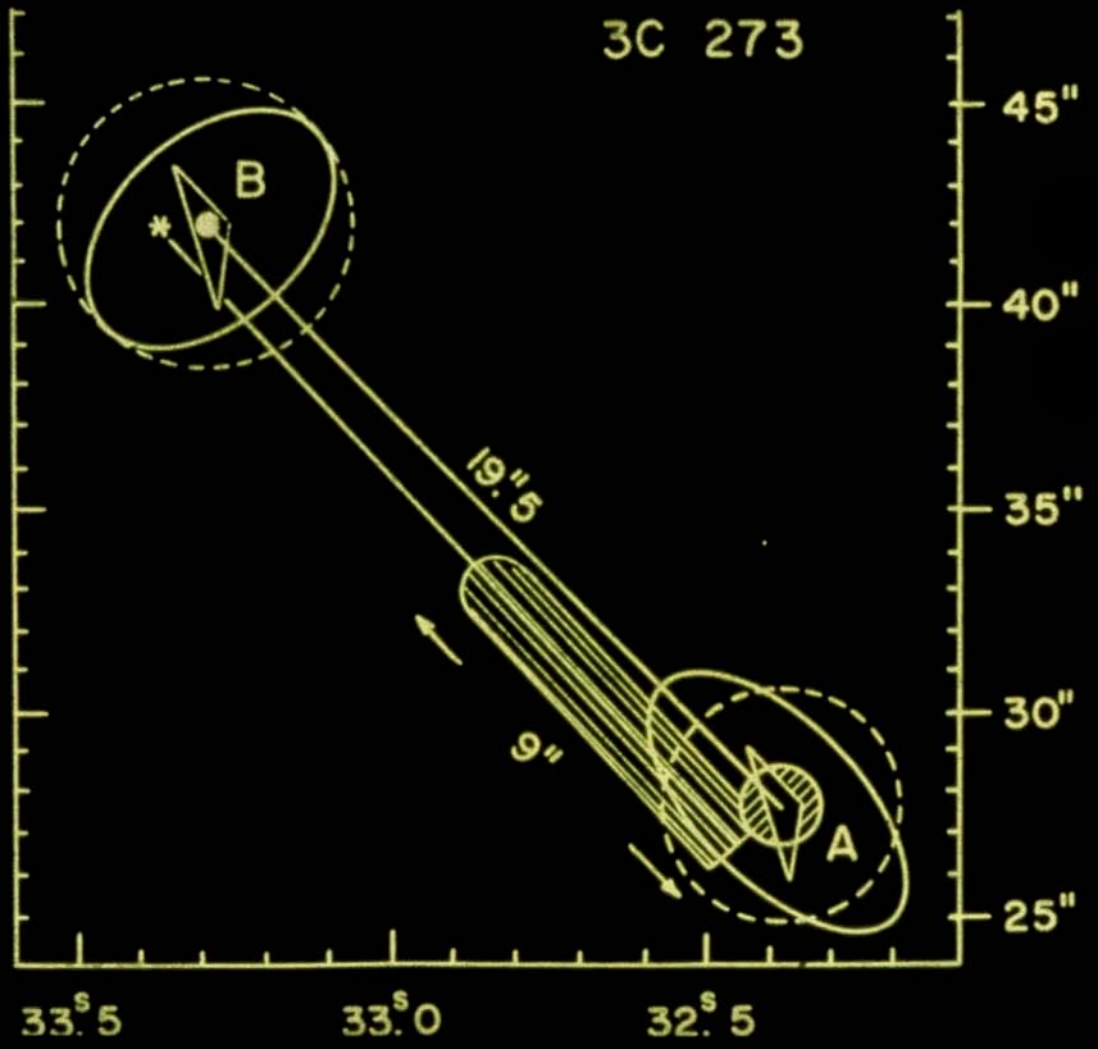
CSIRO's Parkes Radio Telescope – 1961



3C273 Occultation
Parkes, Aug 5 1962, 410MHz

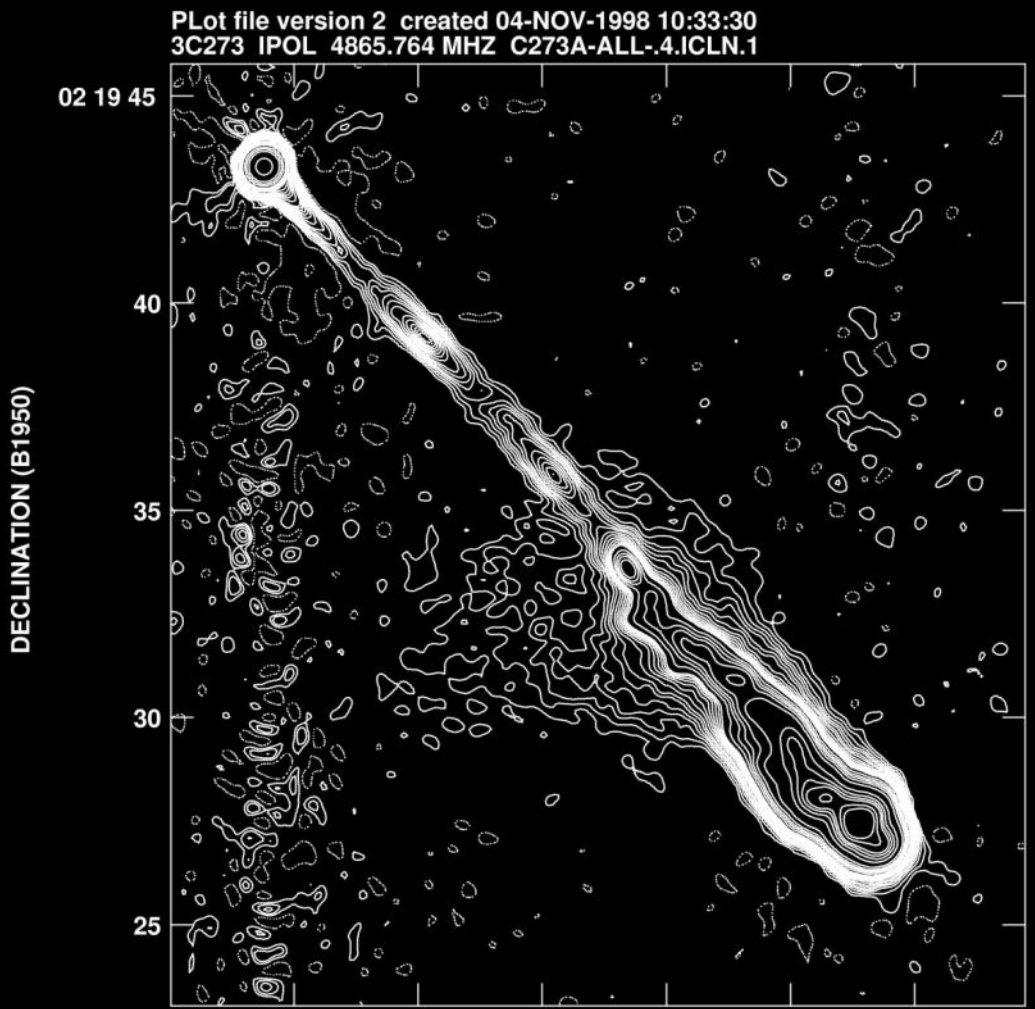


3C273
Parkes Occultation



- Striking difference in radio spectra
- Component A
  $S = \upsilon^{-0.9}$
- Component B
  $S = \upsilon^{0.0}$

3C273
VLA 5GHz



3C273
Optical HST

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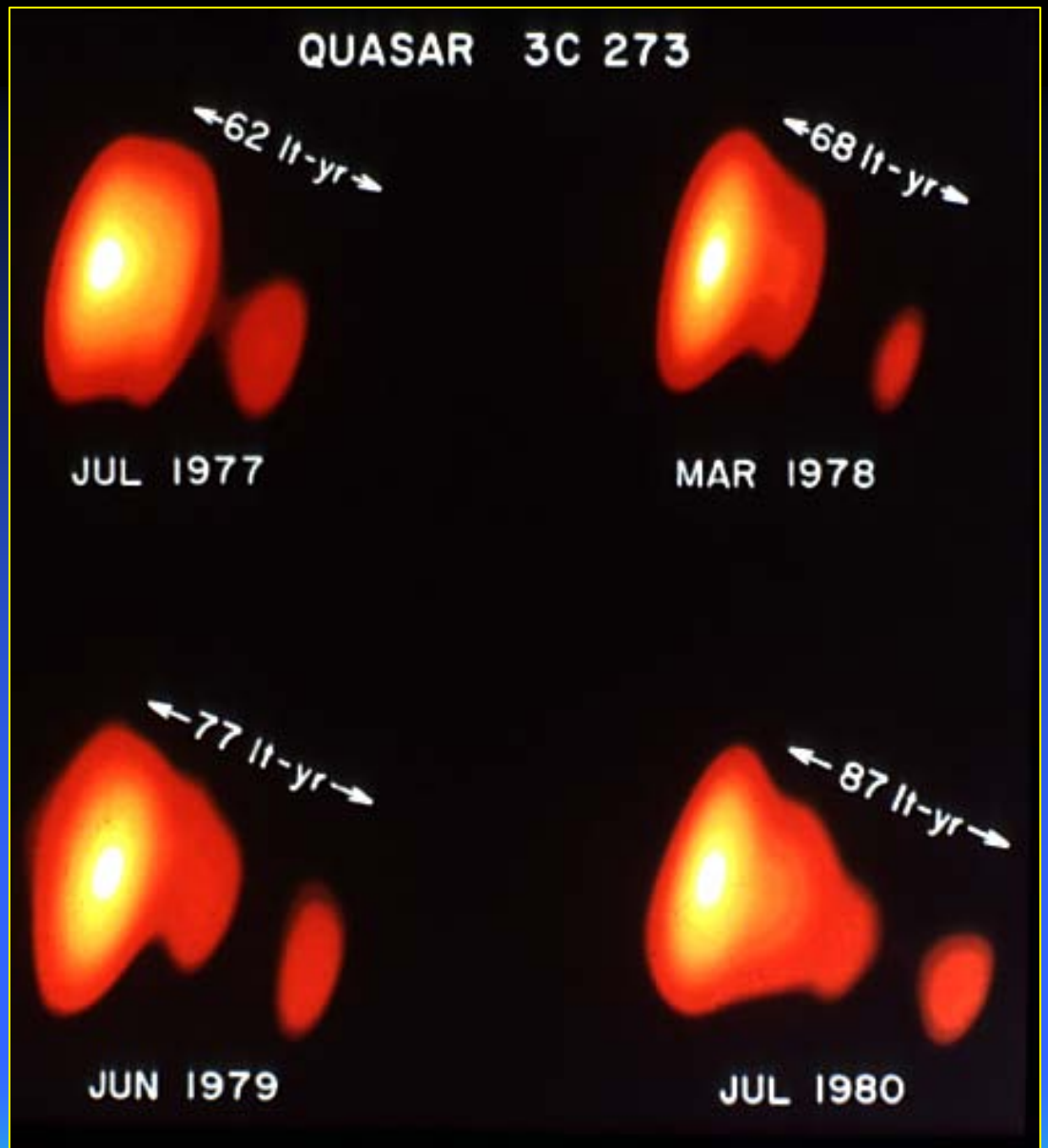
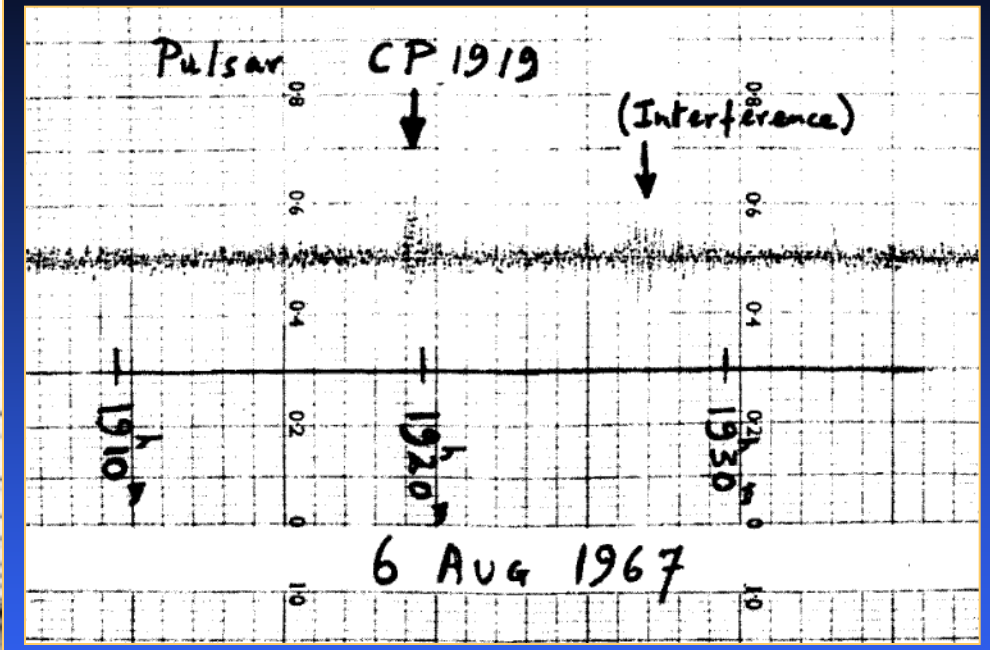
3C273 expansion



Radio astronomers need more resolution

- 1951
  - Christiansen build the Potts Hill grating array
    - 32 steerable paraboloids
- 1953
  - Chris Cross (Fleurs)

1974 Nobel Prize
Pulsar Discovery

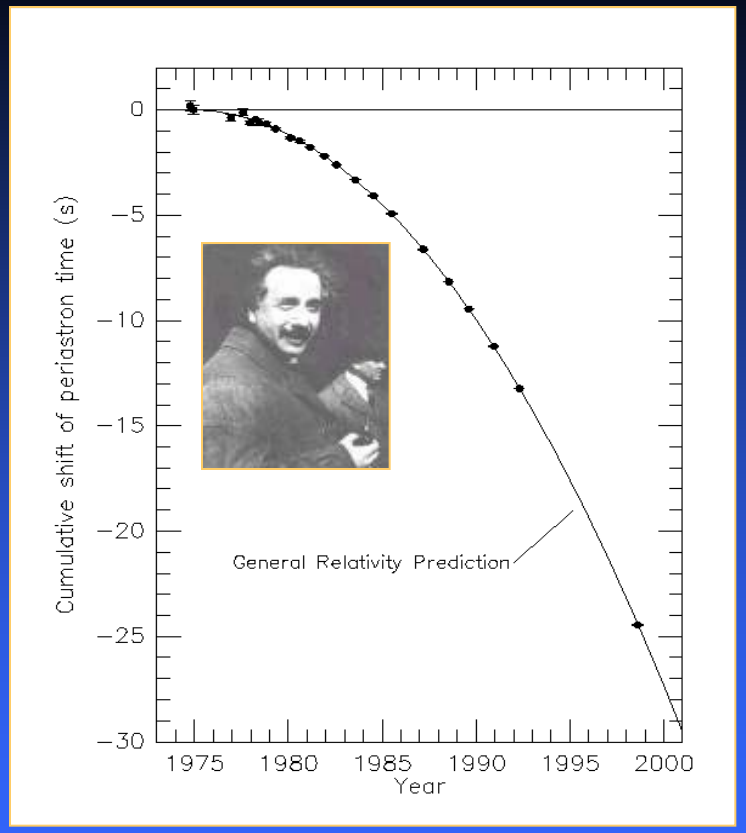


1967 Cambridge

Tony Hewish and Jocelyn Bell discover pulsars

1993 Noble prize Gravitational Radiation

- Verification of Einstein's prediction of gravitational radiation
  - Classic example of the scientific method
  - 1993 Noble prize to Joe Taylor and Russell Hulse
    - the Bell effect?

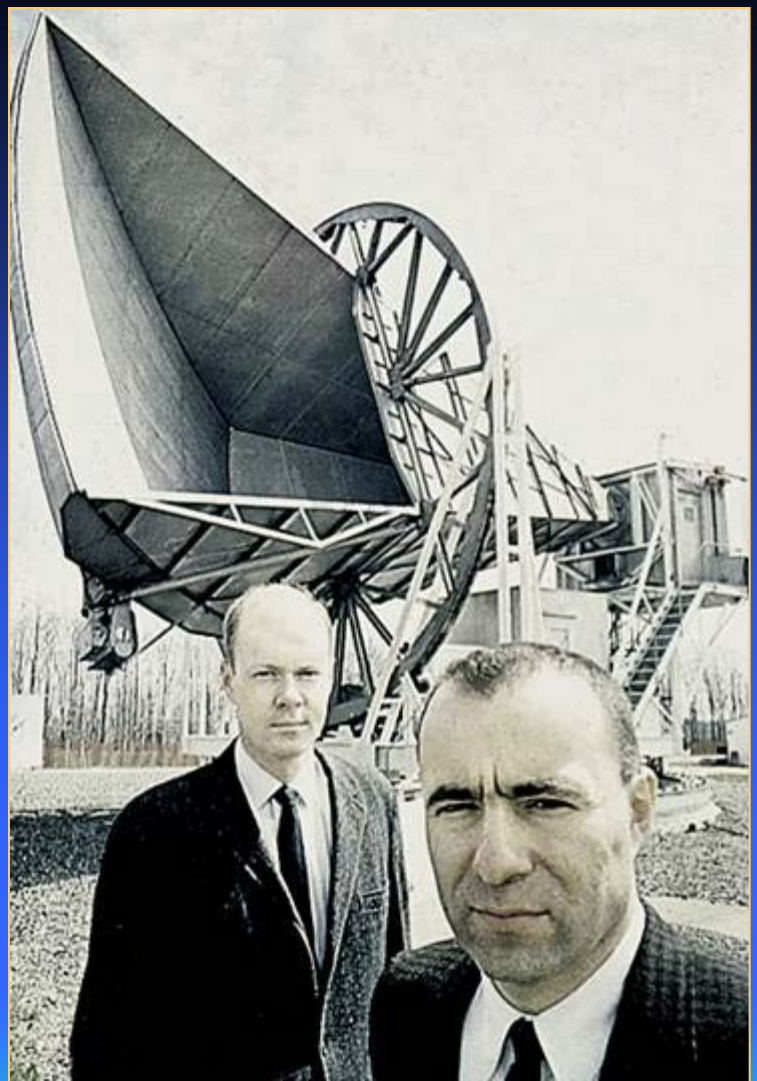


Arecibo Radio Telescope

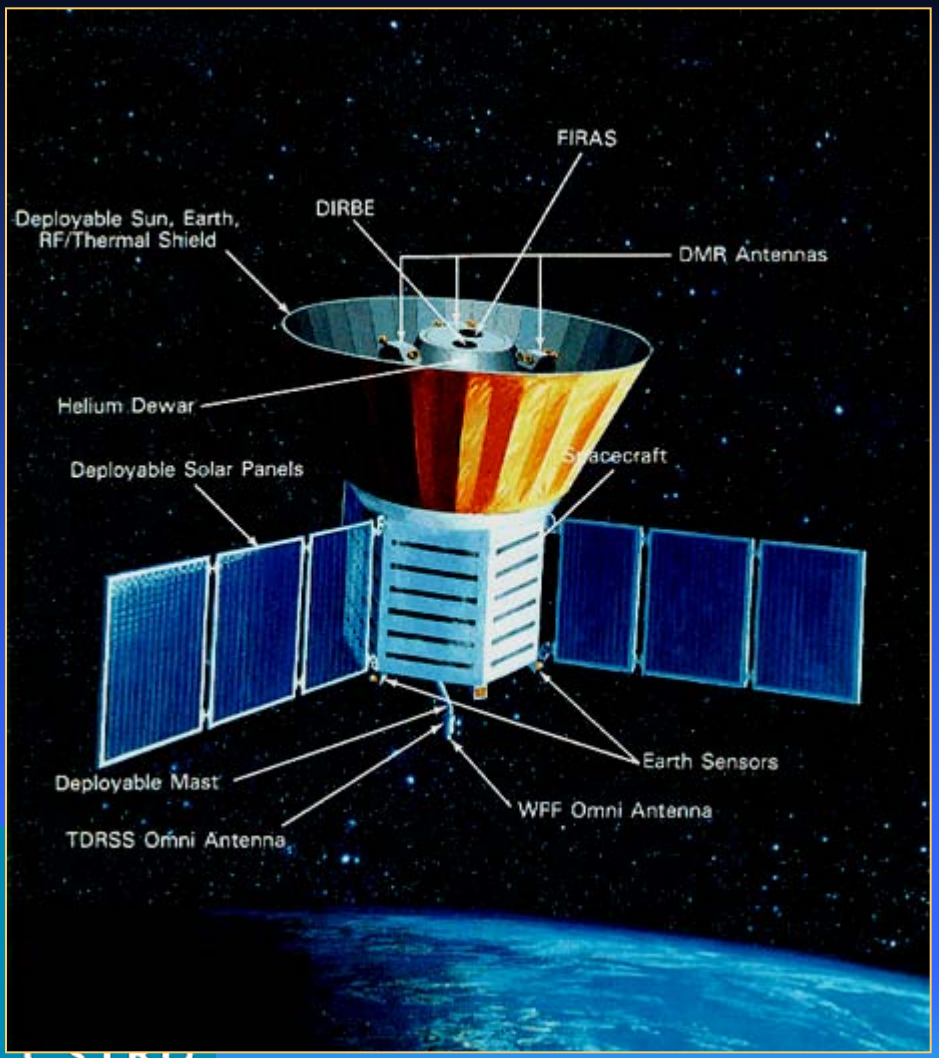
- Largest single dish in the World
  - 300m spherical dish
- Used to confirmed the predictions of General relativity
  - 1993 Noble Prize to Taylor and Hulse

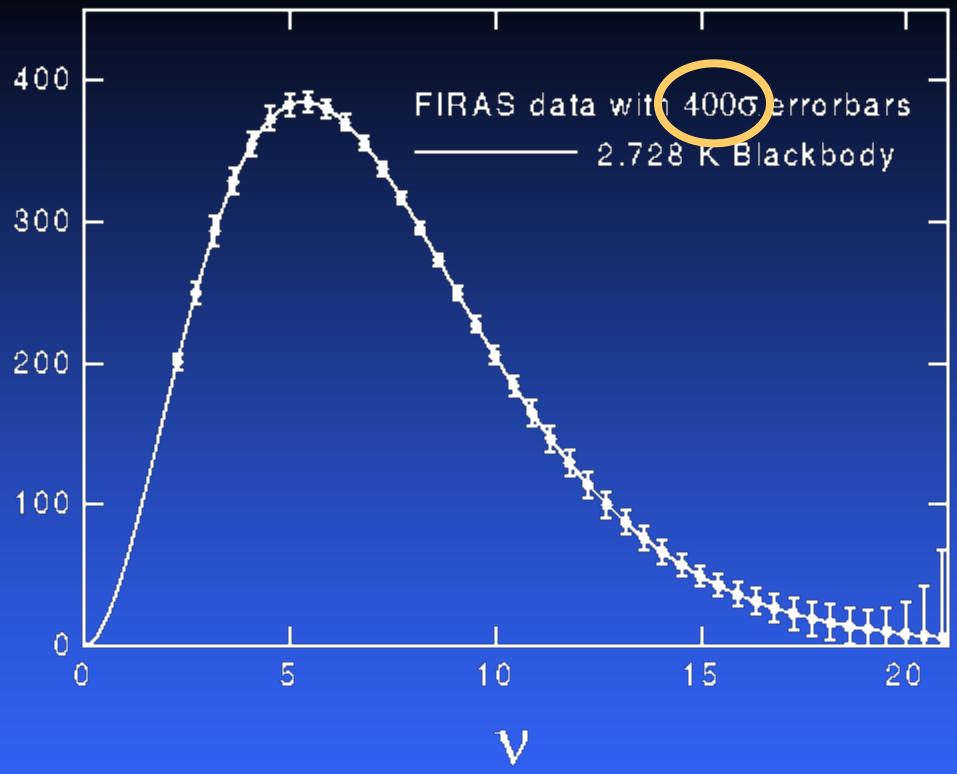
Bell Telephone Laboratories 1965

- 1978 Nobel prize to Penzias and Wilson for discovery of the Big Bang radiation
- Serendipitous observation of a predicted phenomena
  - Bob Dicke's experiment to search for this was already in progress



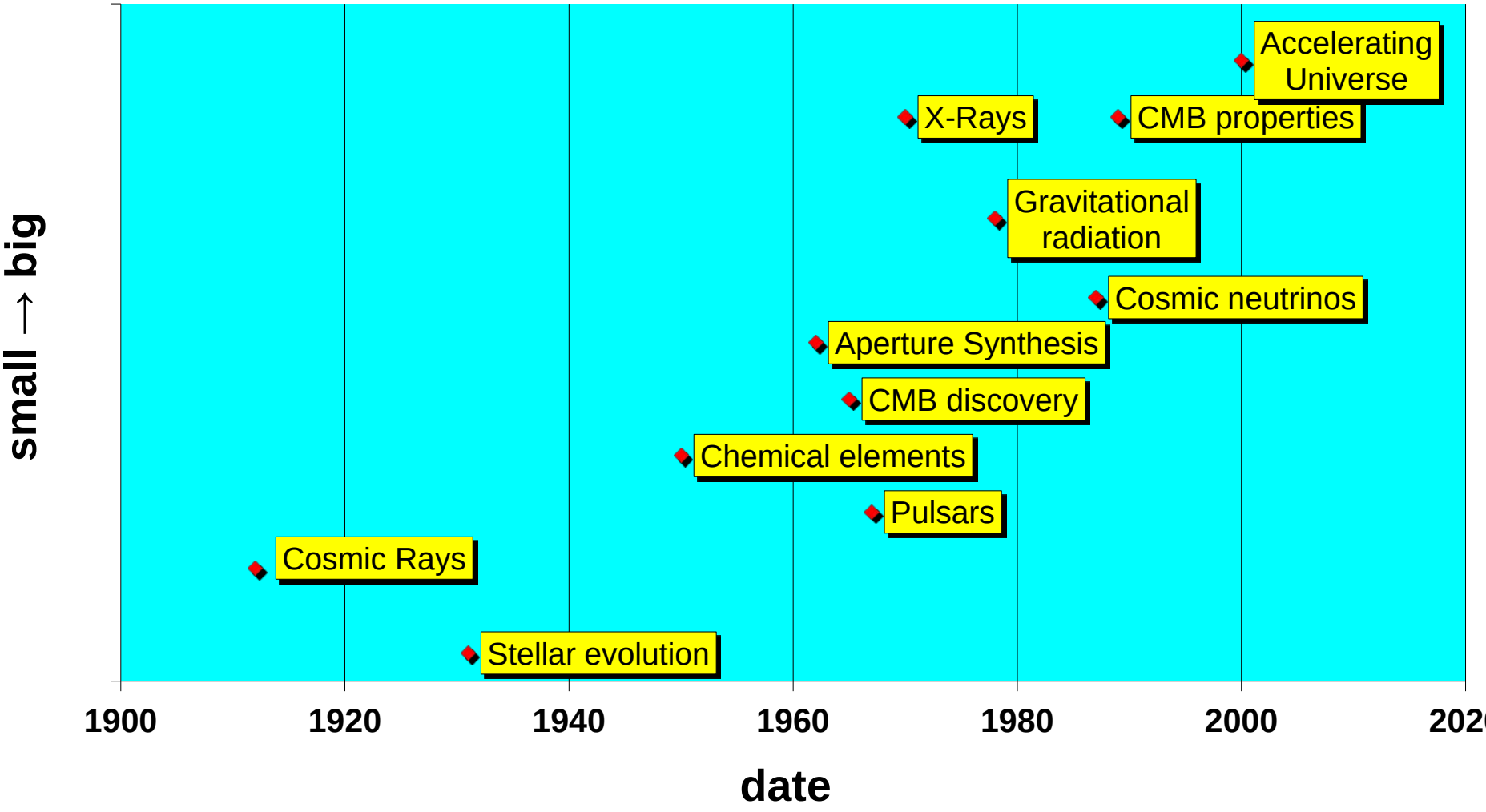
COBE 1989
The microwave background





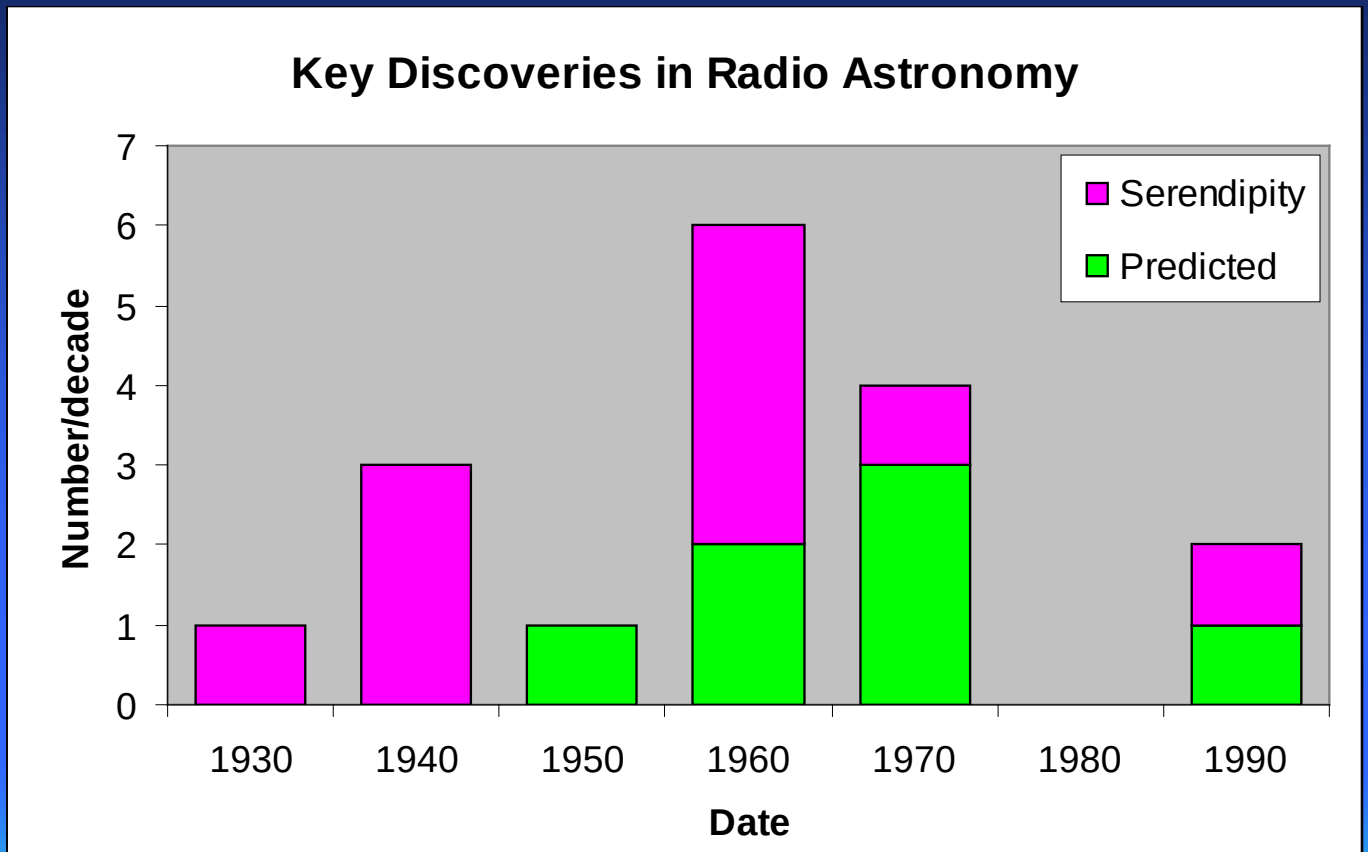
- 2006 Nobel Prize
  - John Mather – spectrum
  - George Smoot - anisotropy

Nobel Prizes in Astronomy
Instrument Scale v Date

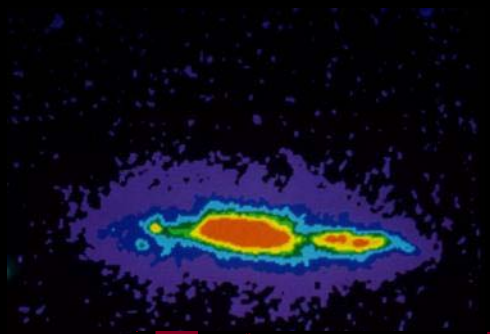


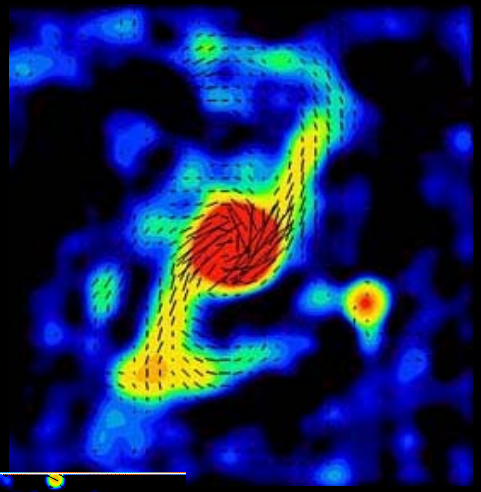
Key Discoveries: Predicted v Serendipity

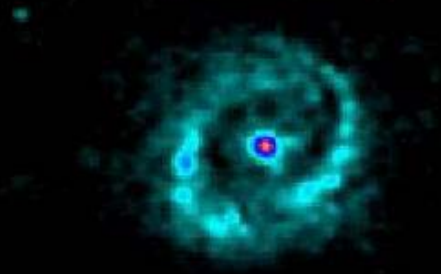
- Are accidental discoveries more prevalent at the inception of a new branch of science?

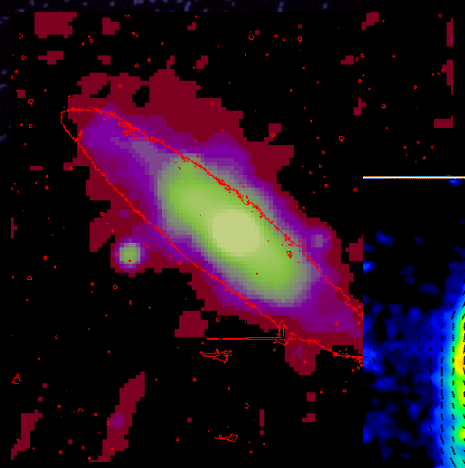


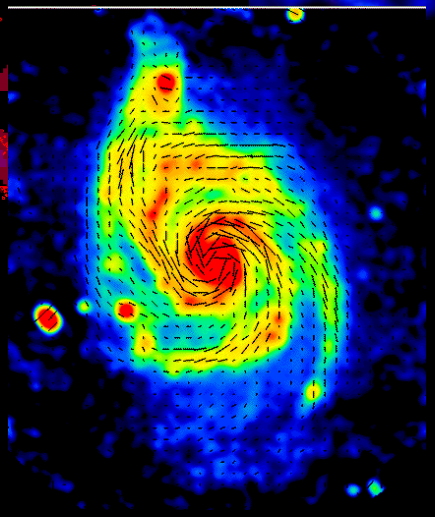
Normal Disk Galaxies
VLA, WSRT ATCA

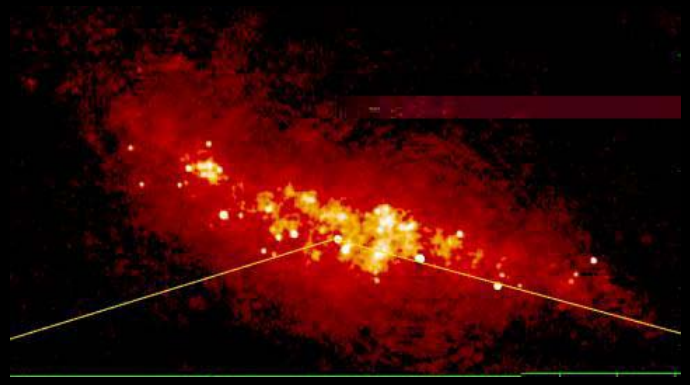




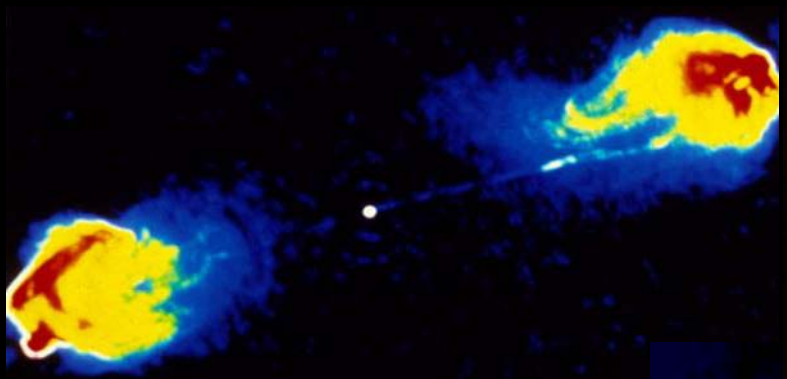


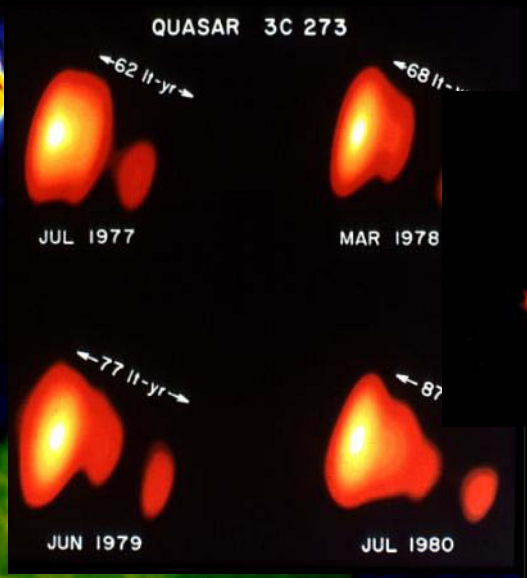


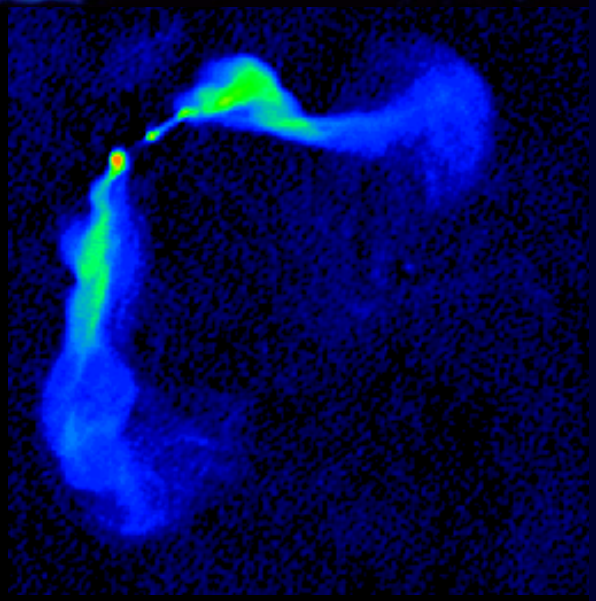


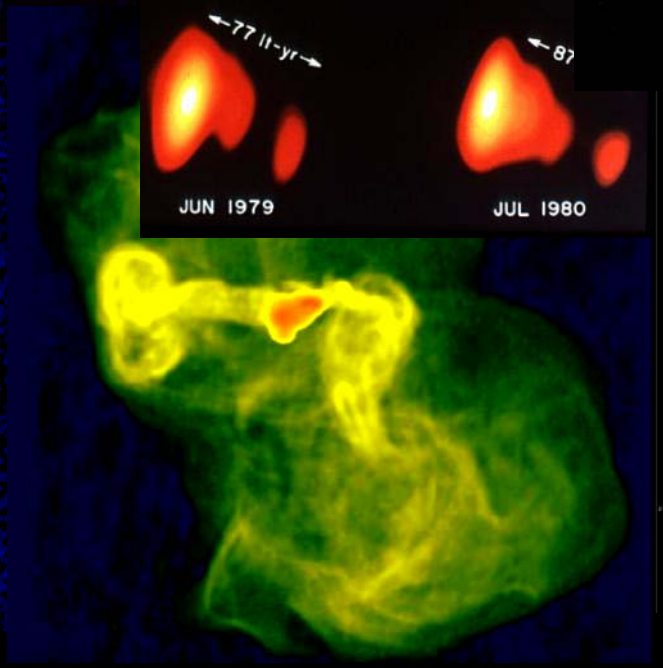


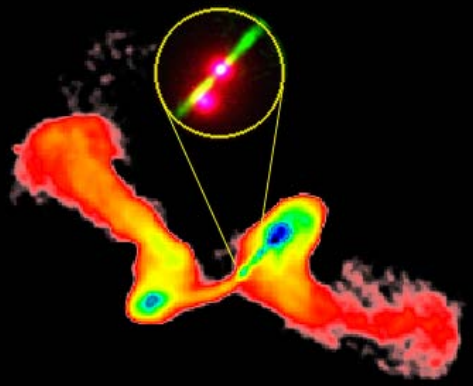
Radio Galaxies and QSOs









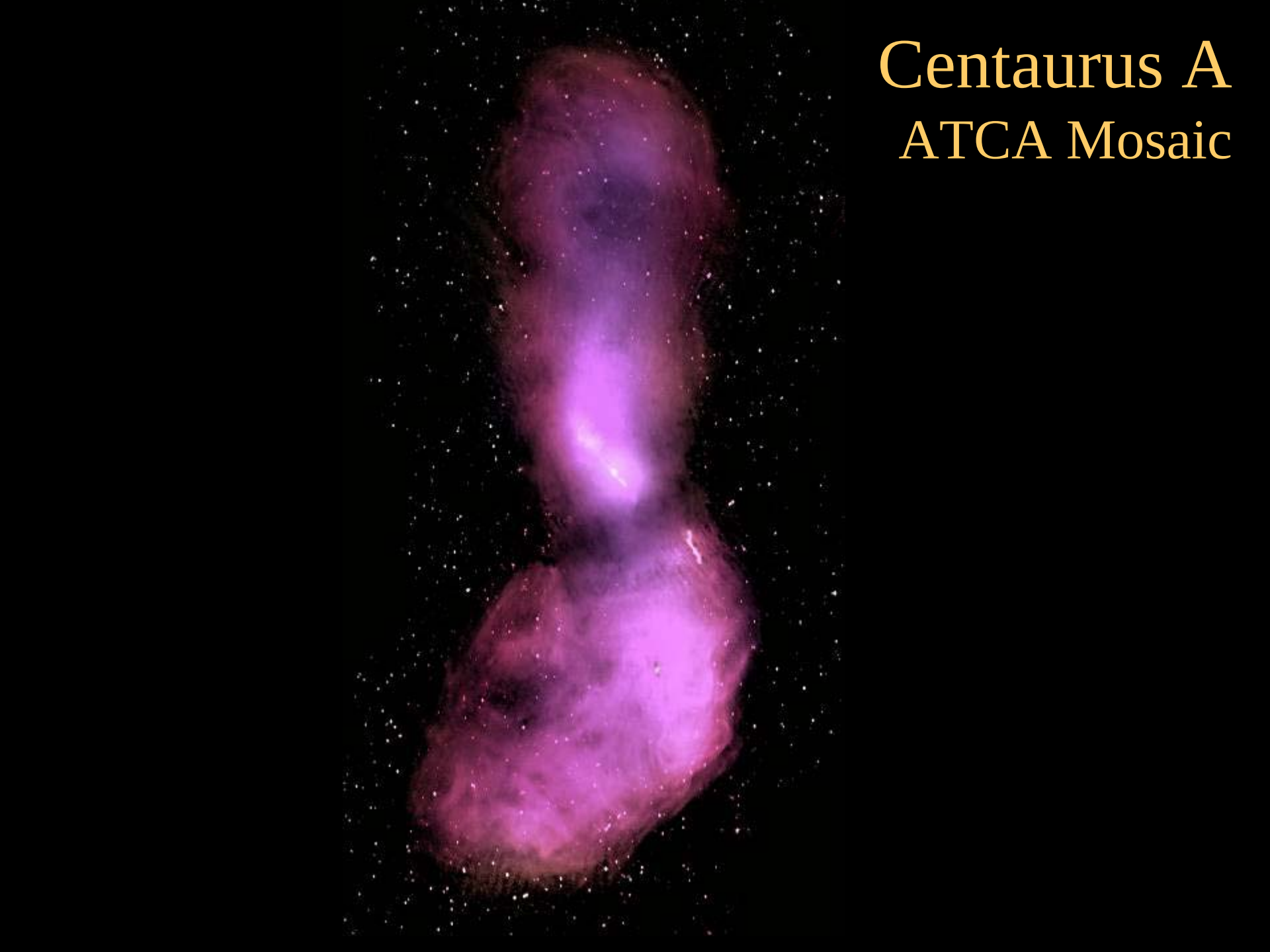


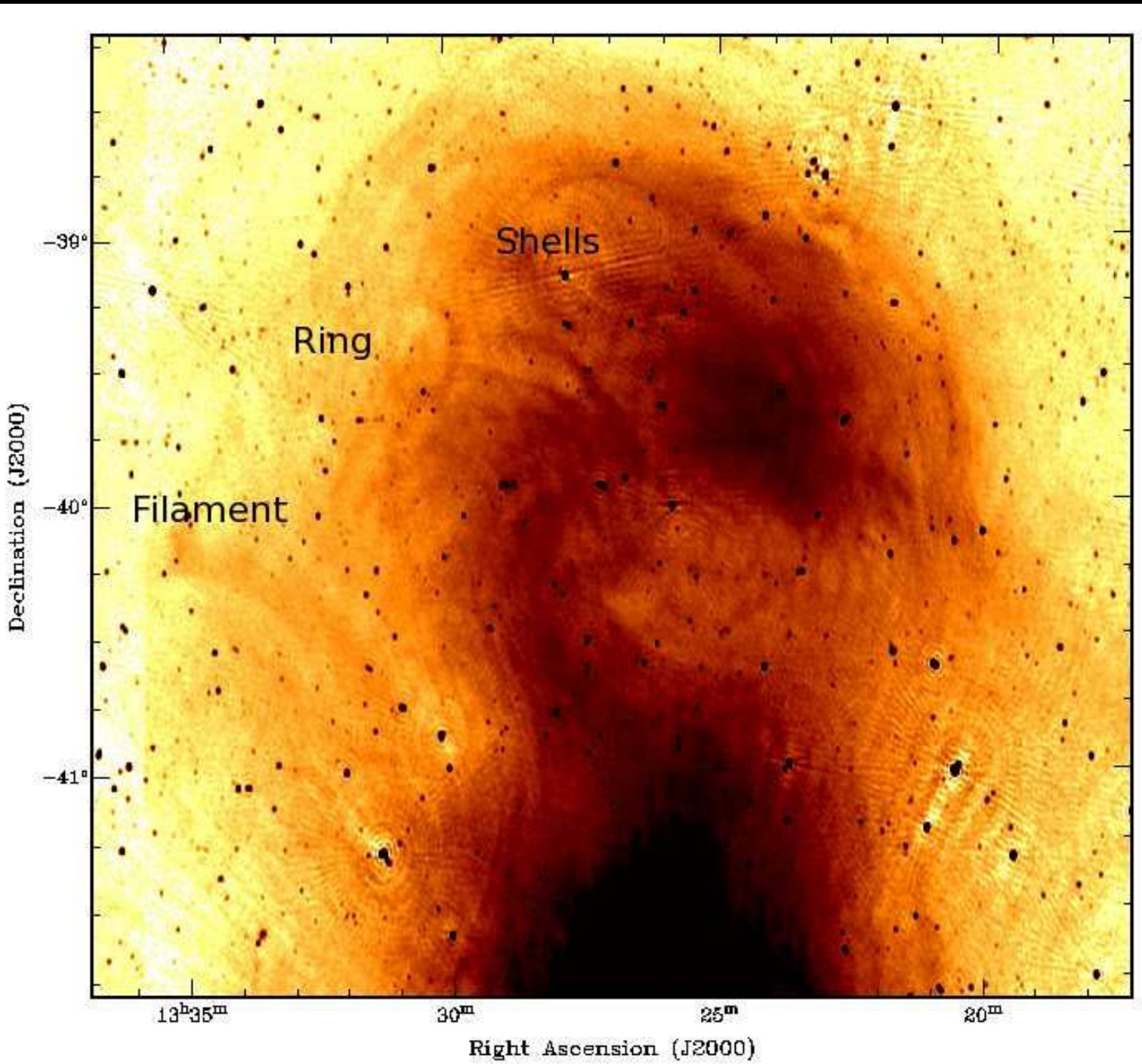
Extragalactic Cosmic Rays

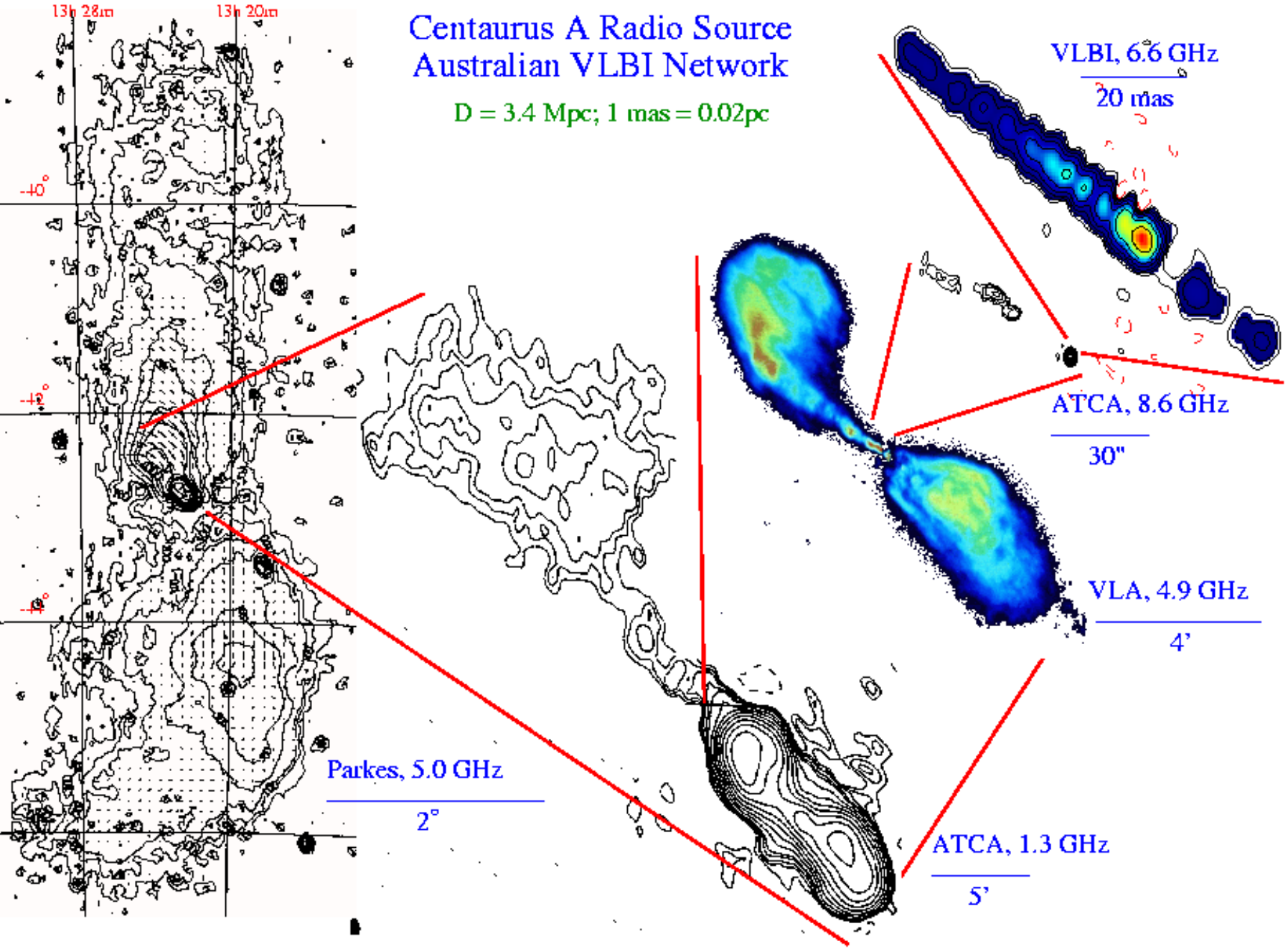
- Ginzburg & Syrovatskii (1963)
  - Predicted that the radio galaxies
    - Centaurus A (= NGC5128),
    - Virgo A (= NGC4486 = M87), and
    - For nax A (= NGC1316)
  - should be good candidates to provide most of the extragalactic cosmic rays.
- and more recently
  - Caramete1 and Biermann, *arXiv: 1106.5109*
  - show that Cen A produces a predicted UHECR flux which is about ten times higher than from M87, and about 15 times higher than For A.

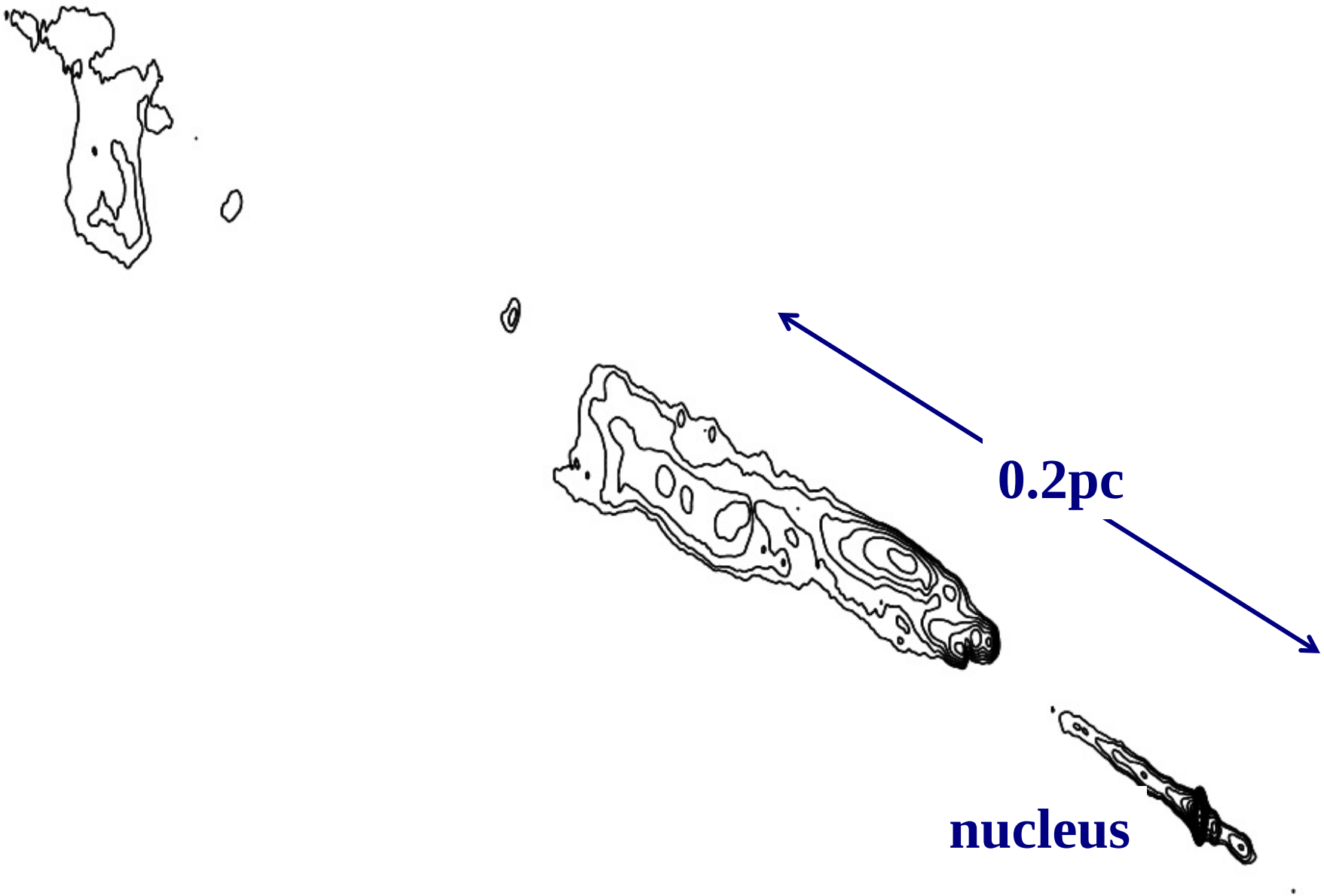
Centaurus A the closest AGN

- Distance 3.4 Mpc
- Next closest comparable AGN M87 at 17 Mpc !
- Luminosity = 10^{42} ergs/sec
- Total Energy = 10^{60} ergs (relativistic particles)
- Giant radio galaxy 0.5 Mpc in size
- Subtends a large angular size (8^{o})

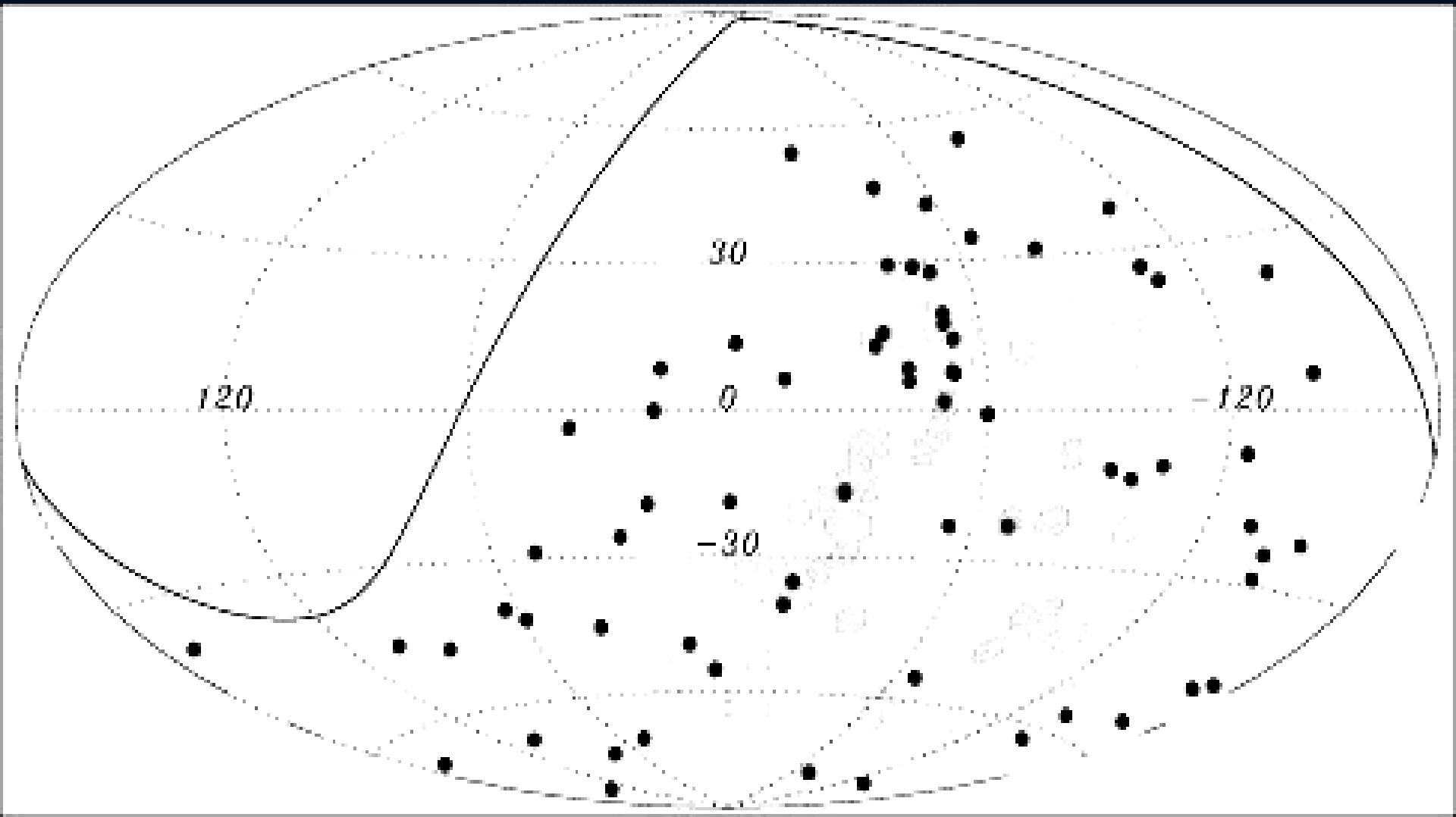

Centaurus A
ATCA Mosaic


Shells
Ring
Filament
−39°
−40°
−41°
Declination (J2000)
13h35m
30m
25m
20m
Right Ascension (J2000)

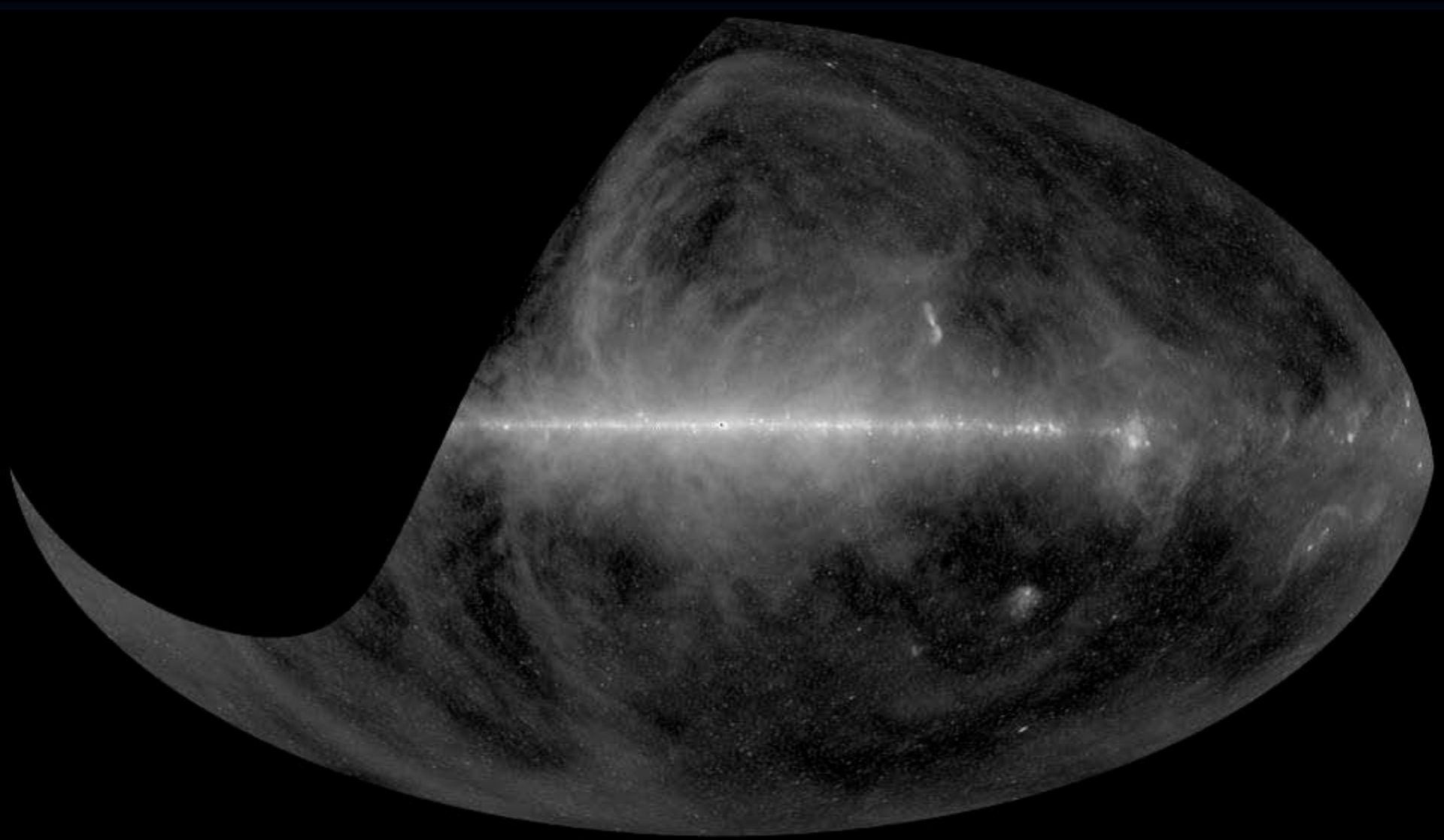

13h 28m
13h 20m
-40°
-42°
-44°
Centaurus A Radio Source
Australian VLBI Network
D = 3.4 Mpc; 1 mas = 0.02pc
VLBI, 6.6 GHz
20 mas
ATCA, 8.6 GHz
30"
VLA, 4.9 GHz
4'
ATCA, 1.3 GHz
5'
Parkes, 5.0 GHz
2°


0.2pc
nucleus

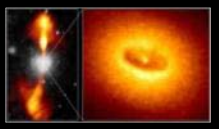
Auger Cosmic Rays



Radio continuum



The Lunar Cerenkof Technique



cosmic ray

neutrino

particle cascade

radio waves
(Askaryan Effect)

Ground-based radio-telescopes


Parkes


Goldstone


Kalyazin

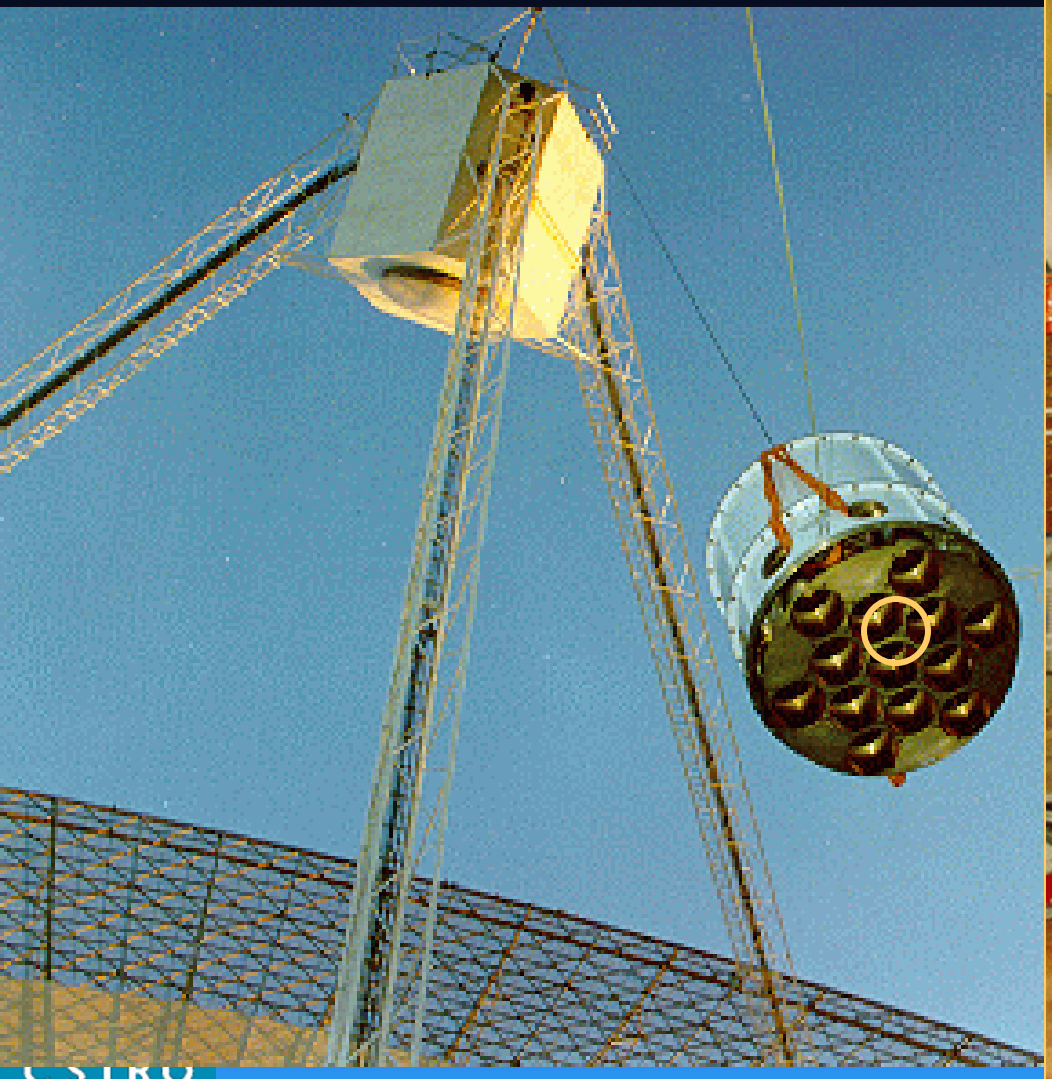

GMRT


ATCA

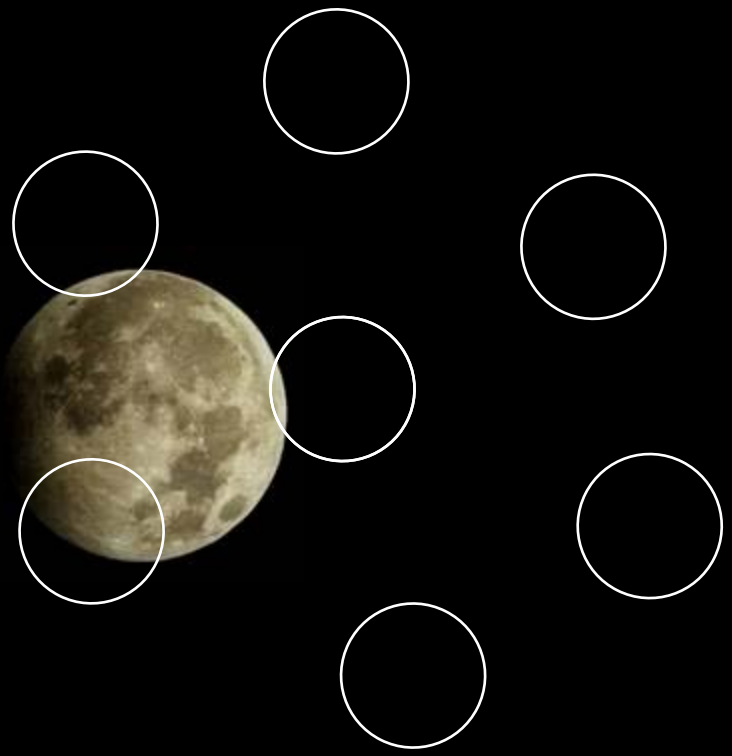

WSRT


VLA

Installing
Mu



Parkes 21cm Multibeam Experiment



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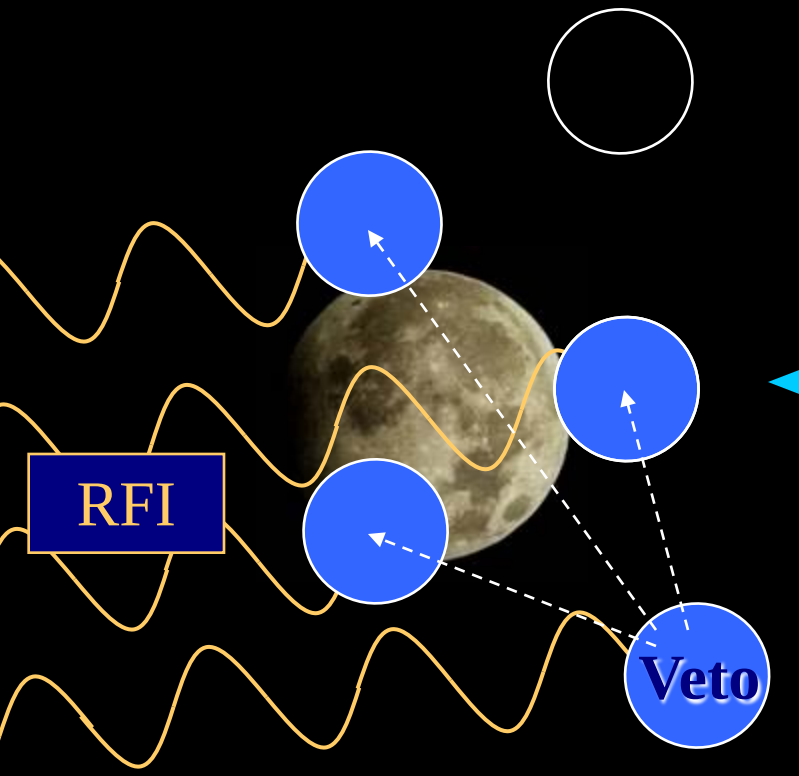
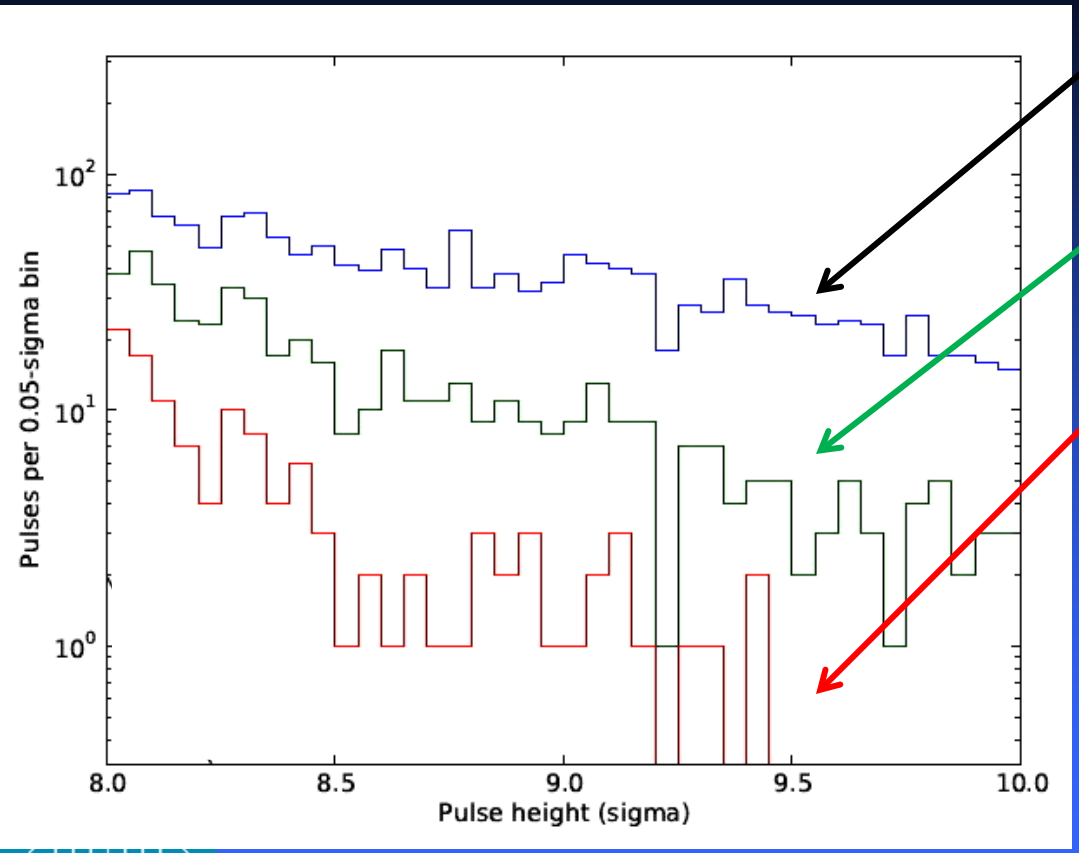


Centaurus A neutrinos

Parkes results
160 hours observing

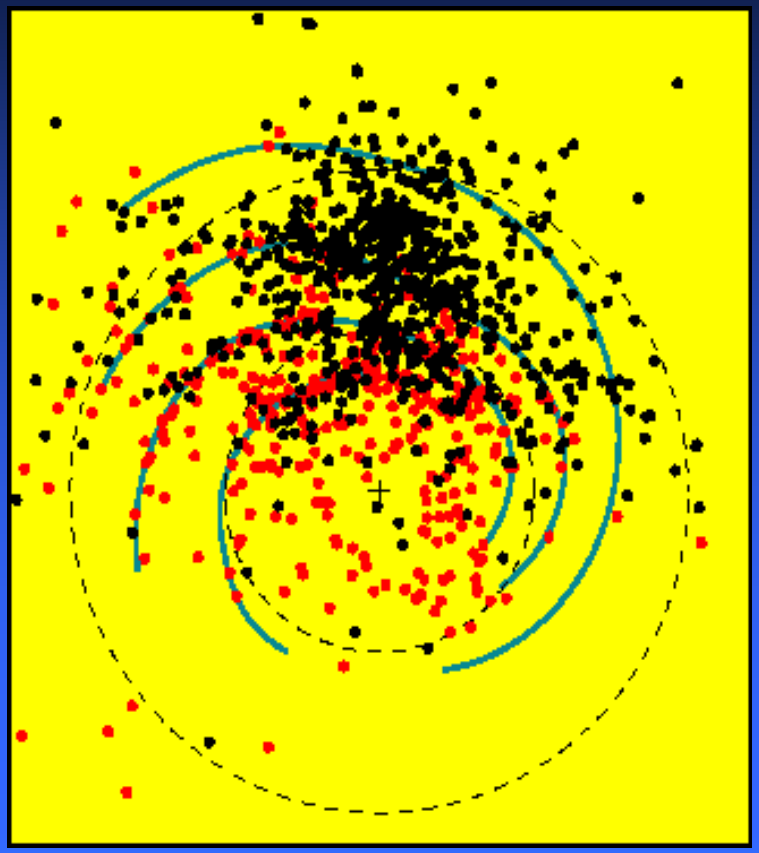


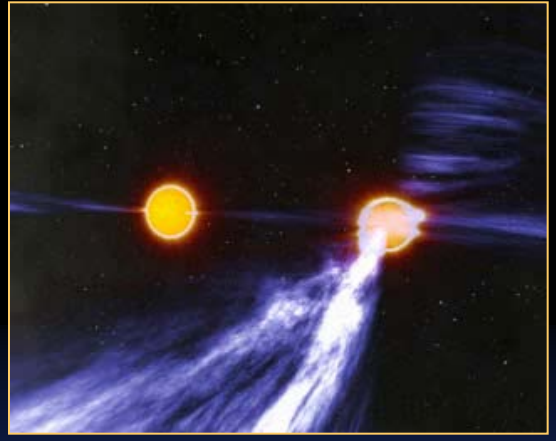
- Real time rfi screening
- Extended and multiple pulse rfi screening
- Multibeam rfi screening
- What are the remaining events???
  - No limb brightening
  - No radial polarisation
  - 27 events > 8.5sigma
    - ≈6hr per event

The Parkes Pulsar Survey

- Parkes 64m
- 1400 MHz
- 13 beams
- International collaboration - Australia, UK, Italy, US
- >600 new pulsars
- Double pulsar

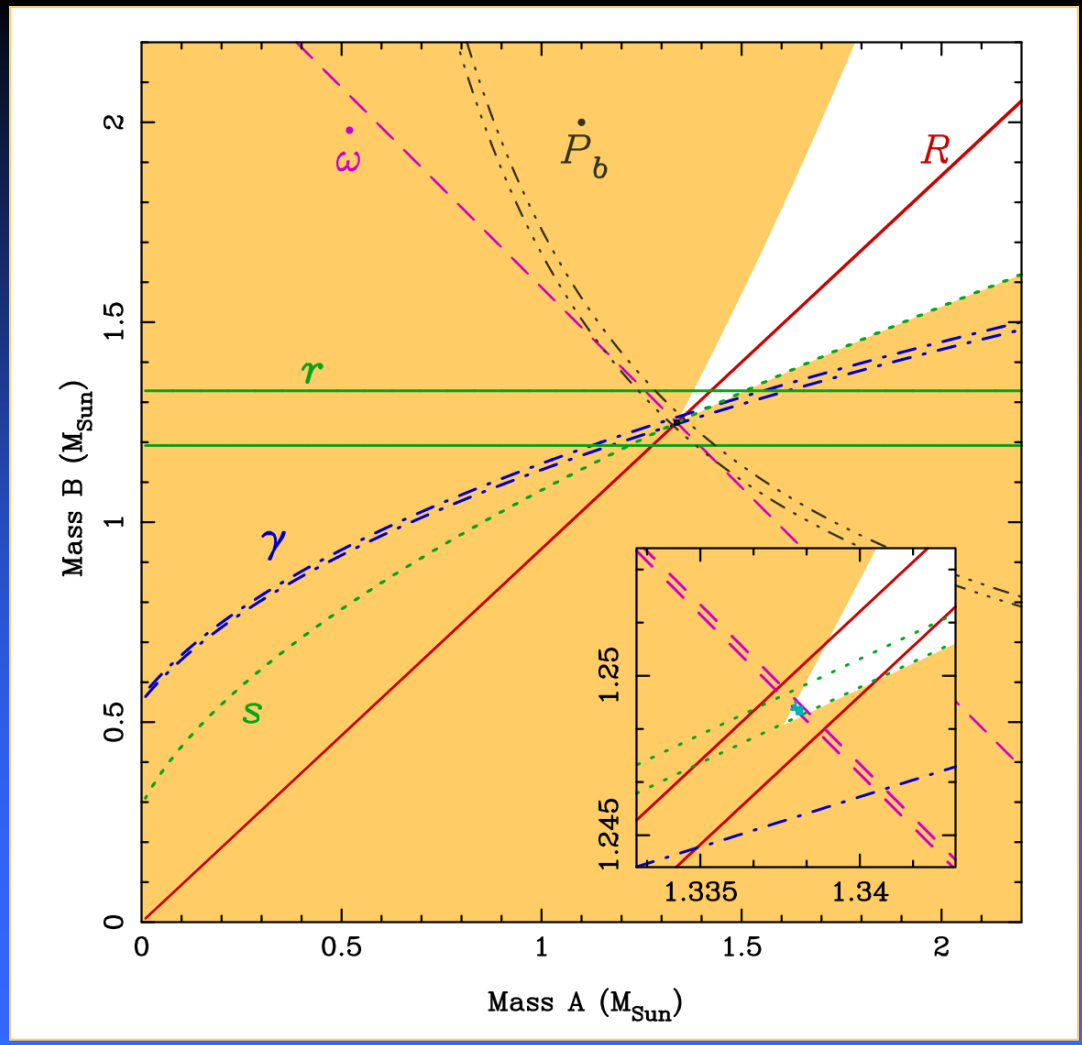
New situation:





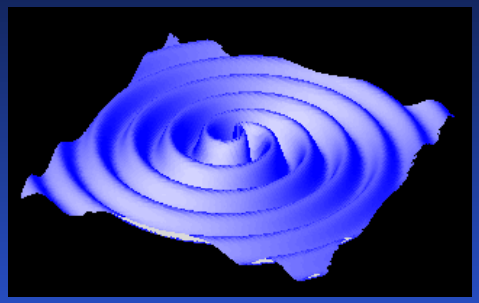
Double Pulsar Tests General Relativity

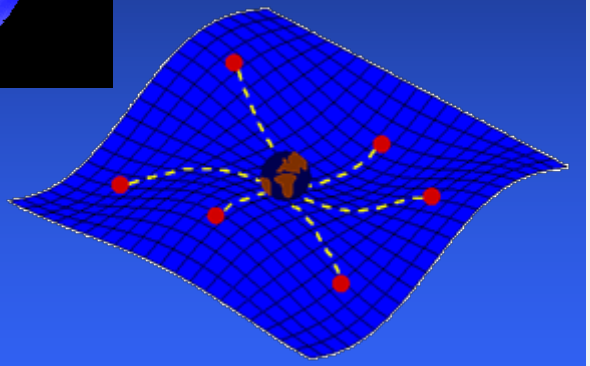
- Parkes Pulsar Survey
- Two neutron stars in 2.4 hour orbit
- General Relativity tested to 0.05%
  - 6 GR parameters tested
  - *Kramer et al (2006)*



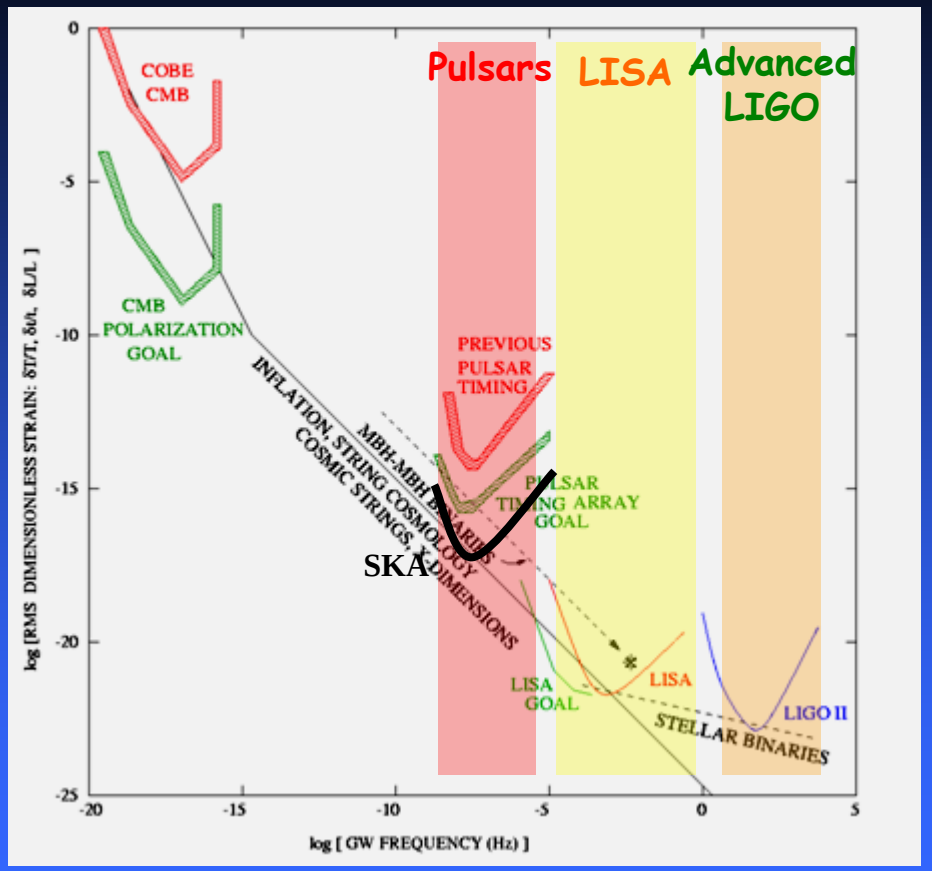
Pulsars as Gravitational Wave Detectors

Millisecond pulsars act as arms of huge detector:





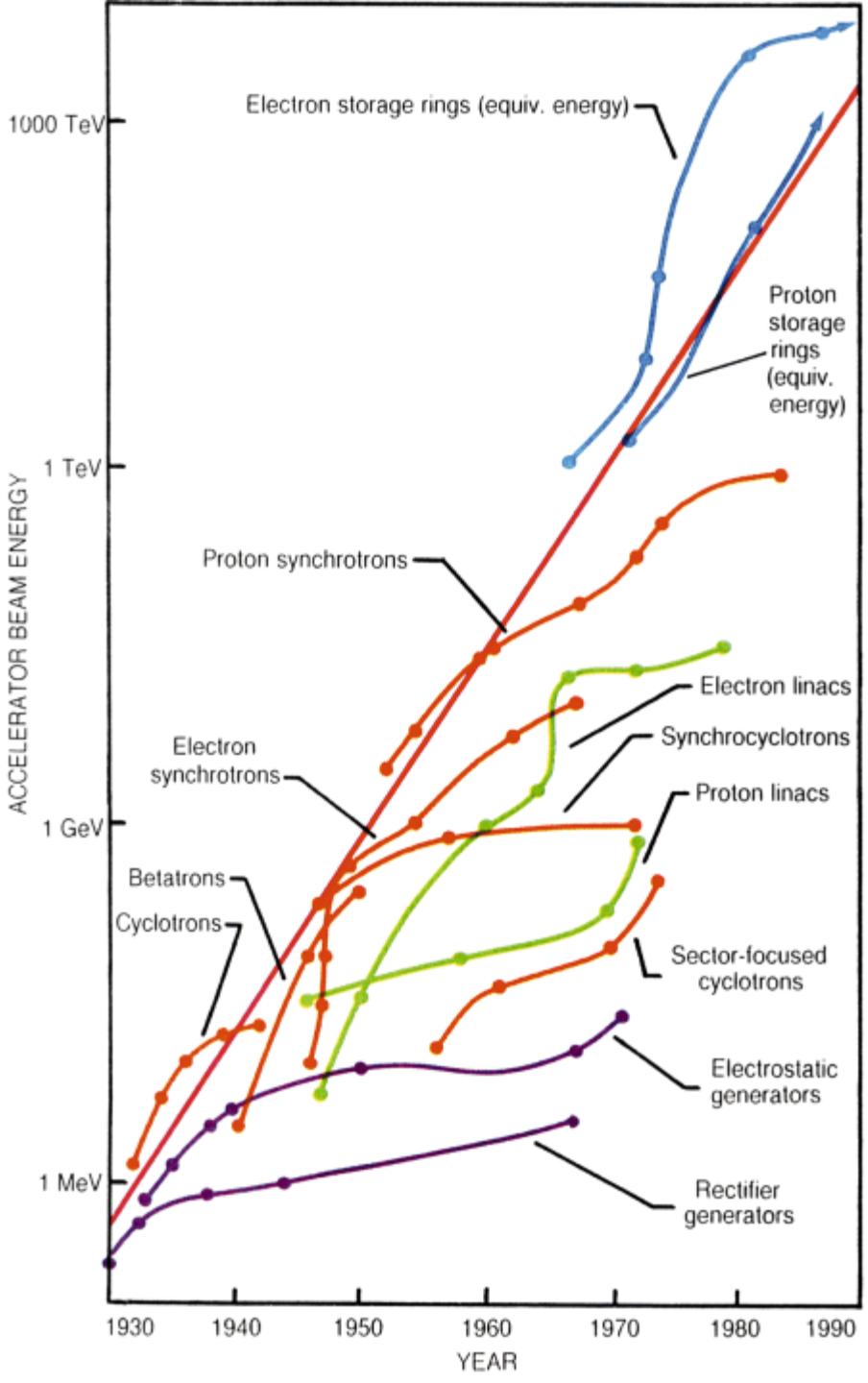
Pulsar Timing Array:
Look for global spatial pattern in timing residuals!



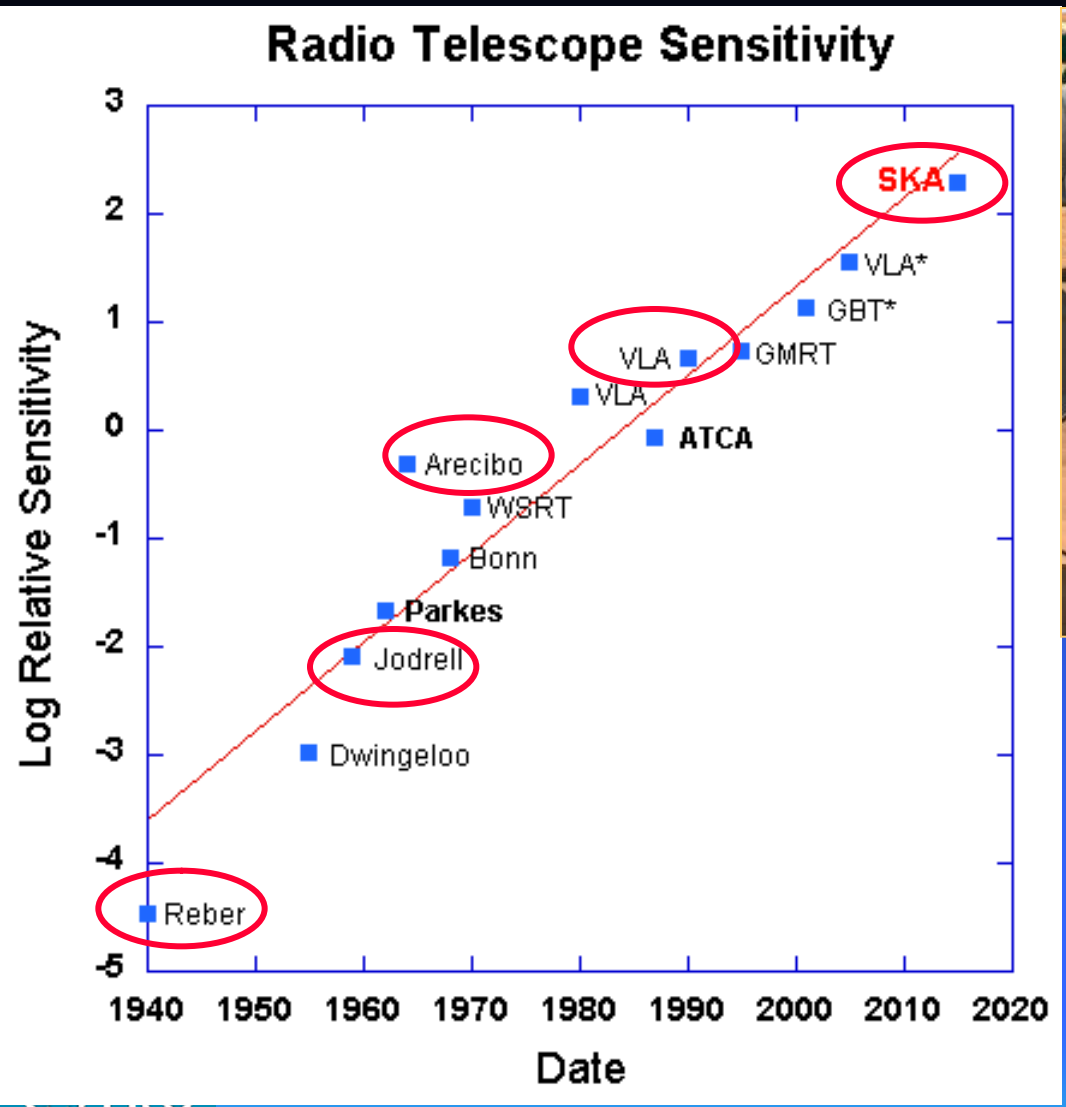
- Complementary in Frequency!

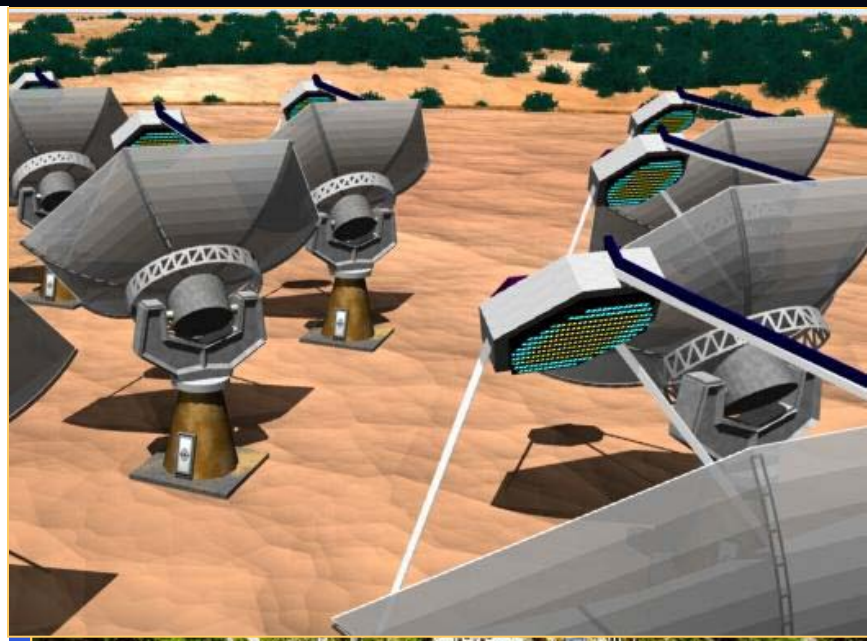
Exponential Growth

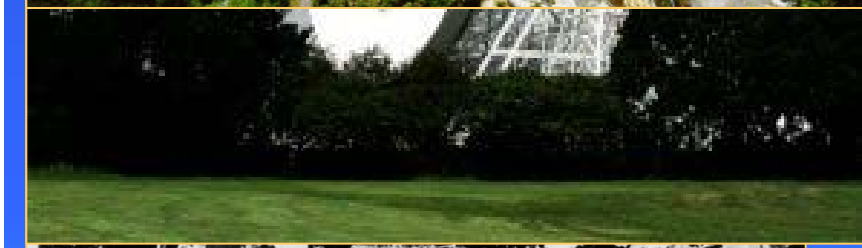
- Livingstone Curve
  - Blewett, Brookhaven 1950
  - Fermi 1954
  - Livingstone 1962
- Envelope is exponential
- Each technology saturates

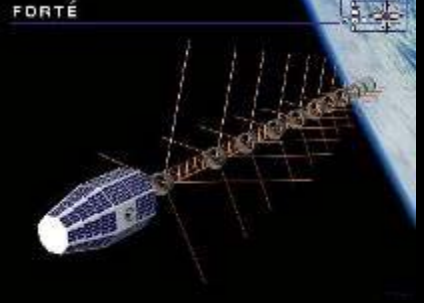


Radio Telescope Sensitivity



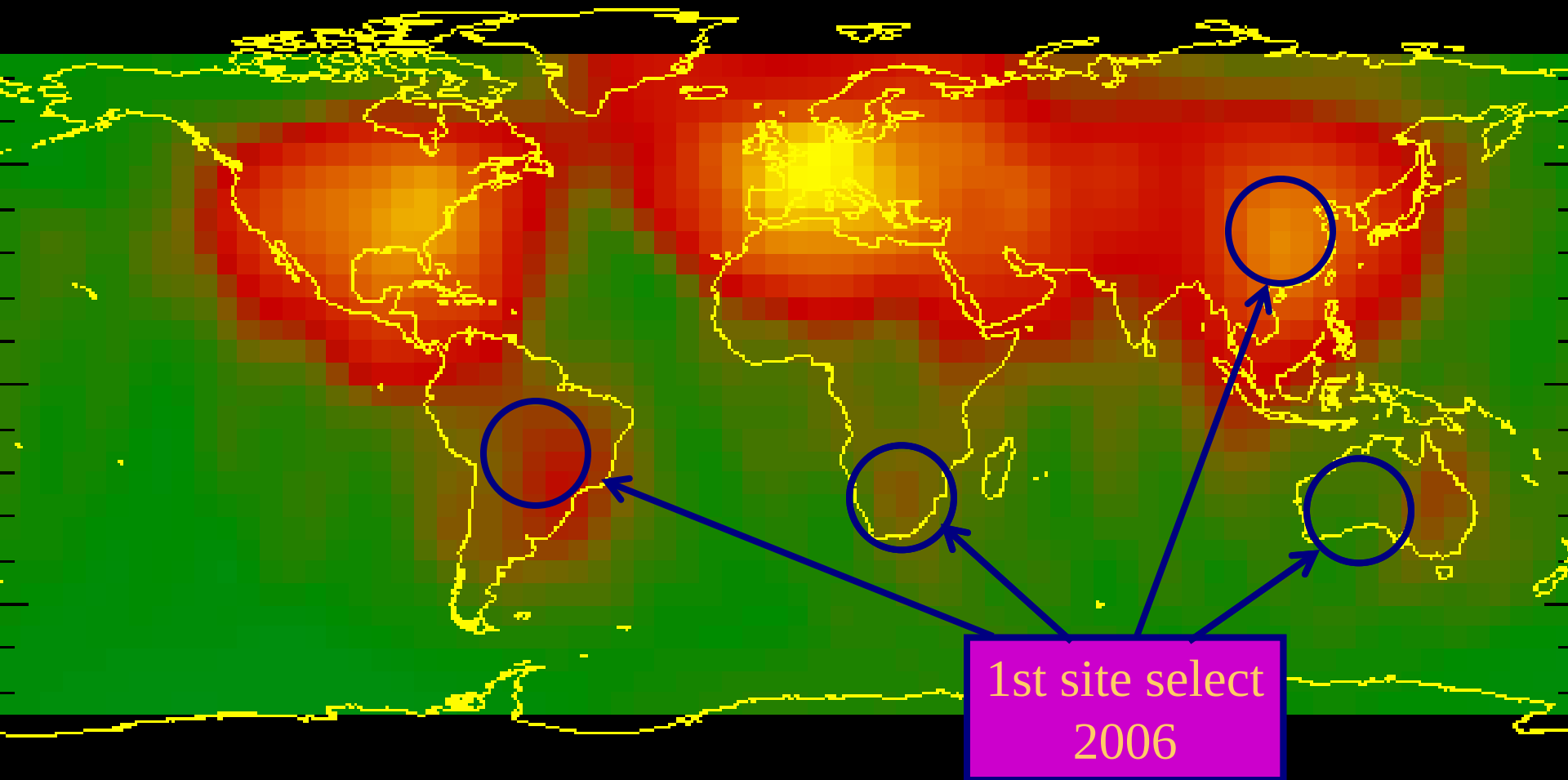


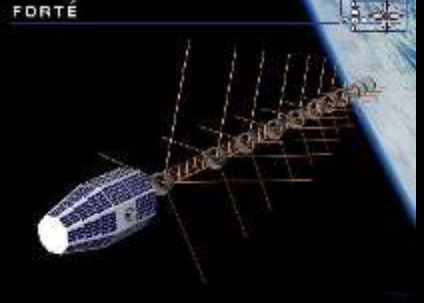




SKA site selection
The Quietest Locations in the World
Radio Noise Levels

Forte satellite: 131MHz





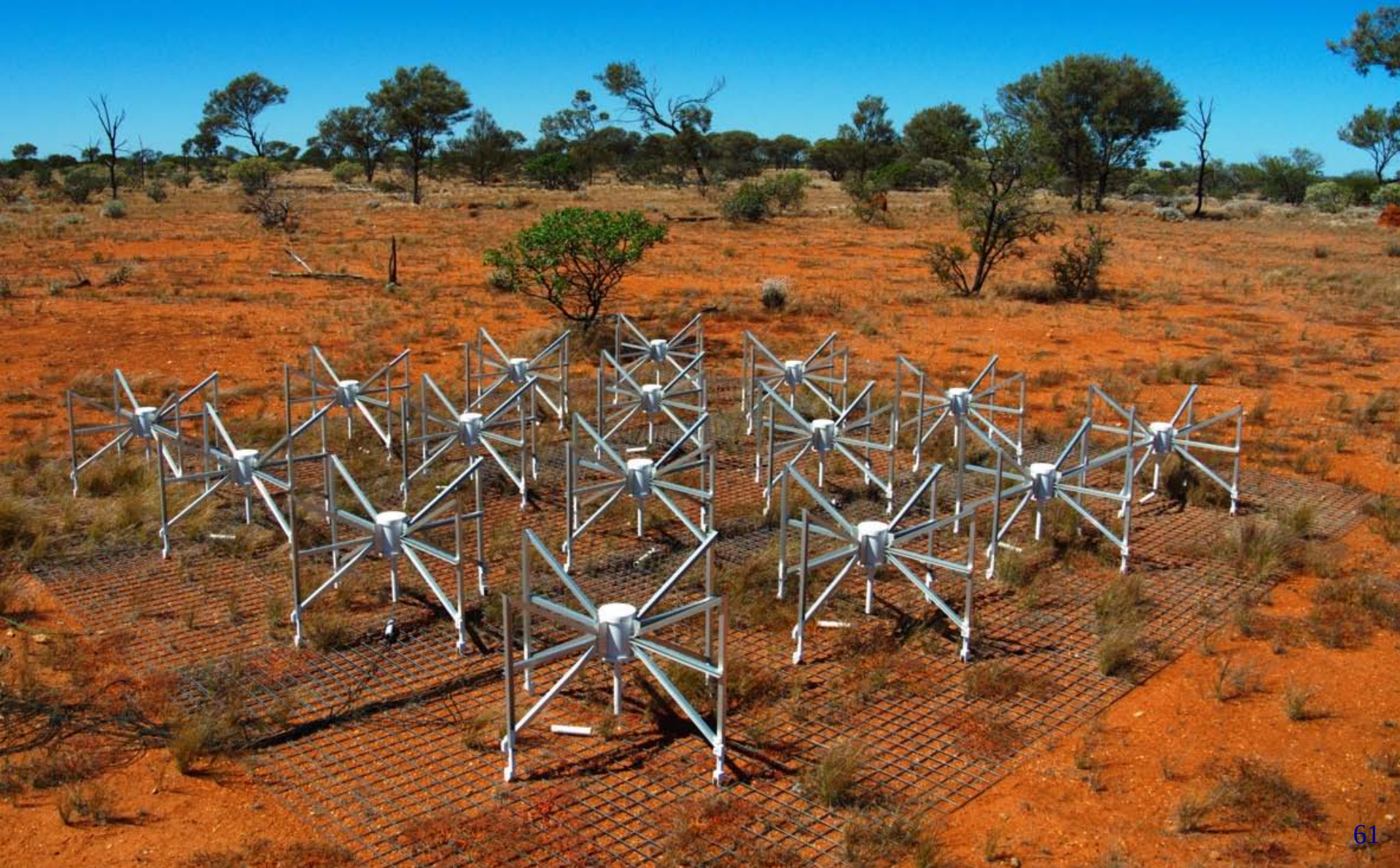
SKA site selection
The Quietest Locations in the World
Radio Noise Levels

Forte satellite: 131MHz

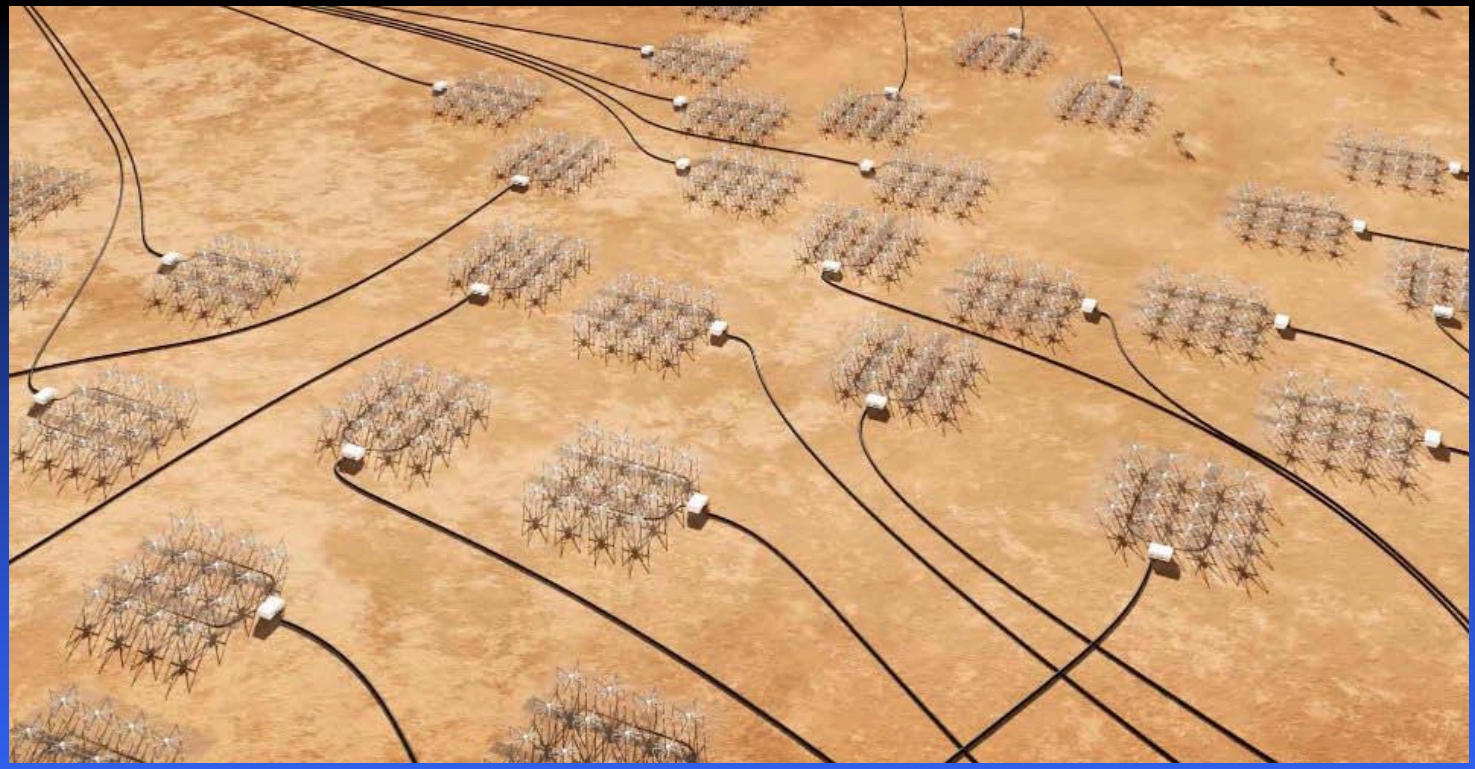
2nd site select 2012


SKA: 0.7 – 10Ghz

MWA: 80-300MHz => SKA1



MWA
128 stations to 2km

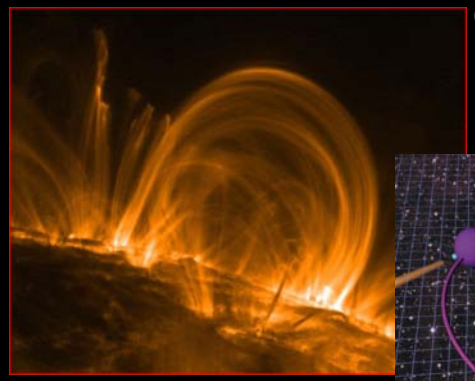


- Potential for time resolved imaging of radio emission from air showers
- 100% duty cycle
- Can this be used for mass composition?

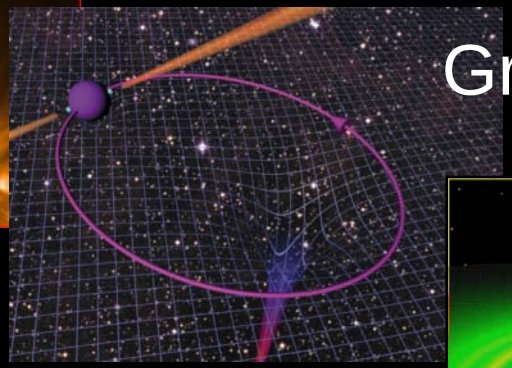
SKA Science Case

The First Stars

Cosmic Evolution



Cosmic Magnetism



Gravitational Physics

Origins of Life

The excitement of these powerful new instruments is not in the old questions they will answer but in the new questions they will raise.