The Australia Telescope National Facility

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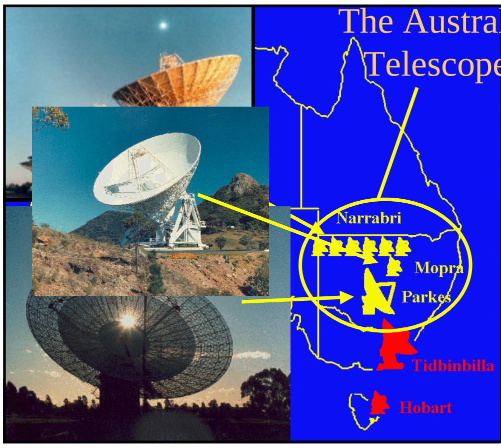
CSIRO ATNF

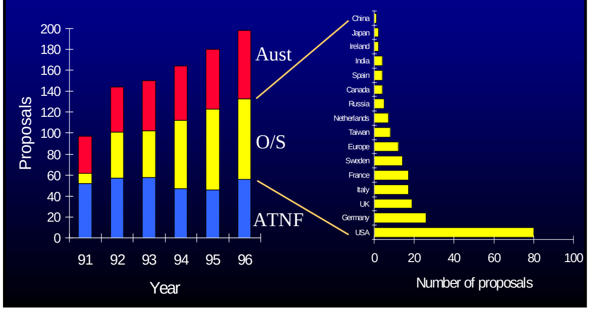
The Australia Telescope



Why is it a “National Facility”?

- Funded by the federal government (through CSIRO)
- Provides radio-astronomical facilities to Australian (+international) astronomers.
- Ranks #2 in the world
  - (in terms of publications, etc.)
- Cost ~$15M p.a.
- Employs ~150 people,
  - of whom ~15 are astronomers,
  - all of whom have support duties.

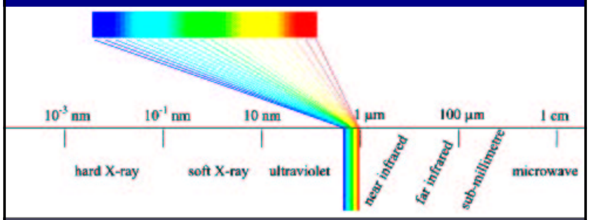
Who uses the AT?



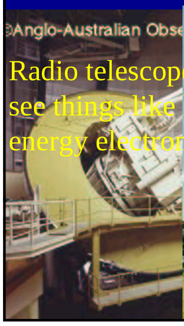
The AT Compact Array

- Formally opened in 1988
- Started routine operation in 1990
- 6 antennas * 22 m diameter on E-W track
- frequency range 1.3 -10 GHz (wavelength range 21 - 3 cm)
- angular scales ~ 1 arcsec to 30 arcmin
- currently being upgraded to 3mm

Why are radiotelescopes so big?



Radio telescopes and optical telescopes can see different things

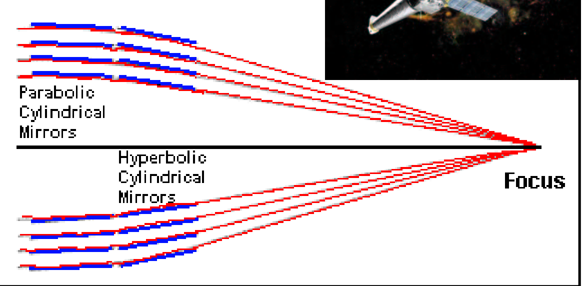


Radio telescopes mainly see things like high-energy electrons

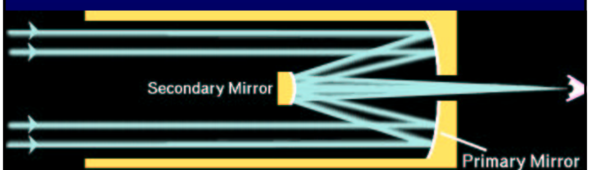
Radio-telescopes show us things which are hidden at optical wavelengths

How telescopes work

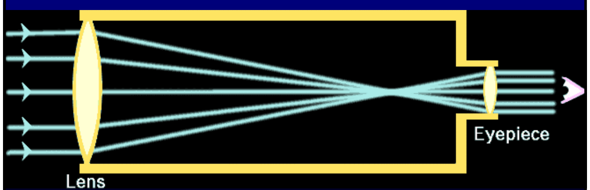
An Xray telescope

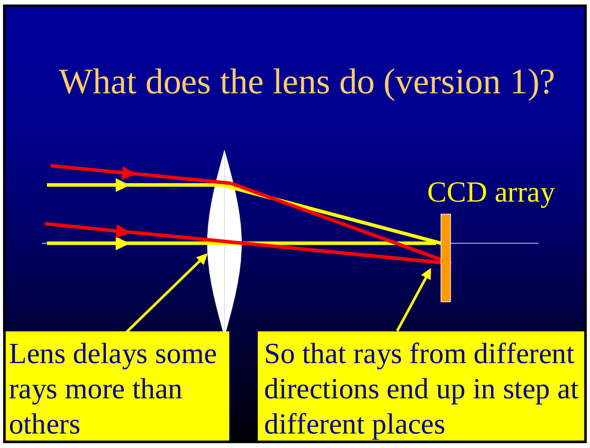


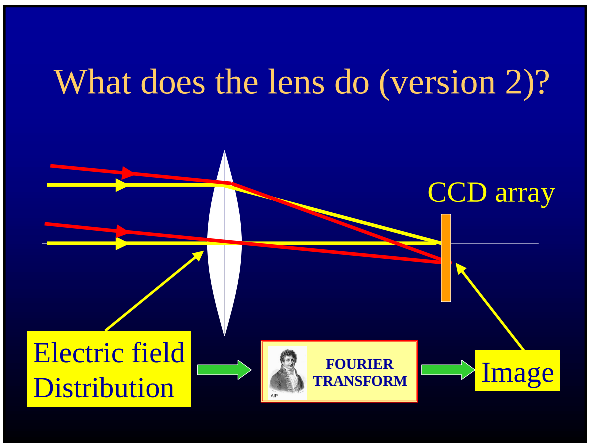
An optical Cassegrain telescope

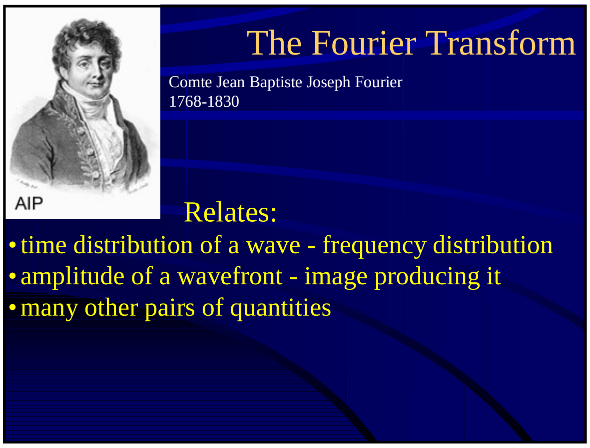


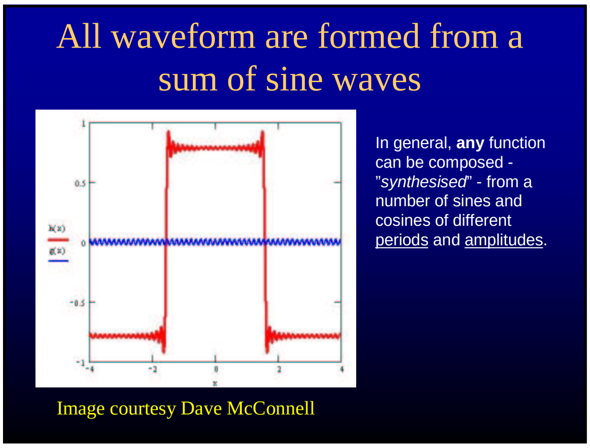
An optical refracting telescope

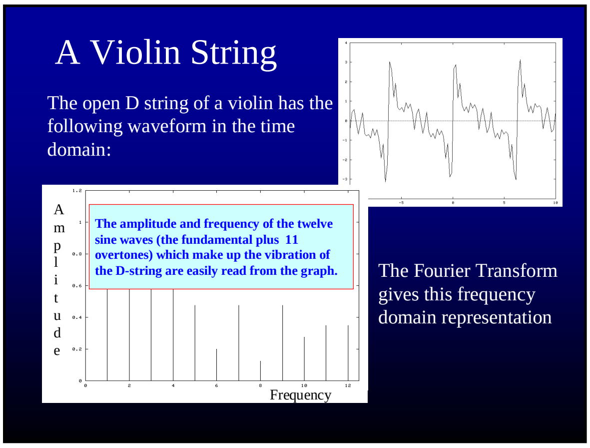


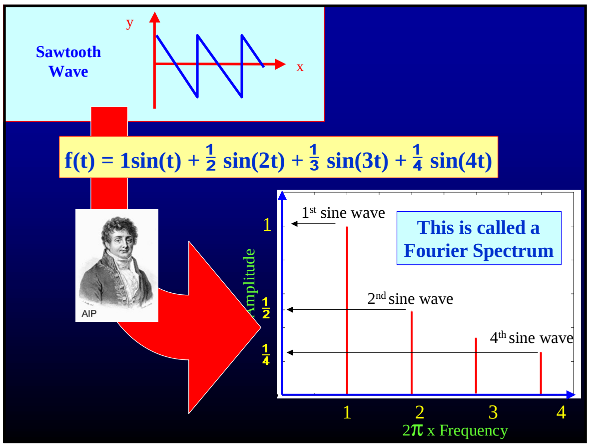

What does the lens do (version 1)?
CCD array
Lens delays some rays more than others
So that rays from different directions end up in step at different places

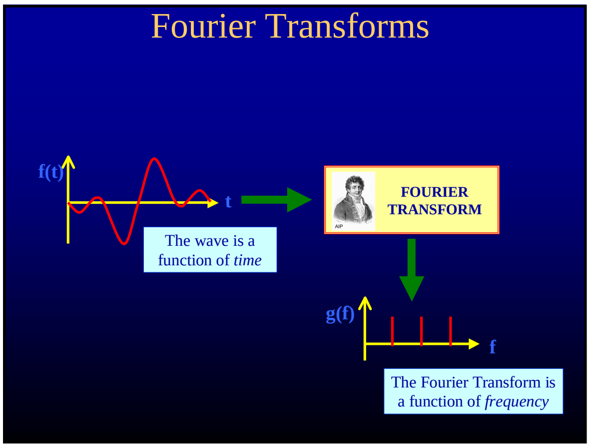

What does the lens do (version 2)?
CCD array
Electric field Distribution
FOURIER TRANSFORM
Image

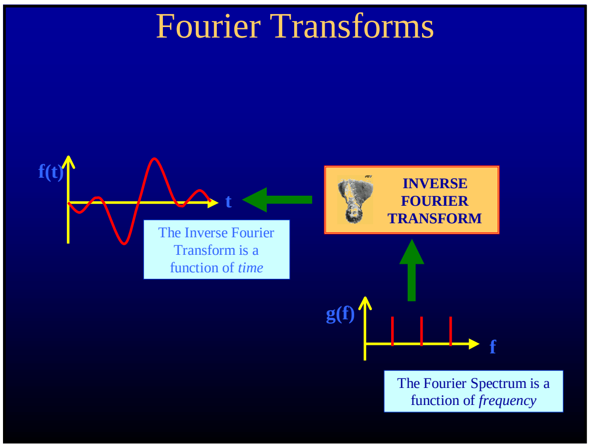

The Fourier Transform
Comte Jean Baptiste Joseph Fourier
1768-1830
AIP
Relates:
• time distribution of a wave - frequency distribution
• amplitude of a wavefront - image producing it
• many other pairs of quantities


All waveform are formed from a sum of sine waves
In general, any function can be composed - "synthesised" - from a number of sines and cosines of different periods and amplitudes.
Image courtesy Dave McConnell


A Violin String
The open D string of a violin has the following waveform in the time domain:
A m p l i t u d e
The amplitude and frequency of the twelve sine waves (the fundamental plus 11 overtones) which make up the vibration of the D-string are easily read from the graph.
Frequency
The Fourier Transform gives this frequency domain representation


Sawtooth Wave
y
x
f(t) = 1sin(t) + ½ sin(2t) + ⅓ sin(3t) + ¼ sin(4t)
AIP
1st sine wave
This is called a Fourier Spectrum
2nd sine wave
4th sine wave
Amplitude
1
½
¼
1
2
3
4
2π x Frequency

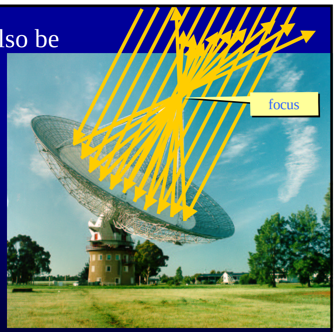

Fourier Transforms
f(t)
t
FOURIER TRANSFORM
The wave is a function of time
g(f)
f
The Fourier Transform is a function of frequency


Fourier Transforms
f(t)
t
INVERSE FOURIER TRANSFORM
The Inverse Fourier Transform is a function of time
g(f)
f
The Fourier Spectrum is a function of frequency

Back to telescopes

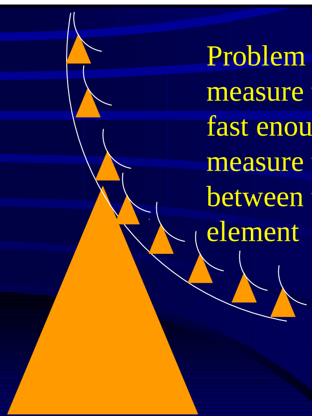
A parabolic dish can also be viewed in this way

- The shape of the dish delays different rays so they are in step at one place (the focus)
- The image formed at the focus is the Fourier transform of the wavefront



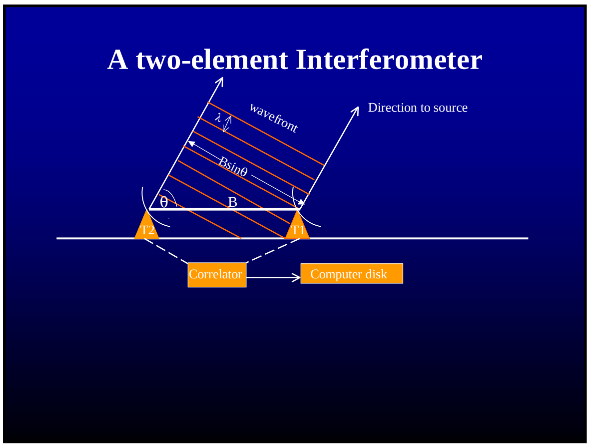
So how can we synthesise a really large telescope?

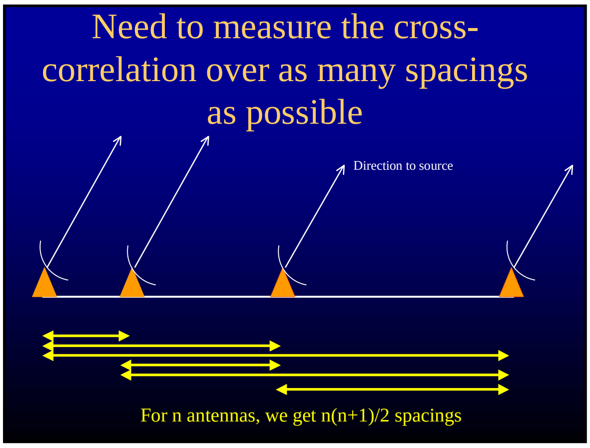
- View 1: we capture the rays at different palces, and then delay them by the right amount, bring them together to form an image
- View 2: we measure the electric field in various places, and then calculate the Fourier transform of that distribution

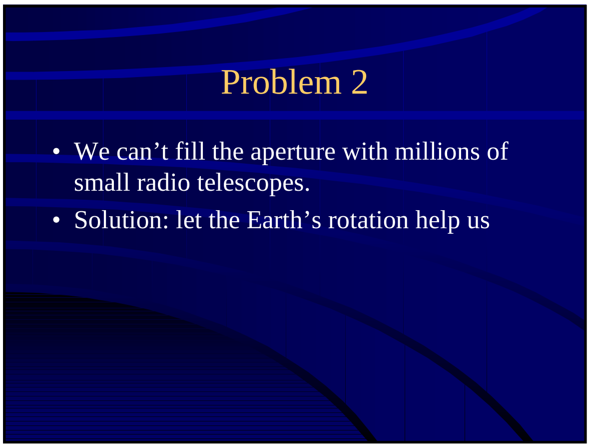


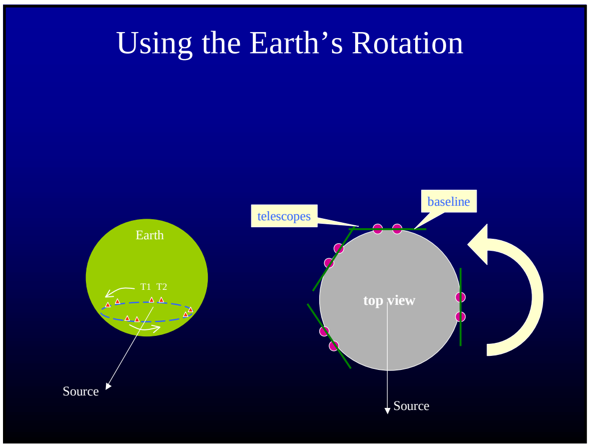
Problem 1: we can’t actually measure the electric field fast enough. Instead we measure the cross-correlations between the signals at each element

A synthesised radio telescope


A two-element Interferometer
wavefront
Direction to source
λ
Bsinθ
θ
B
T2
T1
Correlator
Computer disk

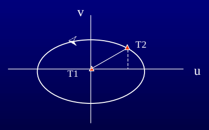

Need to measure the cross-correlation over as many spacings as possible
Direction to source
For n antennas, we get n(n+1)/2 spacings


Problem 2
• We can’t fill the aperture with millions of small radio telescopes.
• Solution: let the Earth’s rotation help us


Using the Earth’s Rotation
Earth
T1 T2
Source
telescopes
baseline
top view
Source

The u-v Plane

- As seen from the source, each baseline traces out an ellipse with one telescope at the centre of the ellipse:

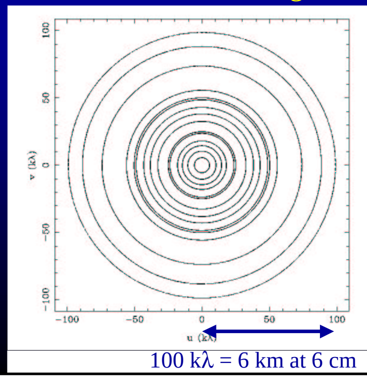


The projected baseline can be specified using u-v coordinates, where

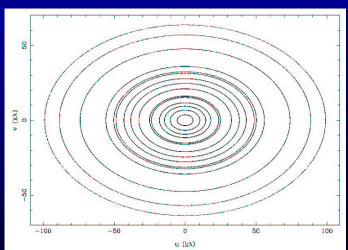
- u gives the east-west component of the baseline; and
- v gives the north-south component of the baseline.

The projected baseline is given by $B \sin\theta = (u^2 + v^2)^{1/2}$

Example 1: ATCA at declination = -85 degrees

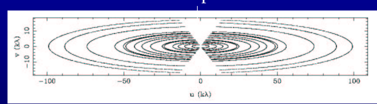


Example 2: declination = -40 degrees

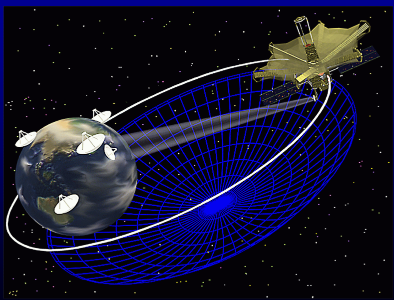


Example 3: declination = -10 degrees

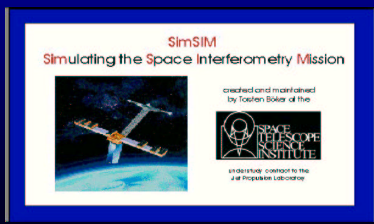
Gap



VLBI - The Highest Resolution Instrument



The effect of increasing coverage in the u-v plane



The process of synthesis observing

- Observe the source for some hours, letting the Earth rotate the baseline
- Correlate the signals between telescopes, and store the results of those multiplications on disk
- At the end of the observation, assign the results of the multiplications to the correct position on the u-v disk
- Fourier Transform the uv plane to produce an image

So is that all?

- If we were able to cover all the u-v plane with spacings, we could in principle get a perfect image
- In practice there are gaps, and so we have to use algorithms such as CLEAN and Maximum Entropy to try to guess the missing information
- This process is called deconvolution

Cleaning dirty images

- A process was designed by Högbom in the early 1970s to clean dirty images.

- Estimate value and position of peak
- Subtract off the ‘dirty beam’ due to a point source of this flux
- repeat until only the noise is left on the image.
- Add back the flux, convolving each point source with an ideal “clean beam”
- The result is the ‘cleaned image’.

So is that all?

Other problems include

- calibration errors
  - use calibrator sources
- bad data
  - edit the data
- “twinkling” in the atmosphere or ionosphere
  - use techniques such as “Selfcal” and phase referencing