Radio Astronomy School 2009

Radio Astronomy: the wider context

Ron Ekers, CSIRO

25 Sep 2009

Galileo Galilei - 1609

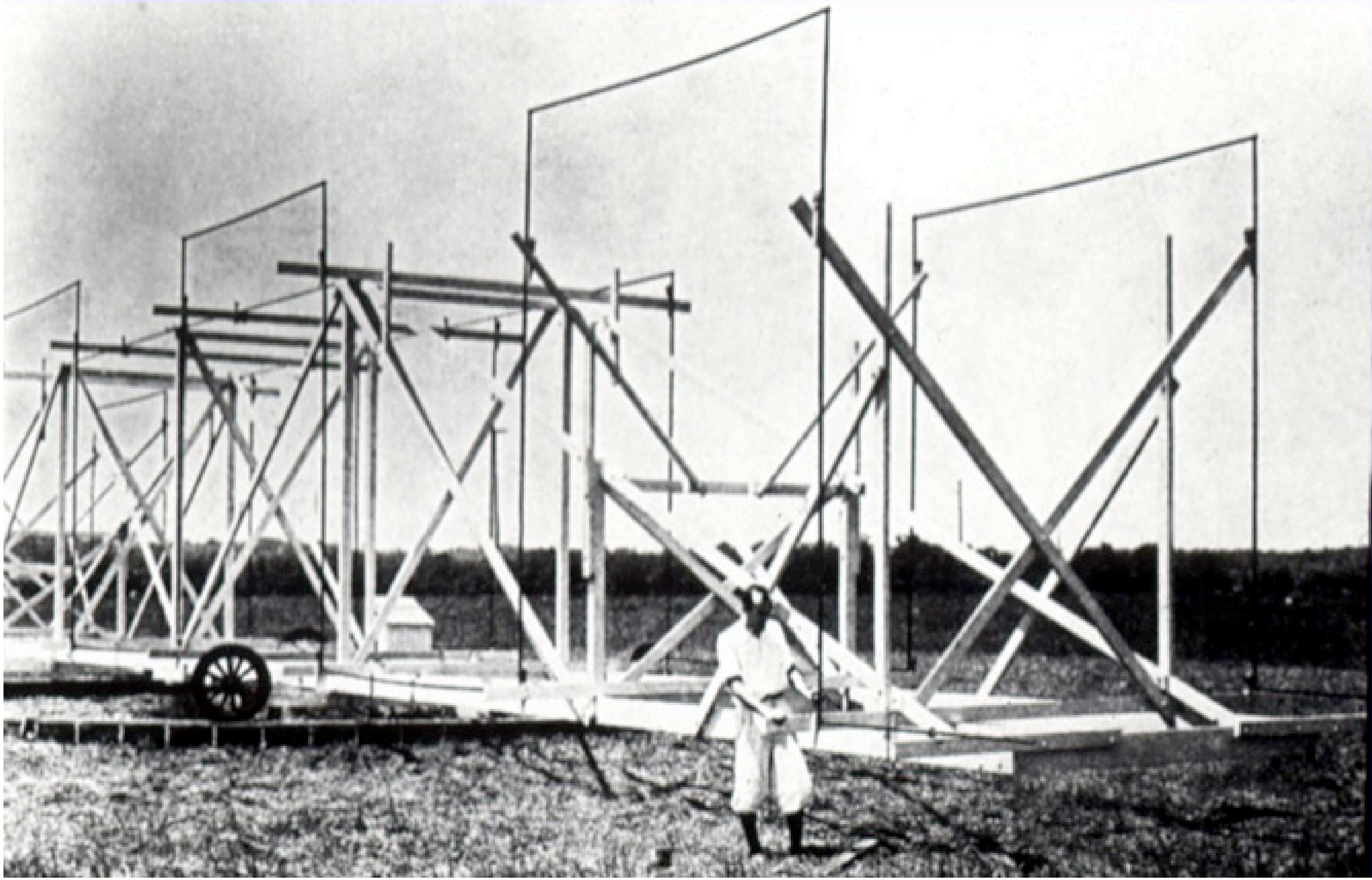
- Galileo builds a telescope and he sees the moons of Jupiter.

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

323 years later

- Mankind had its next new view of the Universe
- The discovery of a new kind of telescope opens a new window on the Universe using radio waves

Karl Jansky
Bell Telephone Laboratory 1932



Beginning of Radio Astronomy

- Jansky's Cosmic Hiss
  - Unexpected source of noise peaking each day
  - signal arrives *4 min* earlier each day
  - reaction from Bell Labs *"so faint not even interesting as a source of radio interference!"*
  - not accepted by the astronomical community at the time
    - » no theoretical framework
- Pasteur
  - *In the field of observation, chance favours the prepared mind*

Cliff Interferometer

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

Cliff interferometer CSIRO, Australia (1948)

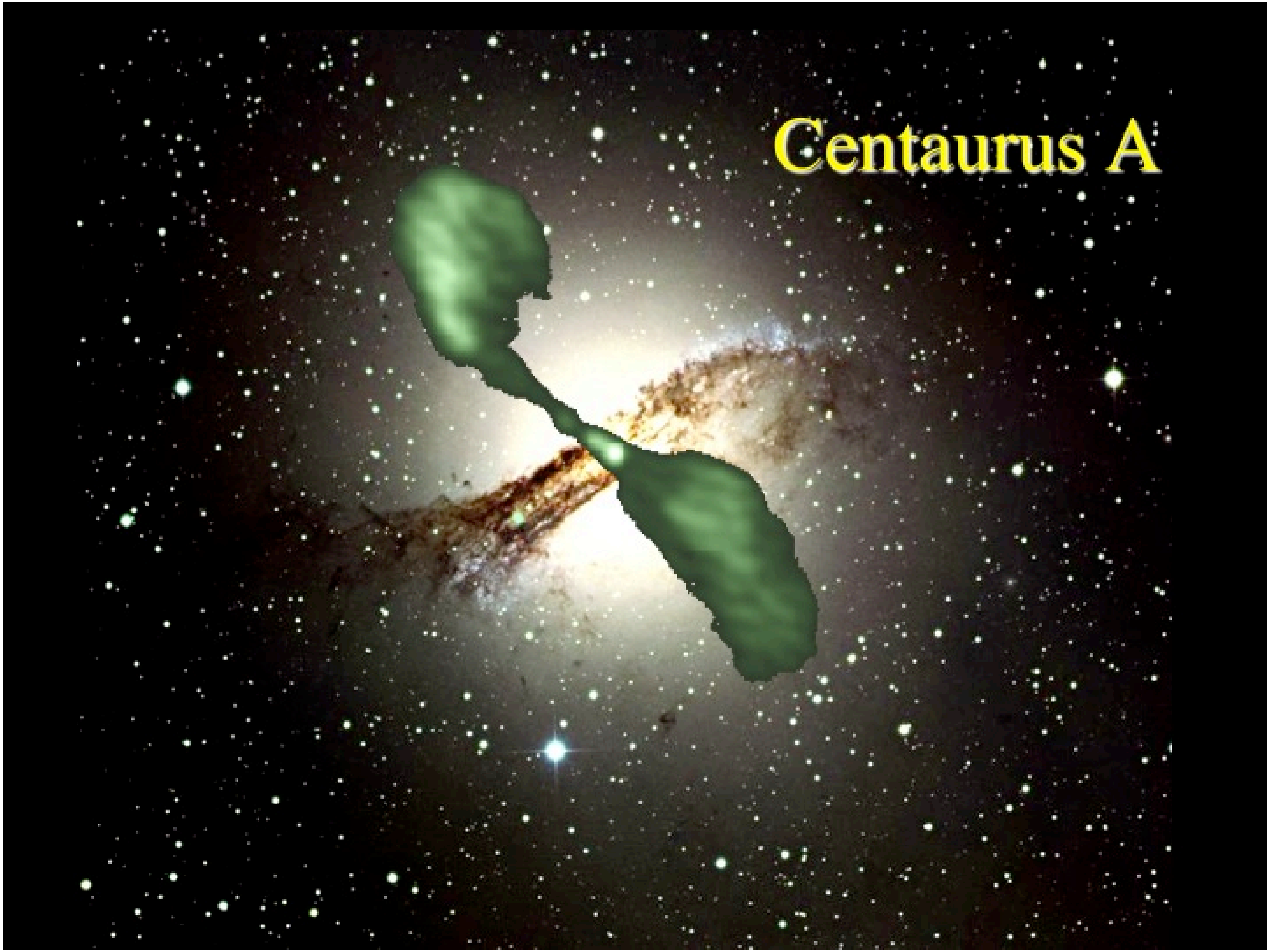
Built to identify the radio stars (John Bolton)

Idea from multiple path interference in ship borne radar

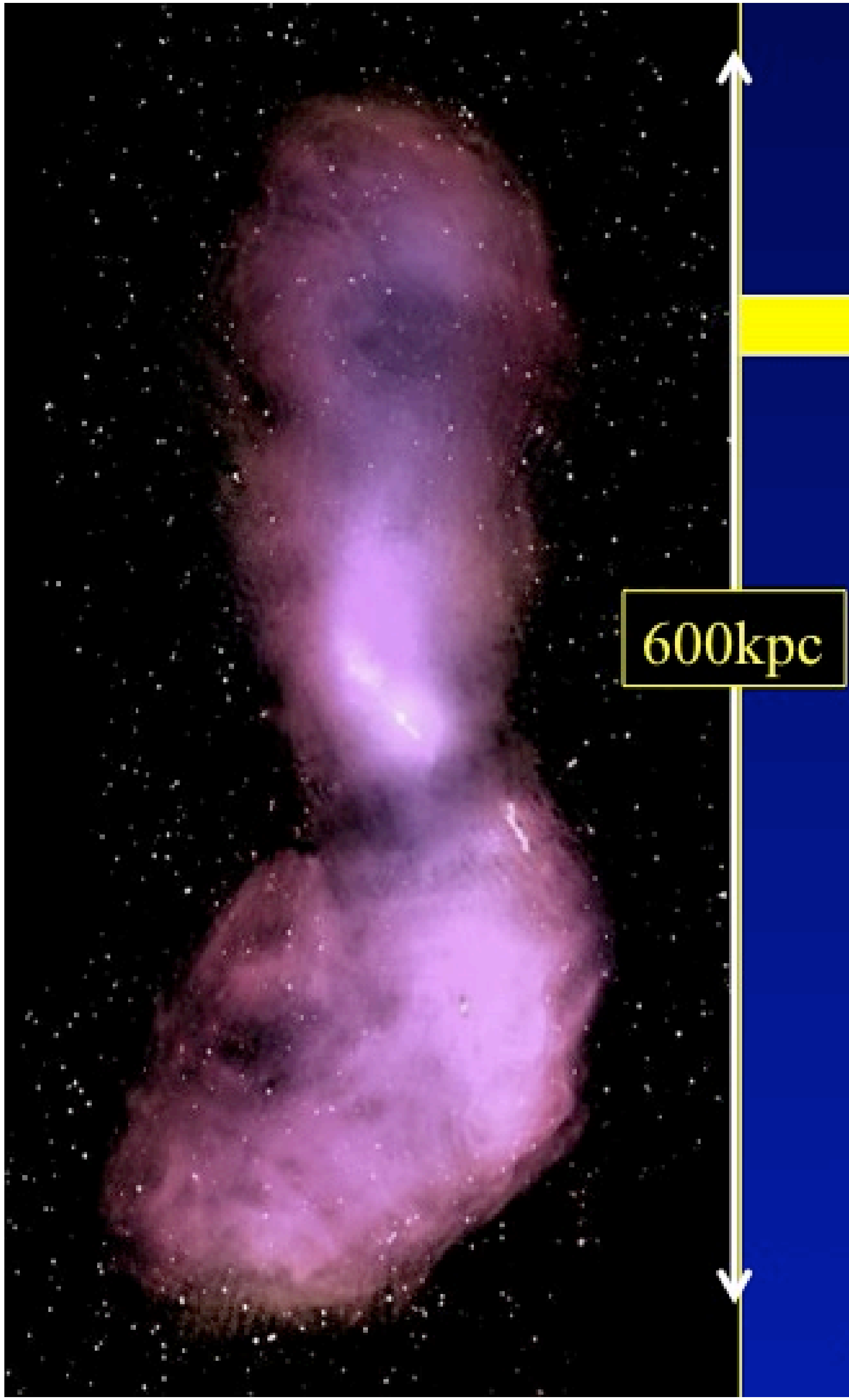
Discovery of extragalactic radio sources at great distances

Centaurus A , Virgo A, Cygnus A, Fornax A

Had to hedge on extragalactic origin to get paper published

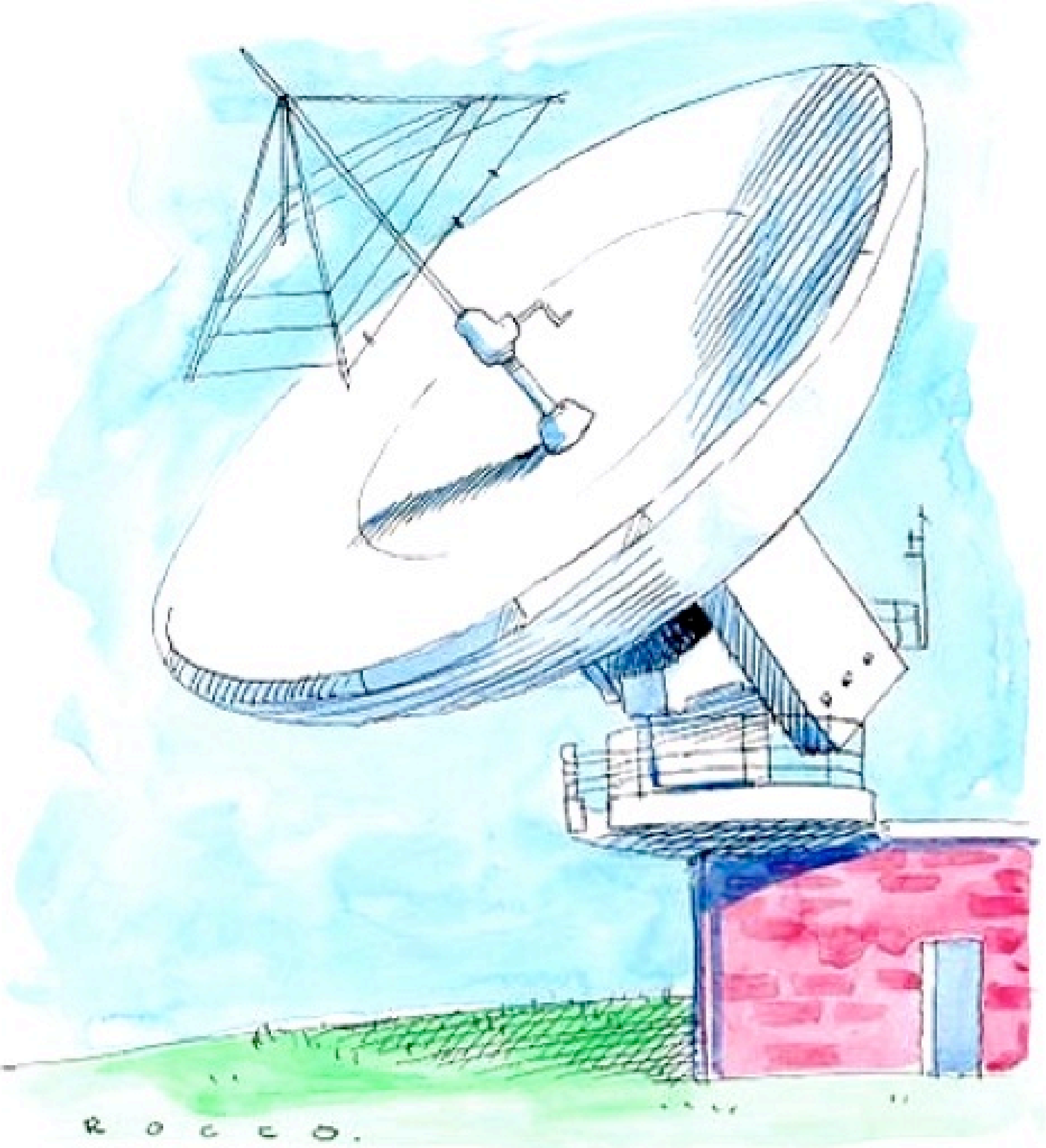

Centaurus A

Centaurus A
ATCA Mosaic



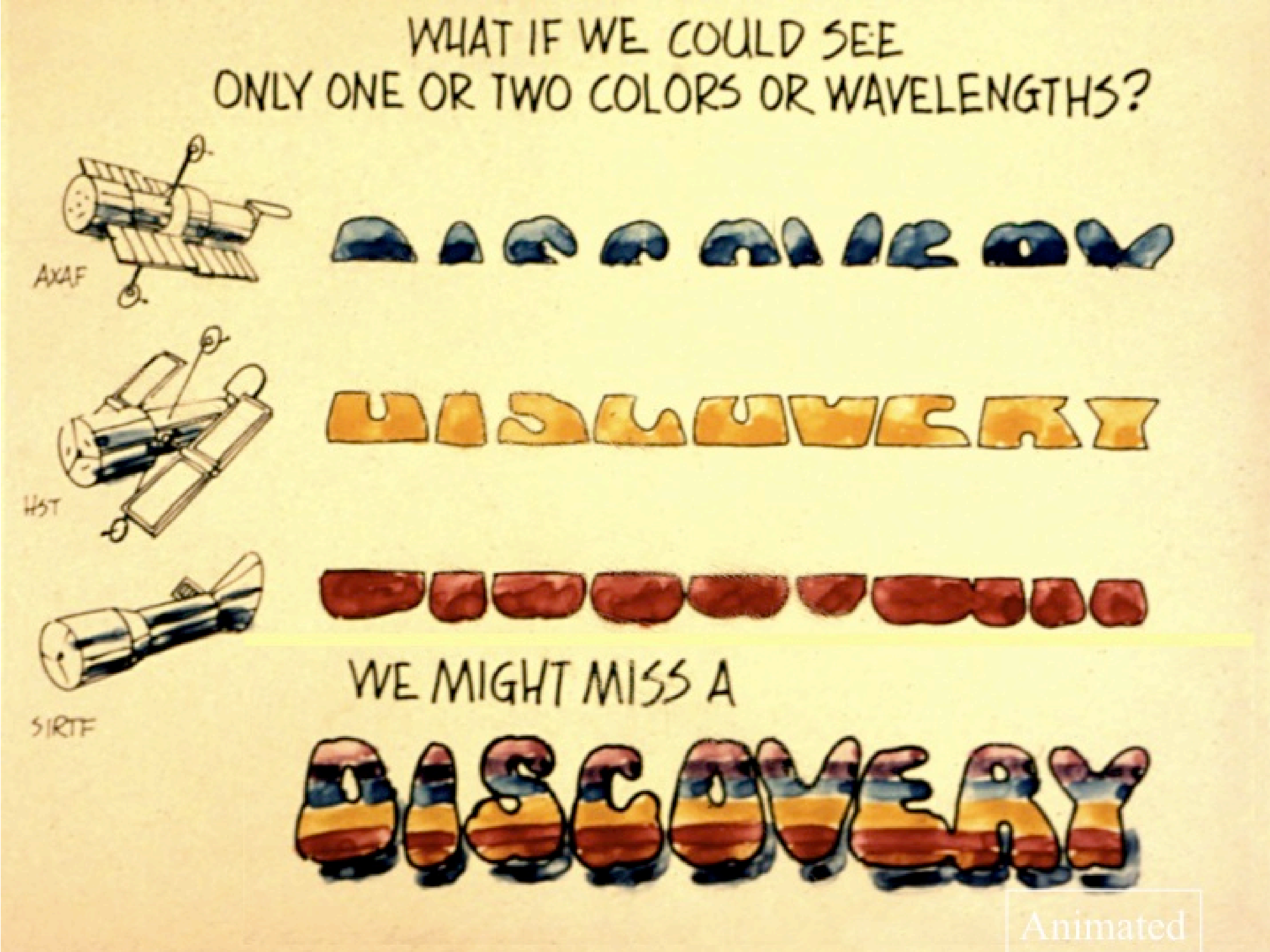
- 1.4GHz continuum
- full polarization
- 4 x 750m array configuration
- 406 pointings, hexagonal grid
- Σ FOV 45 deg^2
- θ~45"
- σ~0.26mJy/beam (0.1K)
- *Ilana Feain, Tim Cornwell, Ron Ekers*

Feain 2009


ROCCO.

Why we need more than one wavelength

- We can only explore the distant universe by observing the radiation which reaches us


WHAT IF WE COULD SEE
ONLY ONE OR TWO COLORS OR WAVELENGTHS?
AXAF
HST
SIRTF
WE MIGHT MISS A
DISCOVERY
Animated

CSIRO

Nobel Prizes in Astronomy

1936 Cosmic Rays	Victor Franz Hess (shared)
1974 Aperture Synthesis	Sir Martin Ryle,
1974 Pulsars	Antony Hewish
1978 CMB	Arno A. Penzias, Robert W. Wilson
1983 Stellar evolution	Subrahmanyan Chandrasekhar
1983 Chemical elements	William Alfred Fowler
1993 Gravity radiates	Russell A. Hulse, Joseph H. Taylor, Jr.
2002 Cosmic neutrinos	Raymond Davis, Jr., Masatoshi Koshiba,
2002 Cosmic X-rays	Riccardo Giacconi
2006 CMB	John C. Mather, George F. Smoot

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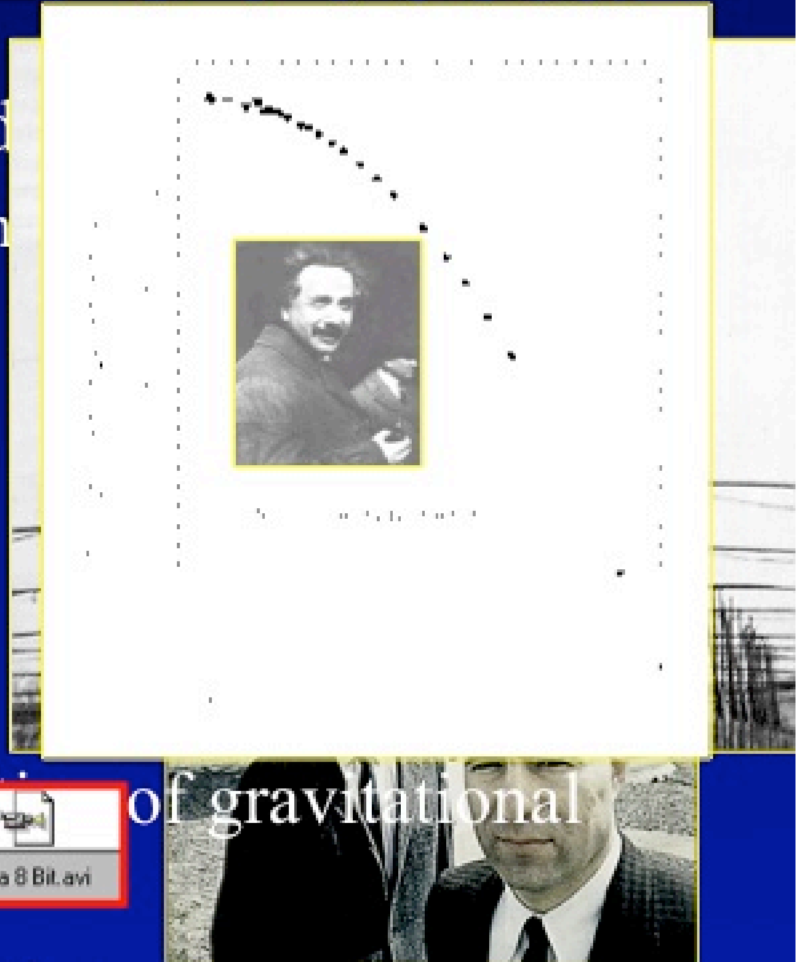
The 3 Nobel prizes in Radio Astronomy

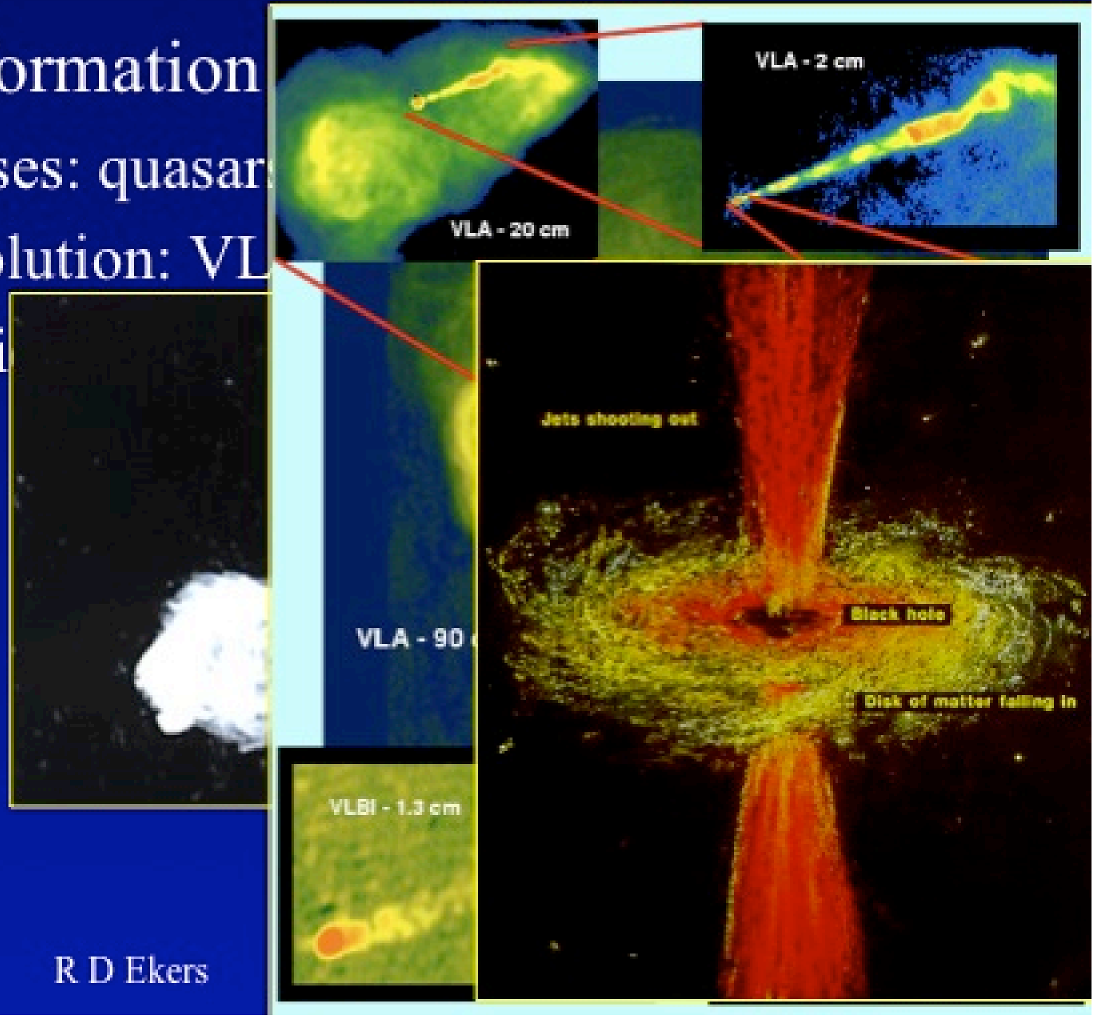


- Cosmic Microwave Background
  - Nobel prize to Penzias and Wilson
    - » Bell Telephone Labs
  - Technology driven serendipity
- Discovery of neutron stars
  - radio pulsations (pulsars)
  - Joclyn Bell & Tony Hewish
- Verification of Einstein's predi[illegible] of gravitational radiation
  - 1993 Noble prize to Taylor and Hulse

Vela 8 Bit.avi

Radio Astronomy

- Provides unique information
  - non-thermal processes: quasar
  - highest angular resolution: VL
  - low opacity: Galacti



Doing the best science

- The telescope as an analytic tool
  - how to use it
  - integrity of results
- Making discoveries
  - discoveries are driven by instrumental developments
  - recognising the unexpected phenomenon
  - discriminate against errors

Imaging at Radio Wavelengths

- Bad news
  - Radio waves are big
- Good news
  - Radio frequencies are low

Resolving Power

- Angular resolution = wavelength/aperture

	Light	Radio
Wavelength	**0.00005cm**	**10cm**
Aperture	**10cm**	**200m**
Resolution	**0.00005/10 rad = 1" arc**	**10/2000 rad = 100" arc**


Greenbank 300’ Radio Telescope

Greenbank 300' Radio Telescope

Array Imaging

Examples of Technology Spin-off from Radio Astronomy

- Microwave Landing System
  - Selected as the International Standard in 1981
  - Designed by Australian Radio Astronomers
- Communications Antennas
  - Based on Australia Telescope design
  - $50m export industry - radio telescope cost $40m
- Wideband feeds
  - High performance with 3:1 wavelength coverage
- Space antennas arrays with shaped beams
- Holographic measurement of antenna surfaces

IEEE 802.11 wireless network standard

- 1970's John O'Sullivan searches for Exploding Black Holes using the WSRT
  - There has to be a better way!
- 1977 O'Sullivan explains why adaptive optics works
  - Paper based on redundant calibration in radio astronomy
- 1980's Fourier Transform on a chip
- 23 Jan 1996 CSIRO obtains US patent #5,487069
  - O'Sullivan, Daniels, Percival, Ostry, Deanne
- 150 million devices sold using this technology
  - Estimated that 500million will be sold by 2009

802.11 WLAN patent

CSIRO patent case closes with secret deals

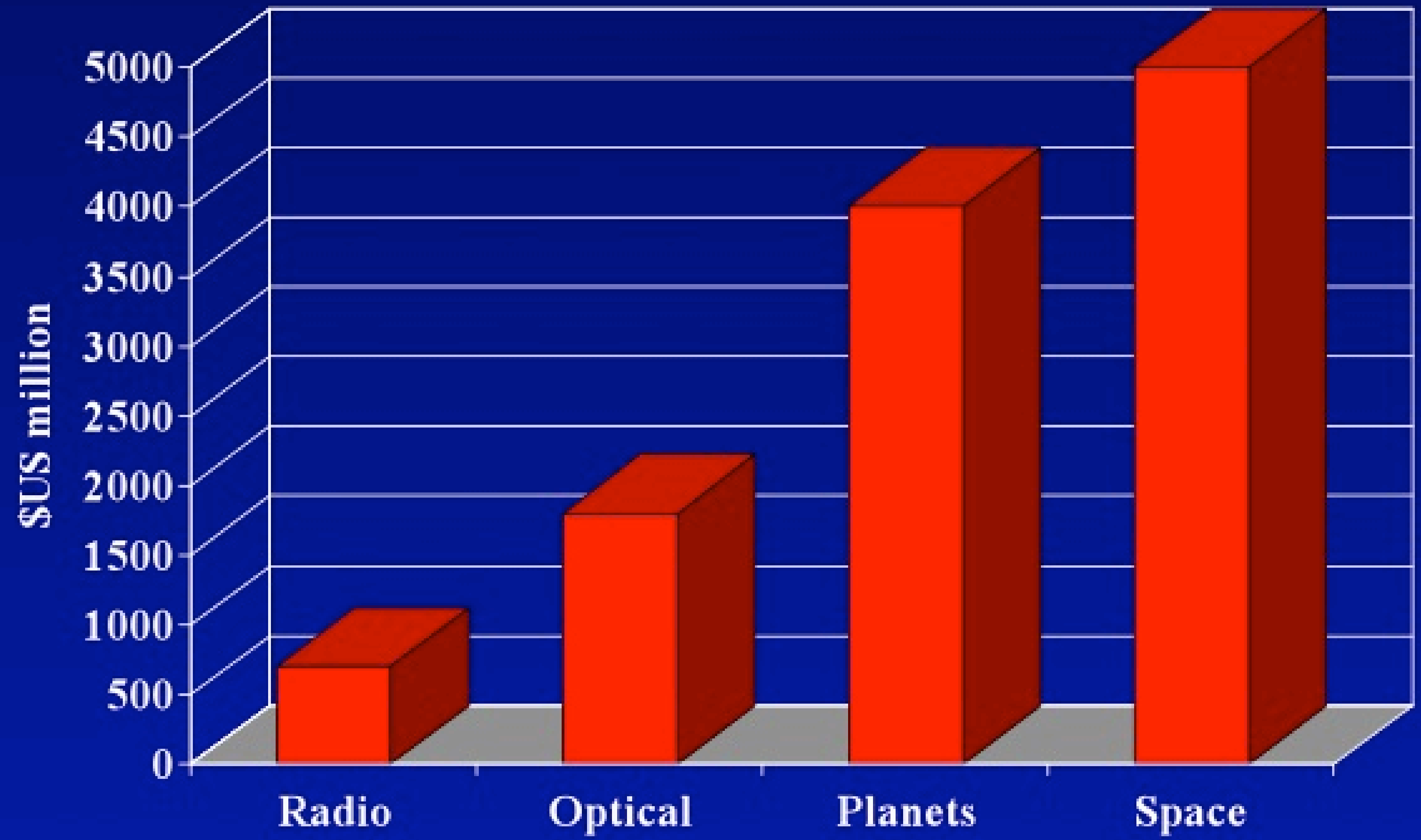
By Brett Winterford
22 April 2009 11:00AM
Tags: csiro | wireless | lan | wlan | buffalo | microsoft | hp | dell | intel | toshiba | fujitsu

SHARE

A patent battle between Australia's CSIRO and 14 of the world's largest technology companies has settled out of court with a series of secret deals.

CSIRO today confirmed that the patent case being fought in the Eastern District Court of Texas over CSIRO's claim to inventing the technology behind Wireless Local Area Networks (WLANs) has concluded "successfully".

Astronomy Projects: Funded 2000-2005



22 August 2001: Sen. Minchin awards $23.5m to the MNRF astronomy proposal

$50Australian bill

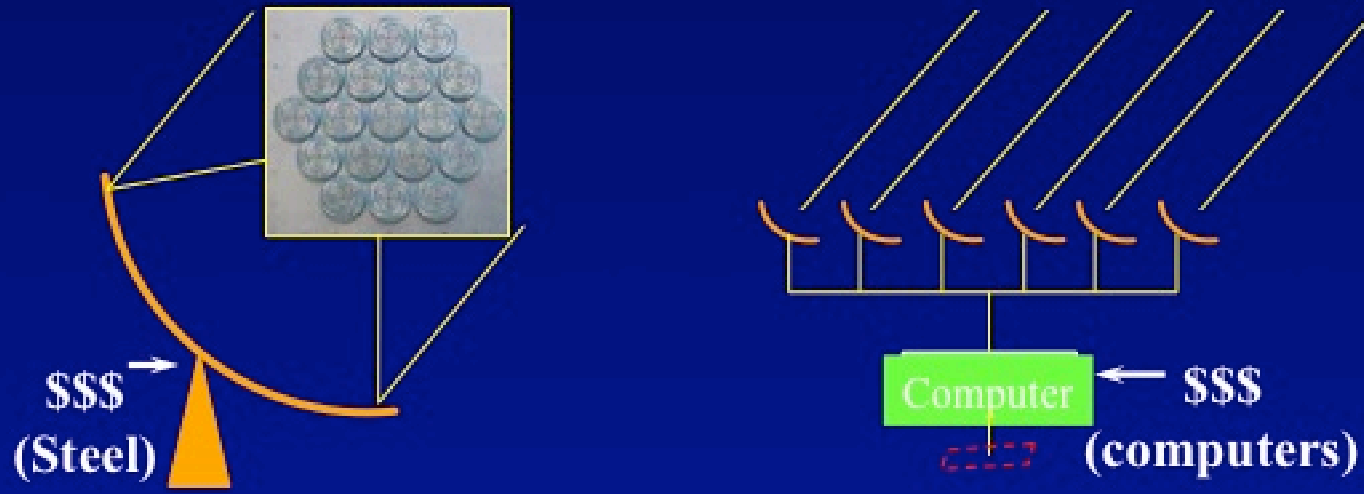
Big Telescopes are expensive

- Make optimal use of the collecting area
- Space
  - Focal or Aperture plan arrays
- Frequency
  - Simultaneous frequency coverage
  - Wide bandwidth
- Time
  - Funding for an upgrade path

Parkes Multibeam Receiver

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

Big Dishes or Arrays



- At high frequency the balance shifts to larger dish size
  - Increased cost contribution of the lowest noise receivers
  - Cost of backend bandwidth

Focal & Aperture Plane Arrays

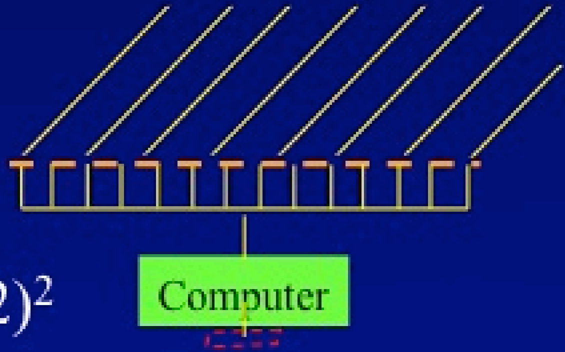
- There is an equivalence between focal plane arrays and aperture plane arra

Dishes & Arrays

- Similarities
  - Survey sensitivity for a given total collecting area is determined by the number of receivers in both cases
- Differences
  - Compactness (single dish) v Resolution (aperture array)
  - Analog v digital signal processing
  - Cost in mechanical structure v computers

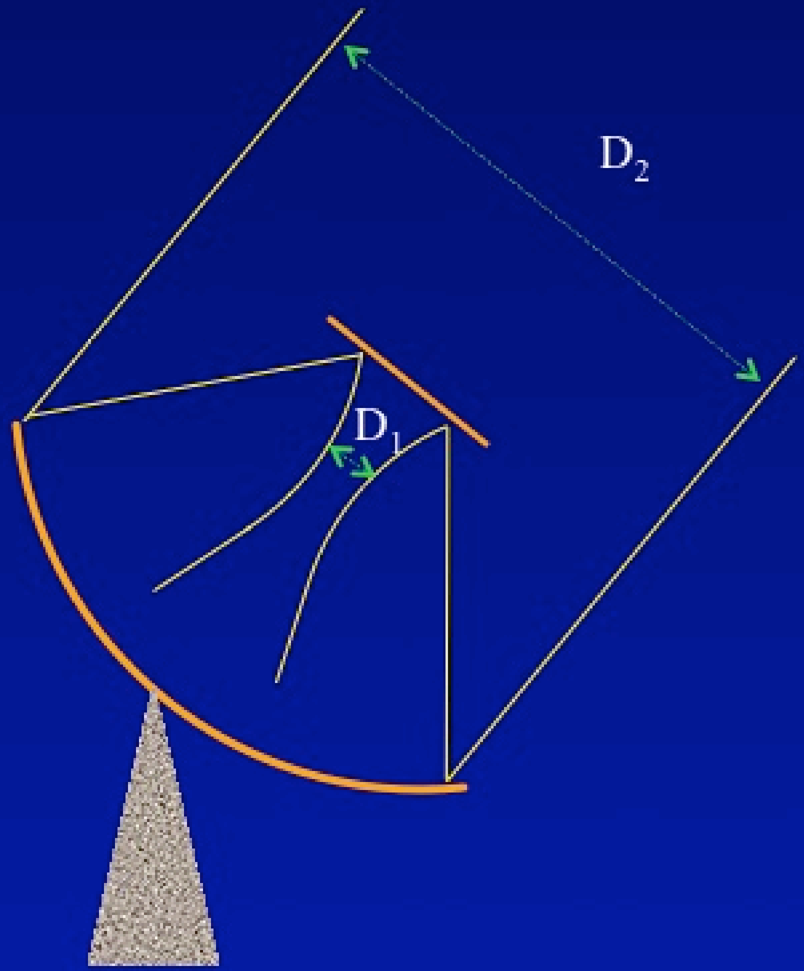
Aperture Array or Focal Plane Array?

- Why have a dish at all?
  - Sample the whole wavefront
  - n elements needed: $n \propto \text{Area}/(\lambda/2)^2$
  - For 100m aperture and λ = 20cm, $n=10^4$
    - » Electronics costs too high!



- Phased Array Feeds
  - Any part of the complex wavefront can be used
  - Choose a region with a smaller waist
  - Need a concentrator

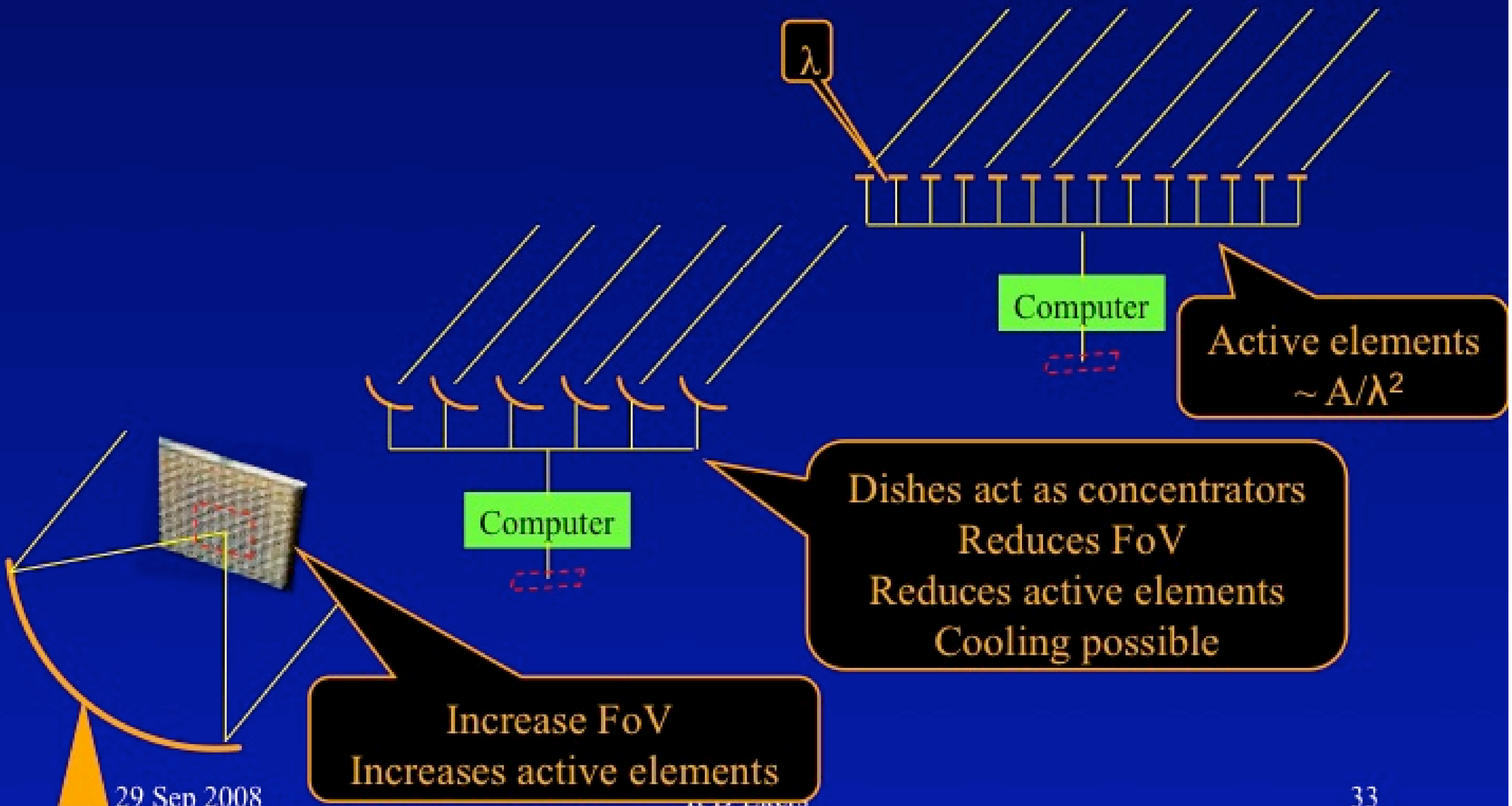
Find the Smallest Waist use dish as a concentrator



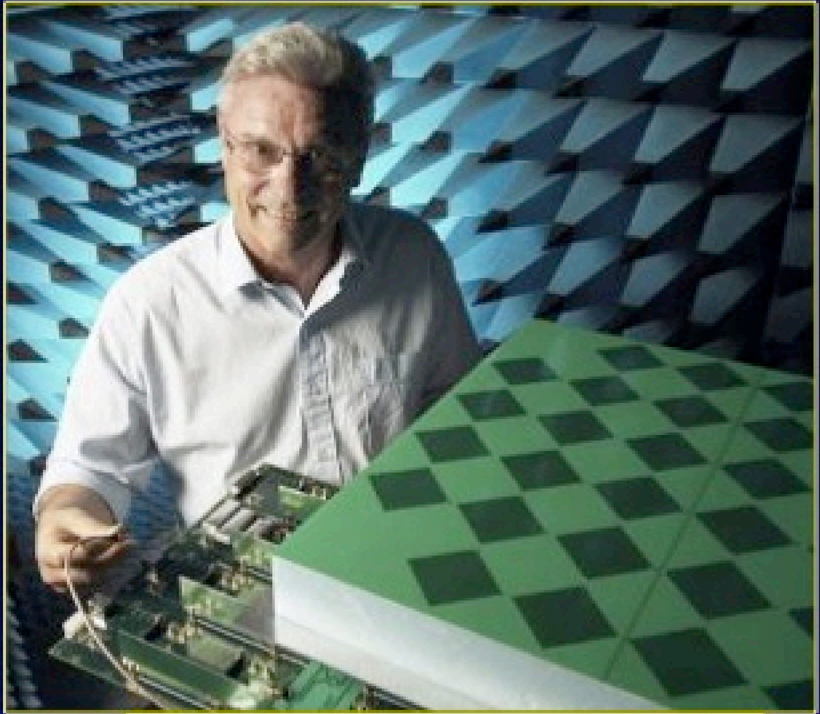
$D_1 < D_2$

$n_1 < n_2$

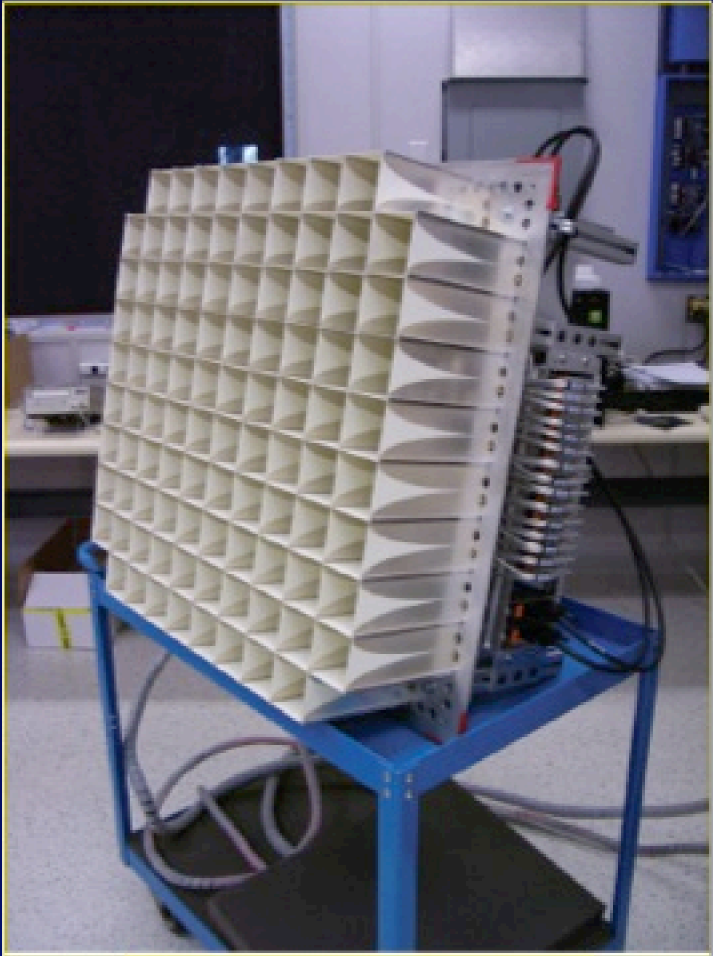
Radio Telescope Imaging image v aperture plane



Some PAF designs



Checker board - ATNF

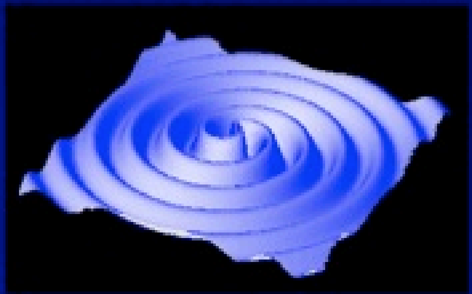


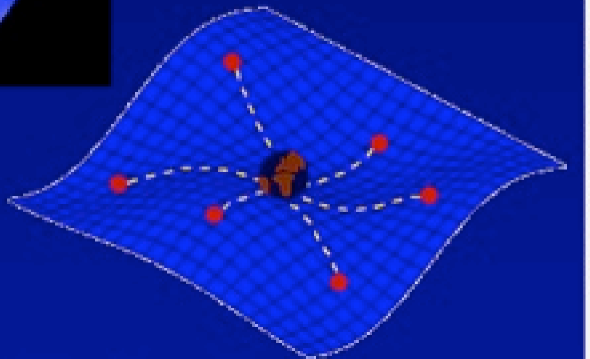
Vivaldi - DRAO

What more is there to know?

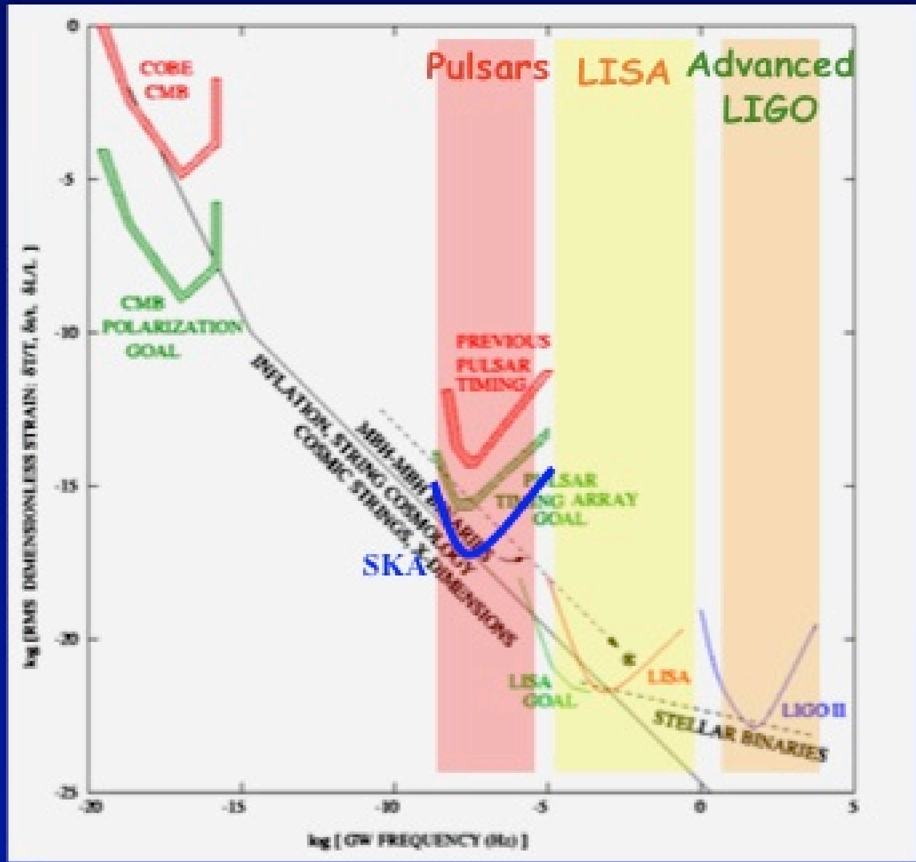
Pulsars as Gravitational Wave Detectors

Millisecond pulsars act as arms of huge detector:



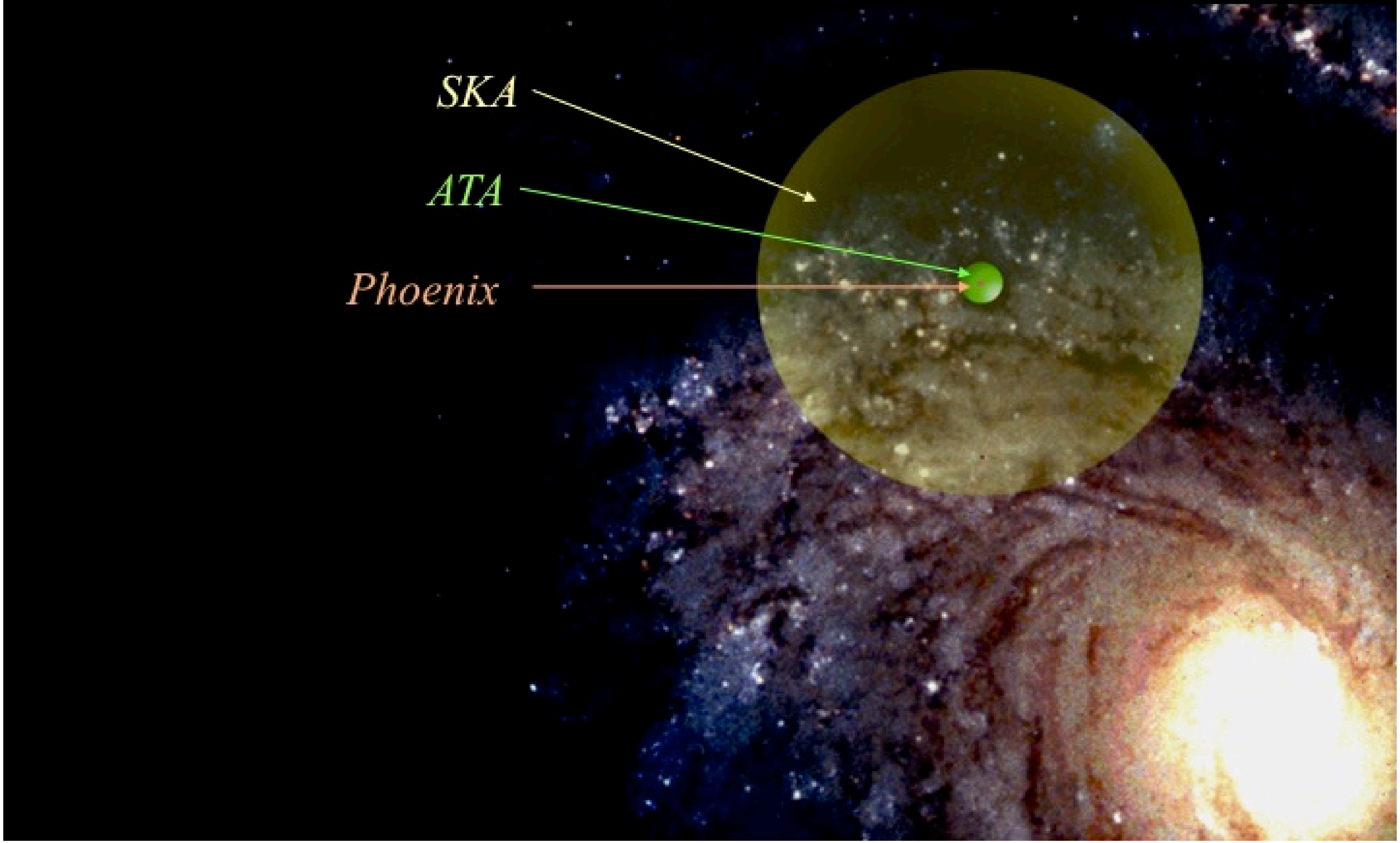


Pulsar Timing Array:
Look for global spatial pattern in timing residuals!

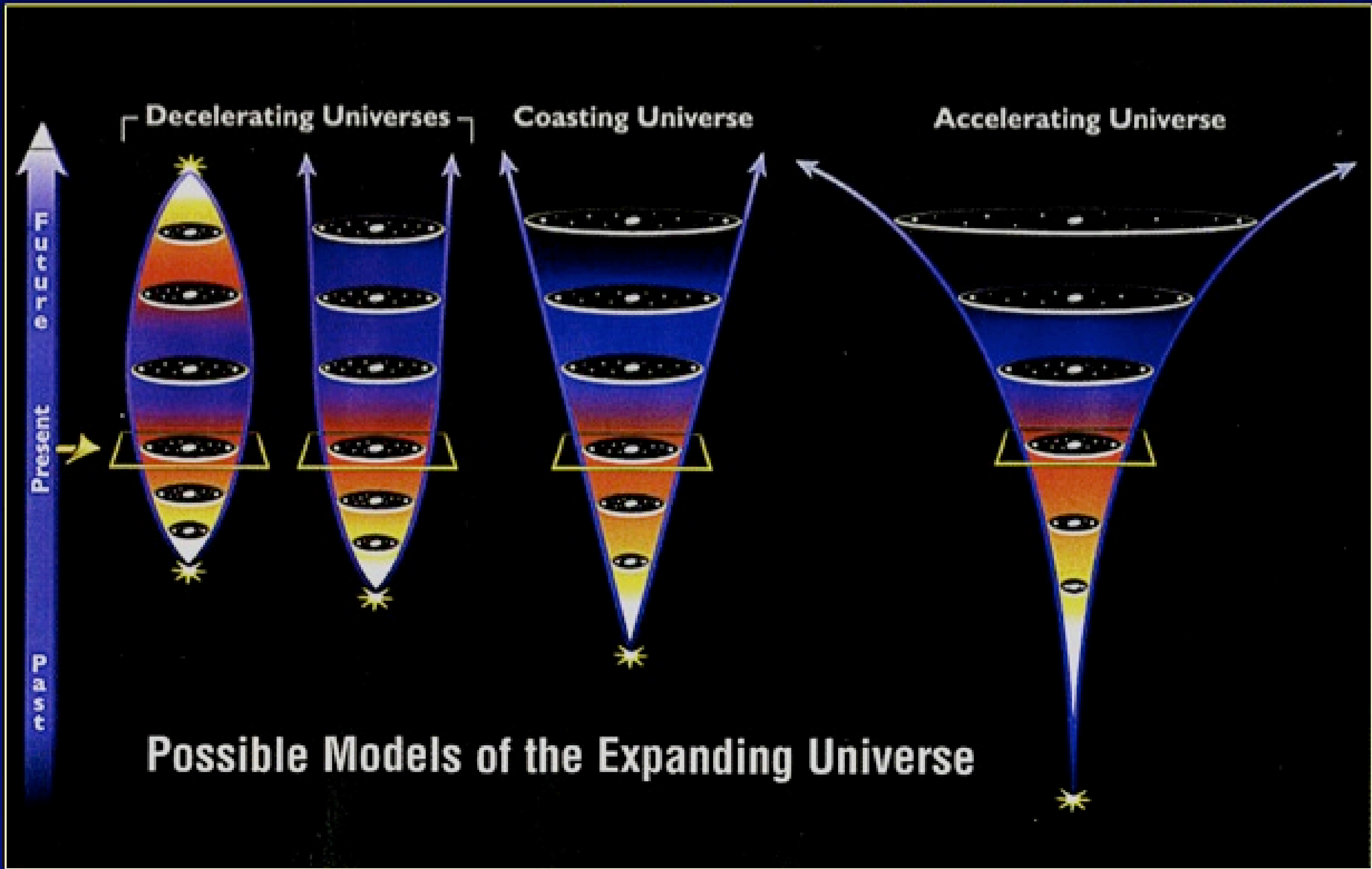


• Complementary in Frequency!

Enhanced SETI Searching

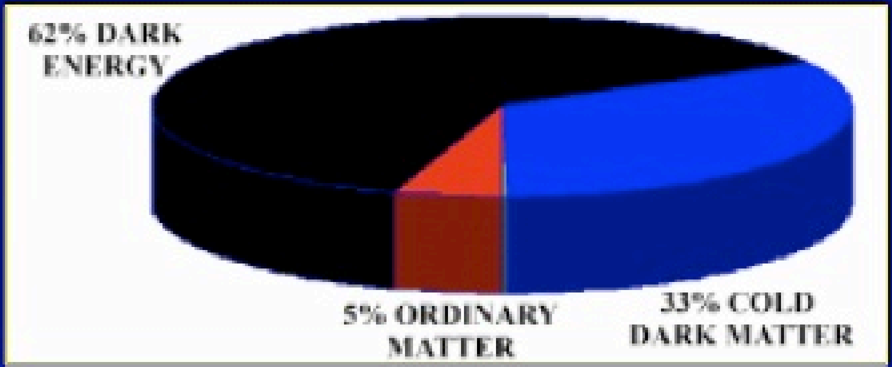


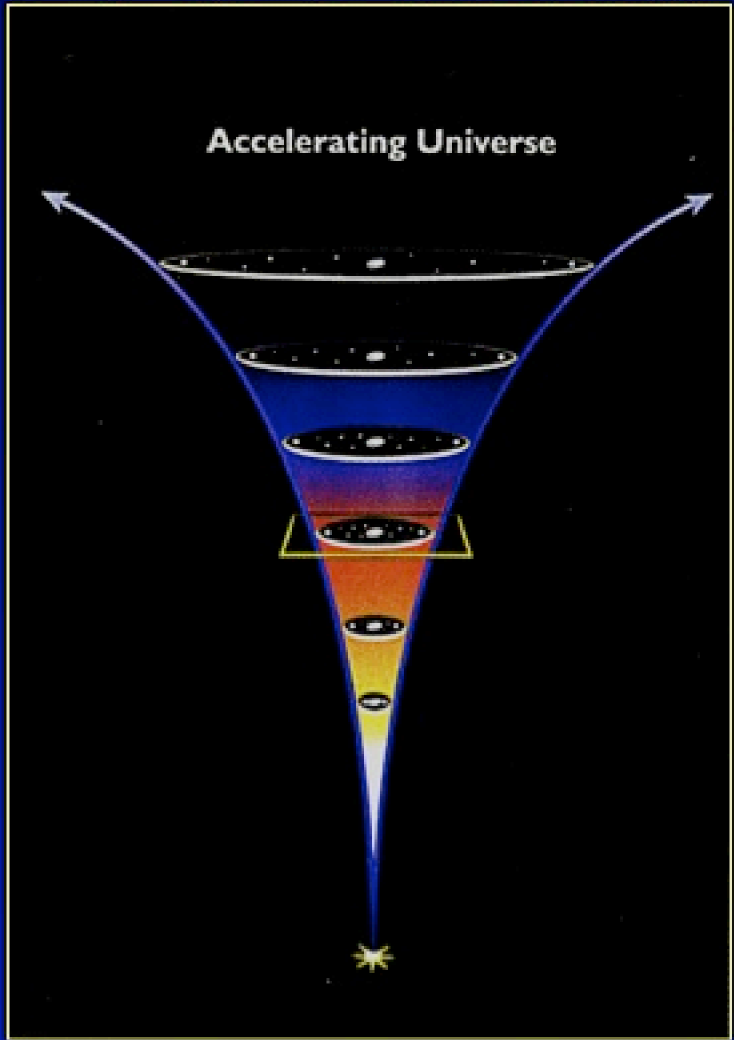
The Universe



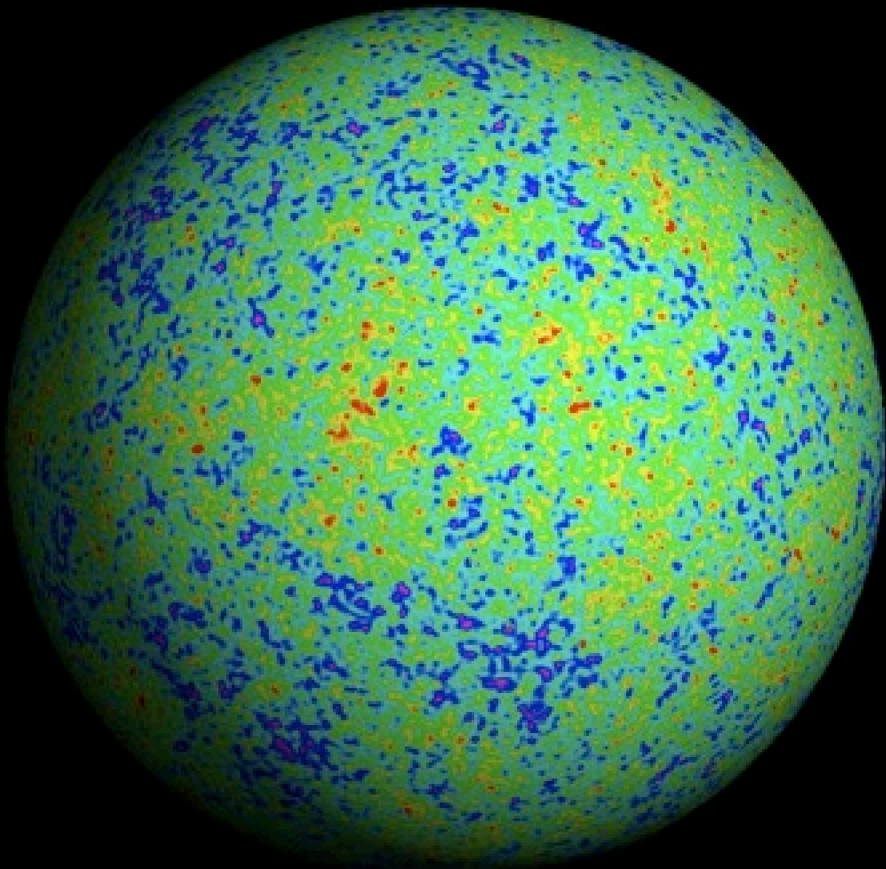
The Universe
Dark Matter – Dark Energy

- Big Questions
  - Dark matter?
  - Dark energy?





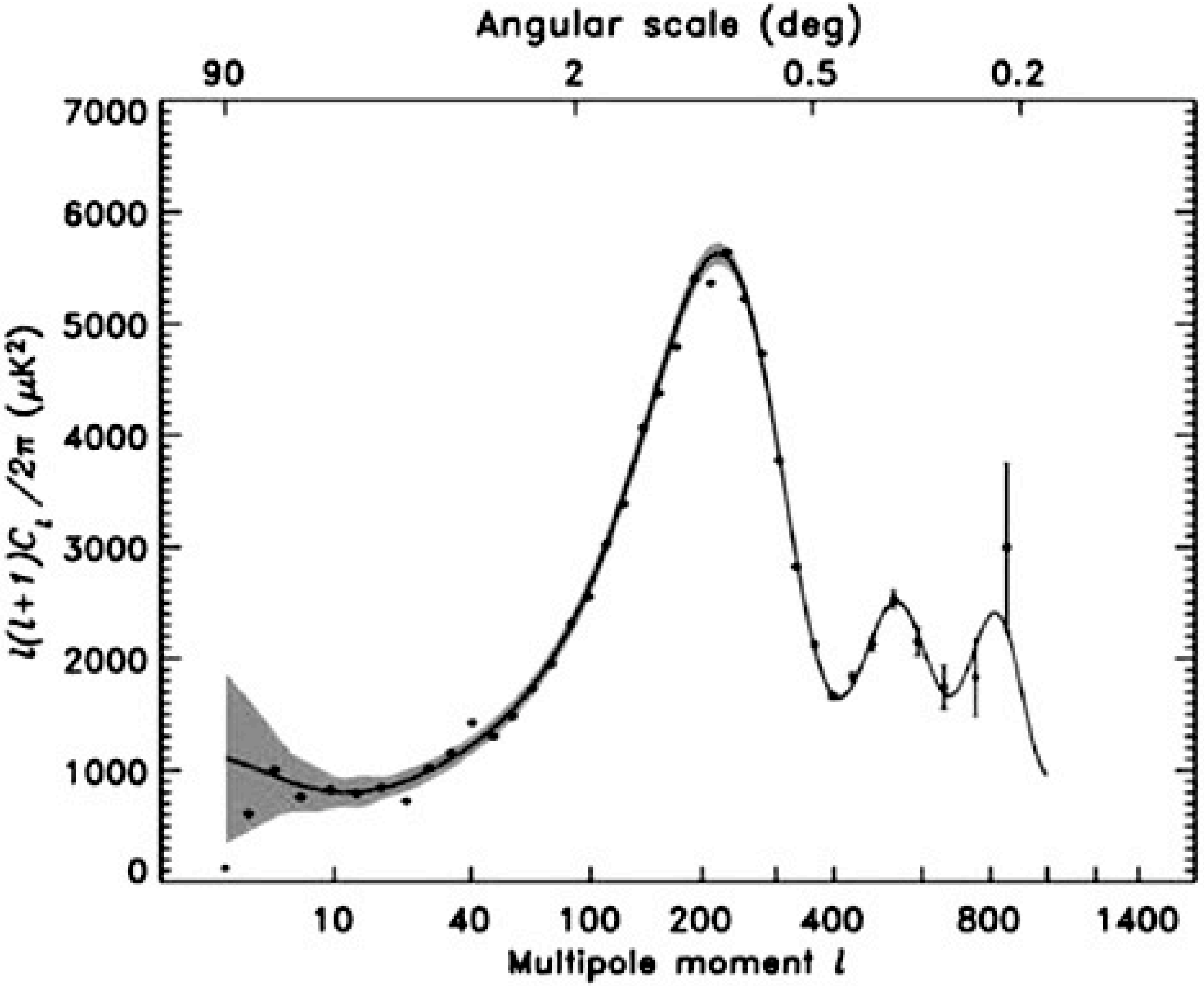
WMAP
Structure in the Big Bang Radiation



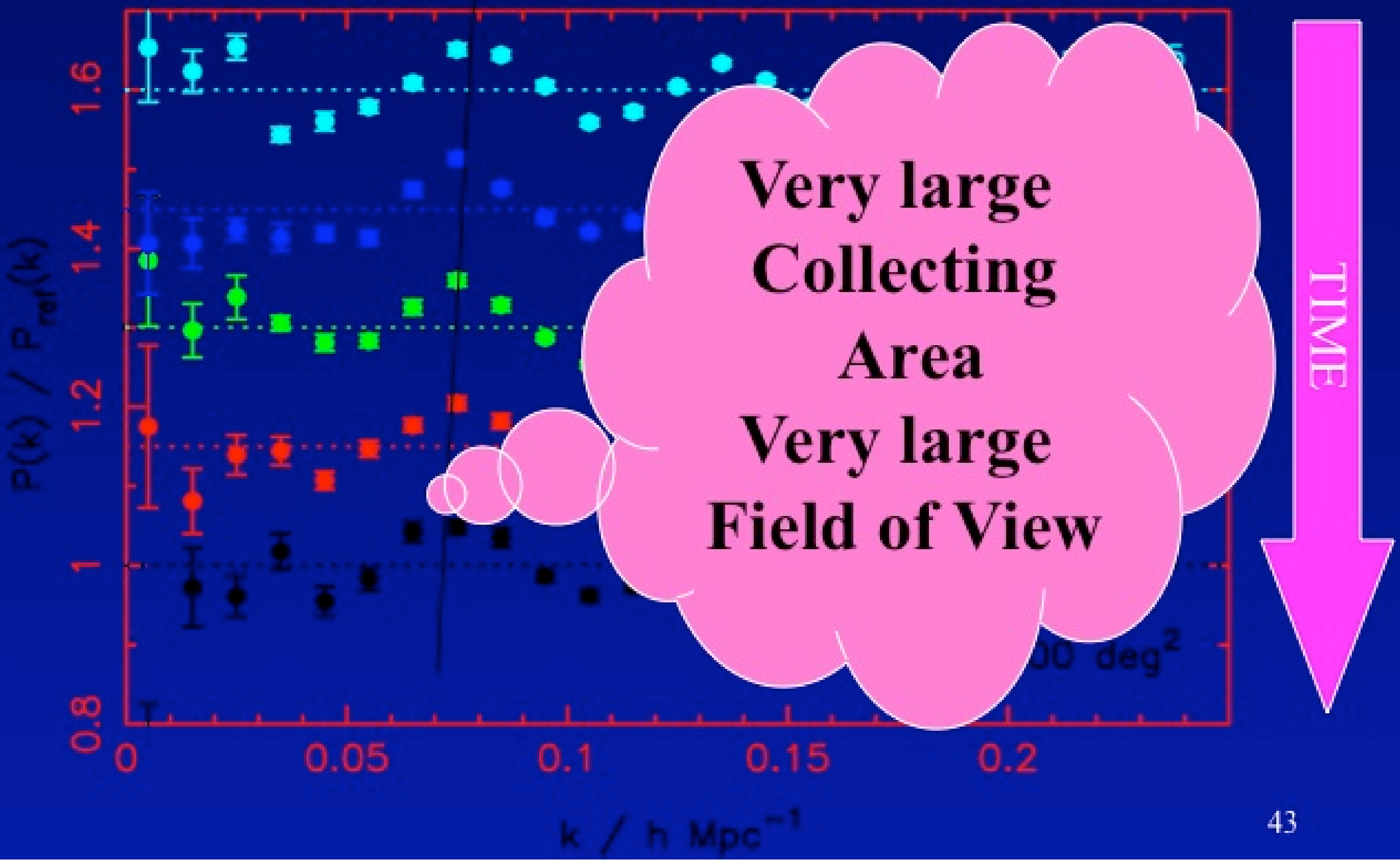
Big Ben and the Big Bang

- Big Bang
  - Derogatory name introduced by Fred Hoyle
- But the Universe rings like a bell
- As the “bell expands the tone will change
- Very faint but SKA can measure it

CMB temperature power spectrum (WMAP)

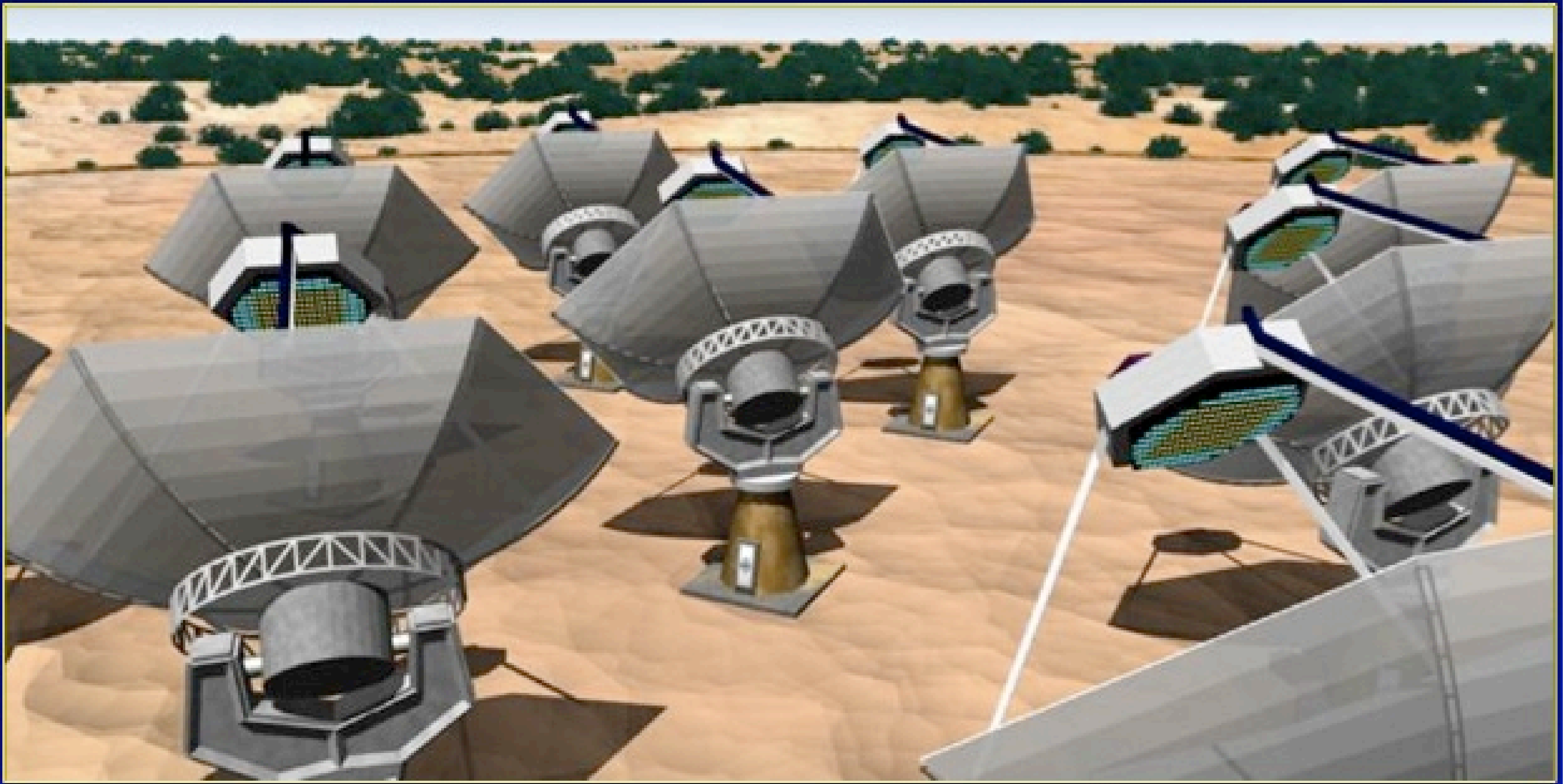


Dark energy oscillations change scale with time



How do we find out?

- We need a Square Kilometre Array !



Achieving the vision - International Collaboration?

- To build facilities which no single nation can afford
- Coordination
  - Avoiding wasteful competition
- Broader knowledge base, cross fertilisation
- Wealth creation

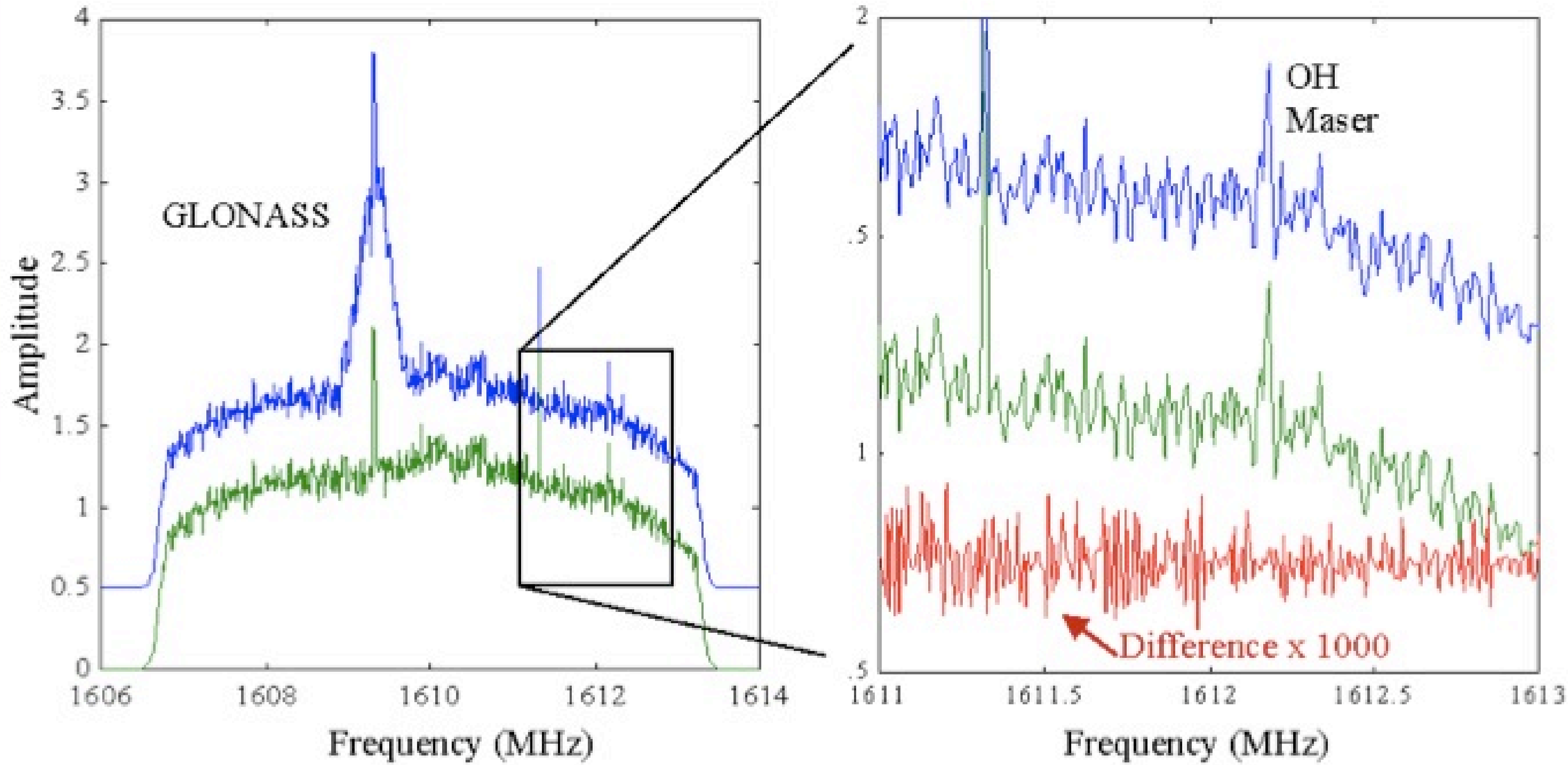
Interference Management
The Two Paths

- Regulation
  - ITU: WRC-2000
  - Essential for ultimate sensitivity
  - Only path at very high frequencies
- Mitigation
  - Sharing the same spectrum
  - Only way to observe redshifted spectral lines from the the distant universe

Both Paths must be pursued vigorously for Radio Astronomy to have a future

GLONASS signal removed from astronomy data

Data obtained at CSIRO ATCA. Adaptive cancelling algorithm by Steve Ellingson, Ohio. Left plot: top (blue) curve: raw data (raised for clarity), OH maser source @ 1612 MHz, test tones inserted (in software, prior to cancellation) at 1609.3 and 1611.3 MHz. Left plot: lower (green) curve: data with GLONASS removed. Right plot: blow up of region around OH source. The bottom (red) curve shows the difference of the pre and post cancellation spectra multiplied by 1000 (and raised for clarity), indicating that the rest of the spectrum is not changed by more than a few parts in 10000.



Terrestrial Interference

Forte satellite: 131MHz